Improving the reliability of chainsaws based on alignment of reliability of component links

V S Volkov* and D Ju Kastyrin

Department of Automobiles and Service, Voronezh State Forestry University named after G.F. Morozov, 8 Timiryazeva st., Voronezh, Russian Federation

*E-mail: af_volkovvs@vgtu.ru

Abstract. A method is proposed for calculating the reliability of components of a chainsaw and its construction as a whole based on a passive experiment to collect information about the failures of components and cases of inoperable condition. The design of a gasoline saw is considered as a mechanical system with sequential connection of elements, when the failure of one element causes the failure of the entire structure as a whole. The proposed calculation method can be used for the modernization and design of such structures in order to increase the failure time of low-reliability units and equalize the reliability indicators of all components of the chainsaw. It was found that the least reliable node of the MP-5 chainsaw is the ignition system with an average time to failure of 114 hours. At the same time, the most reliable element of a chainsaw is its frame, the average time to failure of which is 264 motor hours. The average time to failure of the remaining chainsaw links for a period of 300 hours is in the range of 20 to 80 hours.

1. Introduction

The chainsaw tool during its use cannot be isolated from the influence of the environment in which it operates, from the influence of processes occurring in the implementation of working functions, from the effects of residual phenomena caused by imperfection of technological processes used in the manufacture of the product. All types of energy (mechanical, thermal, chemical, electromagnetic, etc.) affect the chainsaw and cause it to reverse and irreversible processes that reduce its initial characteristics. According to the recommendations of the standard [1], the structural scheme of the reliability of a mechanical system, including a chainsaw, can be considered as a chain with a serial connection of component elements, when the failure of one element causes the failure of the entire system. This circumstance can be considered as proof of the hypothesis of independence of failure of one element from failures of other elements of the system. As mentioned earlier, it was found in previous studies [2] that such changes in the state of the mechanical system are random, determined by the quality of manufacturing of components, the quality of Assembly of nodes and the system as a whole, as well as the types of operational loads and the quality of service during operation. This circumstance determines the use of probability theory and mathematical statistics methods for evaluating the reliability of machines of this type. In [3], the author examines the safety of the operator when working with a chainsaw and draws attention to the insufficiently reliable operation of the frame vibration damper. At the same time, the paper [4] suggests an improved design of this node, which increases its reliability and safety. Authors [5] compare the performance characteristics of a chainsaw with an internal combustion engine and a battery electric saw. At the same time, they pay attention to
the fact that with a significantly higher performance, the chainsaw has less reliability and is more dangerous. The authors [6] draw attention to a number of design and operational shortcomings of chain saws from different manufacturers and provide recommendations for their elimination. In [7], a new design of the centrifugal clutch is proposed, which increases the reliability of this element and the chainsaw as a whole. A detailed analysis of the state of reliability of the primary elements of a chainsaw and the formation of a summary indicator of its reliability as a system as a whole, which allows predicting the need for spare parts during its service, is discussed very little. This study took into account the experience of research on the reliability of mechanical systems of a similar profile.

2. Formulation of the problem

As the experience of operation of chainsaws in the system of the forest complex of Russia shows, the working process of domestic-made chainsaws is accompanied by a large number of failures due to the low reliability of individual components of the chainsaw. The negative impact of such failures is accompanied by an increase in the cost of restoring the power of the chainsaws and a decrease in labor productivity.

The aim of the study was to draw up a design scheme for the reliability of a gasoline saw with the identification of its least reliable components under operating conditions, followed by the determination of the mean time between failures of each component and the entire structure of the chainsaw as a whole. The data obtained can serve as the starting material for upgrading or constructive processing of unreliable nodes to increase the reliability of chainsaws.

3. Materials and methods

As the practice of operating a chainsaw tool [2] shows, the most frequently encountered malfunctions, the Taiga-214 gasoline-powered saw or the Ural-2 MP-5, are:

- malfunction of the ignition system;
- slip or non-disengage clutch;
- violation of the qualitative composition of the fuel mixture;
- destruction of the crankshaft support bearings;
- gas breakthrough in the exhaust system;
- no engagement in the starter;
- clogging of channels in the lubrication system of the saw apparatus;
- spring breakage of the vibration damping system of the frame;
- destruction of the sawing apparatus.

In practice, the following characteristics are often used to assess the reliability of a mechanical system: the differential distribution function \( f(x) \), the probability of failure-free operation \( P(t) \), the mean time between failures \( t_{ср} \) and \( MTBF \). T.

On the structural scheme of reliability, the elements of a mechanical system are depicted as a sequential chain, the failure of any of which causes the failure of the entire system. The condition for the parallel connection of elements in any section of the structural scheme is the ability of each of the elements connected in parallel to ensure satisfactory operation in the system if other parallel elements fail.

In the standard [1] shows the formulas by which the probability of failure-free operation of the mechanical system is determined in the case of sequentially and parallel connected elements in the structural reliability scheme,

\[
F_i = \frac{m_{ai}}{N + 1},
\]

where \( F_i \) is the probability of failure; \( m_{ai} \) - accumulated frequency; \( N \) is the total number of products in the sample.

In determining the reliability indicators, a structural scheme of reliability and a consolidated list of chainsaw failures that occur during the operation of chainsaws are compiled. Only those elements that have a failure during the studied interval of operating time, most often, in the interval of operating
time up to the limiting state of the mechanical system, are included in the block diagram of reliability. Therefore, the chainsaw reliability block diagram includes only those of its elements that had structural-production failures according to operational observations. To decide on the inclusion of one or another element in the calculated block diagram of reliability, first a consolidated cumulative list is compiled, where data on the operating time of each chainsaw to failure are recorded, separately for each type of failure. Assumptions that the failure of any element of the structural scheme leads to the failure of the chainsaw, while the failures of the elements are independent, allow the use of the standard technique [1]. According to the formulas [1], the mean time between failures and the probability of uptime for each type of failure is determined; mean time to failure and the probability of uptime for the individual elements of the nodes and chainsaws in general are also defined.

The adopted method for determining reliability indicators (probability of failure-free operation, parameters of the distribution law, average time to failure, time between failures), first for each type of failure, then for each element, node and chainsaw as a whole, is convenient in that it allows a reasonable approach to forecasting estimates of the same indicators of the reliability of elements, assemblies and chainsaws in general, other manufacturers and models. The adopted method for determining the time between failures according to the formulas [1] gives a much more accurate estimate of the time between failures of chainsaws.

Time to failure components of the chainsaw is determined by the formula

\[ T_o = \frac{t}{\Omega(t)} \]  

(2)

where \( t \) is the time between the element and the first failure; \( \Omega(t) \) is the mathematical expectation of the number of failures.

For the elements that have a low operating time before the first failure and without taking into account secondary failures, a significantly overestimated \( T_o \) will be obtained, since the expected number of failures of the recovered object \( \Omega(t) \) during the operating time \( t \) will not include secondary failures.

Standard [1] establishes the principles, rules and procedures for predicting the reliability of engineering products in design. According to [1], when predicting the reliability of products, it is necessary to use the calculated, expert, experimental-statistical methods and research test methods. Background information for predicting reliability, in particular, is: design documentation for the product; a data bank of products - analogues, including statistical data on their operational reliability; information about operating conditions. Standard [1] recommends to give preference to the calculation method, which most fully takes into account the factors forming the reliability:

- physics of failures;
- limiting states of parts and assembly units;
- kinematic and dynamic characteristics of structures;
- direct and indirect links between parts and assembly units;
- external influences.

In the standard [1], the basic principles of reliability prediction are formulated. When predicting the reliability of a product as a whole, its structural scheme should be presented in the form of a hierarchical system "part - assembly unit - product".

The block diagram of reliability represents the image of a mechanical system in the form of a combination of elements made in series and in parallel.

On the structural scheme of reliability, elements of a mechanical system are depicted in the form of a sequential chain, the failure of any of which causes a failure of the entire system. The condition for the parallel connection of elements in any section of the structural scheme is the ability of each of the elements connected in parallel to ensure satisfactory operation in the system if other parallel elements fail.

For the research, a sample of 34 MP-5 chainsaws used at the enterprises of the forest complex of the Central Chernozem zone of Russian Federation was determined. Fixing the developments to failure of these products was carried out from the beginning of their operation. According to the values
of developments to failure of specific components of the chainsaws, a data bank was formed, on the basis of which the average time between failures of the corresponding components was determined.

**Table 1.** Time between failures of component parts of the MP-5 chainsaw in the range of 300 hours.

| Motor          | Starting device | Ignition system | Clutch | Sawing machine | Frame vibration absorber | Frame |
|----------------|-----------------|-----------------|--------|----------------|--------------------------|-------|
|                |                 |                 |        |                |                          | 145   |
|                | 121             | 114             | 181    | 136            | 132                      | 264   |

The data presented in table 1 indicate the presence of a significant range of node-by-unit unequal reliability of the MP-5 chainsaw. The total time between failures $T_2$ of the whole construction of the chainsaw, is determined by the formula

$$T_2 = \left( \sum_{i=1}^{m} n_i t_0^i \right)^{-1},$$  \hspace{1cm} (3)

where $m$ is the total number of nodes in the system, for the case under consideration $m = 7$; $n_i$ is the number of subsystems in the $i$-th node, for the case under consideration, $n_i = 1$; $t_0^i$ is the time between failures of the $i$-th node, in this case contained in the bottom line of table 1.

The total time between failures of the chainsaw and the total of the operating times $t_0^i$, which are contained in table 1 according to this formula, will be 20.77 hours. This means that during this interval, with a probability of 90% in the operation of the MP-5 chainsaw, one failure will occur, due to the imperfect design of the $i$-th node or the mismatch of the design characteristics of such a node with the existing load modes in operation.

In any case, the operating time of the chainsaw to $T_2$ failure is a function of the current operating time $t_0^i$ in operating hours. At the same time, an increase in the current operating time causes a decrease in this indicator in terms of dependence, which is close to exponential, and, moreover, is not the same for different types of products.

As can be seen from figure 1, the change in time between failures of composite chainsaw nodes in the range from the start of operation to 500 hours occurs with a decrease in non-linear dependencies. The most reliable element of the chainsaw is the frame. However, as can be seen from figure 1 along curve 7, over the period of operation, its mean time to failure at the end of the period of operation at 500 hours decreases to the level of 215 operating hours. The main causes of the frame failure are the destruction of welded joints at the joints of the frame with the engine, which indicates significant vibration loads at the engine attachment points.

During operation of the chainsaw within the operating time from 100 to 500 hours, the mean time to failure of the clutch (curve 4 in figure 1) varies from 215 to 174 hours. In this case, as the main causes of failures are breakage coupling springs weights.

In the same range of the period of operation of the chainsaw, the time between engine failures (curve 1 in figure 1) is reduced from 170 to 145 hours. The main causes of engine failure are the destruction of gaskets between the crankcase and the cylinder, between the cylinder and its head, as well as a violation of the crankshaft oil seal. As a single case, the destruction of the crankshaft support bearing was noted.

The time between failures of the sawing apparatus and the frame vibration damper (curves 5 and 6 in figure 1) in the indicated range of operation, respectively, decreased from 152 to 130 and 148 to 115 hours. In all cases, the failure of these assemblies was caused by failure of the coupling springs of the mating elements.

The time between failures of the starting device (curve 2 in figure 1) when operating a chainsaw in the same range decreases from 135 to 100 hours. The main causes of failures of this unit are considered the failure of the return spring, the destruction of the starting cord and the deformation of the working surfaces of the ratchet.
The ignition system turned out to be the least reliable node of the chainsaw, the mean time between failures (curve 3 in figure 1) in the considered range of operation decreased from 120 to 85 hours. The main reasons for the failures of this system were the loss of the spark plug working capacity, destruction of the high voltage supply cap to the spark plug, breakdown of the high voltage wire mass.

![Figure 1](image)

**Figure 1.** Change of time between failures $T_2$ components of a chainsaw depending on the duration of the current time $t_0$: 1 – Motor; 2 – Starting device; 3 – Ignition system; 4 – Clutch; 5 – Sawing machine; 6 - Frame vibration absorber; 7 – Frame; 8 – Chainsaw in general.

The time between failures of the chainsaw as a whole (curve 8 in figure 1), determined by the formula (1) in the range of operating time from 100 to 500 hours, decreases from 45 to 5 hours. In practical application, this means that when using a chainsaw for 100 hours with a probability of 90% with 45 hours of operation, one failure should occur. When operating the chainsaw for 500 hours with the same probability, one failure will be observed with 5 hours of time.

4. Discussion of the results
The results of the work on determining the reliability indicators of the MP-5 chainsaws were presented to the specialists of enterprises operating such products. It was noted that the reduction in time between failures can be considered as the reason for sending chainsaws for repair or for stopping its operation, since the average value of 1.8 failures per shift over 8 hours causes a significant increase in the cost of restoring the power saws and certain loss of working time.

The replacement of defective springs of the sawing apparatus and the frame vibration damper is promoted by the replacement of low-quality springs with similar products manufactured in Europe or by domestic springs from products of the defense industry.

Replacing a high-voltage wire with a shielded braided wire with a lug from the GAZ-4901 allowed more than double the time to failure of the ignition system of the chainsaw. Additional research is needed to determine the exact index.

Performance of the work to increase the reliability of the engine of a chainsaw in operation is accompanied by an improvement in its fuel and economic characteristics and an increase in
environmental safety [5, 7] with a decrease in the release of toxic substances into the atmosphere. As noted [3], improving the performance of any mechanical system is a significant factor in the growth of productivity of operators in combination with an increase in its environmental and ergonomic properties. The introduction of the device proposed by the author [4] will increase the reliability of the vibration damper of the chainsaw frame and improve its ergonomics.

5. Conclusion
A significant difference in the failure time for the components of the chainsaw can be considered as the main reason for reducing the reliability of the chainsaw as a whole.

The design of such chainsaw components as the ignition system, starting device and frame vibration damper must be changed accordingly in order to increase the reliability of both these components and the chainsaw as a whole. The redesign of the frame vibration damper should aim at both improving the reliability of the chainsaw and improving its ergonomic properties. It is advisable to introduce the device proposed by the authors into the chainsaw design [4].

At an interval of up to 500 hours of operation of the chainsaw, there is a decrease in the failure time of all its components, while the greatest flow of failures comes from the ignition system and the starting device. With a 90% probability, it can be stated that at the turn of 500 hours after the previous failure is eliminated, a new failure will follow after 4 hours of operation.

To establish the effect of the changes being made to the design of chainsaws to increase their time to failure, additional research is needed.

References
[1] VNIINMash 1980 Reliability in technology: System for collecting and processing information. Methods for assessing reliability in the case of multiple truncation of samples. Guidelines [in Russian] (Moscow: Gosstandart)
[2] Volkov V S and Burdinsky I A 2018 Estimated developments circuit failures chainsaws Modern resource-saving technologies and technical means of the forestry complex [in Russian] (Voronezh: FSBEI HE "VGLTU") pp 288-293 doi: 10.12737/issn.2308-8877
[3] Dąbrowski A 2015 Kickback risk of portable chainsaws while cutting wood of different properties: laboratory tests and deductions International Journal of Occupational Safety and Ergonomics 21(4) 512-523 doi: 10.1080/10803548.2015.1095547
[4] Davydov V F, Sherbakov A S, Oblivin V N and Belovol T I 1997 Vibration damping nozzle [In Russian] Patent RU 2131348 (10.06.1999)
[5] Colantoni A, Mazzocchi F, Cossio F, Cecchini M, Bedini R and Monarca D 2016 Comparisons between battery chainsaws and internal combustion engine chainsaws: performance and safety Contemporary Engineering Sciences 9(27) 1315-1337 doi: 10.12988/ces.2016.68133
[6] Korman T, Kujundžič T and Klanfar M 2015 Analysis of constructional and operational parameters of chain saw Rudarsko-geološko- Naftni Zbornik 30(1) 45-54 doi: 10.17794/rgn_zbornik.v30i1.3512
[7] Kolesnikov V V and Fedin V V Centrifugal clutch [In Russian] Patent SU 1038650 A1 (30.08.1983)