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MANUFACTURING AND QUALIFICATION OF DRIVES WITH GOOD EFFICIENCY AND HIGH LOAD CAPACITY

Summary. A worm-gear drive with good efficiency and high load capacity was developed as a result of our research work, the manufacturing of which has got a protection by patent [8].

In this paper the essence of the manufacturing method will be described, which is exact from geometrical point of view, as well as the most important results obtained during the operation of worm-gear drives will be outlined. In the course of manufacturing such a method has been worked out, as a result of which a geometrically identical thread-surface (worm, gear-hobbing machine, etc.) comes into being independently of the change of diameter of the grinding wheel. Its mathematical bases can be found in the papers publicated earlier by the author.

The mathematical model has a universal validity and it is valid for the manufacturing and scientific investigation of every helicoid surface. The driving-pairs produced such a way can be advantageously used for any kinds of drives, so for the elements of mine drives, because these drives have a good efficiency, a high load capacity, a high endurance as well as a low noise-level.

1. INTRODUCTION

The worm gears with concave arched profile have been developed in order to increase the load capacity of the driving elements as well as to improve the efficiency. In case of these worms, the radiuses of curvature of the contact surfaces are on the same side of the normals of tooth surfaces, therefore the Hertz-stress, developing on the contact surfaces, is small, comparing with the convex-convex pairs of surface. Thereupon an oilfilm of satisfactory carrying capacity comes into being more easily.

The tooth form of the worm can be very favourable if the centre of the radius of arching is placed suitably, by which a relatively great thickness of S_1 dedendum can be reached on the worm and on the worm wheel (Fig. 1). Due to the favourable conditions of contact and lubrication these drives have a good efficiency and a high load capacity. These types of drives are much better than the cylindric worm gear-drives of straight generatrix.

The technological factors can significantly improve the effect of the favourable geometrical properties, or they can damage it, in unfavourable case, as the technological factors determine the accuracy of shape of contact surfaces as well as the quality of the surfaces (their roughness). The accuracy of shape of the contact elements has a significant importance from the point of view of the efficiency and endurance of worm gear-drives, and the quality of the tooth-surface plays also an important role.

The worms of gear-drives, serving for the transmission of great energies, are everywhere ground in the manufacturing works using up-to-date machinings nowadays. The favourable result of grinding is that the pitch improves, (especially in case of worm with more starts) and the roughness of the machined surface decreases. However, the inaccurate technology of grinding, the limited accuracy of shape of the disc-like tool, the approximate solution of the machining-method can cause certain problems. The machined profiles can become deformed because of these problems (the geometrical accuracy of shape of the worm can become wrong), and as a consequence the goodness of gear-drive can also suffer a loss.

2. METHODS OF GRINDING USED TILL NOW

The first method suitable for worm-gear grinding was developed and patented by NIEMANN, G. in West-Germany [10, 11].

The axis of the grinding wheel and the worm includes an angle, the greatness of which is equal to the greatness of the angle of pitch of the dividing cylinder. During grinding the normal transversal of the axis of grinding wheel and worm is a symmetry axis of the grinding wheel if its adjusting to the grinding is considered. The disadvantage of this grinding method is that the profile changes because the diameter of the grinding wheel changes too, because of its repeated profiling. Namely in the course of machining the contact line of the surfaces of tool and worm is a space curve, the character of which changes in consequence of the wear and resharpening of the grinding wheel [9]. However, it impairs the accuracy of shape of the machined surface.

The other well-known grinding method has been worked out and patented by LITVIN, F.L. [11, 12]. At this method the wheel is clamped in a special way. During machining the worm, the grinding wheel is adjusted in such a way that the centre of the radius of arching intersected by the axis of the tool should be in the normal transversal of the axis line of the wheel and the worm and the axis of the worm should be in one of the so-called "contact axis". In this case the contact line between the surfaces of the grinding wheel and worm is not a space curve, but it is a plane-curve. The character of the contact curve does not depend on the diameter of the grinding wheel, the wear and resharpening of the tool does not influence the surface of the worm.

This very accurate grinding method can be used only on such machine, where the grinding wheel can be adjusted to a great extent in the direction of axis. The adjustment after reprofiling is quite complicated.

The purpose of this paper is to describe a new grinding method differing from the above mentioned machinings.

3. THE NEW GRINDING METHOD

Therefore a new principle had to be elaborated for the new grinding method. According to our home possibilities, a Matrix type machine made by Csepel Machine Tool Factory has been used for manufacturing. Because of the given possibilities of the wheel-dressing as well as in order to simplify the supervision of worm, the circular arc generatrix of the worm has been placed in the principal section [2] (Fig. 2).

The possibility of placing the circular arc generatrix in the principal section is justified by KRIVENKO, I.S. too [7].

The manufacturing of worm with a circular arc generatrix in principal section has been made as follows:

The thread cutting of the worms by lathe does not cause the distortion of profile but this distortion arises during grinding, mainly in case of worms of great pitch, especially if the tool is not satisfactory profiled. The distortion increases by increasing the diameter of grinding wheel. The nature of the distortion of profile can be understood on the basis of the following explanation:
The grinding of worm can be considered as if the machining were made by means of many - an infinitely great number - of single edged fly cutter, instead of grinding wheel. A cutter, working just in normal section, would give a proper profile. When rolling to the normal plane, the tool damages the surface. As a result of it the thread profile necessary in normal section will be defective, i.e. a distorted profile will be generated in normal section, and it causes the distortion of the profile in the principal section. The worm machined such a way, will not be always identical from geometrical point of view at the different diameters of grinding wheel. Therefore it is necessary to determine the profile of the wheel so that the surface of the worm will not suffer a distortion and it should have always the desired and prescribed profile respectively. For this purpose it is necessary to remove those parts of the wheel, which cut the missing parts from the whole thread.

In order to meet this demand, the author has worked out such an instrument and method, by means of which the insufficiencies of the different grinding methods mentioned above, as well as the distortion of profile can be eliminated unambiguously. The method and the equipment has been patented [8].

By means of this equipment we can bring in a determined position the generatrix radius of the worm (ρ_{ax}) to be ground, and to roll in it in front of the wheel, imitating the geometrical shape of the worm (Figures 3 and 4).

The system of the machine (the clamping of the wheel) ensures, that the symmetry plane of the wheel falls always into the axial plane of the worm, i.e. into the normal transversal. Otherwise the accuracy of its adjustment has no great significance at the new method. The control unit has been built into the kinematic chain of grinding, so it adjusts the wheel to the kinematically proper counterprofile. The profile of the wheel obtained by the new method has been compared with the wheel-profiles, which have not been hobbed (traditionally cut to ρ_{ax}). The result can be seen in Fig. 5. The mathematical verification of it can be found in the author's dissertation [3]. As it can be seen in this Figure we have ground those parts of the wheel (head-part), which causes the distortion of worm in case of machining, during rolling in and out, in normal section.

Besides the machining of worm, it is necessary to speak about the machining of the other element of the contact pair, namely about the machining of the worm wheel. The tool necessary for machining the worm wheel can be machined on a direct way, that is identically with the worm - by means of the grinding wheel profiled identically. If the tool, machining the worm wheel, is ground also in such a way, then the transformed surfaces will be the conjugates of each other.

The distortion of profile caused by the size-change of the wheel disappears at this new grinding method, i.e. always an identical helicoidal surface is obtained independently of the diameter of wheel, because the profile of the wheel is received in each case by retransferring it from the worm [3, 4]. So, if the worm has a circular arch profile in the principal section, it can be ground in an exact way, it is not necessary to use a special machine for grinding.

4. THE QUALIFICATION OF DRIVES

The qualification test of the driving-pairs, which includes the geometrical supervision of the worm, the examination of the contact of the built-in driving-pairs, the supervision of some of their important characteristics (efficiency, warming up, noise level, etc.) gave favourable results. [2].

In this paper we described only the most characteristic geometrical data of manufacturing, i.e. the measurement of the profile-error. Its measurement was carried out on a PSR-750 type machine (made by Klingelnberg) according to the arrangement shown in Fig. 6 and 7. The principle of measurement has been worked out as follows: it is necessary to measure the profile-error in the principal section of the worm (in the profile-plane of the nominal circular arc), therefore the declination of the theoretical and real profiles from the straight line marked "a" have to be determined, and taking their differences, it is necessary to determine the greatness of the profile error. The "a-a" straight line is a chord, perpendicular to the normal of the tooth profile being in the profile-point on the dividing cylinder. The difference between the theoretical and real profile is in a general form:

$$\Delta h = h' - h$$

where h' is the declination of the real profile from the "a-a" straight line, and h is the declination of the theoretically proper profile from the "a-a" straight line (it is to be determined by calculation). The greatness of the profile-error is the sum of the absolute values of the maximum (positive) and minimum (negative) deflections of the differences:

$$\Delta pl = \left|\Delta h^{+}_{max}\right| + \left|\Delta h^{-}_{min}\right|$$

The shape-error of the produced worms was only the fraction of the allowed degree of tolerance. The results showed, that the placing of the circular arc generatrix of the worm in an axial section, and the new production method according to it is suitable for industrial application.

After finishing the geometrical test, the driving-pairs were built into their gear-boxes, and then they were run in. After running the final contact patterns were also supervised. The contact patterns obtained before and after running, and their prints are shown in Figures 8, 9, 10.

During the examination of some important characteristics of the driving-pairs the following parameters were tested:

- the running-in of the drive, the determination of optimum oil-level;
- the measurement of the efficiency, and noise-level of the drive.

Fig. 11 illustrates one of the efficiency-curves obtained during our measurements, as a function of the output power of driving motor. Table 1 shows some of the important characteristics of the produced drives.

5. CONCLUSIONS

It can be stated from the literature and on the basis of our own experiences, that the worm-gear drive with arched profiles meets the demands concerning the power transmission, efficiency as well as noise-level, so it can be advantageously used in high power drives.

The manufacturing of the worms with circular arc profile in the principal section (parameters ρ_{ax} and r_k) can be realized by using the wheel-profiling unit planned by the author, on any of the thread-grinding machine.

Because of the simplicity of the profile in the principal section, the control of driving-pairs can be made simply. The obtained geometrical accuracy of the manufactured driving-pairs proves, that this new grinding method is suitable for application in the works.

The efficiency of the produced drives is much better than that of the worm with straight generatrix, and it reaches, nay at some types it exceeds the efficiency of similar drives made by other grinding methods.

The contact patterns of the driving-pairs are better than those of the references [7]; they have a satisfactory greatness, and their place is localized. The drives prove to be satisfactory concerning the heatlimit power.

Comparing with the worm with arched profile, the worm made by the new method can be made and controlled in a simpler way.

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[11] BRD Patentbeschreibung No. 855929 47 h.3.
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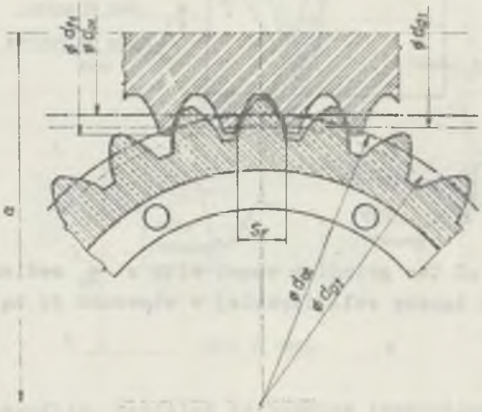

Fig. 1. The principle of tooth-forming, the position of the rolling line
Rys. 1. Zasada odwzorowania zębów, położenie linii styku

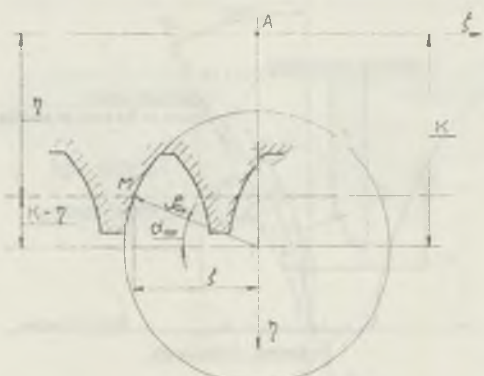

Fig. 2. The profile of the worm in the principal section with ρ_{ax} and K parameters
Rys. 2. Zarys i parametry ślimaka w przekroju osiowym

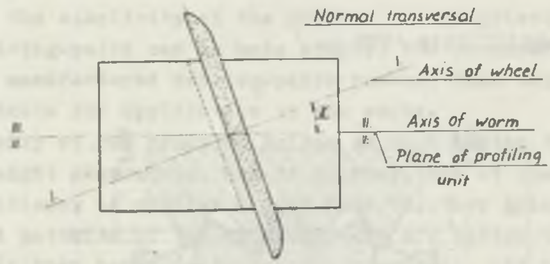

Fig. 3. The banking of the grinding wheel with a γ_0 medium angle of pitch
Rys. 3. Pochylenie tarczy szlifierskiej w stosunku do kąta podziałki

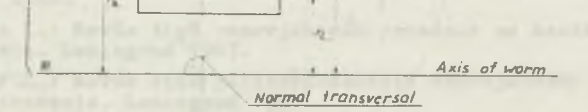

Fig. 4. The position of the profiling unit in the main plane
Rys. 4. Zasada działania urządzenia profilującego tarczę szlifierską w przekroju osiowym

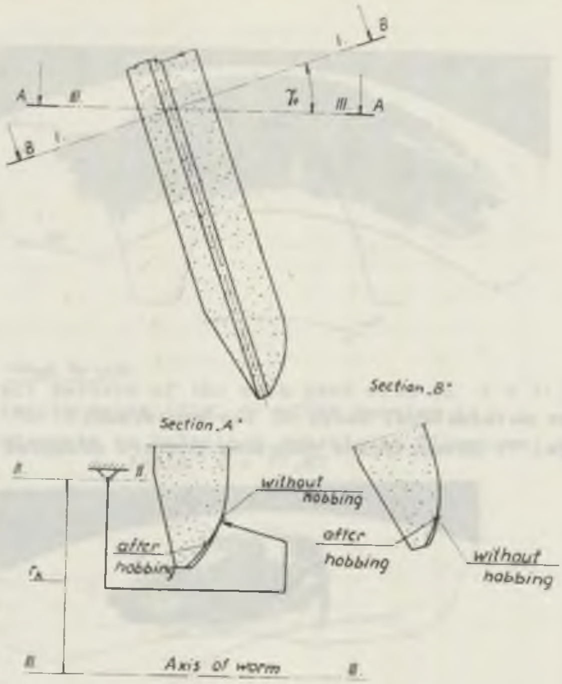

Fig. 5. Wheel-profile, profiled by hobbing (according to the new method), and without hobbing

Rys. 5. Profil tarczy szlifierskiej skorygowany przy pomocy przedstawionej metody i bez korekcji

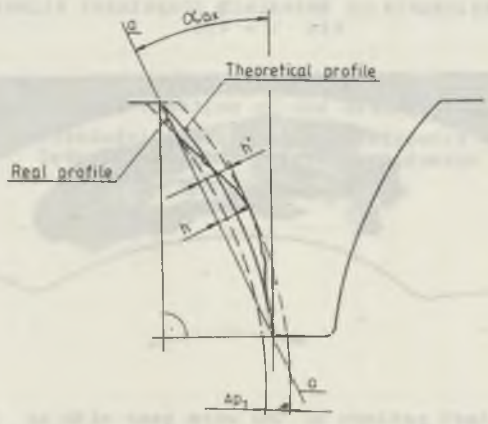

Fig. 6. The interpretation of the profile-error

Rys. 6. Odchyłki zarysu ślimaka

Fig. 7. The mathematical bases of the measurement of profile-error

Rys. 7. Matematyczne podstawy pomiaru odchyłek zarysu

Fig. 8. The contact pattern of the worm gear with an $i = 4,8$ transmission-value, and an $a = 80$ mm axial distance, after running in (modul $m = 16$ mm)

Rys. 8. Ślad przylegania po badaniach przekładni ślimakowej o przełożeniu $i = 4,8$

Fig. 9. The contact pattern of the worm gear with an $i = 11,67$ transmission value, and an $a = 280$ mm axial distance, before running in

Rys. 9. Ślad przylegania przed badaniami przekładni ślimakowej o przełożeniu $i = 11,67$

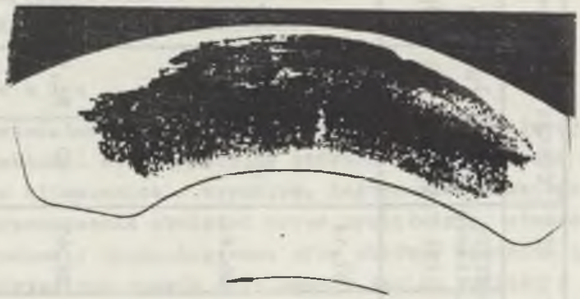

Fig. 10. The contact pattern of the worm gear with an i = 11,67 transmission value (fig. 9) after running in

Rys. 10. Ślad przylegania po badaniach przekładni ślimakowej o przełożeniu i = 11,67

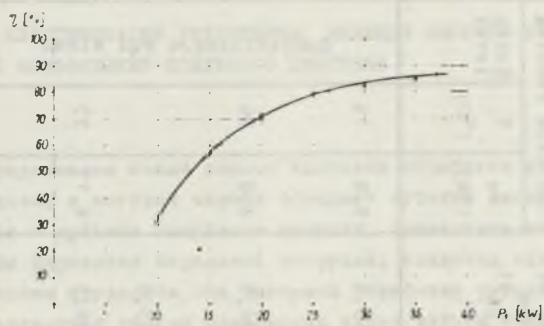

Fig. 11. The efficiency of the worm gear of an i = 4,8 transmission value, as a function of the output of gear

Rys. 11. Sprawność przekładni ślimakowej o przełożeniu i = 4,8 w zależności od mocy silnika napędowego

Table 1

The characteristics of different worm drives summarized on the basis of the appendixes of work

Type of worm gear pair	Transmission z_2/z_1	Modul m (mm)	Pitch circle d_{o1} (mm)	Revol. No. of worm $n_1 (S^{-1})$	Characteristics of idle running			Characteristic of load				Contact pattern		
					p_o (kW)	T (^oC)	Noise level	p_1 (kW)	T (^oC)	Noise level	Efficiency (%)	Tooth edge b_2(mm)	l_h (%)	h_k (%)
				13,5	3,8	19		26,4	34,5		87,14			
								35	43					
Experi-	24/5	16	Ø 152				Meets the prescriptions	26,4	55	Meets the prescriptions		130	48	90
mental	(4,8)			24,5	4,6	26					86,44			
								30	56					
worm drive														
with								35	54					
arched				13,5				19	41					
profile														
								16	51,5					
a=280 mm	(11,67)	12,5	Ø 97,5	24,5	4,11	33					82,65	90	85,5	90
								28	58,5					
								32	61,5					

PRODUKCJA I KLASYFIKACJA SILNIE OBCIĄŻONYCH
PRZEKŁADNI ŚLIMAKOWYCH O DUŻEJ SPRAWNOŚCI

S t r e s z c z e n i e

W referacie przedstawiono nowy sposób obróbki wykańczającej szlifowaniem uzębień przekładni ślimakowych, w których ślimak posiada zęby o zarysie wklęsłym, a ślimacznica - wypukłym. Zastosowanie takiego zarysu poprawia warunki przenoszenia obciążeń przez przekładnię, stwarzając jednak określone trudności technologiczne przy obróbce wykańczającej uzębień. W referacie przedstawiono sposób szlifowania takich uzębień z równoczesną korektą zarysu tarczy szlifierskiej, dzięki czemu zwiększa się dokładność wykonania. Sposób ten daje możliwość przenoszenia przez przekładnię większych obciążeń i zwiększa jej sprawność. Eksperymentalnym potwierdzeniem tego faktu są przedstawione w referacie ślady przylegania współpracujących zębów przed i po badaniach.

ПРОИЗВОДСТВО И КЛАССИФИКАЦИЯ РЕДУКТОРОВ, ИМЕЮЩИХ ВЫСОКУЮ НАГРУЖАЕМОСТЬ
И БЛАГОПРИЯТНЫЙ КОЭФФИЦИЕНТ ПОЛЕЗНОГО ДЕЙСТВИЯ

Р е з ю м е

В докладе представлен новый способ чистовой обработки шлифованием зубьев червячной передачи, в которой червяк обладает зубьями вогнутого профиля, а червячное колесо - зубьями выпуклого профиля. Применение такого профиля улучшает условия переноски передачей нагрузок, создавая однако определенные технологические трудности при чистовой обработке зубьев.

В докладе рассмотрен способ шлифования таких зубьев с одновременной корректировкой профиля шлифовального круга, благодаря чему увеличивается точность выполнения. Этот способ даёт возможность передаче переносить больние нагрузки и увеличивает её коэффициент полезного действия.
Экспериментальным подтверждением этого факта являются представленные в докладе "пятна контакта" взаимодействующих друг с другом зубьев перед испытаниями и после них.