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SIMULATION TESTS OF THE STARTING SYSTEM

The purpose of the investigation was to work out a simulation model for the starting system and to verify it on a real object. The reliability analysis of the starting system was carried out on the worked out model. Experimental tests were carried out on the ELKON-SUPER 3 test stand. Angular velocity, torque, voltage and current drawn by the starter were recorded during the tests.

KEYWORDS: modelling, simulation, starting system

1. INTRODUCTION

In the course of the starting system operation in the means of transport, as a result of the processes which force ageing. a change in the value of structure parameters occurs and it causes the worsening of the technical condition. Changes which gradually build up may make structure parameters reach their boundary values, at which either damage to an element or a change in technical properties of the starter occurs.

When structure parameters reach their boundary values, the starter or its unit may lose the assumed technical-operational properties completely. However, even if structure parameters do not reach their boundary values, further operation of the starter or its unit may be inadvisable or impermissible because of many technical-operational factors, e.g.lower performance efficiency of the starting system. The analysis of these factors makes it possible to determine permissible values of structure parameters characterizing such condition of the starter at which its use is still possible [1, 2, 9].

Consequently, in simulation tests it is advisable to distinguish the following classes of starter technical conditions:

– efficiency,
– inefficiency,

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– fitness for use,
– unfitness.

If none of the structure parameters from the U set, which describes the starter technical condition, reaches the admissible value, the starter is technically efficient. It means that its technical-operational properties correspond to those assumed in the construction and production stages. The starter can perform all the functions according to its purpose.

If any parameter from the U set reaches or exceeds the admissible value, the object can still perform its major operational functions, i.e.it is in the fitness state. However, if various criteria are taken into consideration, the starter`s technical-operational properties will not fully correspond to the assumed ones (e.g.decrease in the starter`s torque). The starter will be in the state of incomplete efficiency, i.e.technical inefficiency. If any of the U set parameters reaches its boundary value, the starter will lose its technical-operational properties and will not be able to perform its operational functions. The starter will be in the state of unfitness [4, 17, 18, 19].

In the course of investigation, an attempt to simulate chosen fitness states of the starting system has been made.

2. RELIABILITY MODEL OF THE STARTER

The theoretical model was developed on the basis of start-up system equations [3, 8, 11, 14, 16]. Figure 1 presents the diagram of start-up circuit connections in which characteristic electric values are indicated. It can be concluded from the figure that voltage *UR* on the clamps of the starter in steady state can be calculated by summing drops in voltage (1):

$$U_R = E_A - (R_w + R_p)I \tag{1}$$

where: *EA* – battery electromotive force, *Rw* – battery interior resistance, *Rp* – resistance of conductors connecting the starter and the battery, *I* – current taken by the battery.

Counter-electromotive force can be expressed by the following formula (2):

$$E_R = U_R - \Delta U_{SZ} - R_R I \tag{2}$$

Considering the state of full braking (n = 0, *ER* = 0), it is possible to determine the value of current taken from the battery at start-up (fault current I) (3):

$$I = \frac{E_A - \Delta U_{SZ}}{R_w + R_p + R_R} = I_z \tag{3}$$

The power of the starter is expressed by the following formula (4):

$$P_e = E_R I = (E_A - \Delta U_{SZ})I - (R_w + R_p + R_R)I^2 \tag{4}$$

The power value equals zero in two points: an initial one (where ER = 0 and n = 0) and in the point of work corresponding to the theoretical no-load state (I = 0).

The current at which electromagnetic power reaches its maximum value can be determined from the following relation (5):

$$I_{p\,max} = \frac{E_A - \Delta U_{SZ}}{2(R_w + R_p + R_R)} = \frac{I_z}{2} \tag{5}$$

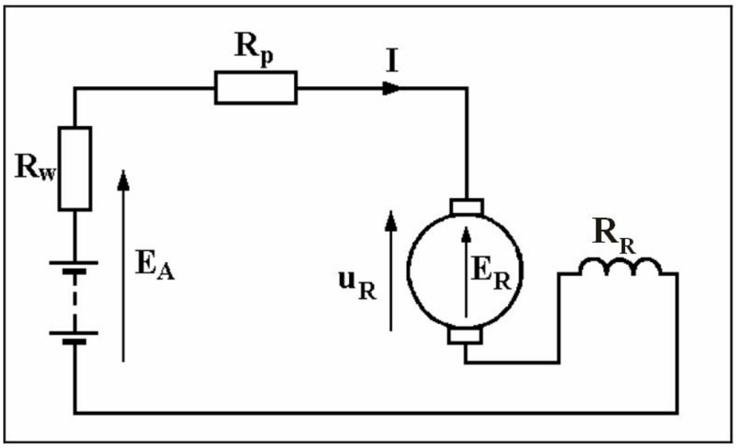

Fig. 1. Connection diagram of the start-up circuit in which characteristic values are indicated (E_A – electromotive force, R_W – battery interior resistance, R_p – resistance of conductors, U_R – voltage on the starter, E_R – counter-electromotive force, R_R – starter resistance)

The maximum power of the starter is determined by substituting the current from the formula to the relation (5):

$$P_{e\,max} = \frac{(E_A - \Delta U_{SZ})^2}{4(R_w + R_p + R_R)} \tag{6}$$

The starter electromagnetic efficiency is assumed ηe = 0,85-0,9 – formula (7):

$$P_R = P_e \eta_e \tag{7}$$

The statement of starter modelled characteristics is presented in Fig. 2.

The subject of analysis were three groups of starters: R76, E100, R5, for which damage distribution was determined. The damages which occurred most often were to electromagnetic switches and starter drives.

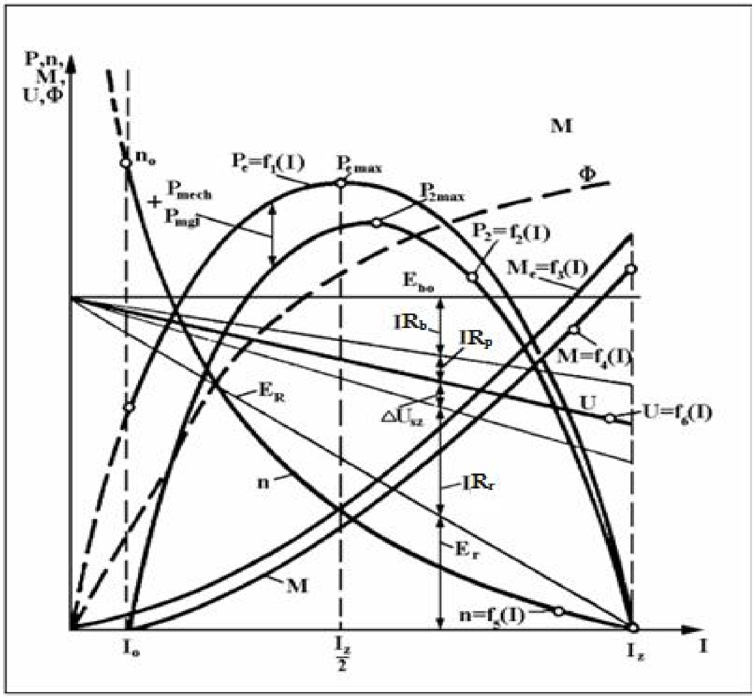

Fig. 2. Characteristics of the car starter (P – power, n – rotational speed, M – starter torque, U – voltage, ϕ – magnetic flux, E_R – starter counter-electromotive force, I_Z – fault current)

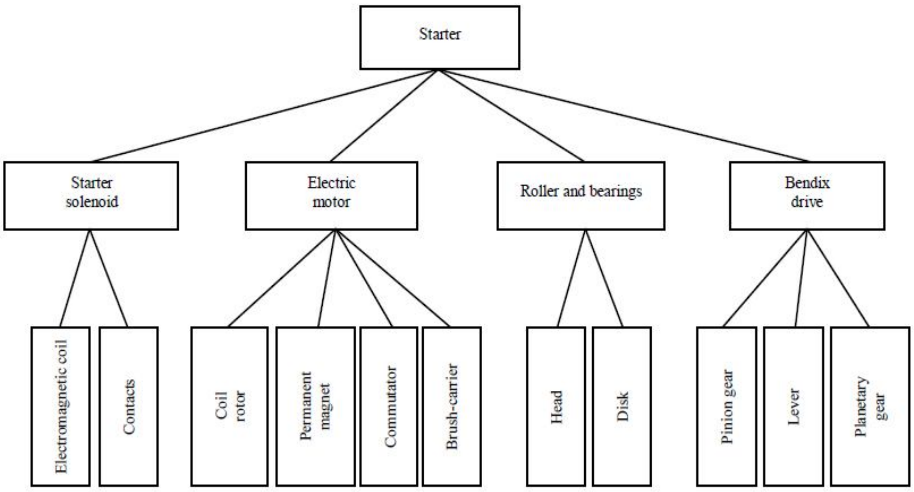

Fig. 3. Structural analysis of the starter

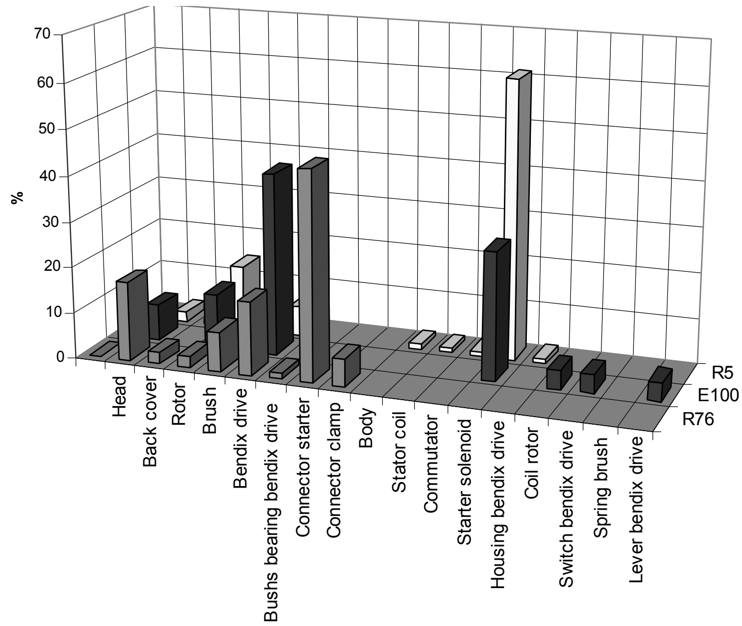

Fig. 4. Percentage distribution of damages for starter elements [5]

3. EXPERIMENTAL TESTS

3.1. Stand for testing starters

The simulation tests of starters were carried out on the measuring stand, which makes it possible to record and store data. Measuring and recording both electrical values (current, voltage) and mechanical values (torque and angular velocity) requires using proper converters.

The ELKON SUPER 3 test stand was used for tests. Its diagram is presented in Fig. 5 and its view in Fig. 6.

The measured values are: angular velocity, torque, current and voltage.

- Angular velocity of the starter`s rotor was measured with the use of the rate generator connected to the rotor`s shaft.
- While testing the starter, voltage and current signals are transmitted to the analogue-to-digital converter.
- Torque was measured with the use of a braking device which contains the following elements: wheel with a toothed ring, braking lever, measuring block (strain bridge).

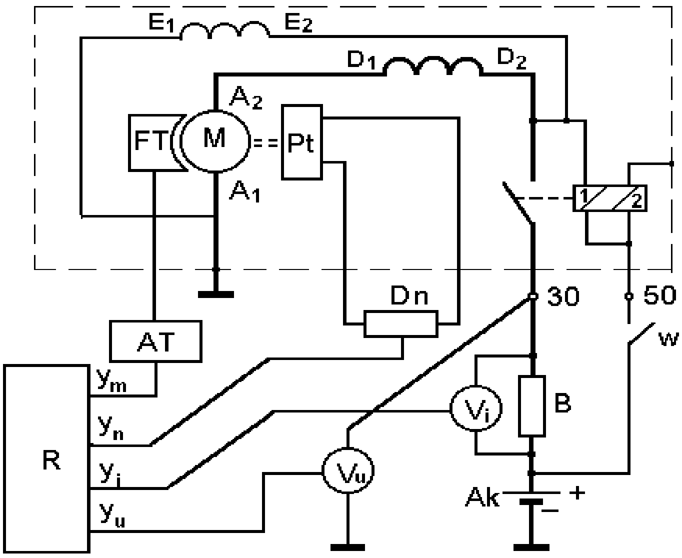

Fig. 5. Diagram of the stand for testing the starter: A1, A2 – armature coil, D1, D2 – series winding, E1, E2 – shunt winding, 1 – drawing winding of the electromagnetic switch, 2 – holding winding of the swich, Pt – rate generator, Dn – voltage divider, FT – strain gauge of force, AT – strain bridge amplifier, B – shunt, Ak – battery, R – recorder (computer), V_i – millivoltmeter, V_u – voltmeter

Fig. 6. View of the test stand

3.2. Results of simulation tests

The following starters were used for carrying out experimental tests:

– R76: U = 12 [V], $I_0 \leq 45$ [A], $I_{SC} = 330$ [A], P = 0,6 [kW], M ≥ 8 [Nm], $\omega \geq 785{,}39$ [rad/s];
– E100: U = 12 [V], $I_0 \leq 65$ [A], $I_{SC} = 540$ [A], P = 1,5 [kW], M ≥ 20 [Nm] , $\omega \geq 523$, 6-710,62 [rad/s];
– R5: U = 12 [V], $I_0 \leq 85$ [A], $I_{SC} = 600$ [A], P = 1,5 [kW], M ≥ 25 [Nm], $\omega \geq 523{,}6$ [rad/s].

According to the technical-operational documentation and trade standards, basic control parameters of starters are: current amperage, voltage, angular velocity and torque. Fig. 5 and Fig. 6 present the results of factory characteristics and those obtained in tests.

On the basis of mathematical model analysis, a change of voltage decrease ΔU_{SZ} for brush wear and a change of magnetic flux in the starter circuit by means of introducing an additional magnetic port was chosen.

In the course of experimental tests, the following kinds of starter damages were simulated: wear of the mass brush, wear of the main circuit brush, simultaneous wear of the mass brush and the main circuit brush and additional magnetic circuit port.

The obtained courses of characteristics for the mentioned above kinds of damages are presented in Fig. 7 – Fig. 10.

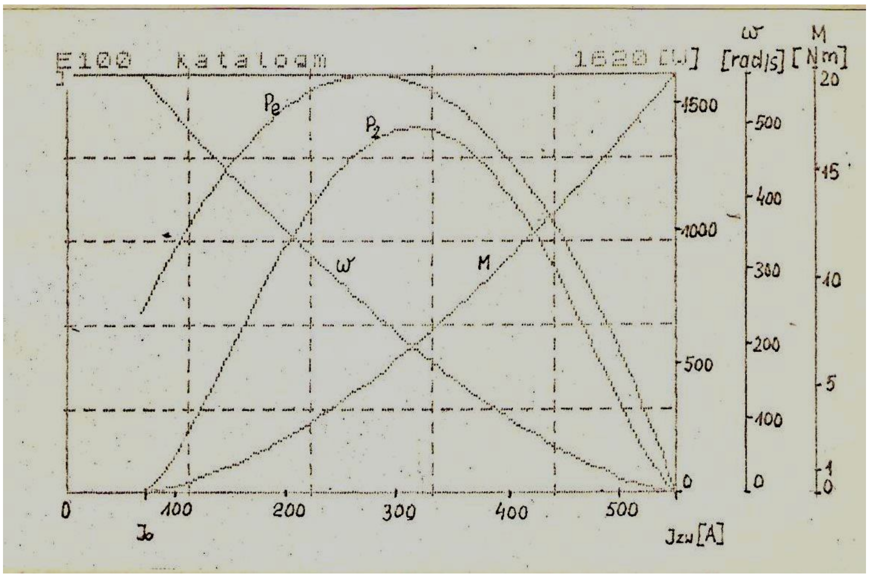

Fig. 5. Catalogue characteristics of the E100 starter

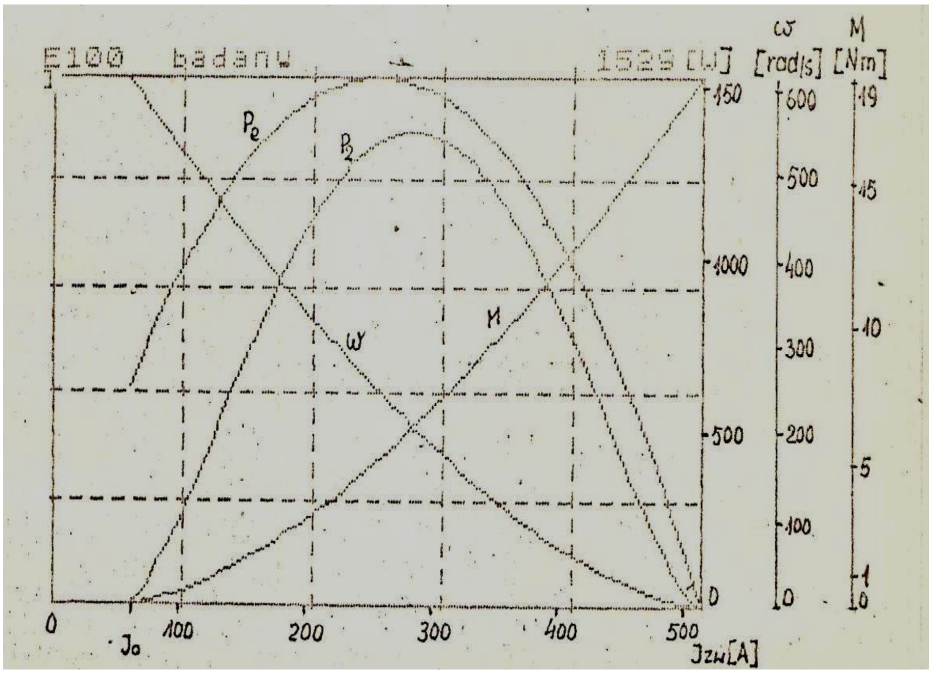

Fig. 6. Experimentally determined characteristics of the E100 starter

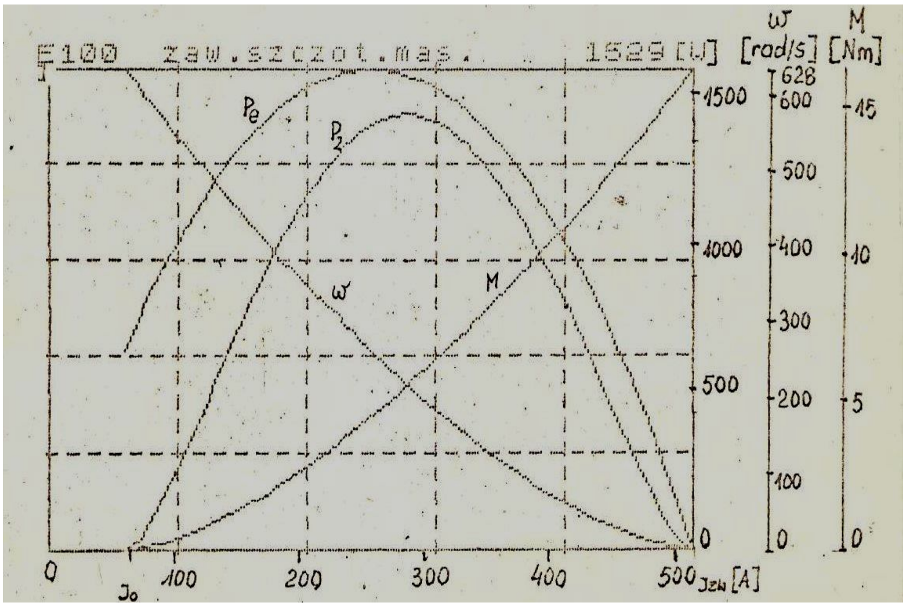

Fig. 7. Recorded characteristics of the E100 starter for the worn mass brush

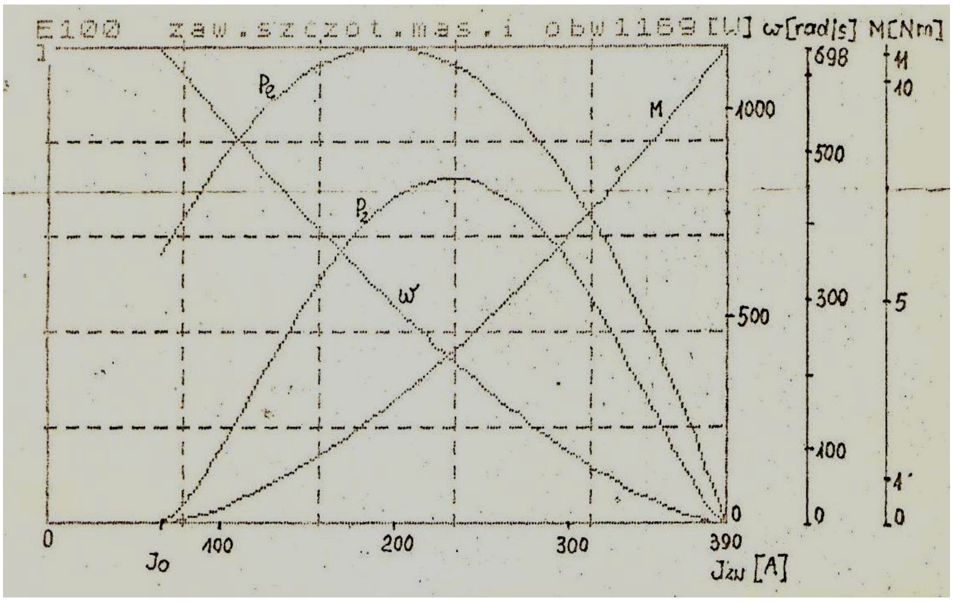

Fig. 8. Recorded characteristics of the E100 starter for the simultaneous wear of the mass brush and the main circuit brush

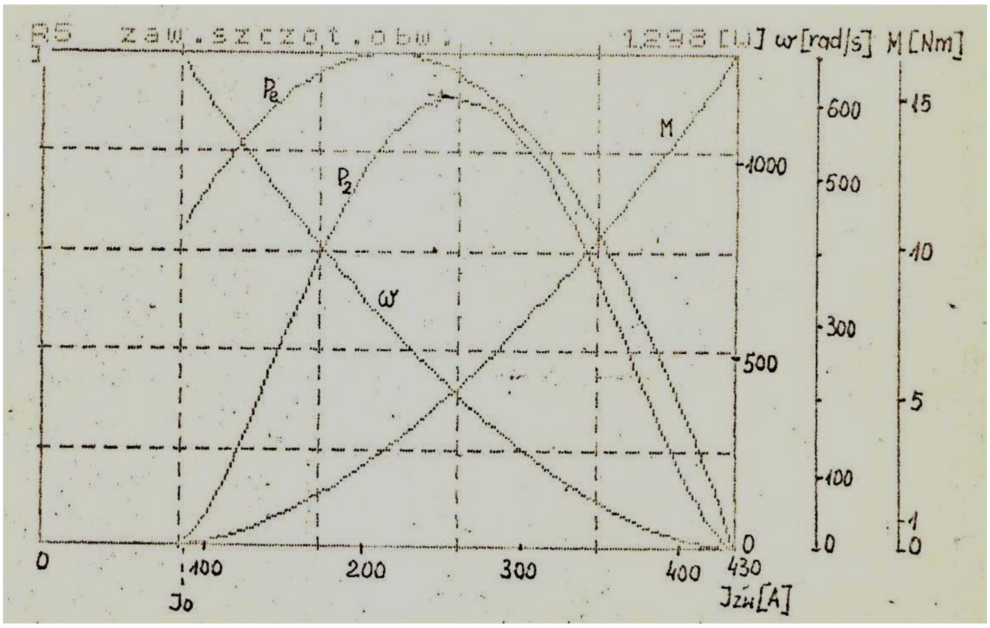

Fig. 9. Recorded characteristics of the R5 starter with the worn main circuit brush

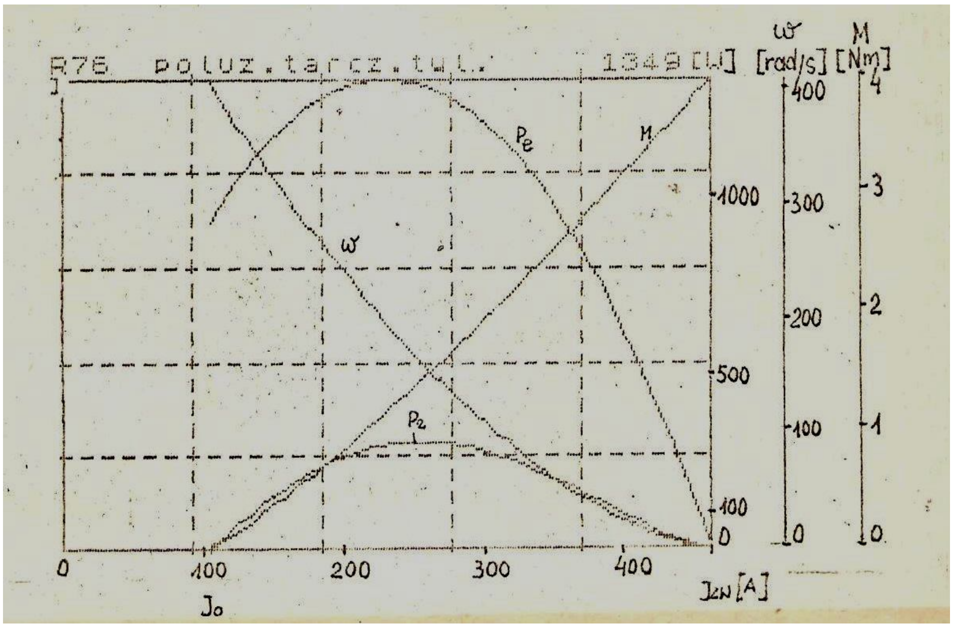

Fig. 10. Recorded characteristics of the R76 starter with an additional magnetic circuit port

4. SUMMARY

On the basis of the carried out calculations and simulation tests, it has been stated that the shapes of speed, torque and power characteristics are comparable to the catalogue ones. At the wear of the mass brush, it has been noticed that for the E100 starter the maximum of electric power decreased by 137 W in relation to the catalogue state. Mechanical power on the rotor decreases by 221W, and the maximum torque decreases by 4 Nm. Current amperage of idle running also changed, and short-circuit current equals I_{ZW} = 390 A.

Simultaneous wear of the mass brush and the main circuit brush in the E100 starter results in the decrease of mechanical power value to P_m = 800 W, whereas electric power equals P_e = 1169 W. Maximum torque of the E100 starter reaches the value of M_{max} = 11 Nm at current I_{ZW} = 390 A.

The simulated state of an additional port in the magnetic circuit of the R76 starter results in the increase of the absorbed current at idle running to I_Q = 100 A and the decrease of mechanical power by 80%.

The purpose of the carried out simulation tests is to work out diagnostic standards for stand tests of starters with the use of computers.

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