

Operability of MAN F2000 Trucks in the North

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Abstract—Experience in operation of trucks shows a significant increase in a failure number of their systems and parts in natural and climatic conditions of a permafrost zone compared with the conditions of a moderate climate. This article presents a study of operability of the forty MAN F2000 trucks used in Yakutia for long-haul transport. The systems were identified that limit reliability of these vehicles in the severe operation conditions of the North. These are an engine, suspension and brake system. Regularities of changes in the main operability parameters (operating time to failure and operating time between failures) of these systems and truck as a whole were investigated. Regression models of dependences of the operating time between failures on truck mileage for the engine, the suspension and brake system show a significant decrease in this operating time with the increase in the mileage. Taking into account this decrease, an improved technique of calculating the planned repair number for the systems and parts of automobiles, based on statistical information about the failures of these assembly units in the specific operation conditions is proposed. This technique can be used when planning the repairs of the vehicles with the different mileage and calculation of the required number of the spare parts.

Keywords—truck; operability; operating time to failure; operating time between failures; mileage; natural and climatic conditions of the North

I. INTRODUCTION

A product range of the MAN trucks includes a wide assortment of the heavy-duty trucks for various types of transport tasks. These trucks are equipped with the powerful engines, the anti-lock braking system, the traction control system and other modern safety systems. The trucks intended for export outside the European Union have characteristics that improve their operability in the conditions of bad roads and adverse climate.

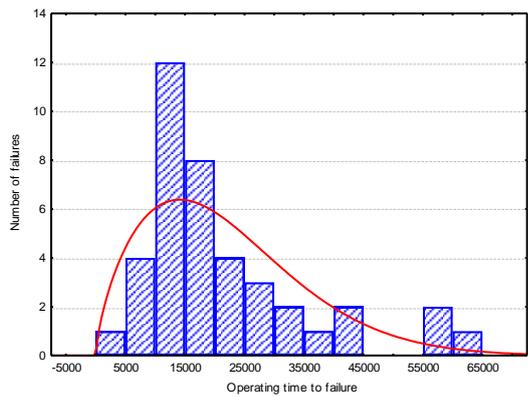
In this article an analysis of the operability of the forty MAN F2000 trucks in the first seven years is presented. The trucks of a transport company of PJSC ALROSA in the Republic of Sakha (Yakutia) were used for the long-haul transport on the dirt roads with a gravel and aggregate surface

in low air temperatures. The mileage of the particular trucks exceeded 600 thousand km during this period. The MAN trucks are very reliable, so during these seven years only 2150 trips of the vehicles for the repairs were. As a rule, one to three malfunctions were eliminated at each trip.

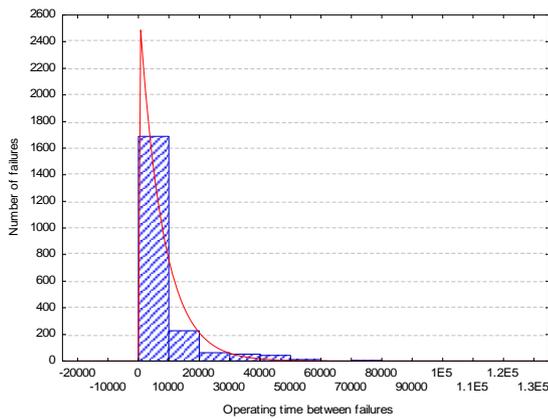
II. RESULTS AND DISCUSSION

The defining parameters to assess the operability of technical facilities are the operating time to failure and operating time between failures. These parameters are used in the conventional techniques for the calculation of the required number of the spare parts [1]. For the MAN truck, distributions of the operating time to failure and operating time between failures are shown in Fig. 1. The distribution of the operating time to failure of the MAN F2000 trucks is best described by the Weibull distribution. This distribution of the failures corresponds to normal wear and gradual accumulation of damage in the operation of new cars. The exponential distribution, which is typical of the sudden failures, is the most suitable for the operating time between failures. An average value of the operating time to failure (21.5 thousand km) is approximately greater by a factor of three than the average operating time between failures (7.8 thousand km). It should be noted that there is a large scatter of data of the operating time between failures. If a standard deviation of the operating time to failure (14.3 thousand km) is 0.66 of the average value of this operating time, then the standard deviation of the operating time between failures (10.5 thousand km) is 1.3 times the average value of the corresponding operating time. These basic statistics and different distribution laws of the operating times to failure and between failures indicate low quality of the repair at the transport company and possible use of the non-original spare parts. In addition, accelerated depletion of operating life of truck elements is associated with both increased vibration impacts while driving on the bad roads and the negative impacts of the extreme climatic factors as well as a synergetic effect of these impacts. Therefore, the decrease in the operating time between failures of the trucks in

the severe climatic conditions of the permafrost zone is associated with the increase in their mileage.



a



b

Fig. 1. Distributions of operating time to failure (a) and operating time between failures (b) of MAN truck

For the considered MAN trucks a scatter plot of the values for two different variables (the mileage and operating time between failures corresponding to this mileage) was made (Fig. 2). To determine a relationship between these variables, a regression model was created by a method of the robust locally weighted regression. The operating time between failures drops from about 17.5 thousand km at an initial period of the truck operation to a level of 4 thousand km when the mileage reaches 350 thousand km, i.e. more than four times. Then the operating times between failures stabilize at this level.

Thus, with the increase in the mileage there is the significant decrease in the operating time between failures for the MAN truck. Influence of each system of the vehicle on its operability is different, so it is advisable to study the statistical dependences of the operating time between failures on the mileage for the systems limiting the car reliability. To determine such systems, the distribution of the failures of the main systems of MAN truck was created (Fig. 3).

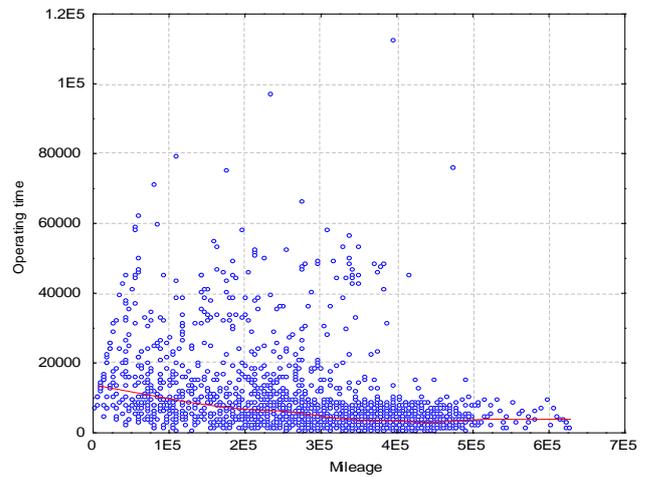


Fig. 2. Regression and scatter plot of operating time between failures and mileage of truck

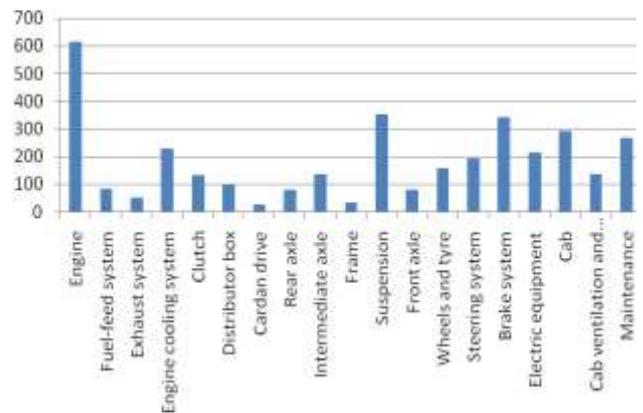


Fig. 3. Failures of MAN truck systems

The engine, the suspension and brake system have the largest numbers of the failures. The basic statistics of the operating times to failure and between failures for these systems are determined with the help of their distributions. The average operating time to failure of the engine is 84.7 thousand km, the standard deviation is 46.9 thousand km. The average value of the operating time between failures is more than half as low and amounts to 38.9 thousand km, the standard deviation is 47.3 thousand km.

The scatter plot of the operating times between failures of the engine and MAN truck mileage is shown in Fig. 4. For the engine and other considered systems, a regression line has several parts. In the first part, the values of the engine operating time to failure are mainly presented, and in the remaining parts, the values of the operating time between failures are shown. Therefore, the first part is not considered for both the engine and other systems. Beginning from the second part, the operating time between failures gradually decreases from the maximum value of 50 to 40 thousand km with the increase in the mileage from 80 to 320 thousand km. The sharp decrease in the operating time between failures to

almost 20 thousand km is observed on the next part up to the mileage of 350 thousand km, and subsequently this operating time keeps the value (20 thousand km).

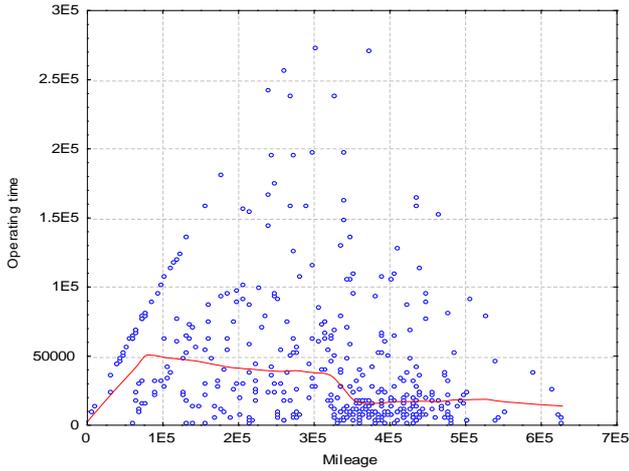


Fig. 4. Regression and scatter plot of operating time between failures of engine and mileage of MAN trucks

The average operating time to failure of the MAN truck brake system is 184.6 thousand km, and the standard deviation is 81.4 thousand km. The average operating time between failures is significantly lower (almost 5 times) and equal to 37.7 thousand km, the standard deviation is 45.2 thousand km. This reduction of the operating time of the brake system is due to the severe road conditions in the permafrost zone. The scatter plot of the truck mileage and operating time between failures of the brake system is shown in Fig. 5. The maximum value of this operating time (100 thousand km) is observed when the truck mileage is 150 thousand km. Then there is the decrease in the operating time: at first, the sharp decrease to the value of about 35 thousand km at the mileage of 300 thousand km and the subsequent smooth decrease to 20 thousand km.

The average operating time to failure of the MAN truck suspension is 140.7 thousand km, the standard deviation is 75 thousand km, and the average operating time between failures is more than three times lower (44.9 thousand km), the standard deviation is 52.2 thousand km. The suspension failures are affected by the difficult road conditions when driving on the ice roads and dirt ones.

The regression and scatter plot of the truck mileage and operating time between failures of the suspension are shown in Fig. 6. The regression reflects the relationship between these variables. In the second part of the regression line (with the mileage from 100 to 170 thousand km), this operating time is about 80 thousand km. Then there is the sharp decrease in the operating time to the value of 35 thousand km with the mileage of 250 thousand km, afterwards the operating time is stabilized at about the level of 25 thousand km.

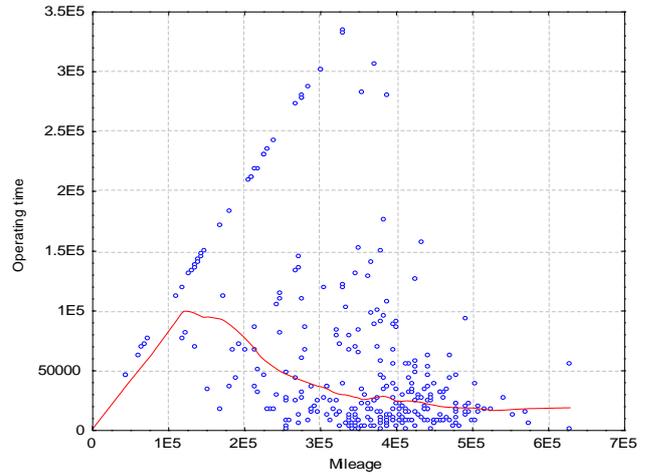


Fig. 5. Regression and scatter plot of operating time between failures of brake system and mileage of MAN truck

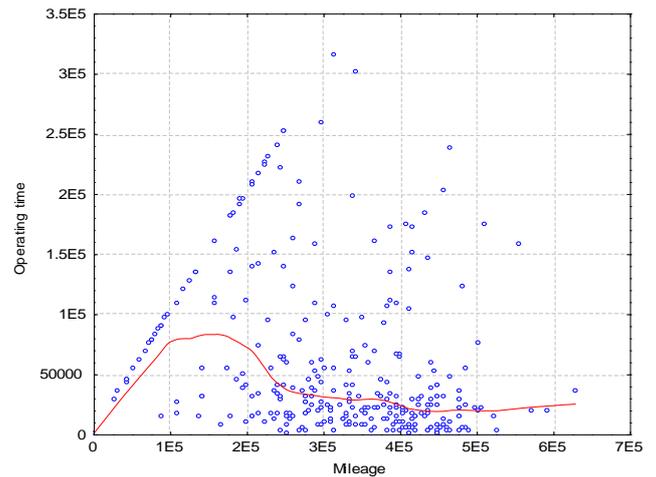


Fig. 6. Regression and scatter plot of operating time between failures of suspension and mileage of MAN truck

Thus, the dependences of the operating times to failure and between failures of the considered systems of the MAN trucks on the mileage have its own peculiarities, which must be taken into account in a prediction of the repairs and required quantity of the spare parts. The most suitable technique of the calculation of the required number of the spare parts for the transport company is presented in papers [1, 2, 3]. This technique uses the information on the failures and part replacements and its basis is a renewal theory developed in works by W. L. Smith and D. R. Cox [4, 5]. In a case of a general renewal process, a mathematical expectation of the repair number is determined by the equation:

$$H_t = \frac{L - R_1}{R_{sp}} + 0.5 \cdot (1 + V_{sp}^2), \quad (1)$$

where L is the mean operating life of the product; R_1 is the mean operating life of the element installed in the product during manufacture; R_{sp} is the mean operating life of the spare part installed during the repair; V_{sp} is a coefficient of variation of the spare part operating life. As the operating life means the operating time, to evaluate the vehicle operability, the

operating time to failure R_{sp} , the operating time between failures R_1 , the mileage till discarding L and the coefficient of variation of the operating time between failures V_{sp} are used in formula (1).

This technique does not take into account the coefficient of variation of the operating life of the element installed in the product during the manufacture. In the initial period of the product operation, results of the calculation of the mathematical expectation of the event number significantly deviate from the empirical data. In addition, in formula (1), the mean operating life of the spare part is assumed to be constant for the entire useful life.

The companies that operate machinery typically have the vehicles with the different mileage in their fleets, but the operating time between failures significantly decreases as the mileage increases as shown above on examples of the MAN truck systems. Therefore, for the vehicles with the different mileage for the calculation of the mathematical expectation of the repair number, the following formula can be proposed:

$$H_t = \frac{\Delta l}{R_{sp}^{\Delta l}} + 0.5 \cdot (1 + V_{sp}^2), \quad (2)$$

where Δl is the value of an interval of the planned changes in the vehicle mileage; $R_{sp}^{\Delta l}$ is the operating time between failures for the actual mileage, received from the corresponding scatter plot of the operating time between failures and mileage; V_{sp} is the coefficient of variation of this operating time.

As the example, the calculation of the number of the repairs for the MAN truck engine was carried out. When calculating according to formula (1), the predicted number of the repairs per the truck for each 100 thousand km of the mileage is 2.65 and does not depend on the truck mileage. This calculation will correspond to the actual number of the repairs, only if the average mileage of the entire fleet of cars is about 300 thousand km. Proposed formula (2) quite well describes the change in the number of the engine repairs for the entire range of the MAN truck mileage during the first seven years of their operation in Yakutia. The calculation results are presented in the following table.

TABLE 1. Calculation of predicted number of repairs for MAN truck engine

	Mileage, thousand km	Number of repairs, calculated according to formula (2)	Actual repair of repairs
1	0-100	2.68	1.07
2	100-200	2.57	1.25
3	200-300	2.54	1.80
4	300-400	4.05	3.22
5	400-500	4.83	3.37
6	500-600	4.71	3.36
7	600-700	12.47	10.23

The proposed technique allows predicting the number of the repairs, close enough to the actual number of repairs for the car engine, taking into account the changes in the operating time between failures with the increase of the mileage. With the mileage of more than 300 thousand km, the calculations and actual data show the increase in the predicted number of the engine repairs, associated with the decrease in the values of the engine operating time between failures during the operation in the harsh climatic conditions. The sharp increase in the number of the engine repairs should be expected when the truck mileage is above 600 thousand km.

III. CONCLUSIONS

In this article, the operability study of the MAN F2000 trucks operated in the extreme climatic conditions of Yakutia is carried out. These heavy-duty trucks were mainly used for the long-haul transport on the dirt roads, which determined the high level of vibration loads on the car elements. The systems limiting the reliability of the MAN F2000 trucks in the real operating conditions of the North were determined. These are the engine, the suspension and brake system.

The regularities of the changes in the basic parameters of the operability (the operating times to failure and between failures) of these systems and the entire truck were studied. The regression models of the dependence of the operating time between failures on the truck mileage for these systems show the sizable reduction in this operating time with the increase in the mileage. To take into account this decrease, the improved technique of the calculation of the repair number for the systems and parts of the cars in the specific operation conditions was developed. Having the statistical information on the failures of the vehicles of a certain make, it is possible to calculate the operating times between failures of the assembly units at the corresponding mileages. This will allow determining the regression between these variables for the specific systems and parts of the vehicle, used for the calculation of the planned repair and maintenance. The number of the repairs of the systems and parts of the particular car of this make can be predicted depending on its actual mileage according to proposed formula (2). This technique can be used during planning of the repair works and calculation of the required number of the spare parts in the transport companies.

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