Determination of the Probability of Failure of the Starter of a Passenger Car

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Abstract. The paper presented the mathematical processing of data on the probability of failures for 150 starter electric motors of the car type application of a Poisson distribution law. The data regarding the situation of the faults occurred, at the starting electric motors, on 200 thousand km were provided by a company specialized in the maintenance of the analyzed car model. Possible faults that may occur in the starting electric motors of cars during operation are shown. At the end of the works, the probabilities of producing defects (0, 1, 2, 3, …, 7 failures) and the variation of the failure function (reliability) F(k) for these eight situations are determined..

Keywords: Poisson's Law · Electric Starter Engine · Car · Reliability

1 Introduction

The electric starter motor consists in principle of a tubular pole housing in which the pole shoes, excitation windings and permanent magnets are housed. The electrical armature with armature winding is situated in this pole housing. The engaging relay, also known as a solenoid switch, is a combination of a relay and solenoid magnet, and is mounted at the top in the drive-end bearing. The single-pinion gear with pinion, free-running roller, engaging lever, carrier and in-line spring is situated in the drive-end bearing [1].

The electric motor is a very important component of the starting system of the vehicles equipped with internal combustion engines, and keeping it in a good technical condition, by applying the maintenance system, is the guarantee of a good start, under normal operating conditions of the engine systems.

The causes of the failures of the electric starter motor are divided into two categories: electrical and mechanical.

Electrical faults in the starter are mainly caused by overloads. This can manifest itself in ground and winding short circuits in the field and armature winding, but sometimes also in the coils of the control elements (solenoid switch). Carbon brushes and collectors are subjected to high loads, and clamping carbon brushes in the starter leads to the formation of significant arcs due to the high currents. These arcs often destroy the collector [1].

Figure 1 shows a type of electric starter motor for internal combustion engines with the main components.

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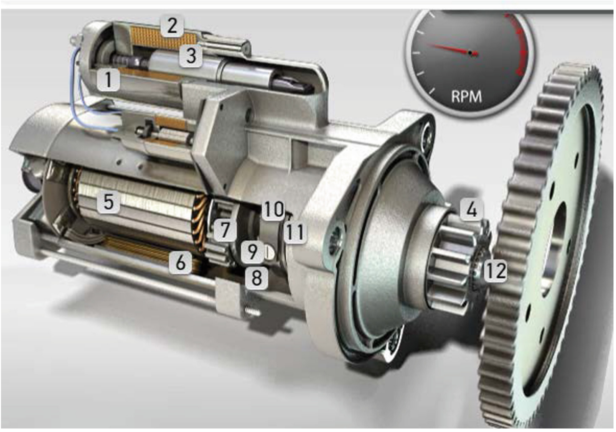

Fig. 1. Electric starter motor for internal combustion engine [1]: 1-Starter solenoid, 2-Winding, 3-Through-bolts, 4-Pinion, 5-Armature, 6- Winding, 7-Planetary gear, 8- Ring gear, 9- Planetary gearset, 10-Engaging lever, 11- Carrier, 12-Armature shaft

Possible electrical failures of the starter: faulty relay or contact switch, failure of the solenoid relay, short circuit in the windings of the stator, rotor or solenoid, discharged or defective car battery, oxidation of contacts, imperfect contacts [2].

Possible mechanical failures of the starter occur due to the over-the-limit wear of some components (collecting brushes, electric motor shaft bearings, clutch with the coupling sprocket to the crown of the heat engine flywheel, the collector on the rotor, the clutch drive mechanism, the planetary reducer) or the breaking of teeth from the coupling sprocket or the leverage of the clutch drive mechanism.

In the paper [3] a method of predicting the reliability of the starter from cars is presented using a program that allows forecasting the technical condition of the starter and providing service intervals according to the technical condition. Simulation studies for selected failures in the electrical and mechanical circuits of the starter allowed performing an analysis of the parameters that define the technical condition of the starter.

In the paper [4] various failures and the causes of these failures, diagnostic methods, and also various developments in the control of the failures of the starting electric motor from cars are presented in detail.

2 Primary Data of the Study

For this study, data on the failure of the starting electric motor, from a number of 150 cars used for taxi or urban distribution activities, were recorded over a period of about three years, during which time the cars traveled approximately 200,000 km.

Cars were registered whose starter electromotor had no faults, which had one or more different defects or defects that were repeated.

The most common defects were those related to the collecting brushes, followed by defects in: the bearings of the electric motor shaft, the clutch with the coupling sprocket to the crown of the flywheel of the thermal motor, the electromotor rotor, the collector on the rotor, the solenoid, the drive mechanism of the pinion clutch, the planetary reducer, the battery of accumulators, the contacts of the conductors, the way of fixing the electromotor on the frame.

The following numbers of failures have been recorded according to Table 1.1, in which N_c is the number of electro motors that have recorded k failures, and k is the number of possible failures in the N_i tests (k = 0, k = 1, k = 2, …, kmax, $N_0 = 150$, integers).

The probabilities of occurrence of 0, 1, 2, 3, …, 7 faulting (malfunctions) and the variation of the failure function (defiability) F(k) for these eight situations are further determined.

3 Processing of Data on Falls (Malfunctions)

The data processing was done according to Poisson's law (the law of rare events) for samples consisting of a large number of elements, when the probability of failure is reduced, respectively the malfunctioning function $F < 0{,}1$, provided that the average number of malfunctions in different strings of experiments $N_0 \cdot F = m = a =$ constant, in which N_0 is the number of elements taken in the study [5].

Poisson's law is specific to the distribution of rare events, such as: the occurrence of accidents, malfunctions of machines and installations, the appearance of quality inappropriate products from the manufacture in a batch of high-quality products, etc.

The average number of falls with the relation [6] is determined:

$$m = M[X] = \sigma^2[X] = \frac{1}{N_0}\sum_{k=0}^{k=k_{\max}} k \cdot N_c \tag{1}$$

Substituting in relation (1) results in the average number of falls:

$$m = \frac{1}{150}\sum_{k=0}^{k=7} k \cdot N_c = \frac{1}{150}(0 \cdot 53 + 1 \cdot 44 + \ldots + 7 \cdot 1) = 1,306667 \textit{ malfunctions}$$

The probabilities of occurrence of the P(∞,k) falls and the failure (defiability) function F(k) are calculated with the following relations [7]:

$$P_{(\infty,k)} = \frac{m^k}{k!} \cdot e^{-m} \tag{2}$$

$$F_{(k)} = \sum_{k=0}^{k_{\max}} P_{(\infty,k)} \tag{3}$$

The values of the probability function P(∞,k) were obtained using the relation (2), as follows:

$$P_{(\infty,0)} = \frac{1,306667^0}{0!} e^{-1,306667} = 0,270721$$

Table 1. The situation of the failures of the starting electro motors

N_c	53	44	25	19	4	2	2	1
k	0	1	2	3	4	5	6	7

Table 2. Variation of the functions P(∞,k) and F(k) as a function of k

N_c	53	44	31	13	4	2	2	1
k	0	1	2	3	4	5	6	7
$P_{(\infty,k)}$	0.270721	0.353742	0.231111	0.100662	0.032883	0.008593	0.001871	0.000349
$F_{(k)}$	0.270721	0.624463	0.855574	0.956236	0.989119	0.997713	0.999584	1

$$P_{(\infty,1)} = \frac{1,306667^1}{1!} e^{-1,306667} = 0,353742$$

$$P_{(\infty,2)} = \frac{1,306667^2}{2!} e^{-1,306667} = 0,231111$$

$$P_{(\infty,3)} = \frac{1,306667^3}{3!} e^{-1,306667} = 0,100662$$

$$P_{(\infty,4)} = \frac{1,306667^4}{4!} e^{-1,306667} = 0,032883$$

$$P_{(\infty,5)} = \frac{1,306667^5}{5!} e^{-1,306667} = 0,001871$$

$$P_{(\infty,6)} = \frac{1,031579^6}{6!} e^{-1,031579} = 0,000597$$

$$P_{(\infty,7)} = \frac{1,306667^7}{7!} e^{-1,306667} = 0,000349$$

The results of the calculations are given in Table 2.

The calculations for the function F(k) were performed until the value F(k) = 1, the maximum possible value, was reached. The attainment of the unit value for F(k) at k = 7 is due to the values of N_c for the other values of k.

In other situations, for other values of N_c, it can be reached F(k) = 1 and for k < 7 or k > 7.

The variation of the functions P(∞,k) and F(k) is shown in Fig. 2 and Fig. 3.

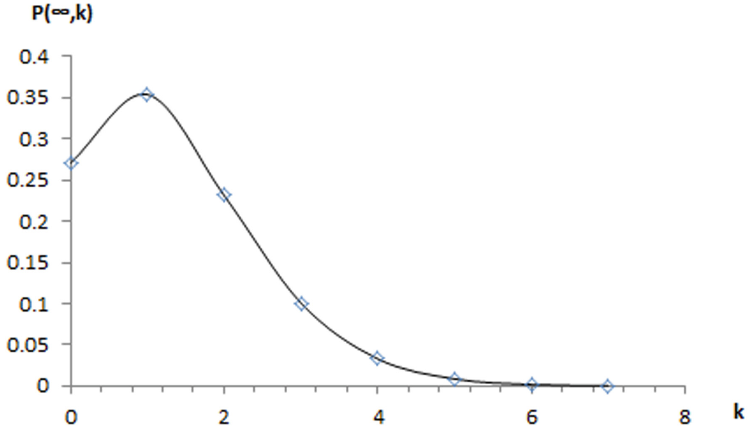

Fig. 2. The variation function P(∞,k)

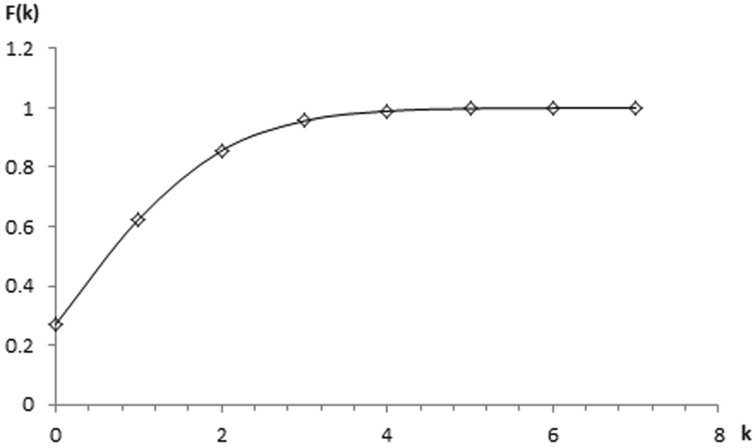

Fig. 3. The variation function F(k)

4 Conclusions

- The probability of no failures occurring at the starters is about 27.07% (41 pieces);
- The probability of a single failure occurring at the starters is about 35.37% (53 pieces);
- The probability of two failures occurring at the starters is about 23.11% (35 pieces);
- The probability of three failures occurring at the starters is about 10.06% (15 pieces);
- The probability of five failures occurring at the starters is about 0.18%, respectively less than one starter;
- The probability of six or seven failures occurring at the starters is negligent;

It is noted that the highest probability, of 35.37%, is the occurrence of a single defect at the starter, corresponding to a number of 53 cars out of the total of 150, for a journey of 200 thousand km.

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