SECTION

B

HYDRAULICS

AND

HYDRAULIC

MACHINERY

CHAPTER 33

Hydraulic Physics

As an introduction to this subject, an outline of Physics relating to hydraulics will be helpful for convenient reference.

Ques. What is the difference between *hydrostatics* and *hydraulics?*

Ans. Hydrostatics treats of the laws governing fluids at rest, and hydraulics fluids in motion.

Ques. Define hydrodynamics.

Ans. Hydrodynamics treats of the principles of mechanics applicable to the motion of liquids.

Water.—This remarkable substance is *a compound of hydrogen and oxygen in the proportion of* 2 *parts by weight of hydrogen to* 16 *parts by weight of oxygen.*

Properties of Water.—Under the influence of temperature and pressure water can exist as:

1. A solid
2. A liquid, or
3. A gas

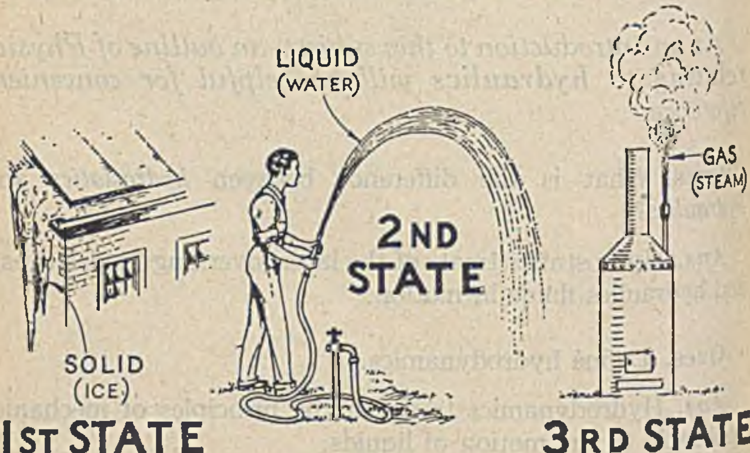
Ques. What is it called in these states?

Ans. As a solid it is called *ice;* as a liquid, *water*, and as a gas, *steam*.

These three transformations being known as the three states, are illustrated in figs. 1 to 3.

Ques. What is the nature of water?

Ans. It is a practically unyielding substance.



Figs. 1 to 3.—The three states: Solid, liquid and gas. In changing from a solid to a gas, there are two changes of state. The first one from solid to liquid is called fusion; the second from liquid to gas, **vaporization.**

This is especially noticeable when confined in pipes and pump passages, necessitating very substantial construction to withstand the pressure and periodic shocks or water hammer.

Ques. What is the most remarkable characteristic of water?

Ans. Water at its maximum density (39.1° Fahr.) will expand as heat is added and it will expand slightly as the temperature falls from this point.

Head and Pressure of Water

(according to Kent)

One foot of water at 39 1° Fahr.	=	62.425 lb. on the square foot;
" " "	=	0.4335 lb. on the square inch;
" " "	=	0.0295 atmosphere;
" " "	=	0.8826 inch of mercury at 32°;
" " "	=	773.3 feet of air at 32° and atmospheric pressure;

One lb. per square foot, at 39.1° Fahr	=	0.01602	foot of water;
One lb. per square inch, at 39.1° Fahr.	=	2.307	feet of water;
One atmosphere of 29.922 in. of mercury	=	33.9	feet of water;
One inch of mercury at 32°	=	1.133	feet of water;
One foot of air at 32°, and 1 atmosphere	=	0.001293	foot of water;
One foot of average sea-water	=	1.026	feet of pure water;
One foot of water at 62° F.	=	62.355	lb. per sq. foot;
One foot of water at 62° F	=	0.43302	lb. per sq. inch;
One inch of water at 62° F = 0.5774 ounce	=	0.036085	lb. per sq. inch;
One lb. of water per square inch at 62° F	=	2.3094	feet of water;
One ounce of water per square inch at 62° F.	=	1.732	inches of water.

Expansion of Water.—The following table gives the relative volumes of water at different temperatures, compared with its volume at 4° C. according to Kopp, as corrected by Porter.

Expansion of Water

Cent.	Fahr.	Volume.	Cent.	Fahr.	Volume.	Cent.	Fahr.	Volume.
4°	39 1°	1.00000	35°	95°	1.00586	70°	158°	1.02241
5	41	1.00001	40	104	1.00767	75	167	1.02548
10	50	1.00025	45	113	1.00967	80	176	1.02872
15	59	1.00083	50	122	1.01186	85	185	1.03213
20	68	1.00171	55	131	1.01423	90	194	1.03570
25	77	1.00286	60	140	1.01678	95	203	1.03943
30	86	1.00425	65	149	1.01951	100	212	1.04332

Head and Pressure. Head is *the height from a given point of a column or body of water, considered as causing pressure due to its weight.*

There are two kinds of head:

1. Static
2. Dynamic

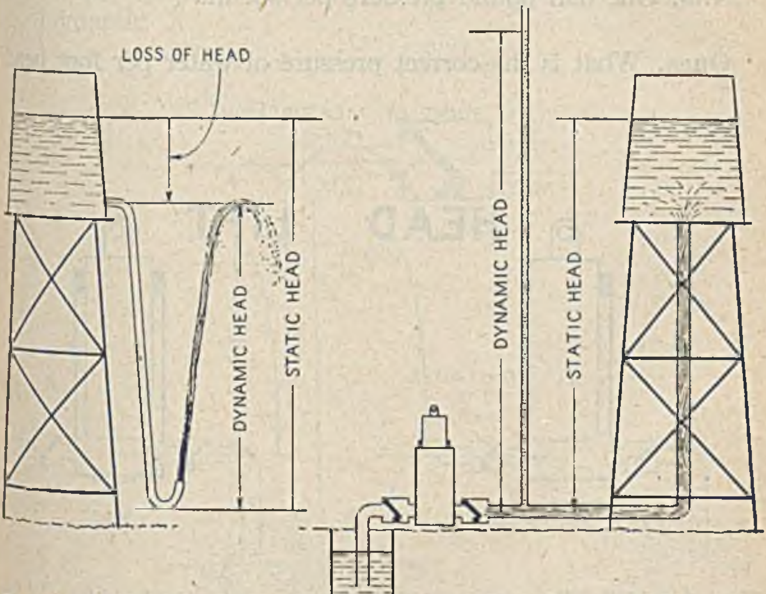
WEIGHT OF WATER

PER CU. FT. OF DIFFERENT TEMPERATURES

Temp., deg. F.	Lb. per cu. ft.	Temp., deg. F.	Lb. per cu. ft.	Temp., deg. F.	Lb. per cu. ft.	Temp., deg. F.	Lb. per cu. ft.	Temp., deg. F.	Lb. per cu. ft.	Temp., deg. F.	Lb. per cu. ft.	Temp., deg. F.	Lb. per cu. ft.	Temp., deg. F.	Lb. per cu. ft.
32	62.41	62	62.35	91	62.10	121	61.69	150	61.19	180	60.57	208	59.92	440	51.87
33	62.41	63	62.34	92	62.08	122	61.68	151	61.17	181	60.55	209	59.90	450	51.28
34	62.42	64	62.34	93	62.07	123	61.66	152	61.15	182	60.53	210	59.87	460	51.02
35	62.42	65	62.33	94	62.06	124	61.64	153	61.13	183	60.51	211	59.85	470	50.51
36	62.42	66	62.32	95	62.05	125	61.63	154	61.11	184	60.49	212	59.82	480	50.00
37	62.42	67	62.32	96	62.04	126	61.61	155	61.09	185	60.46	214	59.81	490	49.50
38	62.42	68	62.31	97	62.02	127	61.60	156	61.07	186	60.44	216	59.77	500	48.78
39	62.42	69	62.30	98	62.01	128	61.58	157	61.05	187	60.42	218	59.70	510	48.31
40	62.42	70	62.30	99	62.00	129	61.56	158	61.03	188	60.40	220	59.67	520	47.62
41	62.42	71	62.29	100	61.99	130	61.55	159	61.01	189	60.37	230	59.42	530	46.95
42	62.42	72	62.28	101	61.98	131	61.53	160	60.99	190	60.35	240	59.17	540	46.30
43	62.42	73	62.27	102	61.96	132	61.51	161	60.97	191	60.33	250	58.89	550	45.66
44	62.42	74	62.26	103	61.95	133	61.50	162	60.95	192	60.30	260	58.62	560	44.84
45	62.42	75	62.25	104	61.94	134	61.48	163	60.93	193	60.28	270	58.34	570	44.05
46	62.41	76	62.25	105	61.93	135	61.46	164	60.91	194	60.26	280	58.04	580	43.29
47	62.41	77	62.24	106	61.91	136	61.44	165	60.89	195	60.23	290	57.74	590	42.37
48	62.41	78	62.23	107	61.90	137	61.43	166	60.87	196	60.21	300	57.41	600	41.49
49	62.41	79	62.22	108	61.89	138	61.41	167	60.85	197	60.19	310	57.08	610	40.49
50	62.40	80	62.21	109	61.87	139	61.39	168	60.83	198	60.16	320	56.75	620	39.37
51	62.40	81	62.20	110	61.86	140	61.37	169	60.81	199	60.14	330	56.40	630	38.31
52	62.40	82	62.19	111	61.84	141	61.36	170	60.79	200	60.11	340	56.02	640	37.17
53	62.39	83	62.18	112	61.83	142	61.34	171	60.77	201	60.09	350	55.65	650	35.97
54	62.39	84	62.17	113	61.81	143	61.32	172	60.75	202	60.07	360	55.25	660	34.48
55	62.38	85	62.16	114	61.80	144	61.30	173	60.73	203	60.04	370	54.85	670	32.89
56	62.38	86	62.15	115	61.78	145	61.28	174	60.71	204	60.02	380	54.47	680	31.06
57	62.38	87	62.14	116	61.77	146	61.26	175	60.68	205	59.99	390	54.05	690	28.82
58	62.37	88	61.13	117	61.75	147	61.25	176	60.66	206	59.97	400	53.62	700	25.38
59	62.37	89	62.12	118	61.74	148	61.23	177	60.64	207	59.95	410	53.19	706.1	19.16
60	62.36	90	62.11	119	61.72	149	61.21	178	60.62	.....	......	420	52.74	...	...
61	62.35			120	61.71			179	60.60			430	52.33		

Static Head.—By definition, *the height from a given point of a column or body of water* **at rest**, considered as causing pressure due to its weight.

Dynamic Head.—By definition, *the equivalent or virtual head of water* **in motion**, *which represents the* **resultant pressure** *due*



Figs. 4 and 5.—Static and dynamic head illustrating "loss of head".

to the height of the water from a given point and the resistance to flow due to friction.

The dynamic head may be *less* or *greater* than the static head as shown in figs. 4 and 5.

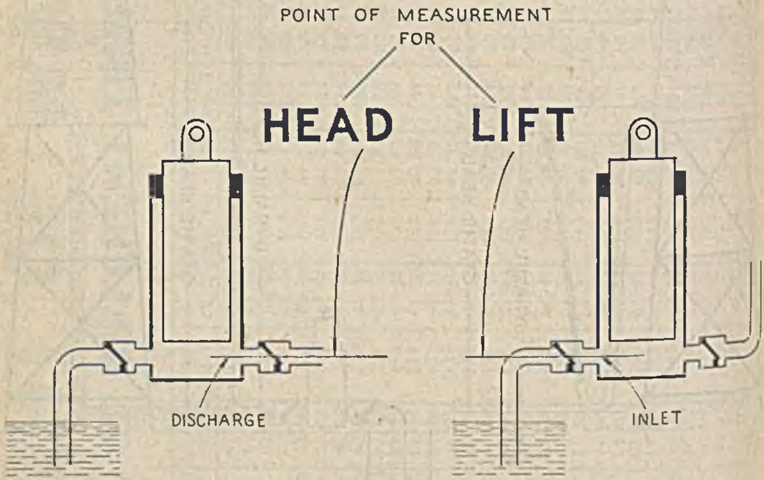
Ques. What is the given point from which head is measured with respect to pump operation?

Ans. From the center of the pump outlet connections as shown in fig. 6.

Ques. In ordinary calculations what is the ordinary practice in estimating the pressure per foot head?

Ans. One half pound pressure per sq. in.

Ques. What is the correct pressure of water per foot head?



Figs. 6 and 7.—The proper point of measurement for head or lift.

Ans. For every foot static head it is equal to .43302 lb. per sq. in.

This is correct when the temperature of the water is 62° Fahr.

Lift.—Hydraulically, lift is defined as *the height to which unbalanced atmospheric pressure forces or "lifts" water above the elevation of the source or supply.*

With respect to pumps, it is defined as *the height measured from the elevation of the source of supply to the* **center** *of the inlet opening of the pump, as shown in figs. 7 and 8.*

As in the case of head, there are two kinds of lift:

1. Static
2. Dynamic

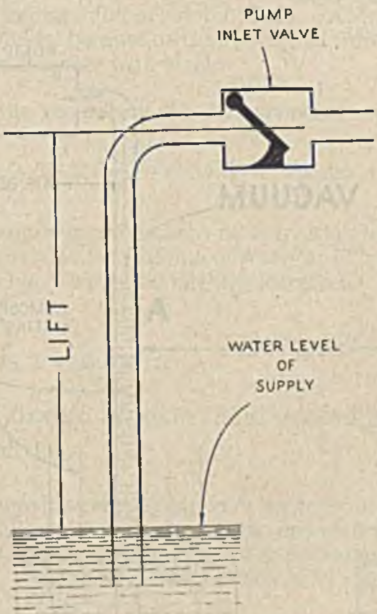


Fig. 8.—Measurement of static lift. It is the vertical distance from the surface of the water supply to the center of the inlet opening.

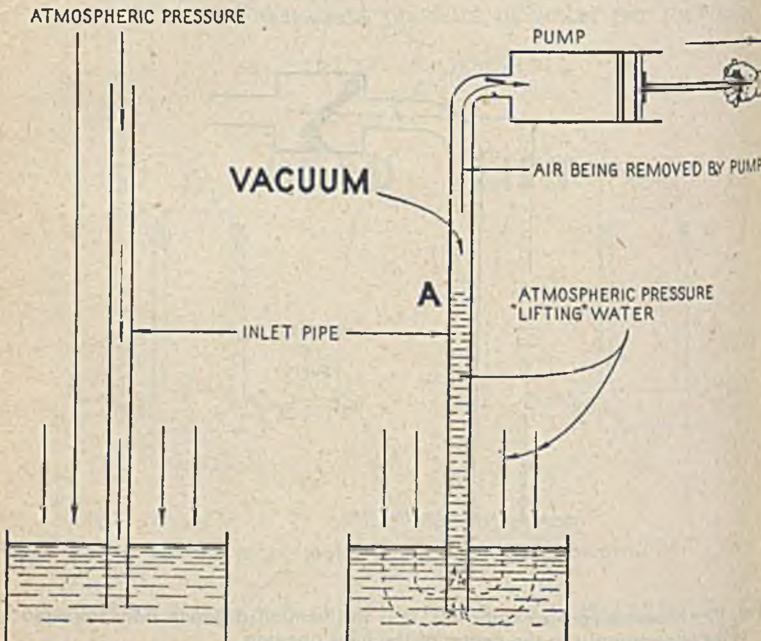
Static Lift.—By definition, *the height from the source of supply to which a column of water will rise to restore equilibrium due to unbalanced atmospheric pressure.*

Here the weight of the column of water (of 1 sq. in. cross section) is equal to the pressure exerted by the atmosphere in lbs. per sq. in. to restore equilibrium.

Ques. How is the pressure of the atmosphere made available to raise water from the source to an elevated pump?

Ans. By removing air from the inlet pipe.

Thus in fig. 9, the inlet pipe (before connection with pump) being open at the top the atmosphere presses down on the water both *inside* and *outside* of the pipe; the system being in equilibrium there is no tendency to raise the water inside the pipe.



Figs. 9 and 10.—Elementary diagrams showing how the pressure of the atmosphere is made available to raise water from the source to an elevated pump.

If, as in fig. 10, the end of the pipe be connected to a pump, the operation of the pump will remove more or less air from the pipe creating a (partial) *vacuum* and the water will rise in the pipe to a height A, corresponding to the amount of atmospheric pressure thus made available to lift the water.

Ques. What is the maximum height to which atmospheric pressure will lift water?

Ans. Approximately 34 ft. for a 30-inch barometer when the temperature of the water is 62° Fahr.

When the water is warm, the height to which it can be lifted decreases on account of the increased pressure of the vapor. That is, for instance, a boiler feed pump taking water at say 153° Fahr. could not produce a vacuum greater than 21.78 ins. because at that point the water would begin to boil and fill the pump chamber with steam.

Accordingly, the theoretical lift corresponding would be

$$34 \times \frac{21.78}{30} = 24.68 \text{ ft. approx.}$$

The result is approximate because no correction has been made for the 34 which represents a 34 foot column of water at 62°; of course at 153° the length of such column would be slightly increased.

Ques. What is a vacuum?

Ans. A *space* **devoid** *of matter* and accordingly one in which the pressure is zero.

The word vacuum has come by ignorant usage to mean *any space in which the pressure is less than that of the atmosphere*, and accordingly, it is necessary to accept this definition of the ignorantia as nothing can be done about it. Strictly speaking, what these fellas call vacuum is a ***partial vacuum***.

Ques. For water at standard temperature what governs the maximum height to which it may be lifted?

Ans. The height of the barometer.

Figs. 12 and 13 show two water barometers which register directly the maximum lifts corresponding to various pressures of the atmosphere. Thus in fig. 12 for 30 inch barometer the water rises in the tube 34.1 feet;

for say 24 inch barometer the water rises 27.28 feet. These calculations are indicated in the figures, .49116 = lbs. per sq. in. per inch of mercury. 2.30947 = feet head of water per lb. per sq. in.

Dynamic Lift.—By definition, *the equivalent or virtual lift of water in motion* which represents the resultant weight of the water (per column of 1 sq. in. cross section) due to the height of the water from the supply level plus the resistance flow due to friction.

Ques. What is the practical limit of lift?

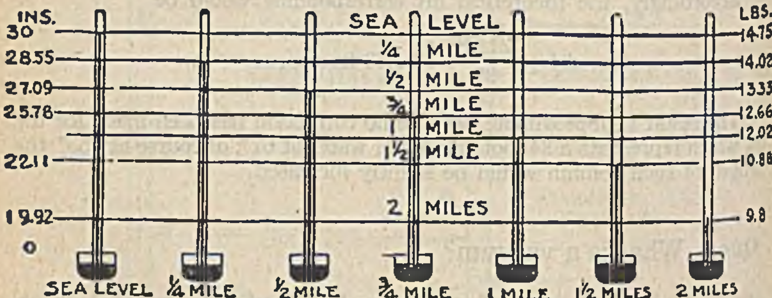


Fig. 11.—Readings of the barometer in ins. of mercury with equivalents in lbs. per sq. inch for different elevations. It should be noted that although ordinarily the atmospheric pressure at sea level is taken at 30 in. corresponding to 30 × .49116 = 14.74 lbs. per sq. in. or roughly 14.7 lbs. there is a standard atmosphere which as taken by Marks and Davis in their steam tables is defined as 29.921 inches of mercury or 14.696 lbs. per sq. in.

Ans. From 20 to 25 feet.

Since dynamic lift is greater than static lift if the pump were 25 feet above the level of the water there would be only 30−(25×1.113)=2.2 inches of the barometer to cover the frictional resistance due to the water in motion. Accordingly better lower pump so that it is not more than 20 feet above elevation of the water supply.

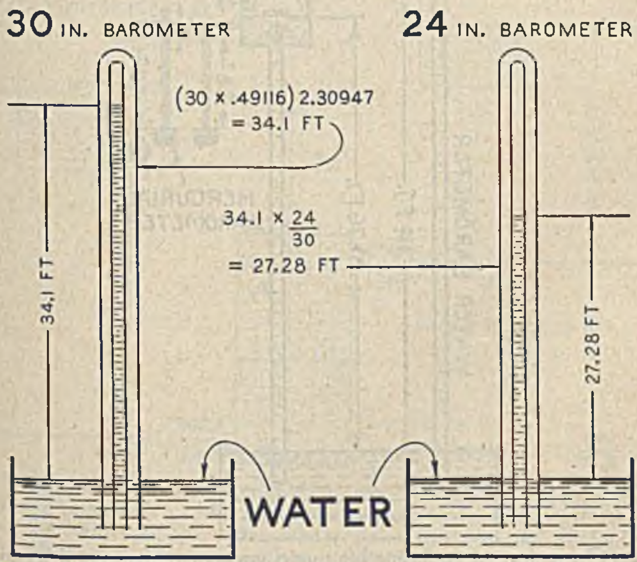
Negative Lift.—A term applied to the hydraulic condition when the level of the water supply is higher than the pump inlet.

By definition negative lift is: *The vertical distance from the water supply level to the lower level of the pump inlet.*

Ques. What is the effect of so called negative lift?

Ans. It assists the pumping operation.

That is, it exerts a pressure on the piston which opposes the pressure on the other side of the piston due to the head. These conditions are illustrated in fig. 15.



Figs. 12 and 13.—Maximum lift for different readings of the barometer.

Ques. Is the measurement of lift from center of outlet to level in tank, as in fig. 15, correct?

Ans. No. The "instantaneous" lift for the instant depicted would extend from the level in tank to the upper face of the piston (vertical distance).

Similarly for the negative lift, that is, height level of supply above lower face of piston. Evidently these strictly correct definitions would not conveniently apply in practice.

Theoretical Lift for Various Temperatures.—When water is warm, the height to which it can be lifted decreases on account of the increased pressure of the vapor. That is, for instance, a

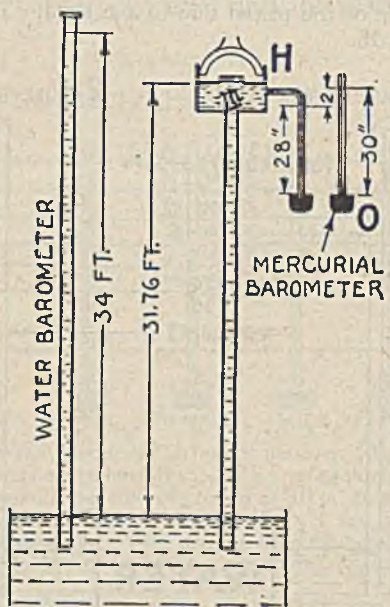


Fig. 14.—Operation of ordinary lift pump vacuum as measured by inches of mercury and feet of water. **As shown,** the mercury in the barometer O, is at 30 ins. corresponding to atmospheric pressure of 14.74 lbs. Now for each lb. per sq. in. the corresponding head of water is 2.30947 ft., hence if water were used in the barometer instead of mercury the height of the column of water corresponding to atmospheric pressure of 14.74 lbs. (30 ins. of mercury) is 14.74 × 2.30947 = 34.042 ft., say 34 ft. The pump piston is 31.76 ft. above the water level, at which elevation a mercurial gauge attached at H, would read 28 ins. leaving only two ins. margin of available pressure to overcome friction and to lift the foot valve m. The distance 31.76 ft. is about as high as would be possible to lift the water with the barometer of 30 ins., and in practice about 25 ft. is considered the maximum lift for satisfactory operation.

boiler feed pump taking water at say 201.96° Fahr. could not produce vacuum greater than 5.49 ins. because at that point the water would begin to boil and fill the pump chamber with steam.

Accordingly the theoretical lift corresponding would be

$$34 \times \frac{5.49}{30} = 6.2 \text{ ft. approx.}$$

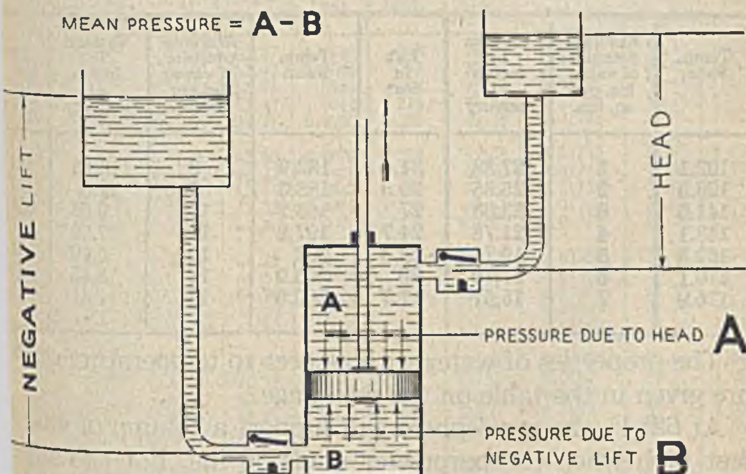


Fig. 15.—Negative lift; very objectionably sometimes called "suction head" (a ridiculous expression). Although the standard measurement for negative lift is from the surface of the water supply down to the center of the pump inlet, the pressure due to negative lift varies depending upon the position of the piston. For instance, as shown, the column to piston balances part of the total column, hence the actual amount of negative lift at the instant shown is the difference between these two columns. **It should be noted,** the pump is double acting but for simplicity the second set of valves is not shown.

Ques. How could water at such temperature be handled at greater lift.

Ans. By employing a two-stage pump with inter stage heating as exemplified by the "Doctor" Western river steamer boiler feed pump.

See page 316, Section I, for drawing of this type pump as formerly designed by the author.

The following table shows the theoretical maximum lift for different temperature leakage not considered.

Theoretical Lift for Various Temperatures.

Temp. Fahr.	Absolute pressure of vapor lbs. per sq. ins.	Vacuum in inches of mercury	Lift in feet	Temp. Fahr.	Absolute pressure of vapor lbs. per sq. ins.	Vacuum in inches of mercury	Lift in feet
102.1	1	27.88	31.6	182.9	8	13.63	15.4
126.3	2	25.85	29.3	188.3	9	11.6	13.1
141.6	3	23.83	27	193.2	10	9.56	10.8
153.1	4	21.78	24.7	197.8	11	7.52	8.5
162.3	5	19.74	22.3	202	12	5.49	6.2
170.1	6	17.70	20	205.9	13	3.45	3.9
176.9	7	15.67	17.7	209.6	14	1.41	1.6

The properties of water with respect to temperature changes are given in the table on the next page.

At 62° F. the atmosphere will support a column of water 34 feet high when the barometer reads 30 ins. For rise in temperature the water expands which of itself alone would lengthen the column.

For instance fig. 16 shows a 34 foot column of water at a temperature of 60° in a tube closed at the bottom and open at the top. From the table, page 4, a cubic foot of the water at 60° weighs 62.36 lbs. If heated to say 180° the weight decreases to 60.57 lbs.

Accordingly, due to expansion of the water the length of the 34 ft. column, fig. 16, becomes

$$34 \times \frac{62.36}{60.57} = 35 \text{ ft.}$$

Properties of Water at Saturated Pressure

(From Marks and Davis's Steam Tables)

Temp., deg. fahr.	Pressure, lb. per sq. in.	Specific volume, cu. ft. per lb.	Density, lb. per cu. ft.	Specific heat	Temp., deg. fahr.	Pressure, lb. per sq. in.	Specific volume, cu. ft. per lb.	Density, lb. per cu. ft.	Specific heat
20	0.06	0.01603	62.37	1.0168	240	24.97	0.01692	59.11	1.012
30	0.08	0.01602	62.42	1.0098	250	29.82	0.01700	58.83	1.015
40	0.12	0.01602	62.43	1.0045	260	35.42	0.01708	58.55	1.018
50	0.18	0.01602	62.42	1.0012	270	41.85	0.01716	58.26	1.021
60	0.26	0.01603	62.37	0.9990	280	49.18	0.01725	57.96	1.023
70	0.36	0.01605	62.30	0.9977	290	57.55	0.01735	57.65	1.026
80	0.51	0.01607	62.22	0.9970	300	67.00	0.01744	57.33	1.029
90	0.70	0.01610	62.11	0.9967	310	77.67	0.01754	57.00	1.032
100	0.95	0.01613	62.00	0.9967	320	89.63	0.01765	56.66	1.035
110	1.27	0.01616	61.86	0.9970	330	103.0	0.01776	56.30	1.038
120	1.69	0.01620	61.71	0.9974	340	118.0	0.01788	55.94	1.041
130	2.22	0.01625	61.55	0.9979	350	135.0	0.01800	55.57	1.045
140	2.89	0.01629	61.38	0.9986	360	153.0	0.01812	55.18	1.048
150	3.71	0.01634	61.20	0.9994	370	173.0	0.01825	54.78	1.052
160	4.74	0.01639	61.00	1.0002	380	196.0	0.01839	54.36	1.056
170	5.99	0.01645	60.80	1.0010	390	220.0	0.01854	53.94	1.060
180	7.51	0.01651	60.58	1.0019	400	247.0	0.0187	53.5	1.064
190	9.34	0.01657	60.36	1.0029	410	276.0	0.0189	53.0	1.068
200	11.52	0.01663	60.12	1.0039	420	308.0	0.0190	52.6	1.072
210	14.13	0.01670	59.88	1.0050	430	343.0	0.0192	52.2	1.077
220	17.19	0.01677	59.63	1.007	440	381.0	0.0194	51.7	1.082
230	20.77	0.01684	59.37	1.009					

NOTE.—*Evaporation in a Closed Space.*—When a liquid is placed in a closed chamber (which is otherwise empty and at a uniform temperature evaporation will take place more or less rapidly at first. After some time, however, the space outside the liquid will become partially filled with stray molecules which have escaped through the surface film. These, after escape, move about discriminately in the chamber, and are reflected from its walls and from each other. In this manner some, after a fitful career, will return to the liquid, and once they fall upon its surface they may be attracted into the interior. It will thus happen that a certain stage will be ultimately attained at which as many molecules will return to the liquid per second as leave it, and an equilibrium will be established. At this stage evaporation may be said to have ceased. There is no further loss to the liquid or gain to the vapor outside it; there is, however, a continual exchange going on, new molecules are being continually projected from the surface, and others are falling into it in equal number. In this case the chamber is said to be filled with saturated vapor, or the vapor is simply said to be saturated; while in any state before this final stage is arrived at the vapor is said to be non-saturated. A saturated vapor is thus one which is in equilibrium with its own liquid.—*Preston.*

Example.—What is the maximum theoretical lift with water at 180°. See fig. 18.

Vacuum corresponding to 180° = 13.63 ins. approx.

Lift corresponding to this vacuum

$$= 34 \times \frac{13.63}{30} = \ldots\ldots\ldots\ldots\ldots\ldots \quad 15.5 \text{ ft.}$$

Correction for expansion (previously obtained)............. 1

Maximum theoretical lift = ... 16.5 ft.

This is shown in fig. 18.

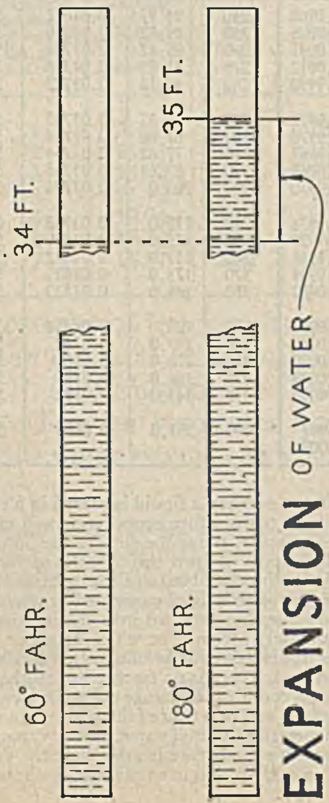


Fig. 16.—Showing Increase in maximum theoretical lift due to rise in temperature. The effect of rise in temperature is to cause expansion, that is, lengthen the column of water that can be supported by atmospheric pressure.

The Total Column.—The author in an attempt to avoid such a *ridiculous expression as "total head," has coined the term **"total column."**

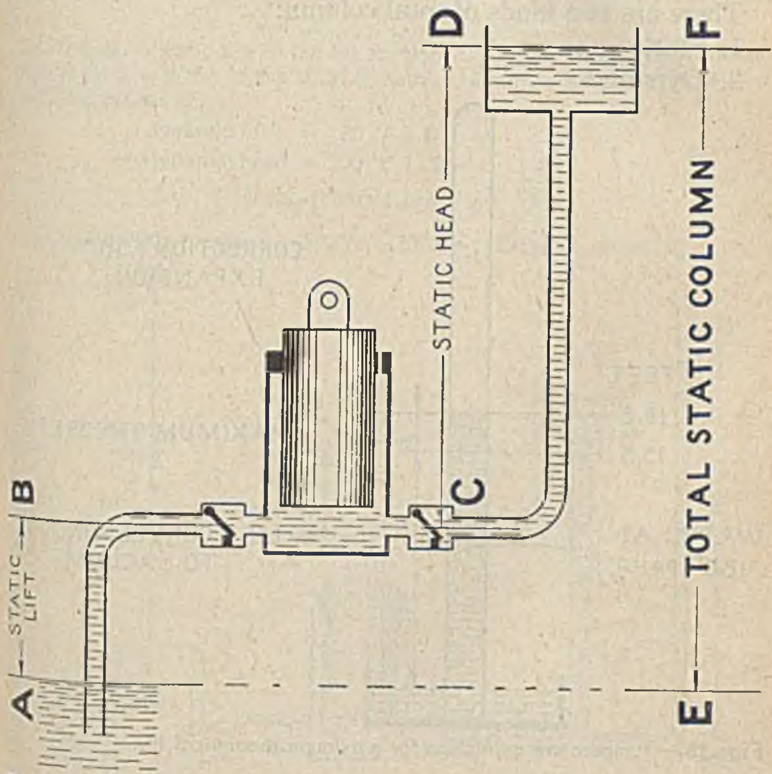


Fig. 17.—The total static column being made up of the static lift + the static head in length extending vertically from the level of the water supply to the point of discharge which in this case is the elevation of the surface of water in the tank.

*NOTE.—Such ridiculous expressions as "*suction*" *lift* should never be used. What's the idea of adding the word "*suction*"? It's virtually an insult to the intelligence of the reader.

By definition, the total column is *head plus lift*.

When they say total head they mean head + lift. Under no circumstances should lift be called head.

There are two kinds of total column:

1. Static
2. Dynamic

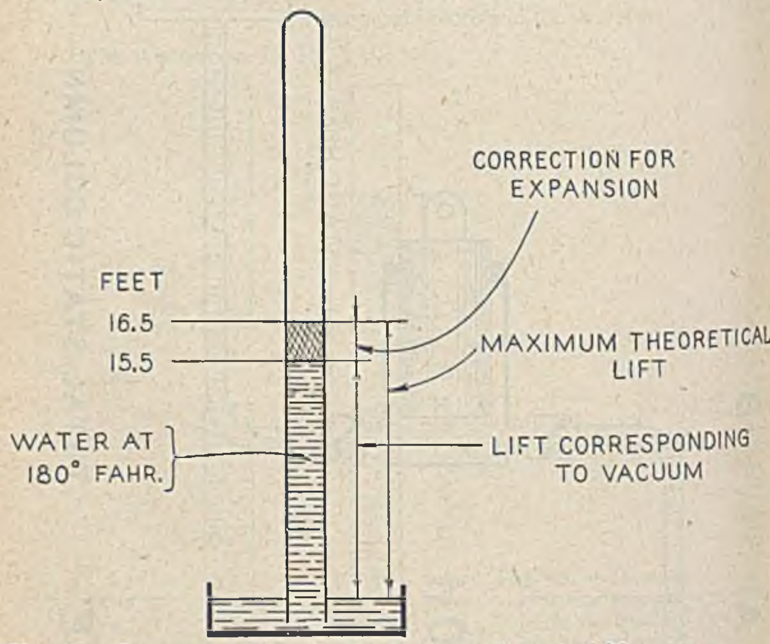


Fig. 18.—Temperature correction for maximum theoretical lift.

Static Total Column.—By definition the *static lift* + the *static head*, or height from the level of supply to the level in tank, in feet or considered as causing pressure due to its weight.

Thus in fig. 17

Static lift **AB** + static head **CD** = total static column **EF**.

Dynamic Total Column.—By definition, *the dynamic lift + the dynamic head, or the equivalent or virtual total column of water in motion, which represents the pressure due to the total static column plus the resistance to flow due to friction* as shown in fig. 19.

Example.—Static lift 20 ft.; lift friction 10%; static head 200 ft.; head friction 20%. What is the total dynamic column? What is the corresponding pressure?

dynamic lift	=	20 × 1.1	=	22 ft.
dynamic head	=	200 × 1.20	=	240 "
Total dynamic head			=	262 "

Corresponding pressure = 262 × .43302 = 113.5 lbs. per sq. in.

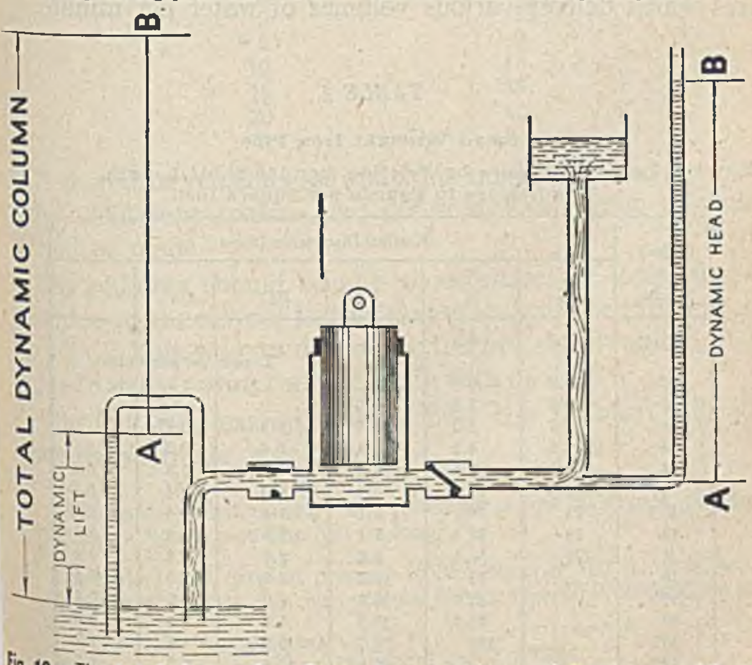


Fig. 19.—The **total dynamic column** being made up of the dynamic lift + the dynamic head. Note **AB** at left = **AB** at right.

Friction of Water in Pipes

According to Prof. Geo. E. Russell there is wide misunderstanding in the plumbing trade concerning the laws governing rates of discharge of water from faucets, and the relations of pressure and discharge. This misunderstanding produces great waste.

Prof. Russell has prepared the accompanying table based on his experiments and which will be found of great value in calculating the loss of pressure due to friction in pipes of various sizes which deliver various volumes of water per minute.

TABLE 1

Small Wrought Iron Pipe

Loss in Pressure by Friction, per 100 ft. of Length. Figures are in Pounds per Square Inch

Gallons per Minute	Nominal Diameter in Inches					
	½	¾	1	1¼	1½	2
1	0.9	0.2	....	....	....	....
				Pounds	per squar	e inch
2	3.2	0.8	....	....	....	....
3	6.9	1.8	0.6	....	....	....
4	11.7	3.2	0.9	0.3	0.1	....
5	17.8	4.5	1.4	0.4	0.2	....
6	24.8	6.4	2.0	0.5	0.3	0.1
8	42.6	10.9	3.4	0.9	0.4	0.1
10	64	16.5	5.1	1.4	0.6	0.2
12	90	23.1	7.1	1.9	0.9	0.3
14	120	30.4	9.6	2.5	1.2	0.4
16	....	40	12.2	3.2	1.5	0.5
18	....	48.7	15.2	4.0	1.8	0.7
20	....	59.2	18.3	4.8	2.3	0.8
30	....	120	38.7	10.2	4.8	1.7
40	....	....	66	17.4	8.2	2.9
50	....	....	98	26.1	12.4	4.3

In addition to the friction encountered in pipes there is *additional friction in faucets.* This varies more or less according to the type and make of faucet.

Prof. Russell in his experiments on a ½ in. faucet, obtained results upon which he based the following table:

TABLE 2

Friction of Water Through Small Faucet

(½ in. Commercial Faucet)

Rate of Flow Gals. per min.	Loss in Pressure Lbs. per sq. in.
4	2
5	3½
8	9
10	15
15	33
20	60

It should be remembered that this table relates to *one faucet only.* Different makes give different loss, hence allowance should be made.

The plumber should be able to estimate the losses in pressure due to the several factors that enter into the problem, and be able in this way to determine the pressure required at fixtures to deliver water at a certain rate of flow.

The following examples show how the problem will illustrate the methods of calculation.

Example.—What pressure is required for a flow of 10 gals. per minute through a ¾ in. pipe line 350 ft. long?

In table 1, the drop in pressure is 16.5 lbs. per 100 ft. of ¾ in. pipe for a flow of 10 gals. per min. and for 350 ft. the required pressure is

$$\frac{16.5 \times 350}{100} = 16.5 \times 3.5 = 57.8 \text{ lbs.}$$

Example.—The height of water in a wind mill tank is 60 ft. How many gals. per min. will flow through 500 ft. of 1½ in. pipe with a vertical rise of 23 ft.?

2.3 ft. head = 1 lb. pressure

Hence

Pressure due to elevation of tank is

= 60 ÷ 2.3 = ... 26.1 lbs.

Pressure due to 23 ft. rise

23 ÷ 2.3 = ... 10 lbs.

Pressure available to cause flow = ... 16.1 lbs.

Pressure available per 100 ft. of pipe is

16.1 ÷ 5 = ... 3.2 lbs.

In table 1, two nearest values per 100 ft. 1½ in. pipe are given.

Pressure	Gals. per min.
2.3 lb.	20
4.8 lb.	30

from which 3.2 lbs. corresponds to a flow of $20+\frac{3.2-2.3}{4.8-2.3}$ of $10=23.6$ gals. per minute.

Example.—A ¾ in. pipe runs 75 ft. with a vertical rise of 23 ft. What pressure will be required at the mains in the street in order to deliver 10 gals. per minute through a ½ in. faucet?

From Table 1

Loss through 75 ft. of pipe, due to friction

$=16.5\times\frac{75}{100}=$ .... 12.4 lbs.

Loss due to rise of 23 ft.

= 23 ÷ 2.3 = ... 10 lbs.

From Table 2

Loss in flowing through faucet at 10 gals. per minute = ... 15 lbs.

Total pressure required .... 37.4 lbs.

In most installations the loss due to flowing through the meter, must be allowed, for Prof. Russell's experiments show the meter loss to average about as follows:

TABLE 3

Meter Loss

Size of Meter	Gals. per min.	Loss in Pressure Lbs.
⅝ in.	10	2 to 7
⅝ in.	30	16 to 65
¾ in.	30	14 to 30
1 in.	30	4 to 7

At the same rate of flow, 30 gals., it will be seen that as the size of meter increases, the loss in pressure in passing through the meter drops off rapidly.

Example.—A ¾ in. pipe passes through a meter, runs 125 ft. from the main to a faucet. The faucet is 23 ft. above the street main, and must deliver 10 gals. per min. What pressure will be required at the main to obtain this rate of discharge?

From Table 1,

Loss due to friction in 125 ft. of pipe $=16.5\times1.25=$	20.6 lbs.
Loss due to height $=23\div2.3=$	10 lbs.
Loss in passing through faucet = (From Table 2)	15 lbs.
Loss through meter arbitrarily taken as	3 lbs.
Pressure required at street main	48.6 lbs.

In these calculations no account has been taken of the loss in pressure due to the use of fittings. Unless these are somewhat numerous, the loss may sometimes be overlooked or estimated.

According to Prof. Russell: "A rough rule for calculating the loss in pressure due to an elbow in small pipes is *to allow from ¼ to ½ lb.* which points to the desirability of using *as few fittings as possible.* The reaming of pipe is advisable for the same reason."

Loss of Head Due to Friction

Loss of Head in Feet in Various Sizes of Smooth 90° Elbows							Loss of Head in Feet per 100 Feet of Smooth Pipe						
Gallons Per Min. Delivered	PIPE SIZES, INCHES—INSIDE DIAMETER						Gallons Per Min. Delivered	PIPE SIZES, INCHES—INSIDE DIAMETER					
	1	1¼	1½	2	2½	3		1	1¼	1½	2	2½	3
20	2.52	.89	.42	.146	.067	.038	20	42.0	11.1	5.2	1.82	0.61	0.25
25	3.84	1.33	.62	.218	.101	.057	25	64.0	16.6	7.8	2.73	0.92	0.38
30	5.44	1.88	.88	.307	.142	.083	30	89.0	23.5	11.0	3.84	1.29	0.54
35	7.14	2.50	1.18	.408	.189	.107	35	119.0	31.2	14.7	5.1	1.72	0.71
40	9.12	3.20	1.50	.528	.242	.137	40	152.0	40.0	18.8	6.6	2.20	0.91
45	......	4.00	1.86	.656	.308	.173	45	....	50.0	23.2	8.2	2.80	1.15
50	......	4.80	2.27	.792	.365	.207	50	....	60.0	28.4	9.9	3.32	1.38
70	......	9.04	4.24	1.43	.683	.286	70	....	113.0	53.0	18.4	6.21	2.57
75	......	......	4.80	1.67	.781	.458	75	....	....	60.0	20.9	7.1	3.05
90	......	......	6.72	2.32	.991	.600	90	....	....	84.0	29.4	9.81	4.01
100	......	......	3.16	2.86	1.32	.744	100	....	....	102.0	35.8	12.0	4.96
125	......	......	......	4.32	2.06	1.14	125	....	....	....	54.0	18.2	7.6
150	......	......	......	6.08	2.81	1.58	150	....	....	....	76.0	25.5	10.5
175	......	......	......	8.16	3.72	2.10	175	....	....	....	102.0	33.8	14.0
200	......	......	......	10.32	4.74	2.67	200	....	....	....	129.0	43.1	17.8
250	......	......	......	......	7.26	4.08	250	....	....	....	....	66.0	27.2

Loss of Head Due to Friction.—The above table prepared by Higgins gives the loss due to friction in terms of head in feet for various sizes of smooth 90° elbows and for 100 feet of various sizes of smooth pipe.

The Flow of Water in Pipes.—The quantity of water discharged through a pipe depends upon:

1. Head
2. Length of the pipe
3. Character of interior surface
4. Number and sharpness of bends

Ques. How is the head measured?

Ans. The vertical distance is measured between the level surface of still water at the entrance end of the pipe and the level of the center of the discharge end.

Ques. Upon what is the flow independent?

Ans. It is independent of the position of the pipe whether horizontal or inclined.

Total Head Causing Flow.—The total head operating to cause flow is divided into three parts:

1. The velocity head
2. The entry head
3. The friction head

Ques. What is the velocity head?

Ans. It is the height through which a body must fall in a vacuum to acquire the velocity with which the water flows into the pipe.

Expressed as a formula

$$\text{Velocity head} = v^2 \div 2g$$

in which

v = velocity in feet per second
$2g$ = 64.32

Ques. What is the entry head?

Ans. The head required to overcome the resistance to entrance to the pipe.

With sharp edged entrance entry head = about ½ the velocity head.

With smooth rounded entrance the entry head may be disregarded.

Ques. What is the friction head?

Ans. The head due to the frictional resistance to flow within the pipe.

In the case of long pipes the sum of the entry and velocity heads required scarcely exceeds a foot.

In the case of long pipes with low heads the sum of the velocity and entry heads is generally so small that it may be neglected.

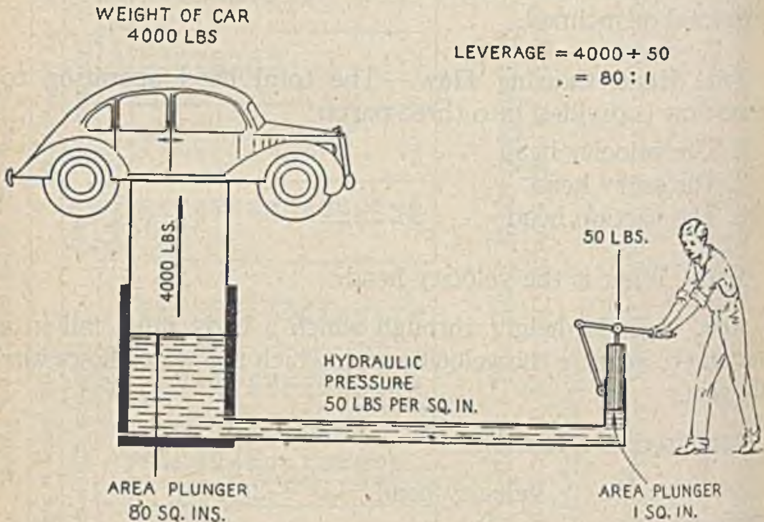


Fig. 20.—Surface pressure exerted by a liquid in effect depending upon the ratio of face areas of the two plungers. The size of the large plunger is tremendously exaggerated to emphasize the principle involved.

Surface Pressure Exerted by a Liquid.—It is an important hydraulic principle that *the pressure exerted by a liquid on a surface is* **proportional** *to the area of the surface.*

Due to this principle, jacks capable of lifting great weight and pumps capable of pumping against pressures are possible.

Two examples are given illustrating this principle, but which give opposite results. First consider the familiar auto lifting jack at a service station, as shown in fig. 20.

The little plunger is assumed to have an area of 1 sq. in. If the man exert a pressure of 50 lbs. on this plunger, it will result in a pressure of 50 lbs. per sq. in. in the system. Evidently the larger the lifting plunger the greater its lifting power, because a pressure of 50 lbs. per sq. in. will be exerted upon each sq. in. of area of its face. Hence with the man exerting a 50 lb. pressure, the area of the large plunger required to lift a car weighing 4,000 lbs. is

$$4000 \div 50 = 80 \text{ sq. in.}$$

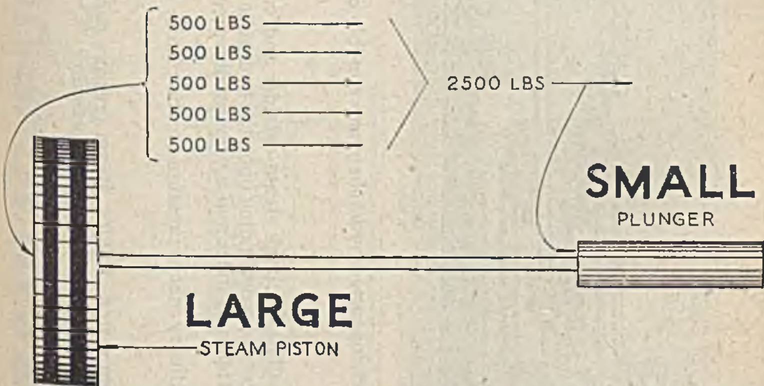


Fig. 21.—The multiplication of pressure per sq. in. by driving a small plunger with a large steam piston. The method employed in extra high pressure pumps generally known as hydraulic pumps. The big plunger is purposely drawn ridiculously out of scale to emphasize once and for all the considerable difference in plunger areas to get the necessary leverage.

$$\text{diameter of large plunger} = \sqrt{\frac{\text{area}}{.7854}} = \sqrt{\frac{80}{.7854}} = 10 \text{ ins. (approx.)}$$

Sometimes it is desired to obtain the reverse of the condition just given, as where for instance water is to be pumped against great pressure.

Pumps for such service are known as *hydraulic pumps*.

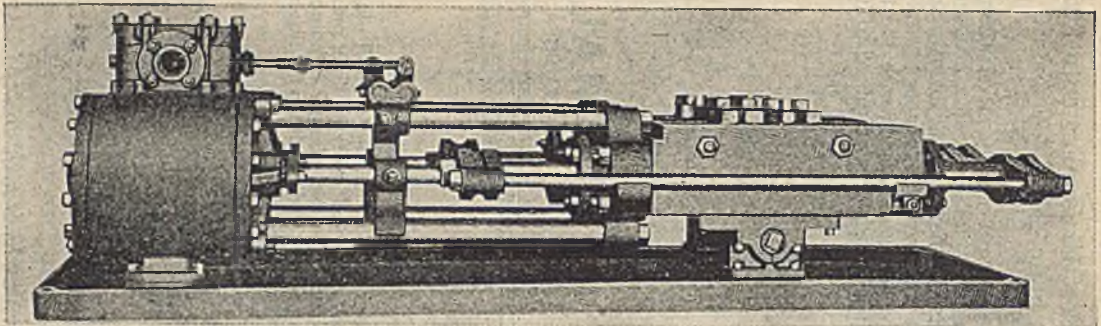


Fig. 22.—External appearance of direct connected hydraulic pump capable of pumping at pressures of 8,000 lbs. per sq. in. or higher.

These pumps have a proportionally very large steam cylinder and very small plunger directly connected, the ratio of piston and plunger areas depending upon the hydraulic pressure to be pumped against. Thus in fig. 21 note the very large steam cylinder and a very small water plunger.

It must be evident that with ordinary steam pressure on the piston, the small plunger will produce very great hydraulic pressure.

Example.—With a 10 inch steam piston, 100 lbs. steam pressure per sq. in., what must be the size of the plunger to pump against 8,000 lbs. per sq. in. water pressure?

Area 10 in piston $= \frac{1}{4} \pi d^2 = .7854 \times 10^2 = 78.54$ sq. ins.

HYDRAULIC PUMP

(FOR PRESSURES UP TO 8000 LBS. PER SQ. IN. OR MORE)

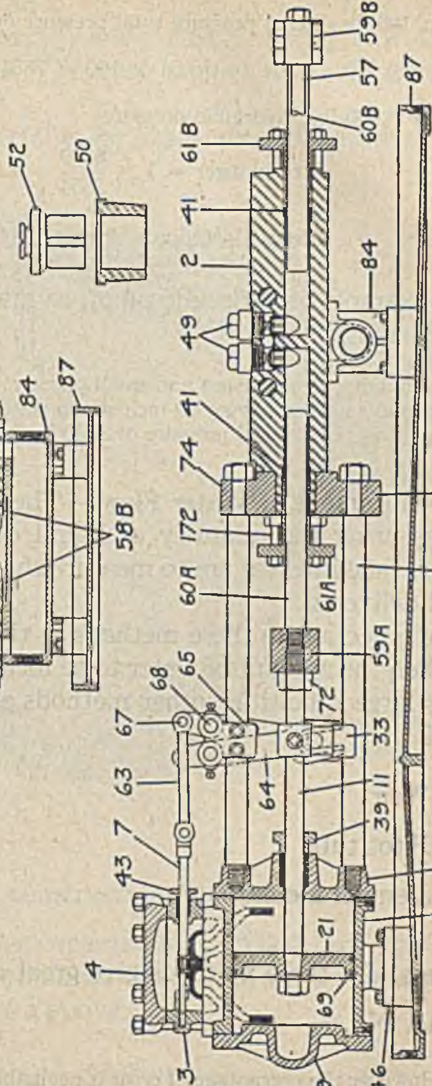


Fig. 23.—Sectional views showing construction of the pump shown in fig. 22.

At 100 lbs. steam pressure total pressure on steam piston

$$= 78.54 \times 100 = 7854 \text{ lbs.}$$

For 8,000 lbs. hydraulic pressure

$$\text{Area plunger} = 1 \times \frac{8000}{7854} = 1.02 \text{ sq. ins.}$$

Diam. $1\frac{3}{16}$ (approx. from table).

An example of hydraulic pump as manufactured is shown in figs. 22 and 23.

Note large steam piston and small plunger. Typical of proportions is a size pump listed as having 10 inch steam piston and 1 inch water plunger designed for a balanced pressure of 8100 lbs. with 90 lb. steam pressure.

Measurement of Water Flow.—The most accurate methods of measuring the quantity of liquid delivered by a pump in a given time interval are to measure the volume or to weigh the liquid delivered.

The objection to these methods is that they are only possible when the amount of water to be measured is small.

For large quantities other methods are used such as by the use of

1. Weir
2. Pitot tube
3. Venturi meter

Ques. Do these methods give great accuracy?

Ans. No.

However the percentage of error is negligible for commercial purposes.

Measurement by Weirs.—By definition a weir is: *A device commonly used for measuring water flow consisting of a notch in the vertical side of a tank or reservoir through which the water may flow to be measured.*

Weirs are used especially for measuring the flow of small streams.

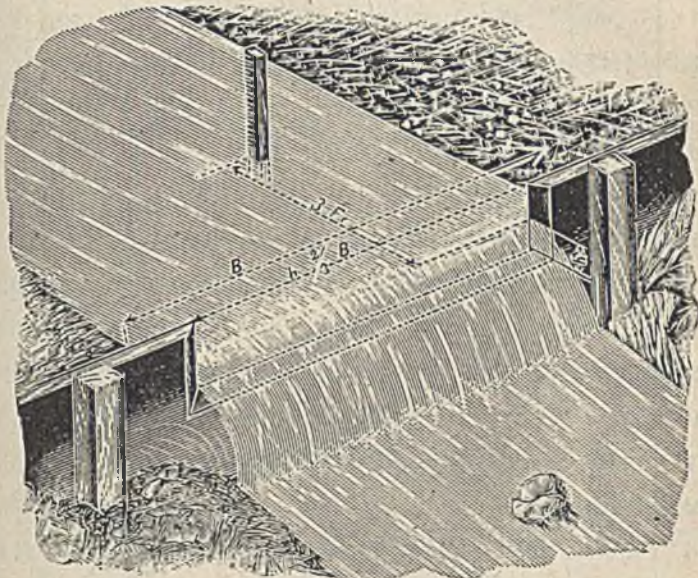


Fig. 24.—Typical weir.

Ques. Describe the construction and installation of a weir.

Ans. The weir proper consists of a notched board as shown in fig. 24. Place the board across the stream at some point which will allow a pond to form above.

Ques. How should the notch be cut in the board?

WEIR TABLE

INCHES		1/8	1/4	3/8	1/2	5/8	3/4	7/8
0	.00	.01	.05	.09	.14	.19	.26	.32
1	.40	.47	.55	.64	.73	.82	.92	1.02
2	1.13	1.23	1.35	1.46	1.58	1.70	1.82	1.95
3	2.07	2.21	2.34	2.48	2.61	2.76	2.90	3.05
4	3.20	3.35	3.50	3.66	3.81	3.97	4.14	4.30
5	4.47	4.64	4.81	4.98	5.15	5.33	5.51	5.69
6	5.87	6.06	6.25	6.44	6.62	6.82	7.01	7.21
7	7.40	7.60	7.80	8.01	8.21	8.42	8.63	8.88
8	9.05	9.26	9 47	9.69	9.91	10.13	10.35	10.57
9	10.80	11.02	11.25	11.48	11.71	11.94	12.17	12.41
10	12.64	12 88	13.12	13.36	13.60	13.85	14.09	14.34
11	14.59	14.84	15.09	15.34	15.59	15.85	16.11	16.36
12	16.62	16.88	17.15	17.41	17.67	17.94	18.21	18.47
13	18.74	19.01	19.29	19.56	19.84	20.11	20.39	20.67
14	20.95	21.23	21.51	21.80	22.08	22.37	22.65	22.94
15	23.23	23.52	23.82	24.11	24.40	24.70	25.00	25.30
16	25.60	25.90	26.20	26.50	26.80	27.11	27.42	27.72
17	28.03	28.34	28.65	28.97	29.28	29.59	29.91	30.22
18	30.54	30.86	31.18	31.50	31.82	32.15	32.47	32.80
19	33.12	33.45	33.78	34.11	34.44	34.77	35.10	35.44
20	35.77	36.11	36.45	36.78	37.12	37.46	37.80	38.15

Ans. The notch should be cut in the board with both side edges and the bottom sharply beveled as shown in the cut.

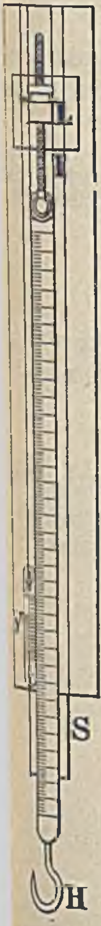


Fig. 25.—Hook gauge.

Ques. What name is given to the bottom of the notch?

Ans. It is called the *crest* of the weir.

The crest should be perfectly level and the sides vertical.

Ques. What device is used to measure the depth of the water?

Ans. In the pond back of the weir, at a distance less than the length of the notch drive a stake near the bank with its top exactly level with the crest.

Ques. How is the depth of the water over the top of the stake measured?

Ans. With a graduated rule as shown.

Ques. How is the depth measured with precision?

Ans. By means of a hook gauge.

Ques. What is a hook gauge?

Ans. An adjustable instrument for measuring depth of water over a weir.

A typical hook gauge is shown in fig. 25.

A slide having a scale attached is arranged to slide up and down in the frame and capable of fine adjustment by means of the screw T which passes through a lug L, and having a milled nut. A vernier V is also provided.

Ques. How is the depth of the water measured?

Ans. The gauge is first set to zero (at which reading the point of the hook will be level with the crest of the weir) and the slider raised until the hook pierces the surface of the water.

This causes a distortion of the light reflected from the surface. On moving the hook downward again very slightly, the exact surface of the water will be indicated.

Ques. Where is the hook gauge located and why?

Ans. It must be located some distance back of the weir in order to avoid the effect of the curvature of the surface of the liquid as it approaches the weir.

Weir Formulae.—All formulae for weirs do not give the same results. The Francis formula is widely used. It was obtained from a series of experiments on 10 ft. weirs. The Francis formulae are:

$$Q = 3.33\ (L - .1H)\ H^{\frac{3}{2}} \text{ for one end contracted.}$$

$$Q = 3.33\ (L - .2H)\ H^{\frac{3}{2}} \text{ for both ends contracted.}$$

$$Q = 3.33\ (L - H^{\frac{3}{2}}) \text{ without end contractions.}$$

NOTE.—A weir with the vertical edges of the notch distant from the sides of the tank or reservoir, so that the sides of the stream may be fully contracted, is known as a *weir with end contractions*.

NOTE.—A weir with the vertical edges of the notch coincident with the sides of the tank or reservoir so that the filaments of liquid along the sides pass over the crest without being deflected from the vertical planes in which they move, is known as a *weir without end contractions*.

In these formulae

Q = cubic feet per second

L = length of weir in feet

H = head over crest in feet

A formula used for the triangular or V notch weir (for measuring small flows) is

$$Q = 2.544\ H^{\frac{5}{2}}$$

Here H = head in feet above apex of triangle.

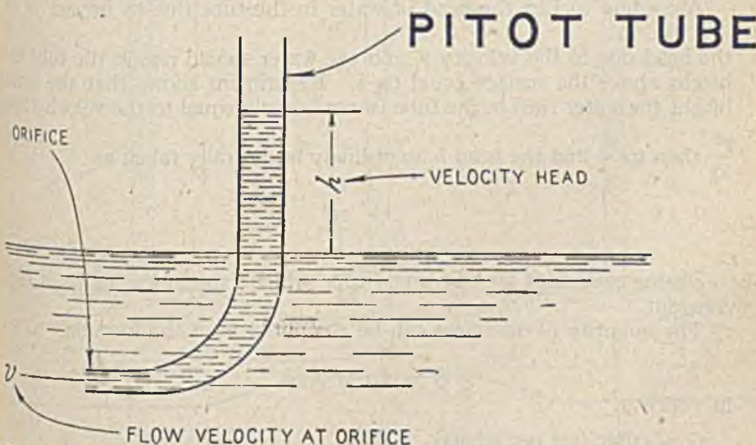


Fig. 26.—Elementary pitot tube showing essentials and placement in the water whose flow is to be measured.

Water Flow Measurement with Pitot Tube.—By definition, a pitot tube is: *A bent tube used to determine the velocity of running water, by placing the curved end under water and observing the height to which the fluid rises in the tube.* A kind of current meter. Its essential feature is the orifice at the curved end of the tube which is thin edged.

Ques. What is the principle upon which the tube is based?

Ans. When placed in running water with the orifice turned up stream, *the impact of the fluid causes an* **excess pressure** *in the tube equal to the* **velocity head.**

Pitot Tube Formula.—The simplest form of Pitot tube as proposed by Pitot consists of a glass tube with a small orifice at one end which may be turned to receiving the impact of the water flow as in fig. 26.

According to Lea the head of water in the tube due to impact $= \frac{v^2}{g}$, the head due to the velocity v, and the water should rise in the tube to a height above the surface equal to h. Experiment shows that the actual height the water rises in the tube is more nearly equal to the velocity head $\frac{v^2}{2g}$ than to $\frac{v^2}{g}$ and the head h accordingly is generally taken as

$$h = \frac{cv^2}{2g}$$

c being coefficient for any given tube which experiment shows is fairly constant.

The quantity of discharge can be computed from the formula

$$Q = ca\sqrt{2\,gh}$$

in which

Q = cubic feet per second

c = coefficient of discharge for the orifice (= .95 to .98)

a = area of the orifice in square feet

h = velocity head in feet

Water Measurement with Venturi Meter.—By definition, a venturi meter is: *An instrument similar in shape to an hour glass for accurately measuring the discharge of fluid or gas through a pipe.* It consists of a conical nozzle-like reducer followed by a more gradual enlargement to the original size, which is that of the pipe line in which the meter is laid.

The essentials of such meter are shown in the elementary drawing fig. 27.

By means of the vertical tubes **A, B, C,** the pressure heads in the pipe at these points are shown as they appear when measured by open water columns. Experiments show that h_2

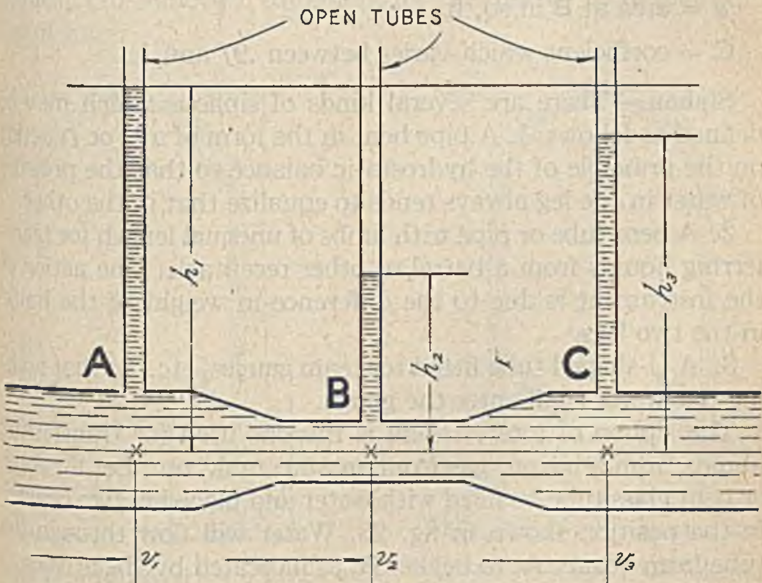


Fig. 27.—Elementary venturi meter showing pressure heads at points **AB** and **C.**

is less than h_1 by very nearly the difference in velocity heads, that is,

$$\frac{v_2^2}{2g} - \frac{v_1^2}{2g}$$

The head h_3 at **C,** is nearly that at **A,** or h_1 the diminution being accounted for by loss due to friction of the flowing water.

An equation for the discharge past the meter as given by Kent is

$$Q = (CAa\sqrt{2gh}) \div \sqrt{A^2 - a^2}$$

in which

Q = discharge in cu. ft. per second

A = area at **A** in sq. ft.

a = area at **B** in sq. ft.

C = coefficient which varies between .97 and 1.

Siphon.—There are several kinds of siphons which may be defined as follows: 1. A pipe bent in the form of a **U** or **∩** acting on the principle of the hydrostatic balance so that the pressure of water in one leg always tends to equalize that in the other.

2. A bent tube or pipe with limbs of unequal length for transferring liquids from a barrel or other receptacle. The action of the instrument is due to the difference in weight of the liquid in the two legs.

3. A U-shaped tube fitted to steam gauges, etc., so that nothing but water shall enter the gauge.

The siphon of interest here is the one used for transferring liquids from a barrel, gas from an auto tank, etc. Let a rubber or bent glass tube be filled with water and placed in two beakers in the position shown in fig. 28. Water will flow through the tube from beaker **A**, to beaker **B**, as indicated by the arrows.

Ques. Why does the water flow from **A** to **B**?

Ans. Because the height h, of the column at **A**, above the surface of the water is less than height h_1, of column at **B** above surface of the water.

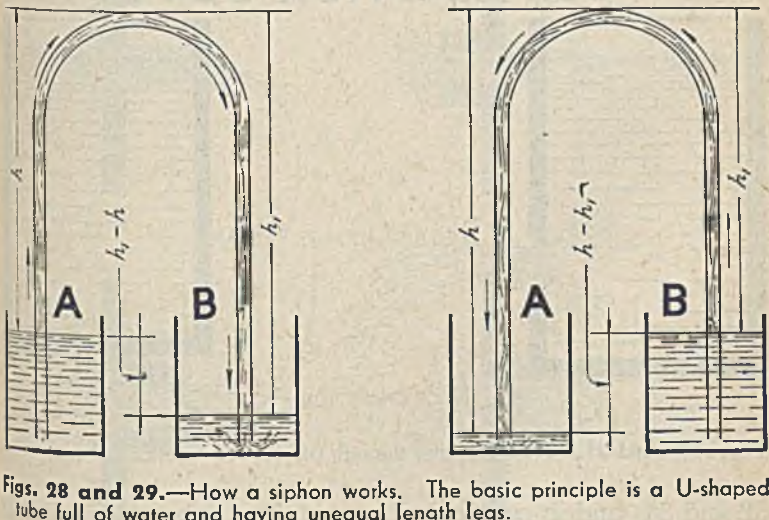
The motive force is due to the weight of a column of water of length $= h_1 - h$.

Ques: If the water in beaker **B**, be at a higher elevation than that in **A**, what happens?

Ans. The flow will be reversed as indicated in fig. 29.

Here leg h is longer than h_1 and the motive force is due to the weight of a column of water of length $= h - h_1$.

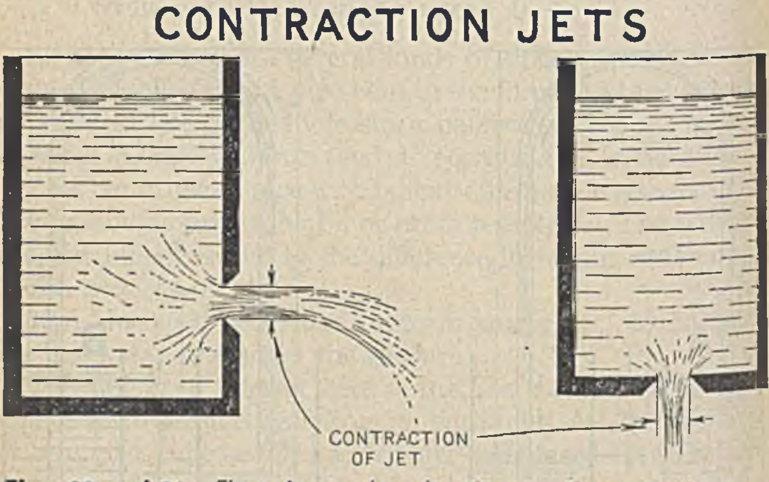
Ques. Give another statement for the motive power causing flow of water.



Figs. 28 and 29.—How a siphon works. The basic principle is a U-shaped tube full of water and having unequal length legs.

Ans. The atmosphere presses equally upon the water in each beaker, tending to force the water up in the columns. This is resisted by unequal weight of water in the two columns which upsets equilibrium and causes the water to flow from the beaker having the shorter column to the beaker having the longer column.

Flow Through Orifices.—If an orifice be cut through the flat side or bottom of a vessel and have sharp edges as in figs. 30 and 31, the stream lines set up in the water approach the orifice in all directions as shown, and the directions of flow of the particles of water except very near the center converge, producing a contraction of the jet when the orifices are not properly shaped. Accordingly the area of the jet is not as great as that of the orifice. For properly rounded approaches to orifices (as in figs.



Figs. 30 and 31.—Flow of water through orifices 1. Contraction jets.

32 and 34) and in constant diameter short tubes (as in figs. 33 and 35) the diameter of the jet equals the area of the orifice or tube. In the tube fig. 35, an initial contraction takes place in the tube as shown because the tube has no rounded entrance.

The general velocity equation for water flowing from an orifice or tube is

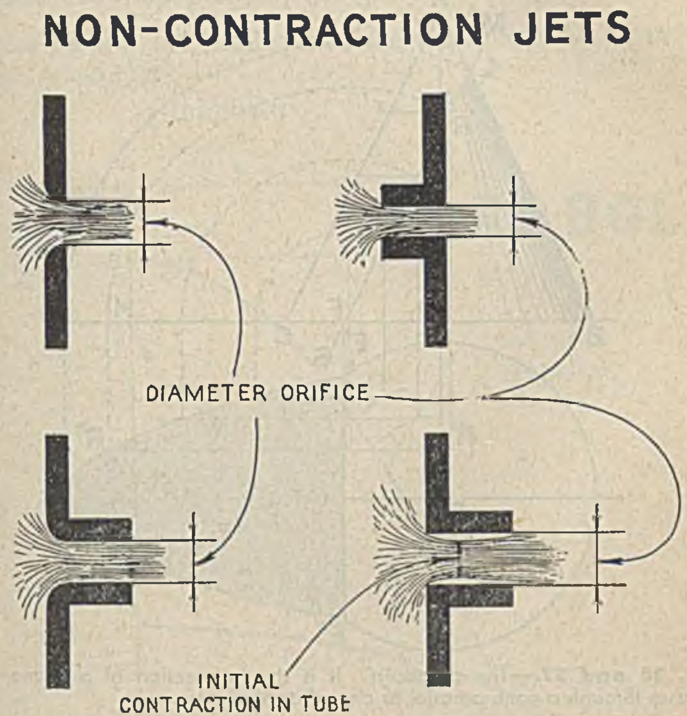
$$v = \sqrt{2gH}$$

in which

v = theoretical velocity ft. per sec. Corresponding to head H.

H = head of water in ft. on the center line of a freely flowing jet from an orifice or tube.

g = acceleration due to gravity = 32.2 ft. per sec.



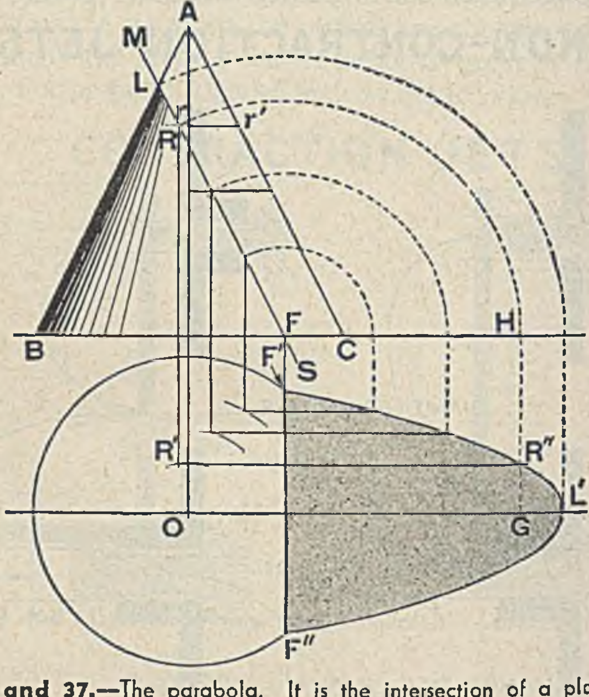
Figs. 32 to 35.—Flow of water through orifices 2. Non-contraction jets.

Considering friction and contraction of jet the general equation for discharge is

$$Q = Ca\sqrt{2gH}$$

in which

Q = discharge in cu. ft. per sec.
C = coefficient of discharge which = product of coefficient of friction C_1, and coefficient of contraction C_2.
a = area in sq. ft. of the orifice or tube.



Figs. 36 and 37.—The parabola. It is the intersection of a plane which passes through a cone parallel to one of its elements.

Ques. What is the path described by a jet issuing from a horizontal orifice or tube?

Ans. It describes a parabola.

Ques. What is a parabola?

Ans. *A plane curve* (being one of the conic sections) *such that the distance of every point in it from a fixed point called the* **focus** *is equal to the distance of the same point from a fixed line called the* **diretrix.**

Ques. How is a parabola generated?

Ans. By a plane cutting a cone parallel with an element as in figs. 36 and 37.

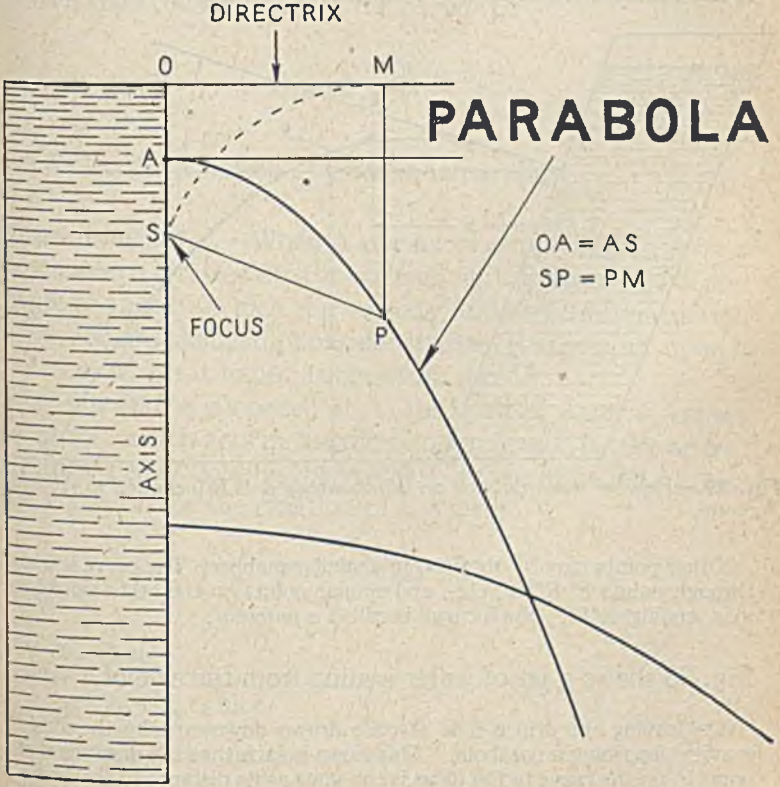


Fig. 38.—Flow of water through an orifice whose axis is horizontal.

Here let the plane MS, cut element AB, at L, and the base at F. Project F down to plan cutting base at F′ and F″ which are two points in the curve.

With F, as center and radius LF, swing point L, around and project down to axis of plan, obtaining point L′ in the curve.

Now any other point as R, may be obtained as follows: swing R around with F as center and project down to plan with line HG.

Describe an arc in plan with a radius (=radius rr′ of cone at elevation of point R), and where such cuts the projection of R at R′; project R′ over to line HG, and obtain point R″, which is a point in the curve.

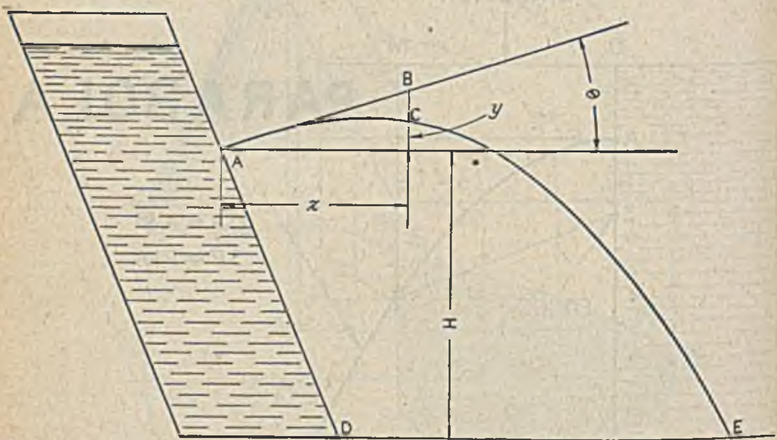


Fig. 39.—Flow of water through an orifice whose axis is inclinded to the horizontal.

Other points may be obtained in a similar manner. The curve is traced through points F′,R″,L′, etc., and similar points on the other side of the axis, ending at F″. Such curve is called a *parabola*.

Fig. 38 shows a jet of water issuing from the side of a vessel.

On leaving the orifice it is at once drawn downward by the force of gravity describing a parabola. This curve is such that the distance of any point P, on the curve to the focus is the same as its distance to the directrix that is

$$PS = PM$$

as indicated by the dotted arc described with P, as center.

A more general case is shown in fig. 39 when the side AD of the vessel is inclined to the vertical at an angle Θ. Here according to Merriman the jet issues normal to AD, rises to a highest point C, and then curves downward. If x and y are horizontal absassa and vertical ordinate measured from A, it may be shown that the equation of the curve is

$$y = x \tan \Theta - \frac{x^2 \sec^2 \Theta}{4\,h}$$

which is also the equation of a common parabola.

Reaction of a Jet.—When a stream of water impinges on a solid surface it presses on the surface with a force equal and opposite to that by which the velocity and direction of motion of the water are changed. Consider the reaction of a jet upon a vessel from which it issues as shown in fig. 40.

When the orifice is opened at A, the head of water h, causes a pressure P, which acts in the direction indicated by the arrow; this causes the car holding the vessel to move to the left.

The equation for the reaction of the jet is

$$P = 2\,A\,hw$$

in which

P = reaction

A = area of the orifice

h = head of water on the orifice

w = weight of unit volume of the water

Again, the head of water on the jet causes a pressure which acts toward the left and causes W lbs. of water to move during every second with a velocity v, feet per second; this is *impulse*.

The effect of impulse produces a pressure which acts toward the right and causes the car to move in a direction opposite to the direction of jet flow; this is *reaction*.

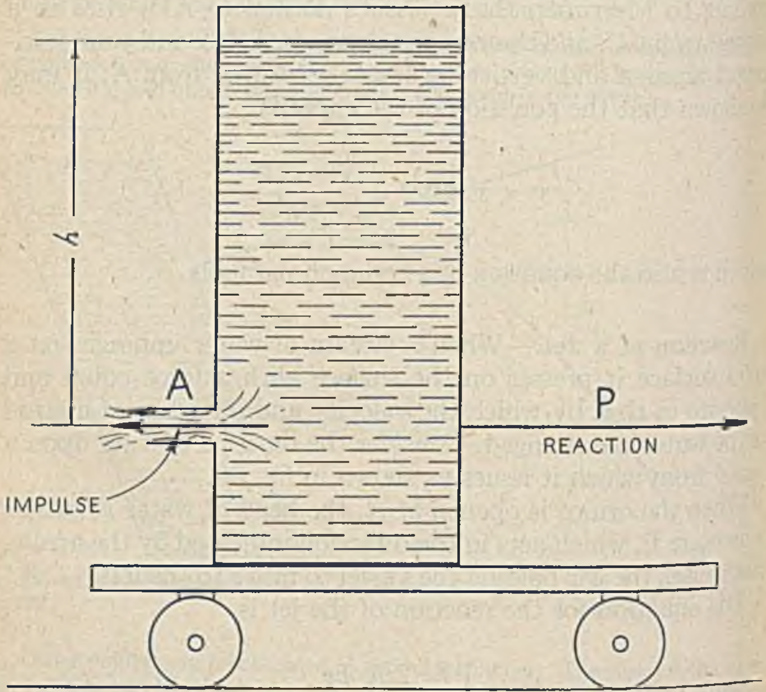


Fig. 40.—Water flowing through orifice illustrating **impulse** and **reaction.**

Specific Gravity.—By definition, the weight of a given substance relatively to an equal bulk of some other substance, which is taken as a standard of comparison. Water is the standard for liquids and solids, and that is the standard that will here be considered.

In the case of solids, specific gravity is the ratio of the weight of a substance in air to that of an equal volume of water. That is, it is a number indicating how many times a certain volume of a substance is heavier than an equal volume of water.

Ques. What should be noted as to the temperature of the water?

Ans. Since the density of water varies with the temperature, comparisons should be made with the water at a temperature of 62° Fahr.

Ques. What is the weight of one cu. in. of pure water at 62°?

Ans. .0361 lbs.

Ques. If the specific gravity of any material be known how is its weight per cu. in. found?

Ans. By multiplying its specific gravity by .0361.

To find the weight of a cu. ft. of the material multiply its specific gravity by 62.35 which is the weight of one cu. ft. of water at 62° Fahr.

Example.—If the specific gravity of wrought iron be 7.85 what is its weight per cu. in.?

Water at 62° weighs .0361 lb. From which weight of one cu. in. of wrought iron

$$=7.85\times0.361=.2834 \text{ lb.}$$

Ques. What is the specific gravity of liquids?

Ans. A number which indicates how much a certain volume of the liquid weighs compared with an equal volume of water (at 62° F.).

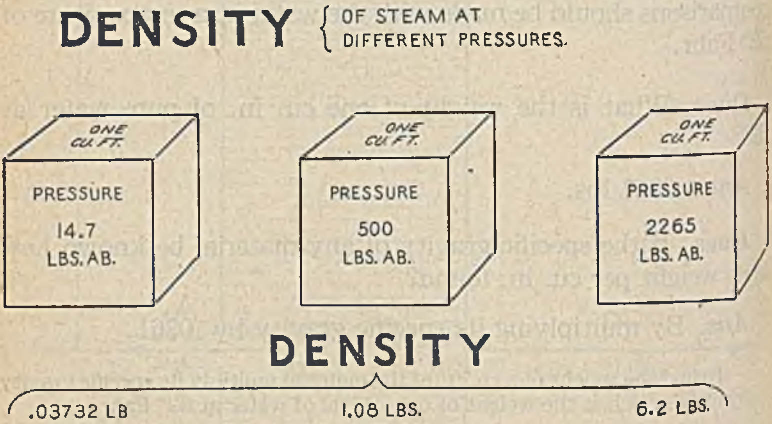
Ques. What is the density of a substance?

Ans. The mass of that substance per unit volume.

If *weight* be used in the ordinary sense as being equivalent to *mass*, then the density may be defined as *the weight per unit volume*. A striking illustration is the density of steam at different pressures as indicated in figs. 41 to 43.

Note how the weight or density of the steam increases with the pressure.

Another striking example is the effect of temperature on the density of water as shown in figs. 44 to 46.



Figs. 41 to 43.—Density of steam at different pressures.

It's simply a case of *expansion*, with *rise* of temperature. That is, as the temperature rises the original volume of water at the low temperature rises and occupies more space and becomes lighter per unit volume. For instance, place in a long vertical tube a unit volume of water in amount, say a column one foot high and at a temperature of 32° Fahr. Heat the water to the boiling point (at atmospheric pressure) 212°. The water will expand and rise to a level 1.04. Since the volume is greater the weight for the original volume becomes less.

The effect is much more pronounced at a very high temperature.

Now to heat the water above 212° it is necessary to close the top of the tube, otherwise vaporization would take place without rise of temperature.

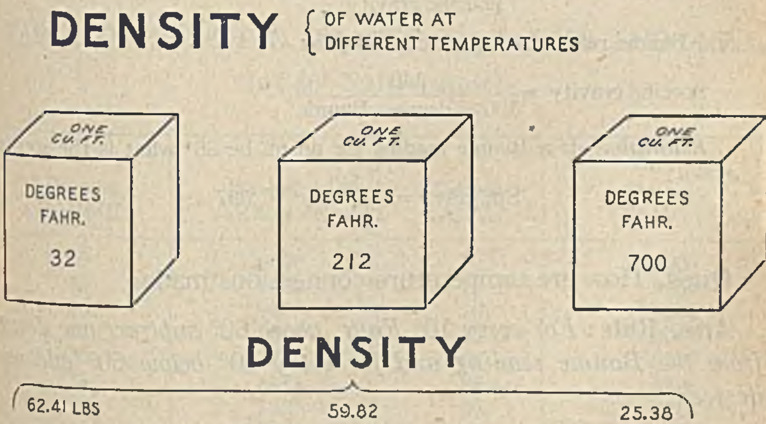
Accordingly with top of the vessel closed, raise the temperature to say 700°. *For a given temperature of the water there is a certain external pressure above which steam will not form.* This temperature for water at 700° is (from the steam table) 3075 lbs. abs.* The density of water at 32°, 212° and 700° Fahr. is shown in figs. 44 to 46.

Ques. How is the density of liquids usually expressed?

Ans. In degrees on a hydrometer.

Ques. What is a hydrometer?

Ans. An instrument for determining the density of liquids provided with graduations made to an arbitrary scale.



Figs. 44 to 46.—Density of water at different temperatures, with rise of temperature.

Ques. Describe the construction of a hydrometer.

Ans. Its principal part is a glass closed tube with a weighted bulb at one end and containing air. The weighted bulb at the

*NOTE.—For steam tables see Audels Engineers and Mechanics Guide volume No. 1, pages 40 to 46, by the author.

lower end causes it to float upright in the liquid whose density is to be measured. The depth to which the hydrometer sinks in the liquid is read off on the arbitrary scale which gives the specific gravity.

Ques. What scale is generally used?

Ans. The Baume.

The value of degrees on the Baume scale differs depending upon whether the liquids be lighter or heavier than water. Specific gravity can be converted to Baume reading by the formula:

$$\text{Degrees Baume} = \frac{140}{\text{Specific gravity}} - 130$$

and Baume reading to specific gravity by

$$\text{Specific gravity} = \frac{140}{130 + \text{degrees Baume}}$$

Example.—If a Baume reading for an oil be 26° what is the specific gravity?

$$\text{Sp. grav.} = \frac{140}{130+26} = .897$$

Ques. How are temperature connections made?

Ans. **Rule:** *For every* 10° *Fahr. above* 60° *subtract one degree from the Baume reading and for every* 10° *below* 60° *add one degree.*

Example.—If a hydrometer indicate a specific gravity of 27.5° Baume and the temperature of the oil being tested be 75° Fahr., what is the correct reading?

Subtracting one degree for each 10° Fahr.

$$\text{Subtract } \frac{15}{10} = 1.5°$$

From which, corrected reading

$$= 27.5° - 1.5° = 26°$$

Ques. What is the A.P.I. (American Petroleum Institute) scale for measuring petroleum products.

Ans. The scale is obtained from the following formula:

$$\text{Degrees A.P.I.} = \frac{141.5}{\text{sp. grav.}} - 131.5$$

The A.P.I. degrees may be converted to specific gravity by the following formula:

$$\text{Specific gravity} = \frac{141.5}{131.5 + \text{degrees A.P.I.}}$$

TABLE OF SPECIFIC GRAVITIES, BAUMÉ AND A.P.I.

(at 60° Fahrenheit)

Degrees BAUMÉ	Specific GRAVITY	Degrees A.P.I.	Specific GRAVITY
10	1.0000	10	1.0000
15	.9655	15	.9659
20	.9333	20	.9340
25	.9032	25	.9042
30	.8750	30	.8762
35	.8485	35	.8498
40	.8235	40	.8251
45	.8000	45	.8017
50	.7777	50	.7796
55	.7568	55	.7587
60	.7368	60	.7389
65	.7179	65	.7201
70	.7000	70	.7022
75	.6829	75	.6852
80	.6666	80	.6690
85	.6511	85	.6536
90	.6363	90	.6388

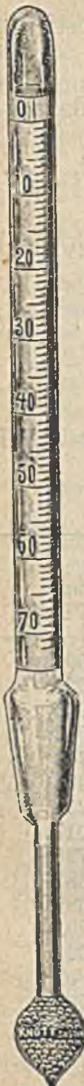


Fig. 47.—Ordinary hydrometer with Baumé scale reading from zero to 70°.

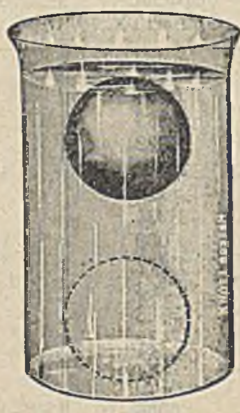


Fig. 48.—Density indicating ball for illustrating the changes in a liquid induced by variations in temperature. The hollow metal ball is adjusted to float in cold water. It will sink in warm water.

Ques. Name an important use made of hydrometers?

Ans. They are used for testing anti-freeze solutions in automobile radiators.

Fig. 47 shows a typical hydrometer having Baume scale 0–70 and specific gravity scale 1.000 to 2.000 for finding specific gravity of heavy liquids. A similar hydrometer for finding specific gravity of light liquids is provided with a Baume scale 70–10; specific gravity scale .7000 to 1.000. Included with the hydrometer is a tall glass jar in which the liquid and hydrometer are placed in testing.

Anti-Freeze Solutions.—In selecting anti-freeze, local conditions and type of service must be considered.

Alcohol.—Alcohols are sold in various concentrations as well as under various trade names. Therefore, alcohols should always be used in the proportions recommended by the anti-freeze manufacturer.

Alcohol solutions are volatile; therefore, it is impractical to use a higher opening thermostat in connection with hot water car heaters than the standard thermostat furnished by the car manufacturer.

Alcohol is not injurious to the materials used in the cooling system and no particular damage results when small quantities get into the crank case.

The car finish can be damaged by contact with alcohol or its vapors, and any material accidentally spilled on the finish should be flushed off immediately with a large quantity of clean, cold water.

Slight evaporating losses occur with all alcohol anti-freeze solutions. A major loss of solution results when the solution is allowed to boil. This is usually the result of using a solution too highly concentrated, the use of high opening thermostats, idling the engine for long periods of time, or suddenly stopping the engine following a hard run.

Radiator Glycerine (Anti-Freeze Grade).—Radiator glycerine produced under the formula approved by the Glycerine Producers Association and sold in the United States for anti-freeze purposes, is chemically treated to covercome the difficulties presented with untreated glycerine and under normal operating conditions should be satisfactory for use in the cooling system.

Glycerine in first cost is more expensive than alcohol, but as it is not lost by evaporation, only water need be added to replace evaporation losses. Any solution lost mechanically must be replaced by additional new anti-freeze solution. Cooling solution should be checked from time to time with a proper hydrometer for freezing point.

Because of the high boiling point of glycerine, a higher opening accessory thermostat (160°) can be used and more heat obtained from car heaters than would be possible with the standard thermostat. The solution under ordinary conditions is not injurious to the car finish.

The principal objection to glycerine is the gumming and sticking of the moving engine parts in event the solution leak into the crank case.

All radiator anti-freezes on the market should be used in accordance with the instructions and in proportions recommended by the anti-freeze manufacturer.

Testing Solutions.—Use only hydrometers which are calibrated to read the gravity and temperature and have a table or other means of converting the freezing point at various solution temperatures.

Care must be exercised to use the correct float or table for the particular solution. It is not practical to mix various types of anti-freeze in the same solution as it will not be possible to determine freezing point, using a hydrometer.

NOTE.— *The Spheroidal State.*—An apparently singular phenomenon connected with vaporization is that known as the spheroidal state. When a drop of water is let fall on a hot metal plate the drop ordinarily boils away violently with a hissng noise. If, however, the temperature of the metal be sufficiently high, the drop does not enter into ebullition, neither does it spread over the surface and wet it as at lower temperatures, but it rolls about on the surface like a globule of mercury. The phenomenon may be easily studied by raising a metal capsule to a white heat over a bunsen flame, and dropping a globule of water carefully into the dish from a pipette. While the temperature of the dish is maintained the drop remains as if on a greased surface. If the lamp be removed and the dish allowed to cool, a point will be reached at which the drop comes into contact with the surface, and violent ebullition sets in with the formation of a cloud of vapor. During the spheroidal condition it may be easily verified that the drop is out of contact with the hot metal. It is supported on a cushion of its own vapor. The eye placed on a level with the surface can easily observe through the interval between the drop (especially if it be colored dark) and the surface any bright object, such as a flame placed on the other side.—*Preston.*

CHAPTER 34

Hydraulic Drives

If it were not for the internal combustion engine with its **inherent** **defects**, *lack of power*, *torque flexibility*, *etc*., there would be no need of hydraulic drives.

To quote: "Make her do the job just like a steam engine."

This, in the words of the operator, has been the problem confronting engineers *ever since the introduction of the internal combustion engine.*

With a mechanically connected drive it is impossible for the internal combustion engine to attain the smoothness and flexibility of the steam engine no matter how many cylinders—and it never will.

Ques. What is the reason for the lack of flexibility of the internal combustion engine?

Ans. It depends upon a series of explosions in quick succession to produce torque and power and upon momentum stored in a heavy fly wheel to keep it going between explosions.

Ques. Why has the steam engine superior power characteristics?

Ans. It can deliver high torque at slow speeds which enables it to exert its maximum torque to start a heavy load.

Moreover without any shifting of gears or the use of complicated controls, the steam engine is able to deliver rapid smooth acceleration of the load to maximum speed without its power range—and this without any pauses and slow-downs as in shifting gears with the internal combustion engine.

Definition.—The term hydraulic drive (variously called fluid drive, liquid drive and what not) is: *A method of delivering power*

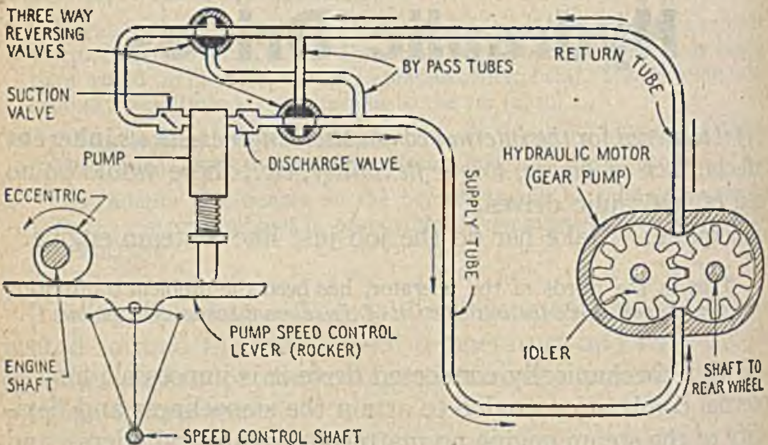


Fig. 1.—The pioneer of hydraulic drives, invented and built in 1900 by H. E. Raabe, M.E. **In construction,** a separate hydraulic motor (similar to ordinary gear pump) is attached to axle of each rear wheel, which permits differential rotation on curves. The illustration shows one of these motors, connecting piping, reversing valves, pump and pump drive. **In operation,** the eccentric on engine shaft gives an oscillating motion to rocker which operates pump, forcing oil through the system as indicated by the arrows. By turning the two reversing valves in unison 90°, the flow of oil and motion of car are reversed. Variable speed is obtained by shifting position of rocker fulcrum which varies stroke of pump. To avoid flow pulsations and jerky movement of car, a multi-cylinder pump is used.

from a prime mover to a driven member through the medium of a liquid with no mechanical connection. In other words a hydraulic drive is *a flexible hydraulic coupling.*

Ques. What is the object sought in this arrangement?

Ans. To overcome an inherent defect in the gas engine—lack of flexibility.

In other words it is an attempt to put the gas engine in a class with the steam engine with respect to flexibility and to a lesser degree, the electric vehicle.

Ques. What is the power transmitting medium used in the hydraulic drive?

Ans. Oil.

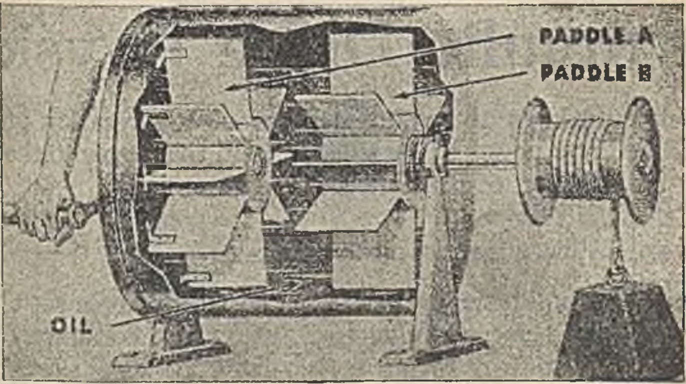


Fig. 2.—Elementary hydraulic drive consisting of two paddle wheels mounted on independent shafts and submerged in a liquid contained in an enclosing casing. Illustrating in part basic principles.

Ques. What kind of oil is used?

Ans. A low viscosity mineral, oil one having a pour point such that the oil will pour at the lowest anticipated temperature.

Ques. Can any kind of oil be used?

Ans. No.

A substitute oil lacking in any of the recommended properties is liable to cause trouble.

Essential Parts of the Hydraulic Drive.—This simple mechanism contains only three essential parts:

1. Driver
2. Follower (objectionably called runner)
3. Enclosing casing

Power from the engine is delivered to the driver and transmitted (flexibly) to the follower through the hydraulic medium. The basic idea is shown in fig. 2.

Hydraulic Drive Physics

Basic Principles of Hydraulic Drives.—In operation of the hydraulic drive power is transmitted from the driver to the follower by the effect of circulation of the oil.

Ques. What causes the oil to circulate?

Ans. The difference between the centrifugal force set up in the driver and the centrifugal force set up in the follower.

Ques. What is centrifugal force?

Ans. That force which acts upon a body moving in a circular path tending to force it farther from the axis of rotation.

Ques. If both driver and follower rotate at the same speed why doesn't the oil circulate?

Ans. Because the centrifugal force set up in the driver is opposed by an equal centrifugal force set up in the follower. Hence there is no excess force tending to circulate the oil.

Accordingly the oil circulates only when the centrifugal force set up in the driver is greater than that set up in the follower. To obtain this condition *the driver must rotate faster than the follower* since the intensity of centrifugal force depends upon the speed of rotation.

Ques. What is the percentage of difference between the speed or rotation of the driver and follower called?

Ans. The slip.

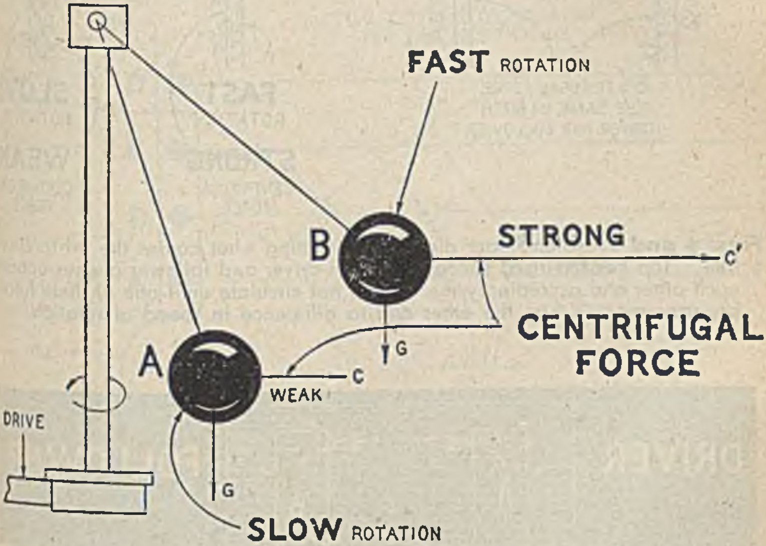
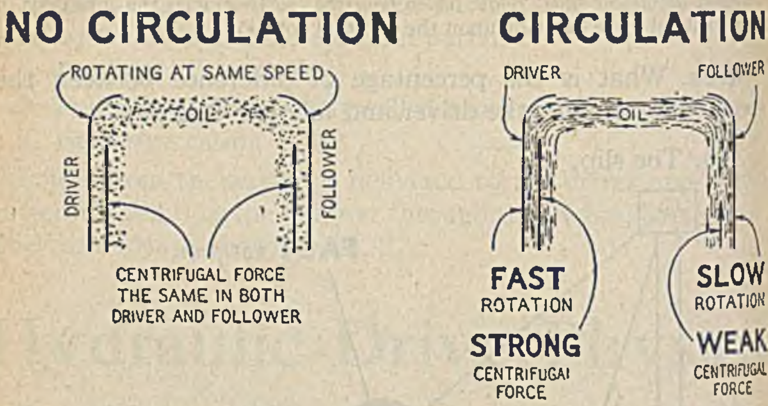


Fig. 3.—Elementary diagram showing half of familiar ball engine governor illustrating **centrifugal force.** If the governor rotate slowly, centrifugal force will "pull" the heavy ball outward to some position **A,** overcoming the downward pull **G,** due to gravity. If the engine load decrease, the engine will speed up increasing centrifugal force which will cause ball to move outward to some position **B.** In both cases the downward pull due to gravity **G,** is constant; the increase in centrifugal force is indicated by the lengths of arrows **C** and **C′.** **Similarly,** for the hydraulic drive, centrifugal force is strong in the fast rotating driver, and weak in the slow rotating follower. The **difference** in strength of the two opposing centrifugal forces is what causes circulation of the oil.

Ques. Essentially what is the driver?

Ans. A centrifugal pump.



Figs. 4 and 5.—Elementary diagram illustrating what causes the oil to circulate. The **centrifugal forces** set up in driver and follower always oppose each other and accordingly the oil will not circulate until one of these forces becomes greater than the other due to difference in speed of rotation.

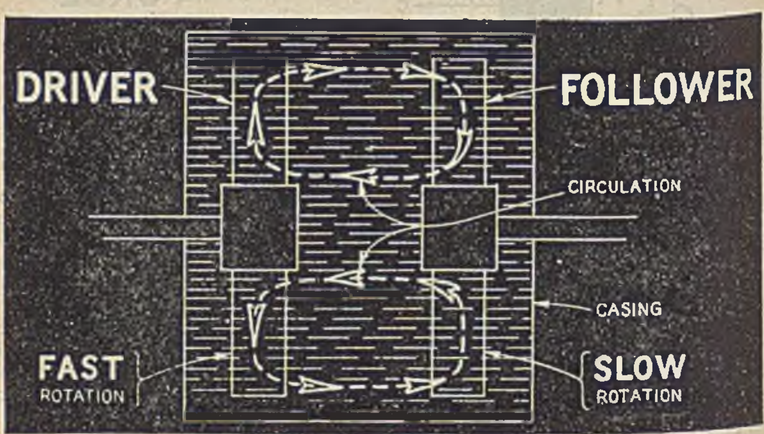


Fig. 6.—Section through elementary paddle wheel hydraulic drive showing how the oil circulates passing from driver to follower at the rim and returning at the hub.

Ques. How does the oil circulate?

Ans. In circular paths.

Ques. How does the oil accelerate and decelerate in traversing its circuit?

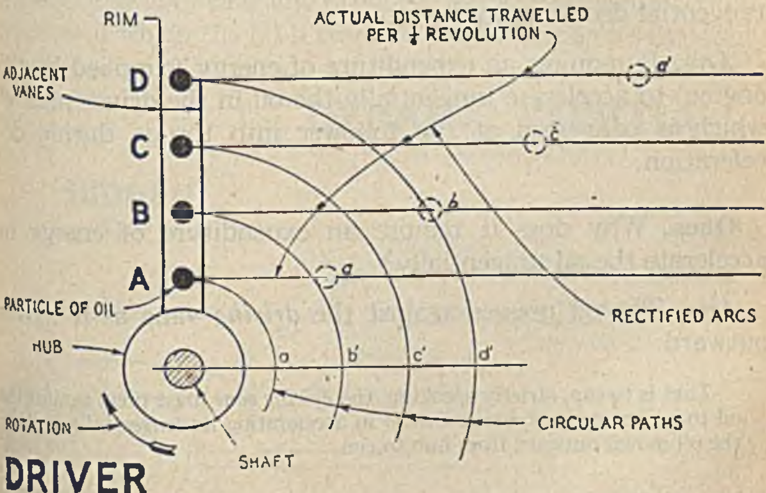


Fig. 7.—Detail of driver showing two adjacent vanes forming a passage for the oil and illustrating tangential acceleration. The length of the tangents **Aa, Bb,** etc. = lengths of corresponding 90° arcs **Aa′, Bb′,** etc. These arcs (circular paths) are shown for only ¼ revolution instead of complete revolution so that the diagram will appear larger and clearer. Distinguish between the tangential (lateral) movement of the oil and its axial flow, as shown in fig. 9.

Ans. Tangentially.

As the oil is forced outward by *centrifugal force* from hub to rim, the length of its circular path increases for each revolution, which means it is given *tangential acceleration.*

In fig. 7, let **A, B, C, D,** be successive positions of a particle of oil as it is thrown outward from the hub to the rim.

Evidently in position **A**, the distance travelled by the oil in one revolution around the axis is less than in position **B**, the distance increasing as the oil moves outward to positions **C**, and **D**. Accordingly the *tangential velocity* increases, that is, there is *tangential acceleration*. This is shown graphically by the lengths **Aa**, **Bb**, **Cc**, and **Dd**.

Ques. What is the significance of tangential acceleration and tangential deceleration?

Ans. It requires an expenditure of energy (supplied by the engine) to accelerate tangentially the oil in the driver most of which is converted at the follower into torque during deceleration.

Ques. Why does it require an expenditure of energy to accelerate the oil tangentially?

Ans. The oil presses against the *driving* vane as it moves outward.

That is to say, strictly speaking, the *driving vane* must press against the oil to overcome its *dynamic inertia* in accelerating its *tangential velocity* as the oil moves outward from hub to rim.

Ques. To what is the actual driving force applied to the follower due?

Ans. To the tremendous *dynamic inertia* of the oil impinging on the follower vanes at great velocity.

Strictly speaking, the tangential component of the dynamic inertia—later explained.

Ques. What is dynamic inertia?

Ans. *That property of a moving body which causes it to continue in a state of uniform motion unless acted upon by some force compelling it to change that state.* See fig. 8.

Ques. Explain how dynamic inertia of the oil acts to drive the follower.

Ans. The oil entering the passages formed by the follower vanes has both a *forward* (axial) motion and a *lateral* (tangential) motion. This lateral movement causes the oil to press against the *leading* vane and drive the follower in the tangential direction in which the oil tends to continue due to its dynamic inertia.

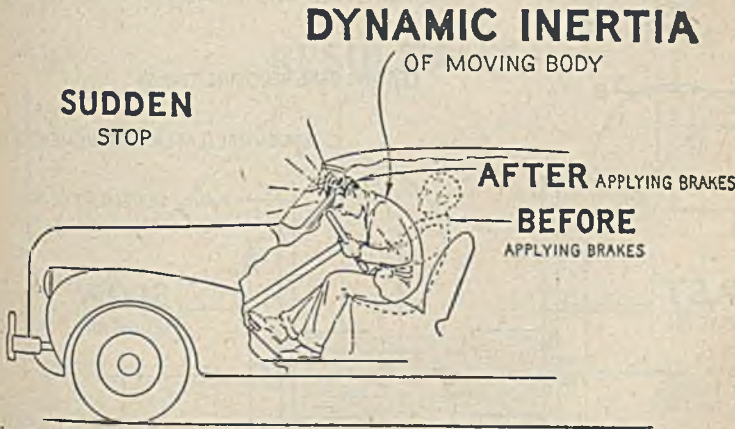


Fig. 8.—Usual method of stopping a car as practiced by alleged drivers illustrating **dynamic inertia.** When considerate they will say: "Brace yourself, I'm going to stop, otherwise you will probably go through the windshield."

Fig. 9 is a detail showing two adjacent vanes as seen near the rim with oil flowing from driver to follower. Arrow **A**, shows the axial movement of the oil and arrow **T** its tangential movement. This sidewise movement (referred to the follower) is due to the driver moving faster than the follower.

Ques. What is the actual or resultant direction of oil flow to the follower?

Ans. It strikes the leading vane of the follower at an angle.

In fig. 10 if arrow **OA** = direction and velocity of axial movement and **OB** = direction and velocity of tangenial movement, then completing the parallelogram, **OR** = direction and velocity of the actual movement resulting from the two component movements.

This parallelogram is reproduced in part in fig. 11 from which it is seen that **OR,** being the actual direction of flow, the oil strikes the leading vane at an angle **AOR.** Here **AR**(= **OB**), is the component or thrust normal to the vane which, producing torque, tends to rotate the vane.

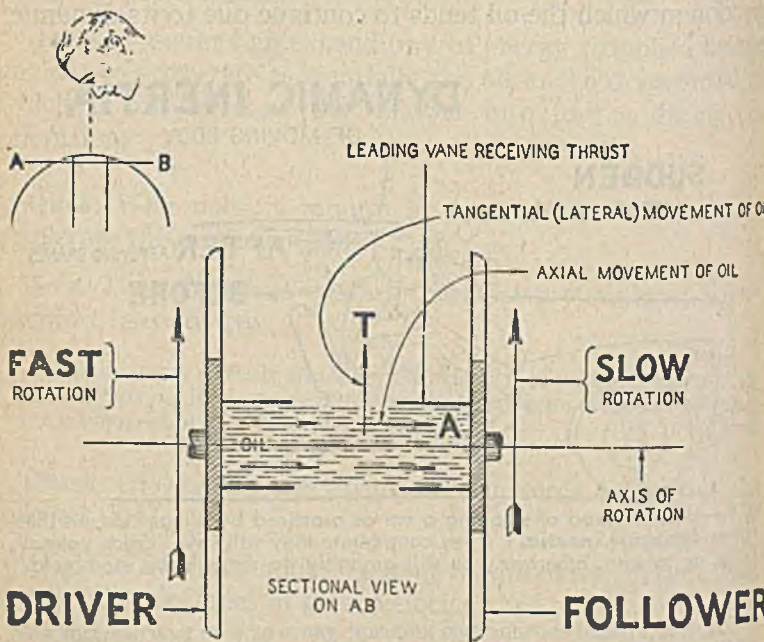


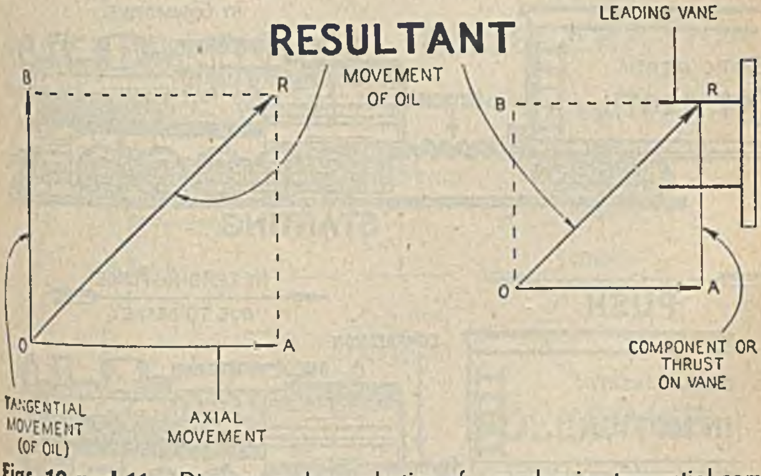
Fig. 9.—Elementary diagram of driver and follower showing only two adjacent vanes, illustrating basic principles. Note that this diagram is viewed as indicated in the little detail at left and that part of the rim is cut away (on the line **AB**) to show more plainly the action of the oil.

Tangential Acceleration and Tangential Deceleration.—It requires an expenditure of energy to either increase the velocity of a moving body or to slow it down.

For instance, work is done by a locomotive in bringing a train up to speed and the *kinetic energy* thus acquired (that is, stored capacity for performing work possessed by a moving body by virtue of its momentum) is expended in slowing down the train by application of the brakes. In this case it is converted into heat as is evident from the heating of the brake shoes.*

Ques. Why is power required for tangential acceleration?

Ans. As the oil moves outward from hub to rim (due to centrifugal force) it presses against the driving vane of the driver, thus opposing the driving force.



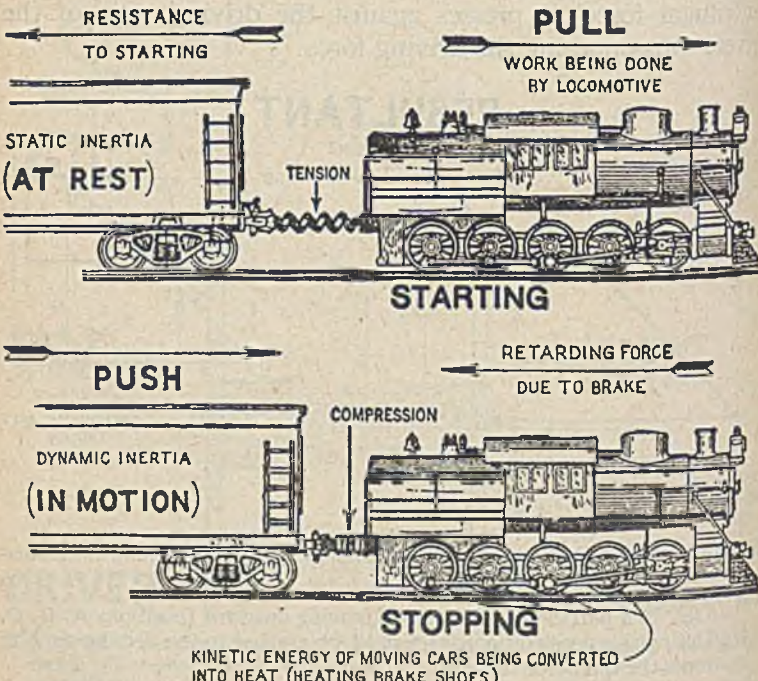
Figs. 10 and 11.—Diagram and reproduction of same showing tangential component or actual thrust on vane.

In fig. 14 a particle of oil is shown moving outward (positions **A, B, C, D**). During this acceleration, force must be applied to the driving vane to overcome the *inertia* of the oil.

Ques. How is torque produced during tangential deceleration?

*NOTE.—In physics **heat** *and* **work** *are said to be identical and convertible.* Independently of the medium through which heat may be converted into mechanical action, the same quantity of heat is converted into the same quantity of work and vice versa.

Ans. The oil on entering the follower is forced (by excess forward centrifugal force) to flow from rim to hub which *decelerates* its tangential velocity. During this process the tangential (lateral) component (**AR** fig. 11) of the **kinetic** *energy** originally possessed by the oil on entering the follower is expended against the leading vane to produce torque and rotation.



Figs. 12 and 13.—Train analogy illustrating work done by locomotive in starting, and work done by moving cars in stopping—note work being converted into heat in stopping.

*NOTE.—**Kinetic energy** is *the stored capacity for performing work possessed by a moving body by virtue of its momentum.* It represents the work necessary to bring the body from its actual velocity to a state of rest.

This is shown in fig. 15. Note positions **A, B, C, D,** of a particle of oil moving toward the hub. This is also shown in fig. 9 looking from rim end of vane passage toward the hub. The positions **A, B, C, D** (with respect to distances from axis) are the same as **A, B, C, D,** of fig. 14. Evidently tangential deceleration of the oil produces a driving force on the leading vane of the follower.

Fluid Drive.—A sectional view of the so-called fluid drive system is shown in fig. 17. As here shown there are two revolving elements called the *driver* and *follower.*

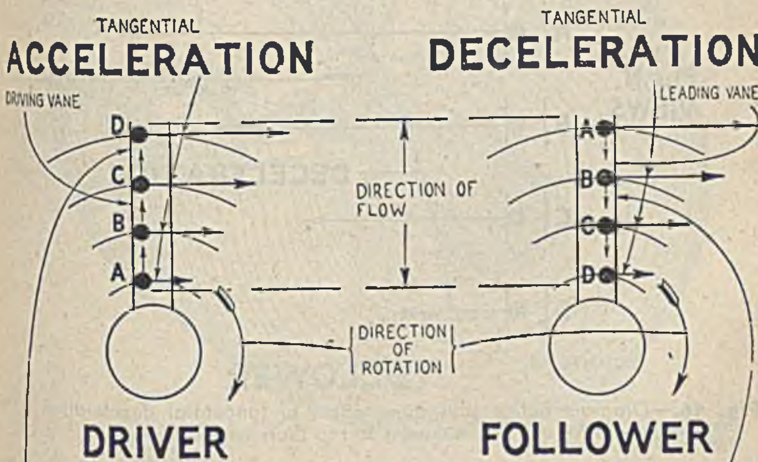


Fig. 14.—Diagram illustrating why force must be applied to the driver to obtain tangential acceleration of the oil.

Fig. 15.—Diagram illustrating why tangential deceleration of the oil produces a driving force on the follower.

The difference between the rotary speeds of the two members, or *slip* is said to amount to only about 1% in ordinary driving at normal speeds over a level road. When the pulling is hard the slip is greater, and it amounts to 100% when the car is left in gear while the engine is idling and the car is stopped.

The chief advantages claimed are:

1. The car may be placed in high gear and normal traffic followed without declutching or shifting gears.

2. The kick down overdrive in conjunction with fluid drive gives virtually an automatic two speed transmission in high gear.

3. Declutching is unnecessary when stopping, as the engine will not stall.

4. The clutch pedal is not sensitive as in a standard car.

5. The fluid drive damps out engine tortional vibrations.

6. Eliminates gear shifting or clutch pedal operation in normal traffic.

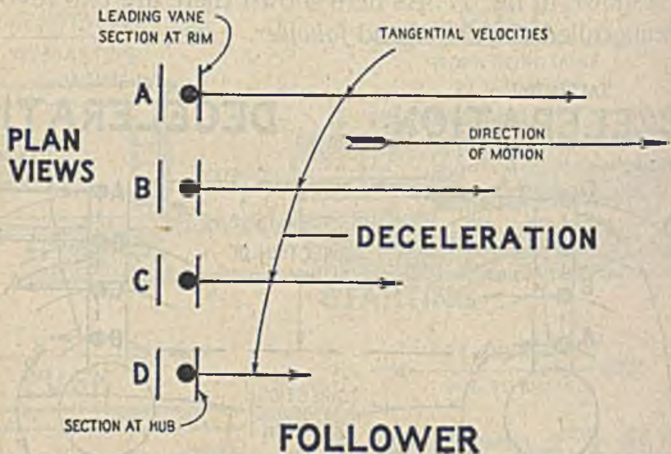


Fig. 16.—Diagram further illustrating effect of tangential deceleration. The deceleration positions shown correspond to those of fig. 15.

7. In starting the engine, it is not necessary to shift out of gear or declutch.

8. The engine may be used as a brake.

"Hydra-matic" Drive.—This is a form of hydraulic drive (called "Hydra-matic" by the manufacturer) combined with a fully automatic four speed transmission which eliminates the conventional clutch and its pedal.

Ques. How is the car started?

Ans. Entirely by means of the accelerator.

Ques. What happens when the accelerator pedal is depressed?

Ans. The drive unit transmits power firmly yet smoothly.

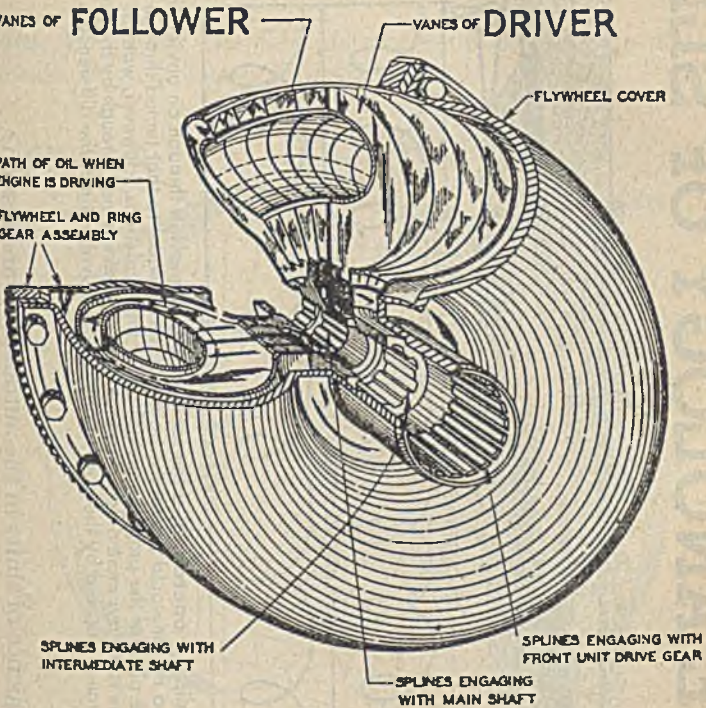


Fig. 17.—Typical fluid drive showing details of construction. **In construction,** the drive is made of stamped, pressed and forged parts. The forgings used in the unit consist of the hubs for the impeller housing and the runner. The large outer housing and the runner disc are made of pressed cold-rolled steel. The vanes, 22 in the impeller and 24 in the runner, are made of stamped cold-rolled steel. They are permanently assembled into the impeller and runner discs by three spot welds on each vane. The runner disc is permanently riveted to the runner hub. The runner is mounted in the impeller on a ball bearing, located in the forward part of the assembly. The runner is supported in assembly by the transmission drive pinion shaft. The oil used in the fluid coupling is a low viscosity mineral oil. It provides the lubrication required by the bearing enclosed with the coupling, and it will pour at the lowest anticipated temperature.

MARINE ANOLOGY OF SLIP

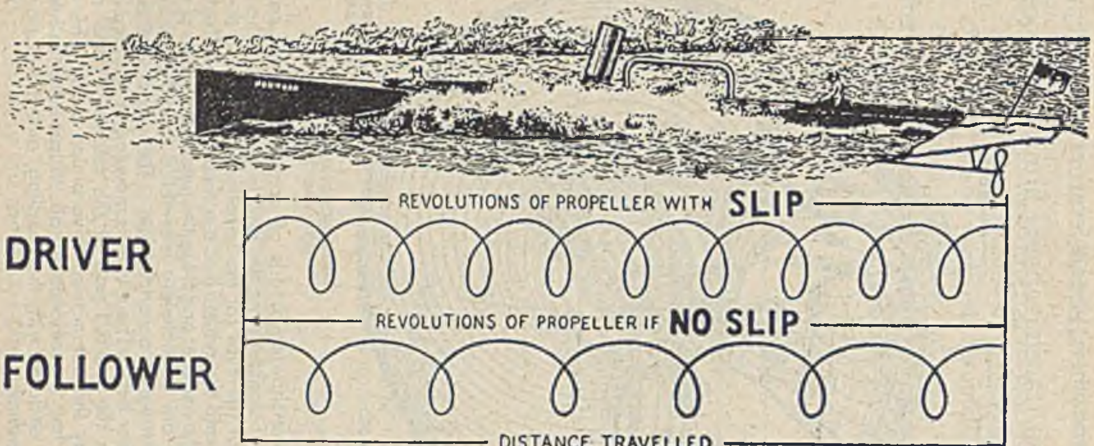


Fig. 18.—Marine analogy of slip. **In operation,** if the screw propeller revolved through an unyielding substance (as a screw turning in a nut) it would propel the boat a distance equal to that turned through by the propeller, that is, equal to the pitch of the propeller multiplied by the revolutions. However, water is not an unyielding substance and there is always more or less slip; that is, the distance turned through by the propeller is always greater than the distance traveled by the boat in any given interval of time; the difference is called the slip.

Ques. What is the sequence of shifts in the automatic transmission?

Ans. It starts in low gear, shifting to second, third and fourth.

Ques. Upon what do the shifts depend?

Ans. The amount of throttle opening.

Ques. What are the two members of the "hydro-matic" drive called by the manufacturer?

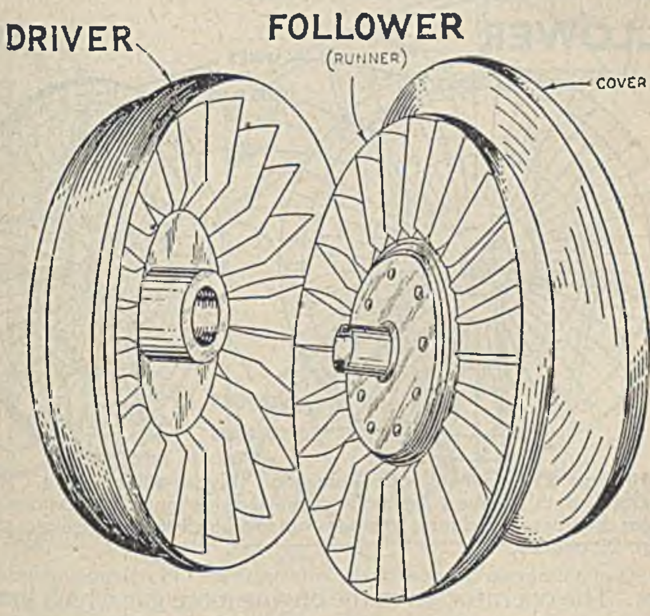


Fig. 19.—General appearance of so called liquid drive.

Ans. The *driver* and the *driven*.

Ques. What happens when both *driver* and *driven* members run at the same speed?

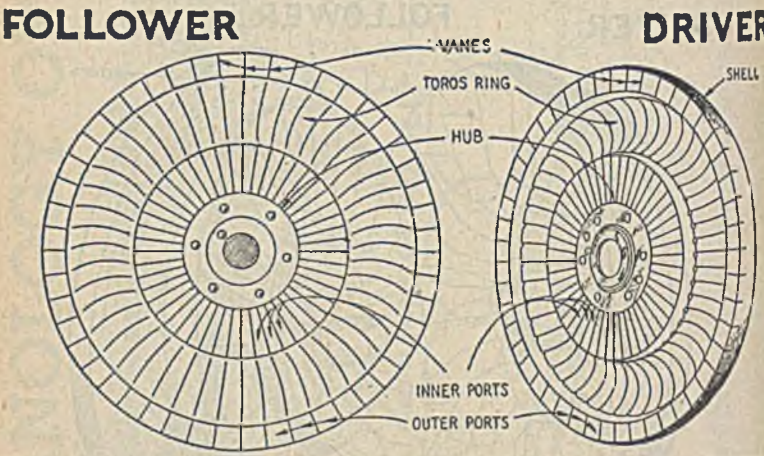
Ans. There is no oil circulation and therefore no torque.

Ques. When does oil circulate to produce torque?

Ans. When one member rotates faster than the other.

The speedier one becomes the *driver* and the other the *driven* member. This explains why the car can drive the engine just as readily as the engine can drive the car.

Ques. How is more power obtained?



Figs. 20 and 21.—General appearance of "Hydra-matic" drive. **In construction,** both members are made of pressed steel and each contains 48 half circular divisions called torus passages around which the oil circulates as shown in figs. 22 and 23.

Ans. The operator gives the engine more gas which increases the engine speed and that of the driver to circulate the amount of oil needed to meet the increased load.

That is, the speed of the *driver* increases relative to that of the *driven* member, which in effect, delivers more power to the rear wheels.

Ques. With engine idling why does the car not start?

Ans. Because the speed of the *driver* is too slow to overcome *static* inertia of the car.

Ques. Upon what does torque depend?

Ans. Upon oil circulation.

Ques. When does oil circulate to produce torque?

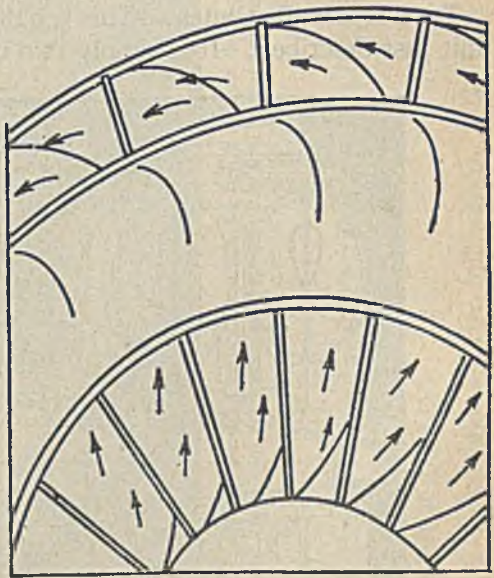


Fig. 22.—Cross section of "Hydra-matic" drive showing circulation in driver and follower.

Fig. 23.—Pictorial view of "Hydra-matic" rotor further illustrating circulation.

Ans. When the driver rotates faster than the follower.

Ques. What would happen if the follower rotate faster than the driver?

Ans. Power would be delivered to rotate the engine.

That is, the cycle would be reversed, the follower becoming the driver and the driver the follower.

Ques. How is more power obtained?

Ans. By increasing the speed of the driver relative to that of the follower.

Twin Hydraulic Clutch.—This is a development of the single unit just described. It is simply two units working in parallel

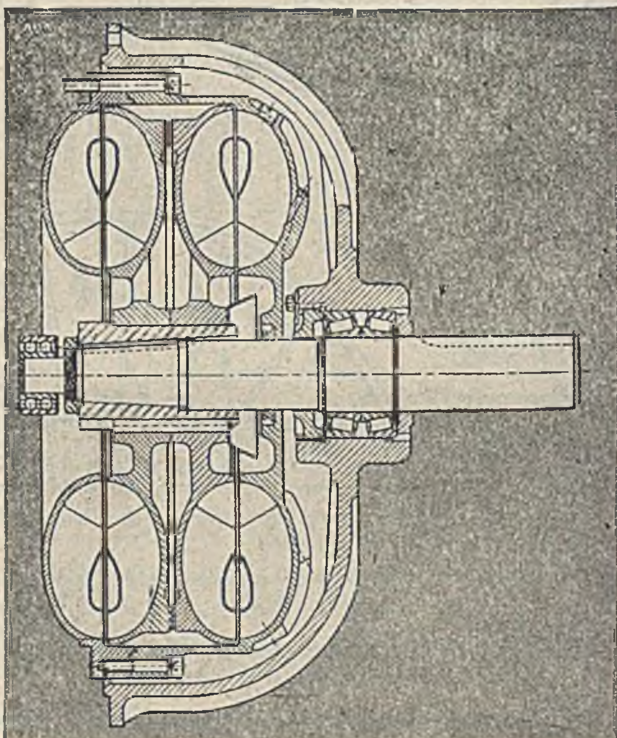


Fig. 24.—Cross sectional view showing twin disc hydraulic drive, variously called hydraulic clutch, hydraulic power take off.

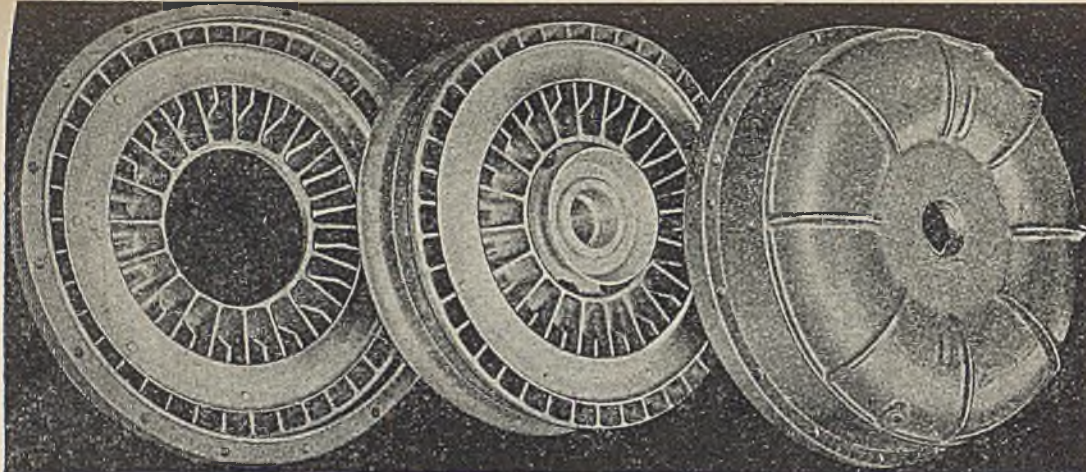


Fig. 25.—Appearance of principal parts of twin disc hydraulic drive. From left to right these parts are known as: 1, front impeller; 2, runner; 3, rear impeller. Better names for these parts are: 1, front driver; 2, follower, rear driver.

to deliver power to the same shaft. The sectional view fig. 24 shows the general arrangement and a better idea of its appearance is seen in fig. 25.

Here the parts are (from left to right):

1. Front driver. 2. Twin follower (two followers). 3. Rear driver.

Figs. 24 and 25 show very plainly the construction and no further description is necessary.

Hydraulic Torque Converters.—The operation of the torque converter depends upon the same basic principles as the

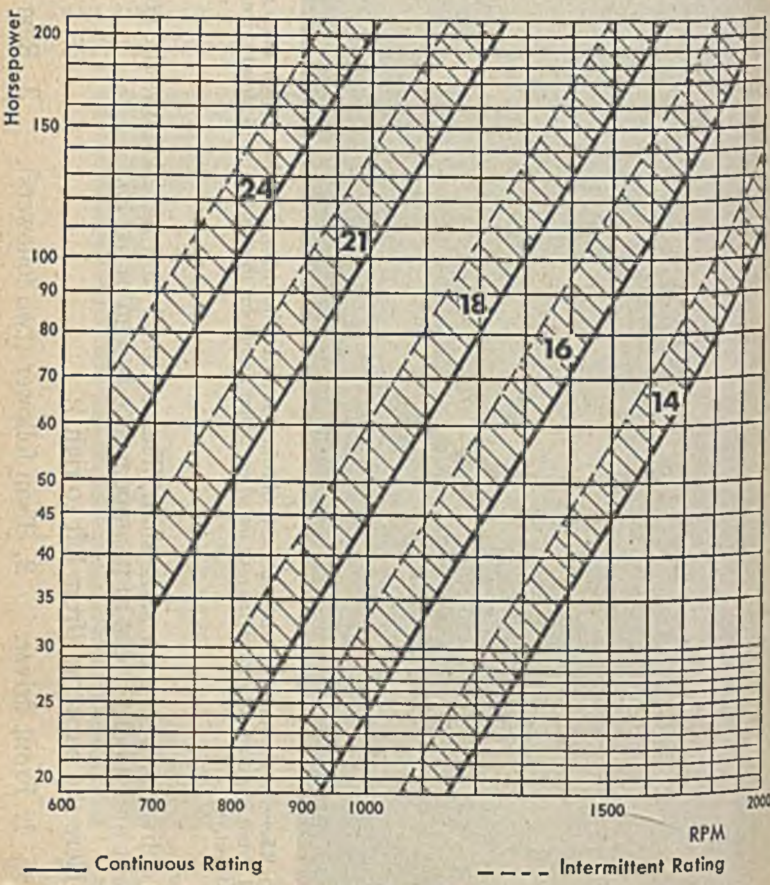


Fig. 26.—Hydraulic clutch capacities.

hydraulic clutch, that is, upon the circulating movement of the fluid for the transmission of power with this exception: In the torque converter a third or reactionary member is introduced between the pump and the turbine to change the direction of the fluid.

Ques. How does the torque converter work?

Ans. The pump which is coupled to the engine, circulates the fluid and the fluid through the velocity imparted to it by

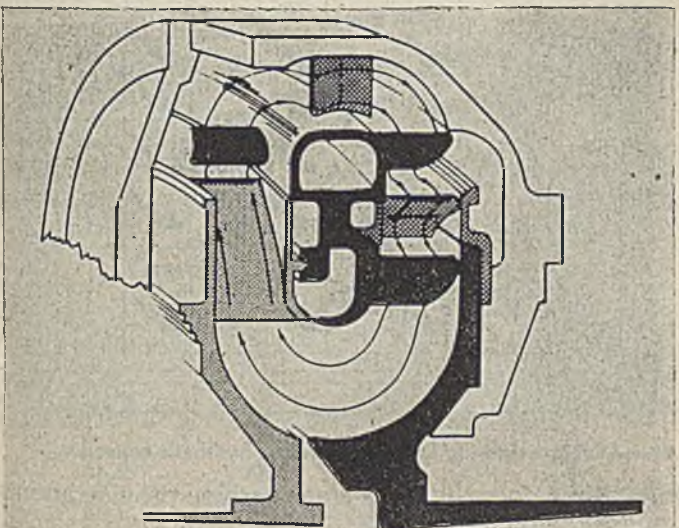


Fig. 27.—Sectional pictorial of hydraulic torque converter.

the pump, becomes the transmission medium for the power delivered by the engine.

As the fluid is forced against the turbine blades and the blades mounted to the stationary housing, it releases its energy in the form of torque and speed. As a result of the fluid reacting upon the turbine and stationary blades, the input or engine torque is increasingly multiplied, as the speed of the output shaft is slowed down. Since there is no mechanical connection between the engine and the turbine, the engine cannot be stalled.

Ques. Describe the flow of power.

Ans. The pump which is of the centrifugal type, imparts the power developed by the engine to the fluid in the form of fluid velocity, thus giving the fluid capacity to perform work. When the fluid leaves the pump, it flows directly into the first stage of a three stage turbine.

The principle of the torque converter is the resistance of fluid in motion to any change in the direction and speed of its flow.

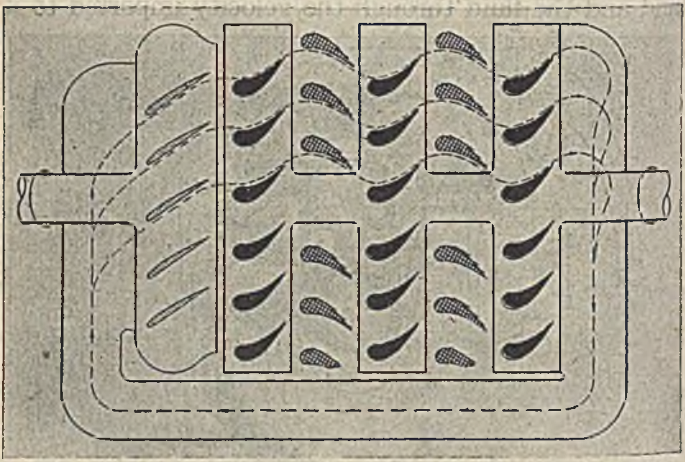


Fig. 28.—Diagram showing fluid circulation in hydraulic converter.

Ques. How does the three stage turbine provide an increase in output torque?

Ans. By re-directing the flow of the fluid, taking advantage of its resistance to change. In this way the torque supplied by the engine is, built up, that is multiplied.

Ques. How is this done?

Ans. In construction, two sets of stationary blades are located between the turbine. When the reactionary blades (the stationary blades that re-direct the fluid flow) are mounted in the stationary housing and the housing assembled to the engine or to a solid base, these blades cannot move when the fluid is forced against them, so the fluid flow is re-directed and the fluid's resistance to this change results in torque multiplication —an increase in torque at each turbine stage.

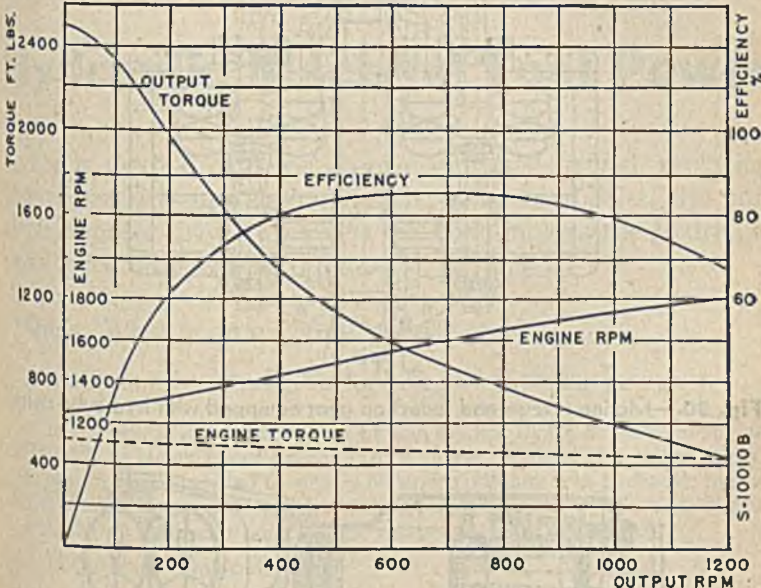


Fig. 29.—Characteristics of hydraulic torque converter. The curve indicates output torque obtained with an engine delivering 500 ft. lbs. of torque at 1800 **r.p.m.** which is the full throttle speed of the engine. No partial throttle characteristics are shown. The top efficiency is a broad, practically flat curve with a peak of approximately 85%. As the output shaft speed approaches two-thirds of the engine's speed, the engine and converter torques become equal.

Were it not for these stationary blades, there would be no torque multiplication and the output torque would be equal to that put into the unit by the engine. Due to the fact, however, that the stationary blades, by re-directing the fluid flow, do multiply the torque delivered by the engine, the unit becomes a torque converter.

Figs. 27 and 28 show construction and fluid circulation of the torque converter and the performance characteristics are shown in the diagram fig. 29.

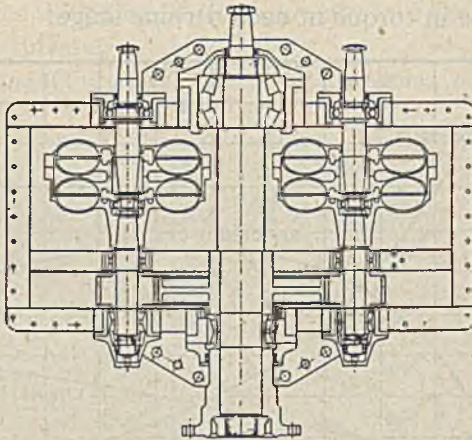


Fig. 30.—Marine reverse and reduction gear equipped with hydraulic clutch.

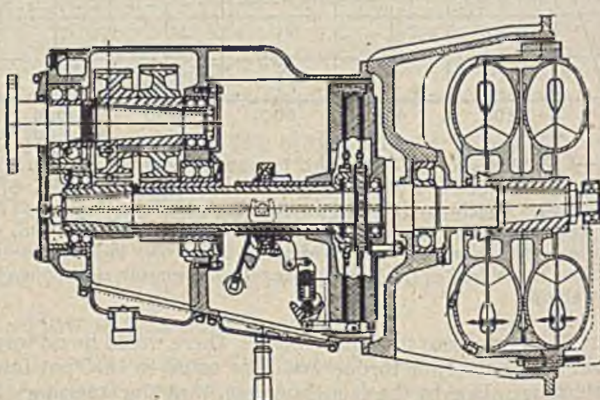


Fig. 31.—Marine reduction gear incorporating hydraulic clutches for multiple engine drive to single propeller.

CHAPTER 35

Hydraulic Machine Tool Power

A new method of power transmission has arrived, replacing former practice such as line shafting pulleys and belts, also unit electric motor drive. This new method employs the hydraulic or so called oil power fluid motor.

Ques. What is an oil power fluid motor?

Ans. It is a hydraulic motor run by oil under pressure.

In a sense, it is a prime mover like an electric motor or a steam engine. Similarly as steam under pressure from a boiler is piped to a steam engine, so must a pump be used to supply oil under pressure to a hydraulic motor. The pump may be located near the motor, assembled with it as a unit or installed at a remote point. The motors may be classed as:

1. Constant displacement
2. Variable displacement.

Ques. How are speed changes made with the constant displacement motor?

Ans. By varying the volume of oil flowing through the motor.

Ques. How are speed changes made with the variable displacement motor?

Ans. By varying the displacement of the motor in addition to the control of the oil supply from the pump.

Ques. What is the feature of the variable displacement motor?

Ans. A wider speed range is obtained than with the other type.

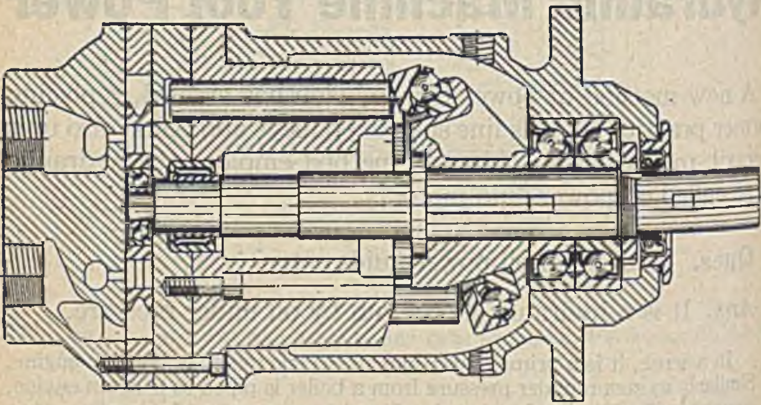


Fig. 1.—Section view showing construction of typical hydraulic drive motor.

Ques. Describe the construction and operation of the constant displacement motor.

Fig. 1 shows a sectional view of the 5 h.p. motor.

Ans. Oil under pressure enters the end cap section and through suitable openings in a port plate is forced into the cylinders. The passage of the oil through the ports is controlled by a single circular valve which is mounted on an eccentric stud formed on the end of the shaft. This valve does not rotate but receives a gyrating motion as the shaft is turned.

Ques. Describe the action of the oil on the pistons.

Ans. Oil pressure forces the pistons against the non-rotating wobbler. Due to the angle at which the wobbler is inclined, the thrust of the pistons is both perpendicular and tangential to it. The resultant force is transmitted through ball bearings to the wobbler plate on the shaft and imparts a rotating action to it.

Ques. What happens on the return stroke?

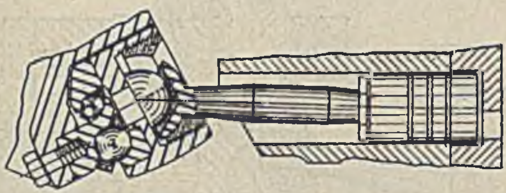


Fig. 2.—Detail of piston and connecting rod used in larger sizes of motor shown in fig. 1.

Ans. The cylinders are emptied through the same ports in the port plate.

Ques. How do units called "torque motors" differ from the type just described?

Ans. They have two sets of pistons and are designed especially for machine tool feeding.

Ques. How is the piston stroke varied in the variable displacement motors?

Ans. By changing the angle at which the wobbler is inclined.

Ques. How is this done?

Ans. The construction is such that it may be done either manually or automatically.

Pumps for Hydraulic Drive Motors.—There are numerous types of pumps used to supply power to hydraulic drive motors. They may be classed variously as:

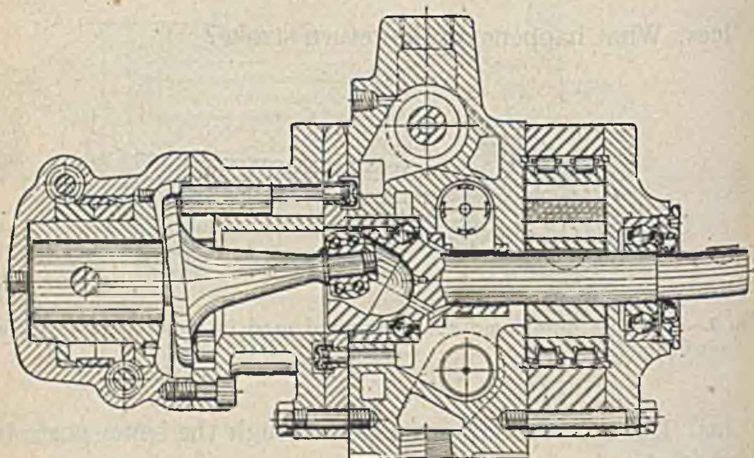


Fig. 3.—Sectional view of hydraulic motor with main control valves in same casing.

1. Single acting. 3. Internal gear. 5. Non-rotating, etc.
2. Double acting. 4. Rotating.

One design of pump unit consists of the pumps only and to complete a *hydraulic circuit** a separate control valve must be added.

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*NOTE.—By definition, *hydraulic circuit* as here used *consists of the combination of a pumping unit and a main control unit suitably connected to deliver oil at the pressure and in the volume required.*

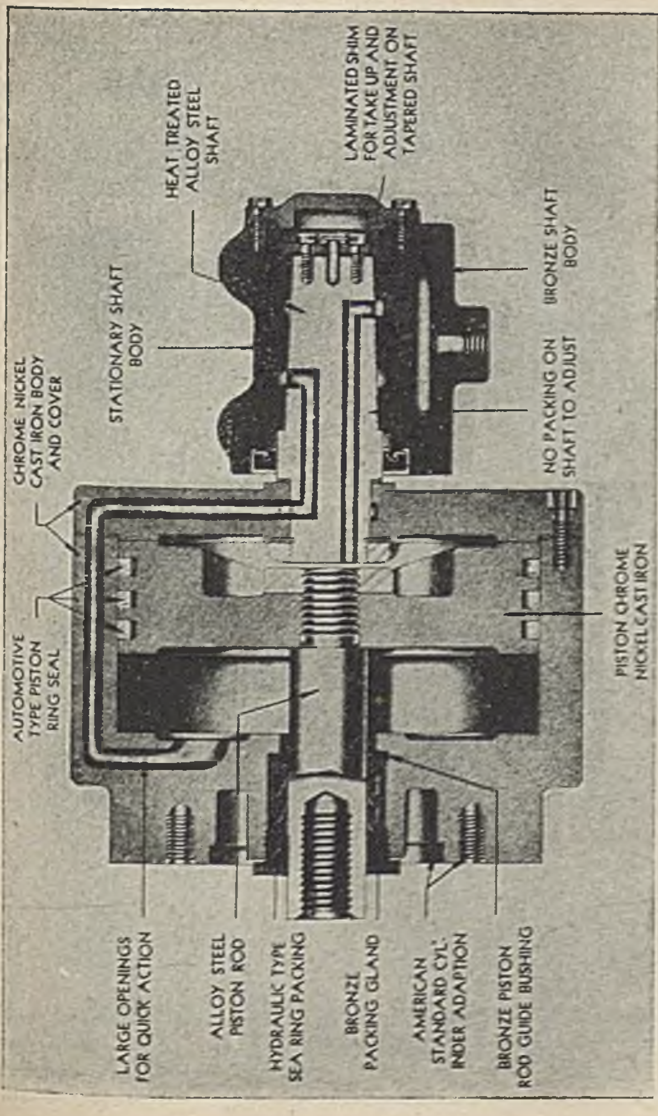


Fig. 4.—Hydraulic motor, rotating type with double acting cylinders.

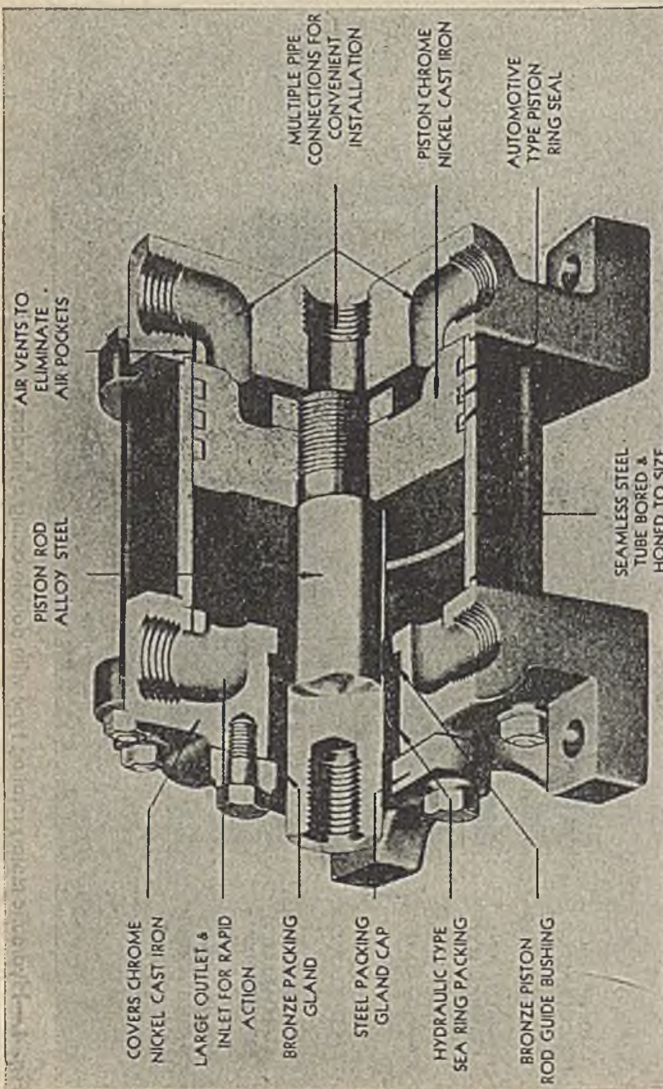


Fig. 5.—Hydraulic motor; non-rotating type double acting cylinders.

In construction, a variable displacement pump for feeding and a constant displacement pump for rapid traverse are mounted on a common shaft and assembled in a compact housing.

In the sectional view, fig. 3, a single shaft is mounted in two large anti-friction bearings. At the right are the members of the

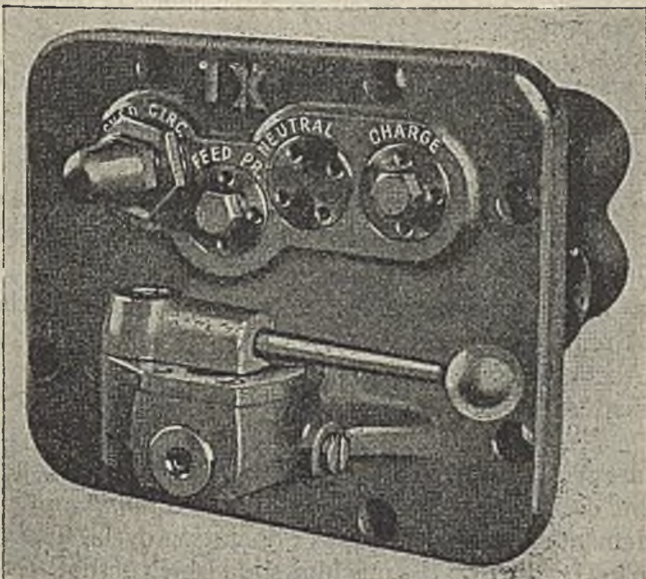


Fig. 6.—Control valve. This is the valve used with pump not having control valve in the pump assembly. It constitutes the main control valve of this circuit and includes four way directional valve, a neutral valve, a selector valve for feed and rapid traverse, a slow feed valve, a safety or relief valve and a locked circuit valve. The valve provides rapid approach, two rates of feed and quick return. For automatic operation a solenoid valve is needed.

constant displacement pump. A hardened and ground roller keyed to the shaft revolves in positive contact with a rotor or ring. This ring turns in its housing on roller bearings.

The shaft extends through the main control valve section and is provided at the end with a socket bearing, the axis of which is at an angle to the axis of the shaft.

In this socket is carried the ball bearing end of the shank of a wobbler plate. Pistons contact the wobbler plate near its outer edge.

As the shaft rotates, a wobbling action without rotation, is imparted to the wobbler plate. The effect of this action is to impart a reciprocating movement to the pistons. The constant displacement pump charges the piston pump and the oil pressure keeps the pistons in contact with the wobbler plate.

Piston stroke is varied by forward movement of the stroke adjuster which brings the axis of the wobbler plate shank and that of the shaft more nearly in line and consequently reduces the "wobble". The piston stroke can be changed manually or automatically.

The Hydraulic Circuit.—The term circuit as before stated covers *the combination of a pumping unit and the necessary control valves*.

The main control valves may be actuated either by

1. A remote pilot valve, or
2. A remote electric solenoid valve

described in the following sections.

Hydraulically Controlled Circuits.—The circuit consists of *a control valve such as shown in fig.* 6, *and a pump unit.* These two elements produce a complete operating cycle. The cycle is controlled by dogs on the machine slide which actuate the valve arm.

One design of control valve and circuit provide two rates of feed in one direction only. Skip feeds can be obtained such as rapid traverse, fast or slow feed or both, then rapid traverse again followed by either fast or slow feed or both as many times as desired and finally quick return.

For remote control for starting the cycle a solenoid valve is added to the circuit and the starting is accomplished by means of an electrical push button station.

The actuated unit can be returned to the starting position at any time during the feed action (but not the rapid approach) by again pressing the push button. Reversal is effected at the rapid traverse rate.

Dwell period at the end of the feed stroke is obtained by adding a definite time relay to the electrical circuit.

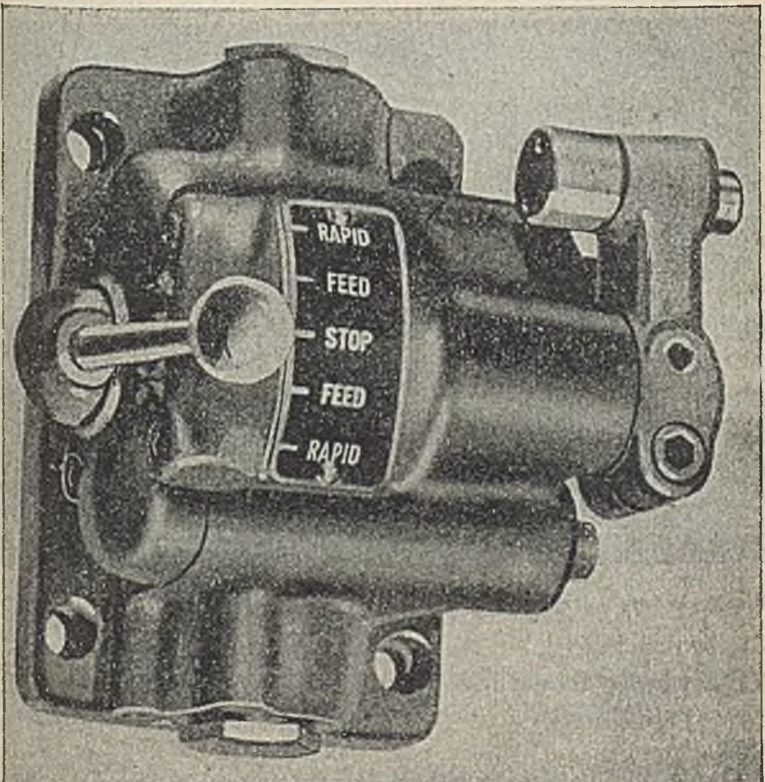


Fig. 7.—Remote hydraulic control valve for actuating the main control valves in the pumping unit.

This relay goes into operation after a dog on the machine slide contacts a limit switch. Following a time interval, adjustable to suit machining conditions, the solenoid valve is momentarily energized to produce the quick return action. With this installation, the dog for tripping the pilot valve into the return position is not necessary, but the travelling machine member must register against a positive stop at the end of the feed stroke and during the dwell period.

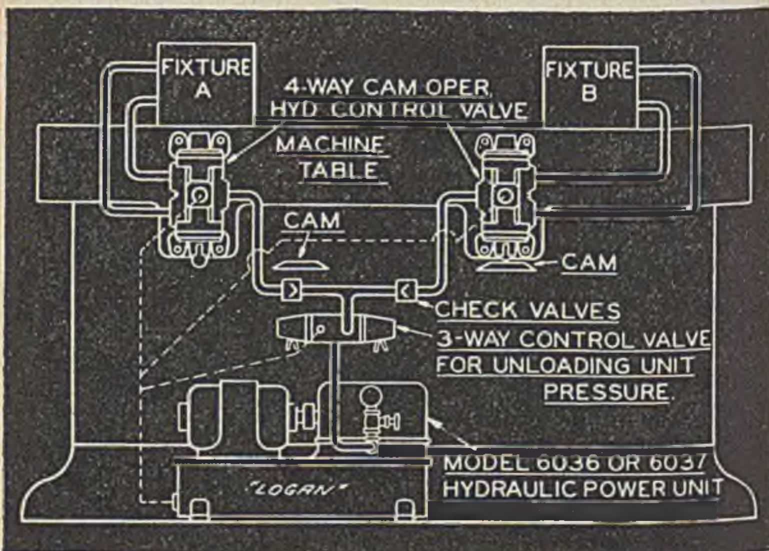


Fig. 8.—Power unit application.

Electrically Controlled Circuits.—*The hydraulic elements of this circuit include a triple solenoid valve and a suitable pumping unit.*

The solenoid valves serve to actuate the main control valves in the pumping unit and are in turn actuated by means of limit switches contacted by dogs on the machine slide.

One solenoid valve starts the cycle when energized and produces neutral when de-energized.

A second solenoid valve produces rapid traverse during the time it is energized and feed when de-energized.

A third causes reversal when momentarily energized.

The standard circuit provides rapid approach, one rate of feed and quick return.

The addition of a fourth solenoid valve gives two rates of feed and a fifth can be added to the circuit to give three feed rates when the proper pumping unit is used.

Dwell against a positive stop can be had with the addition of a definite time relay. No further valves are required as the time relay operates in conjunction with the reversing solenoid valve.

Principle of the Hydraulic Circuit.—The essential parts are:

1. Pump
2. Control valves
3. Hydraulic motor

In the pump housing are two pumps, known as:

1. Variable displacement
2. Constant displacement

The variable displacement pump is for feed and the constant displacement pump for rapid traverse.

The circuit is controlled by varying the pressure from the rapid traverse pump to obtain neutral or stop, feed and rapid traverse.

Neutral or Stop Position.—There is practically no pressure from the constant displacement pump, all the oil flowing back to the tank under no pressure. The piston pump is not pumping.

Feed.—The pressure from the constant displacement pump is increased to around 50 or 60 lb. per sq. in. which charges the piston pump, the excess oil returning to the tank. The adjustable piston pump provides the desired rate of feed.

Rapid Traverse.—All the oil from the constant displacement pump is directed through the piston chambers in the piston

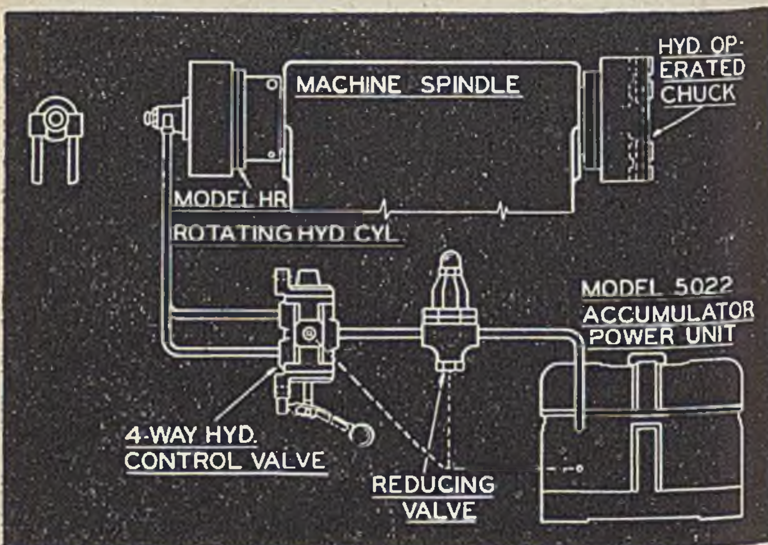


Fig. 9.—Power unit application accumulator model.

pump and on to the main cylinder to furnish rapid traverse. Fig. 10 shows the principle elements in the circuit.

Detailed Description.

A Special description of the Hydraulic Circuit with Combined Variable and Constant Displacement Pump is given in the paragraphs following:

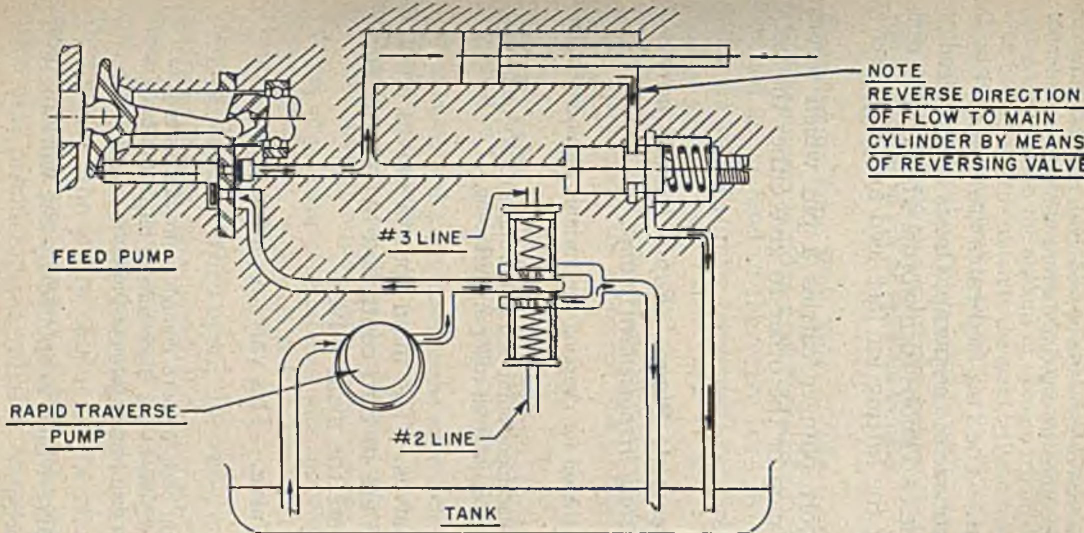


Fig. 10.—Principal elements of the hydraulic circuit.

Variable Displacement Pump.—This is **the feed pump** *and is of the multiple piston type.* There are five pistons, each with an intake and outlet check valve. With the piston chamber filled, the piston forces the oil out through the outlet check valve to feed the main cylinder.

The inlet valve automatically closes so all trapped oil is used for feeding the main cylinder.

The pump provides one or two rates of feed, both adjustable from zero to maximum. Some pumps are especially arranged for three feed rates.

Feed Adjustment.—The two feed rates are adjusted by the two knobs on the outside of the pump. One is for fast feed, the other slow feed. The two knobs turn worms which rotate cams, one cam providing the setting for fast feed and the other for slow feed.

A wobbler support plunger carries a pin which registers against either one cam or the other to give either the fast or slow rate.

Constant Displacement Pump.—*Rapid traverse actions are produced by the constant displacement pump.*

It also furnishes the oil for charging the variable displacement piston pump.

The constant displacement pump is a self-priming rotary pump consisting of an external rotor, internal roller and crescent.

Main Control Valves.—The main control valves are in the pump housing and are in turn controlled by pilot or solenoid valves. Following are the main valves:

Locked Circuit Valve.—This valve is on the return side of the main cylinder.

It produces a slight back pressure, enough to provide a steady feed under no load. This valve also blocks the return of oil to the tank when in a climb cut or when a drill breaks through the work.

It is a simple valve which is opened by the working pressure and closed by a spring.

The spring determines the minimum (but not maximum) working pressure so there is always a certain fixed minimum working pressure. The spring also controls the amount of opening required in the valve during a climb cut to keep the piston in the main cylinder from traveling faster than the rate the piston pump is set for.

During a climb cut as on a milling machine, there is no need for the piston pump to build up any pressure because the milling cutter pulls the work forcing the oil out of the main cylinder.

Reversing or Four Way Valve.—The four way valve is between the main cylinder and the locked circuit valve. It is positioned at one end of the valve bore by means of a spring, creating forward cylinder movement by directing oil to one of the outlet ports.

Reverse movement occurs when hydraulic pressure is exerted against the plunger end opposite the spring end, the oil being directed in the other outlet port.

Neutral Valve.—The entire output of the rapid traverse pump returns to the tank when the neutral valve is open.

When in feed and rapid traverse, the valve is closed and remains closed during the entire cycle.

There is a small hole in the valve plunger which permits oil to return to the tank through a pilot line to the pilot valve.

Closing off the escape of oil through this hole with the pilot valve closes the neutral valve.

Charging Valve.—When open, this valve creates the pressure necessary to charge the variable displacement piston pump with oil from the rapid traverse pump and allows the surplus oil to return to the tank at the charging pressure.

When closed, the entire output of the rapid traverse pump is forced through the check valves in the piston pump to the actuated unit producing the rapid traverse rate.

There is a small hole in the valve plunger which permits oil to return to the tank through a pilot line to the pilot valve. Closing off the escape of oil through this hole with the pilot valve closes the charging valve.

Slow Feed Valve.—This valve determines which of the two set rates of feed will be obtained.

When open fast feed is produced and when closed, slow feed is produced. Where a third rate is used, this valve must be open during the intermediate feed.

Relief Valve.—A relief valve is connected to the pump pressure supply source and acts as a safety valve during overload or when actuated machine member feeds against a positive stop. It is normally set for a pressure of 1000 lb. per sq. in.

Pilot Valves.—The main valves in the pump housing require pilot valves such as the 14X and 16X valves or electrical solenoid valves to govern them.

These auxiliary valves are connected to the main control valves by pilot lines and are actuated by dogs on a moving member of the machine.

The dogs trip the pilot valves or open and close limit switches to operate the electric solenoid valves.

Pilot Lines.—The various pipe lines are numbered as in fig. 11, and the following is a word about the purpose for each. Line from pilot valve to tank is not numbered. This line returns excess of oil to tank.

No. 1 and No. 2A lines, one connected to each end of the four-way valve, control the position of the valve stem.

Actuating the pilot or solenoid valve will admit pressure to one of the lines and simultaneously open the other to the tank. This forces the four-way valve stem to the position desired.

On some models the four-way stem is held in position for forward travel by a spring and only the No. 1 line connected to the four-way valve is necessary.

Pressure in the No. 1 line overcomes the spring resistance and shifts the valve stem to position for rapid return.

When the No. 1 line is opened to the tank, the spring forces the valve stem to its former position.

No. 2 line connects the spring end of the charging valve chamber with the pilot valve. Closing the No. 2 line with the pilot valve causes the valve plunger in the charging valve to seat.

This is done by preventing the oil escaping through the No. 2 line to the pilot valve and back to the tank. When the No. 2 line is open, the charging valve is open and feed occurs. When the No. 2 line is closed, the charging valve is closed and rapid traverse occurs.

No. 3 line connects the spring end of the neutral valve chamber with the pilot valve. Closing the No. 3 line with the pilot valve causes the valve plunger in the neutral valve to seat.

This is done by preventing the oil escaping through the No. 3 line to the pilot valve and back to the tank.

When the No. 3 line is closed, the neutral valve closes and feed or rapid traverse occurs.

When the No. 3 line is open, the neutral valve is open, putting the circuit in neutral.

No. 5 line connects the slow feed valve chamber with the feed adjustment housing.

No. 6 line is used only with valves in conjunction with solenoid valve for remote push button starting and emergency return.

No. 7 line leads charging pressure from the rapid traverse pump to the remote control valve which in turn distributes it to accomplish various functions.

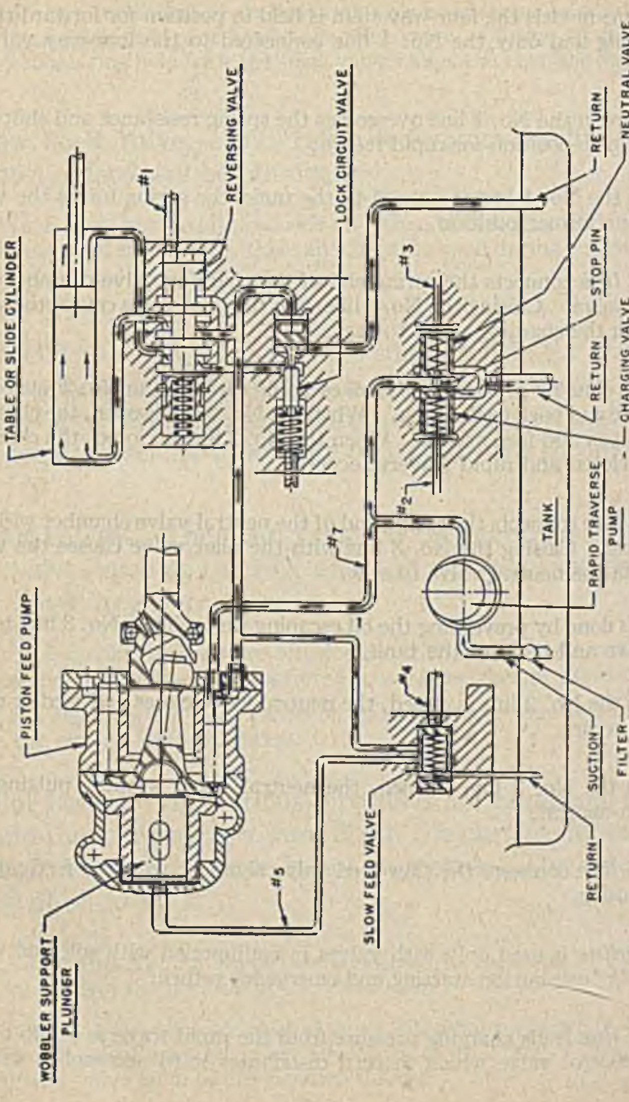


Fig. 11.—Schematic diagram of the hydraulic circuit as described in the accompanying text.

Operation of Hydraulic Circuit

The constant displacement pump which is self-priming, pumps oil to a chamber open to the valve side of both the neutral valve and the charging valve.

Opening and closing these two valves controls both the constant and variable displacement pumps. A schematic layout of the circuit is shown in fig. 40.

Rapid traverse takes all the oil from the constant displacement pump, forcing it through the piston chambers in the piston pump and on to the main cylinder. This is accomplished by actuating the pilot valve which closes the No. 2 line as well as the No. 3 line, thus closing both the neutral and charging valves.

The direction of rapid traverse is determined by the position of the four-way valve stem.

On some models the four-way valve is so constructed that when put in reverse rapid traverse, the No. 2 line is automatically blocked off, which eliminates a reverse feed.

Feed, either fast or slow, is obtained by opening the charging valve which establishes sufficient pressure to keep the pistons in the piston pump up against the wobbler plate, thus charging the piston pump which is not self-priming.

The excess oil from the constant displacement pump returns through the charging valve to the tank.

In fast feed the No. 2 and No. 4 lines are open to the tank and the No. 3 line is closed.

In slow feed the No. 2 line is open to the tank, the No. 3 line closed and the No. 4 line open to the charging pressure. This pressure shifts the slow feed valve plunger, opening pressure in the No. 5 line from the piston pump to the wobbler support plunger in the piston pump, which is forcing the plunger forward to provide the slow feed rate by decreasing the piston travel.

Third Feed Rate.—The third or intermediate feed rate is obtained with a special feed adjustment housing containing an auxiliary wobbler plunger, feed adjusting screw, and feed adjusting cam, used in conjunction with the solenoid operated valve control.

A special valve is added and is connected to a high pressure port in the pump housing and to a port in the feed adjustment housing. When this solenoid valve is energized, pressure from the high pressure port in the pump is admitted to the feed adjusting housing and acts on the auxiliary wobbler plunger.

De-energizing the solenoid valve blocks the high pressure port and opens the port in the feed adjustment housing to the tank. The feed adjusting mechanism is then free to be shifted to one of the other rates.

Charging Pressure.—When starting the moving member of a machine and in feed, *the charging pressure is about* 60 *lb. per sq. in.* In rapid traverse the charging pressure is the same as the working pressure which pressure is determined by whatever force it takes to actuate the moving machine member at the rapid traverse rate.

Feeding Pressure.—The operating or working pressure in feed depends entirely upon the force required to do the work. There is a minimum working pressure established by the locked circuit valve.

CHAPTER 36

Hydraulic Accumulators

By definition an accumulator is: *A cylinder in which water is stored under pressure, to serve as a reservoir and regulator of power, so that an intermittent and fluctuating demand may be met by pumps running under a uniform load.*

A hydraulic accumulator is a device designed to *accumulate energy, to be expended intermittently.*

It may be compared to the familiar storage battery, in that the energy which has been put into it is stored "there till wanted." The accumulator stores *hydraulic energy* and the storage battery (called "accumulator" in England) stores electric energy.

The essential parts of an accumulator are:

1. Plunger or "ram"
2. Cylinder
3. Weights

Ques. Describe an elementary accumulator.

Ans. A long plunger is placed within a vertical cylinder closed at the lower end and having a stuffing box at the upper end. At the upper end of the plunger are secured weights necessary to produce the desired pressure. There is a water outlet and inlet at the lower end.

The essentials of an accumulator are shown in fig. 1.

Ques. How does an accumulator work?

Ans. In fig. 1, water is forced into the cylinder by the force pump A. This causes the weighted plunger to rise. The weight

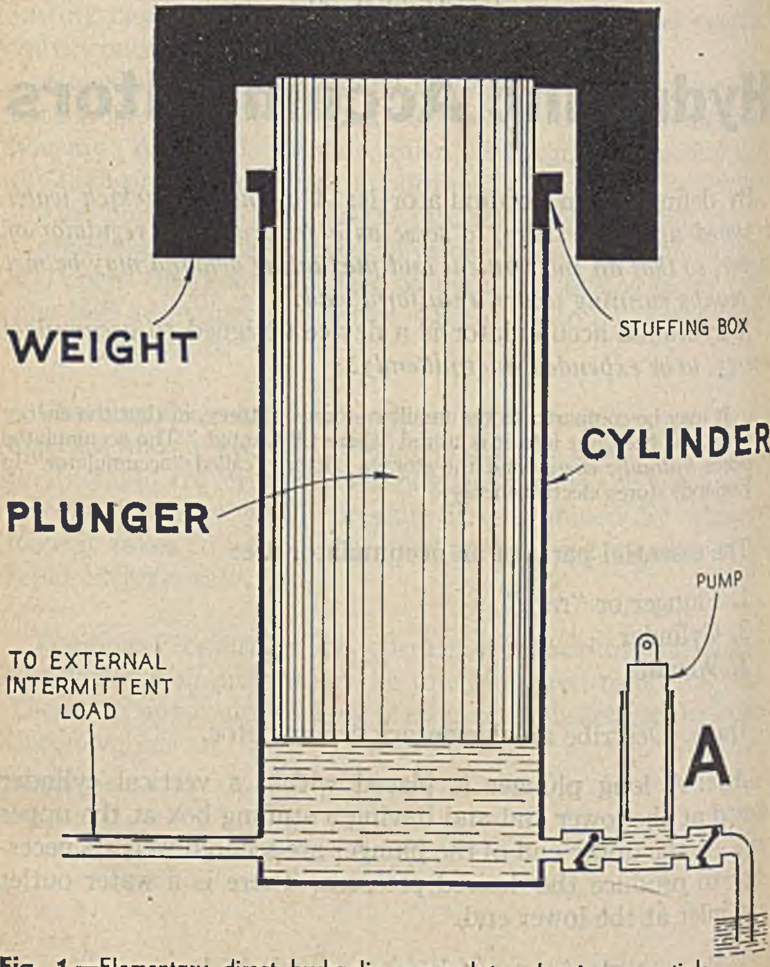


Fig. 1.—Elementary direct hydraulic accumulator showing essentials.

reacting upon the water will transmit the pressure to the machinery operated by it as long as the plunger is not at the lower end of its stroke.

Ques. What prevents the plunger rising too high and coming out of the cylinder in case of no power demands?

Ans. A suitable stop is provided to arrest the motion of the plunger when it arrives at the upper end of its stroke.

This is not shown in the elementary drawing fig. 1.

Ques. What happens when there is a power demand?

Ans. If the load be light the force pump will by continuing to run, supply the amount of water required.

Ques. What happens in case of a heavy load?

Ans. When more power is required than the pump can supply, the excess is supplied by the slow descent of the accumulator plunger.

Ques. What happens when the load goes off?

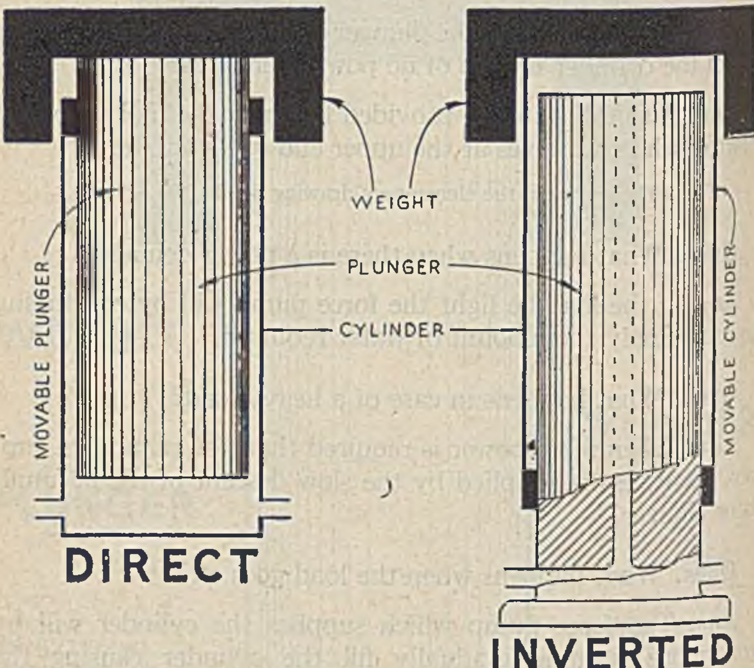
Ans. The force pump which supplies the cylinder will by continuous running gradually fill the cylinder causing the plunger to rise to the top, thus accumulating in the cylinder an amount of energy equal to that expended by the descent of the plunger.

Accumulator Types.—To meet varied conditions several kinds of accumulators have been introduced. They may be classed as:

1. Direct
2. Inverted
3. Differential (intensifier)

Other classifications may be given as with respect to some construction feature as:

1. Weighted tank. 2. Ring weight. { Concrete / Cast Iron



Figs. 2 and 3.—Elementary direct and inverted accumulators. Fig. 2, direct type; fig. 3, inverted type.

Figs. 2 and 3 show the direct and inverted types. The distinguishing feature of these is that the direct form has a movable plunger, and the inverted form, a movable cylinder. This is plainly shown in the illustrations.

Ques. What is the construction of an actual direct type accumulator?

Ans. Fig. 4 shows a typical design.

In construction the plunger is provided with a yoke at its upper end. At the ends of the yoke two rods are suspended, the necessary weights being threaded on these rods as shown. A typical accumulator of this pattern will have a 24 inch plunger and weighted to develop 600 lbs. per sq. in.

Ques. What should be noted about this type?

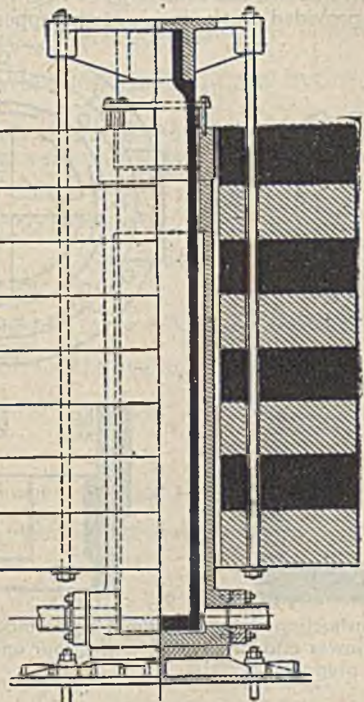


Fig. 4.—Ring weight direct accumulator showing construction.

Ans. It is self contained, requiring no frame or guide posts. An important feature is that the packing is readily accessible at the top of the cylinder.

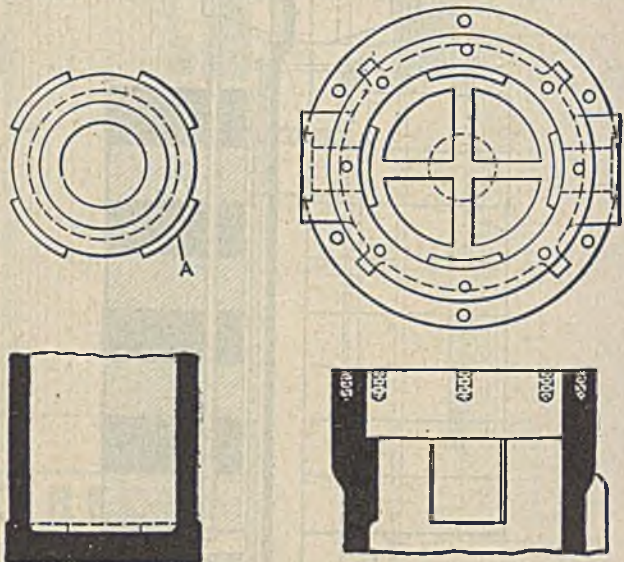
Ques. What is the usual pressure employed in plants having hydraulic power?

Ans. 600 lbs. per sq. in.

Ques. What provision is made to prevent the plunger over-running its stroke?

Ans. Stops, as shown in figs. 5 to 8.

The design here shown has four *stops* or lugs A, on the lower end and similar lugs are provided on the inside of the upper end of the cylinder.



Figs. 5 to 8.—Construction details of direct accumulator cylinder and plunger showing lugs at lower end of plunger and upper end of cylinder to prevent overtravel of the plunger.

Ques. With lugs on both plunger and cylinder how is the plunger placed in the cylinder?

Ans. By turning plunger around in inserting, till the lugs come into position where they will pass each other.

When the lugs have passed each other the plunger is given ⅛ of a turn and fastened in this position. With this setting the ends of the lugs will register so that the piston cannot overtravel. Suitable provision is made to prevent the yoke turning.

Ques. What type of direct accumulator is the design in fig. 4?

Ans. The ring weight accumulator.

As shown in the figure there are a number of cast iron rings.

Ques. How many rings are provided?

Ans. Enough to develop the required hydraulic pressure.

Example.—A direct accumulator has a 14 inch plunger weighing 10,000 lbs. What additional weight is required to develop a hydraulic pressure of 600 lbs. per sq. in.?

Cross sectional area plunger, or

$$a = .7854 \times d^2$$

For a 14 inch plunger

$$a = .7854 \times 14^2 = 153.94, \text{ say } 154 \text{ sq. ins.}$$

Total weight to balance the hydraulic pressure

$W = Pa$

in which

W = weight of plunger + weight to be added.

a = area plunger hydraulic pressure per sq. in.

Substituting

$$W = 600 \times 154 = 92400 \text{ lbs.}$$

Additional weight or weight of rings required

$$= \text{total load} - \text{weight of plunger}$$

$$= 92400 - 10{,}000 = 82400 \text{ lbs.}$$

Dimensions of Plunger.—In design it is required to find the plunger or "ram" dimensions to meet certain conditions. With respect to the proportion between length of stroke and diameter of plunger, it should be noted that the less the diameter the less will be the amount of ring weights required to balance the hydraulic pressure. Accordingly, if plenty of vertical space be available there will be a saving in ring metal by employing a long stroke.

Fixing one dimension the problem is to determine the other dimension for a given displacement. It should be understood that displacement here means *the volume displaced by the plunger per stroke*.

Example.—What length stroke is required for an accumulator having a displacement of 250 gallons. Diameter of plunger 14 ins.

$$1 \text{ gal.} = 231 \text{ cu. ins.}$$

Accordingly displacement

$$= 250 \times 231 = 57750 \text{ cu. ins.}$$

Area 14″ plunger = $.7854 \times 14^2 = 154$ sq. in. (approx.).

$$\text{Length of stroke} = \frac{\text{displacement}}{\text{area plunger} \times 12}$$

here the 12 in. denomination is to change length of stroke from inches to feet.

Substituting

$$\text{Length of stroke} = \frac{57750}{154 \times 12} = 31.2 \text{ feet.}$$

Ques. What difficulty is encountered with the inverted accumulator?

Ans. The stuffing box being at the bottom is hard to get at and consequently difficult to adjust or renew packing.

Ques. What is an intensifier?

Ans. Another name for a differential accumulator.

Ques. Well, what is it?

Ans. A hydraulic device for converting a low pressure into a high pressure.

In analogy it functions similarly as an electric transformer which converts low voltage current into high voltage current.

Ques. How does the differential accumulator or intensifier work?

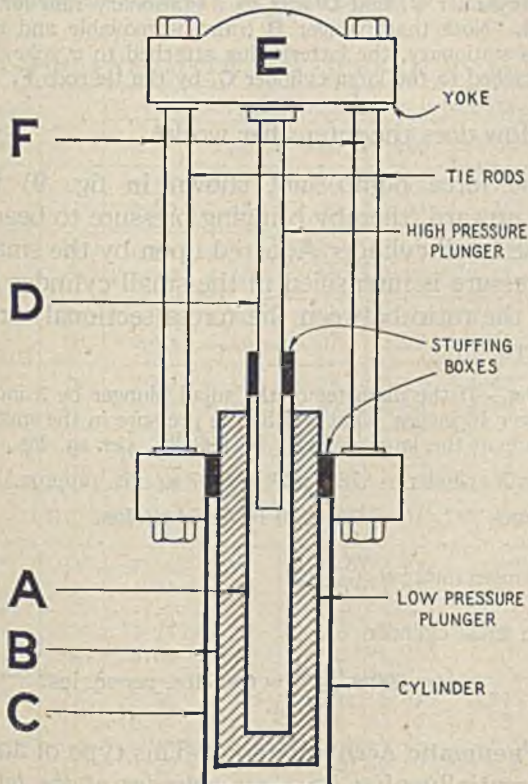


Fig. 9.—Elementary differential accumulator or "intensifier". A, small cylinder (inner wall); B, large plunger (ram); C, large cylinder; D, small plunger (ram); E, yoke; F, tie rods. Water connection to small cylinder not shown.

Ans. The water supplied at low pressure operates a piston in a large cylinder which in turn operates a ram of smaller diameter in a smaller cylinder.

The device as shown in elementary form in fig. 9 consists of two cylinders of different diameters, the smaller cylinder **A**, being part of the plunger **B**, that fits into the larger cylinder **C**. Into the smaller cylinder **A**, fits the small high pressure plunger **D**. **B** acts as a movable ram for the larger cylinder **C**, and **D** acts as a stationary ram for the smaller cylinder **A**. Note that plunger **B** (ram) is movable and that plunger (ram) **D** is stationary, the latter being attached to a yoke, **E**, which in turn is attached to the large cylinder **C**, by the tie rods **F**.

Ques. How does the intensifier work?

Ans. The force pump (not shown in fig. 9) forces the plunger **B**, upward, thereby bringing pressure to bear upon the water in the small cylinder **A**, acted upon by the small plunger **D**. This pressure is intensified in the small cylinder **A**, in proportion to the ratio between the (cross sectional) areas of the two plungers.

Example.—If the diameter of the small plunger be 3 inches and the large plunger 10 inches, what will be the pressure in the small cylinder if the pressure in the large cylinder be 600 lbs. per sq. ins.

Area small cylinder $= .7854 \times 3^2 = 7.07$ sq. ins. (approx.)

" large " $= \frac{1}{4}\pi \times 10 = 78.54$ sq. ins.

$$\text{Plunger ratio} = \frac{78.54}{7.07}$$

pressure in small cylinder

$$= 600 \times \frac{78.54}{7.07} = 6665 \text{ lbs. per sq. ins.}$$

Hydro-Pneumatic Accumulators.—This type of accumulator consists essentially of *a large air cylinder at the top which is rigidly tied to a base.* On the center of this base is mounted a relatively small hollow hydraulic piston.

Working between the air cylinder above and the hydraulic system below is the air piston—hydraulic cylinder unit, which slides up and down as the accumulator is charged and discharged.

Pneumatic and Hydraulic Pressures

FOR PNEUMATIC PRESSURE OF 100 p.s.i.

Diameter of Air Cylinder		HYDRAULIC PRESSURES, in p.s.i. (Approx.)					
		1500	2000	2500	3000	4000	5000
18″	D	4.50	3.875	3.50	3.125	2.75	2.375
	G	3.50	2.48	2.00	1.63	1.24	0.92
24″	D	6.00	5.125	4.625	4.25	3.625	3.25
	G	5.90	4.30	3.50	2.95	2.15	1.7
26″	D	6.50	5.625	5.00	4.625	4.00	3.50
	G	6.88	5.16	4.07	3.50	2.61	2.00
30″	D	7.50	6.50	5.75	5.25	4.625	4.125
	G	9.20	6.89	5.39	4.50	3.49	2.76
34″	D	8.50	7.375	6.625	6.00	5.25	4.625
	G	11.79	8.87	7.16	5.87	4.49	3.49

FOR PNEUMATIC PRESSURE OF 150 p.s.i.

Diameter of Air Cylinder		1500	2000	2500	3000	4000	5000
18″	D	5.50	4.75	4.25	3.875	3.375	3.0
	G	4.93	3.68	2.90	2.45	1.86	1.46
24″	D	7.25	6.25	5.625	5.125	4.50	4.00
	G	8.60	6.37	5.16	4.28	3.30	2.61
26″	D	8.00	6.875	6.25	5.625	4.875	4.375
	G	10.40	7.75	6.37	5.16	3.83	3.11
30″	D	9.25	8.00	7.125	6.50	5.625	5.00
	G	14.00	10.44	8.30	6.93	5.16	4.00
34″	D	10.50	9.00	8.125	7.375	6.375	5.75
	G	17.90	13.20	10.70	8.87	6.63	5.40

For operation, the air or pneumatic side of the accumulator along with the air receiver tank, is loaded with compressed air. This air can be supplied either by the plant air line or a small, independent compressor.

Pneumatic and Hydraulic Pressures—Continued

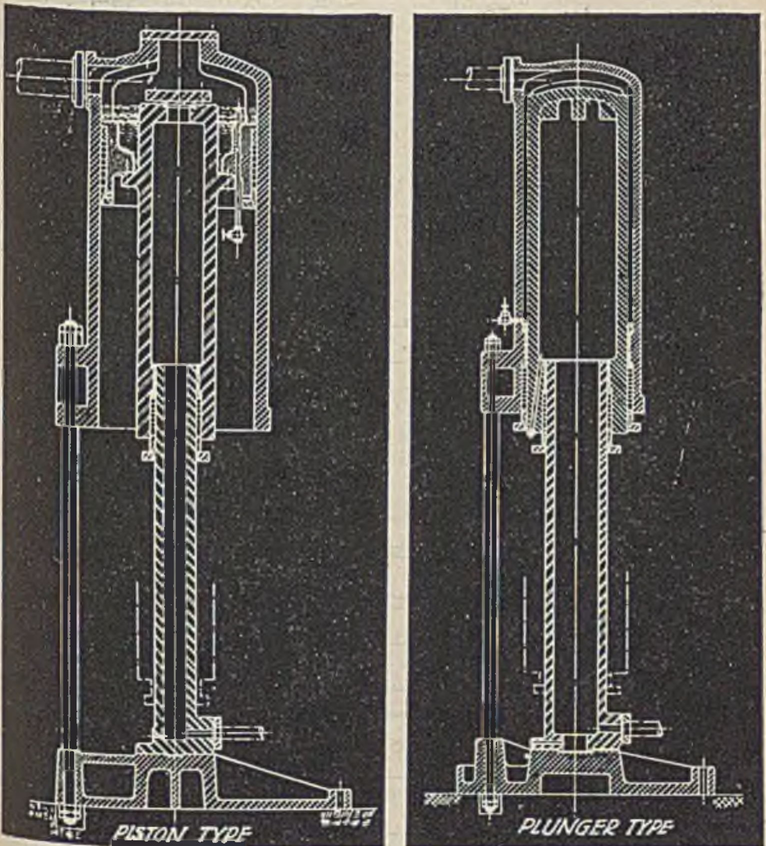
FOR PNEUMATIC PRESSURE OF 200 p.s.i.

Diameter of Air Cylinder		HYDRAULIC PRESSURES, in p.s.i. (Approx.)					
		1500	2000	2500	3000	4000	5000
18″	D	6.375	5.50	4.875	4.50	3.875	3.50
	G	6.63	4.93	3.90	3.30	2.45	2.00
24″	D	8.50	7.375	6.625	6.00	5.25	4.625
	G	11.78	8.87	7.16	5.87	4.50	3.50
26″	D	9.25	8.00	7.125	6.50	5.625	5.00
	G	13.9	10.40	8.28	6.90	5.16	4.07
30″	D	10.75	9.25	8.25	7.50	6.50	5.875
	G	18.80	13.90	11.10	9.10	6.89	5.61
34″	D	12.125	10.50	9.375	8.50	7.375	6.625
	G	24.00	18.00	14.30	11.79	8.80	7.16

FOR PNEUMATIC PRESSURE OF 250 p.s.i.

18″	D	7.25	6.125	5.5	5.00	4.375	3.875
	G	8.57	6.10	4.93	4.08	3.12	2.45
24″	D	9.50	8.25	7.375	6.75	5.875	5.25
	G	14.80	11.10	8.87	7.40	5.60	4.40
26″	D	10.375	9.00	8.00	7.375	6.375	5.625
	G	17.10	13.20	10.50	8.87	6.64	5.16
30″	D	12.00	10.375	9.25	8.50	7.25	6.50
	G	23.40	17.50	13.90	11.79	8.57	6.89
34″	D	13.50	11.75	10.50	9.625	8.25	7.375
	G	29 74	22 53	18.00	15.10	11.10	8.88

The capacity of the air receiver tank should be sufficient to hold the pneumatic pressure (and corresponding hydraulic pressure) fairly constant throughout the operating range of the accumulator.



Figs. 10 and 11.—Hydro-pneumatic accumulators. Fig. 10, piston type; fig. 11, plunger type.

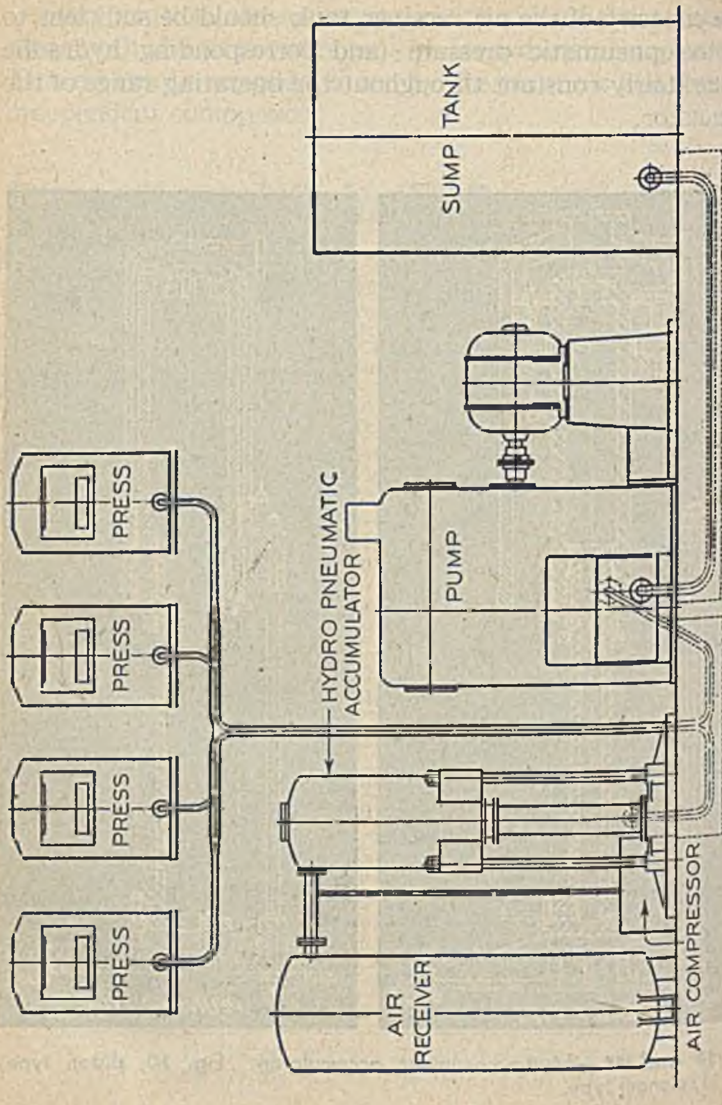


Fig. 12.—Hydro-pneumatic accumulator system.

Figs. 10 and 11 show two types of hydro-pneumatic accumulators and in fig. 12 is shown a typical system.

The pneumatic and hydraulic pressures in an accumulator are in indirect proportion to the areas of the respective pistons. Consequently, any change in the loading of the pneumatic side will change the hydraulic pressure proportionately.

The table accompanying shows combinations of capacities and pressures of various size units.

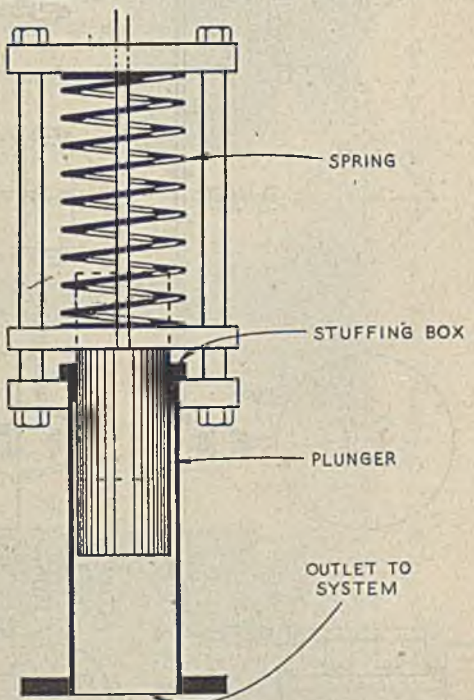
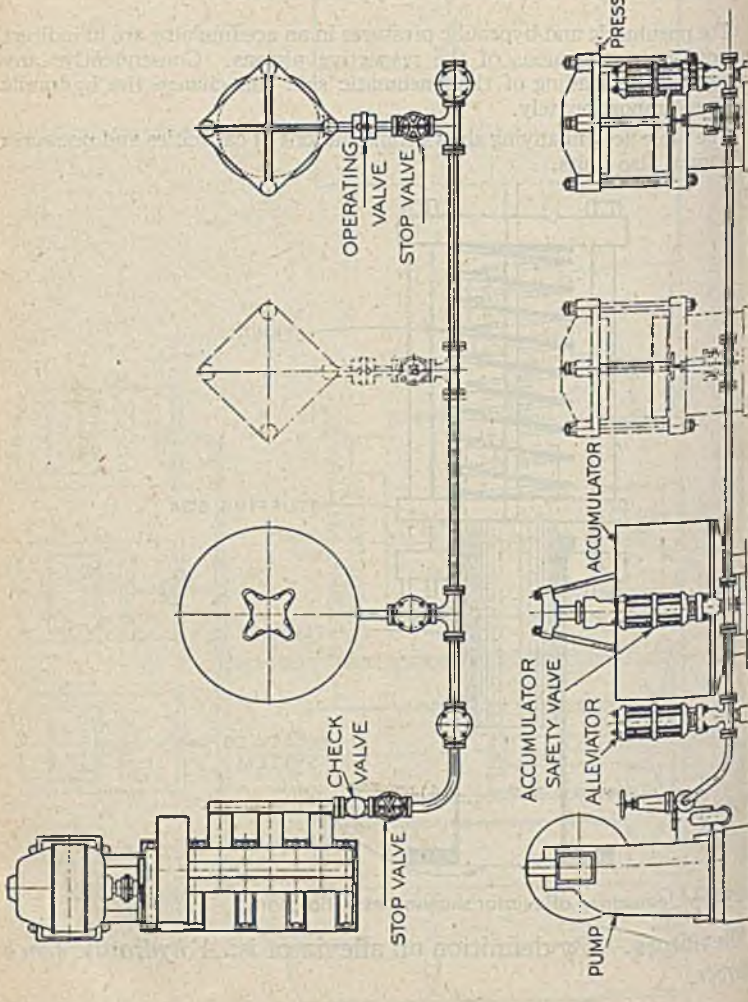


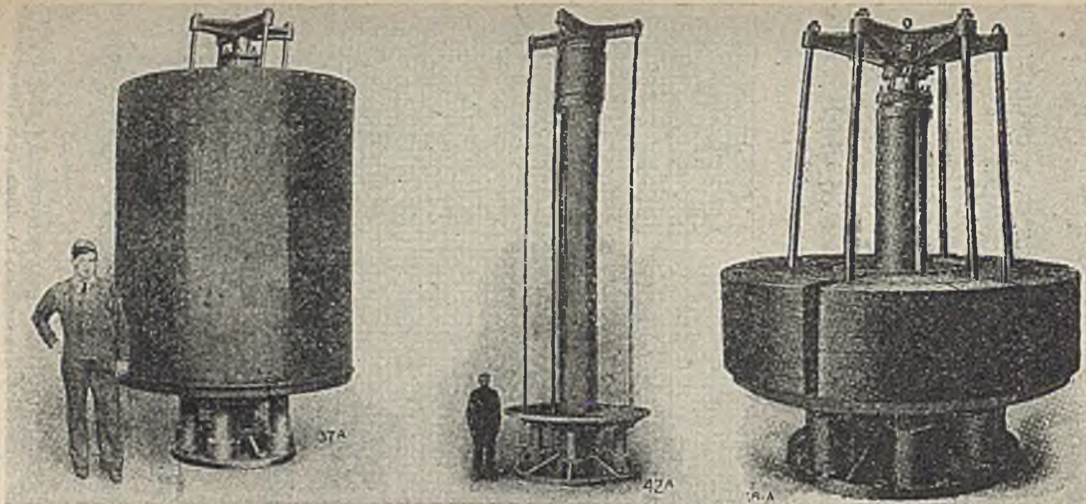
Fig. 13.—Elementary alleviator showing essential parts.

Alleviators.—By definition an alleviator is: *A hydraulic shock absorber.*

Ques. Where are alleviators used?



Figs. 14 and 15.—Installation of alleviators on pump accumulator and press.



Figs. 16 to 18.—Types of accumulator for various ballast. Fig. 16, weighted tank; fig. 17, concrete weights; fig. 18, cast iron weights.

Ans. They are used in conjunction with high pressure hydraulic systems and pipe lines.

Ques. For what purpose?

Ans. To absorb shock caused by the sudden stopping of liquid.

Ques. Of what does an alleviator consist?

Ans. A spring loaded plunger working in a cylinder long enough to give it sufficient travel to function.

The essentials are shown in fig. 13.

Ques. How does it work?

Ans. If a sudden shock come on the line to which it is con-

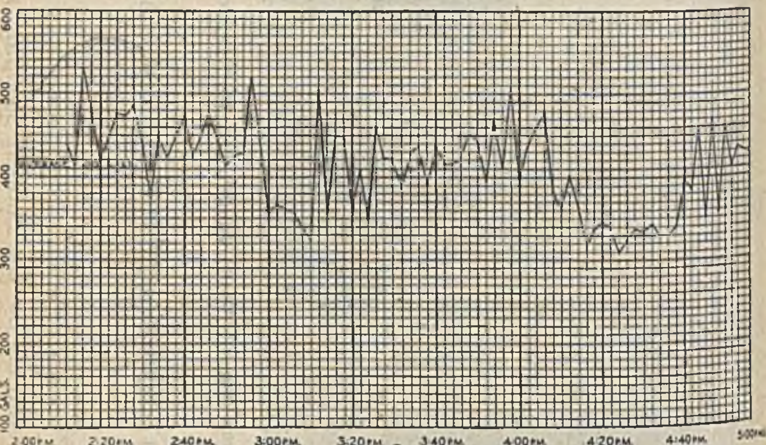
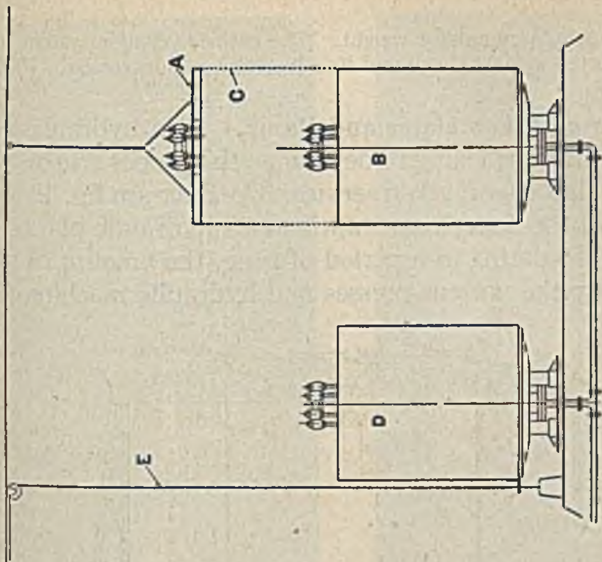


Fig. 19.—Load diagram of hydraulic plant.

nected, the shock will be absorbed by the piston moving up in the cylinder to some position A, shown in dotted lines.

The movement of the piston, it should be noted, does not allow the liquid to escape.

Installation of the alleviators at the pump, accumulator and hydraulic press would absorb shock caused by the sudden closing of a valve or sudden



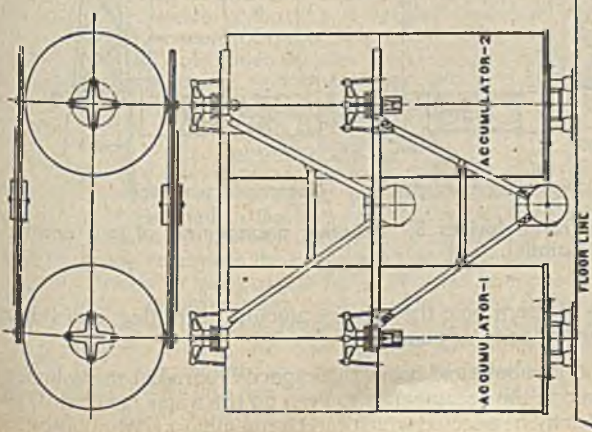


Fig. 20.—Equalizing devices 1. Arrangement of two accumulators working in parallel.

Fig. 21.—Equalizing devices 2. Arrangement of two accumulators operating in series.

stopping of the accumulator weight. The entire hydraulic system is thus fully protected against shock and its effectiveness is increased.

Selection of Accumulator and Pump.—In a hydraulic plant it is sometimes perplexing to determine the proper size of pump and accumulator for a given service. The diagram fig. 19 shows a plotting of the water consumption of a hydraulic plant. This consists of tabulating in a period of time, the amount of water consumed by the various presses and hydraulic machines.

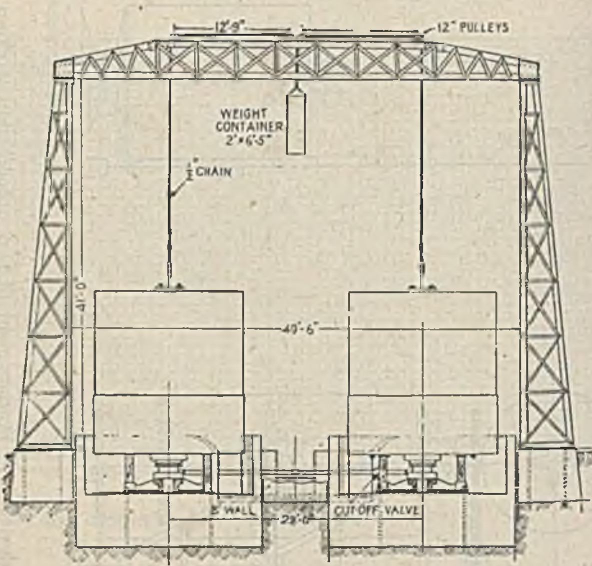
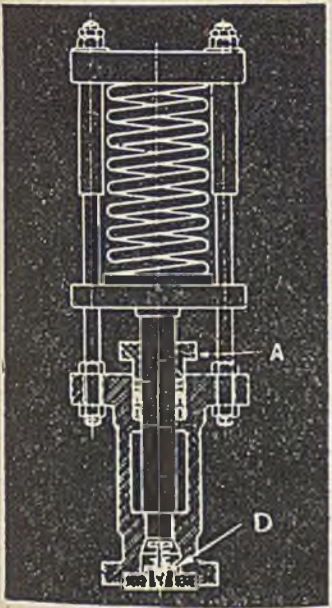


Fig. 22.—Equalizing devices 3. Another arrangement of two accumulators connected in parallel.

With this diagram take the average amount of reading, and this equals the minimum capacity of pump.

The variations above and below this capacity represent the volume which must be stored in the accumulator to even up the water demand. With this data a pump may be selected which can be run almost continuously, and an



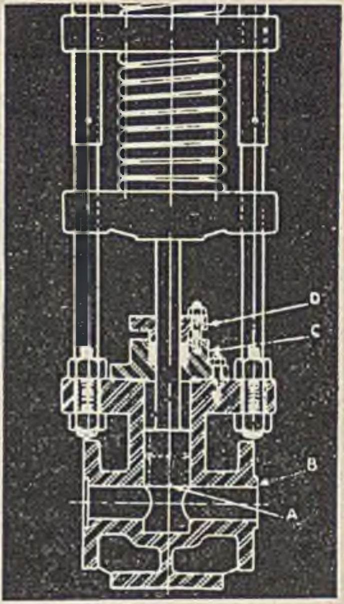


Fig. 23.—Special alleviator with check on cushion valve. The check valve D, acts to prevent shock or pounding caused by the quick return of the plunger to its seat when pressure in the line is suddenly reduced. The check valve prevents the sudden return of water from alleviator to line, valve disc being drilled with a small hole which throttles the return and causes plunger to seat slowly and without impact. A shut off valve should be installed between alleviator and main pipe to allow for repacking of the alleviator gland or for repairs.

Fig. 24.—Combined alleviator and safety device. Its object is to prevent an accumulator dropping or discharging quickly in the event of breakage in the pipe line. It is installed in the line near the accumulator and consists of a flanged body casting B, in which operates a spring loaded plunger A. Under normal operating conditions the plunger is held in position shown by pressure of liquid in the line, a free passage being afforded from pump to accumulator and vice versa. Should a break occur between safety device and pump, the pressure is immediately reduced, allowing spring to force plunger into liquid passage, partially closing the opening, but permitting sufficient liquid to escape to allow accumulator to return slowly to its unloaded position. The spring loaded plunger also acts as an allevitaor, absorbing any shocks caused by quick stopping of a press or accumulator.

accumulator of such size as will meet the variable quantity of water demand and thereby produce a balanced and economical installation.

In the contemplation of a new plant which might consist of one or more presses, it will be necessary to assume a definite number of operations per minute, so as to work at a probable cycle of operation.

To these figures add proper margin to take care of leaky valves, etc., or to take care of increased operation and growth of plant.

Figs. 14 and 15 illustrate an application of alleviators to a hydraulic system with installation at points subject to the greatest shocks.

Equalizing Devices.—Fig. 20 shows an arrangement of two accumulators, working in parallel, which are controlled by an equalizing device. This device consists of weights suspended from two arms on the sides of accumulators so arranged that if one accumulator be raised ahead of the other, the weights swing slightly over toward the one in advance, overloading this accumulator and maintaining the same level on both.

The arrangement shown in fig. 21 is used when two accumulators are operated in series. Accumulator B, is slightly underloaded so that it fills up first until it reaches suspended weight A. The addition of this weight overloads accumulator B, as compared with accumulator D, and allows accumulator D, to fill. This second accumulator is directly controlled by the unloader on pump which thus controls both accumulators.

Fig. 20 also shows an equalizing arrangement where two accumulators are connected in parallel. Both accumulators fill and discharge in unison. Balance is maintained by a suspended ballast weight container connected to each accumulator by a set of ropes and sheaves.

CHAPTER 37

Hydraulic Elevators

Water as a medium for transmitting power has been extensively employed to operate elevators and is still in use for that purpose today, especially for freight elevators. In fact the hydraulic plunger type elevator is a satisfactory type largely used for factory purposes, garages, etc. The mechanism is simple and as designed by the leading manufacturers will operate on any water pressure from 30 lbs. per sq. in. up.

There are two types of hydraulic elevator:

1. Plunger
2. Geared or piston

Ques. How does the plunger type work?

Ans. Instead of pulling the elevator and load up, it is pushed up by means of a hydraulic plunger.

Ques. How does the geared or piston type work?

Ans. A hydraulic piston of sizeable diameter is connected to pulleys over which run lifting cables from which the car is suspended.

Any suitable gearing ratio may be used so that the car will move two or more times the distance moved by the piston.

Plunger Hydraulic Elevation.—This is a direct drive and is the simplest type mechanism.

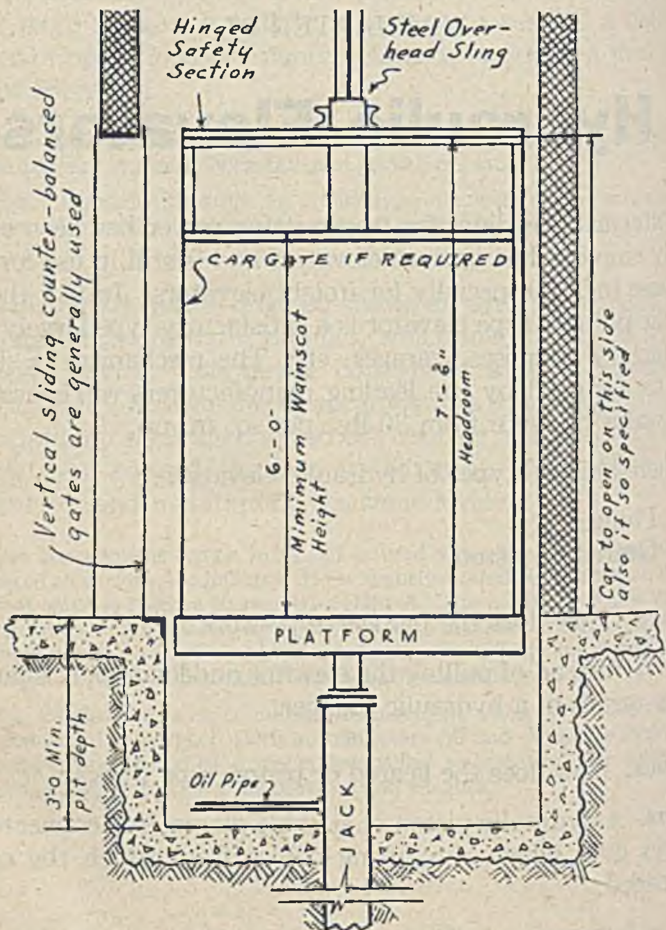


Fig. 1.—Working drawing showing elevation of typical installation.

Ques. Describe briefly the plunger system.

Ans. The elevator is supported underneath by a steel plunger instead of being hung from above by cables, although cables are attached to the top of the car leading over pulleys at the top of the shaft to counter weights.

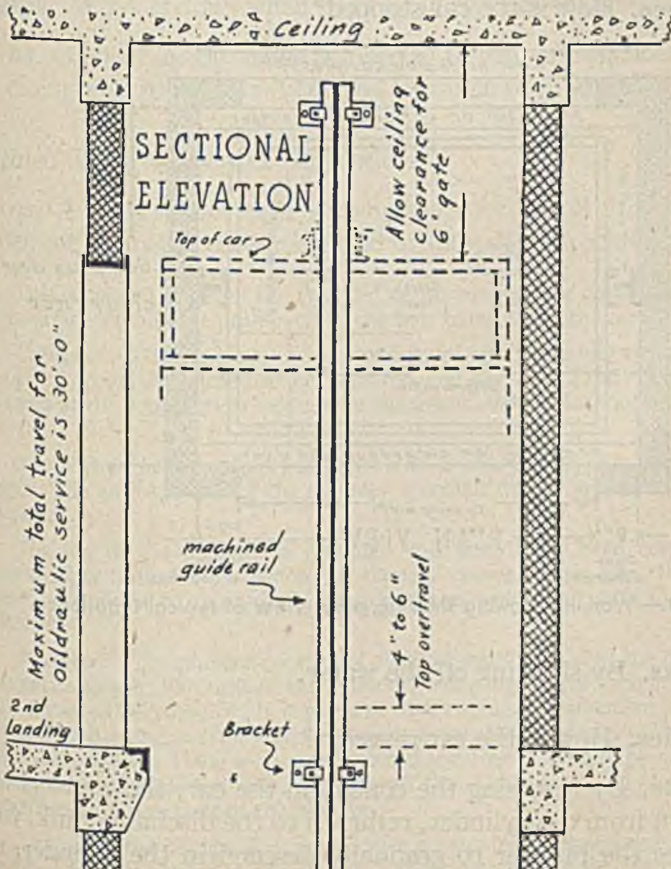


Fig. 2.—Working drawing showing **side elevation** of typical installation.

Ques. How is the car started?

Ans. By a control lever, hand rope or push button operating a valve which permits water under pressure to enter the cylinder in which is the plunger, thus forcing up the elevator.

Ques. How is the car stopped?

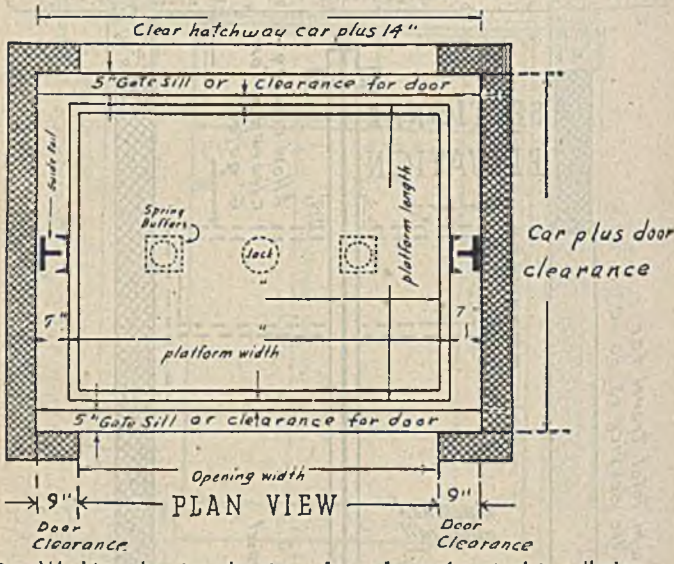


Fig. 3.—Working drawing showing **plan view** of typical installation.

Ans. By shutting off the water.

Ques. How is the car reversed?

Ans. By reversing the control in the car, the water is withdrawn from the cylinder, returned to the discharge tank, which causes the plunger to gradually descend in the cylinder, thus the car which is attached to the plunger, comes down.

Plunger Elevator Construction.—The first operation when installing the hydraulic system is *to drill a vertical hole into the ground by driving down a casing of steel pipe and removing the earth from inside of it.*

Ques. What is done when the casing reaches solid rock?

Ans. A short inside sleeve is inserted to form a joint between the casing and rock to prevent the entrance of mud and silt.

Ques. What is the next operation?

Ans. A rotary shot drill to which a core barrel is attached is then set up inside the casing and drilling of the rock is begun.

This is carried down to the required depth by bringing cores of rock to the surface as they are broken off in the hole filling the core barrel.

Cylinder.—This is made of steel tubing, of approximately twenty-foot lengths, accurately straightened, squared and threaded. Butt joints are formed at the couplings to secure true alignment, smooth interior and exact length.

The bottom of the cylinder is fitted with a heavy steel plug, welded in place. The entire length of the cylinder is coated with a preservative preparation.

The top of the cylinder is provided with a cylinder head containing the stuffing box through which the plunger passes. Here, also, the connection is made to receive and discharge the water that acts upon the plunger.

Plunger.—The plunger consists of a hollow shaft, closed at the bottom, its entire length, like that of the cylinder, being also slightly greater than the travel of the elevator. It is made of steel tubing of convenient lengths, each length being carefully straightened, accurately turned to a uniform size and polished. These sections are joined together internally by specially constructed threaded nipples, so designed that the strength of each joint equals that of any part of the plunger.

The top of the plunger is provided with a cast steel flanged head, shrunk in place and hot riveted to the plunger, the head securely bolted to the steel plate forming the lower part of the car platform.

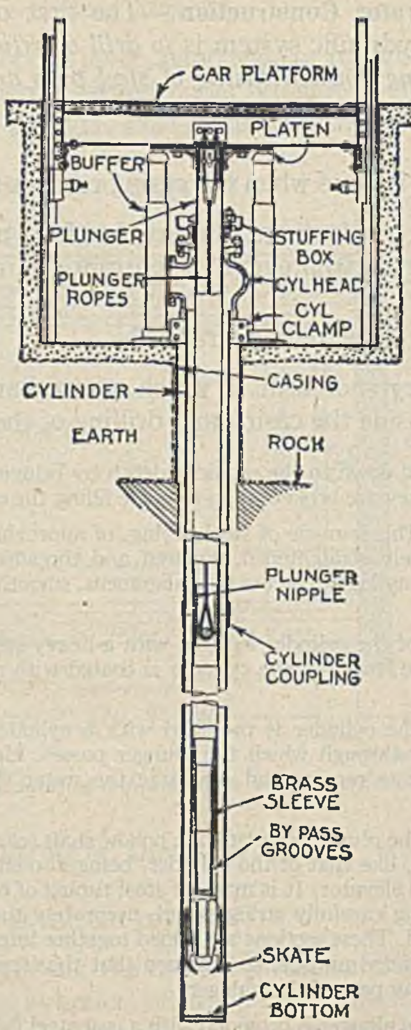
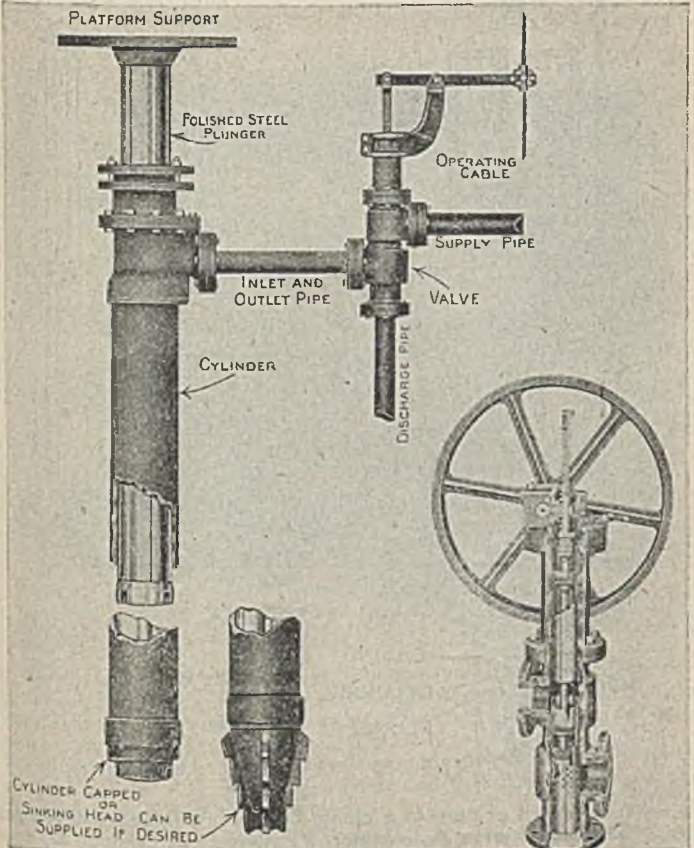


Fig. 4.—Sectional view of plunger elevator showing bottom of shaft, plunger casing, etc.

Two plough steel, galvanized ropes of large size are run through the center of the plunger and securely fastened around a steel pin at the bottom, the other two ends being attached to the car plate by heavy steel eye bolts.

Plunger By Pass.—The lower end of the plunger is a grooved, tapered casting, fitted with shoes, or skates, which act as guides for the plunger to prevent it rubbing against the walls of the cylinder.



Figs. 5 to 7.—Detail showing latest practice in design of lifting plunger, cylinder and operating mechanism. Fig. 7, shows rack and pinion type operating valve used on high speed elevators.

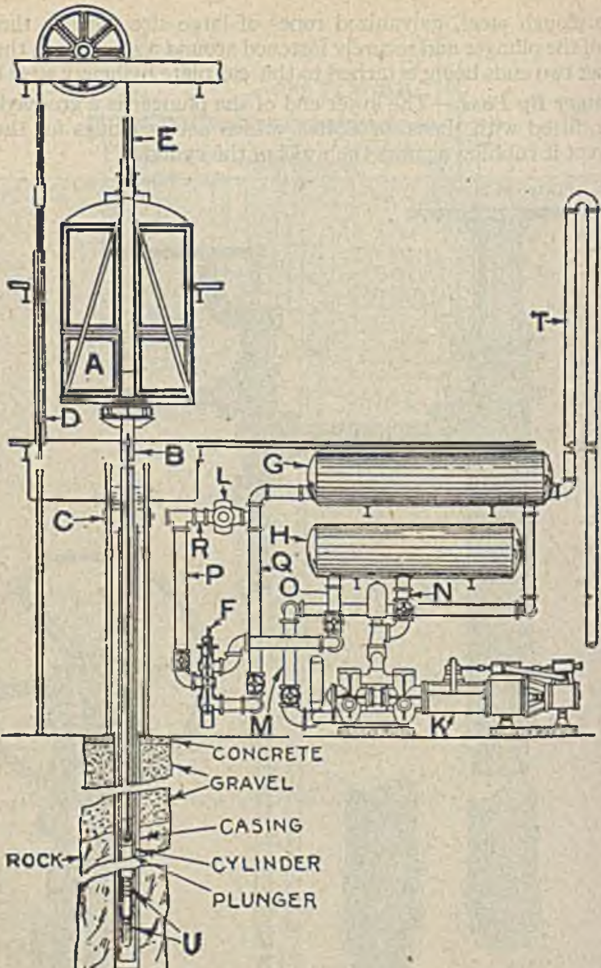


Fig. 8.—Arrangement of parts in a plunger elevator with steam driven power system. **The parts are: A,** elevator; **B,** plunger; **C,** cylinder; **D,** counter weights; **E,** counter weight cables; **F,** valve; **G,** discharge tank; **H,** pressure tank; **K,** pump; **O,** supply piping; **P,** "to and fro" piping; **Q,** exhaust piping; **T,** back pressure loop; **U,** plunger bottom. The operation of this system is explained in the text.

The grooved plunger end is known as the *plunger by pass*, which prevents upward movement of the car beyond a fixed point by releasing the water from the top of the cylinder which relieves the pressure.

Counter Weight.—The compensating counterweight ropes are attached to the car cross head, passing over a grooved sheave of large diameter to the counter weight frame.

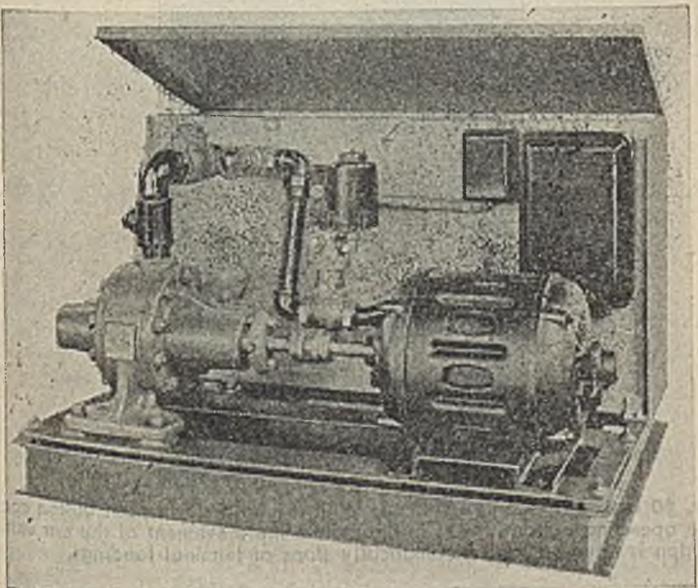


Fig. 9.—Typical direct connected push button type rotary pump electric motor power unit and tank. The power unit consists of a steel foundation base with motor and efficient pump, relief valve, check valve, electric lowering valve and automatic leveling valve, all compactly assembled and sound proof. The oil reservoir and controller are mounted directly over and form an integral part of the unit. On small units motor and pump are directly connected. On larger units, the belt drive is used.

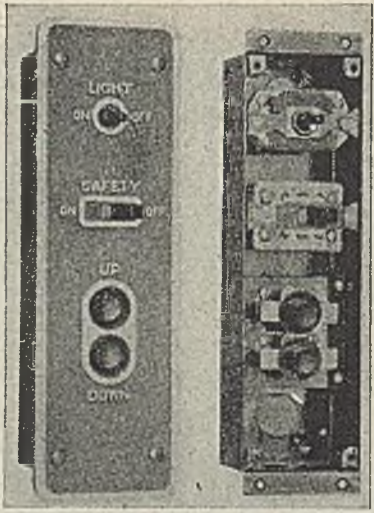
A detail of the lifting plunger and control mechanism is shown in figs. 2 to 4.

Ques. What two types of control valves are used?

Ans. The lever, fig. 5 and the rack and pinion type, fig. 7.

Ques. What is the adaptation of the two types?

Ans. The lever valve is used for the slow plunger speeds (20



Figs. 10 and 11.—Control systems. With the hold down push button control, the operating button is held in throughout the movement of the car until the button is released, and automatically stops at terminal landings.

to 50 feet per minute) and the rack and pinion valve for higher speeds.

Ques. What type of power supply unit is generally used?

Ans. A rotary pump direct connected to an electric motor with suitable control devices.

Ques. When reciprocating steam pumps are used how are "pulsations" in the water discharge cushioned?

Ans. By the combined hydro-pneumatic system employing pressure and discharge tanks as shown in fig. 8.

Ques. How does it work?

Ans. The pressure tank is filled two-thirds with water and air of the desired pressure is pumped into the remaining third, to prepare the system for operation. When the car operator throws the lever so that the elevator may ascend, the supply ports of the main valve are opened and the compressed air forces the water out of the pressure tank, through the supply piping, the valves, and into the elevator cylinder.

Ques. What is the effect on the air in the tank?

Ans. It expands and its pressure is reduced.

Ques. How is the pump automatically started?

Ans. The volume of air in the pressure tank thus expands and its pressure is reduced. A pipe leading from the pressure tank to a regulator on the steam supply of the pump automatically starts the pump when the air pressure begins to drop.

Ques. What happens when the pump starts?

Ans. It takes water from the discharge tank and delivers it into the pressure tank from which it may continue to flow into the elevator cylinder until the car operator shuts it off with his lever or the automatic stop valve does it for him at the terminal landing.

Ques. How long does the pump run?

Ans. Until the pressure tank is ⅔ full when the automatic regulator stops the pump's operation.

Ques. What occurs when the main operating valve is opened to allow the elevator to descend?

Ans. The water from the cylinder is returned through the exhaust side of the valve to the discharge tank, and the pump remains inoperative. The pump operates only for the up travel of the elevator or approximately half the time.

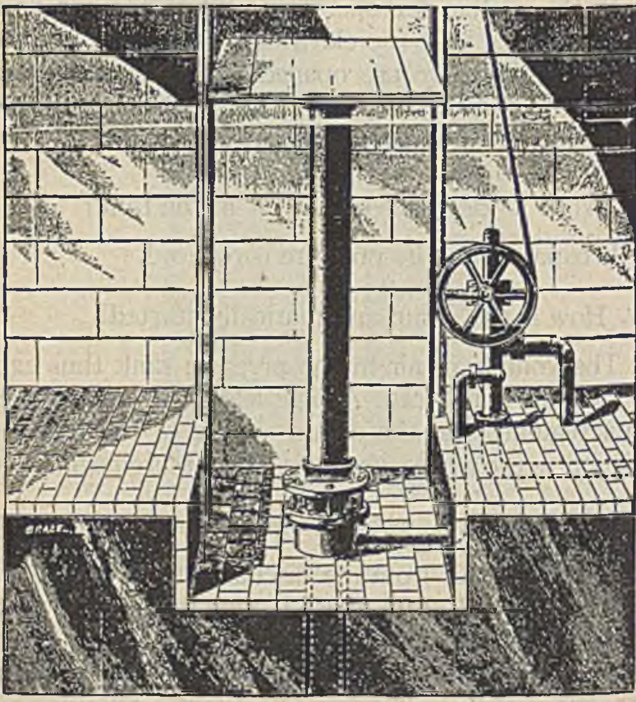


Fig. 12.—Sidewalk type plunger elevator with rope operated rod and pinion valve control.

Piston or Geared Elevators.—The mechanism of this class of hydraulic elevator consists of a cylinder and *piston*, the latter being connected by one or more piston rods to a cross head which carries the sheaves over which run the lifting cables from which the car is suspended.

Fig. 12 shows the general arrangement.

Ques. How is the movement of the elevator controlled?

Ans. By means of suitable valves and controlling mechanism operated from the car, water, under pressure from city main,

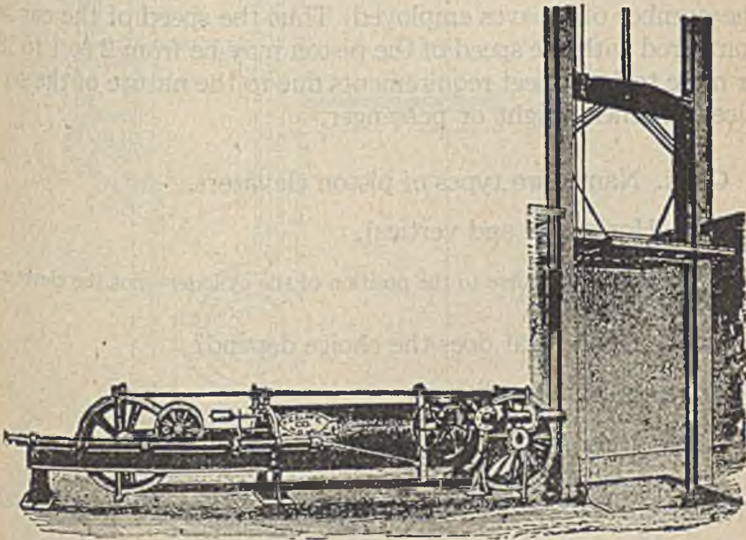


Fig. 13.—Piston or geared elevator with horizontal cylinders.

air or gravity tank is caused to flow into and out of the cylinder, thus causing the piston to move from one end of the cylinder to the other, and back again.

Ques. How is this to and fro motion of the piston and cross head transmitted to the car?

Ans. Through the lifting cables which pass over sheaves at the top of the elevator hatchway, and which hold the car in suspension, thus moving it up or down, according as the water flows into or out of the water cylinder.

Ques. What is the feature of this arrangement?

Ans. The motion of the piston transmitted to the car is multiplied to a greater or less degree, according to the design, by the number of sheaves employed. Thus the speed of the car as compared with the speed of the piston may be from 2 to 1 to 12 or more to 1, to meet requirements due to the nature of the service, whether freight or passenger.

Ques. Name two types of piston elevators.

Ans. Horizontal and vertical.

This relates of course to the position of the cylinder—not the elevator.

Ques. Upon what does the choice depend?

Ans. On local conditions.

Thus, if the floor space be limited, vertical cylinders are used.

Ques. What gearing is generally used on vertical cylinders?

Ans. 3 and 4 to 1, though ratios of from 2 to 1 up to 6 to 1 are quite common.

Pneumatic Hydraulic Automobile Lift.—The style lift shown in fig. 14 is air operated with remote control; hand raising and lowering valves. The control is adapted to "inching" the lift for adjusting axle supports to low clearance axles and knee action pads on cars with skirted fenders and bodies.

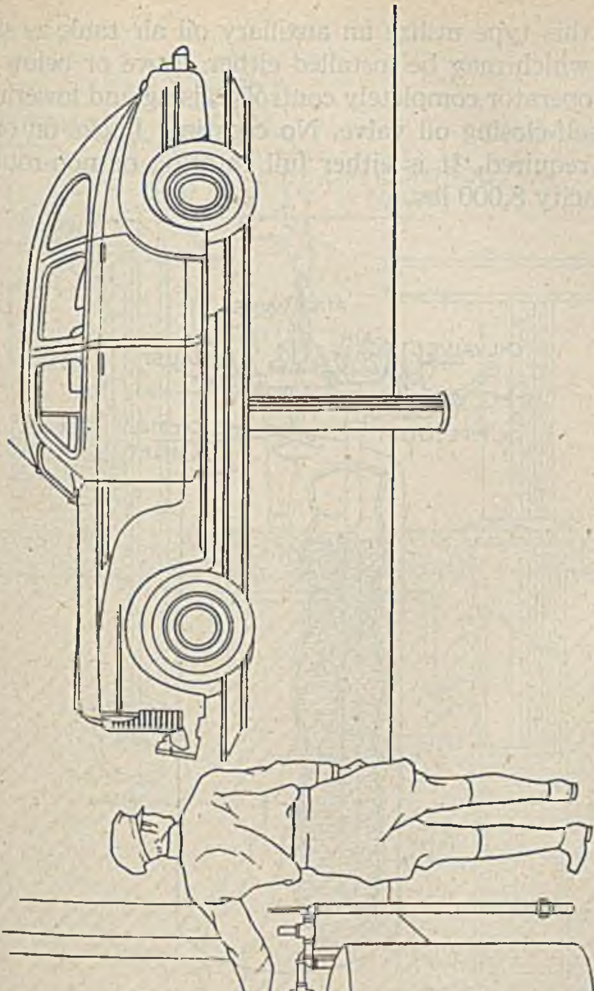


Fig. 14.—Pneumatic hydraulic automobile lift.

Lifts of this type utilize an auxiliary oil air tank as shown in fig. 15, which may be installed either above or below floor level. The operator completely controls raising and lowering by means of self-closing oil valve. No coasting. Locks on oil, no safety leg required. It is either full rotating or non-rotating. Rated capacity 8,000 lbs.

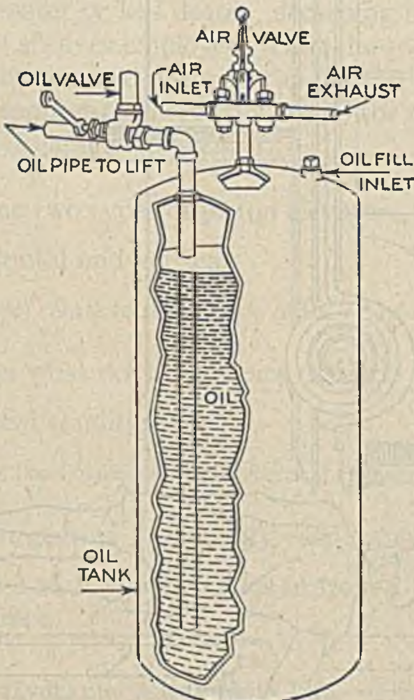


Fig. 15.—Sectional view of pneumatic hydraulic tank. The lifting and lowering valve control is in the oil line. In admitting air, the air valve is locked in inlet position. To control lifting operation the hand oil valve is manipulated. Oil under air pressure flows through the oil pipe line to hand oil control valve, then into lift, under control of operator at oil valve.

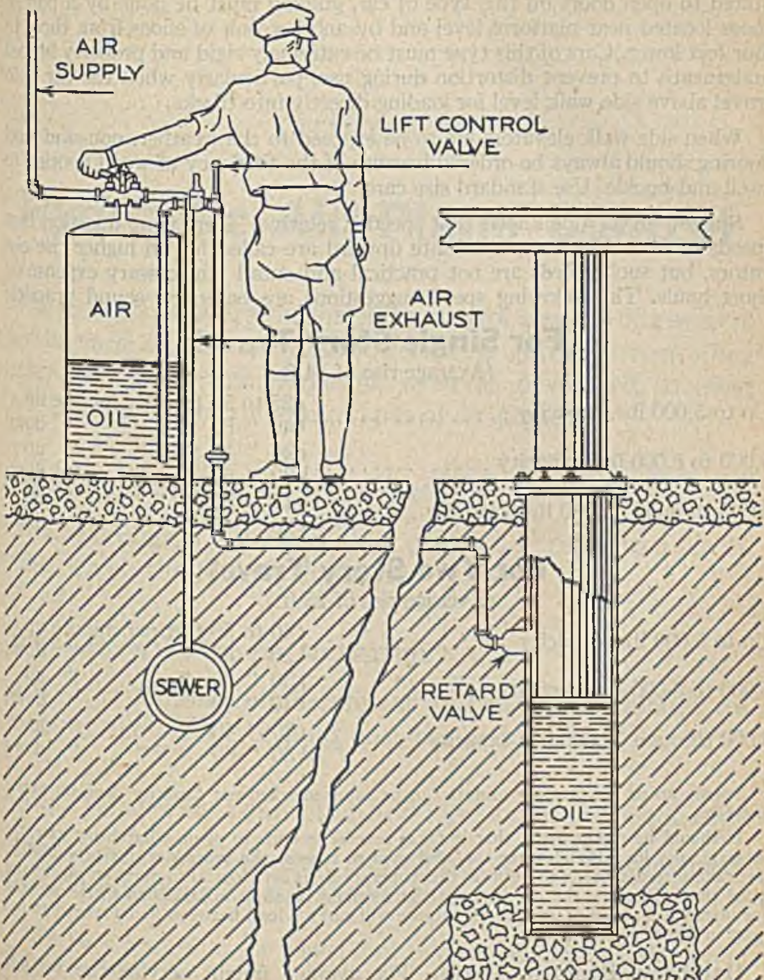


Fig. 16.—Hydro-pneumatic automobile jack showing tank and piping connections.

Notes on Side Walk Cars.—Because of the bow iron arrangement required to open doors on this type of car, guiding must be done by a pair of shoes located near platform level and by another pair of shoes from three to four feet lower. Cars of this type must be extremely rigid and properly braced underneath to prevent distortion during use, particularly when the car is to travel above side walk level for loading directly into trucks.

When side walk elevators are to be exposed to the weather, non-skid steel flooring should always be ordered because of the tendency of wood flooring to swell and buckle. Use standard size cars.

Speed.—Everyone knows that speed is relative. There is no question that speeds of from 150 feet per minute upward are called for on higher rise elevators, but such speeds are not practical and entail unnecessary expense on short hauls. The following speed suggestions are based on sound practice:

For Single Story Travel

(Average rise of 14 ft.)

Up to 5,000 lbs. capacity	25 to 50 feet per minute	up
	40 " 50 " " "	down
5,000 to 8,000 lbs. capacity	20 " 40 " " "	up
	30 " 60 " " "	down
8,000 through 12,000 lbs. capacity	15 " 30 " " "	up
	20 " 45 " " "	down

For Two Story Travel

(Average rise of 25 ft.)

Up to 5,000 lbs. capacity	40 to 50 feet per minute	up
	50 " 80 " " "	down
5,000 to 8,000 lbs. capacity	30 " 50 " " "	up
	40 " 70 " " "	down
8,000 through 12,000 lbs. capacity	20 " 40 " " "	up
	30 " 60 " " "	down

Speeds up to 100 feet per minute can be supplied when net capacity does not exceed 6,000 lbs.

It should be remembered that it takes several seconds to open a hatchway gate, the car gate, and load the elevator car, and then to reverse the procedure during unloading. If it take fifteen seconds to perform these operations, it isn't logical to purchase an elevator speed that will carry the car between the terminal landings in less than fifteen seconds. For instance, a speed of 40 feet per minute will carry a load between floors spaced 10 feet apart in fifteen seconds.

Hatchway Doors or Gates.—For average freight service the vertical rising steel mesh, or hardwood slat gates is entirely practical from the use and cost standpoint. In certain classes of building fire-proof doors must, of necessity be used.

CHAPTER 38

Hydraulic Air Plane Control

The method of hydraulic air plane control consists of a system *wherein fluid is used to transmit a force to operate a controlling mechanism*. There are numerous systems developed to meet the requirements for different types of air planes.

Ques. How is the force transmitted?

Ans. Through a column of fluid confined in pipes to a piston against which the force is directed.

Ques. Describe the piston assembly.

Ans. It is contained in a cylinder and means is provided for preventing the escape of fluid past the piston.

Ques. What is the connection and function of the piston rod?

Ans. It is attached to some mechanism so that movement of the piston may operate the mechanism.

The force applied to the piston if of sufficient magnitude will operate the mechanism.

Ques. Describe in general the circulation of the fluid.

Ans. The fluid is forced into and out of the cylinder by a pump. The expelled fluid is returned to its original source or reservoir, thus circulating throughout the system.

Ques. How is the direction of flow to and from the cylinder, and consequently the direction of travel of the piston in the cylinder controlled?

Ans. By a manually operated selector valve.

Hydraulic Control System Parts.—In order to function as just described, a hydraulic system must be made up of numerous parts or units. These essential parts are:

1. Reservoir
2. Power pump
3. Hand pump
4. Pressure manifold
5. Surge chamber
6. Accumulator
7. Pressure regulator
8. Relief valve
9. Check valve
10. Orifice
11. Orifice check
12. By-pass check
13. Selector valve
14. Power control valve
15. Master cylinder
16. Brake control valve
17. Actuating cylinder
18. Return manifold
19. Line disconnect
20. Pressure gauge snubber
21. Bleed

Reservoir.—In any hydraulic system it is necessary to have a vessel or reservoir *for holding a small excess of liquid to replenish any lost through seepage or leakage.*

Fig. 1 shows an elementary reservoir.

Ques. What other duty is performed by the reservoir?

Ans. The reservoir serves as an overflow basin to receive the excess of fluid forced out of the system by expansion or otherwise.

Ques. Any other duties performed?

Ans. It affords an opportunity for the fluid to get rid of any air bubbles brought into the system by certain operating units.

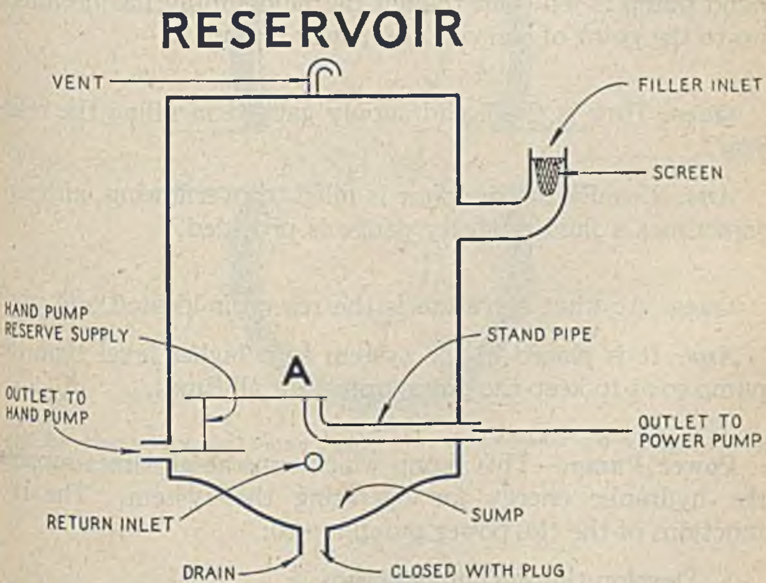


Fig. 1.—Liquid reservoir **out of** and **into** which the liquid circulates.

The reservoir forms a receptacle for the deposit of any foreign matter that may enter the system.

Ques. What provision is necessary on reservoirs?

Ans. There should be a vent at the top.

Ques. How is the vent line run and why?

Ans. It is led overboard so that any excess fluid is disposed of.

Ques. Why is the stand pipe led to an elevated point A?

Ans. To provide a margin of liquid supply to insure that the hand pump is fed even though the fluid supply has been used up to the point of starving the power pump.

Ques. How is the liquid supply gauged in filling the reservoir?

Ans. Usually the reservoir is filled to overflowing, although sometimes a fluid quantity gauge is provided.

Ques. At what elevation is the reservoir located and why?

Ans. It is placed in the system at a higher level than the pump so as to keep the pump primed at all times.

Power Pump.—This pump which runs at all times supplies the hydraulic energy for operating the system. The two functions of the the power pump are to:

1. Develop the working pressure
2. Cause the fluid to circulate throughout the system.

Several types of power pump are used, such as:

1. Gear
2. Vane
3. Gerotor,
   etc.

Fig. 2 shows an elementary gear pump.

Elementary vane and gerotor types are shown in figs. 3 and 4.

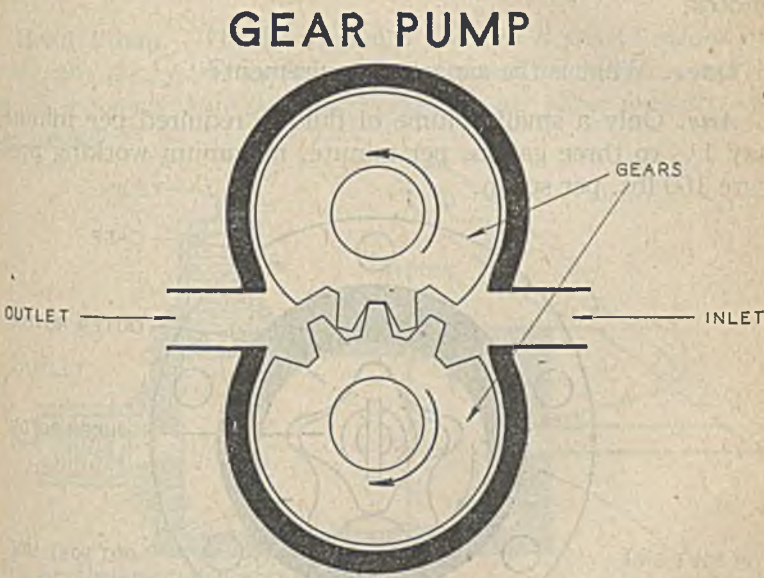


Fig. 2.—Elementary gear power pump. The actual pump is designed for small capacity at high pressure.

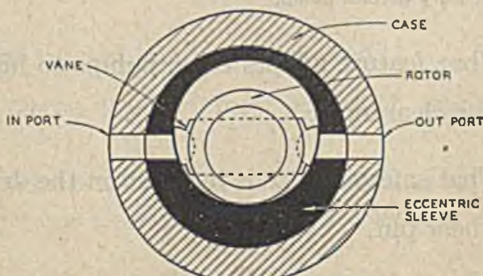


Fig. 3.—Elementary vane pump.

Ques. How is the power pump driven?

Ans. Usually by the engine, sometimes by an electric motor.

Ques. What is the capacity requirement?

Ans. Only a small volume of fluid is required per minute, say 1½ to three gallons per minute, maximum working pressure 160 lbs. per sq. in.

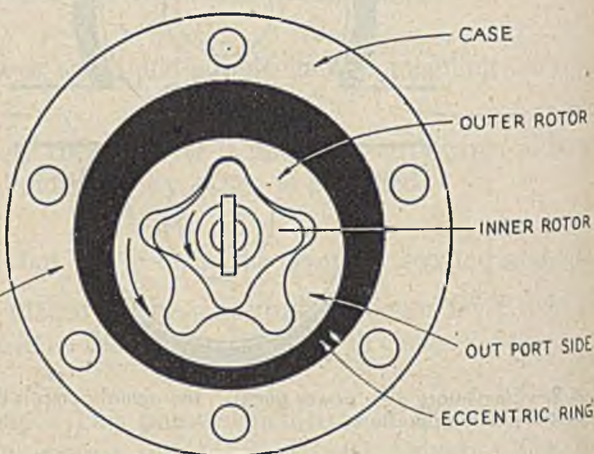


Fig. 4.—Elementary gerotor pump.

Ques. What feature adapts these pumps to high pressures?

Ans. Close clearances.

Ques. What safety device is included in the drive?

Ans. A shear pin.

Ques. When and how does the shear pin function?

Ans. In case of failure of the relief valve the pin shears and frees the pump, thus preventing possible injury to the system by excessive pressure.

Hand Pump.—The hand pump *provides a second means of energizing the system during emergencies and also forms a source of power for checking the system when the air plane is at rest on the ground.*

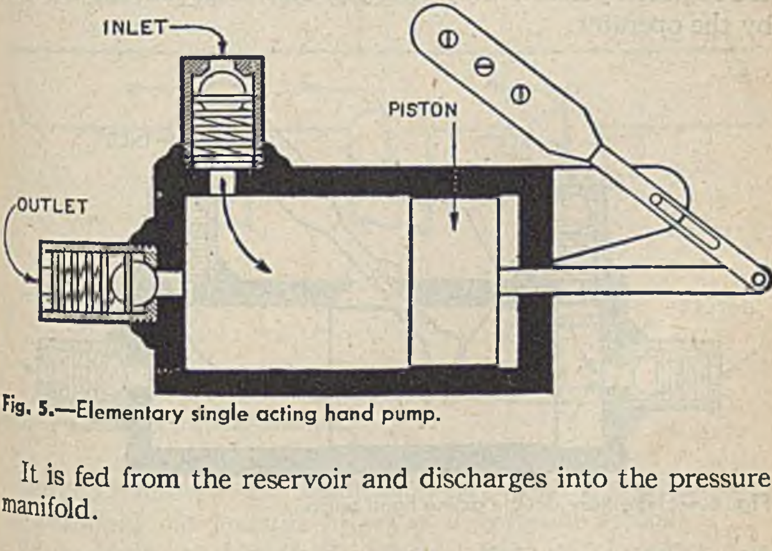


Fig. 5.—Elementary single acting hand pump.

It is fed from the reservoir and discharges into the pressure manifold.

Ques. What type of hand pump is used?

Ans. The piston type; it may be either single or double acting.

Inlet and discharge check valves are used same as on any piston pump. Figs. 5 and 6 show elementary single and double acting hand pumps.

Ques. Where is the hand pump located?

Ans. It must be placed so that the handle is readily accessible to the pilot and also to members of the crew.

Ques. In design how should the handle and piston size be proportioned?

Ans. The hydraulic leverage should be so proportioned that the required pressure may be obtained without undue exertion by the operator.

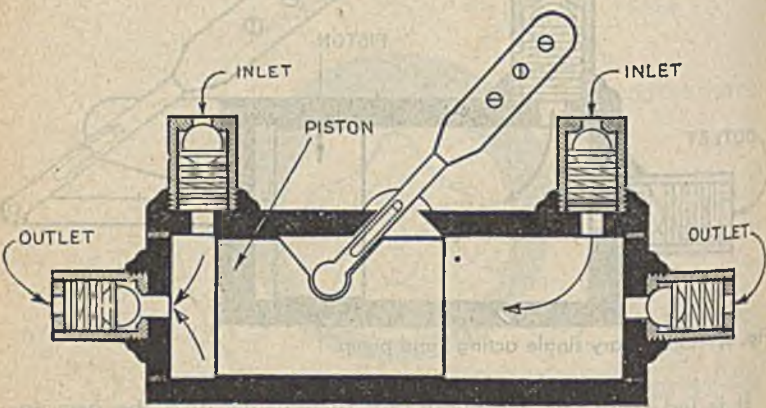


Fig. 6.—Elementary double acting hand pump.

Ques. Where is a directional check valve placed and why?

Ans. In pressure manifold *up stream* from the the point where the hand pump discharges into the manifold.

This is to concentrate the output of the hand pump into that section of the hydraulic system where it will insure operation of the mechanism in case of failure of the power pump.

Pressure Manifold.—This is *a type of header or multi-T having numerous branches to conduct fluid from the hydraulic pump to the selector valves.*

It is the main line of the pressure side of the system.

As shown in fig. 7 the pressure manifold may consist of a fabricated branching tube or may be made up of an assembly of tubes and fittings.

The pressure tank, pressure regulator system, relief valve, etc., are part of or auxiliary to the pressure manifold.

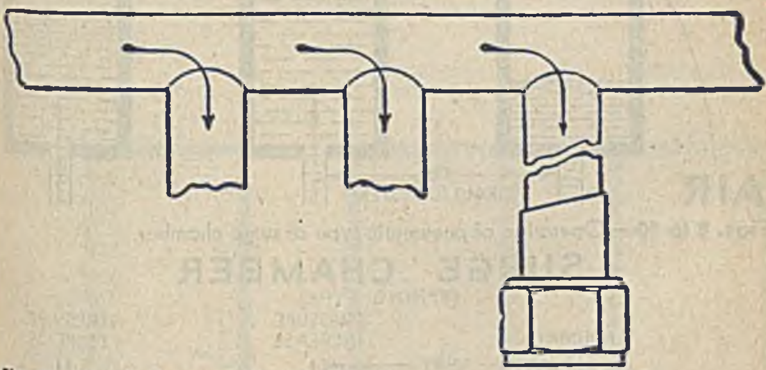


Fig. 7.—Detail of pressure manifold.

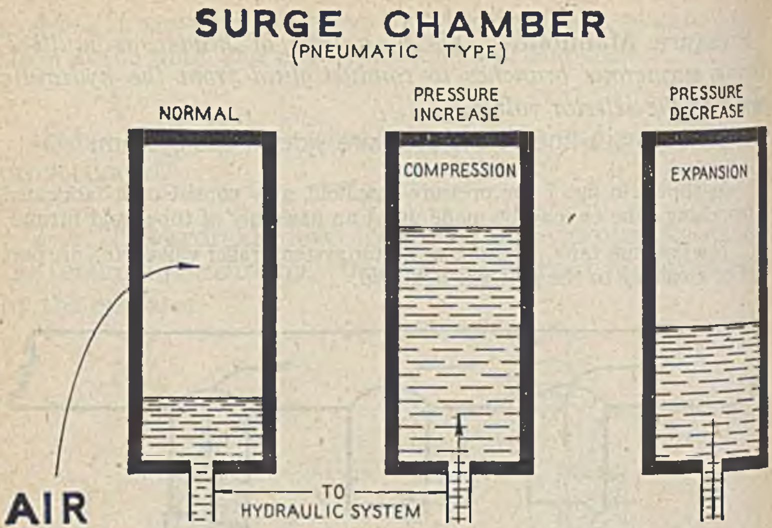
Surge Chamber.—By definition a surge chamber is: *A device for smoothing out pressure surges in a hydraulic system.*

It is simply nothing but a special form of alleviator and there was no need giving it another name.

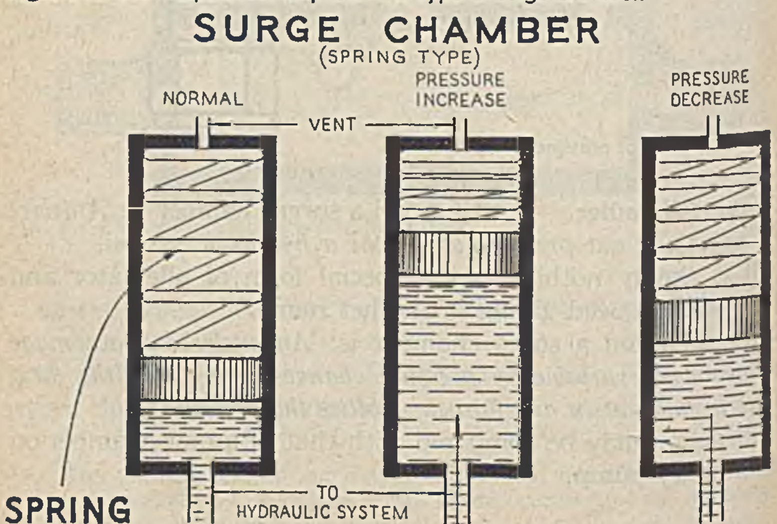
By definition a surge chamber is: *An enclosed space made automatically variable by pressure changes into which the fluid flows in and out in an effort to stabilize the pressure.*

Its action may be compared with that of an air chamber on an ordinary pump.

Ques. Describe the action of a surge chamber.



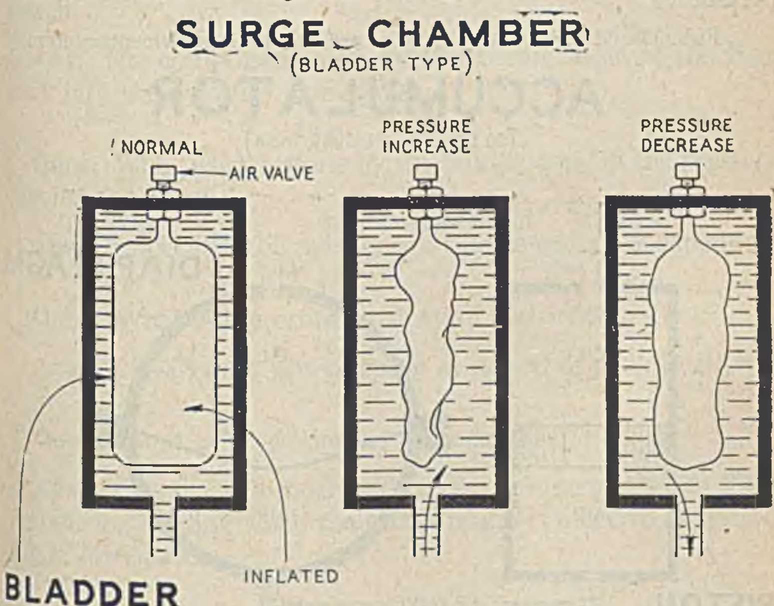
Figs. 8 to 10.—Operation of pneumatic type of surge chamber.



Figs. 11 to 13.—Operation of spring type of surge chamber.

Ans. When the pressure increases, the automatic device (air, spring, pneumatic bladder, etc.) is compressed, and the reverse action takes place when the pressure decreases, thus damping or "putting a brake" on pressure variations; this protects the system from possible destructive hydraulic stresses.

Ques. Where are surge chambers placed?



Figs. 14 to 16.—Operation of bladder type of surge chamber.

Ans. They are connected to the pressure side of the system—often as an adjunct to relief valve or a power control valve.

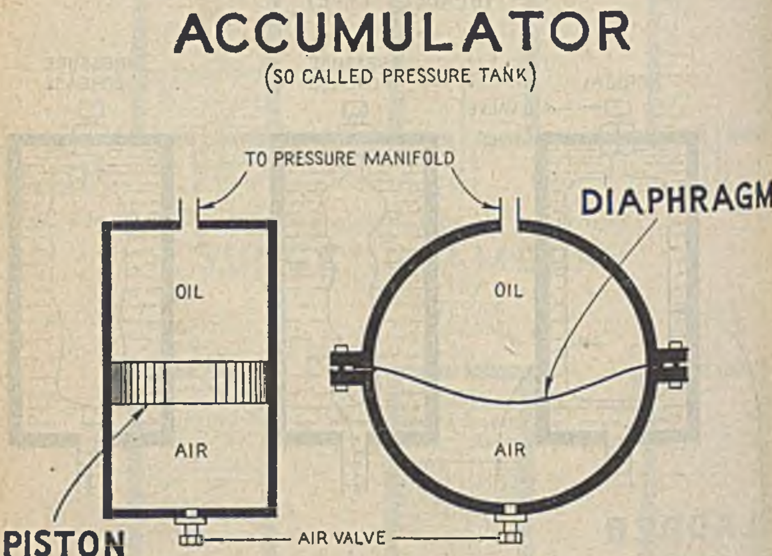
The accompanying illustrations, figs. 8 to 16, show the three types mentioned in elementary form, and their operation on increasing and decreasing pressures.

Pressure Tank.—By definition, a pressure tank is: *A special form of accumulator*, and should be called *accumulator*—the application of the term *pressure tank* here is a misnomer.

Ques. What is the function of the so called pressure tank?

Ans. Its principal duty is to serve as an energy storage device although it acts also to dampen sudden variations in pressure.

Figs. 17 and 18 show two types of pressure tank in elementary form.



Figs. 17 and 18.—Elementary accumulators (alleged pressure tanks) of the piston and diaphragm types.

Ques. When is excess fluid forced into the tank?

Ans. At times when the system does not require the total output of the power pump.

Ques. What happens when excess fluid is forced into the tank?

Ans. The air in the air chamber is compressed, which stores up the energy required to compress it.

Ques. Describe what happens when the output of the power pump falls below the requirements of the hydraulic system.

Ans. The compressed air expands forcing some of the fluid back into the pressure manifold.

Ques. What work is done by the fluid flowing in the pressure manifold?

Ans. It operates the mechanism till the energy is expended.

Ques. What is the ordinary duty of the pressure tank?

Ans. It assists the power pump at period of peak load.

Ques. What other duties are performed?

Ans. It serves as a motive force during emergencies in flight and during landing when the power pump is inactive or operating at low speed.

Ques. Describe the construction of a pressure tank.

Ans. It is built to withstand high pressures and to hold considerable quantity of fluid. The tank is divided into two compartments, one for air and the other for fluid.

The two compartments are separated by a synthetic rubber diaphragm or by a piston.

Ques. What auxiliary devices are necessary?

Ans. An air valve for charging the tank with compressed air and a check valve on the piston or diaphragm.

Ques. What is the object of charging the air chamber?

Ans. It assures that the total fluid output of the tank will be at sufficiently high pressure.

Ques. What is the object of the check valve?

Ans. It operates when the tank is either full of air or full of fluid.

Ques. Where is the pressure tank placed?

Ans. It is usually located near the manifold to which it is connected.

Small Pressure Accumulators.—Small accumulators are sometimes installed in the emergency brake system on large land planes.

The principle involved is to store up energy by compressing a quantity of air.

The diaphragm separates the oil from the air, and contains a check valve which comes into operation when the vessel is either full of air or full of fluid.

The air pressure is therefore the same as the oil pressure, and an air valve is provided to keep it so.

Pressure Regulator.—By definition a pressure regulator *is a pressure regulator*—self defining. A pressure regulator *regulates the pressure in a hydraulic system by* **automatically** *controlling the output of a constantly running power pump, directionally so that it either*

1. *Charges the system, or*
2. *By-passes back to the reservoir.*

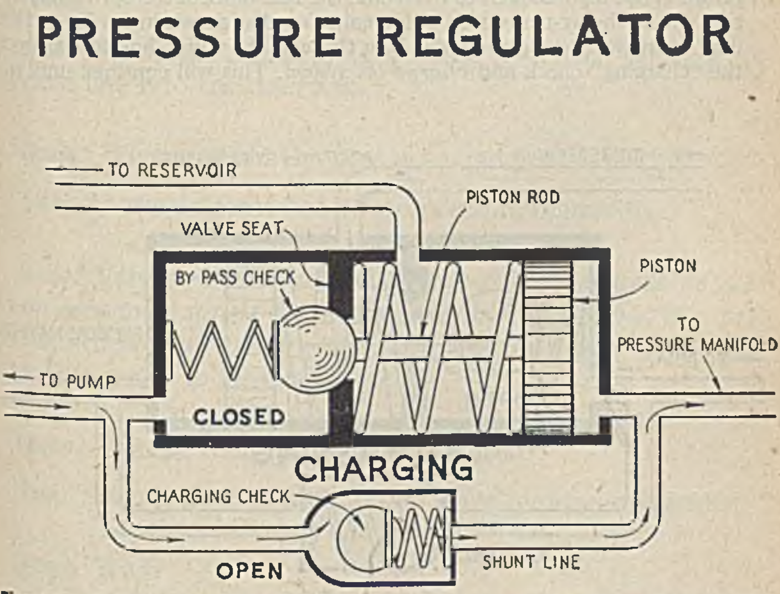


Fig. 19.—Elementary pressure regulator; **charging.**

A pressure regulator in elementary form is shown in *charging* and by-passing positions in figs. 19 and 20.

As shown it consists of a cylinder, one end of which is a by-pass check valve pressed on its seat by a spring. At the other end is a piston with piston rod which contacts with the by-pass check. The piston is acted upon on one side by hydraulic pressure and on the other by opposing spring pressure.

That is to say, the pump charges (pumps directly into the system) until the pressure reaches a fixed limit. At this moment a check valve in the charging line *closes*, which prevents back flow from the system, and simultaneously another check valve in the by-pass line opens, which by-passes the output of the pump back into the reservoir.

Connecting with each end of the cylinder is a shunt line containing a check valve as shown. In operation as long as the hydraulic pressure on the piston is not high enough to overcome the resistance of the spring and by-pass check, the by-pass check will remain closed as shown in fig. 19, and the fluid from the power pump will flow through the shunt line forcing open the "charging" check and ***charge the system***. This will continue until the

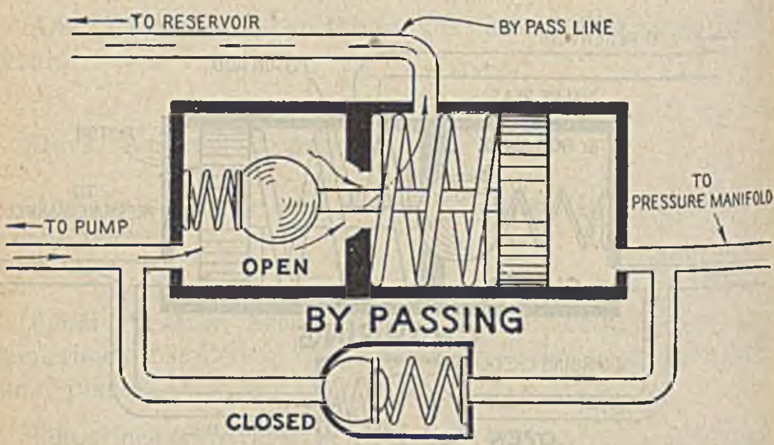


Fig. 20.—Elementary pressure regulator; **by-passing.**

pressure in the system rises to a predetermined limit which will cause the piston to overcome opposing resistance and move toward the left, causing the piston rod to push the by-pass check off its seat as shown in fig. 20. When this happens, pressure on the pump is relieved, the immediate closing of the by-pass check preventing the liquid under high pressure in the system backing up.

With this exit shut off the output from the pump is by-passed back into the reservoir, the pump being relieved of practically all pressure.

This completes the cycle which will be repeated as soon as energy demands on the system cause the pressure therein to drop to a predetermined limit.

Ques. What would happen if the charging check valve failed to close?

Ans. The liquid in the system would flow back through the by-pass line into the reservoir.

Ques. Where should the pressure regulator be placed?

Ans. At the extreme end of the pressure manifold.

Relief Valve.—By definition, *a valve pressed against its seat by an adjustable spring so proportioned that it will open at a predetermined pressure and by-pass fluid from the pressure side of a hydraulic system to the return side.*

Ques. Is more than one relief valve used?

Ans. Several may be required on some hydraulic systems.

Ques. Why?

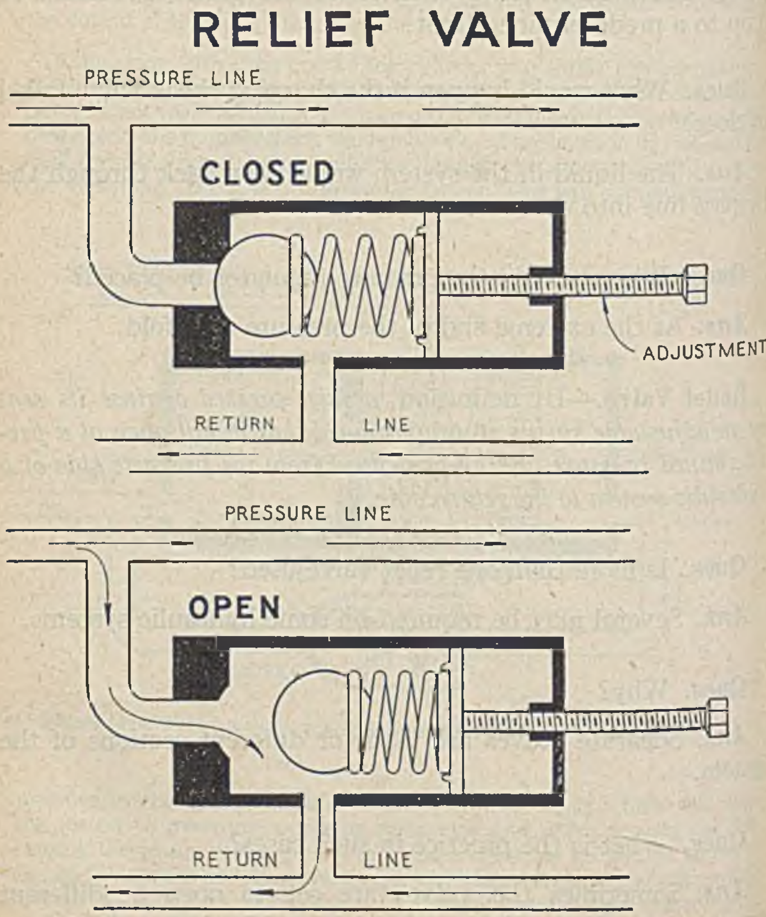
Ans. Separate valves are used for different sections of the system.

Ques. What is the practice in such cases?

Ans. Sometimes the valves are set to open at different pressures.

Ques. What determines setting of a relief valve?

Ans. The opening pressure should be well above the minimum pressure required to operate the mechanisms, but below a pressure estimated to be a safe operating pressure.



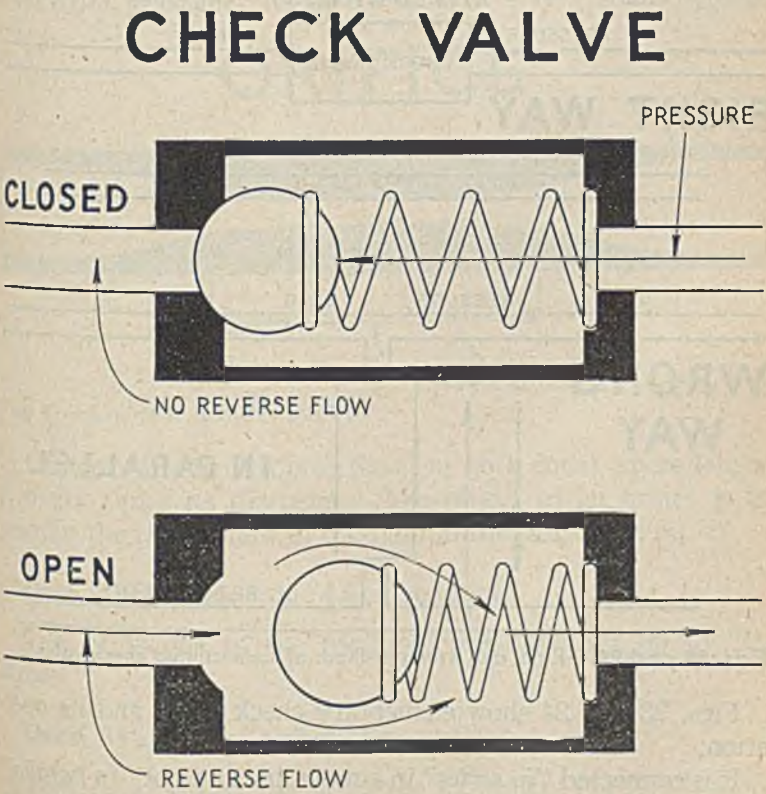
Figs. 21 and 22.—Elementary relief valve in **closed** and **open** positions.

Ques. How is the fluid directed by a relief valve?

Ans. When the valve opens the fluid passes from the pressure side of the system through the valve and to the return side.

This is indicated in the elementary drawings, figs. 21 and 22.

Ques. What is a temperature expansion valve?

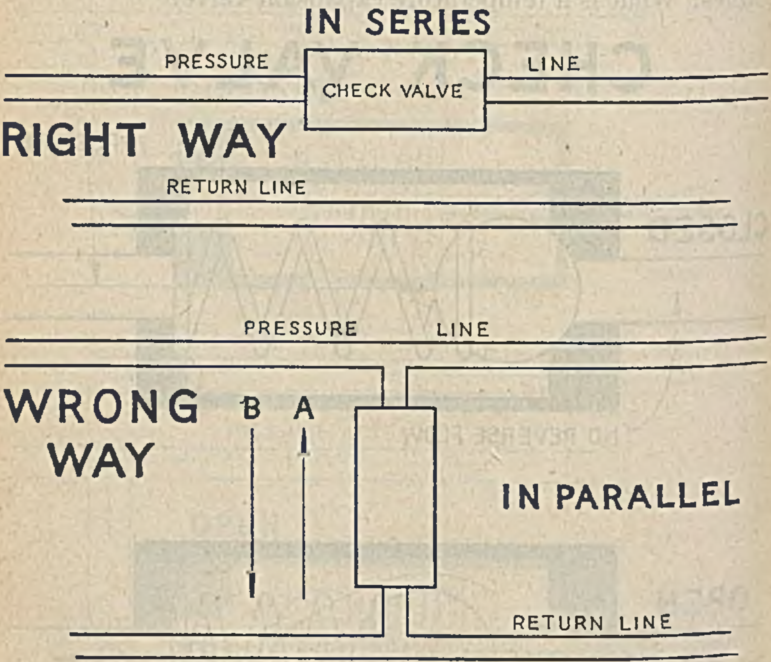


Figs. 23 and 24.—Elementary check valve in **closed** and **open** positions.

Ans. A valve intended only to relieve pressure caused by increase of temperatures.

Such valves are set to open at relatively high pressures.

Check Valve.—By definition, a check valve is: *A discriminating or one way non-adjustable non-shunt valve designed to be placed in a main line without any branch.*



Figs. 25 and 26.—Right and wrong methods of connecting a check valve.

Figs. 23 and 24 show elementary check valve and its operation.

It is connected "*in series*" in a main line and not "*in parallel*" across two lines. This is indicated in figs. 25 and 26.

If connected in parallel as in fig. 26, so as to open in the direction **A**, then the valve would not open, in fact it would be of no use. If connected so as to open in the direction **B**, the liquid would be short circuited back to the reservoir and rendered unavailable to operate the mechanisms.

Accordingly, a check valve should be connected as in fig. 25, headed, so as to stop back flow in direction desired.

Orifice.—An orifice may be defined as *a very small* **opening** *or a restricted* **passage.** As here used it is a very small passage

Fig. 27.—Orifice or restricted passage

in the form of a drilled hole (open at both ends) whose length is many times its diameter. The object of an orifice is to restrain the rate of flow of the fluid in the line. See fig. 27.

Ques. Why is the rate of flow reduced?

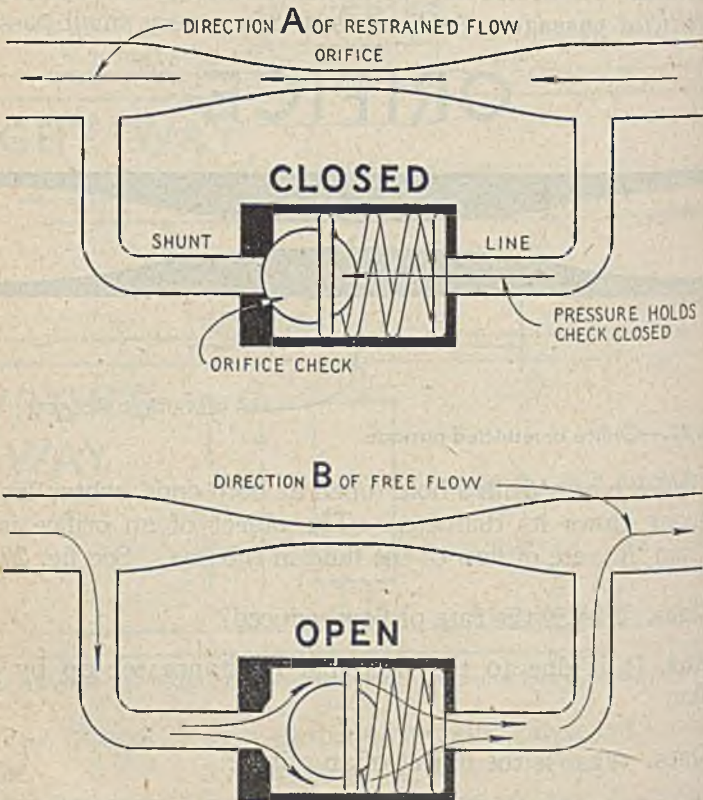
Ans. It is due to the frictional resistance set up by the orifice.

Ques. What is the object of an orifice?

Ans. It is used to slow down the movement of the actuating cylinder which would otherwise be too fast.

Orifice Check Valve.—Since an orifice restrains the flow of fluid similarly in both directions, it cannot be used alone in those sections of the system where it is required that the flow be restrained only in one direction. That is to say provision must be made for:

1. Restrained flow in direction **A.**
2. Free flow in opposite direction **B.**



Figs. 28 and 29.—Elementary orifice check valve in **closed** and **open** positions.

This is done by placing a check valve "*in shunt*" around the orifice as shown in the elementary drawing figs. 28 and 29.

Now, in fig. 28 call flow direction **A,** to the left as indicated by the arrows. Evidently pressure will hold the check closed and restricted flow will take place through the orifice.

However, when the direction of flow is reversed as in fig. 29, the check valve opens and the liquid short circuits the orifices via the shunt line. That is, like the electric current, it takes the path of least resistance and flows freely.

Ques. Mention a frequent use for the orifice check and why.

Ans. It is often placed in the wing flap system where it is desirable that the up travel of the flaps be delayed against the tendency of the air pressure to raise them.

Ques. Where else employed and why?

Ans. In the landing gear system to delay the extension of the gear against the tendency of the weight of the gear to pull it down too fast.

Ques. How is the orifice check connected to the actuating cylinder?

Ans. In either the up line or the down line.

Ques. What determines which stroke of the mechanism is retarded?

Ans. The line in which it is installed and its operating direction in the line.

Ques. How can an ordinary ball check be converted into an orifice check?

Ans. By drilling a hole through the side of its seat as indicated in fig. 30.

By-Pass Check Valve.—By definition a by-pass check valve is: *An ordinary check valve provided with means for manually opening the valve.*

Ques. What is the object of manually opening the valve?

Ans. To permit fluid to flow in either direction.

Ques. Where is this valve usually employed and why?

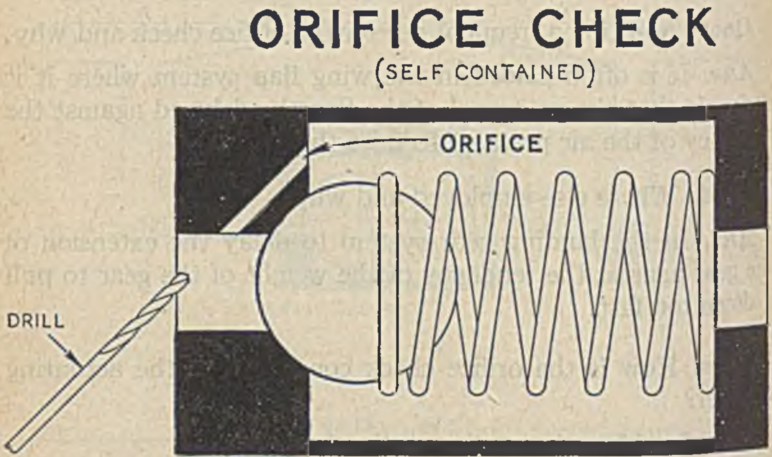


Fig. 30.—Elementary self contained orifice check valve which can be made from an ordinary check valve by drilling as indicated.

Ans. In connection with an accumulator (so called pressure tank) so that the output of the hand pump may be directed into the accumulator.

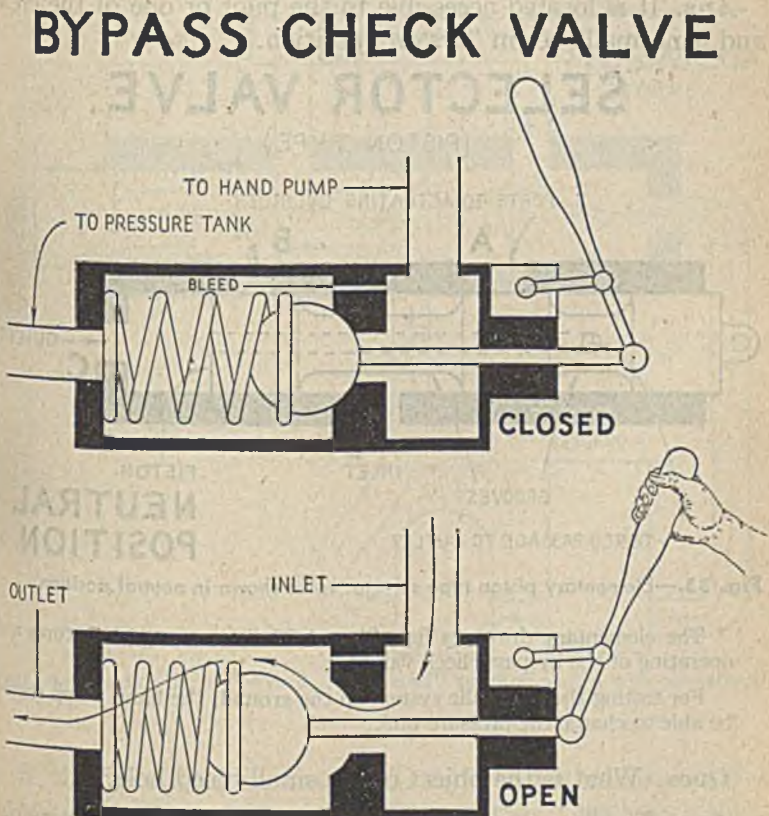
Ques. What result is obtained by the normal setting of the hand pump?

Ans. It concentrates the output of the hand pump into a restricted section of the pressure manifold.

Ques. What flow takes place when the valve is opened manually?

Ans. It provides a passage for liquid from the hand pump to flow to the pressure tank.

Ques. Where is the by-pass check located?



Figs. 31 and 32.—Elementary by-pass check valve. Fig. 31, closed position; Fig. 32, open position.

Ans. In the pressure manifold somewhere between the pressure tank and the point where the hand pump discharges into the manifold.

Ques. Where is the by-pass check valve control lever located and what are the normal settings?

Ans. It is located accessible to the pilot or one of the crew and is normally set in "*system*" position.

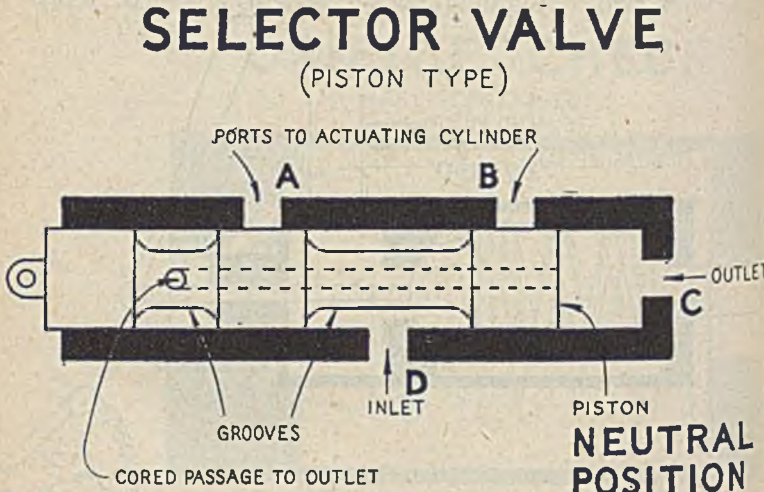


Fig. 33.—Elementary piston type selector valve shown in neutral position.

The elementary drawings figs. 31 and 32 show essential features and operating of the by-pass check valve.

For testing the hydraulic system on the ground, the hand pump should be able to charge the pressure tank.

Ques. What is the object of the small bleed hole?

Ans. To allow thermal expansion from the pressure manifold to bleed through to the pressure tank.

Selector Valve.—By definition a selector valve is: *A multiport valve so arranged that fluid for operating mechanism may flow in the connecting pipe lines in either direction under control of a "selector" lever.*

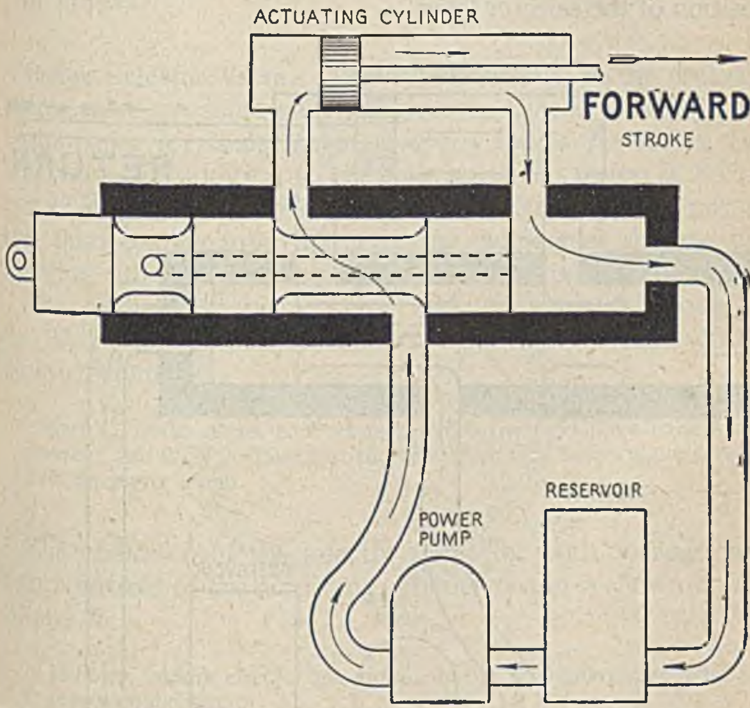


Fig. 34.—Piston selector valve in **"forward"** position shown with connecting units.

In this arrangement two ports connect with lines leading *to* and *from* the pump and two other ports connect with lines leading to ends of the actuating cylinder. The ports connecting with the pump are:

1. Inlet port*
2. Outlet port*

The cylinder ports cannot be given directional names because the flow alternates in direction depending upon the position of the selector lever.

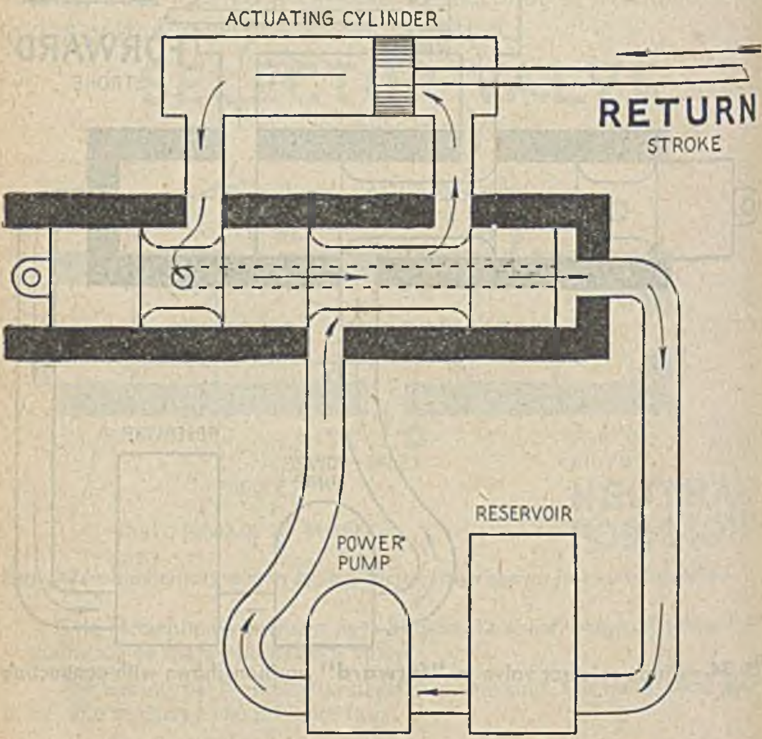


Fig. 35.—Piston selector valve in "**return**" position shown with connecting units.

*NOTE.—The painfully **studied** effort to introduce something new (common with modernistic alleged composers) by calling these ports the *in* port and *out* port respectively is open to criticism.

There are three types of selector valve:

1. Piston
2. Rotor
3. Poppet

Piston Selector Valve.—This type is similar to the ordinary piston valve on some steam engines in that *a grooved piston travels inside a cylinder having properly spaced ports.* In this type valve, in addition to the four ports the piston is hollow part of its length to provide a fluid passage to the outlet port so that fluid coming from the actuating cylinder at the end discharging can get back to the reservoir and pump.

The elementary piston type selector valve is shown in fig. 33. Ports **A** and **B** connect with the two ends of the acuating cylinder.

Port **C,** is the outlet port through which the fluid flows back to the reservoir, and **D,** is the inlet port through which fluid enters under pressure from the power pump.

The operation of the selector valve for both forward and return strokes of the actuating cylinder piston is shown in figs. 34 and 35.

Here the various circuits are shown, that is, to actuating cylinder and to reservoir and pump.

It must be evident that the actuating piston may be held in any intermediate position by placing the selector valve in *neutral position.*

Ques. What is neutral position of the valve?

Ans. The central position, or the mid-point of its travel, overlapping equally the ports. See fig. 33.

Rotor Selector Valve.—This is a form port valve *consisting of an inner rotor which turns in a cylindrical case, and a control handle attached rigidly to the rotor*. It should be noted that this valve does not require a fifth or cored passage leading to the outlet as is required with the piston valve.

Ques. How are the four ports spaced?

Ans. 90° apart.

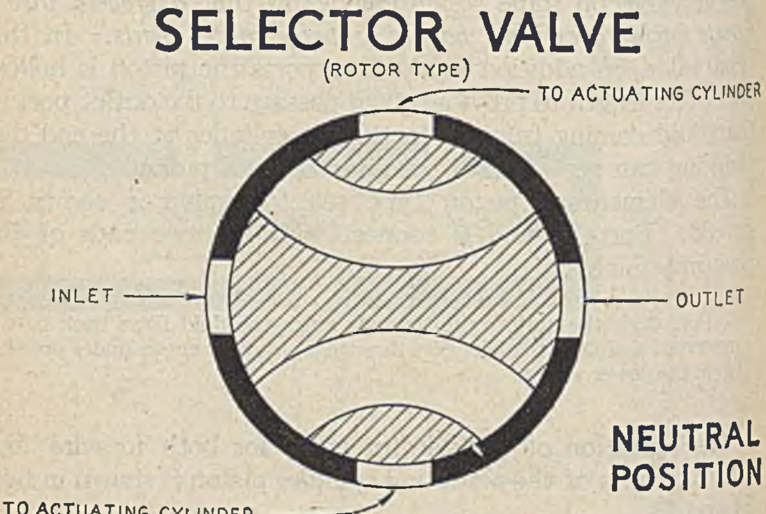


Fig. 36.—Elementary rotor type selector valve shown in **neutral** position.

Ques. Describe the rotor.

Ans. It carries two fluid channels so arranged as to connect adjacent ports.

Ques. Describe the ports in casing.

Ans. The casing which forms the valve seat has four ports at right angles. Two of these at 180° connect with the actuating cylinder ends; the other two are *inlet* and *outlet* ports.

The rotor type selector valve is shown in neutral position in fig. 36 and its operation in figs. 37 and 38.

Poppet Selector Valve.—This type valve consists of *a series of spring loaded cone seat valves.*

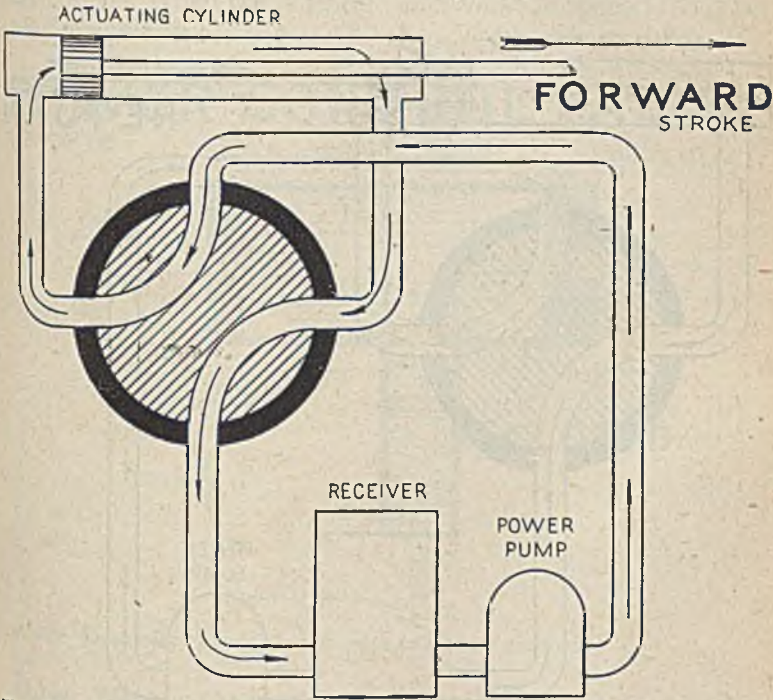


Fig. 37.—Rotor selector valve in **forward** position shown with connecting units.

Ques. How are the valves actuated?

Ans. By cams mounted on a cam shaft.

Ques. How are the cams placed on the cam shaft?

Ans. They are so placed that rotation of the shaft opens the proper combination of valves to effect the desired flow of liquid through the valve assembly.

Ques. How is the cam shaft rotated?

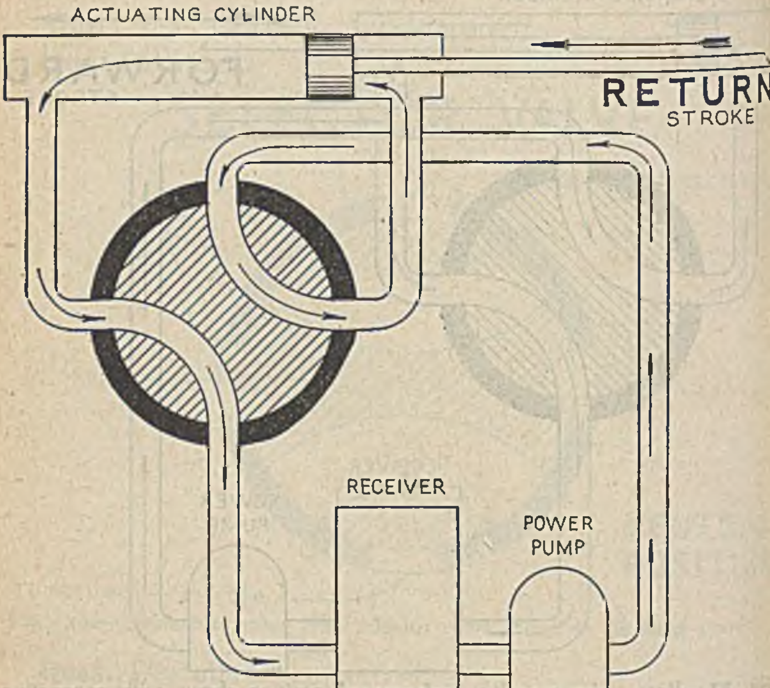


Fig. 38.—Rotor selector valve in return position shown with connecting units.

Ans. By a handle attached to the shaft.

Ques. What valves are included in the assembly?

Ans. There are two inlet valves and two outlet valves.

The outlet valves are sometimes called unloading valves.

Ques. Describe the operation of the assembly.

Ans. When one of the inlet valves opens, a companion outlet valve opens. When the alternate inlet valve is opened the other outlet valve opens.

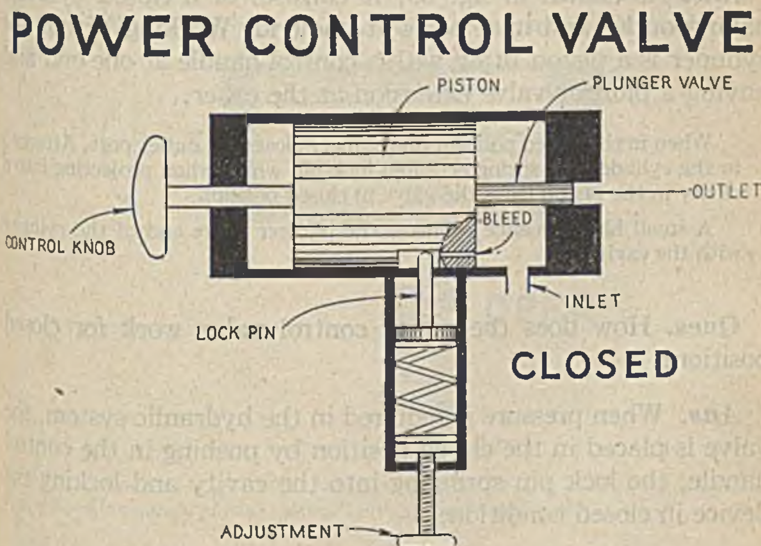


Fig. 39.—Elementary power control valve in **closed** position.

Ques. What is the setting for neutral position?

Ans. All four valves are closed.

Power Control Valve.—By definition, a power control valve is: *A hand shut off valve with an automatic turn on feature.*

Ques. What is the object of this valve?

Ans. It permits the pump to circulate the fluid from the pump to the reservoir without being subjected to the high pressure required to keep a relief valve open.

Ques. Describe the power control valve.

Ans. As shown in fig. 39, it consists of a closed cylinder having outlet and inlet ports at one end. Working within the cylinder is a piston fitted with a control handle at one end and having a plunger valve extension at the other.

When in the closed position this plunger closes the outlet port. Attached to the cylinder is a spring actuated lock pin which when projecting into a cavity in the piston locks the valve in closed position.

A small bleed passage connects the plunger valve end of the cylinder with the cavity.

Ques. How does the power control valve work for closed position?

Ans. When pressure is required in the hydraulic system, the valve is placed in the closed position by pushing in the control handle, the lock pin springing into the cavity and locking the device in closed condition.

Ques. How does the power control valve open automatically?

Ans. When the valve is in closed position, the output of the power pump is directed into the system building up pressure to actuate the mechanism. Pressure also develops this excess pressure, is communicated to the lock pin through the bleed passage and pushes down the pin as in fig. 40. Since the pressure also acts on the piston, the latter moves toward the knob end of the cylinder and opens the valve to outlet.

Ques. What does this do?

Ans. It allows the fluid to circulate freely to the reservoir.

Ques. What controls the pressure at which the valve opens?

Ans. The tension on the lock pin spring which is adjustable.

Ques. Where are power control valves usually located?

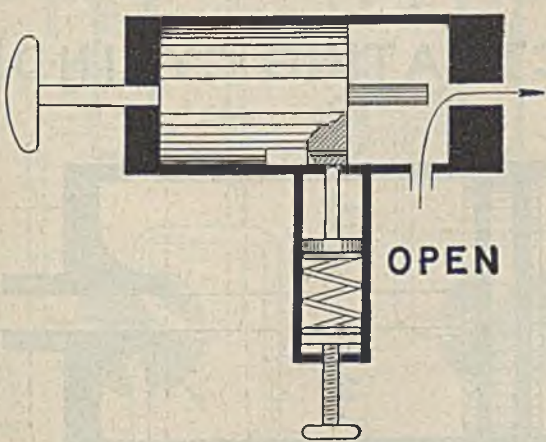


Fig. 40.—Elementary power control valve in **open** position.

Ans. Near the selector valve controls.

Ques. What is the hook up when more than one power control valve is installed?

Ans. They are connected "in series."

Ques. Why?

Ans. So that the manipulation of any one of them is equivalent to manipulating all of them in unison.

The Actuating Cylinder.—This is the unit in which **hydraulic** *power is converted into* **mechanical** *power*. It consists simply of a closed cylinder, having a port at each end and a piston which works within the cylinder and attached piston rod.

The heads of the cylinder have internal projections or "stops" which limit the travel of the piston so that it cannot cover up either port when at the end of a port. These essentials are shown in fig. 41.

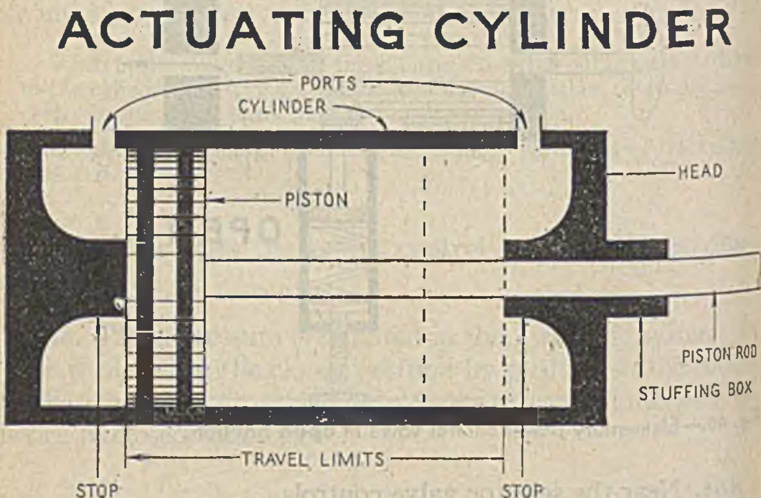
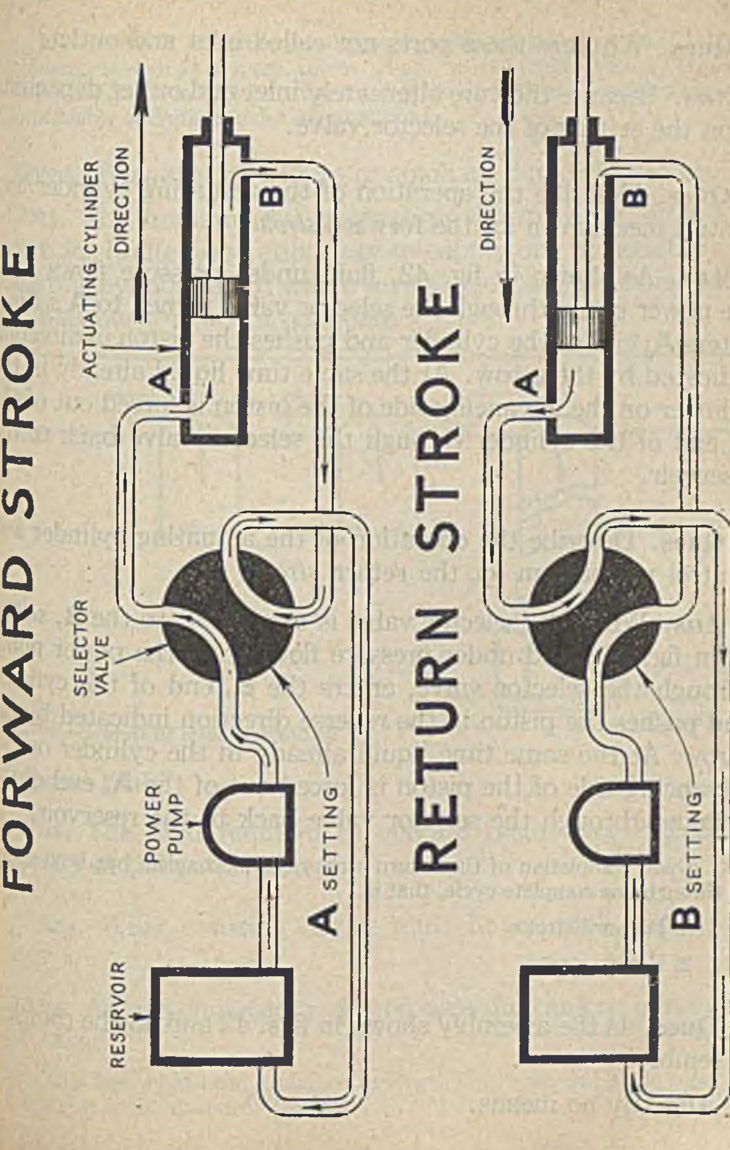


Fig. 41.—Elementary actuating cylinder. Note stops to limit piston travel so as to prevent it covering ports at the stroke ends.

Ques. What is the object of the two ports?

Ans. One is to admit liquid under pressure to move the piston and the other to allow the liquid on the other side of the piston to flow out of the cylinder to the reservoir.



Figs. 42 and 43.—Actuating cylinder with associated units. Fig. 42, forward stroke; fig. 43, return stroke.

Ques. Why are these ports not called inlet and outlet?

Ans. Because they are alternately inlet and outlet depending upon the setting of the selector valve.

Ques. Describe the operation of the actuating cylinder and control mechanism for the **forward** *stroke.*

Ans. As shown in fig. 42, fluid under pressure flows from the power pump through the selector valve turned to **A** *setting,* enters **A,** end of the cylinder and pushes the piston in direction indicated by the arrow. At the same time liquid already in the cylinder on the advancing side of the piston is forced out of the **B,** end of the cylinder through the selector valve back to the reservoir.

Ques. Describe the operation of the actuating cylinder and control mechanism for the **return** *stroke.*

Ans. When the selector valve is turned 90° to the **B,** *setting* as in fig. 43, fluid under pressure flows from the power pump through the selector valve, enters the **B,** end of the cylinder and pushes the piston in the reverse direction indicated by the arrow. At the same time liquid already in the cylinder on the advancing side of the piston is forced out of the **A,** end of the cylinder through the selector valve back to the reservoir.

Upon completion of the return stroke the mechanism has been moved through one complete cycle, that is,

1. Forward stroke
2. Return stroke

Ques. Is the assembly shown in figs. 42 and 43 the complete assembly?

Ans. By no means.

It is shown at this stage to illustrate fundamental operations. Various refinements such as by-pass valves, check valves, relief valves, accumulators, etc., are included in the total hook up to insure satisfactory and dependable operation under all conditions.

Ques. Why are these extra or auxiliary devices necessary?

Ans. The fundamental mechanism shown in fig. 42 would suffice for limited operation, say to supply one or possibly two actuating cylinders, but where several groups must be operated simultaneously it is not adequate.

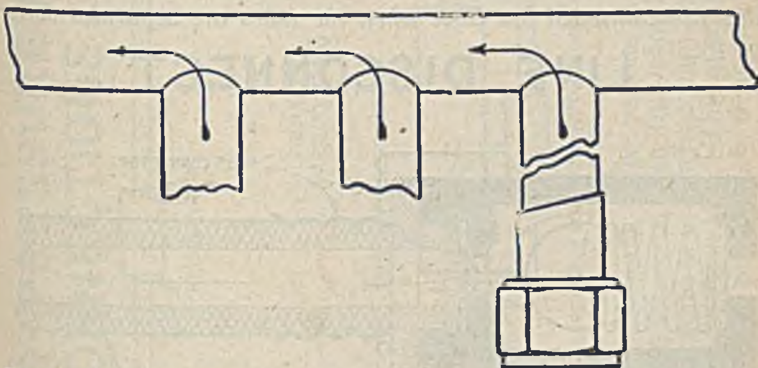


Fig. 44.—Detail of return manifold.

Ques. Why?

Ans. The fluid required to operate them may exceed the capacity of the power pump.

Ques. What assisting device must be resorted to in such cases?

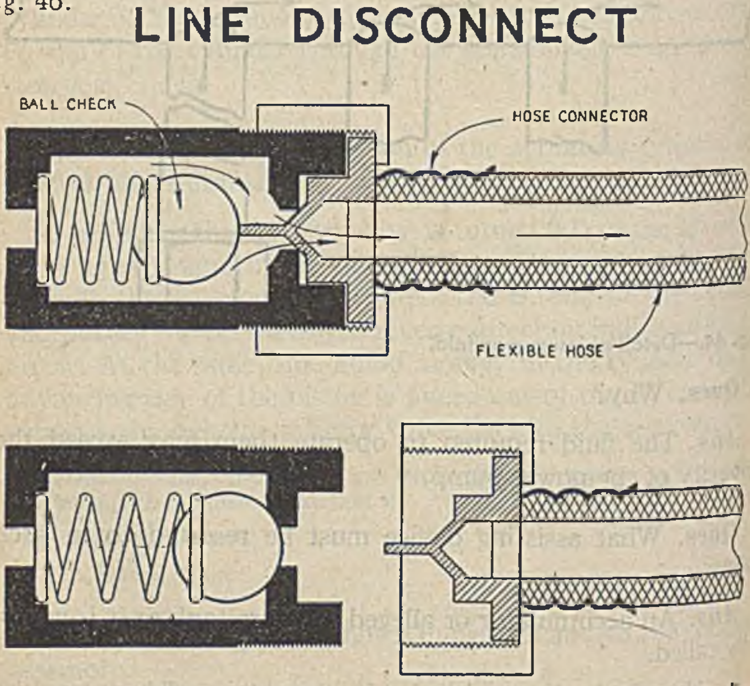
Ans. An accumulator or alleged pressure tank as it is generally called.

This device has been explained at length and there will be no repetition here just to fill up space. See page 150.

Return Manifold.—Evidently after the liquid at high pressure has done its work on the actuating cylinders, it must return to the reservoir on the reverse stroke. The piping from the cylinders *is led into a return header or manifold when the fluid from the various cylinders flows back through a common tube.*

The appearance of this unit is shown in fig. 48.

Line Disconnect.—This is *a check valve installed in the end of a tube and so constructed that when the tube is connected to another tube as shown in fig.* 45, *the check is held off its seat, the check tubes are connected but close when the tubes are separated as in fig.* 46.



Figs. 45 and 46.—Line disconnect. Fig. 45, line connected; fig. 46, line disconnected.

ACCUMULATOR-PRESSURE REGULATOR CONNECTIONS

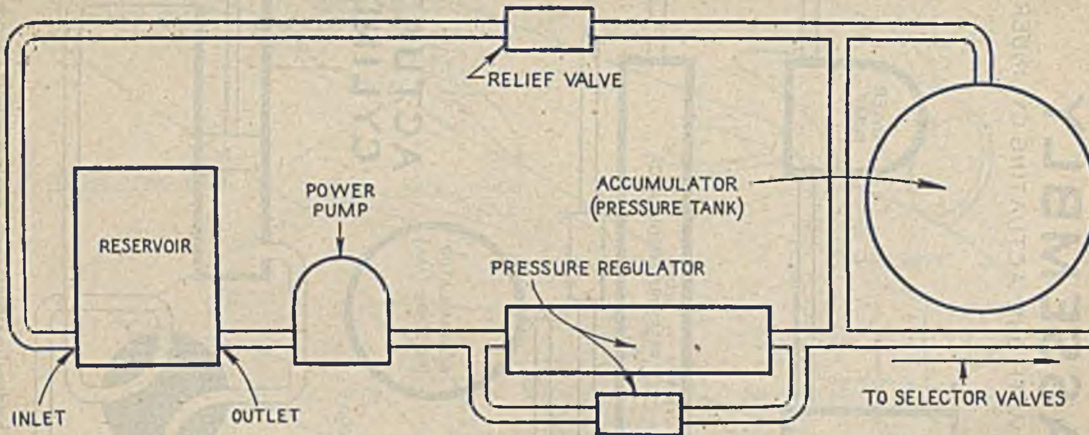


Fig. 47.—Elementary accumulator pressure regulator connections to associated units.

Complete Elementary Hydraulic System.—The various units which enter into the system have been explained in the foregoing text. In a complete system involving the requirement for simultaneous operation of several mechanisms special provision should be made for adequate power on these peak loads. This of course involves the use of an accumulator as auxiliary to the power pump, if the demand exceed the capacity of the power pump.

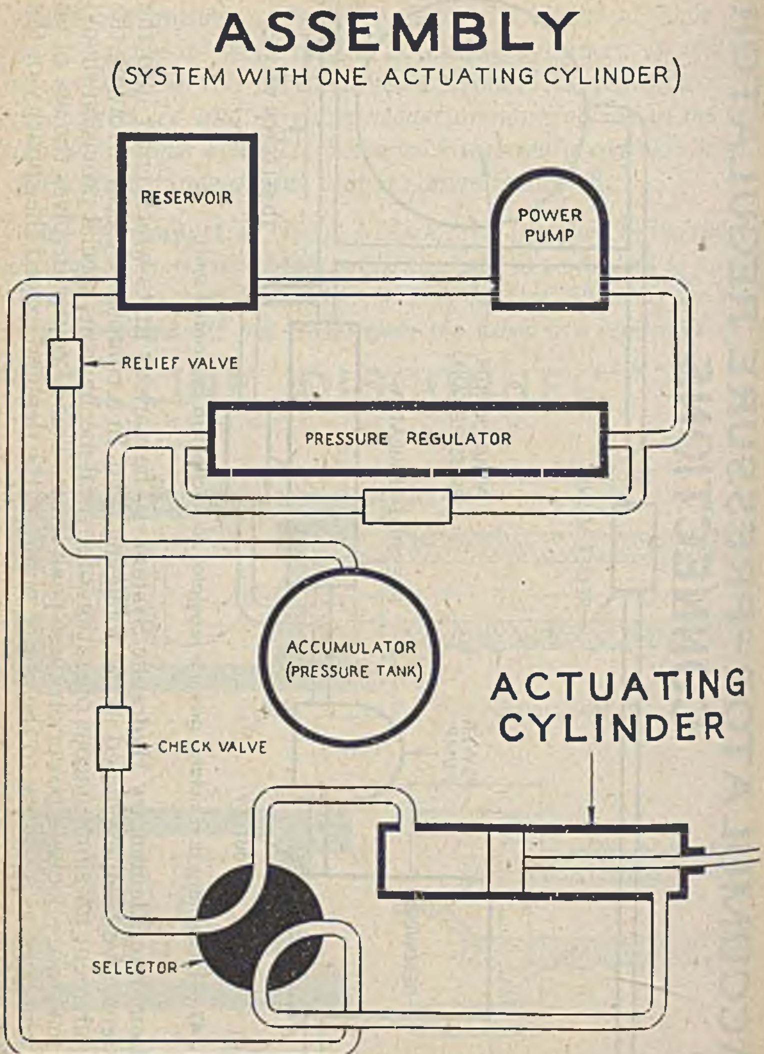


Fig. 48.—Elementary hydraulic system with one actuating cylinder.

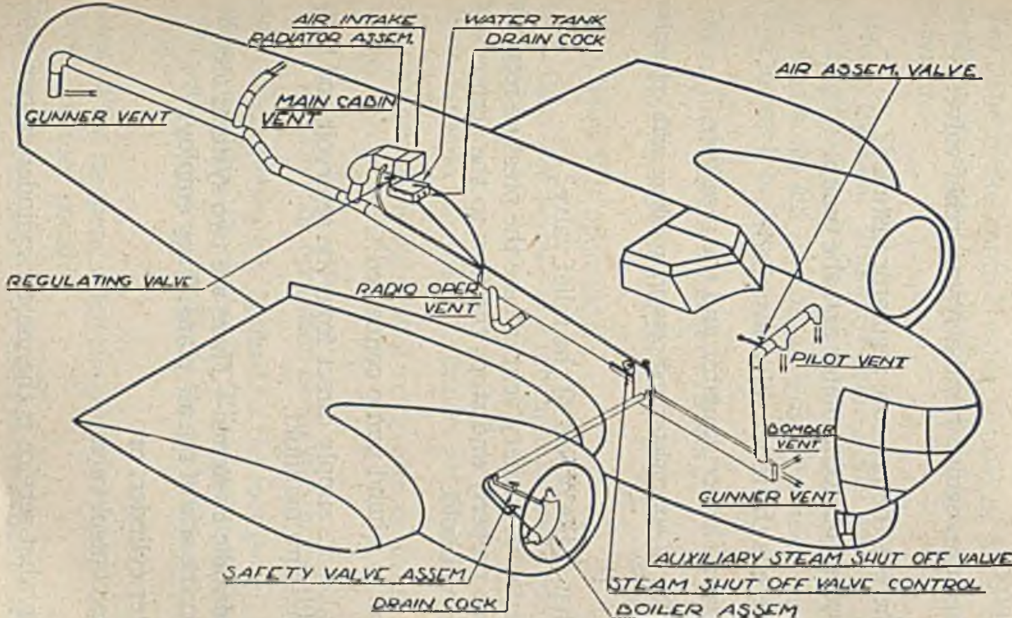


Fig. 49.—Typical heating and ventilating system. **In operation**, when the water shut off valve is opened, the water from the supply tank runs into the boiler tubes where the heat from the exhaust gases passing through the boiler casing converts it into steam. The steam is conducted through a steam duct to the multiple coils in the radiator, forcing the air in this part of the system through the diaphragm type air valve to the overboard vent line. The incoming cold air circulating about these coils absorbs heat from the steam which condenses and returns through the water regulating valve to the water supply section of the system. The hot air passes from the radiator through the distribution or warm air ducts into the compartments of the airplane as determined by the various air controls. The safety relief valve controls the operating pressure of the steam system and opens at a predetermined value.

Ques. What additional units are required as auxiliaries to the accumulator?

Ans. A pressure regulator and a system relief valve.

Ques. Where is the pressure regulator installed?

Ans. Between the accumulator and the pump.

Ques. Where is the relief valve installed?

Ans. Between the accumulator and the reservoir.

The assembly of accumulator and pressure regulator with connections is shown in fig. 48.

Ques. What is the object of the relief valve?

Ans. It serves as a safety vent in case the pressure regulator does not work properly and stops the flow to the accumulator and pressure manifold.

Ques. How is a hand pump connected?

Ans. It takes its supply direct from the reservoir and forces it into the pressure manifold.

Brake Hydraulic Systems.—There are two systems used depending upon the size of the air plane. They employ:

1. A master cylinder, or
2. A brake control valve.

Ques. For what service is the master cylinder system used?

Ans. For small air planes.

Ques. When is a brake control valve used and why?

Ans. The brake control valve is used in place of a master cylinder on the large size air planes because high brake pressure is required.

Master Cylinder Brake System.—This system is separate from the general hydraulic system, having nothing in common. *Each wheel brake has its separate master cylinder*—one hydraulic system for each brake assembly.

Ques. Just what is a master cylinder?

Ans. It is a single acting reciprocating piston pump.

Ques. How is it operated?

Ans. By a foot pedal—one mounted on each side of the two rudder pedals.

Ques. How do the master cylinders get their supply of oil?

Ans. Either from individual reservoirs or from a common reservoir.

Ques. Describe the operation of the master cylinder system.

Ans. When pressure is applied to the foot pedal, the piston is advanced within the cylinder. When pressure is released on the foot pedal, a coil spring forces the piston back to its original position.

Ques. What happens when the piston advances due to pressing down the foot pedal?

Ans. Fluid is forced out of the master cylinder through the fluid line and into the brake actuating cylinder.

Ques. When pressure is released from the foot pedal what happens?

Ans. The return springs in the brake system acting against their respective pistons, force the fluid back to the master cylinder.

That is to say, for a complete cycle, the fluid in the hydraulic system flows back and forth. This cycle is shown in very elementary form in figs. 54 and 55.

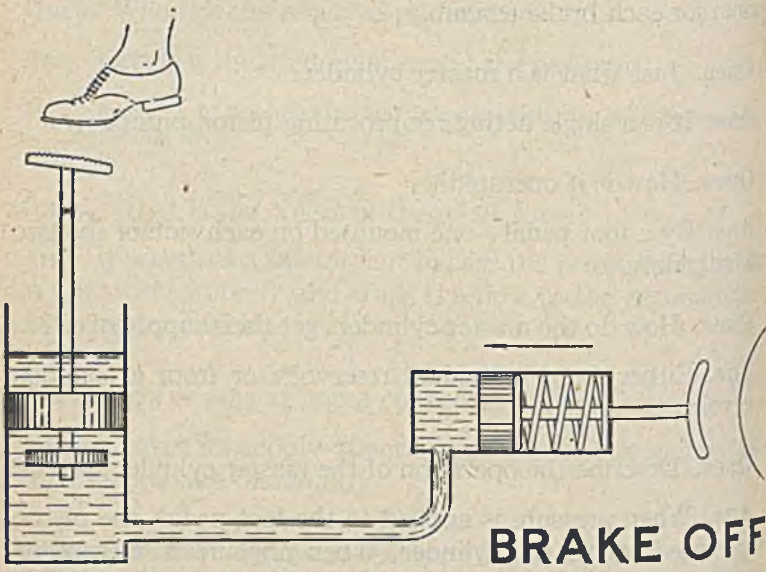


Fig. 50.—Elementary master cylinder hydraulic brake system in **off** position.

Ques. What provision is made to avoid the possibility of brakes being applied by pressure due to temperature expansion?

Ans. This is taken care of by the compensating valve.

Ques. How does it work?

Ans. The compensating valve (as in fig. 55) is always open when the brakes are in the off position.

Ques. What causes it to open?

Ans. Gravity.

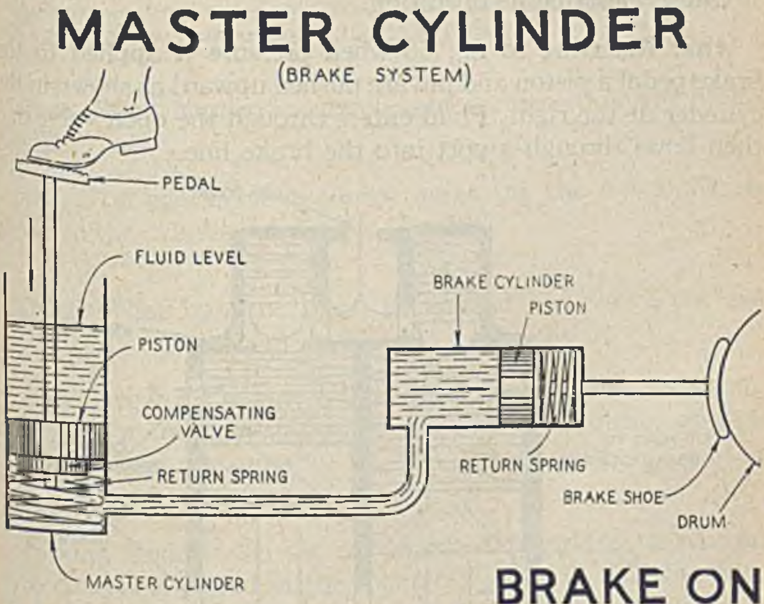


Fig. 51.—Elementary master cylinder hydraulic brake system in **on** position.

Ques. On the actual mechanism what provision is made for holding the brakes *on* when parking?

Ans. A mechanism called a parking brake is included in the system.

Brake Control Valve.—For large air planes requiring more braking effort than can be practically applied by foot a brake control valve is used. The device forms a part of the general hydraulic system (see fig. 53) and in operation *it* **meters** *fluid out of the pressure manifold at a pressure required to operate the brakes.*

Fig. 56 shows the essentials of the brake control valve.

Ques. Describe its operation.

Ans. Referring to fig. 56 when pressure is applied to the brake pedal a piston and pin are pushed upward as shown in the cylinder at the right. Fluid enters through the open valve and then flows through a port into the brake line.

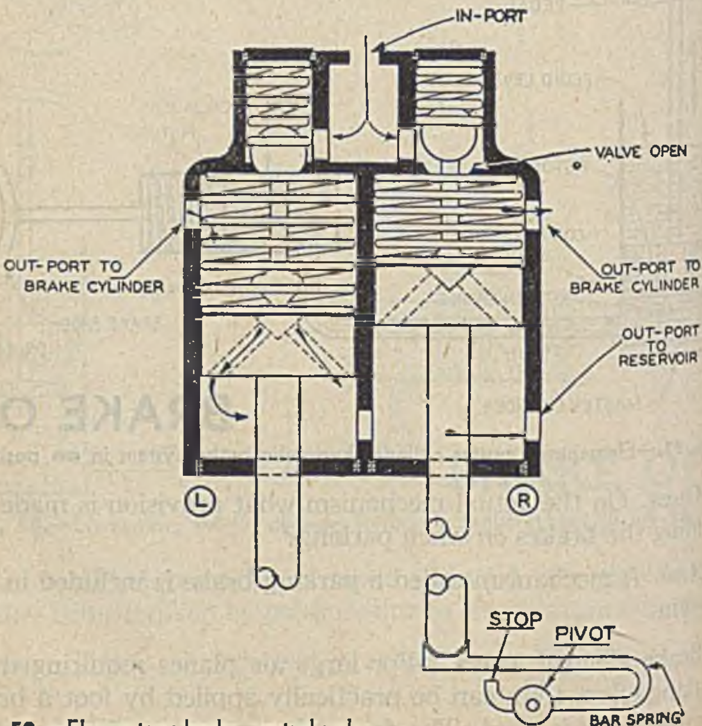


Fig. 52.—Elementary brake control valve.

Ques. How long does fluid flow into the brake line?

Ans. Until the piston pressure and brake pressure are equal.

The piston and pin will now be forced down, allowing the ball to seat and relieving the brake from further increase in pressure. A bar spring in the brake control linkage will accommodate the downward movement of the piston for a given position of the brake pedal.

Ques. What happens when pressure is released on the brake pedal?

Ans. The piston moves down unseating the valve pin as shown in the cylinder at the left (fig. 56).

Ques. What happens when the piston and valve pin are separated?

Ans. Two holes in the piston are uncovered, thus producing an outlet for the fluid to flow into the return manifold and relieve the brake pressure.

Parking Brake.—To set the brakes for parking, a plunger type control is pulled in the cockpit, which will hold the pressure in the brakes.

This is accomplished by a system of levers which act to prevent the pressure in the brakes forcing the upper ball and piston in the brake valve downward.

When the parking brake lever is out, toe pressure is applied until the pressure gauge shows approximately 500 lbs.

To release the brakes it is necessary only to press on each brake pedal.

Hydraulic Equipment.—In the design and construction of the various elements of hydraulic systems, various modifications or types have been developed to meet different operating requirements. For instance, numerous types of selector valves are made and some of these will be described. They are designed for such duties as operating landing gear retracting systems, wing flaps, cowl flaps or any other parts of an air plane requiring intermittent operations in two directions. See fig. 57.

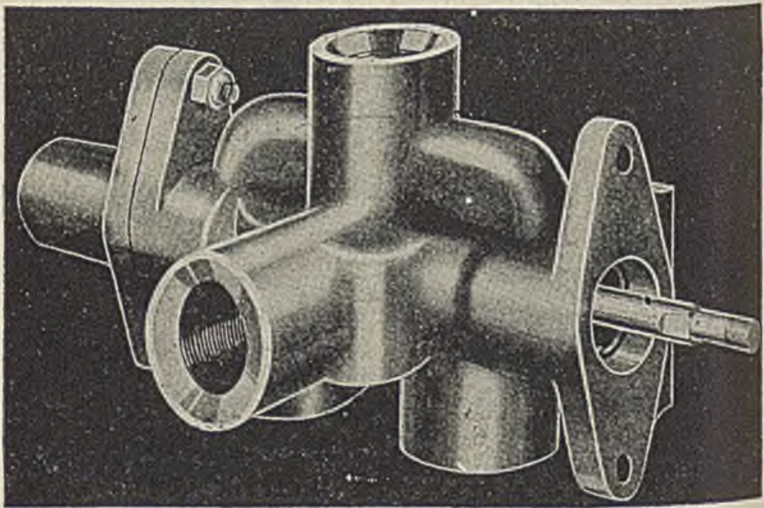


Fig. 53.—Hydraulic selector valve, type H, designed to operate landing gear retracting systems, wing flaps, cowl flaps or any other parts of an air plane requiring intermittent operation in two directions. No accumulator is required in this system.

No accumulator is required in this system. When not in use, the valve allows unrestricted circulation of the hydraulic fluid from the pump through the valve to the reservoir, or through a number of valves in series to the reservoir.

A movement of ⅜ in. of the valve stem in one direction or the other will interrupt the flow through the valve and operate the system desired at the same time accommodating the return flow to the reservoir without restriction.

The circuit diagram fig. 54 will indicate the essentials of a two valve system.

The valve is manually operated. It is held in the neutral or center position by means of a spring quadrant latch as shown.

Fig. 55 shows a valve designed to operate with an accumulator system for operation of any two directional hydraulic jack or engine, where the accumulator pressure is allowed to remain applied to the side whose operation was last completed. *i.e.* there is no neutral point and the valve is placed and left in either the extended or retracted position.

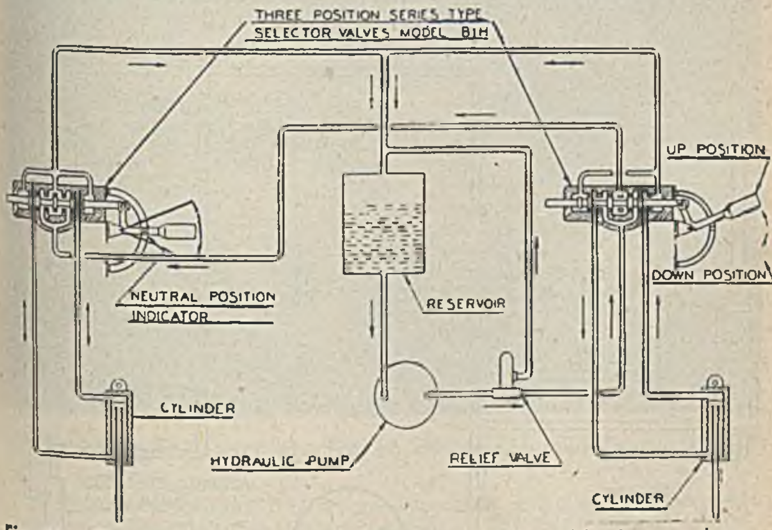


Fig. 54.—Circuit diagram of two valve system using type H selector valves.

It is the simplest available valve for the purpose and consequently the most reliable.

The circuit diagram fig. 56 shows the connections and essential elements for its operation.

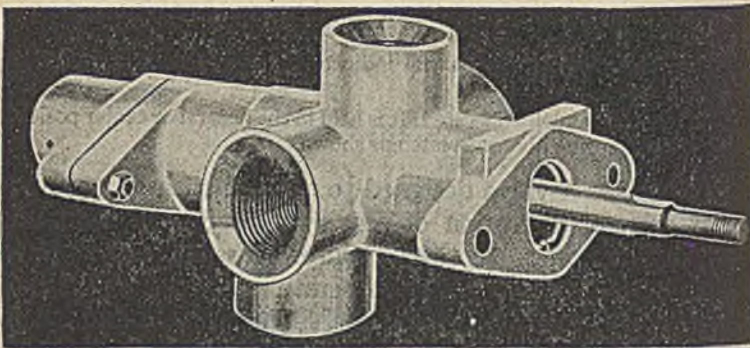


Fig. 55.—Hydraulic selector valve type K, designed to operate on an accumulator system.

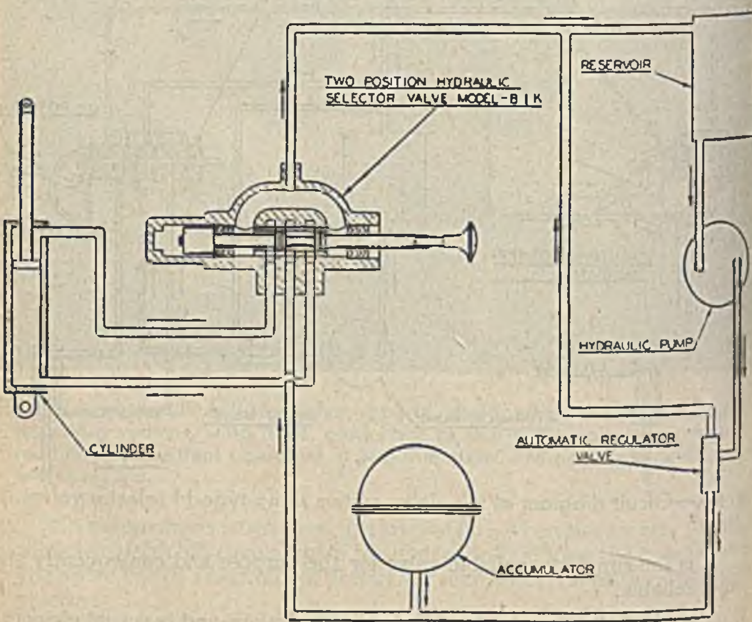


Fig. 56.—Circuit diagram of typical installation of type K selector valve.

Another valve shown in fig. 51 is designed for installation in a dive bomber where it is desirable to be able to open the bomb doors and the diving flaps preparatory to diving on the target.

When the bombs have been released and have left the ship, the bomb door and diving flaps immediately should return to closed position automatically in order to give the pilot the quickest possible get-away with the least effort and thought on his part.

The hydraulic part of the valve is the same as the valve shown in fig. 55, but an electric latching mechanism has been attached to it so that the closing of a switch incorporated in the bomb release mechanism will energize the return mechanism on the valves so that immediately the bomb or bombs have been released and cleared of the air plane, the bomb doors and flaps will return to closed position automatically.

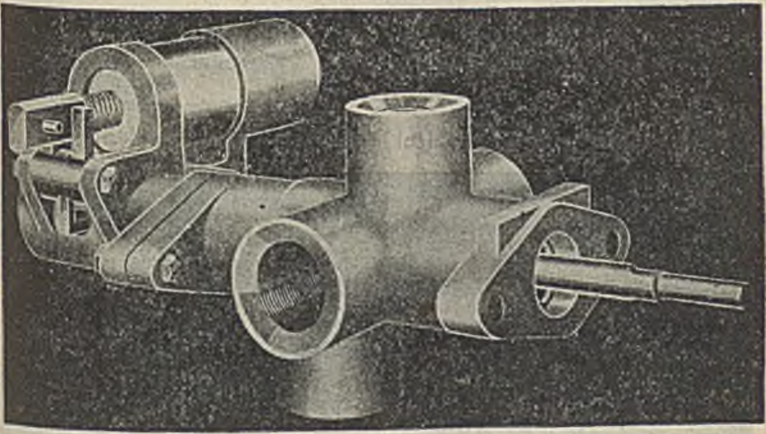


Fig. 57.—Hydraulic selector valve type M, designed for use on a dive bomber.

If desired, the valves can be returned to closed position manually at any time, even when latched in the open position.

The hydraulic part of the valve is designed to operate with an accumulator system for operation of any two directional hydraulic iack or engine where the accumulator pressure is allowed to remain applied to the side whose operation was last completed. There is no neutral point and the valve is placed and left in either the extended or retracted position. The hook up of this valve is shown in fig. 58.

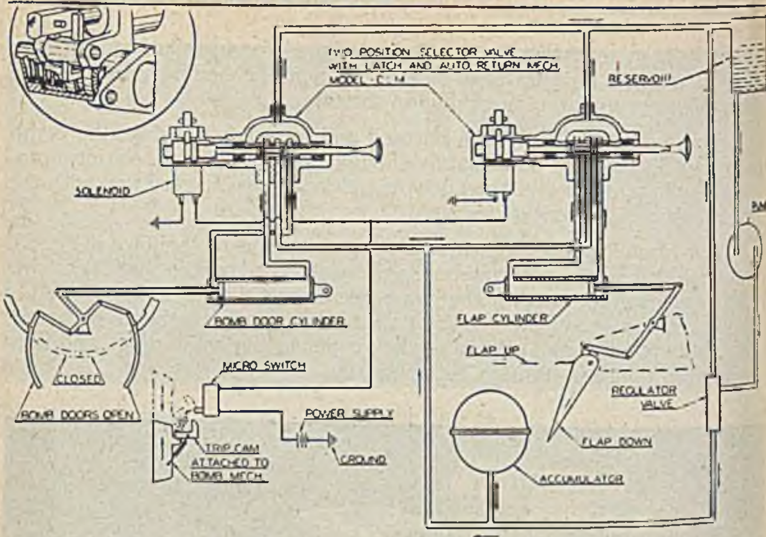


Fig. 58.—Circuit diagram of typical installation of type M selector valve.

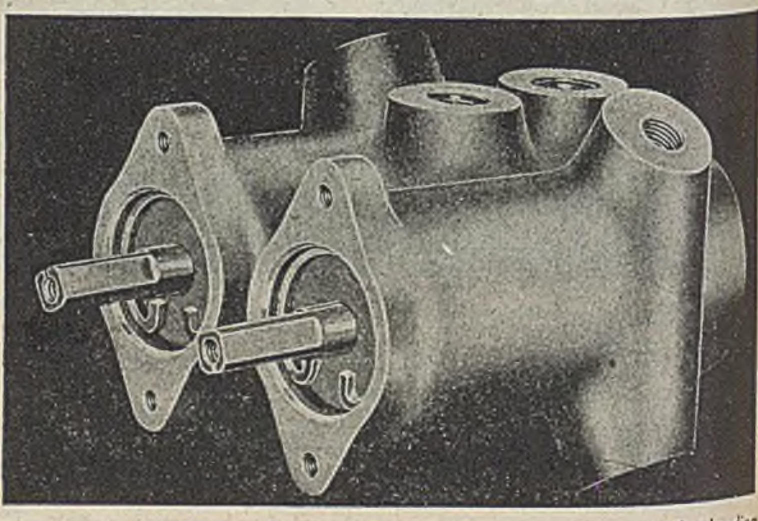


Fig. 59.—Hydraulic two unit selector type F, designed to operate both a landing retraction system and wing flaps, etc.

A two-unit valve is shown in fig. 59, designed to operate both a landing gear retraction system and wing flaps, or any other similar two-unit combination requiring intermittent operation in two directions.

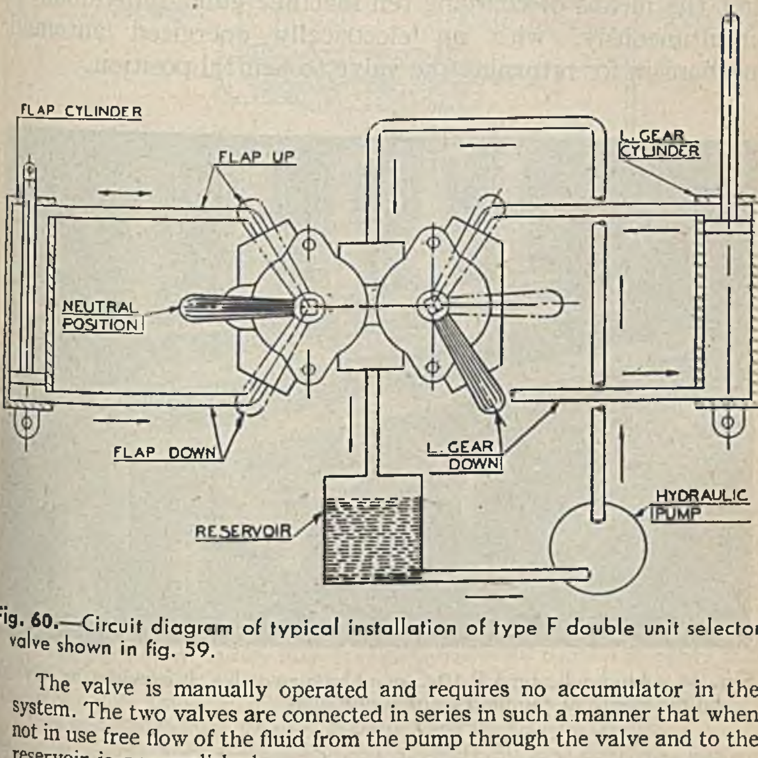


Fig. 60.—Circuit diagram of typical installation of type F double unit selector valve shown in fig. 59.

The valve is manually operated and requires no accumulator in the system. The two valves are connected in series in such a manner that when not in use free flow of the fluid from the pump through the valve and to the reservoir is accomplished.

A movement of 60° of either valve stem in one direction or the other will interrupt the flow through the valve and operate the system desired, at the same time accommodating the return flow to the reservoir without restriction.

The feed sides of the two units are also connected in parallel such that either or both systems may be used simultaneously. A check valve is provided in the flap piston to prevent cross flow of fluid from one side of the system to the other.

The essentials of the two unit system are shown in the circuit diagram fig. 60.

Fig. 61 shows a gun charging valve which provides in a single unit the means of charging ten machine guns, individually or simultaneously, with an electrically energized automatic mechanism for returning the valve to neutral position.

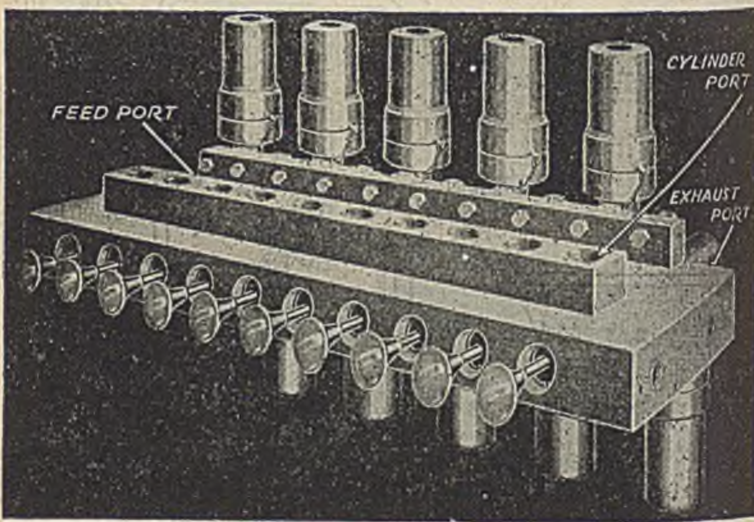


Fig. 61.—Hydraulic type B-10-C gun charging valve. It provides in a single unit the means of charging ten machine guns.

A single line, up to one-half inch in diameter, is provided to each gun for the flow to and from the gun-charging cylinder. One connection, up to one-half inch in diameter is provided for the feed line from a live pressure system and likewise, a connection of the same dimensions is provided for the return to the reservoir.

A one-half inch pull of the proper valve stem will operate the desired gun-charging cylinder. This valve stem remains latched in operating position until the gun is charged, at which time an automatic electric switch causes

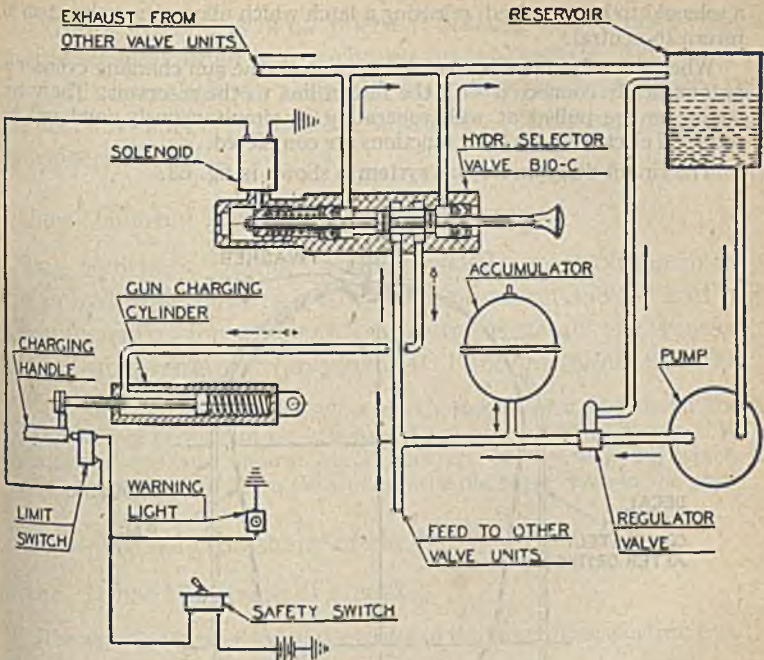


Fig. 62.—Typical flow diagram of hydraulic system using gun charging valve. The hydraulic gun charging valve provides in a single unit, the means of charging ten machine guns, individually or simultaneously. The following are features of this valve:

It will operate without seizure from lower than minus 40 degrees to above 200 degrees Fahrenheit.

The valve is fully balanced, requiring a minimum force (3 to 4 pounds) to operate it over and above the force used in overcoming the centering spring.

Its design assures easy disassembly and assembly by any mechanic, without damage to packing rings or other parts.

Because the piston and sleeve are of glass-hard material, razor sharp at the edges of the piston lands and sleeve parts, any foreign matter passing through the valve, such as a little wood, lint, or aluminum filings, will be readily sheared through and perfect operation maintained.

Normal operating pressure can be carried up to 1500 pounds per square inch. Test pressures are carried to 4000 pounds per square inch.

The valve, including automatic return mechanism, weighs less than sixteen pounds.

a solenoid to be energized, releasing a latch which allows the valve stem to return to neutral.

When the valve stem is returned to neutral, the gun charging cylinder is automatically connected with the return line to the reservoir. The valve stems can be pulled at will, separately or simultaneously, and will be returned electrically as their functions are completed.

The circuit diagram for this system is shown in fig. 62.

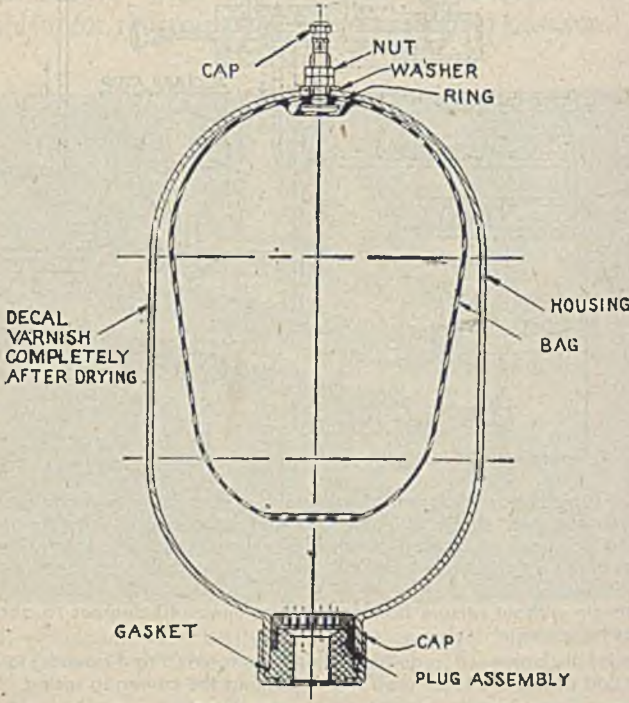


Fig. 63.—Sectional view of bladder type accumulator, showing construction.

Accumulator Construction and Service.—The construction of a well known make of accumulator is shown in fig. 63. The housing or shell is of seamless steel. One end of the housing is hemispherical and has a hole drilled through its center, just large enough to clear the outside diameter of the air valve stem.

The opposite end is hemispherical but contains a boss with a precisioned-machined screw thread on its outside. The boss is bored large enough so that the bag can be drawn into the chamber. A short cylindrical straight section separates the hemispherical ends.

Ques. Of what material is the bag made?

Ans. Synthetic rubber. This material is not soluble in any way in hydraulic fluid (Air Corps Specification 3580C) and will flex sufficientiy for efficient operation through the required temperatures ranging from plus 160° Fahr. to minus 67° Fahr.

The bag has a very high tensile strength, capable of stretching far above 200% without permanent set or failure of any part including its seams. Wall thicknesses are held uniform throughout except the very end which is reinforced to prevent extrusion through the discharge holes in the plug.

Ques. What is the shape of the bag?

Ans. It has the shape of a pear.

The air valve is moulded in the center of the larger hemispherical end.

Ques. Describe the air valve.

Ans. It consists of a high pressure pneumatic tire type stem made of brass or high grade steel, a high pressure valve core which acts as a non-return, or air check valve and a high pressure valve cap.

This valve is capable of withstanding 8,000 lbs. per sq. in. of internal pressure without failure.

Ques. Describe the closure parts.

Ans. A duraluminum plug fits closely into the mouth of the accumulator housing. At one end of the plug a duraluminum plate containing a quantity of specially shaped discharge holes is pressed or shrunk. The opposite end contains a female screw part into which a hydraulic fitting can be connected leading to the hydraulic circuit. A shoulder on the plug clamps a synthetic rubber washer against the mouth of the accumulator, making an effective seal against oil leakage.

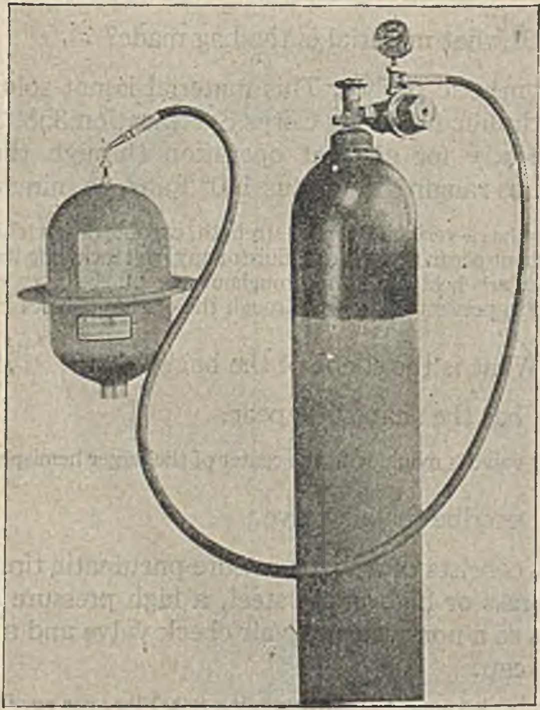


Fig. 64.—Accumulator nitrogen bottle charging set up.

A steel closed nut screws over the mouth of the housing and the shoulder of the plug, holding these parts rigidly together.

Pre-loading the Accumulator.—Before pre-loading the container, it is recommended that it be filled about ⅛ the volume of the container with hydraulic fluid through the oil port.

Keep this port open so that as the bag expands, it can force the oil out of the container without pressure.

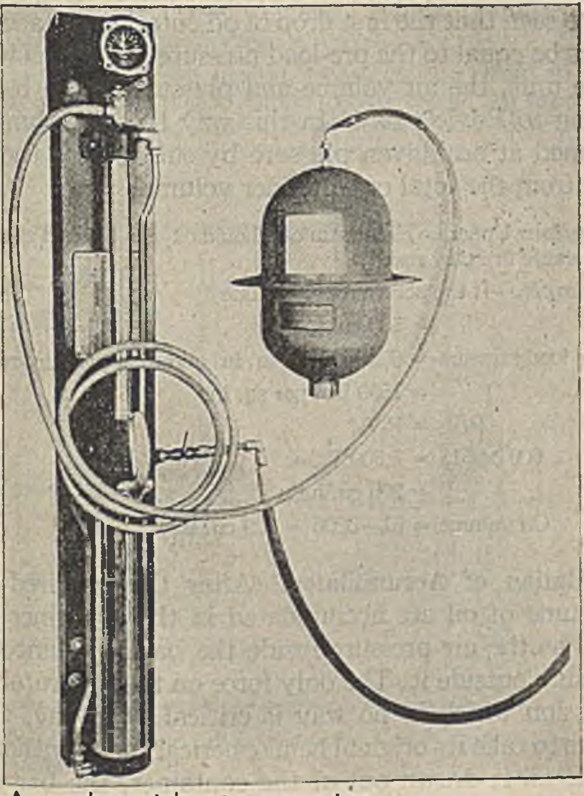


Fig. 65.—Accumulator air booster pump set up.

Ques. How is pre-loading accomplished?

Ans. With a nitrogen bottle as shown in fig. 64, or an air booster pump such as shown in fig. 65.

In either case, the gas connection is made to the air valve so that the pressure on the inside of the bag can be brought up to the required pre-load pressure in the same way that a pneumatic tire is inflated.

Ques. What is done after the unit is pre-loaded?

Ans. Oil is introduced under pressure through the oil port. It can be seen that the first drop of oil entering the accumulator will thus be equal to the pre-load pressure. As the oil is pumped into the unit, the air volume and pressure in the bag change according to Boyle's Law. In this way the oil volume can be determined at any given pressure by subtracting the final air volume from the total or container volume.

Caution: Under no circumstances should oxygen be used as the pre-load gas, because fire may result.

Example.—If the accumulator volume

= 500 cu. ins.

Air pre-load pressure = 600 lbs. per sq. in. and final pressure required

= 1500 lbs. per sq. in.

$P_1V_1 = P_2V_2$*

$600 \times 515 = 1{,}500\ V_2$, or

V = 206 cu. ins.

Oil volume = 51−5206 = 309 cu. ins.

Installation of Accumulator.—After the required pressure and volume of oil are accumulated in the container, the bag "floats" as the air pressure inside the bag is balanced by the oil pressure outside it. The only force on the separator is direct compression which in no way is critical. The bag, therefore, attempts to take its original hemispherical shape without stress.

As the oil is drawn out of the container, the bag expands, forcing the fluid away from the walls of the container, pushing it gradually toward the port until the last drop of fluid is

---

*NOTE.—For most practical purposes this formula will hold true. However, it must be understood that when fluid is pumped into or withdrawn from the accumulator very rapidly, a definite temperature change takes place due to the rapid expansion or contraction of the air. In this case the oil volume at a required pressure must be calculated, using Charles law. For full explanation of Charles law see Section III of this book on Air and Air Compressors.

pushed out. This insures maximum efficiency—made possible by the design and shape of the bag.

In order to save weight in oil and tubing, it is best to mount the accumulator as close to the engine as possible.

It has been found in most applications that the best place for mounting is on the fire wall in the nacelle section directly behind the engine, and for most efficient functioning of the unloader valve, the tubing length between it and the accumulator should be as short as possible.

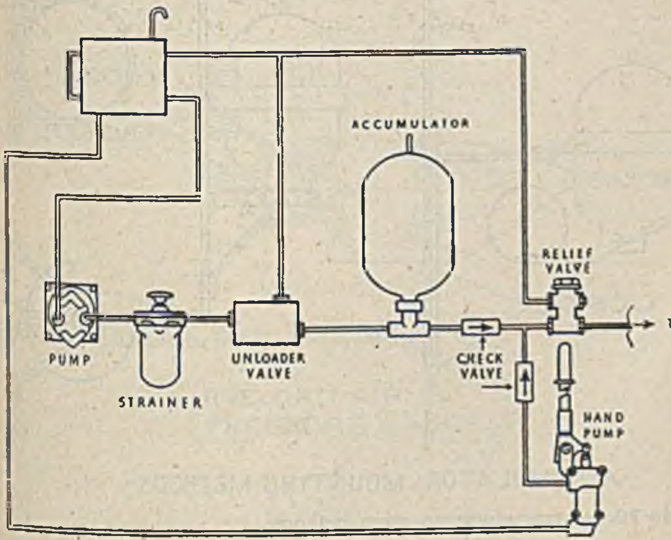


Fig. 66.—Typical installation of accumulator. Circuit diagram showing hook up of associated units.

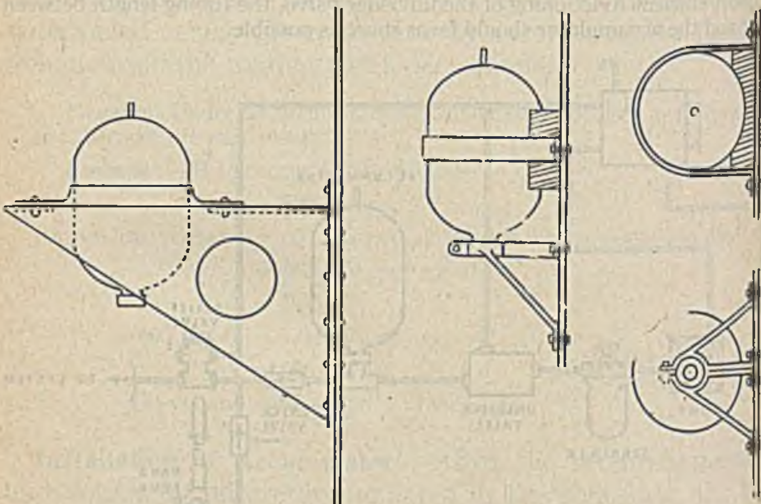
Because the accumulator has a fully enclosed bag containing air, the bag will tend to float on top of the fluid. If the accumulator be mounted in a vertical position with the air valve on top, it is natural for the oil port to be open to oil flow until the last drop of fluid is ejected from the accumulator.

It is best, therefore, that the unit be mounted vertically. This position is favorable for servicing as it is generally easier to get at the air valve to charge the unit. The vertical mounting position with oil port down has been approved by the Bureau of Aeronautics and the U.S. Army Corps.

In the experience of the armed services, condensation in an accumulator of this type is negligible over a period of two years. With proper scavenging, which is necessary in any installation, the danger of trapping air in a hydraulic unit is negligible.

The circuit diagram fig. 66 shows installation of the accumulator.

Ques. Where is the proper place for the accumulator?



ACCUMULATOR MOUNTING METHODS

Figs. 67 to 70.—Accumulator mounting methods.

Ans. Between the unloader valve and the check valve.

Ques. What should be provided for emergency hand pump operation?

Ans. A non-return or check valve should be placed between the accumulator and the hand pump.

Ques. Why?

Ans. So that it will not be necessary to pump up the accumulator with the hand pump when it is necessary to operate a hydraulic unit by hand.

In cases where it is desirable to charge the accumulator with the hand pump, an externally-operated check valve should be installed in place of the regular check valve. This will make it possible to pump up the accumulator by manually opening the check valve or to operate a hydraulic mechanism direct.

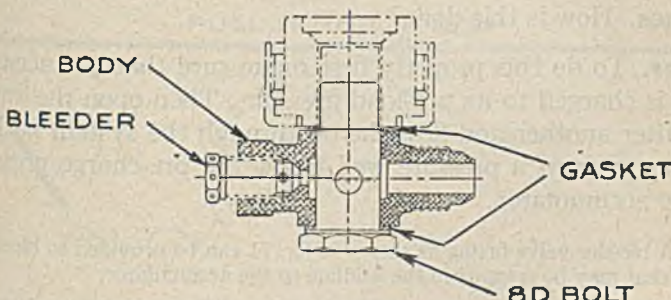


Fig. 71.—Accumulator bleeder valve fitting.

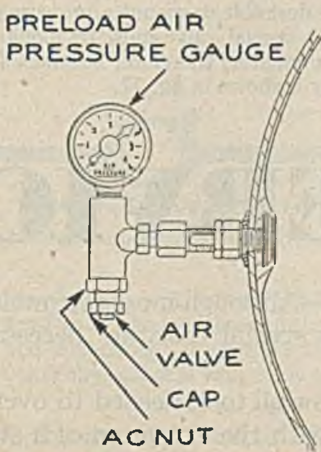


Fig. 72.—Accumulator assembly with special air gauge.

Ques. What should be done after installing?

Ans. After the hydraulic system is installed, or after any hydraulic mechanism or line in the system has been replaced or repaired, it is necessary to scavenge the system of all air that may have been included or introduced into the system during installation.

Ques. How is this done?

Ans. To do this properly first make sure that the accumulator is charged to its pre-load pressure. Then open the valves one after another and flow the oil through the system back to the reservoir at a pressure well below the pre-charge pressure in the accumulator.

A bleeder valve fitting as shown in fig. 71 can be provided to bleed the air that may be trapped in the leadline to the accumulator.

Accessories for the accumulator depend entirely upon the requirements of its installation.

In some cases it is desirable to mount a pressure gauge on the air valve of the accumulator. A special valve must be moulded in the bag for this purpose and the accumulator, therefore, becomes special. An illustration of the gauge assembly is shown in fig. 72.

SERVICE

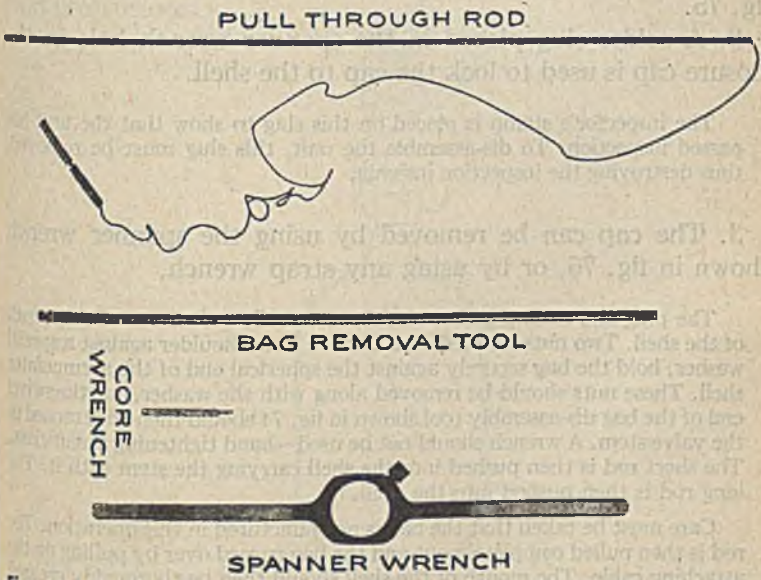
Overhaul Tools.—Although most accumulators are of simple construction a few special tools are necessary to service the unit efficiently.

Figs. 73 to 76 show all tools needed to overhaul the accumulator completely, with the exception of a standard adjustable wrench found in any mechanic's tool box.

Fig. 76 shows a simple spanner wrench used to remove the closure nut.

This wrench is a regular hardware store part.

Fig. 75 shows a core wrench used to remove and re-assemble the valve core, and fig. 74 a special tool used to remove the accumulator bag.



Figs. 73 to 76.—Accumulator maintenance tools.

This tool is made up of two rods. The short one has a swivel joint on one end and a female thread to fit the bag stem on the other. The long rod is smaller in diameter and long enough to protrude through both ends of the accumulator shell. A thin steel cable is swaged on each rod.

Fig. 73 is the pull through rod used to draw the bag into the accumulator shell.

This rod is made from steel tubing and contains a female thread on one end which fits on the stem of the accumulator bag.

Overhaul.—*Caution.*—Proceed according to the instructions here given:

1. Before dis-assembly, make sure that all air is removed from the accumulator. Release pressure by depressing the valve core stem. Then remove the core with the core tool shown in fig. 75.

2. A solder slug placed in the spanner wrench hole in the closure cap is used to lock the cap to the shell.

The inspector's stamp is placed on this slug to show that the unit has passed inspection. To dis-assemble the unit, this slug must be removed, thus destroying the inspection insignia.

3. The cap can be removed by using the spanner wrench shown in fig. 76, or by using any strap wrench.

The plug and sealing gasket can then be easily pulled out of the mouth of the shell. Two nuts screwed on the valve stem shoulder against a special washer, hold the bag securely against the spherical end of the accumulator shell. These nuts should be removed along with the washer, and the swivel end of the bag dis-assembly tool shown in fig. 74 should then be attached to the valve stem. A wrench should not be used—hand tightening is sufficient. The short rod is then pushed into the shell carrying the stem with it. The long rod is then pushed into the shell.

Care must be taken that the bag is not punctured in this operation. The rod is then pulled completely out and the bag turned over by pulling on the attaching cable. The mouth of the shell should then be thoroughly greased and the bag slowly pulled out from the casing. Remove only a portion of the bag by pulling on the cable. The remainder is removed by grasping the protruding portion of the bag with the hands and gently pulling it out.

Inspection.—All parts should be carefully inspected for failures or poor workmanship. Here are the steps to follow:

1. A load of thirty pounds should be applied to pull the stem from the bag. This load must have no effect on the bond.

2. Inflate the bag to 200% its normal size and inspect the surface carefully for weak spots, flaws or breaks.

The bag should then be completely immersed in water to detect leakage. The bag should remain inflated for 24 hours without loss in size or any permanent stretch.

3. The inside of the shell should be thoroughly cleaned and air blasted. Examine the inside surface for sharp edges, pits and protrusions.

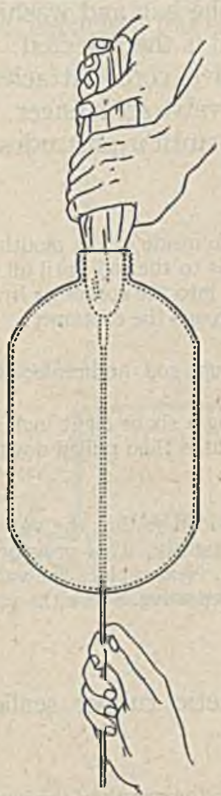


Fig. 77.—Method of drawing bag into accumulator.

4. When inspecting the plug, see that there are no sharp corners on the strainer plate holes.

5. The sealing gasket must be clean and free from cuts and abrasions.

Assembly.—1. Remove the valve core. Thoroughly wet the inside of the bag with hydraulic fluid by inserting a small quantity of the fluid into the bag and washing it around the whole interior. The excess oil is then ejected.

2. Remove the valve core. Attach the pull through rod shown in fig. 75 to the valve stem finger. Thread the rod through the mouth of the shell until it protrudes six or seven inches out of the opposite end.

Thoroughly grease the inside of the mouth of the shell, then wrap the bag lightly along the axis to the rod until all the air is exhausted. Gently pull the bag all the way into the container by pulling on the rod until the valve stem protrudes through the container.

Remove the pull through rod, and replace the washer.

Tighten the nut, using a six or eight inch standard adjustable or open end wrench. A second nut is then pulled down on the first nut to lock the unit in place.

Wrench flats are provided so that the valve stem can be gripped while the nut is drawn down tightly. This prevents the bag turning or twisting during the operation. Next replace the valve core in the stem just like an ordinary pneumatic tire valve. Screw the valve cap on lightly to prevent its loss.

3. Place the synthetic rubber sealing gasket against the shoulder of the plug.

Then insert the plug in the mouth of the housing and draw the nut down tightly on the assembly with the spanner wrench shown in fig. 76.

Testing

Test Equipment.—The following outfit should be procured for testing:

1. Source of air pressure.

   Air booster pump or nitrogen bottle.

2. Air pressure gauge, capacity: 1000 lbs. per sq. in.
3. Air connection line.

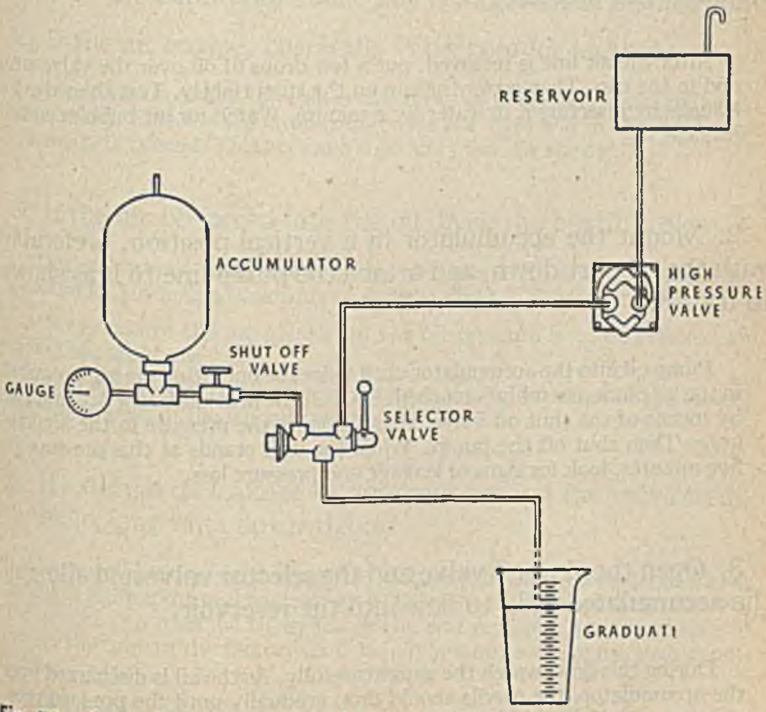


Fig. 78.—Set up for testing accumulator.

4. Hydraulic pump.

5. Hydraulic booster pump or cylinder, capacity: 3000 lbs. per sq. in.

6. Hydraulic lines, valves and fittings.

Test Procedure.—1. Attach the air line to the accumulator valve stem as shown in fig. 78 and pre-load the unit to the required gas pressure.

After the air line is removed, put a few drops of oil over the valve stem and in the cap. Then screw the cap on the stem tightly. Test the valve for leakage by inserting it in water for a minute. Watch for air bubbles and oil leakage.

2. Mount the accumulator in a vertical position, preferably with the oil port down, and attach the pump line to it as shown in fig. 78.

Pump oil into the accumulator until twice the operating pressure required in the air plane assembly is reached. Shut off the pressure in the accumulator by means of the shut off valve, thus trapping the pressure in the accumulator. Then shut off the pump. While the unit stands at this pressure for five minutes, look for signs of leakage and pressure loss.

3. Open the shut off valve and the selector valve and allow all the accumulated fluid to flow into the reservoir.

During this flow, watch the gauge carefully. As the oil is discharged from the accumulator, the needle should drop gradually until the pre-load pressure is reached. At this point the needle should drop suddenly to zero.

Troubles

Causes and Corrections.—All accumulators are thoroughly tested at the factory and no unit is shipped unless it measures up to the standard specified by the U. S. Army and Navy and passes manufacturers' testing procedures. If when the accumulator is installed, it fail to function properly, check for the following:

1. Determine whether the unit has been pre-loaded to its proper air pressure. Sometimes this is forgotten in installation.

2. If the air escape, check the valve core for leakage.

It may be necessary to replace this unit, as it is easily damaged when mishandled. Place a few drops of oil over the stem and in the cap before the cap is tightened. This acts as a secondary seal for the air.

3. If the air be forced into the oil lines, the bag is broken.

This may result from allowing the unit to stand under pre-loaded air pressure for too long a time without sufficient oil.

Always relieve the air pressure if the oil pressure is to be relieved for more than six hours.

If the bag be broken, the accumulator should be returned to the factory for replacement of the bag and retest.

4. If external oil leakage be apparent around the valve stem, pull the locking nuts down tighter.

If external leakage exist about the closure cap, first see that the fitting tubing is tight and free from leakage. If this be not the cause of the trouble, the closure cap must be tightened or the seal replaced. It is advisable to return the unit to the factory as it is fully guaranteed against such conditions.

If oil pressure be not maintained in the accumulator, check the complete system for external or internal leakage.

Air Plane Hydro-Pneumatic Shock Absorbing Struts.—Typical apparatus for this purpose is shown in figs. 79 and 80. When landing an air plane the wheel which is mounted on axle **A**, fig. 79 contacts with the ground and the upward thrust telescopes the piston **G**, into cylinder **H**, causing the oil in chamber **F**, to be forced through the orifice **I**, around the metering pin **J**, thereby creating a hydraulic resistance in chamber **F**.

Ques. How is this resistance controlled?

Ans. By the shape of metering pin **J** (fig. 79) which dissipates the energy.

Ques. Describe the action.

Ans. The flow of the fluid through the orifice into chamber **E**, compresses the air from its normal value, thus creating further resistance to the telescoping motion.

Ques. How is the expansion of the compressed air controlled?

Ans. By a return valve.

Ques. What is the effect of such control?

Ans. It eliminates excessive recoil to the piston.

Ques. Describe the tail wheel strut assembly.

Ans. As shown in fig. 80 it consists of a small strut wheel half fork and supporting arm. The tire and wheel are mounted on axle **K**. The half fork **M** (knuckle) is mounted on roller bearings in the supporting housing which permits the knuckle to caster and trail the air plane when taxiing. At the upper end of the knuckle assembly there is fitted a friction plate at **O**, which

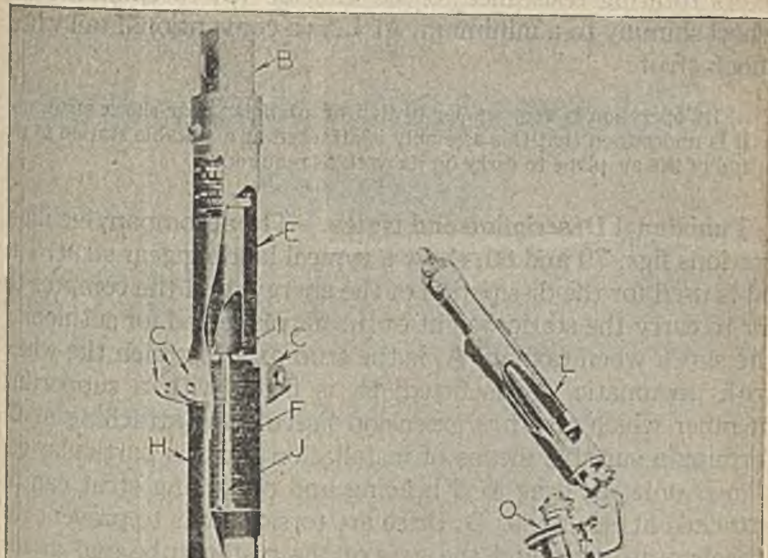


Fig. 79.—Air plane hydro-pneumatic landing gear strut.

Fig. 80.—Air plane tail wheel strut assembly.

offers rotating resistance to the knuckle **M**, to eliminate tail wheel shimmy to a minimum. At **L**, is a conventional tail wheel shock strut.

Its operation is very similar to that of a landing gear shock strut, and it is understood that this assembly is attached at a suitable station in the tail of the air plane to carry on its work as required.

Functional Description and Notes.—The accompanying illustrations figs. 79 and 80, show a typical landing gear strut. The oil is used for the dissipation of the energy, and the compressed air to carry the static weight of the air plane and for cushioning the shock when taxiing. **A**, is the stub axle to which the wheel with pneumatic tire is fitted; **B**, is fitted with a supporting member which also has extension brace arms attaching at **C**, forming a suitable means of installation for this particular designed unit; **C**, drag load bracing and retracting strut can be attached at this point; **D**, these are torsion links to prevent the wheel rotating around the axis of the piston tube and at the same time allowing the piston to telescope into the cylinder.

Double links (or scissors) may be installed when skis are used in place of wheel and tire; **E**, represents the compressed air chamber. The average pressure to sustain the static weight of an air plane is approximately 500 lbs to the sq. in.

The adjustment of this type strut is not gauged as a tire but rather to position of the piston, the average adjustment being approximately 20% of the total extension of the piston.

The required static pressure will diminish to a nominal pressure when the strut is fully extended; F, represents the oil chamber which is normally filled with the proper fluid with the piston fully compressed. The filling is made through a plug provided for this purpose and is so located to give the proper compression ratio to the air chamber.

CHAPTER 39

Hydraulic Automobile Brakes

The term "hydraulic" primarily relates to water, but broadly it includes other liquids and may be defined as: *The science relating to liquids in motion, dealing with their useful applications.*

Ques. What is the principle of hydraulic brakes?

Ans. A liquid confined in a suitable system is used as a medium to transmit and increase an applied force for braking.

Ques. What kind of liquid is generally used?

Ans. A special grade of oil.

Ques. What are the essential parts of hydraulic brake systems as applied to automobiles?

Ans. 1, a master cylinder with reserve tank; 2, brake or wheel cylinders; 3, connecting tubing; 4, linkage to brake pedal.

Ques. Describe the master cylinder.

Ans. It is fitted with a piston to compress the liquid in transmitting braking power and a reserve tank to make up for loss of liquid by leakage. Two ports and two valves are required for the cycle of operations.

The essentials are shown in the elementary drawing, fig. 1.

Ques. How does it work?

Ans. The brake pedal when depressed, moves the piston within the master cylinder, thus displacing the brake fluid from the master cylinder through the tubing and hose connections into the four wheel cylinders.

Ques. What action takes place within the four wheel cylinders?

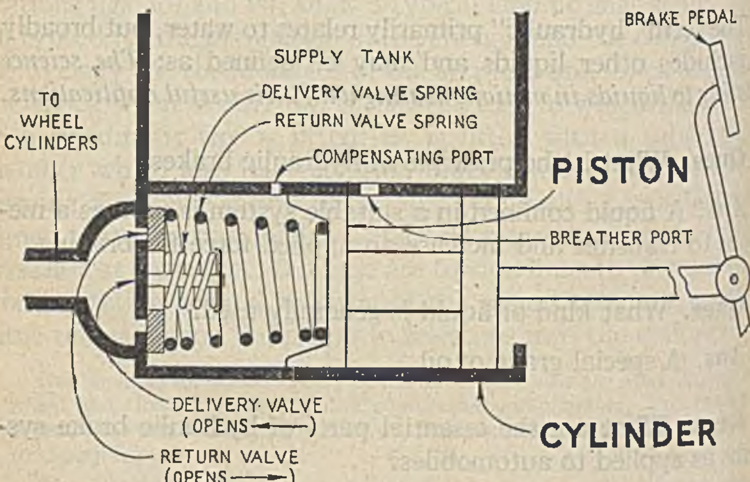


Fig. 1.—Elementary drawing of master cylinder showing essential elements.

Ans. The fluid passes upon the opposing piston of the wheel cylinders, causing them to move outward against the brake shoes, thus bringing the shoes into contact with the brake drums.

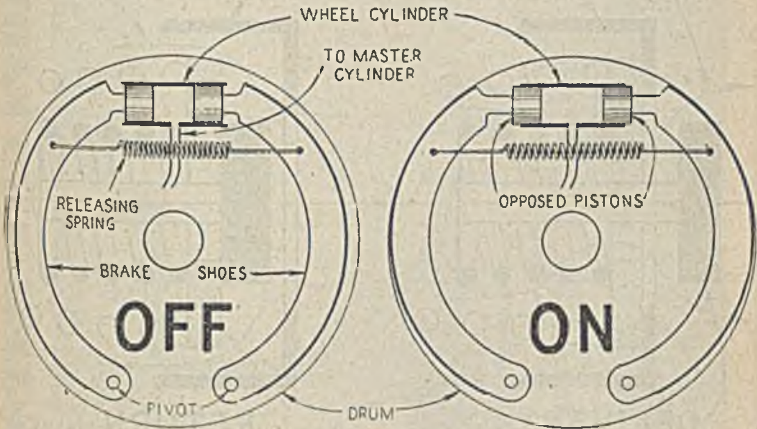
Thus figs. 2 and 3 show brakes and brake cylinder in *off* and *on* positions.

Ques. What happens when pressure on the brake pedal is increased?

Ans. Greater hydraulic pressure is built up within the wheel cylinders and consequently greater force is exerted against the brake shoes.

Ques. What hydraulic principle is here introduced?

Ans. The column of fluid being incompressible and automatically maintained at the correct volume, is transmitted to all surfaces with equal and undiminished force.



Figs. 2 and 3.—Wheel cylinder operations showing brakes in **on** and **off** positions.

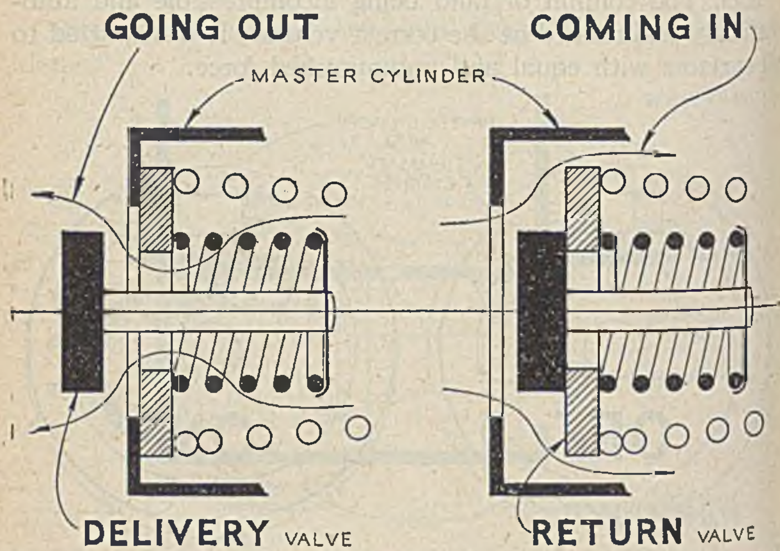
Ques. What happens when pressure on the brake pedal is released?

Ans. The brake shoes releasing springs retract and return the brake shoes to their normal or "off" positions.

The return movement of the brake shoes in turn causes movement of the wheel cylinder pistons toward their off position, thus forcing the working fluid back through the flexible hose and tubing into the master cylinder.

Ques. How is the liquid forced out of the master cylinder when brake pedal is depressed?

Ans. The delivery valve opens allowing the exit of the liquid as in fig. 4.



Figs. 4 and 5.—Detail of master cylinder delivery and return valves showing operation.

Ques. How does the liquid get back into the master cylinder when the brake pedal is released?

Ans. The *return* valve opens allowing liquid to enter the master cylinder as in fig. 5.

From the illustrations it will be noted that the delivery and return valves ride upon each other and open in different directions, being an

MASTER CYLINDER

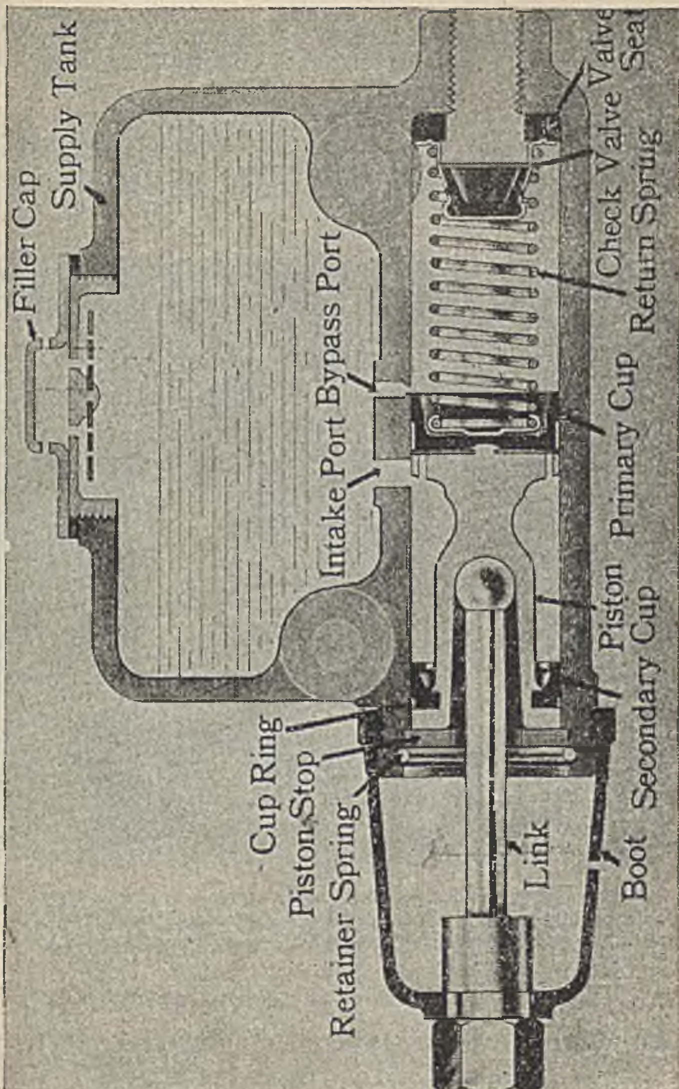


Fig. 6.—Cross sectional view showing construction of typical master cylinder and mechanism.

assembly having their individual springs. These springs operate to close the valves. It will be noted that the return valve forms a seat for the delivery valve and the return valve seats up against the end wall of the master cylinder.

Ques. What does an actual master cylinder look like?

Ans. The sectional view fig. 6 shows the construction of a typical master cylinder.

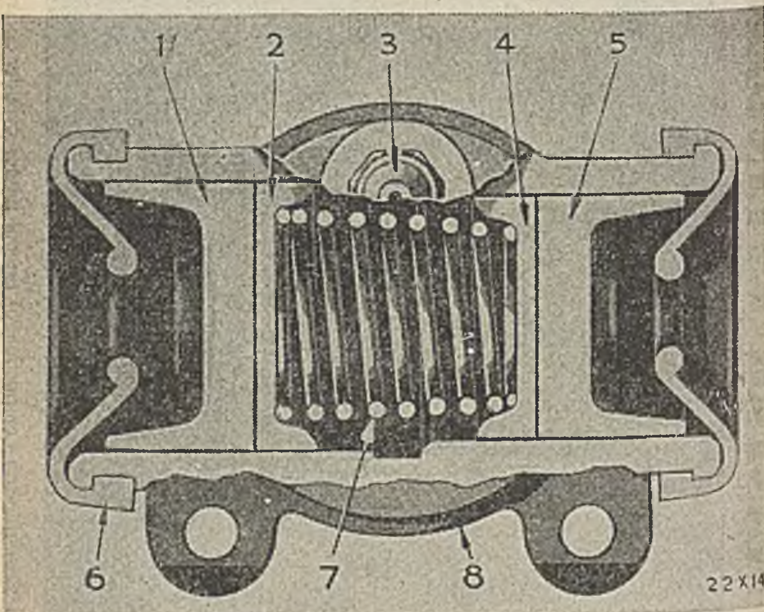


Fig. 7.—Brake wheel cylinder. **The parts are:** 1, piston (large, rear); 2, piston cup (large) rear; 3, bleeder screw; 4, piston cup (small) front; 5, piston (small) front; 6, boot; 7, piston cup spring; 8, cylinder (body).

Ques. What is the object of the compensating port (fig. 1)?

Ans. When the piston is in a fully released position the compensating port is *opened* and excess fluid returns to the reservoir or supply tank, as the brake shoes releasing spring (fig. 2) force the fluid out of the wheel cylinder.

Ques. What is the appearance of an actual wheel cylinder?

Ans. The construction of a typical cylinder is shown in the sectional view, fig. 7.

Brake Maintenance Hints.

1. Pedal goes to floor board.

Cause:

a. Normal wear of lining.

b. Leak in system.

c. Air in system.

d. No fluid in supply tank.

Remedy:

a. When brake linings become worn, it is necessary to set the shoes into closer relation to brake drums. This condition is usually accompanied by the remark from the driver that it is necessary to pump the pedal several times before a brake is obtained. Shoes should be set as close to brake drums as possible without drag. Do not disturb anchor pins when making this adjustment. Adjustment must be made while drums are cool.

b. A connection leak in the system will allow the pedal under pressure, to go to the foot board gradually. A cup leak does not necessarily result in loss of pedal travel, but will be indicated by a loss of fluid in the supply tank. If no leaks be found at wheels or connections, remove master cylinder and check bore of barrel for score or scratches.

c. Air in the system will cause a springy, rubbery action of the pedal. Should a sufficient quantity be introduced into the system, the pedal will go to the board under normal pressure. System should be bled.

2. **All brakes drag.**

Cause:

a. Mineral oil in system.

b. Port hole closed.

Remedy:

a. The introduction into the system of any oil of a mineral base, such as engine oil, kerosene, or the like, will cause the cups to swell and distort,

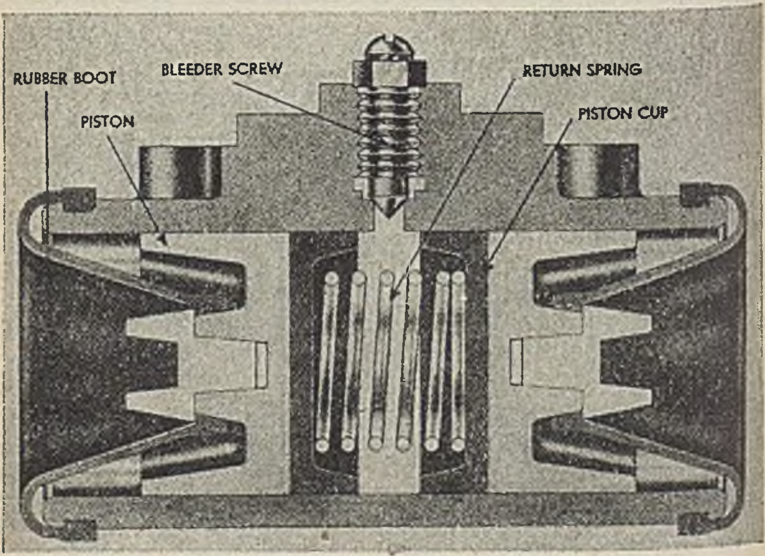


Fig. 8.—Another design of brake wheel cylinder.

making it necessary to replace all rubber parts. Flush system with alcohol and refill with brake fluid.

b. Directly ahead of the master cylinder piston cup (when in normal release position) is a relief or compensating port. It is imperative that this by pass be open when the brakes are released. Should this port, fig. 9, be blocked by piston cup not returning to its proper release position, the pressure in the system will gradually build up and brakes drag. Opening a bleeder screw will allow built-up pressure to escape and give temporary relief. Bleeder screw must be tight before car is driven.

3. One wheel drags.

Cause:

a. Weak brake shoe return spring.

b. Brake shoe set too close to drum.

c. Cups distorted.

d. Loose wheel bearings.

Remedy:

a. Springs sometimes lose their contracting power and take a set. Replace spring.

b. Readjust shoes to proper clearance.

c. If in repairing wheel cylinders, kerosene, gasoline and other fluids are used as a cleaner instead of alcohol, the cups will swell and distort. The return action of the shoes will be retarded and the brake drum will heat. Replace cups and wash unit in alcohol, and dip all parts in fluid before reassembling.

d. Tighten bearings.

4. Car pulls to one side.

Cause:

a. Oil soaked lining.

b. Shoes improperly set.

c. Backing plate loose on axle.

d. Different makes of lining.

e. Tires not properly inflated.

Remedy:

a. Replace with new lined shoes. Grease-soaked linings cannot be salvaged by washing or cleaning.

b. Readjust the shoes to proper clearance.

c. Loose brake support permits the brake assembly to shift on the locating bolts. This shifting changes the predetermined centers and causes unequal efficiency. Tighten backing plates and readjust shoes.

d. Different makes of linings have different braking efficiency. Two different makes, one with high efficiency and one with low efficiency, would cause car to pull to one side.

5. Springy, spongy pedal.

Cause:

a. Brake shoes not properly adjusted.

b. Air in system.

Remedy:

a. Adjust brakes.

6. Excessive pressure on pedal, poor stop.

Cause:

a. Brake shoes not properly adjusted.

b. Improper lining.

c. Oil in lining.

d. Lining making partial contact.

Remedy:

a. Adjust brakes.

b. Replace with new lined shoes of same type, as improper grades of brake linings lose their gripping qualities after a few thousand miles. As the frictional quality decreases, the pressure on the brake pedal is naturally increased to get the equivalent stop.

c. Replace with lined shoes.

d. Remove high spots.

7. Light pressure on pedal, severe brakes.

Cause:

a. Brake shoes not properly adjusted.

b. Loose backing plate on axles.

c. Grease-soaked lining.

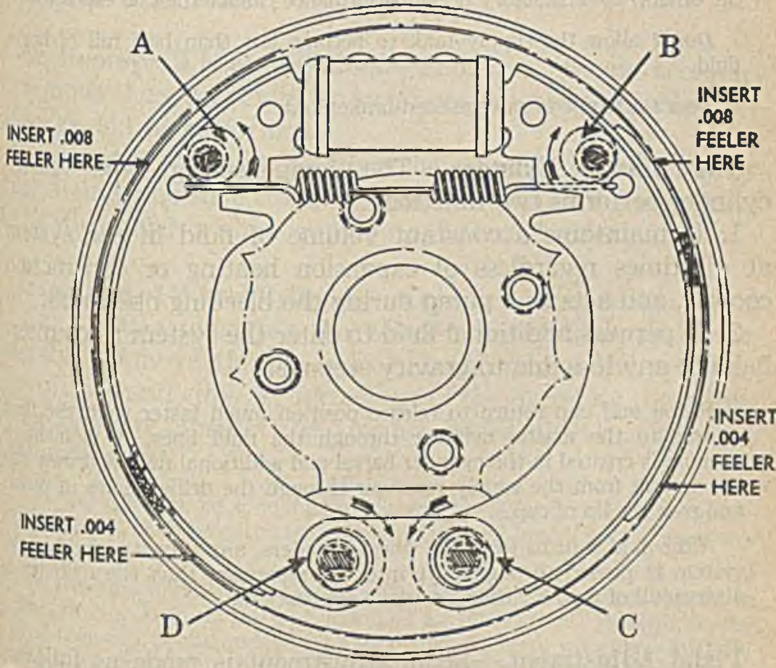


Fig. 9.—Detail of wheel brake mechanism to illustrate brake adjustments.

Remedy:

a. Adjust brakes.

b. The fluid level in the supply tank should be checked. Should the tank become empty air will be introduced into the system, necessitating bleeding.

Caution.

Don't use a substitute for brake fluid. Substitutes are not suitable for this system.

Don't clean rubber parts or inside of cylinders with anything but clean alcohol. Don't use kerosene or gasoline.

Don't reline one wheel with a different type of lining than is used on the others, as satisfactory brake performance cannot then be expected.

Don't allow the supply tank to become less than half full of brake fluid.

Don't attempt to salvage used brake fluid.

The Master Cylinder.—The compensating type master cylinder performs two functions:

1. It maintains a constant volume of fluid in the system at all times regardless of expansion heating or contraction cooling, and acts as a pump during the bleeding operation.
2. It permits additional fluid to enter the system to counterbalance any loss due to gravity seepage.

Piston and cup return to release position much faster than the fluid returns to the master cylinder through the fluid lines. A momentary vacuum is created in the cylinder barrel and additional fluid is drawn into the system from the supply reservoir through the drilled holes in piston and past the lip of cup.

After fluid returns from the wheel cylinders, any excess of fluid in the system is passed through port into the reservoir; thus the cylinder is always full of fluid for the next brake application.

Pedal Adjustment.—Pedal adjustment is made as follows: It is important that the rod be adjusted for clearance where it seats in the piston. There should be ¼ to ½ in. free movement of brake pedal before the pressure starts.

Should the link be adjusted tightly against the piston, by-pass port may be blocked by the cup, and compensating action of the master cylinder will be destroyed.

The primary cup must be clear of by-pass port when piston is in its off or released position. This may be determined by ascertaining if there be ¼ to ½ in. free movement of the pedal before the piston starts to move.

Secondary cup prevents fluid leaking out of the master cylinder into the boot.

Caution.—Before removing supply tank filler cap, extreme care must be used to prevent dirt entering the master cylinder; dirt getting lodged between the pistons in the system and the cylinder walls may cause spasmodic brake failure.

To Remove Wheel Cylinders.—Should it become necessary to remove the wheel cylinder for inspection, the following operation should be performed:

Disconnect the cylinder from the system by removing the inlet fitting; the shoe travel is sufficient to permit the cylinder to be withdrawn without removing the brake shoes.

Inspection of Wheel Cylinder.—Considering the design shown in fig. 7, after removing the wheel cylinder from the brake assembly, remove the boots from both ends of the cylinder. The pistons and cups are forced out of the barrel by the return spring pressure. Inspect the cups for ragged edges and the bore for smoothness.

Should the bore be scratched or pitted, it will be necessary to replace the cylinder, or to have the bore honed to prevent loss of fluid or excessive cup wear.

When reassembling the wheel cylinder, all parts must be first washed in clean alcohol, then dipped in brake fluid for lubrication. Reassemble the small bore cup, piston and boot in the casting. The return spring is installed against the piston cup. Install cup, piston and boot. The unit is now ready for installation. New inlet fitting gaskets must be used when connecting the cylinder to the system.

Bleeding Hydraulic Lines.—Whenever a tubing line has been disconnected at the master cylinder, it is necessary to bleed the hydraulic system at all four wheels to expel all air. Whenever a line is disconnected from any individual wheel, that wheel cylinder only must be bled. Fill the master cylinder reservoir with proper brake fluid (as recommended by the manufacturer) before bleeding and keep reservoir half full at all times.

Loosen the bleeder hose fitting and slip on hose. Allow bleeder hose to hang in clean container, such as pint jar, shown in fig. 10.

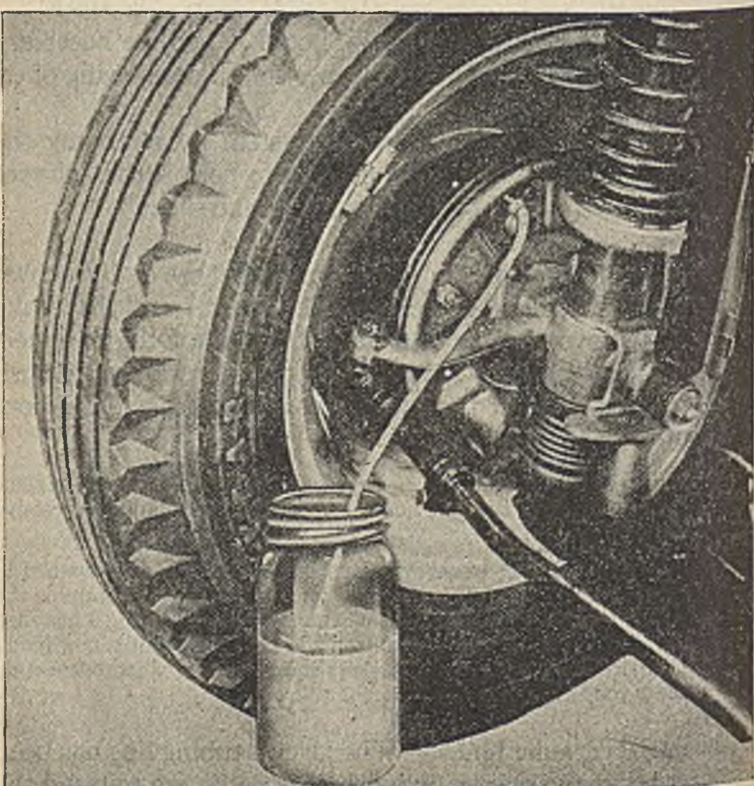


Fig. 10.—The operation of bleeding a hydraulic brake system.

Depress the foot pedal slowly by hand. It is advisable to lock the bleeder screw at the end of the last pressure stroke. Air cannot then follow possible loose threads into the cylinder during the return of the brake pedal.

Allow return spring to return the pedal slowly to off position. This produces a pumping action which forces fluid through the tubing out at the wheel cylinder, carrying with it any air that may be present.

Watch the flow of fluid from hose, the end of which should be kept below the surface of fluid; when all air bubbles cease to appear and when fluid stream is a solid mass, close bleeder connection.

Fluid withdrawn in bleeding operation should not be used again. Fluid should be replenished in supply tank after each cylinder is bled. Should supply tank be drained during bleeding operation, air will enter the system and rebleeding will then be necessary. When bleeding operation is completed, supply tank must be refilled.

To prevent brake drag, it is necessary that the port be open when the brake pedal is in release position.

Brake Fluid.—Manufacturers have done the experimenting and have arrived at the proper fluid to use after plenty of research, so don't be smart and pour any substitute into the system as it won't work.

Adjustment for Wear.—Brakes should be adjusted when the linings have been worn to the extent that there is excessive pedal travel.

Brake drums should be approximately at room temperature when making adjustments. If brakes be adjusted when drums are hot or expanded, the shoes may drag when the drum cools and contracts.

1. Jack up all four wheels.

2. Play in wheel bearing should be taken up.

3. See that parking brake lever is in the fully released position.

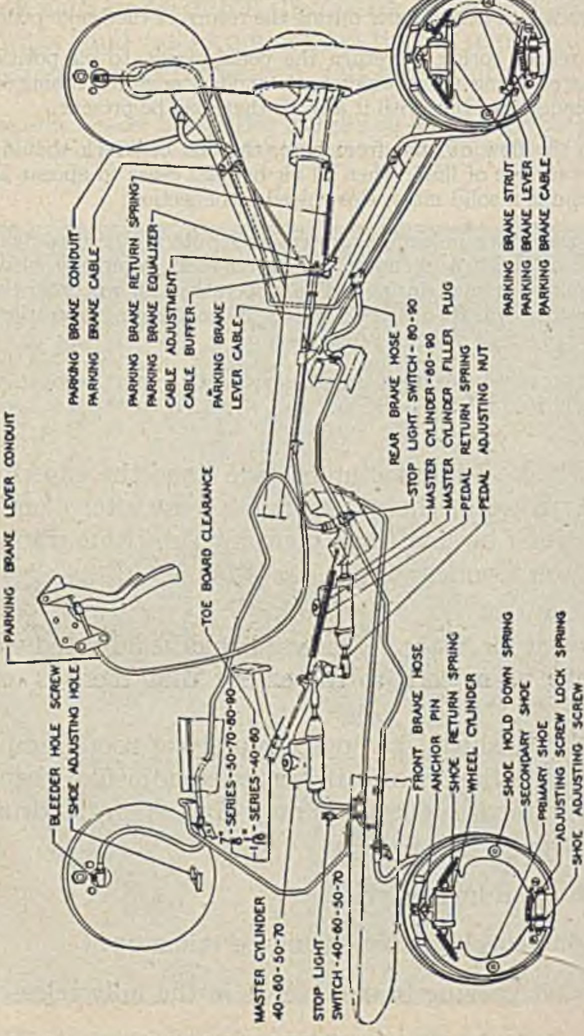


Fig. 11.—Brake adjustment chart.

4. Check pedal adjustment to make sure that pedal pad travels approximately ¼ in. before master cylinder link end play has been taken up and master cylinder piston starts to move.

5. Adjustment is made by rotating the cams A and B, fig .9, with a wrench until the shoes come in contact with the drum, then back off the adjustment slightly until the wheel rotates freely in either direction.

Proceed in a like manner on the brake shoes of all wheels. To bring the shoes into closer relation with the drum, the cam must be turned toward the nearest point of the wheel rim when the wrench is pointing upward.

Ques. What should be noted with respect to inspection or disassembly of the brakes?

Ans. The hydraulic portion of the system should be left intact so that bleeding of the lines will not be required.

Ques. How is this accomplished?

Ans. By disconnecting the brake shoes from the cylinder at the connecting links, without disturbing the hydraulic connections.

Ques. What else must be noted?

Ans. The brake pedal must not be depressed at any time when brake drums are not in place.

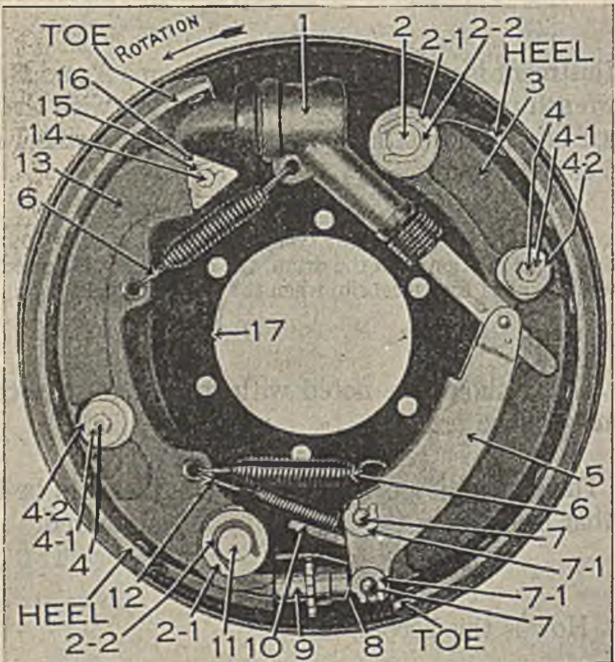


Fig. 12.—Wheel brake shoes with list of parts. ***The parts are:***

1. Wheel Cylinder Assy
2 Anchor Pin, Rear Shoe
2-1 Anchor Pin Plain Washer
2-2 Anchor Pin "C" Washer
3 Rear Brake Shoe
4 Shoe Guide Bolt.
4-1 Shoe Guide Bolt Lock Nuts.
4-2 Shoe Guide Bolt Plain Washer.
5. Lever and Push Rod Assy
6 Brake Shoe Return Spring
7 Lever and Adjusting Screw Hinge Pin
7-1 Hinge Pin "C" Washer
8 Adjusting Screw and Spring Assy.
9 Star Wheel Nut Assy
10. Brake Shoe Guide.
11 Front Shoe Heel Anchor Pin.
12 Lower Shoe Return Spring
13 Front Brake Shoe
14 Reverse Anchor
15 Reverse Anchor "C" Washer.
16 Reverse Anchor Swivel
17 Backing Plate.

CHAPTER 40

Hydraulic Shock Absorbers

By definition a shock absorber is: *A device for insuring the gradual return of a spring to its original shape after being compressed or expanded, so as to deaden its rebounds and after movements by absorbing them.*

If it were not for shock absorbers, travelling in automobiles would be rough riding, especially considering the crazy driving methods of most alleged "drivers."

Ques. What is the hydraulic principle upon which the operation of absorbers depends?

Ans. The frictional resistance and resulting damping or delaying action due to forcing fluid through an orifice (small hole).

Ques. How does a hydraulic shock absorber work?

Ans. A housing filled with fluid and containing an internal mechanism is so designed that as a spring action occurs, the fluid is forced through a calibrated orifice. The frictional resistance thus set up opposes the direction of the spring movement and thus dampens the shock.

Elementary Single Acting Hydraulic Shock Absorber.—The essential parts of a hydraulic shock absorber may be listed as:

1. Cylinder
2. Reservoir (housing)
3. Spring piston
4. Intake valve (having orifice)
5. Relief valve
6. Piston yoke
7. Bell crank and linkage

SINGLE ACTING

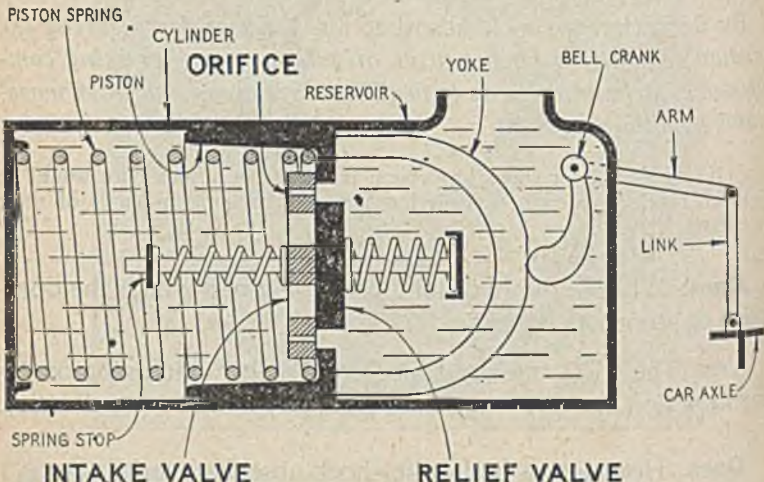


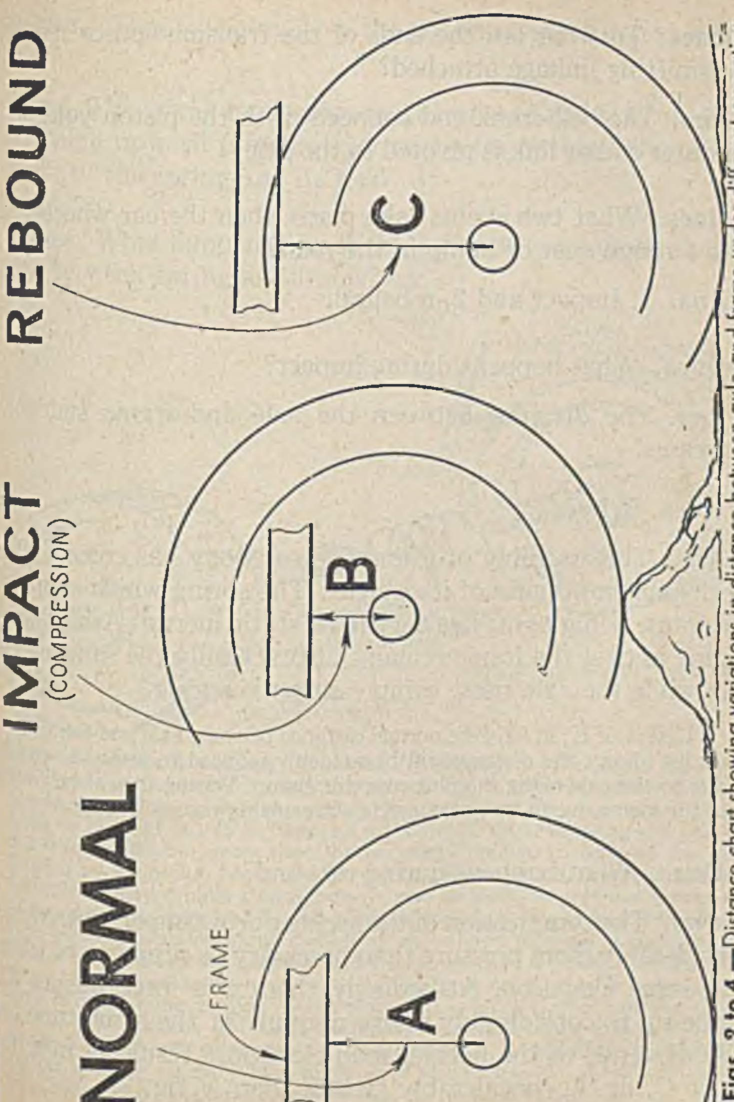
Fig. 1.—Elementary **single acting** hydraulic shock absorber.

The cylinder and reservoir should be at all times full of liquid.

Fig. 1 shows the absorber in normal position and the mechanism with names of parts.

Ques. To what is the absorber attached?

Ans. To the car frame.



Figs. 2 to 4.—Distance chart showing variations in distance between axle and frame under different operating conditions. Fig. 1, normal; fig. 2, impact (usually called "compression"); 3, rebound.

Ques. To what are the ends of the transmission or motion transmitting linkage attached?

Ans. The bell crank end connects with the piston yoke and the outer end or link is pivoted to the axle.

Ques. What two events take place when the car wheels run over a rough spot or bump in the road?

Ans. 1, Impact and 2, rebound.

Ques. What happens during impact?

Ans. The distance between the axle and frame suddenly decreases.

Ques. Why?

Ans. The assembly of frame and car body has considerable static inertia because of its weight. The spring which supports the frame being light, has very little static inertia. Accordingly during impact the frame remains at practically the same elevation while the axle rises, compressing the spring.

That is, if K, in fig. 2 be normal distance between axle and frame, then during impact the distance will be suddenly reduced to some value as B, due to the axle rising in going over the bump. During this, the elevation of the spring due to its static inertia will remain practically normal.

Ques. What happens during rebound?

Ans. The compression of the spring during impact introduces considerably more pressure than necessary to support the frame at normal elevation. Accordingly this extra force pushes the frame up to considerably above normal. At the same time the axle descends to the normal road elevation, resulting in a distance C, fig. 4, considerably greater than A, fig. 2.

Ques. What is the result of the abnormal condition shown in fig. 4?

Ans. The frame moves downward toward the axle until the increasing upward pressure exerted by the spring balances the weight of the spring and its load.

Ques. What happens during this attempt to establish equilibrium between spring and frame?

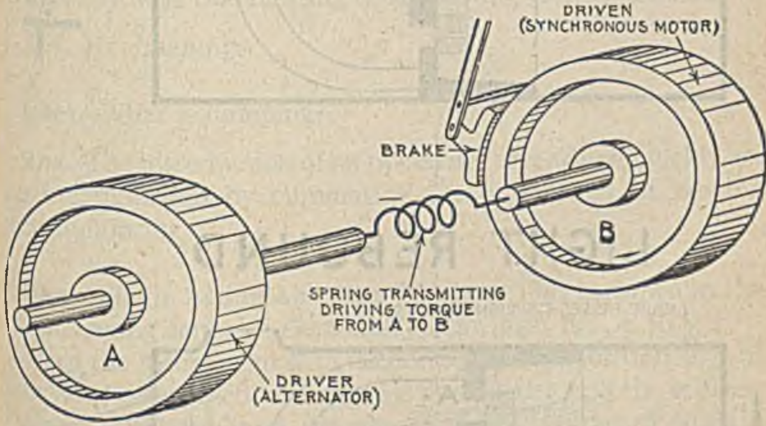
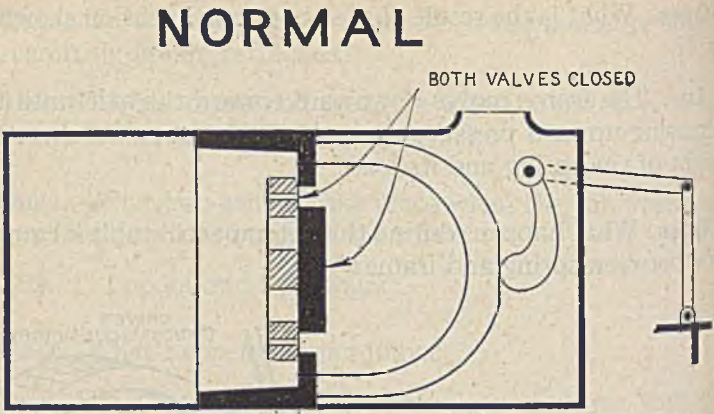


Fig. 5.—Mechanical analogy illustrating **"hunting."** The figure represents two fly wheels connected by a spring susceptible to tortion in either direction of rotation. If the wheels A, and B, be rotating at the same speed and a brake be applied, say to B, its speed will diminish and the spring will coil up, and if fairly flexible, more than the necessary amount to balance the load imposed by the brake; because when the position of proper torque is reached, B, is still rotating slightly slower than A, and an additional torque is required to overcome the inertia of B, and bring its speed up to synchronism with A. Now before the spring stops coiling up the wheels must be rotating at the same speed. When this occurs the spring has reached a position of too great torque, and therefore exerting more turning force on B, than is necessary to drive it against the brake. Accordingly B, is accelerated and the spring uncoils. The velocity of B, thus oscillates above and below that of A, when a load is put on and taken off. Owing to friction, the oscillations gradually die out and the second wheel takes up a steady speed. A similar action takes place in a synchronous motor when the load is varied.



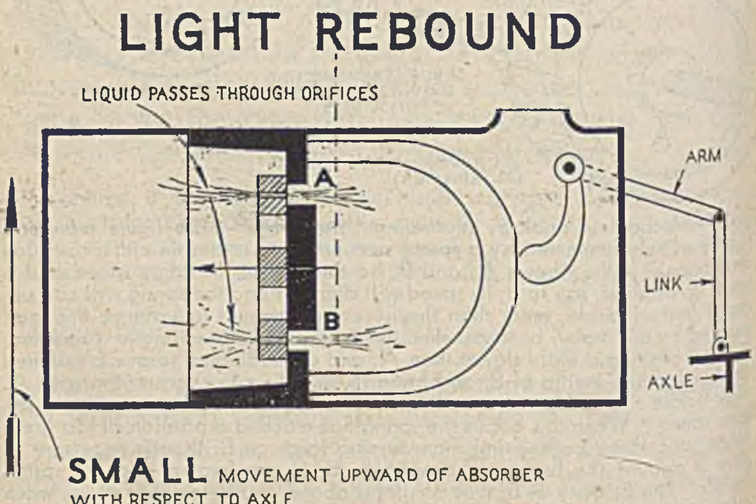


Fig. 6.—Single acting absorber operation 1. Normal.

Fig. 7.—Single acting absorber operation 2. Light rebound.

Ans. A disagreeable bouncing up and down takes place known as *hunting.*

Ques. What is hunting?

Ans. The abortive attempt to restore equilibrium between moving members of a mechanism resulting in reversible movements either too great or too little; "see-sawing."

Ques. How is this hunting or see-sawing greatly reduced?

Ans. By *damping.*

Ques. What is damping?

Ans. The introduction of an opposing force which quickly restores equilibrium by eliminating the oscillations of moving parts in hunting.

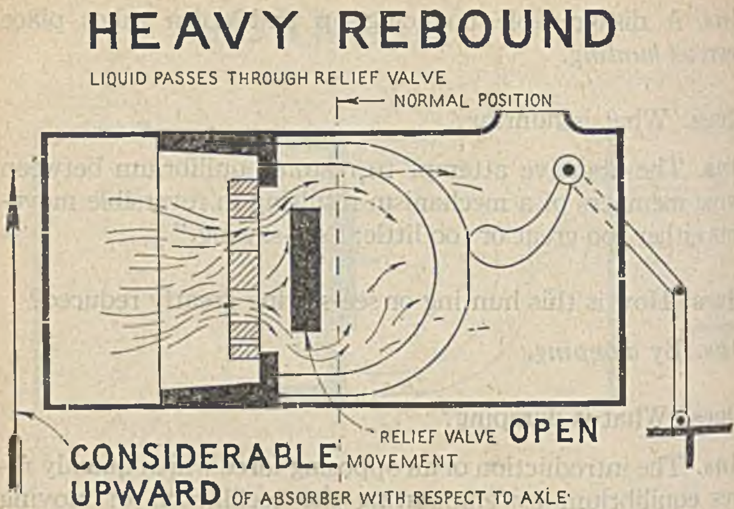
How a Single Acting Absorber Works.—This is shown in the accompanying series of elementary drawings, figs. 6 to 9.

When the mechanism is in its normal at rest position (fig. 6) both valves are closed, and there is no flow through the orifices. During a **light rebound** the absorber moves upward slightly with respect to the axle.*

This permits the absorber arm to move downward in relation to the absorber.

The movement of the arm is transmitted through the bell crank to the piston. This causes the piston to move toward the end of the cylinder (right

*NOTE.—As explained many times before by the author, motion is nothing but a *relative matter*, that is, in order that there be motion something must be regarded as being stationary. For simplicity in explaining the action, figs. 6 to 9, *the axle is regarded as being stationary*. Of course in actual operation such is not the case as both the absorber and axle are continually moving up and down referred to a certain elevation or horizontal axis as being *fixed*.



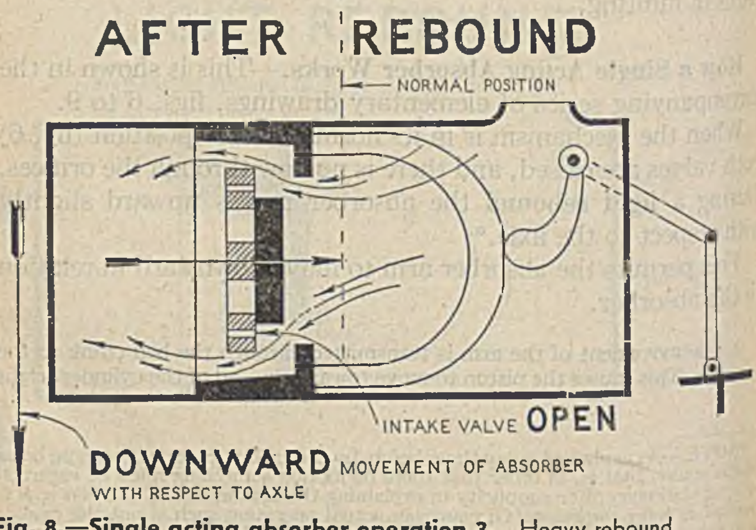


Fig. 8.—Single acting absorber operation 3. Heavy rebound.
Fig. 9.—Single acting absorber operation 4. After rebound.

to left in fig. 7). The resulting oil pressure built up against the advancing piston causing some of the liquid to flow out through the orifices as indicated at **A** and **B.** The oil pressure in the piston opposes the downward movement of the arm, the opposition being transmitted to the axle through the link. This opposes the downward movement of the absorber which is attached to the car frame, thus reducing the amount of rebound and contributing to smooth riding.

During a **heavy rebound** as in fig. 8, the same relative movements take place as with a light rebound, but more sudden and extended.

The absorber which is attached to the car frame moves quickly upward (with respect to the axle) and transmits an equally quick motion to the transmitting gear (link, arm, bell crank and piston). The point to be noted here is that the piston moves so quickly (to the left) that the liquid has not time to escape through the orifices but the excess pressure opens the relief valve overcoming its stiff pressure. The liquid then passes through the port opening of the relief valve as indicated by the arrows in fig. 8, the port opening being sufficient to permit proper flow without introducing too much pressure on the piston.

Ques. How is the moving resistance of the absorber controlled?

Ans. By the strength of the relief valve spring.

The strength of the relief valve spring is predetermined by considerable research and should be such as to harmonize with the characteristics of the various cars.

Ques. What happens in cold weather?

Ans. The liquid becomes more dense with result that the maximum pressure is built up sooner, causing the relief valve to open earlier and wider.

This automatically takes care of viscosity changes in the liquid due to temperature changes.

Ques. What happens at the completion of a rebound movement?

Ans. Fig. 9 shows the relative position of parts, after a rebound movement—that is, coming down to normal.

Always remember that the car frame and body being rigidly attached to the absorber move with it. After a rebound the absorber moves downward with respect to the axle, as in fig. 9. This causes the arm to move upward with respect to the absorber releasing pressure on the piston. At this release, the strong piston spring forces the piston from left to right as indicated by the arrow in fig. 9. The vacuum thus created causes atmospheric pressure on the liquid in the reservoir to force open the intake valve. This allows liquid to flow from the reservoir into the cylinder as indicated by the flow away.

Ques. What should be noted in figs. 8 and 9?

Ans. Absorber movements are in opposite directions. Instead of the relief valve opening, it stays closed and the intake valve opens.

Ques. What is the defect of single acting absorbers?

Ans. They act to dampen rebound only.

Elementary Double Acting Hydraulic Shock Absorbers.—As just stated in answer to the last question, a single acting absorber takes care of rebound only. Of course by changing the relative placement of parts it could be made to respond to impact instead of rebound. However, for most efficient action, the construction should be such that the absorber will dampen both.

1. Impact and
2. Rebound

This is accomplished by making the absorber double acting. An elementary double acting absorber is shown in fig. 10.

DOUBLE ACTING

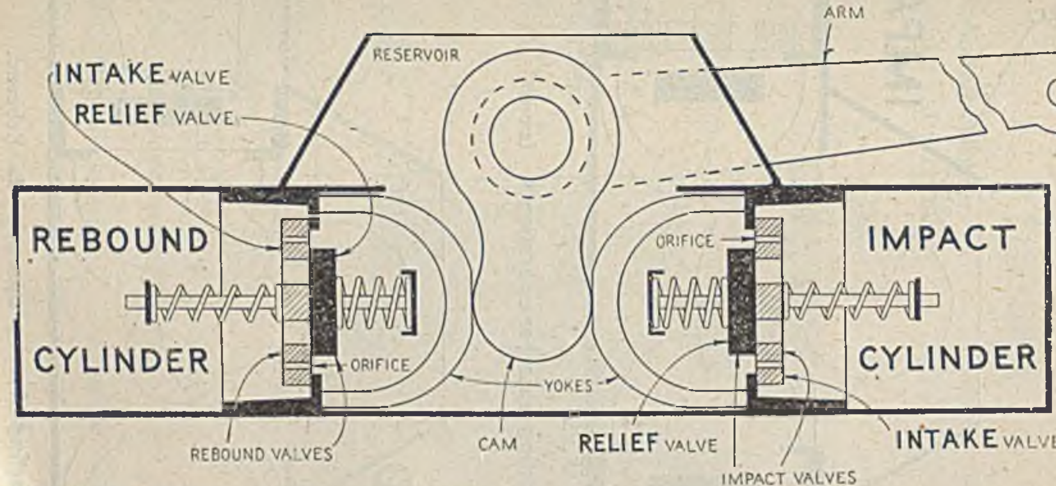


Fig. 10.—Elementary double acting hydraulic shock absorber. Compare with fig. 1.

By comparing this with fig. 1, it will be seen that the double acting absorber is simply two opposing single acting cylinders with identical mechanism. The yokes face each other and contact with a cam. The operation of the double acting absorber for impact and rebound is shown in figs. 11 and 12. The positions of the valves for these operations are plainly shown in the drawings.

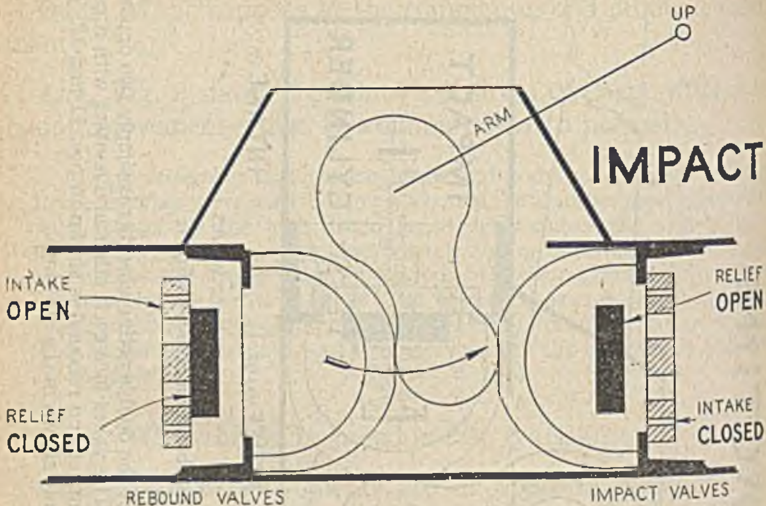


Fig. 11.—Double acting absorber operation 1. Impact.

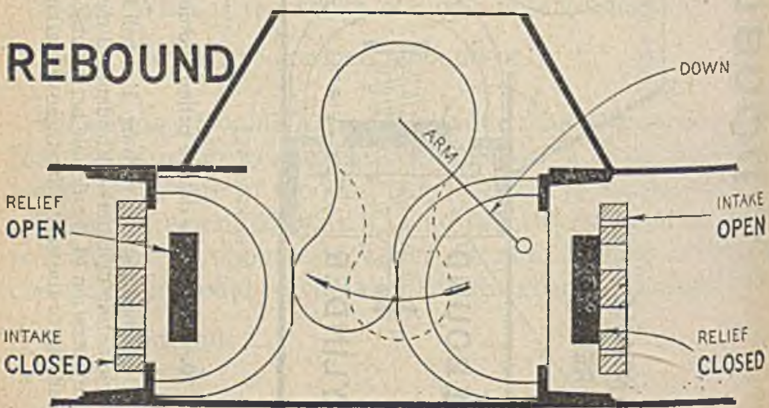


Fig. 12.—Double acting absorber operation 2. Rebound.

The cycle of operations may be tabulated as follows:

Impact

Rebound cylinder	**Impact cylinder**
Intake valve open	Intake valve closed

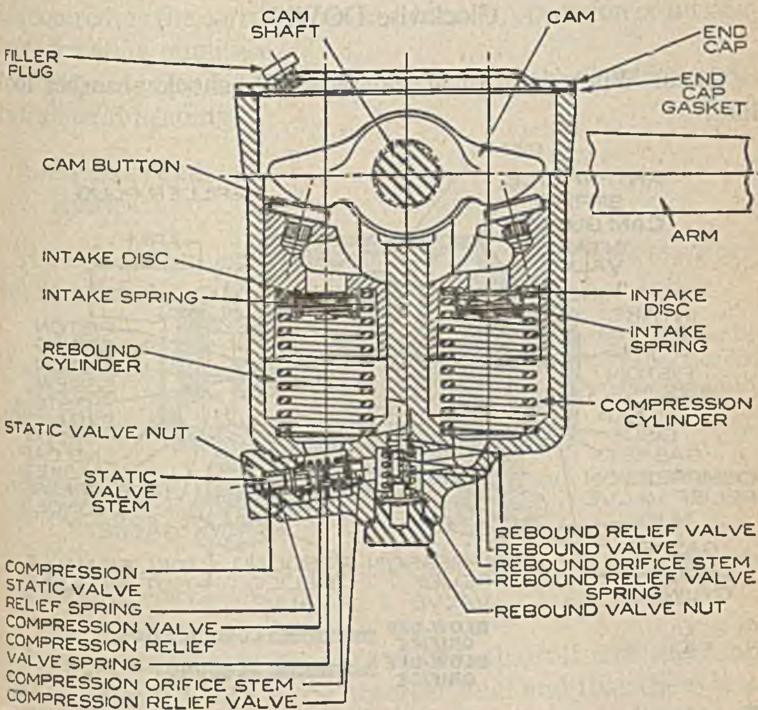


Fig. 13.—Rear absorber showing construction.

Relief valve closed	Relief valve open

Cam arm movement.

Counter-clockwise UP.

Rebound

Intake valve closed	Intake valve open
Relief valve open	Relief valve closed

Cam arm movement.

Clockwise DOWN.

Ques. What does an actual hydraulic shock absorber look like?

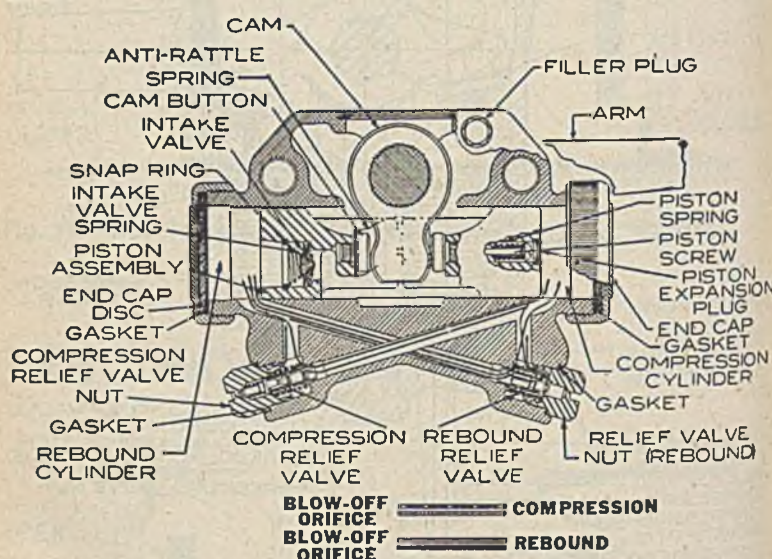


Fig. 14.—Another type rear absorber showing construction.

Ans. Some of the leading absorbers are shown in the accompanying illustrations.

Note difference in design for front and rear absorbers.

Shock Absorber Service

The following hints while mostly general, refer especially to the absorber shown in the accompanying illustrations.

The only service ordinarily required by the shock absorbers, aside from periodic checking of the liquid level and adding fluid as required, is the correction of either noisy operation or unsatisfactory riding qualities.

Noise occurring in the shock absorbers may be classified under two general headings:

1. Squeaks and
2. Rattles

High pitched squeaks from the interior of the shock absorbers are invariably due to the valves.

In such cases, the car should be rocked sharply to determine whether the squeak occurs on rebound or compression. The valve cap over the offending valve should then be removed and the valve rotated 90° on its seat. If the noise still persist, the valve should be replaced.

Rattles in the shock absorbers are usually due to looseness in the shock absorbers or in the linkage.

In such cases, check and tighten the entire shock absorber linkage—use a wrench at every point.

It is also important to make certain that all four shock absorbers are filled with shock absorber fluid and that there is no air in the cylinders or passages.

In some cases it may be necessary to bleed all four shock absorbers to get all of the air out of the cylinders and passages.

To do this properly, make sure that the shock absorber is correctly mounted and thoroughly tightened to the car frame, then remove the filler plug and fill with shock absorber fluid. Reinstall the plug securely and with the link disconnected, move the shock absorber arm up and down several times the full length of its travel.

This operation of adding fluid, reinstalling the plug and working the arm should be repeated until all of the air is worked out of the shock absorber.

This may take three or four operations. The shock absorber is satisfactorily bled when no more fluid can be added after working the arm in the

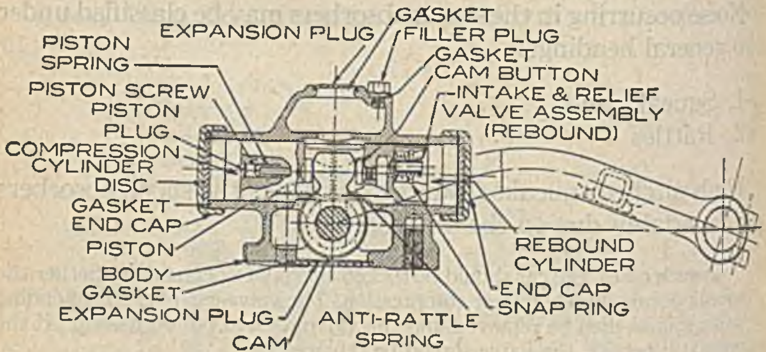


Fig. 15.—Front absorber showing construction.

manner just described. Always have the filler plug tightly in place when moving the arm, otherwise more air will be drawn into the fluid.

In cases of unsatisfactory riding, not due simply to lack of lubrication, correction can ordinarily be made by putting the shock absorbers in good operating condition.

Unsatisfactory riding may be caused by insufficient absorber fluid or dirt in the fluid. The first thing to be done is to check the level of the fluid in the shock absorbers. Insufficient fluid can be corrected by careful bleeding and refilling as previously described.

Only after it is known that all shock absorbers contain the proper amount of fluid should any other tests be made to determine the cause of unsatisfactory riding qualities.

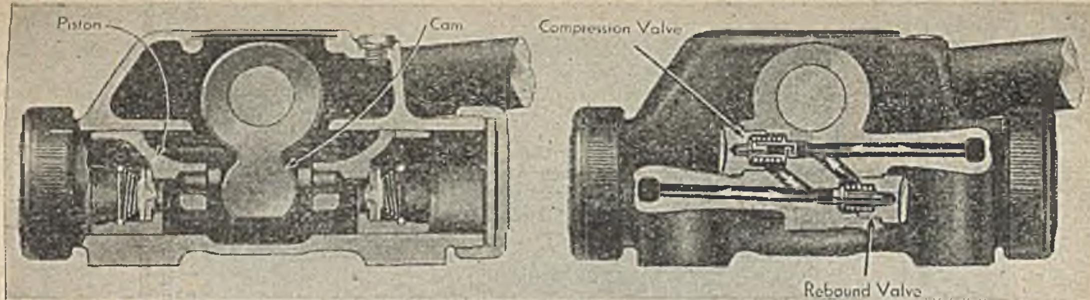


Fig. 16.—Shock absorber details to accompanying service hints.

Dirt in the shock absorber fluid may cause unsatisfactory operation by causing the valves to stick.

In such cases, the difficulty can usually be recognized by moving the shock absorber arm up and down. The presence of dirt on the valves will be indicated by the lack of resistance in one or both directions. In case dirt be present, the shock absorber should be removed, thoroughly cleaned and blown out with air, and refilled with clean shock absorber fluid.

Removal Disassembly and Installations.—The instructions here given refer especially to the type absorber shown in fig. 17.

1. Remove nuts and slide the shock absorbers off the pins.

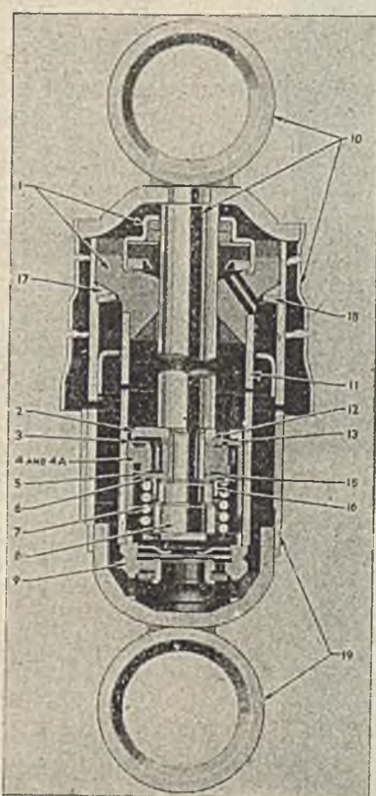


Fig. 17.—Shock absorber. **The parts are:** 1, piston rod; 2, seal; 3, piston rod guide rubber gasket; 4, piston; 5, compression valve; 6, filler plug; 7, dust seal tube; 8, piston rod guide; 9, reservoir tube; 10, cylinder tube.

The front shock absorbers, right and left, are identical. This is also true of the rear. The rear shock absorbers can be readily identified from their outward appearance as they have a protective piece of metal welded to the lower end of the housing. The shock absorbers should be assembled so that this protective piece faces toward the front of the car.

When installing, the wedge shaped rubber bushings should be placed between the pins and loop ends of the shock absorbers with the cup shaped washers at the outer ends of the bushings, the convex side being next to the bushing.

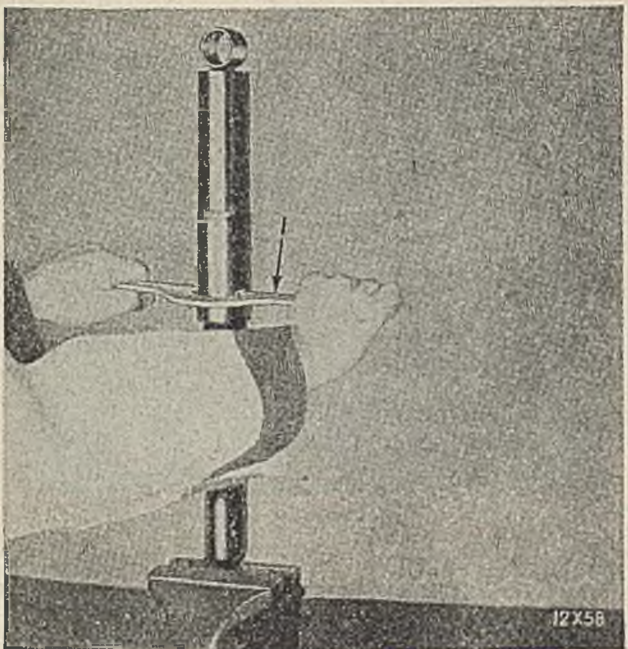


Fig. 18.—Disassembly shock absorber tubes. Tool MT 101.

Never use oil or grease on the rubber bushings.

To disassemble, after removal:

1. Remove drain plug and pump piston back and forth until all liquid is out.

2. Wash all external dirt.

3. Grip the lower eye of the shock absorber in a vise as shown in fig. 18.

4. Insert the prongs of the spanner wrench, 1, fig. 19, through the opening in the outer dust shield tube and engage with the notches in the piston cylinder.

Unscrew the cylinder from the reservoir tube, thereby separating the two ends of the unit.

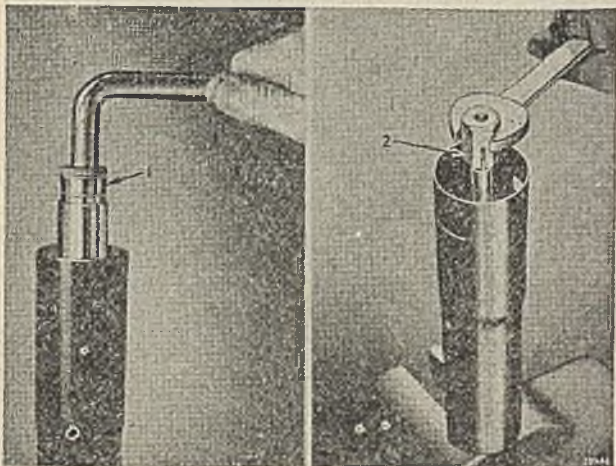


Fig. 19.—Removing nut from piston rod and recutting the threads. 1, thin shell socket wrench; 2, tool C 492.

5: Remove and discard the gasket from the threaded end of the reservoir tube.

Always use new gaskets and seals when installing.

6. Remove the compression valve from tube by light taps on side of hex.

7. Place compression valve on bench and place tool over washer straddling stem, then press down on the tool and push washer from under the head of the stem.

Never grip the pressure tube in a vise or handle in any manner that would cause the tube to be compressed together as this will cause binding of the piston.

8. Remove nut from end of piston rod, and all parts of the rebound valve will slide off the piston rod.

9. Insert the end of tool through seal.

Then tighten wing nut and seal will move up and out.

10. Wash all parts in naphtha or similar cleaner and dry with compressed air.

11. Look for burrs or cracks in all of the flat parts of the valves.

Fig. 20.—Thimble used to prevent damage to seal. 1, piston rod guide; 2, thimble MT 178.

All of the parts, except the star spring of the rebound valve, should be perfectly flat.

12. Check the outside diameter of the piston and if worn more than .003 in. out of round, replace.

Assembly is made in the reverse order except that the thimble (see fig. 20) should be placed over the end of the piston rod to prevent damage to the oil seal, and the hex nut which completes the assembly of the rebound parts to the piston rod should be tightened with a twenty pound pull at the end of wrench handle 5 in. long and stake. The seal must press evenly against the gasket,

To Refill:

1. Clamp eye, at drain plug end, in vise with drain plug hole up and shock absorber extended down at a 45° angle.

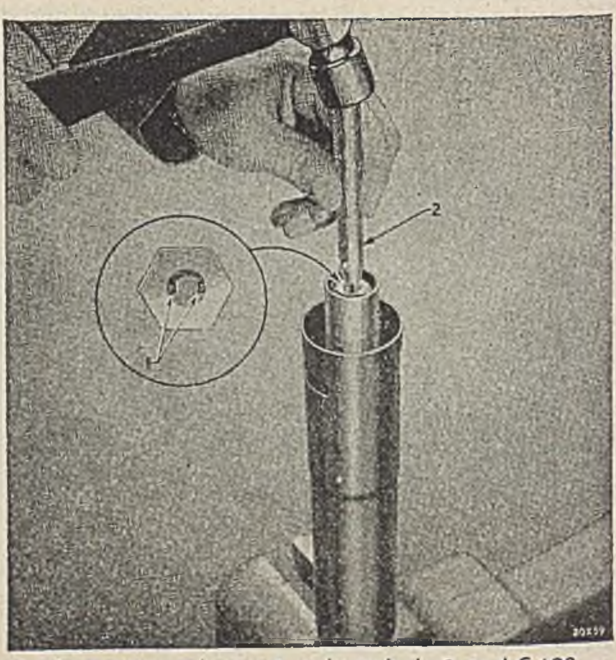


Fig. 21.—Locking piston rod nut. 1, stake to lock; 2, tool C 192.

2. Insert filler cup into hole.

3. Close shut-off valve and pour 6⅝ oz. of liquid in cup for cars with standard wheel equipment or 7¼ oz. for cars with 20 in. wheel equipment.

4. Open shut-off valve and pull shock absorber out to fully extended position.

This will draw part of the liquid into the shock absorber. Work piston back and forth using quick strokes until all fluid is worked into shock absorber.

5. Remove filler cup and replace plug.

6. Operate shock absorber in an upright position to work out any air that may remain in cylinder.

If shock absorbers have not been disassembled for some other purpose make certain that all fluid has been pumped out before adding more.

MAINTENANCE OF SHOCK ABSORBERS

1. It is of extreme importance that the shock absorbers be refilled with the exact quantity of liquid.

2. The thin valve parts, with the exception of the star washers, must be perfectly flat and free from nicks or burrs.

3. All parts must be clean. Use naphtha or similar cleaner for washing parts.

4. Always use new liquid.

5. Always use new seals when assembling shock absorbers.

6. Install rear shock absorbers with the stone shields toward the front of the car.

7. When investigating for noise first make certain the noise is coming from the shock absorber. If there be doubt, try a unit from another vehicle.

8. See that the shock absorbers are tightly assembled, large tube uppermost, to the vehicle and not striking the frame or other parts of the body.

The stone shield on the lower tube and the lettering on the upper tube of the rear shock absorbers must be toward the front of the car to prevent damage by stones.

9. Check rubber mounting bushings and replace if worn.

CAUTION.—Never use anything but approved shock absorber liquid which is obtainable through the Factory Service Parts Department of the car being serviced.

CHAPTER 41

Hydraulic Presses

By definition, a hydraulic press is: *A machine for exerting great pressure, deriving its power from a hydraulic plunger, commonly called a "ram".**

The power is transmitted through a fluid confined and under pressure. The hydraulic press is virtually a "hydraulic lever" peculiarly adapted for exerting tremendous leverage.

Ques. What is the basic principle upon which the operation of hydraulic presses depends?

Ans. Upon Pascal's law.

Pascal's Law.—It was discovered in 1653 by Vlaise Pascal, famous French scientist, mathematician and philosopher, that fluid when confined and subjected to pressure follows a definite law which may be thus stated: *Pressure applied anywhere to a body of confined liquid is transmitted by the liquid so as to act with undiminished force on every square inch of the containing vessel.*

*NOTE.—The hydraulic press was invented in 1795 by an Englishman named Joseph Brahmah who together with Mandslay laid the foundation for the development of metal cutting tools.

Thus in fig. 1, consider two square pistons working in square cylinders. Let the area of the small piston be 1 sq. in. and that of the large piston be 16 sq. ins. Now, if the system below the pistons be filled with a liquid and a pressure of 1 lb. be applied to the small piston, the liquid will according to Pascal's law transmit a pressure of 1 lb. to each square inch of the large piston, that is 16 lbs. Accordingly the 1 lb. pressure

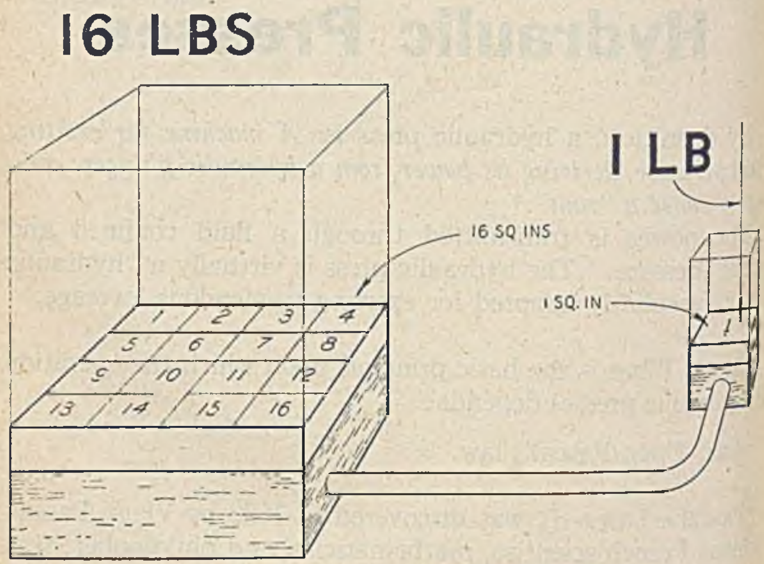


Fig. 1.—Elementary diagram illustrating Pascal's law.

NOTE.—**Pascal's statement.** In the middle of the 16th Century Pascal made the following statement: "If a vessel full of water and closed on all sides has two openings, the one a hundred times as large as the other, and if each be supplied with a piston which fits it exactly, then a man pushing the small piston will exert a force which will equal that of one hundred men pushing the large piston, and will overcome that of ninety-nine."

NOTE.—**Joseph Brahmah.** After Pascal, it remained for an Englishman named Joseph Brahmah to discover how to make the pistons "fit the openings exactly"; he discovered the cup packing in 1785 or 1796, according to what authority you accept. This discovery resulted in the immediate use of Brahmah's hydraulic press" for various purposes requiring large forces.

exerted on the small piston has been multiplied 16 times, or in proportion to the *ratio* of the piston areas.

Although the pressure may be multiplied any number of times by changing the ratio of piston areas, a second law states: *For a given movement of the small piston, the movement of the large piston is decreased as much as the pressure is increased.*

That is, if in fig. 1 the small piston move downward a distance of one inch, the large piston will move upward only $\frac{1}{16}$ inch.

The hydraulic system in fig. 1 may be compared to the familiar lever scales with fulcrum located as in fig. 2. It will be seen from the principle of moments that the system is in equilibrium—in other words, in balance.

Ques. What is the principle of moments?

Ans. When two or more forces act upon a rigid body and tend to turn it about an axis, then equilibrium will exist if the sum of the moments of the forces which tend to turn the body in one direction, equals the sum of the moments of those which tend to turn it in the **opposite direction** *about the same axis.*

Rule.—*A force* **P**, *multiplied by its distance from the fulcrum is equal to the load* **W**, *multiplied by its distance from the fulcrum.* That is:

$$F \times f = L \times l \qquad (1)$$

in which

F = force

f = distance of force from fulcrum

L = load

l = distance of load from fulcrum

Example.—What force in lbs. at a distance of one foot from the fulcrum is required to balance a load of 16 lbs. at a distance of $\frac{1}{16}$ foot from the fulcrum?

Substituting in equation (1)

$$F \times 1 = 16 \times 1/16$$

from which

$$F = \frac{16 \times 1/16}{1} = 1 \text{ lb.}$$

Compare this with fig. 2.

Uses of Hydraulic Presses.—From the foregoing and the application of Pascal's law, it is seen that the hydraulic press is adapted to applications where the development of a tremendous

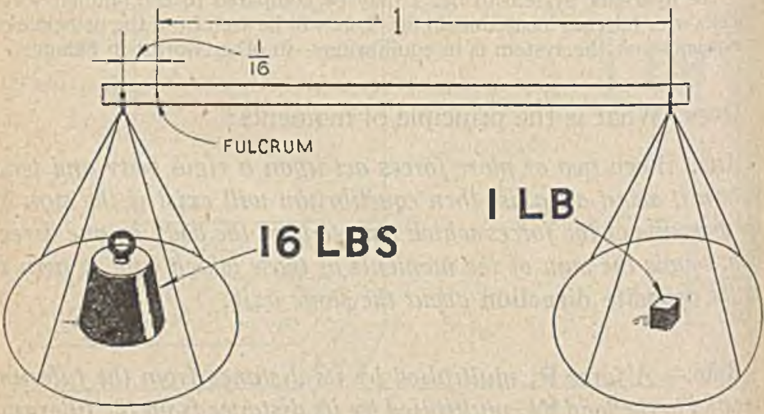


Fig. 2.—Lever analogy of the hydraulic system shown in fig. 1. It depends upon the **principle of moments.**

force exerted through a short distance is desired. This being easily obtained by the application of a very small force exerted through a proportionately longer distance.

Hydraulic presses are used for many classes of work requiring pressures ranging from a few hundred pounds up to 15,000 tons.

Ques. What is the special applications of hydraulic presses?

Ans. Applications requiring tremendous pressures rather than small or medium pressures.

Ques. Name some of the applications of hydraulic presses.

Ans. There are numerous uses such as, die sinking, embossing, cupping and drawing metal blanks, forging hot billets, piercing shells, drawing and pushing rods, bending and straightening, shaping sheet metal parts, etc., etc.

Classification.—There are numerous types of presses which have been developed to meet the many and varied applications such as outlined in the answer to the last question. They may be classed:

1. With respect to setting design, as
   - *a*. Vertical
   - *b*. Horizontal
2. With respect to cylinder position, as
   - *a*. Plain
   - *b*. Inverted
3. With respect to ram, as
   - *a*. Self contained
   - *b*. Jack
4. With respect to pull back, as
   - *a*. Rack and pinion
   - *b*. Hydraulic
   - *c*. Weighted
5. With respect to the cylinders, as
   - *a*. Single

b. Multi-
c. Opposed
d. Single acting
e. Double acting

6. With respect to the frame, as

a. Tie rod
b. Gap
c. Open jaw

7. With respect to service, as

a. Flanging
b. Sectioned flanging
c. Flanging and drawing
d. Plate bending { horizontal / vertical }
e. Drawing { single / double acting }
f. Three ram forming
g. Upsetting
h. Joggling
i. Scarfing
j. Forging and trimming
k. Side rail
l. Pull and push
m. Forcing or bushing { vertical / horizontal }
n. Wheel
o. Crank pin
p. Laboratory
q. Pipe
r. Straightening

s. Bending (bulldozer)

t. Pipe bending

u. Beam bending

v. General service

w. Billet shear
- single power
- quadruple power

w. Shears
- plate
- angle

x. Hole punch
- split stake
- forged stake

y. Riveter
- single power
- multiple power
- portable
- hinged

  - split stake
  - forged stake

z. Spring
- stuffing
- banding (banding and stripping)
- tester
- band forming

etc.

The service classification just itemized will give an idea of the countless number of applications for hydraulic presses.

Plain or Direct Hydraulic Press.—The essentials of a press of this type are shown in the elementary drawing fig. 3.

The press has a movable platen A, and a stationary platen B. The latter is joined by the rods E, to lugs F and F′ forming part of the cylinder casting D. Working in the cylinder is a ram or plunger C, which passes through the stuffing box at the upper end of the cylinder and carries the movable platon A.

Under hydraulic power the ram rises and brings tremendous pressure upon any material placed between the two platens.

Ques. What causes the plunger to return after its working stroke?

Ans. When the release valve is opened the weight of the plunger and platen causes the assembly to return by gravity although opposed by the resistance of the stuffing box packing.

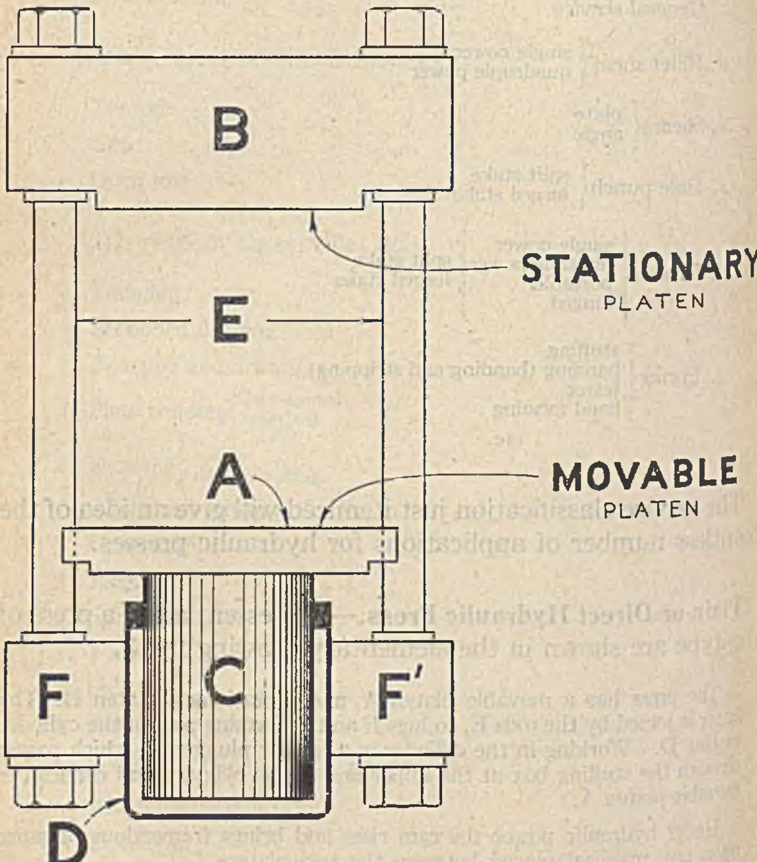


Fig. 3.—Elementary direct or plain hydraulic press. The essential parts are: **A,** movable platen; **B,** top stationary platen sometimes called head; **C,** plunger or "ram"; **D,** cylinder; **E,** columns; **F, F′;** lugs or extensions into which the columns are attached.

Fig. 4 shows a small plain or direct press designed for laboratory work, having a four column frame, movable and stationary platons. This unit is complete in itself having the hand operated hydraulic press on the side on same base. A larger press with lower movable platen is shown in fig. 5.

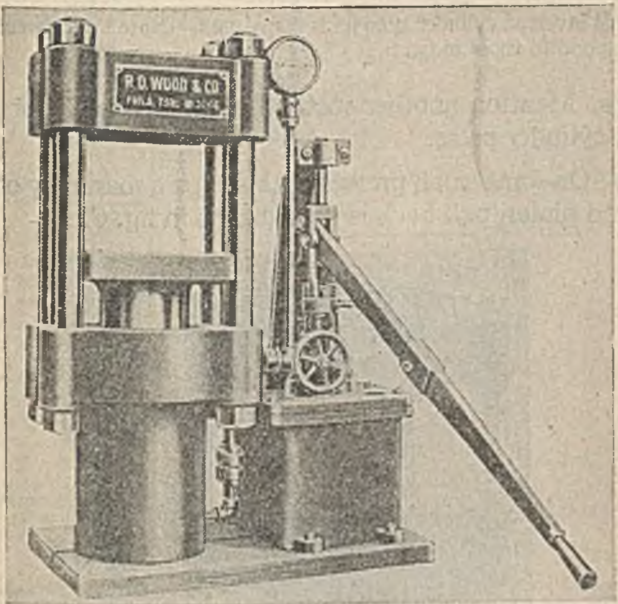


Fig. 4.—Laboratory plain or direct press. This illustration shows a vertical press of 100 tons capacity supplied with double plunger pump and water tank. It is particularly designed for experimental, testing and laboratory work, being fitted up complete with operating valve, piping, and test gauge graduated in pounds per sq. in. as well as tons exerted upon the work. The press has a table 12½ ins. square; the ram is 8 ins. in diameter by 12 in. stroke.

Inverted Hydraulic Press.—This type of press differs essentially from the direct press just described in 1, the position of the cylinder, and 2, means for returning the ram and platen to initial position after a pressure application.

Whereas no mechanical pressure was necessary for the direct press as gravity does the work, it is different when the cylinder is inverted as here gravity acts on the ram and platen to move these parts downward.

To overcome this and provide a force acting to pull the ram and platen back to the top position, counter or return weights are provided as shown in fig. 8.

This inverted cylinder type finds many uses. Note the reference letters correspond to those in fig. 3.

Ques. Mention another method of "pull back" for the inverted cylinder press.

Ans. On some small presses of this type a manually operated rack and pinion pull back is provided as in fig. 6.

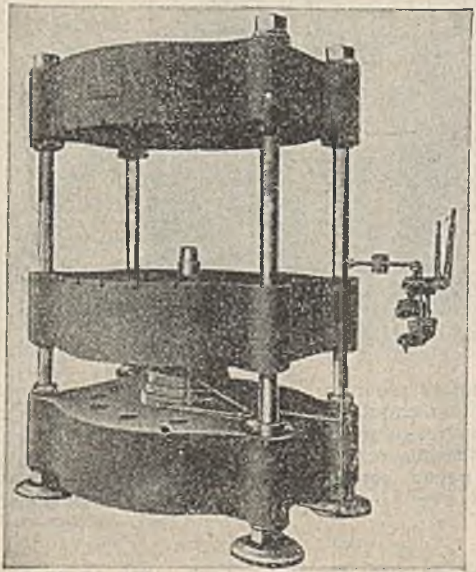


Fig. 5.—Hydraulic 300 ton four column flanging press. This machine is of the up working type and has 8 ft. by 4 ft. clear distance between the columns. The single main ram carries an internal clamping ram. This press is built in various sizes and capacities with circular or rectangular top and moving platens.

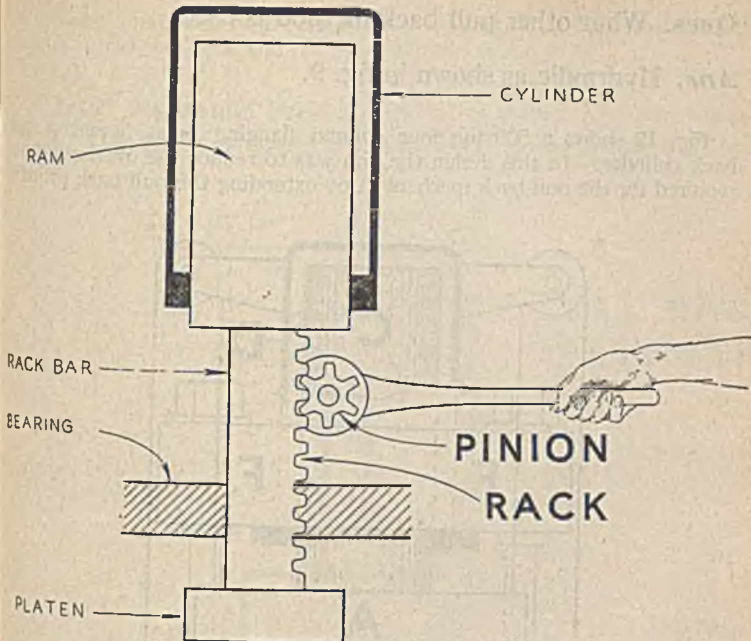


Fig. 6.—Elementary small inverted hydraulic press with rack and pinion pull back.

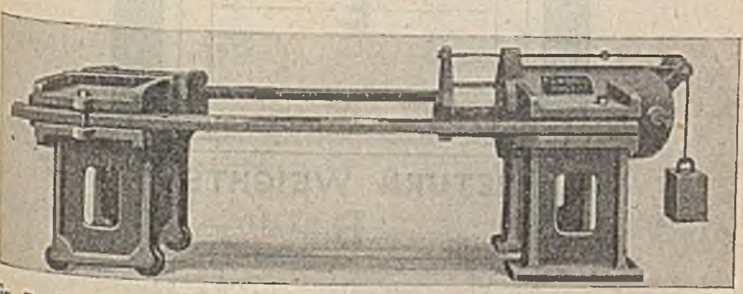


Fig. 7.—Hydraulic horizontal forcing press. It has an adjustable resistance beam. Hydraulic power may be supplied by hand or power pump or from an existing hydraulic pressure line.

Ques. What other pull back method is used.

Ans. Hydraulic as shown in fig. 9.

Fig. 10 shows a 500 ton four column flanging press having a pull back cylinder. In this design the aim was to reduce the overhead room required for the pull back mechanism by extending the pull back cylinder

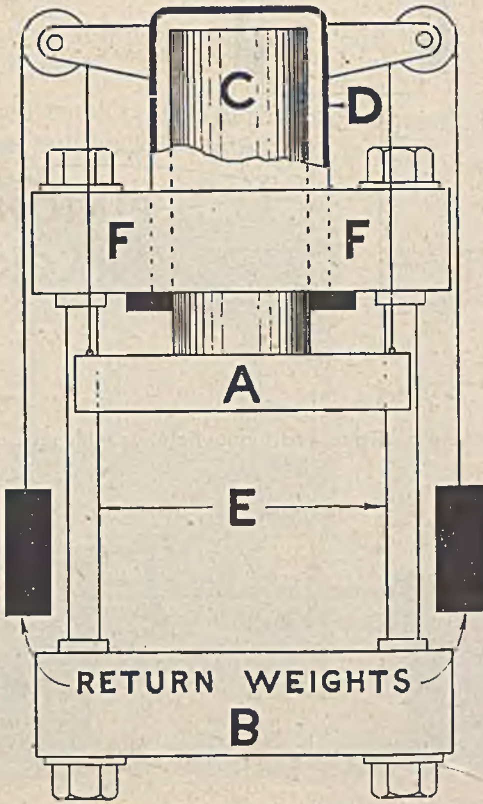


Fig. 8.—Elementary inverted hydraulic press. The parts are lettered to correspond to the letters in fig. 3.

into the cored main ram. Note the two hydraulic pipe lines on the right, one for the pull back and the other for the main ram.

"Jack" Hydraulic Press.—This is *a kind of general purpose press*. The press proper consists simply of a frame unit with

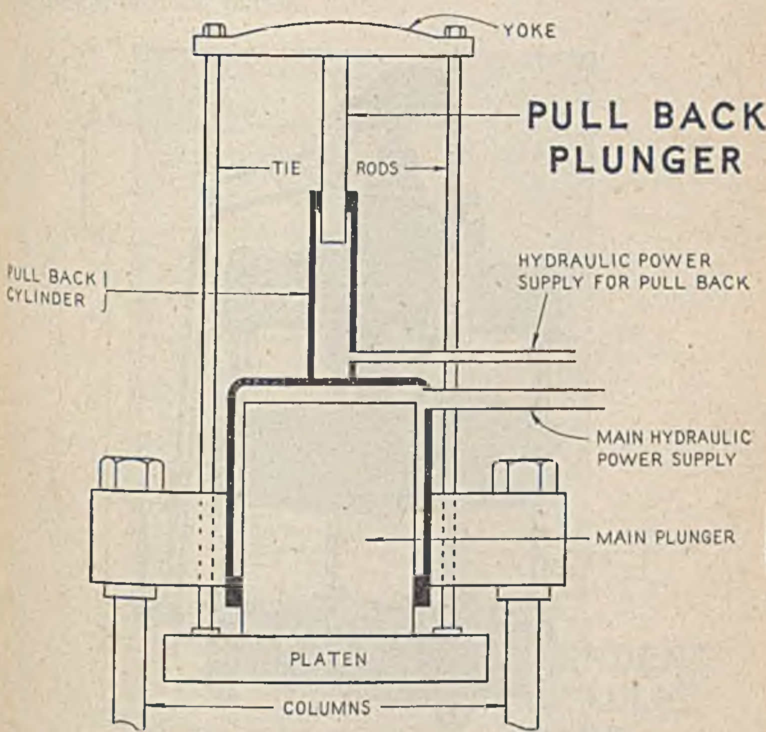


Fig. 9.—Elementary inverted hydraulic press with hydraulic pull back.

movable platen. The hydraulic feature consists of any type independent jack which may be available instead of a self contained ram.

In operation, the jack is placed on the lower platen with the movable platen resting on its ram end. By operating the jack any material placed between the movable platen and the upper platen may be compressed. The essentials of a "jack" press are shown in fig. 11.

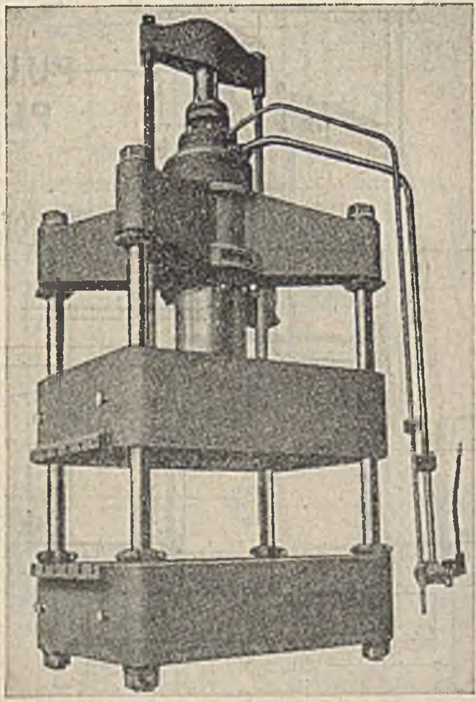


Fig. 10.—Hydraulic 500 ton four column flanging press. This machine is of the down working type, having 6 x 4 ft. clear between the columns. The pull back cylinder extends into the cored main ram, which design requires less overhead room. The pull back ram being under constant pressure, this press is operated by a single three-way operating valve. This machine is also being used for straightening purposes and is built in various sizes and capacities.

Multi-Cylinder Hydraulic Presses.—For service requiring extra large platens, where uniform pressure must be applied to the entire platen surface, multi-cylinders are used instead of a single cylinder, as in the presses already described. In the multi-cylinder press two or more rams operate together on a common moving platen.

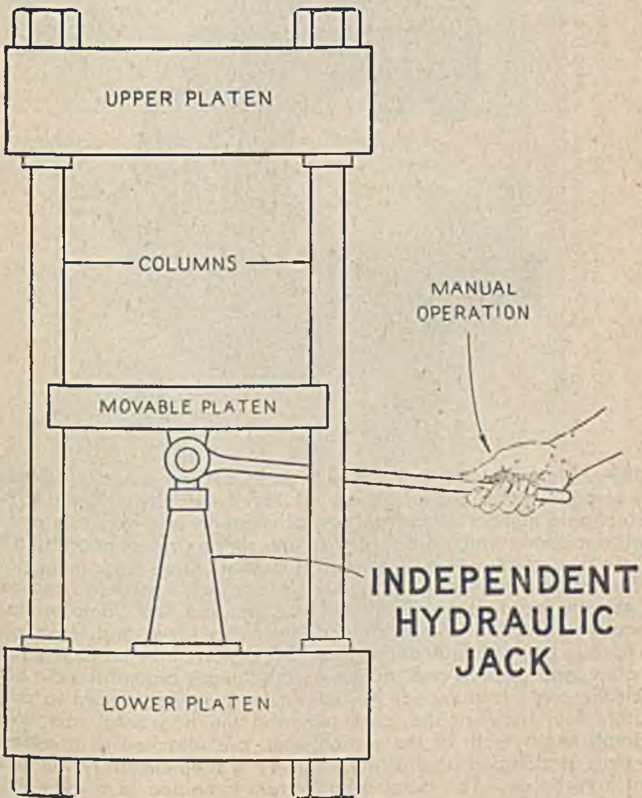


Fig. 11.—Elementary hydraulic "jack" press.

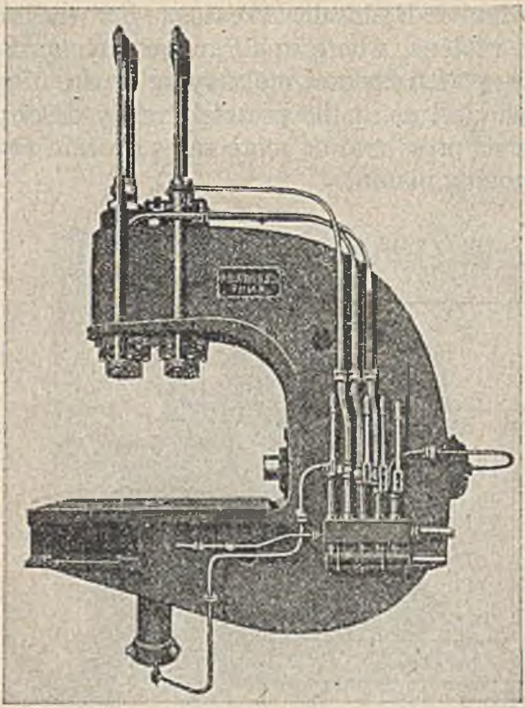
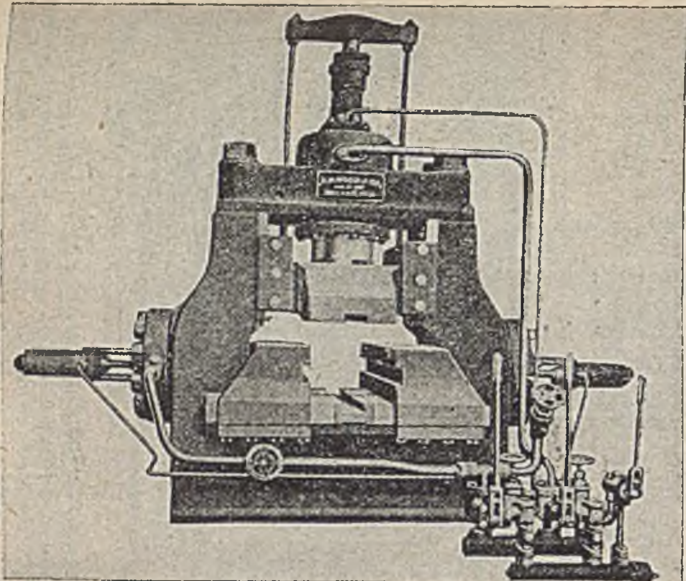


Fig. 12.—Hydraulic sectional flanging press. Except in shops where standard sizes of boiler fronts and of other work can be rigidly adhered to, enabling a reasonable number of dies to cover the range of work, it is preferable to install a machine which is adapted to any shape or dimension, and for which but few dies are required. Although it does its large work more slowly than the four column press, yet on small work for which whole dies can be carried, it is equally rapid. The outer vertical rams are used as a clamp, while the inner vertical ram, having a plow-shaped die at its lower end, turns down from two to three feet of flange at one heat. The action of the horizontal ram follows the plow, and smooths and squares up the flanges around the die block upon which the plate is clamped. An interlocking device is used to prevent any possible foul between the plow ram and the horizontal ram. When used on small heads, both of the vertical rams are attached to a male die, and the plate is clamped against the latter by a supplementary ram moving upward from below. The supplementary ram is carried in a cylinder, hung in the lower jaw of the frame, and located centrally between the two upper rams. The machine is also a useful tool for upsetting and joggling work.



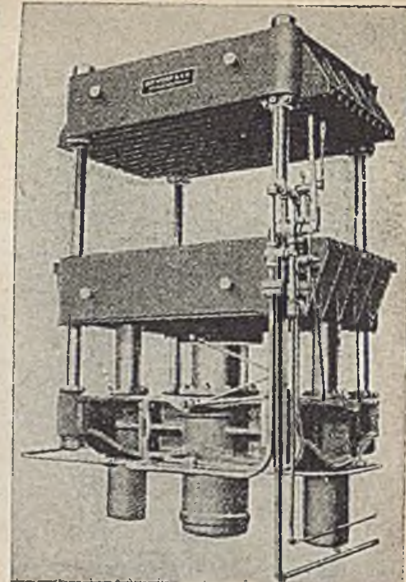


Fig. 13.—Hydraulic three ram forming press. Each ram of this press has a capacity of 300 tons and is well guided on the housing. The two horizontal rams can be operated independent of each other or in exact unison. This machine is designed for forming or bending work, such as rail chairs, frog plates, switches, etc., and also for punching and shearing.

Fig. 14.—Hydraulic 300 ton four column flanging press. This machine is of the triple power type having three main rams. The center ram has a capacity of 200 tons, and each of the two side rams a capacity of 50 tons. The valve and piping arrangement permits the operation of the press with a capacity of 100, 200 and 300 tons.

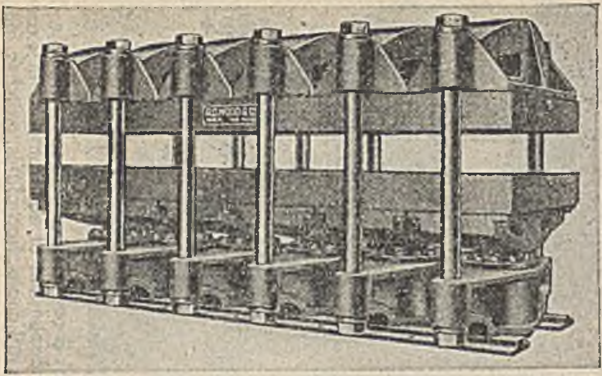


Fig. 15.—Six cylinder hydraulic steam platen press, designed for rubber mills for pressing long, flat material into shapes required. It has a capacity of 700 tons, and is fitted with two steam platens, each 4 ft. 2 ins. wide by 12 ft. long. The columns are securely fastened to the top and bottom castings.

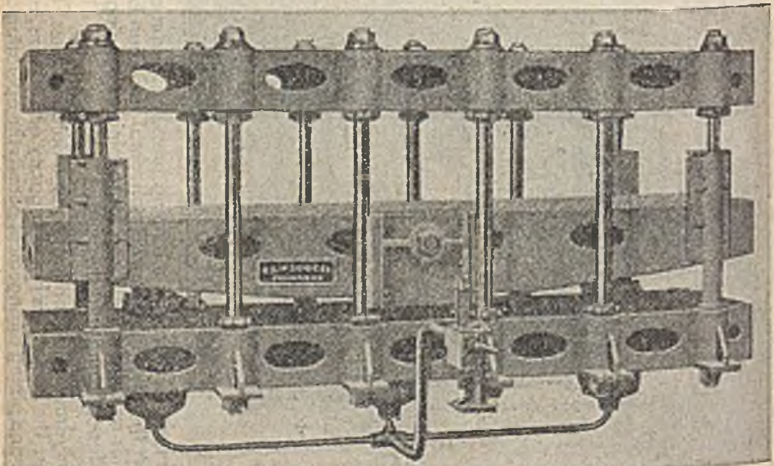


Fig. 16.—Hydraulic side rail press. It is of the three cylinder type, having a capacity of 700 tons and tables 6 ft. 6 ins. wide by 26 ft. long. This type of press is specially designed for forming side rails for automobile frames and is built in various sizes and up to 5000 tons capacity.

Ques. What provision must be made?

Ans. Provision must be made for maintaining a uniform advance of all rams.

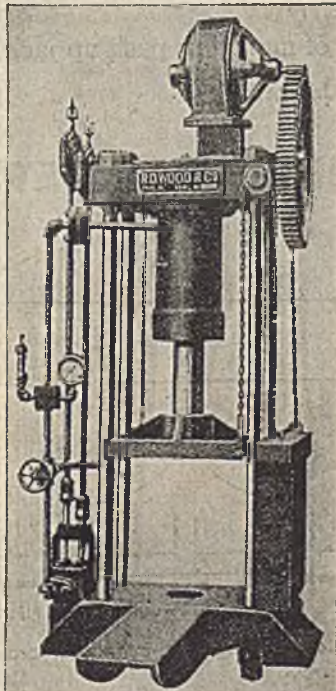


Fig. 17.—Hydraulic forcing or bushing press. This type of press is particularly designed for use in railroad shops for pressing on and off bushings and doing miscellaneous work. The press as shown is equipped with double plunger pump and counter-weighted pull back arrangement.

Ques. How is this accomplished?

Ans. By some kind of mechanical parallel motion, or hydraulically by automatic distribution of water to the different cylinders.

A multi-cylinder press having hydraulic method of maintaining uniform advance is shown in fig. 13. The appearance of a press of this type is constructed in fig. 14.

Ques. What is the method of raising rams of large size?

Ans. By the use of numerous push up jacks.

Fig. 15 illustrates this method.

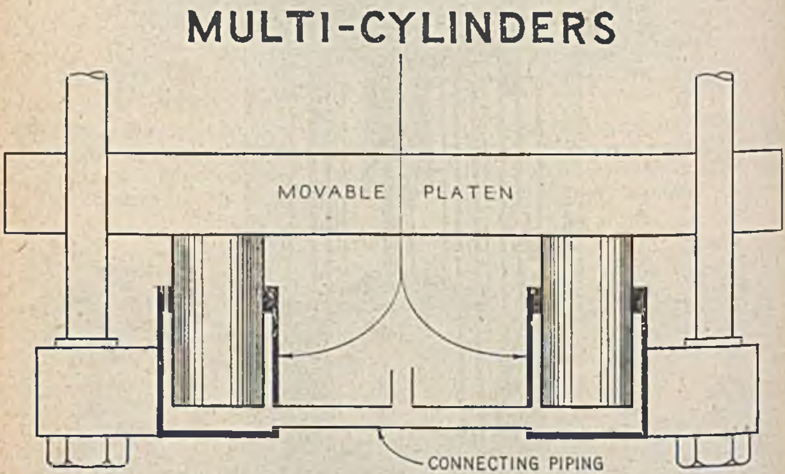
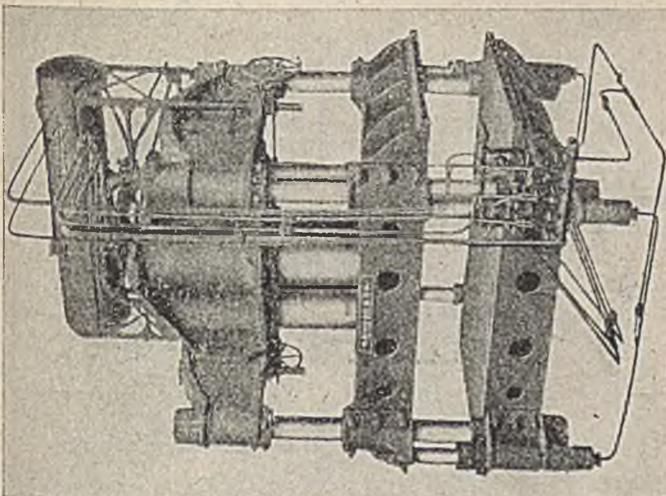


Fig. 18.—Elementary detail showing multi-cylinder hydraulic press.

Horizontal Hydraulic Presses.—There are numerous press applications in which the ram is placed in a horizontal position. These, as with the vertical types, require some pull back arrangement. However, no such powerful pull back mechanism need be employed as with the inverted vertical presses. One type horizontal press consists of two opposing rams with weighted pull backs. The weight operates through bell cranks as shown in fig. 21.



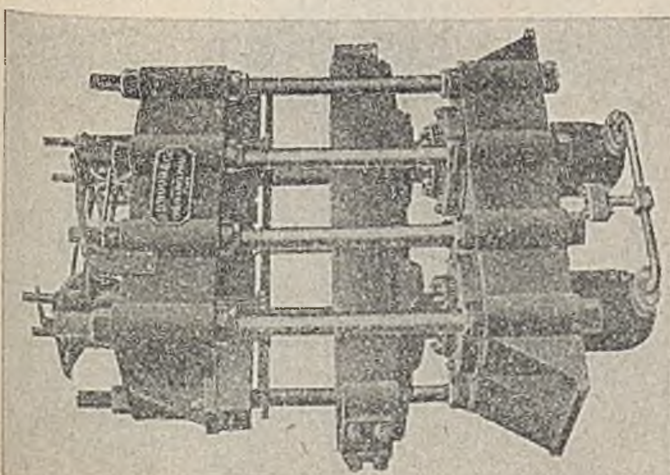


Fig. 19.—Hydraulic 1500 ton for column flanging press. This press has platens 10 x 16 ft. long and is of the triple power type with capacities of 600, 900 and 1500 tons.

Fig. 20.—Hydraulic flanging press. Illustration shows an eight column hydraulic press of the two-cylinder, up working type designed for flanging long shapes.

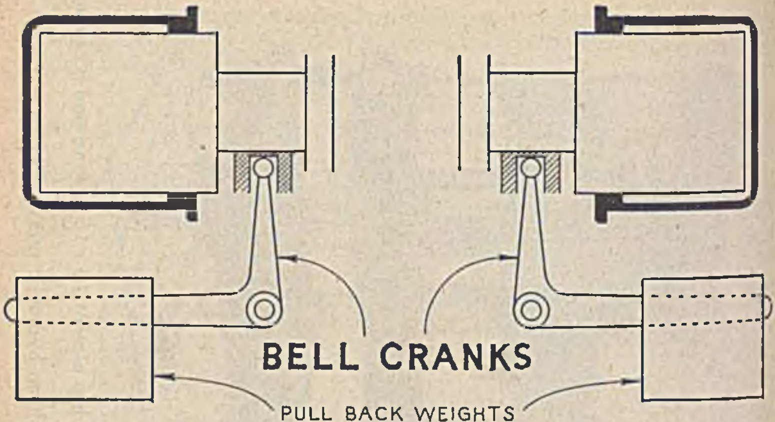


Fig. 21.—Elementary hydraulic two (opposed) cylinder horizontal press.

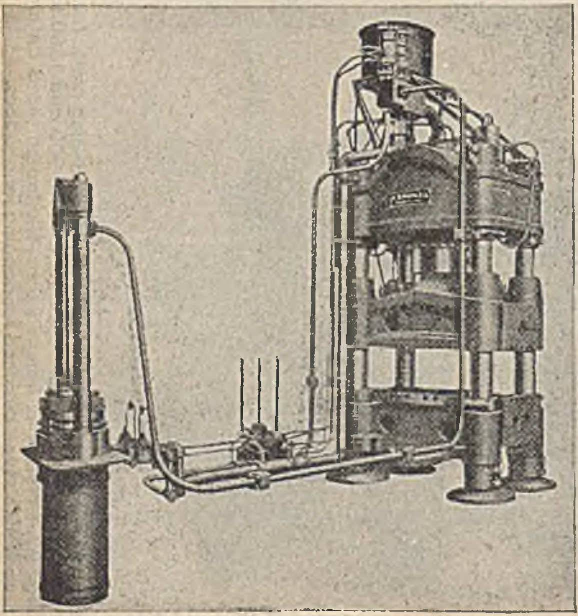
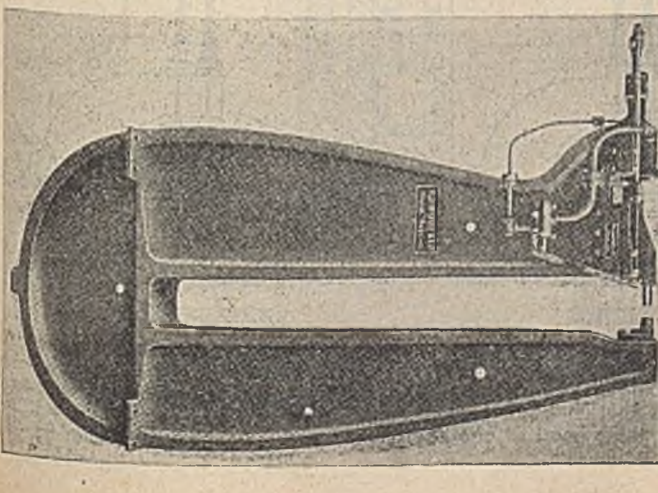


Fig. 22.—Hydraulic forging press. This p.ess is of 2500 tons capacity and equipped with slack water filling system and double power intensifier. This permits a very economical operation, as the cross head will be brought down to the work without the use of pressure water.



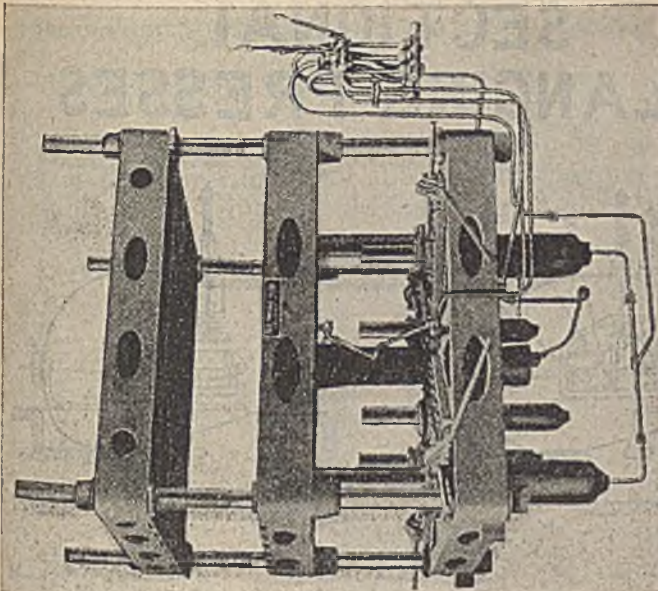
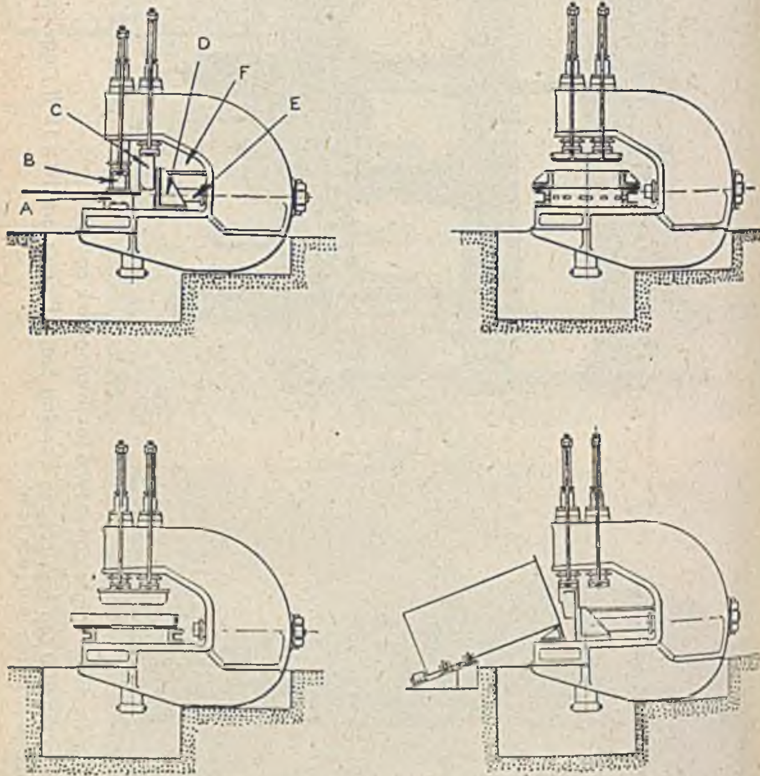


Fig. 23.—Hydraulic riveter single power type for riveting tank cars.

Fig. 24.—Hydraulic 100 ton four column flanging press. Platens are 10 x 15 ft.; equipped with one man ram, one internal ram adn four jack rams.

SECTIONAL FLANGING PRESSES



Figs. 25 to 28.—Hydraulic sectional flanging press showing various operations. The die equipment shown in fig. 25, consists of the following: **A,** bottom die; **B,** clamping die; **C,** plow die; **D,** guide bracket; **E,** horizontal ram extension; **F,** guide bracket bolts. Fig. 25, flanging large head sectionally; fig. 26, flanging entire head at one operation; fig. 27. flanging flue hole; fig. 28, flanging boiler flue.

Ques. What should be noted about this type pull back?

Ans. It is adopted only for short stroke presses.

Gap or Open Jaw Hydraulic Presses.—It is necessary to resort to this construction for applications where the material to be handled is too large to pass through the column of type

Fig. 30.—Sectional view of multiple power hydraulic riveter head.

presses. Presses of this type are used for a variety of work such as flanging, riveting, straightening, bending, etc.

Figs. 25 to 28 show an open jaw press performing various operations.

Miscellaneous Hydraulic Presses.—On account of the great variety of work which must be performed on presses, many types have been developed to meet the requirements for the different service conditions. The leading types of presses have been described here and many others are presented in the accompanying illustrations.

CHAPTER 42

Hydraulic Turbines

By definition, a turbine is: *A machine in which a rotary motion is obtained by transference of the momentum of a moving fluid.* Specifically: *the fluid is guided by fixed blades attached with a casing and impinging on other blades mounted on a drum or shaft causing the latter to revolve.*

Three principal types of turbine cover the entire field of practical development of a water power:

1. Reaction (Francis)
2. Propeller
3. Alleged impulse (Pelton)

It would not be practical to allot to each a fixed field of application within fixed limits of operating head, because proper application overlaps, depending on other operating conditions.

The following division may be made with respect especially to head:

1. Reaction

For medium heads up to 800 or even 1,000 feet, depending upon the output capacity of the unit, the quality of operating water and the character of the load to be carried.

2. Propeller

For any low head for which the development cost per horse power does not become excessive up to heads of 60 ft. normally and in exceptional cases even somewhat higher.

3. So-called impulse

For high heads—no limit. Small units can be built for heads as low as 200 ft. or even for larger capacities if the water condition be such as to prohibit the use of the reaction type on account of excessive hydraulic wear.

Reaction Turbines

The term reaction may be defined as: 1. *Reverse or return action.* 2. *The equal and opposite force exerted on a body* by the body acted upon. 3. *A force acting in opposition to or balancing another force or system of forces.* From this follows the philosophical truism: *Action and reaction are equal but in opposite directions.*

From these considerations it follows that a reaction turbine is: *One in which the* **pressure** *or head of the water is employed, rather than its* **velocity** *or* **impulse.**

The current is deflected upon the wheel by the action of suitably disposed guide vanes, the passages being full of water. Rotary motion is obtained by the change in the direction and momentum of the fluid.

The Scotch Mill.—The first and simplest form of reaction turbine is known as the **Scotch mill** as shown in fig. 1, and was the forerunner of the familiar revolving lawn mower.

As shown it consisted of two arms terminating in tangential nozzles. A central water supply pipe forms part of the system. This pipe is pivoted at its lower end and has an upper bearing.

Ques. What is the real force that causes this crude device to revolve?

Ans. Centrifugal force.

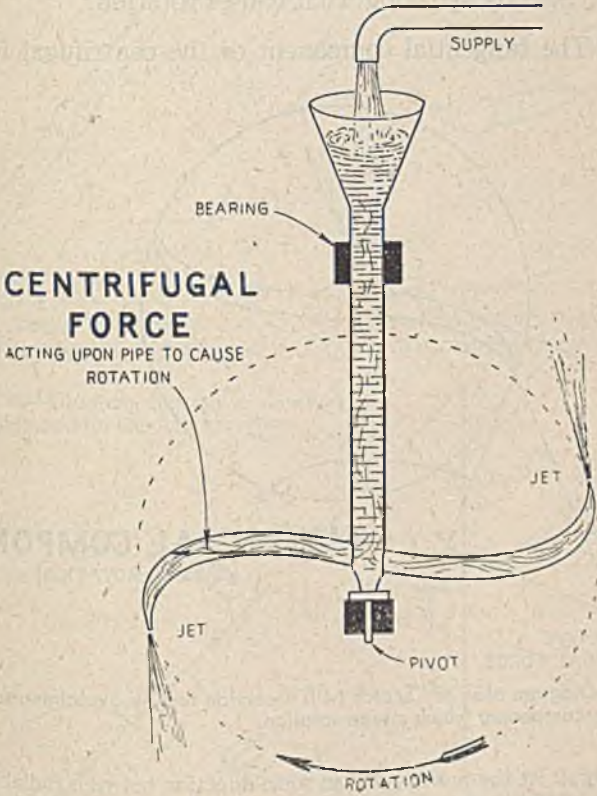


Fig. 1.—Elementary "Scotch Mill" reaction turbine.

Ques. Why is the turbine called reaction?

Ans. Because the curved shape of the pipe "gets in the way" of the flowing water forcing it to change its direction, thus introducing *centrifugal force*, which presses against the curvature of the pipe, the reaction causing rotation.

Ques. Strictly speaking what causes rotation?

Ans. The tangential component of the centrifugal force.

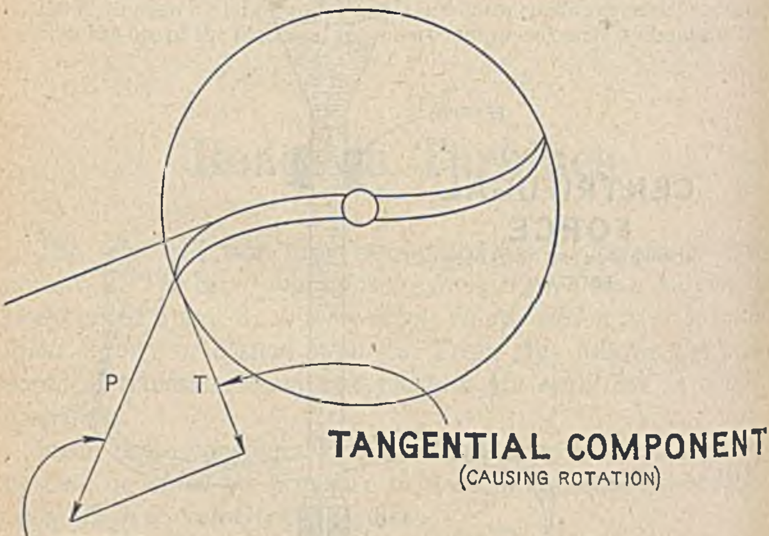
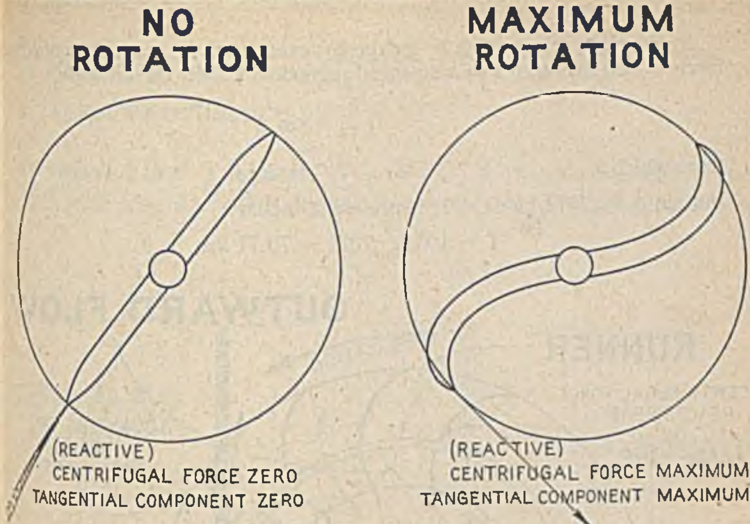


Fig. 2.—Diagram plan of "Scotch Mill" reaction turbine explaining tangential reactive component which causes rotation.

In fig. 2 let the nozzle point in some direction between radial and tangential. If P, be drawn to length to represent the tangential force introduced by the curvature of the pipe, then will tangent T, of the right triangle represent the force available for causing rotation, this in amount = tangential component of the centrifugal force.

Example.—If the reactive centrifugal force be 100 lbs. direction of jet at 45° to tangent what is the reaction or tangential component causing rotation?



Figs. 3 and 4.—Diagram showing jet direction for no rotation and for maximum rotation.

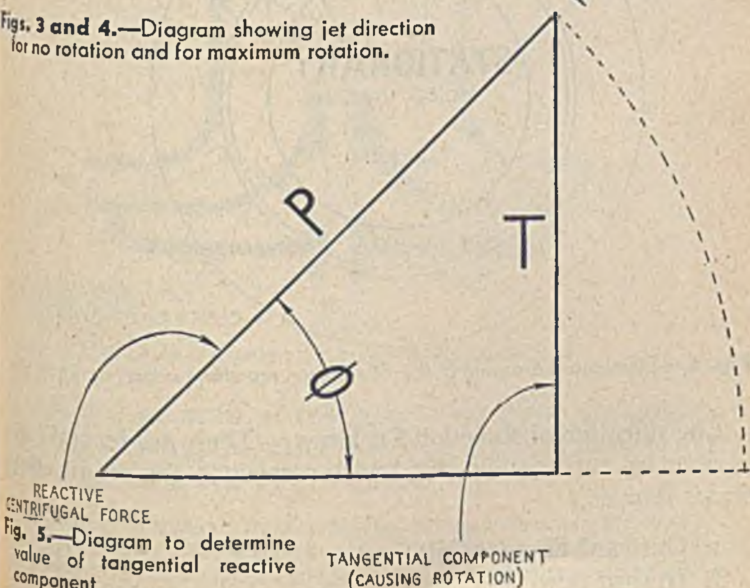


Fig. 5.—Diagram to determine value of tangential reactive component.

In the right triangle fig. 5, let the hypotenuse P, = reactive centrifugal force = 100 lbs. and T = tangential component. In the triangle

$$\frac{T}{P} = \sin \phi$$

from which
$$T = P \sin \phi$$

but $\sin \phi = .7071$ for $P = 1$, hence substituting

$$T = 100 \times .7071 = 70.71 \text{ lbs.}$$

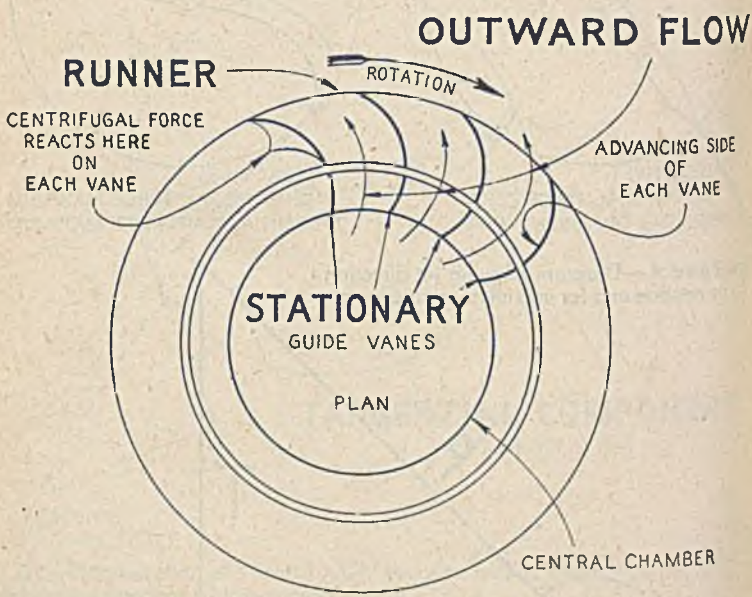


Fig. 6.—Elementary diagram of the Fourneyron reaction turbine, shown in plan.

Classification of Reaction Turbines.—There are several types of reaction turbines classified with respect to the nature of the water flow as:

1. Outward flow (radial)
2. Inward flow

3. Parallel or axial flow { Jouval / Propeller
4. Mixed or radial and axial flow.

Outward Flow Turbines.—A direct development from the Scotch mill (fig. 1) is the outward flow reaction type. Replacing

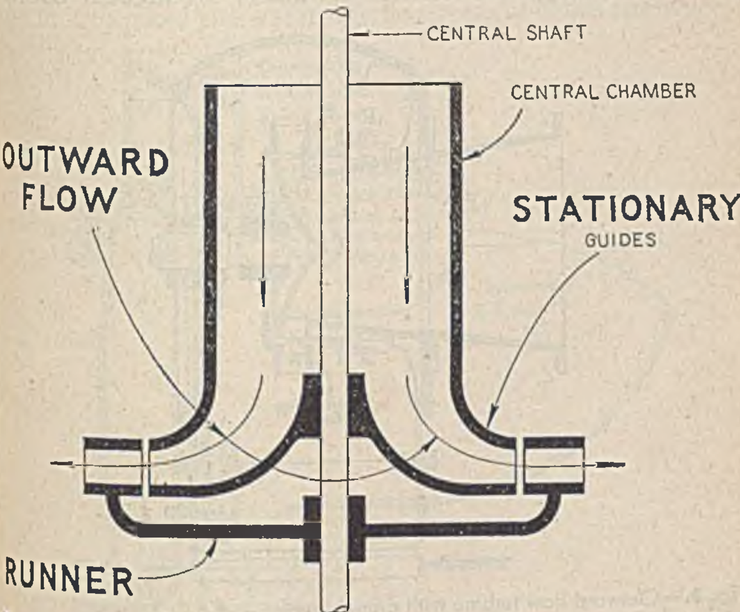


Fig. 7.—Elevation of elementary Fourneyron reaction turbine.

the outward jet arms of the primitive turbine are *stationary* guides for directing the water from a central pipe into the vanes of the wheel or *runner* as it is called.

This was introduced by Fourneyron and is known as the Fourneyron reaction turbine, as shown in elementary form in figs. 6 and 7. The central chamber which at its lower end has a number of stationary guide vanes, is supplied with water under pressure.

Surrounding the stationary vanes is the runner which is free to revolve on the central shaft, or it may be attached to the central shaft and the two revolve together.

Ques. How does the turbine work?

Ans. Referring to figs. 6 and 7, the water comes down under pressure through the central chamber, is directed outward

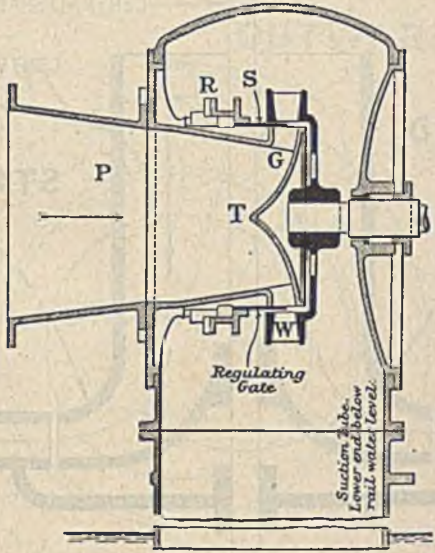


Fig. 8.—Outward flow turbine with draught tube.

(radially) by the stationary guide vanes. The numerous outward flowing jets of water pass through the curved vanes of the runner and in so doing, changing the direction of flow, *introduces centrifugal force*. This centrifugal force reacts on the (advance) side of each runner vane and causes rotation in the direction indicated by the arrow.

Fig. 8 shows an outward flow turbine with horizontal shaft.

Ques. Describe a method of balancing the weight of the moving parts of a vertical turbine.

Ans. By the double runner arrangement shown in fig. 9, the water pressure in the chamber is prevented acting on the lower wheel by the partition MN, but is allowed to act on the lower side of the upper wheel, the upper partition HK, having holes in it to allow the water free access underneath the wheel.

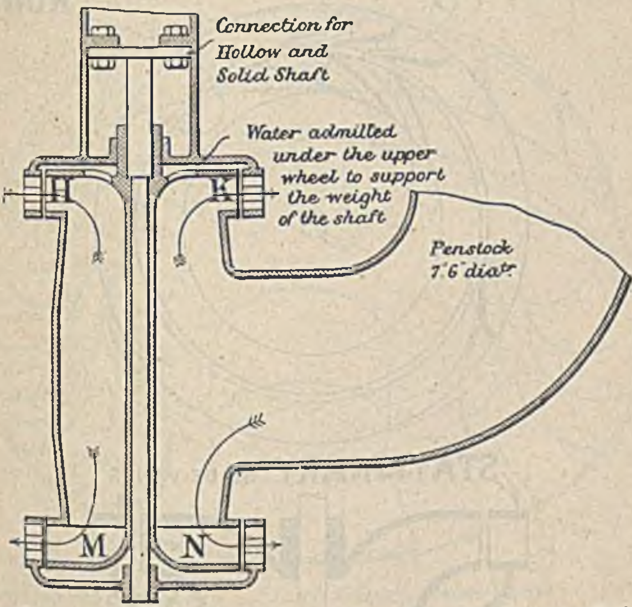


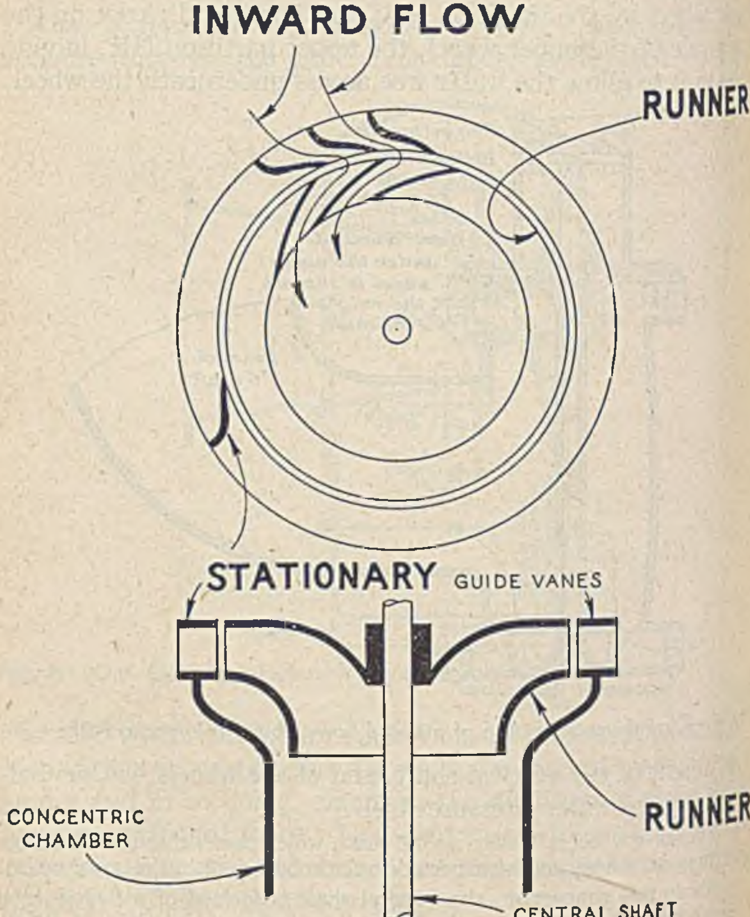
Fig. 9.—Diagrammatic section of outward flow turbine at Niagara Falls.

The weight of the vertical shaft, and of the wheels, is thus balanced by the water pressure itself.

The lower wheel is fixed to a solid shaft, which passes through the center of the upper wheel, and is connected to the hollow shaft of the upper wheel.

Above this connection, the vertical shaft is formed of a hollow tube except where it passes through the bearings, where it is solid. A thrust block is also provided to carry the unbalanced weight.

Inward Flow Turbines.—In this type of reaction turbine *the water is directed to the wheels through guide passages* **externally** *concentric to the runner, and after flowing radially, finally flows downward parallel to the axis.*



Figs. 10 and 11.—Plan and elevation of elementary inward flow turbine.

Ques. When does the water act upon the vanes?

Ans. Only during the radial movement.

Ques. Describe the operation.

Ans. Referring to figs. 10 and 11 water enters between the

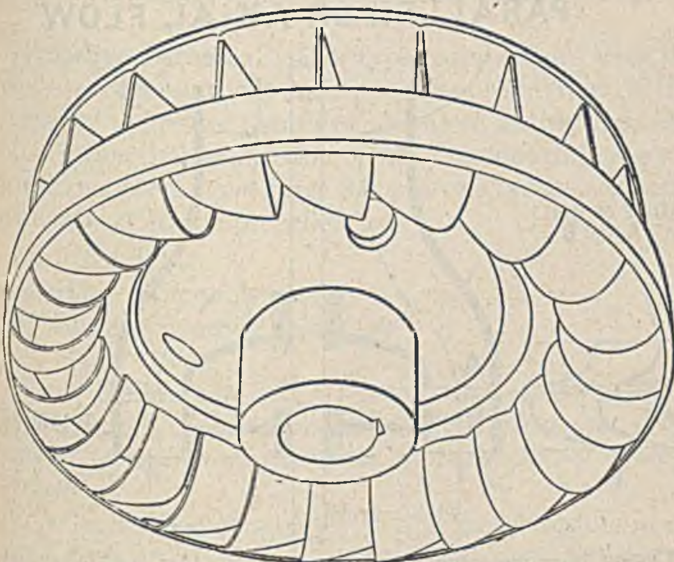
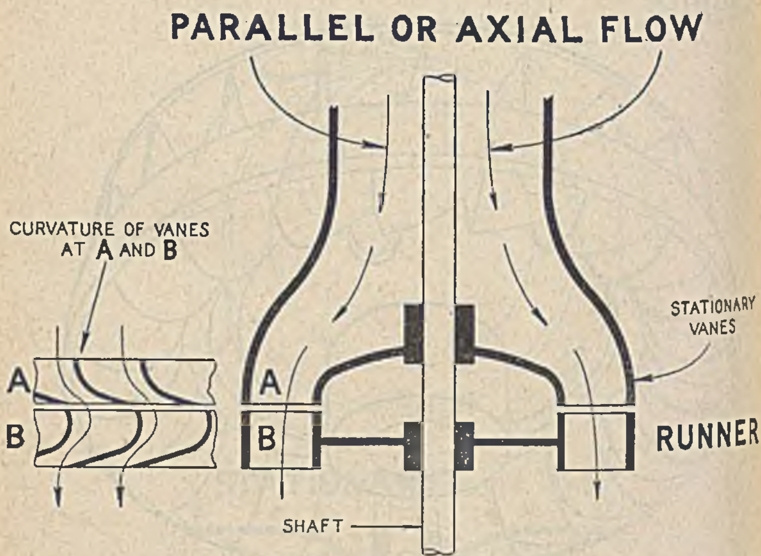


Fig. 12.—General appearance of Francis reaction turbine runner.

stationary guide vanes which are externally concentric to the runner. The water under pressure is directed inwardly by the stationary guide vanes. The inwardly flowing jets of water pass through the curved vanes of the runner and in so doing, changing the direction of flow of the water, introduces centrifugal force. This centrifugal force reacts as the (advance) side of each runner vane and causes rotation in the direction indicated by the arrow.

Fig. 12 shows the general appearance of an inward flow reaction turbine runner.

Ques. What do they usually call this type turbine?



Figs. 13 and 14.—Elementary parallel or axial flow turbine with detail (at left) showing arrangement of vanes.

Ans. The Francis type.

Invented by Francis.

Ques. What is the adaptation of the Francis type turbine?

Ans. It is suited for medium heads up to 800 ft. or even 1,000 ft. depending upon the output capacity of the unit, etc.

Parallel or Axial Flow Turbines.—The principle of parallel or axial flow was introduced by Jouval, the features of which are shown in the elementary drawings figs. 13 and 14.

The action of this turbine is similar to the other types except for the direction of flow. The arrangement and form of the stationary guide vanes A, fig. 13, and the runner vanes B, is shown in the small detail at the left, fig. 13. A late and important type turbine operating with parallel or axial flow is the *propeller* turbine described in the section following.

Propeller Turbines.—This type turbine deals with negative pressures and relatively high velocities of water and is therefore subjected to greater danger of vibration, pitting and instability of operation than some other types. To adapt this type to varied conditions there have been three developments, classing them with respect to the propeller, as:

1. Fixed blade
2. Hand adjustable blade
3. Automatic adjustable blade

Fixed Blade Propeller.—The flow for regulating the output of this type *is controlled exclusively by the movement of the guide vanes in the stationary part of the turbine admitting the water to the propeller.*

The high speed attained with a propeller results in a rather rapid drop of efficiency at part loads (partially closed guide vanes). This type is therefore recommended only when it is not essential that the water be utilized most economically at partial loads. It is the least expensive of any of the previously named types, and its application is also fully justified whenever the unit can be operated at a fixed output near the point of maximum efficiency of the unit, and at heads not changing materially, above or below the normal, or most prevailing head.

Fig. 15 shows appearance of a fixed blade propeller.

Hand Adjustable Blade Propeller.—This is a pioneer development. *The individual blades are pivoted and can be tilted manually when the unit is at rest.*

By changing the tilt three principal objects are attained, viz.:

1. An increased efficiency when the unit is operated at partial load, either by reason of load demand, or shortage of water under a certain operating head.

2. An increase in efficiency under heads above or below normal.

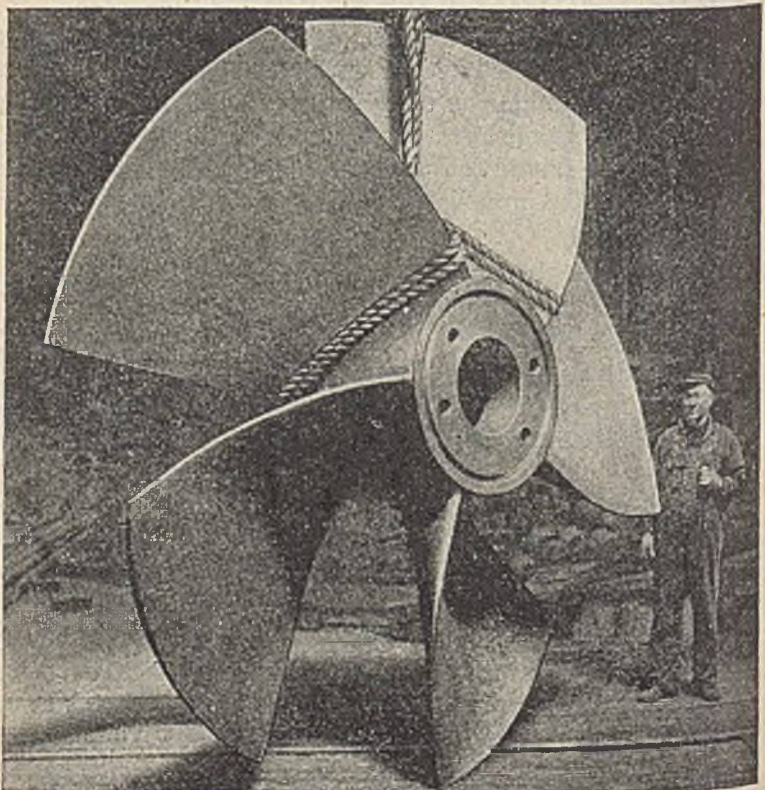


Fig. 15.—Five blade cast steel propeller type runner with **fixed blades.**

3. A reasonable increase in output above the normal, although at some sacrifice of efficiency, either for carrying temporary overloads at normal head, or recovering some of the power sacrifice of output under low heads.

Hand adjustable propeller is shown in fig. 16.

Automatic Adjustable Blade Propeller.—The results obtained with this design are the same as already explained before, except that the adjustment of the tilt of the propeller blades can be made while the turbine remains in operation.

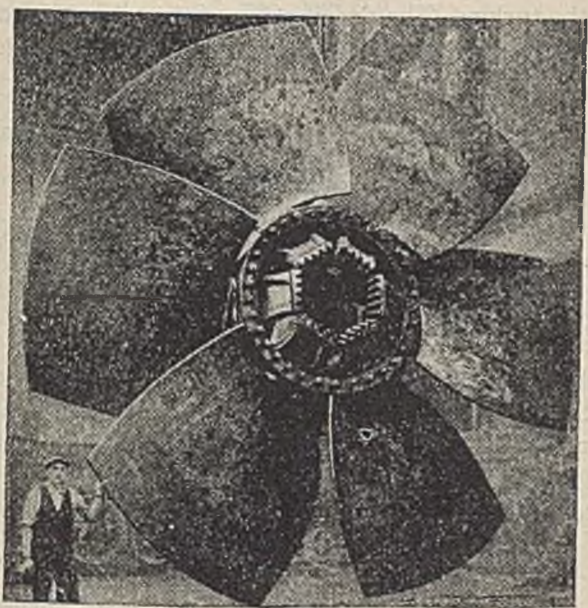


Fig. 16.—Propeller type runner with hand adjusted blades. The propeller blades are individually pivoted in the runner hub and are connected to a certain operating mechanism extending through the hollow turbine shaft into the turbine pit. When the unit is at rest, the so-called tilt of the runner blades can be simultaneously changed by hand or by means of an air drill motor. Thus the characteristics of the turbine may be changed so as to obtain higher efficiencies under the new operating conditions such as higher head, or reduced flow of water, than would be obtainable with a fixed blade propeller. This change from one setting to another is accomplished in less than five minutes.

It permits electric push button operation from the switchboard, either by the operator, or by means of water level recording devices, or automatic electrically from the guide vane movement of the turbine. The latter corrects the tilt of the propeller blades so as to obtain most favorable efficiency in accordance with the setting of the guide vanes by the governor.

Ques. Describe the Kaplan type of adjustment.

Ans. It employs the oil pressure of the governor of the turbine for actuating a piston in the cylinder of the rotating main shaft of the turbine. The distribution of the oil to that cylinder is effected by a control valve either combined with the governor itself or located in a separate auxiliary stand.

This control valve receives its initial motion from a cam operated from the guide vane mechanism and is brought to its neutral position again by reason of its relay connection transmitting the tilting movement of the propeller blades to the control valve.

This type is the most expensive of any type described and its application seems to be justified only when it is essential to obtain highest efficiencies at any conditions of prevailing head and of loads even when momentarily varying.

Mixed Flow Turbines.—A form of runner widely used in the United States is known as the mixed flow or American type. *This is a modification of the Francis type* and is designed for high speed and power under low heads. By modifying the vanes of the Francis or inward flow turbine, the mixed flow turbine is obtained.

Ques. How does it differ from the inward and outward flow turbines?

Ans. In the inward and outward flow turbines, the water acts upon the runner while the water is moving in a radial directions but in the mixed flow turbine the vanes are so formed that the water acts upon them also while flowing axially.

Fig. 17 is an elementary diagram and fig. 18 a section through a mixed flow turbine, giving names of parts.

Ques. Describe the operation of a mixed flow turbine.

Ans. Referring to fig. 17 the water enters the runner in a horizontal direction and leaves it vertically as indicated by the

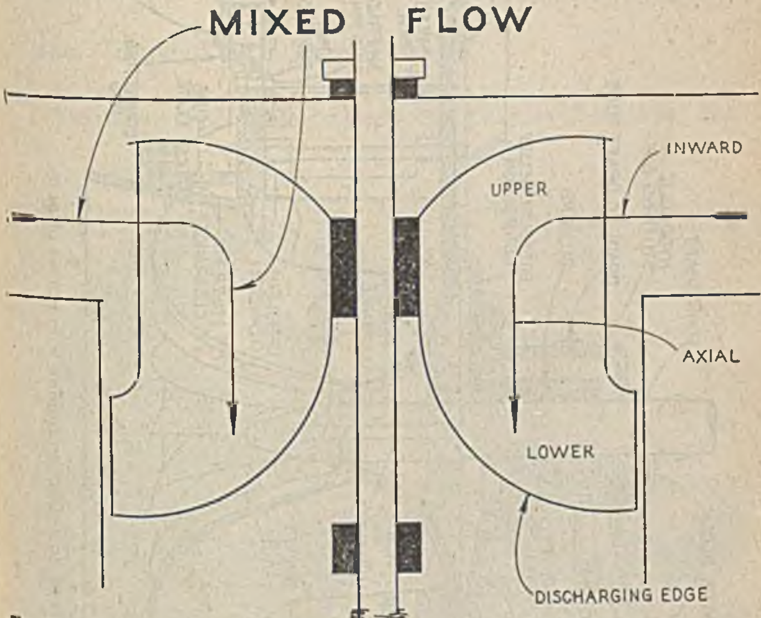


Fig. 17.—Elementary mixed flow turbine.

direction arrows; but it leaves the discharging edge of the vane in different directions.

At the upper part it leaves the vanes nearly radially and the lower part axially.

Ques. How should the inclination of the discharging edge vary?

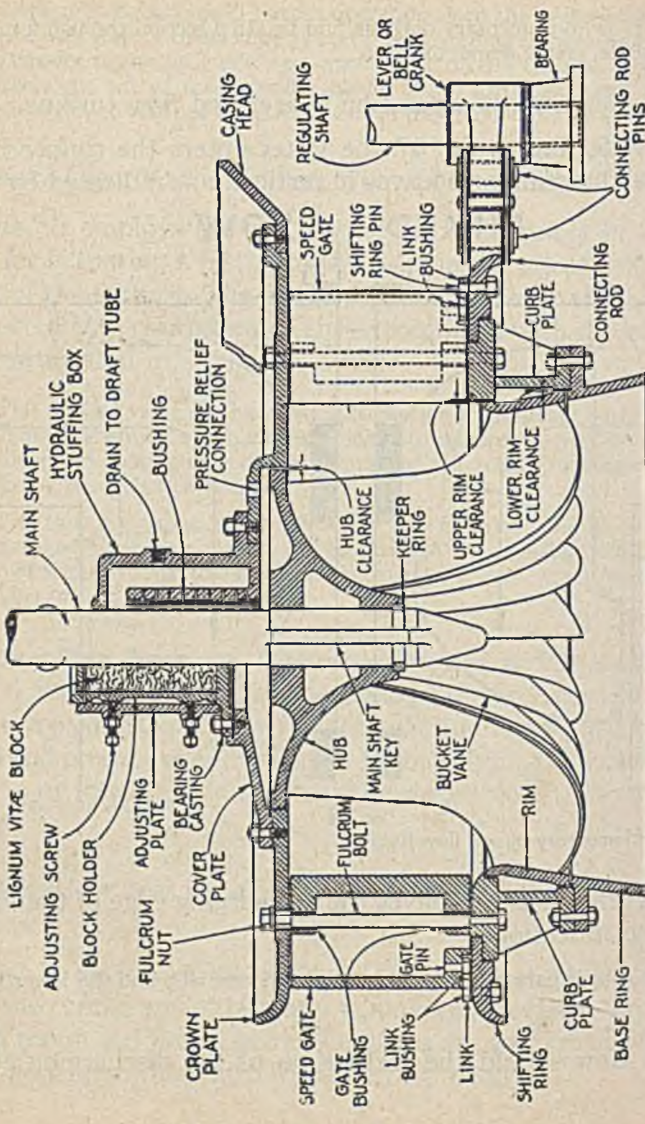


Fig. 18.—Section through mixed flow reaction turbine with names of parts.

Ans. The shape should be such that wherever the water leaves the vanes it should do so with no component in a direction perpendicular to the axis of the turbine.

Ques. Why?

Ans. To avoid turbulence or whirl.

The general appearance of a mixed flow runner is shown in fig. 19.

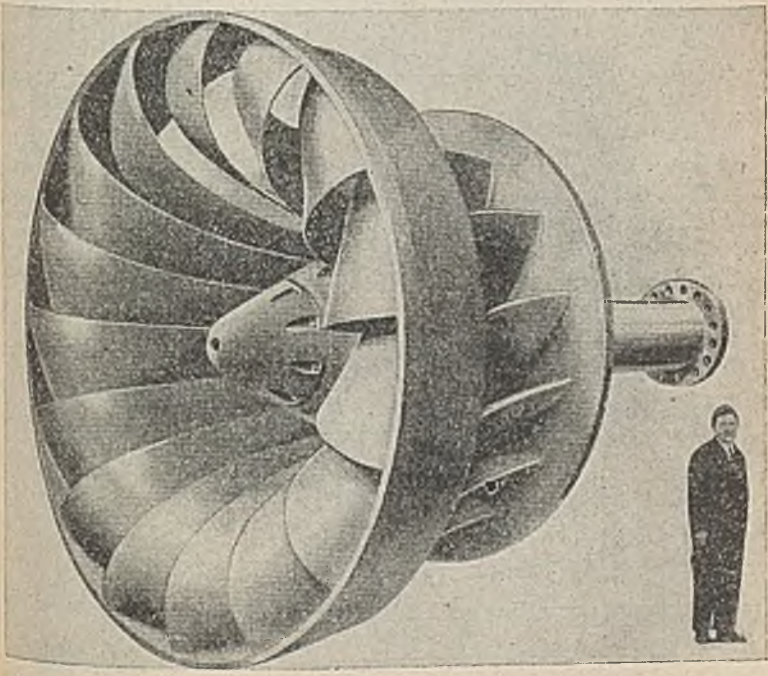


Fig. 19.—General appearance of a mixed flow reaction turbine runner.

2. Impulse Turbines
(So called)

The word impulse may be defined as: 1. *The act of impelling or driving onward with sudden force so as to produce motion suddenly, or without appreciable lapse of time.* 2. **Impact,** *or the sudden application or fall of a load upon an object or structure. A force acting with the effect of a blow.*

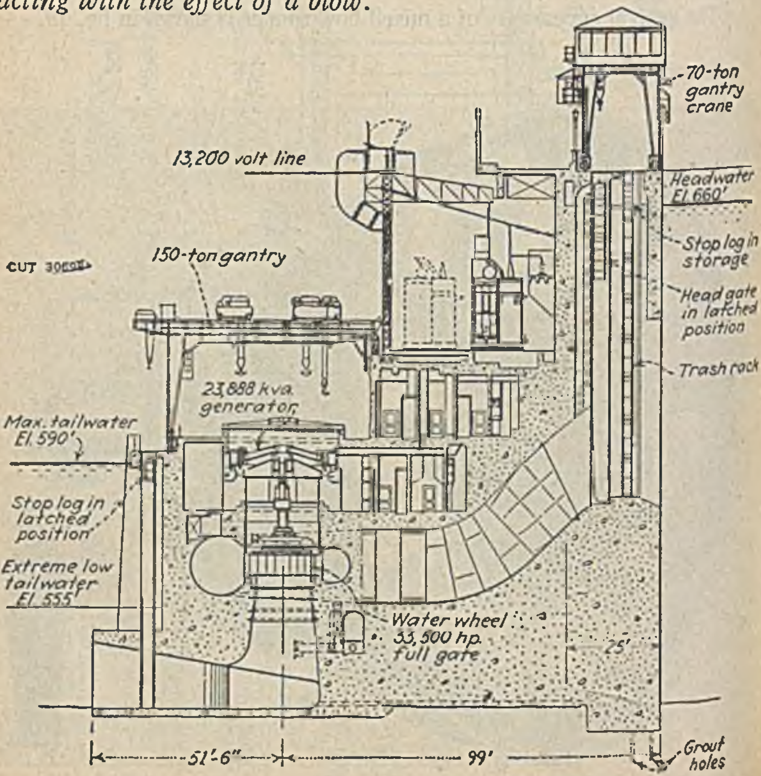


Fig. 20.—Sectional view of Osage plant located near Bagnell, Missouri.

In the first place there is no such thing as an *impulse* turbine—it's a *misnomer.*

It can be shown as will be, that it is not *impulse* but the **reaction** *due to* **centrifugal force** that causes rotation (specifically the reactive component of the centrifugal force). The difference between reaction and impulse is shown in figs. 22 and 23.

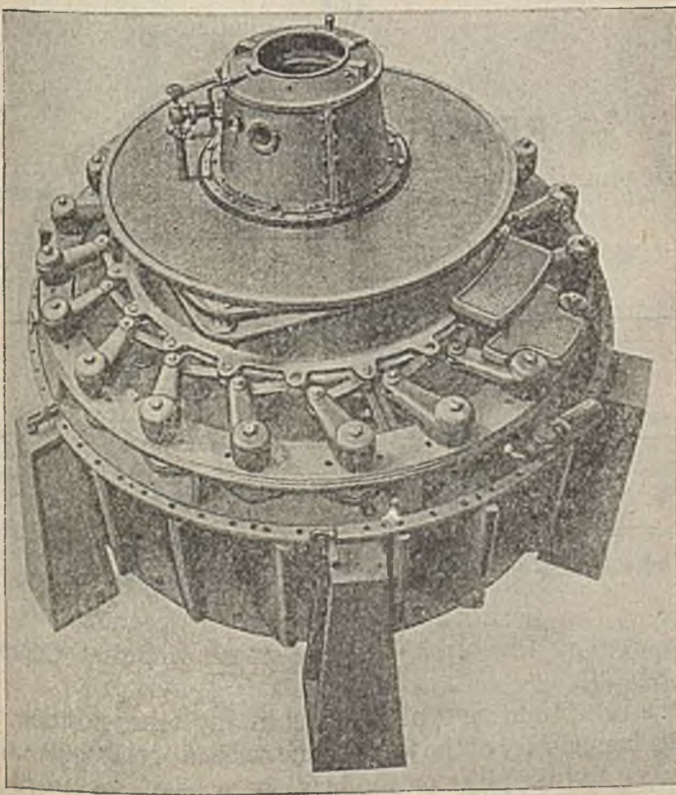
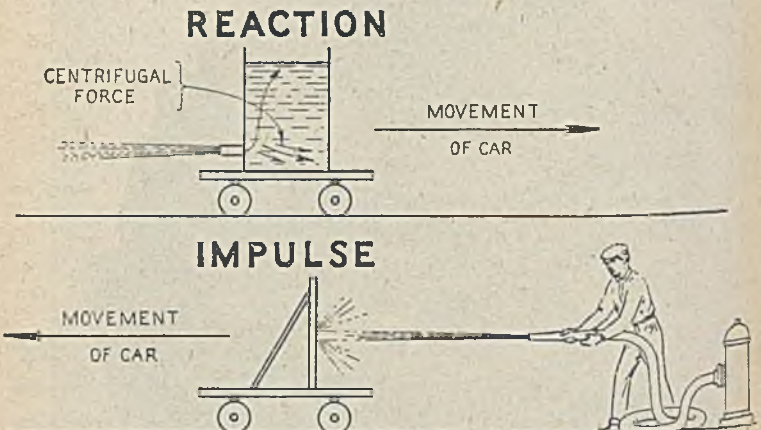


Fig. 21.—Top view of a guide case assembly.

Impulse "(?)" Turbines.—The only kind of alleged turbine in which impulse can possibly occur is one having flat radial vanes, and even with such vanes which are not used in practice there is only one instantaneous position when there is impulse. This is shown in fig. 24. When the flat blade is 90° to the axis of the jet, impulse takes place, but since the time interval of action is

$$dt$$

or zero.



Figs. 22 and 23.—Elementary diagrams illustrating **reaction** and **impulse.**

hence even in this position there is no impulse. Compare with fig. 23.

With this primitive type of wheel in any other position, the changed angularity of the jet with the surface of the blade causes a *reaction* to take place on the blade because of the centrifugal force introduced, due to the change in direction of the jet.

In fig. 26, let the blade be at some angle to the jet other than 90°. Let AB be the kinetic energy of the jet and draw AC normal to the blade.

In the triangle ABC, the kinetic energy of the jet is made up of two components:

AC, which is the force available to cause rotation when the wheel is in the position shown, and

BC, which represents non-active or wasted energy.

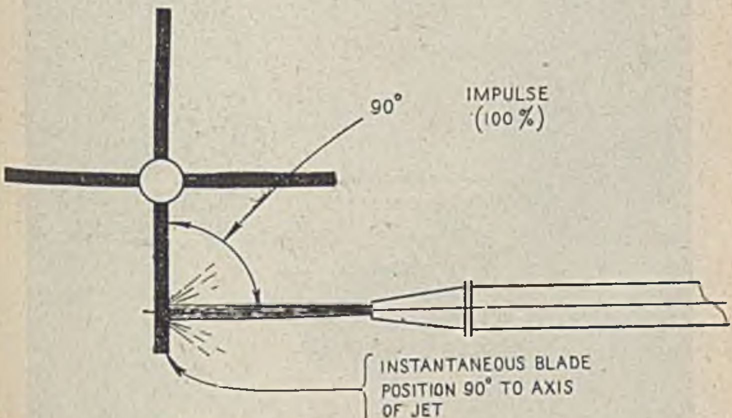


Fig. 24.—Elementary diagram illustrating the only instantaneous position of blade of so called impulse turbine for 100% impulse as explained in the text.

Electrically speaking, BC corresponds to a wattless component when the voltage and current are not in phase.

The component AC, is the *reaction* on the blade due to centrifugal force and that is what causes rotation—not impulse. A better name for the so called impulse turbines would be *jet turbines*.

These turbines as actually made are quite different from the primitive wheel used in the figure to explain principles and as made there is no instantaneous impulse position as in fig. 24.

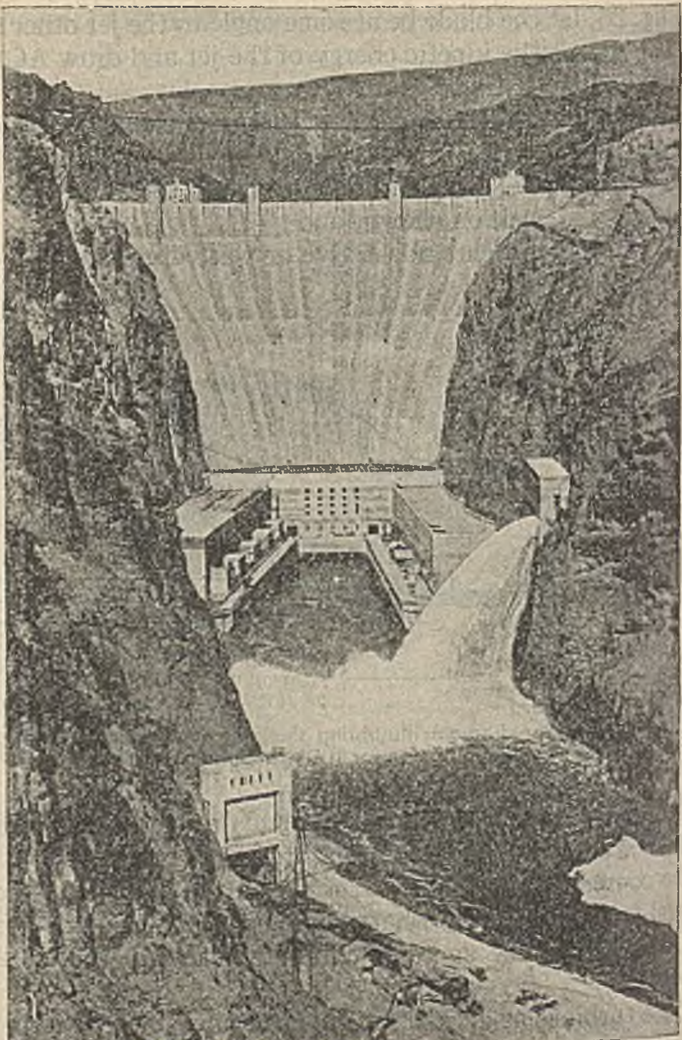


Fig. 25.—Bolder Canyon Dam located on the Colorado River. It is the largest electric plant in the world. Capacity 1,735,000 horse power.

Ques. What is a so called impulse turbine?

Ans. A form of reaction turbine consisting of a series of "buckets" attached to the rim of a wheel, against which a jet of water is discharged at a high velocity from a suitably located nozzle.

Fig. 27 shows appearance of one of these wheels with its buckets and fig. 28 one of the buckets.

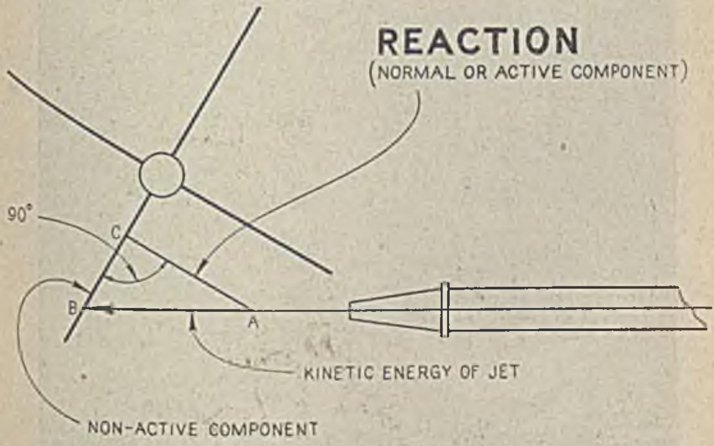


Fig. 26.—Diagram illustrating reaction component.

The general arrangement of wheel nozzle and other parts is shown in the installation, fig. 30.

Ques. What other name is given to the so called impulse turbine?

Ans. Pelton wheel.

Ques. Describe the Pelton bucket and water flow.

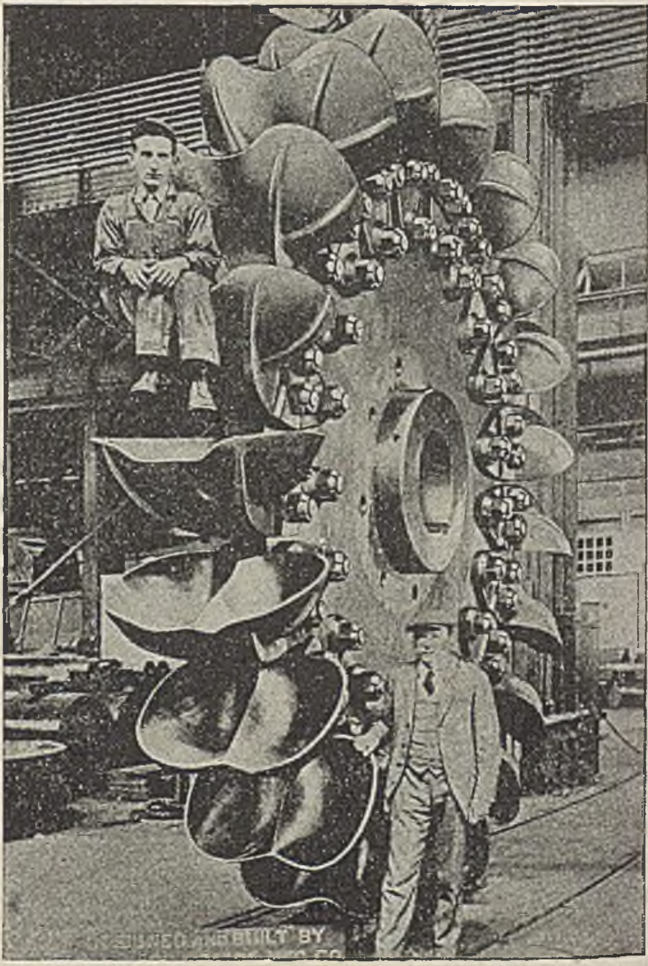


Fig. 27.—Impulse wheel disc with buckets for 30,000 h.p. units.

Ans. The form of bucket and water flow is shown in fig. 31. It is divided midway by a tapered ridge which prevents the accumulation of any "dead water," the stream splitting on the ridge and curving right around to right and left in each half bucket, thus providing the maximum reaction practical.

If the jet could be completely reversed as in fig. 32, the theoretical efficiency of the Pelton wheel would be 100%. In practice, however, as in fig. 33, it is necessary to deflect the reversed jet sufficiently to clear the adjacent

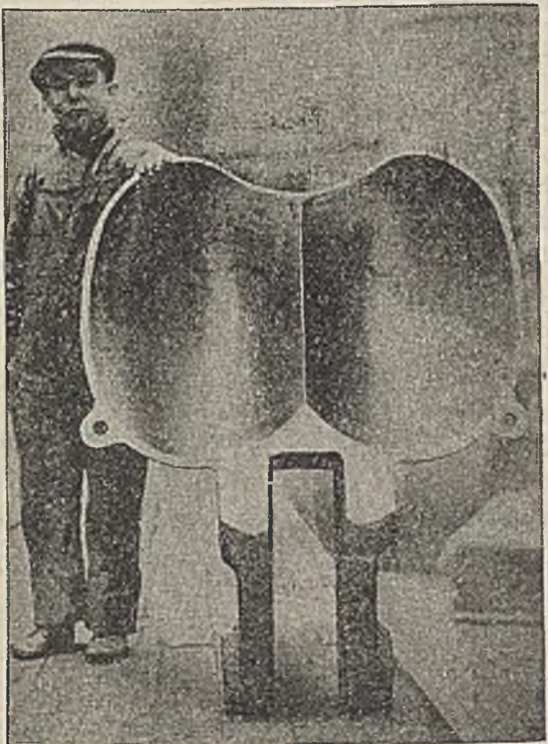


Fig. 28.—Appearance of a large Pelton wheel bucket.

bucket, and this in connection with frictional losses reduces the efficiency to about 80% for average conditions.

Ques. Describe more in detail the shape of the Pelton (Pelton-Doble) bucket.

Ans. Each half is ellipsoidal in form, with a portion of the outer lip cut away to clear the jet when coming into action.

This eliminates shock and permits the water to be discharged from the entire surface. See fig. 28.

Ques. Describe the action of the jet upon the wheel.

Ans. Consider a half bucket as in fig. 29. Let the vector AB at any point of the bucket represent the kinetic energy of the jet in both amount and direction. Then in the triangle of components, AC, is the reactive component of the kinetic energy which causes rotation.

Accordingly it is reaction and not impulse that causes rotation.

Ques. What is the special application of Pelton wheels?

Ans. They are applicable to large capacity units under very high heads.

It is unequaled in continuity of service and low maintenance costs, due to its mechanical simplicity and the minimum of parts exposed to wear by the high velocity of water.

Ques. In construction how are the buckets assembled on the wheel?

Ans. They are placed individually on a disc mounted on the shaft.

Ques. What condition usually exists with high heads?

Ans. High heads naturally involve pipe lines of considerable length for supplying the water to the wheel. The kinetic energy contained in this moving water column cannot be stopped quickly, as this would produce dangerous pressure rises in the pipe line.

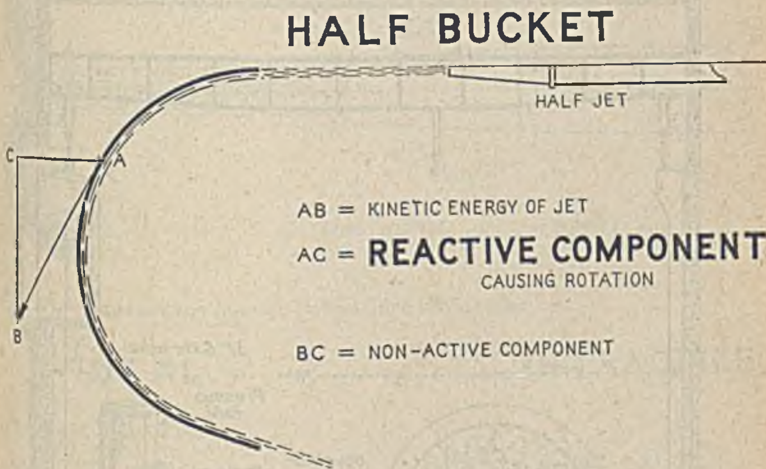


Fig. 29.—Diagram of half bucket illustrating reactive component which causes rotation.

Ques. What is the "water wasting" method of governing?

Ans. The practice of simply diverting the jet quickly from the buckets by the governor.

This method is today used only where economy of water is not essential.

Where water must be economized with, in spite of a long pipe line, the water cannot be permanently wasted. In that case a pressure regulator, or water saving by-pass is used, which, by reason of a dash pot provision, does not open when the governor closes the needle quickly. It then discharges either in full or a part of the water otherwise discharged through the wheel,

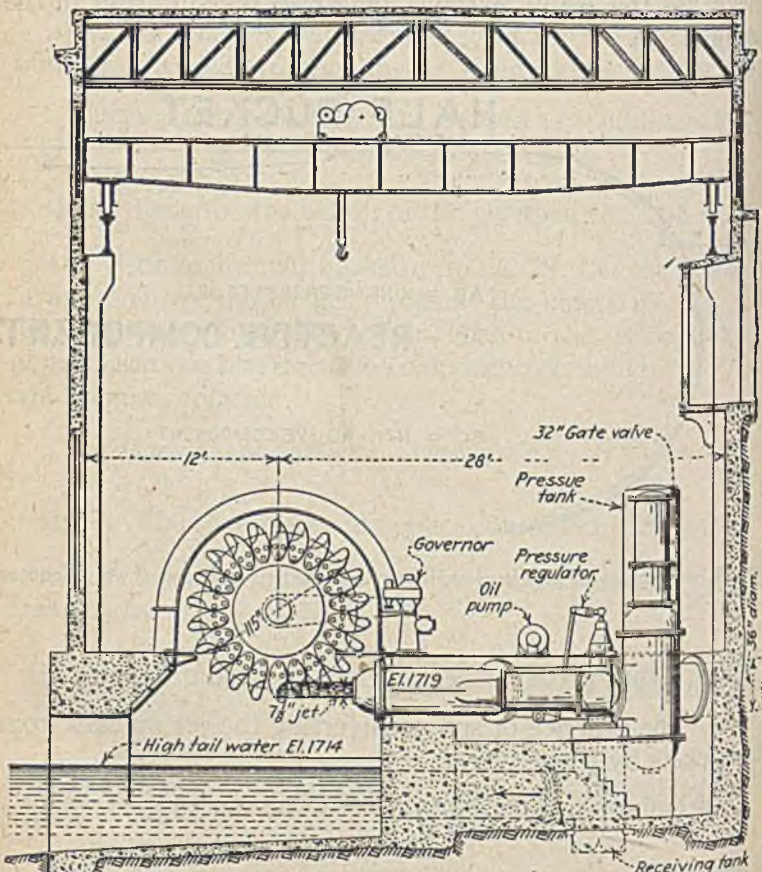


Fig. 30.—Pelton wheel turbine unit installations. Sectional view showing assembly of wheel and accessories.

so that no serious pressure rise will take place in the pipe line. By reason of the dash pot action it then closes at a rate gradual enough to prevent undesirable pressure rises. In other words,

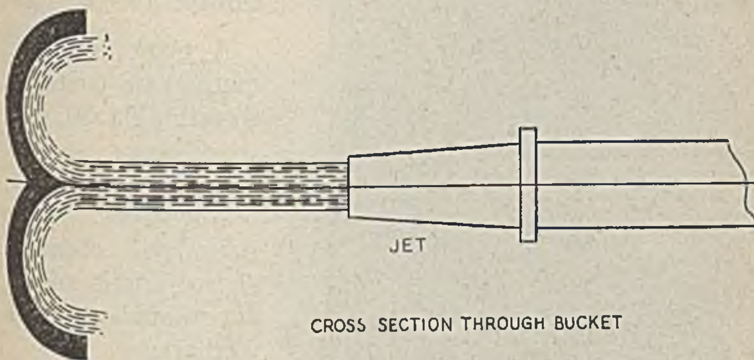
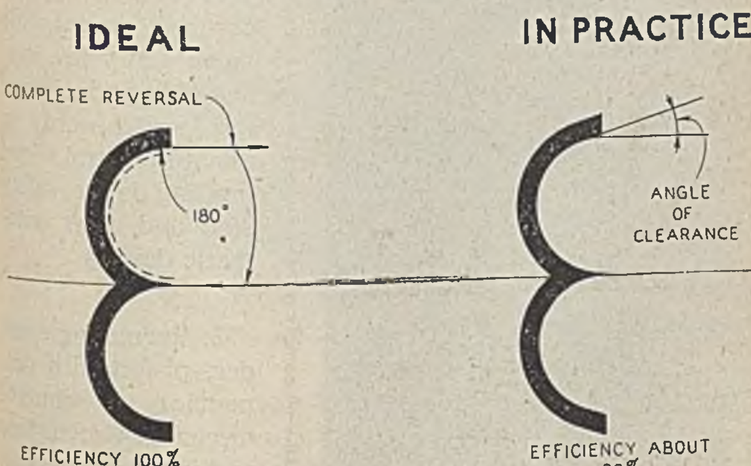


Fig. 31.—Cross section through Pelton brick showing jet flow.



Figs. 32 and 33.—Ideal and commercial cross sectional flows of Pelton bucket.

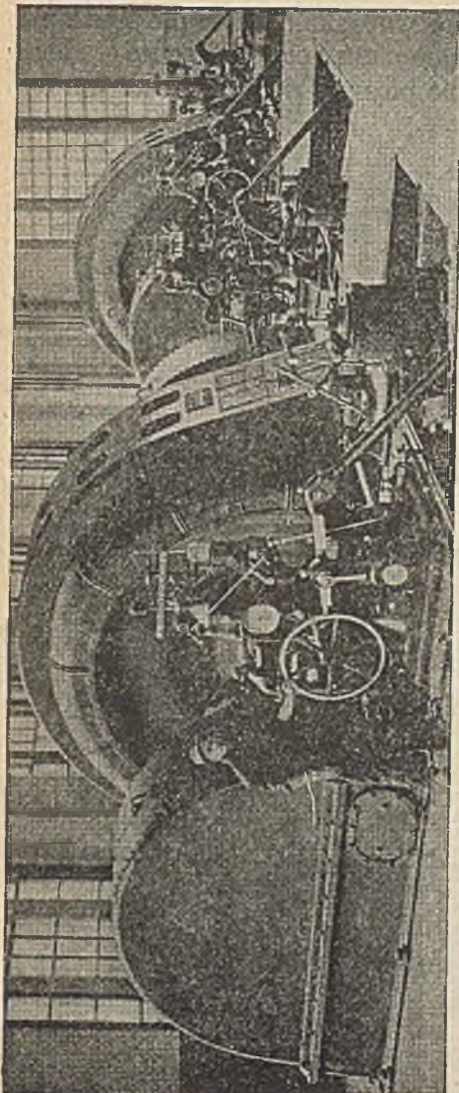


Fig. 34.—Assembly of Pelton wheels, generators and governors in power house.

the total effect on the pipe line is the same as it is when the governor stops the flow slowly.

A plant using this method of control is shown in fig. 30.

Governors. — The principal elements characteristic of the governors here considered are:

1. Fly balls, or speed control, regulating valve and relay, synchronizing attachment for switchboard or remote control, load limiting device, safety stop and other automatic devices.

2. Regulating cylinder, piston with connection to control mechanism of turbine and independent hand control device.

3. Oil pressure system, consisting of pump, main pressure tank, receiver tank and pipe connections between above elements. Governors of very small capacities may have all three elements combined and mounted on one common governor body. Governors of medium capacities have a separate oil pressure system.

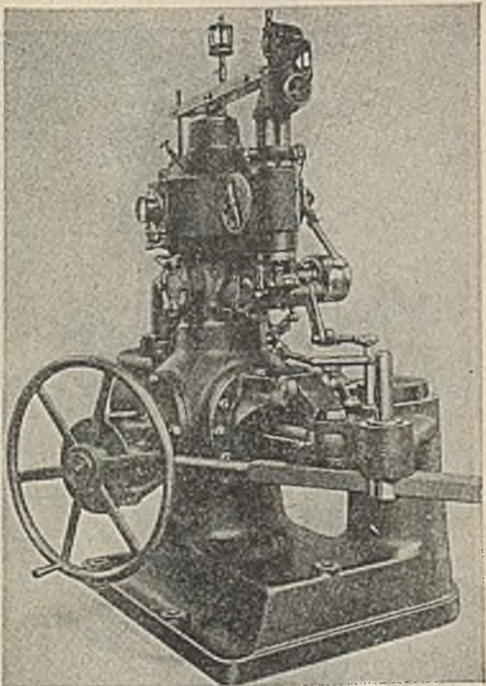


Fig. 35.—Special hydraulic turbine oil pressure governor with gate latch for automatic control.

Governors of large capacities have the three elements individually disposed to best suit local conditions, and the first element, called governor actuator, is generally located on the generator floor, and is provided with a hydraulic hand control device.

The regulating cylinders may be separately mounted, or directly above the cover plate of the turbine, or of the turbine casing. A number of features not referred to in detail are embodied with these governors.

When the head is too low to permit coupling the oil pump directly to an impulse wheel a small spiral case type Francis turbine is used with fixed guide vanes, controlled only by the main shut off valve to this turbine. This is permissible in combination with an induction motor and an unloader

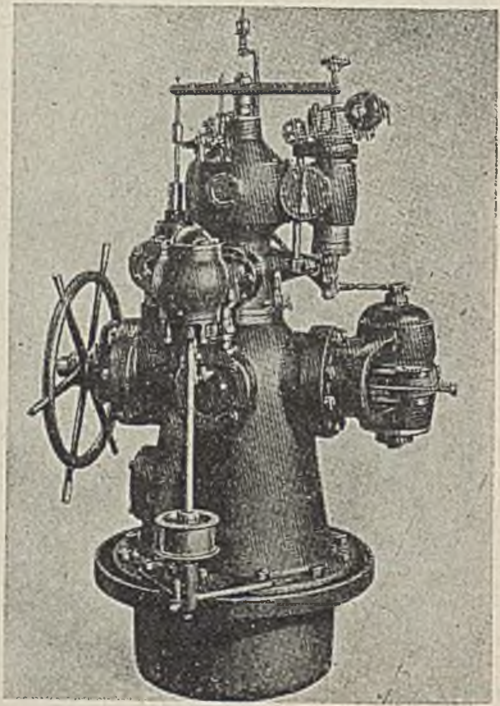


Fig. 36.—Pressure regulator.

valve on the pump, which delivers oil from the pump into the pressure tank during periods of demand and by-passes the oil in the pump when the supply in the pressure tank is ample.

The by-passing of the oil relieves the pump of duty, the surplus energy produced by the turbine (or an impulse wheel) causes the induction motor to act as generator delivering power back into the line.

Pumps driven by motors only are equipped either with these types of unloaders or by an electric switch which stops and starts the set when high and low pressure in the pressure tank is reached.

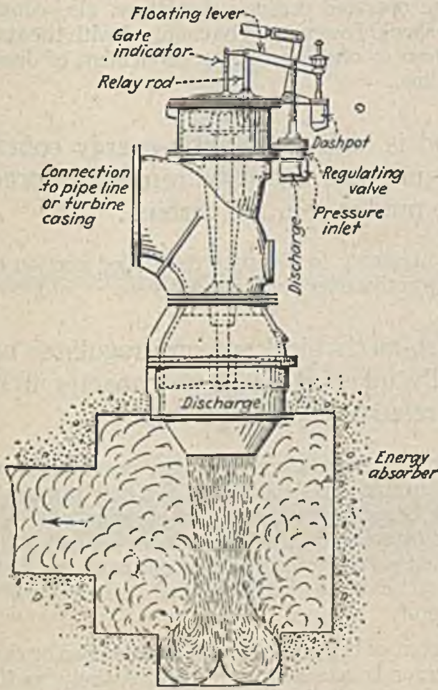


Fig. 37.—Pressure regulator with names of parts.

Pressure Regulators.—In cases where pipe lines are indispensable, it is often necessary to provide means of protection against bursting due to pressure rises caused by the sudden closing of the turbine gates by the governor. This is accomplished by the use of pressure regulators.

Usually the pressure regulators are directly connected to the turbine gates, and are therefore called governor operated pressure regulators.

There are also pressure regulators which operate independently by responding directly to the pressure variation in the pipe line. These devices are called pressure operated pressure regulators, also commonly termed relief valves; they should however not be confused with the standard safety, or pop-valves, which so often constitute an element of danger instead of protecting a pipe line.

When the head is high the kinetic energy contained in the discharge of the pressure regulator represents practically the energy otherwise produced in the turbine.

It is therefore necessary to dissipate the major portion of this energy so as to avoid destructive effect in the tailrace.

A type of hydro-mechanical pressure regulator has been developed, especially adapted for large capacity units supplied with water from relatively long pipe lines.

This design insures absolute safety in that provision is made that the movement of the turbine gates controlling the flow through the runner is retarded when due to some reason the pressure regulator valve sticks. A power dash pot is combined with the hydraulic control located accessibly outside and designed in such a manner that normally the hydraulic control functions so that practically no force is required from the governor to actuate the pressure regulator.

On failure, however, of the pressure regulator to open or close, the movement of the governor is retarded or blocked entirely so that no undue velocity changes of water in the pipe line can take place.