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SOME PARAMETERS OF A STARTER MOTOR

Summary. One major aspects for determining a starter motor characteristics are combustion engine resistance torque on starting, mimimal starting speed and battery parameters.

The presented work describes method for determining of starting parameters for some engines – for example Škoda, Zetor,etc.

PARAMETRY ROZRUSZNIKA SAMOCHODOWEGO

Streszczenie. Głównymi czynnikami określającymi charakterystyki rozruszników samochodowych są: moment oporu silników spalinowych, minimalna prędkość rozruchowa oraz parametry baterii akumulatorów.

Przedstawiona praca opisuje metodę określenia parametrów rozruchowych dla kilku silników, np. Skoda, Zetor.

1. STARTER MOTOR

The electric machinery used in motor vehicles and aircraft works either as a constituent part of the drive, i.e. it functions as the actuator here in fact, or as the electric power source, being the generator. The field of use of small voltage electric machinery can be extended to cover the automation devices which, however, is not the main subject of interest in this report. According to the above classification, the main electric motors are for example the starter, wiper motor, heating, electrohydraulic steering booster, electric water pump, window lifter, seat adjuster and the like.

A starter is an actuator with a very important function, since it puts the internal combustion engine into motion. However, its use is very short-term, practically only several seconds. This has driven and continues to drive the development to ever lighter constructions with both the magnetic and electric circuits highly exploited.

In the development of starters the world manufacturers aim at using permanent-magnets for the excitation attempting to reduce dimensions and weight through increasing the speed of the starter motor (min. 3 times). The speed increase is made possible by introducing a reduction member (into the transmission) between the shaft of the electric motor and the starter pinion. Mostly a planetary gearing is used enabling to maintain the same diameter of the starter (Fig. 2). In this context we point out that it is the use of the permanent-magnets for the starter excitation that enables to increase the planetary gearing gear ratio and thus the speed of the starter motor.

Starters with permanent-magnet excitation are reduced in weight by approx. 15%, they have smaller dimensions and lower winding losses. Permanent-magnet starters with a gearbox are reduced in weight by approx. 40% and have smaller dimensions by one third. According to literature[1] the weight of the ferrite magnets of a 1kW starter is about 220g with the total weight of the starter of 3,0kg. If the NdFeB material was used, then the weight of magnets would only be 68g and the weight of the starter would be 2,7kg. These data relates to a starter with a gearbox.

Lower output starters for passenger cars with the engine capacity of up to 1,9 litters use permanent-magnets in their exciting system without having any gearbox since the manufacture of the latter is demanding technologically and its cost per output would be too high. It is only for the engine capacity of 2 litters and more that a starter with a gearbox is used. In view of possible demagnetisation due to armature reaction, for higher outputs over 2,0kW, classic starter motors with series or compound excitation will remain in use.

2. COMBUSTION ENGINE RESISTANCE TORQUE ON STARTING

The starting of combustion engines at low temperatures is a problem area that deserves constant attention, particularly when the vehicles or motors are exported to areas with low average temperatures. In the winter period also tractors, building machines, earthwork machines, etc. are operated and this all necessitates a more detailed analysis of the starting properties of combustion engines, which can only be carried out experimentally. This requires a number of difficult and time consuming tests in cooling chambers, which considerably extends the development of motors as well as starting systems. Therefore the development of analytic computational methods for the determining of combustion engine resistance torque for low-temperature starting is of great use.

The starting process is influenced by a number of factors that cannot be expressed analytically. This means that formulas derived experimentally can be of limited applicability - they can only be applied to a given group of engines and to a small range of speed. Despite this, it may be of advantage to compile these formulas and use them at least for check calculations, for example when changing lubricating oil, the size of friction parts and also for a rough determination of the speed of the motor driven by a starting system.

2.1. Combustion engine mean torque

The output of the starting system is given by the resistance torque value while the turning of the engine is stabilised. The mean torque, which is acting against the turning of the engine, may be thought of as consisting of two partial torque values:

$$M_{str} = M_{ke} + M_t, \qquad (2.1)$$

where M_{ke} - torque from the compression and expansion forces,
M_t - friction torque.

M_{ke} is given by the difference between the compression and the expansion work in a situation where the fuel is not burnt in the cylinder, it decreases as the mean value of the crankshaft speed increases, and virtually does not depend on the temperature. The increase in Mke with a drop in speed is principally caused by an increase in the rotation irregularity. As recommended in [1], Mke may be roughly established by using an empirical formula that depends on the compression stage and on the rotation irregularity coefficient.

$$M_{ke} = 0{,}39\, V\left(\varepsilon + 6\sqrt{\delta}\right), \qquad (2.2)$$

where V - engine cylinder volume [dm^3],
ε - compression stage,
δ - rotation irregularity coefficient.

2.2. Friction Torque

Combustion engine starting friction is a complex and as yet little known process. Depending on temperature, viscosity and oil volume, crankshaft speed, material, the quality, condition and geometric area of the surfaces acting upon each other, the friction may be, in different engine parts, fluid, limiting, or mixed. The friction process cannot be generally classified in the whole engine such as limiting friction or fluid friction since it may be different for each kinematic pair.

Analysing the facts obtained from the literature [1,2,3] some conclusions may be drawn concerning the friction character. It is known that at the main and connecting rod points it is semifluid, while the friction of piston rings and piston pins is closer to limiting friction even if it is admitted that at moments where the piston, approximately in the middle of its stroke, attains its maximum speed, the friction of the piston rings may be semi-fluid.

Since fluid and semi-fluid friction, which is dependent on oil viscosity, the speed and area of surfaces acting upon each other, is the predominant constituent in each of the kinematic pairs of an engine, the overall resistance torque caused by friction (in the sequel only friction torque) increases as the viscosity of the oil used is higher and as the engine size grows. As the speed increases, the friction torque grows more slowly, which may be accounted for by the oil films on the friction surfaces getting warmer, as the turning of the engine progresses, and assuming different physical properties. This also changes the value of the friction torque in the course of the turning. Therefore the values measured vary and are dependent on the length of the time the engine is turned. A more precise definition would be that the measurement results vary with the time elapsed from setting the crankshaft to motion to the point of measurement. During the first few seconds of the turning, the change of the resistance torque is particularly fast, which, among others, is due to crankshaft rotation irregularities. In literature, detailed explanations are mostly provided to account for the influences of oil viscosity, starting speed, and engine (friction surface) area. On the other hand, questions concerning the influence of the rotation irregularity coefficient on the engine resistance torque, the influence of the compression stage, number and position of cylinders, are given less attention, and this all affects the accuracy of the resistance torque calculation, all these influences are analysed using values acquired from experiments - always a limited number of them and related only to certain types of engine.

2.3. Resistance Torque Calculation (Friction Torque)

It follows from the above conclusions that the engine resistance torque may be thought of as an exponential function of speed and motor oil viscosity. The areas of friction surfaces are given as certain size constants. Then the torque M can be written as:

$$M_t = K\,A\,\nu^{\alpha}\,n^{\beta}, \tag{2.3}$$

where A - is a quantity, comprising the influence engine design parameters,

ν - kinematic oil viscosity,

n - crankshaft speed,

α, β - engine type conditioned constants.

The most serious problem, apart from the determination of constant A, is to obtain the constant K, and exponents α,β. The exponents should lie between zero and one thus expressing the fluid-limiting friction ratio in the main kinematic pairs of the engine. However, for certain ranges of motor oil viscosity and crankshaft speed, they may be considered as constant.

The following formulas for the calculation of the resistance torque mean value, caused by friction, depending on the cylinder volume of the engine in question, may be derived using a similar analysis:

$$M_{str} = 52{,}46 A v^{0,5} n^{0,38} 10^{-6} \left\lfloor Nm, cm^3 cSt, \min^{-1} \right\rfloor. \qquad (2.4)$$

By substituting the value of the (SAE 5W-40) motor oil viscosity at -25°C (3846 cSt) and performing some simplification, we get the following simplified formula:

$$M_{str} = 10{,}796 n^{0,38} \left\lfloor Nm, cm^3, cSt, \min^{-1} \right\rfloor. \qquad (2.5)$$

These formulas are valid for speed ranging from 50 to 200 rpm. The results of the calculation, with combination of the starter characteristics are shown in *Fig. 1.*

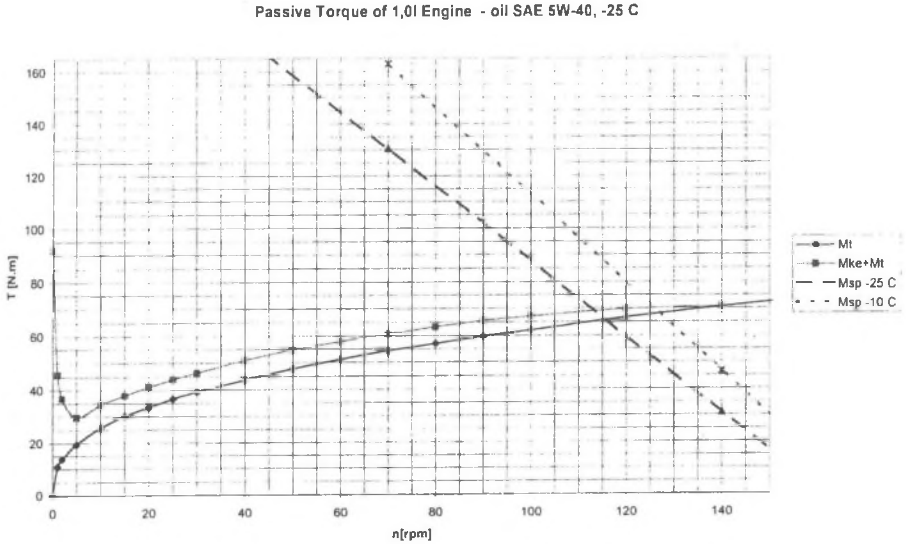

Fig.1. Passive torque curves of the 1,0 l engine
Rys. 1. Wykres momentu biernego silnika o pojemności 1,0 l

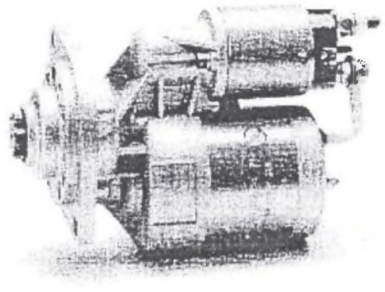

Fig .2. Geared starter MAGNETON, 12V/1 kW
Rys. 2. Rozrusznik z przekładnią firmy Magneton, 12V/1kW

The improvement of methods for calculating the resistance torque depends on analysis of measurements for engines of one type and similar output. It may not be possible to obtain a formula to be used for all engines, regardless of the type, number and arrangement of cylinders.

In this light, such a procedure will be suitable which focuses on individual engine groups defined by the type and output. This means that the data from the experiments should be concentrated, analysed, and more general conclusions should be drawn from the measurement results. In principle, this entails establishing a different empirical formula for each engine group to calculate the resistance torque at starting.

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