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Model of Parametric Reliability of Woodworking Machine Tools

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Abstract. The article aims to develop a model of the parametric reliability of woodworking machine tools based on the criterion of technological accuracy. For this purpose, a mathematical model of the operating time of a woodworking machine to parametric failure was created using a scheme for changing the size of the workpiece. A linear differential equation characterizing the change in the dimensions for the machined workpiece was obtained based on the assumption of a linear relationship between the wear rate of the machine tool components and its technological accuracy. The differential equation was solved analytically using a Bernoulli approach. As a result, an analytical dependence was obtained for changing the workpiece dimensions. This dependence characterizes the technological accuracy of the machine tool during the overhaul period. The operating time intervals for woodworking machines between parametric failures were also evaluated. The probabilities of failure-free operation were calculated by considering the alpha probability density function for operating time intervals to failure of woodworking machine tools. Finally, it was found that the probability of failure-free operation of machine tools significantly depends on the time-depending parameter, which characterizes the relative durability of the machine tool.

Keywords: operating time, process innovation, failure analysis, Bernoulli approach, failure-free operation probability, interrepair period, machining accuracy.

1 Introduction

Woodworking on machine tools is characterized by high cutting speeds, sometimes more than 30 m/s, high coefficients of friction between the wood and the tool, significant temperatures in the cutting zone, and high pressure in contact between the tool and the wood. The operating modes of woodworking machines cause processes of varying intensity and speed of their occurrence in the machines' structural elements and the cutting tool.

High-speed processes during very short periods occur within the operation cycles of the mechanical units of the machine and the woodworking tool. The factors of high-speed processes are vibrations of the cutting tool and structural elements of the woodworking machine; changes in friction forces in kinematic pairs between the links of the kinematic chains of the machine mechanisms during the transmission of motion; fluctuations in the working load of the cutting tool due to the heterogeneity of the machined wood, and parametric vibrations of the cutting tool. The reverse processes of temperature changes in the structural elements of the woodworking machine and the irreversible wear of the wood-cutting tool occur from several minutes to several hours of machine operation.

Over a long period of operation, slow degradation processes occur, such as wear of machine parts in kinematic pairs, stress redistribution in parts, fatigue of materials of the machine's structural elements, and corrosion. Both fast and slow degradation processes cause parametric failures of woodworking machine tools. These failures occur when the processed wood's dimensions exceed the permissible limits. Consequently, the parametric reliability of woodworking machines according to the criterion of technological accuracy is determined by systematic and random factors. Indicators of parametric reliability of woodworking machine tools are decisive for technological maintenance and repair since timely maintenance is necessary to ensure the accuracy of wood cutting.

2 Literature Review

The main tasks of the reliability of machines are to establish patterns of failure occurrence and to determine quantitative indicators of reliability. These tasks are solved mainly based on the probabilistic concept when failures are considered abstract random events without considering the causes of their occurrence. The approach to establishing reliability indicators is based on studying the parameters of the objects that characterize their technical condition. Such parameters of woodworking machines include indicators of their technological accuracy.

The reliability problems of mechanical systems, including woodworking machine tools, have been considered in several works. The work [1] presents a method for modeling failure rates by analyzing strength and loads. Failure rate models for components and systems are developed, and the cause-and-effect relationship between the shape of the failure-rate curve and load/strength characteristics is illustrated. Operating load can be described as a random process for most mechanical systems. Material properties deteriorate under load and the dynamic relationship between load and strength results in a constantly changing failure rate. Since failure occurs at a load exceeding the strength, failure rate models are developed by analyzing the competition behavior between load and strength. This parametric reliability model calculates the probability of non-destruction of structural elements in strength problems.

The prediction of parametric reliability of metal-cutting machine tools is mentioned in the work [2], where the use of drives with the ability to redistribute or control the load of working elements is proposed to increase the accuracy of processing. The proposed approach to load redistribution makes it possible to develop a methodology for designing the drive of technological machines according to the initial characteristics of operation. The authors of the work claim that the methodology additionally involves predicting the parametric reliability and efficiency of the machine tool. However, the work does not consider specific proposals regarding the parametric reliability prediction according to the technological accuracy criterion, and no reliability indicators for the machine tool are defined.

The work [3] notes that parametric reliability is a valuable reliability factor. Parametric reliability characterizes the ability of the device to meet the technical characteristics and not just perform the functions assigned to it but also perform it with the specified quality. Parametric reliability is determined by probabilistic compliance indicators, which determine parameters with given values and predict their change. This research proposes a method for predicting the parametric reliability of radio-electronic equipment with a two-sided constraint of the change in the determining parameter. The normal distribution law was used to study the proposed approach for random parameter distributions. However, the proposed method for predicting parametric reliability is complicated when applied to woodworking equipment, where, as indicated in [4], the Weibull distribution describes the random process of changing the accuracy of wood processing.

In [5], it is stated that the reliability of mechanical equipment is important to ensure the accuracy of processing and service life. It is not easy to assess reliability using traditional statistical inferences based on a large sample of lifetime test data for long-life products. Therefore, the research proposes a method for assessing reliability based on the distribution of the degradation pathway of the cutting tool. The random process of tool wear is described by a normal distribution density function and a logarithmic distribution function to obtain a more reliable model of cutting tool degradation. However, the proposed model only considers the tool wear process without considering the machine tool’s degradation processes.

In [6], it is noted that for complex systems, it is often necessary to determine reliability indicators such as the average number of failures, mean service life, or reliability over a specified period. By reliability, the authors mean the ability to operate without failure for a particular time. The authors analyzed the primary methods for distributing the reliability of complex systems with a linear structure, for which the probability of failure-free operation over a specific operating period is equal to the product of the probability of failure-free operation of series-connected elements of the system. The research proposes a method that makes it possible to estimate the impact on the reliability of each element of a complex system. The authors claim that the method applies at different design stages and can be used in different industries. However, the method uses an exponential distribution of operation-to-failure, which is not typical for mechanical systems. As is known, with an exponential distribution of operating time, the obtained values of reliability indicators are underestimated.

For evaluating the reliability indicators of complex systems at the design stage, a method is proposed in [7] to obtain an accurate analytical solution for predicting system reliability. Based on the solution of the reliability equation for a sequential system, it is possible to calculate the exact values of the probability of failure-free operation, the frequency of failures, and the mean time to failure. Based on the solution of the reliability equation for a sequential system, accurate values of the probability of failure-free operation, failure rate, and mean time to failure can be calculated. However, as in the previous work, the operation-to-failure of complex systems in this work is described by an exponential distribution.

According to [8], the exponential law does not make it possible to consider the processes of aging and wear of system elements (primarily mechanical), which is unacceptable for the analysis of the reliability of mechanical systems of long-term use.

In [9], wear-related reliability for mechanical systems with frequent maintenance, such as numerically controlled machine tools, is assessed using a limited failure rate process. Point maximum likelihood and interval estimates of parameters and reliability indicators of the process model with limited intensity are specified using the asymptotic normal logarithmic distribution of operating time. Reliability assessment should be carried out to predict the service life [10] and maintenance time [11].

Degradation processes in woodworking machines that have been in operation for a long time directly impact the accuracy of wood cutting, reducing the efficiency of the machine use. In most cases, slow degradation and fast dynamic processes cause mechanical equipment malfunctions. Therefore, studies on the reliability assessment of mechanical equipment based on the analysis of the degradation process are of great importance [12].

Reliability assessment based on operation-to-failure is performed in [13]. A two-parameter Weibull distribution describes operation-to-failure. Accelerated failure tests obtain the parameters of the Weibull distribution. However, if the statistical sample during reliability tests is small, product failure formation is not always straightforward. New methods for assessing reliability based on quality loss and evolution of quality characteristics are proposed in works [14, 15]. An assessment of the reliability of the tool using acoustic emission signals was carried out in [16].

An approach to assessing the reliability of mechanical equipment based on operational data on performance degradation was applied in the research work [17]. To describe the operation-to-failure, the authors used the Weibull distribution statistical model. In the work, the sampling probability function matches the distribution of operative time intervals between failures according to the Weibull law.

Parametric reliability of mechanical equipment based on the strength criterion is assessed in [18]. This research indicates that the classical assessment of strength, when the stresses in the structure are compared with the strength limit, does not consider the degradation processes in the materials. Therefore, the authors propose a model of equipment reliability in which the strength parameters are considered constant, and the stresses are discrete values. In [19], an analysis of the reliability of a high-speed train bearing was carried out based on the Wiener process. The authors used a model of a random, slow degradation process. The unknown coefficients of the model are treated as unknown quantities. However, a small sample was used to perform reliability studies.

The authors of the research work [20] created a complete model of the reliability of the rotary table of the machine tool. The Markov process describes the transition between the faulty and normal states.

The reliability analysis of technical systems using the Bayesian networks is considered in [21, 22]. In [21], a failure tree model of a technical system was created. The work [22] aims to create a consistent Bayesian model for estimating the reliability of a system with partially overlapping failure information. Based on the physical model of the mechanical drive, a corresponding Bayesian model in the form of a directed acyclic graph is constructed. For example, the research considers a drive mechanism whose physical model contains only five elements. Using such an approach to assess the parametric reliability of a woodworking machine tool, the physical model, which is much more complex in terms of reliability, requires both the creation of complex graphs and knowledge of the probabilities of parametric failures of individual machine components. Parametric failures of machine components are eliminated during routine maintenance work.

However, as noted in [23], improper maintenance can cause breakdowns that can significantly reduce equipment availability and result in significant cost increases due to loss of productivity and possible further damage. Therefore, the failure-free operation of woodworking machine tools during the period between repairs is a determining factor in routine maintenance work.

The review of the studies and publications shows that the reliability problems of technical systems, particularly mechanical ones, are still relevant and have not been solved in practical applications. Predicting the reliability of woodworking equipment based on the criterion of technological accuracy will make it possible to carry out routine maintenance of machines between repairs promptly and ensure high-quality wood processing. The article aims to develop a model of parametric reliability of woodworking machine tools based on the criterion of technological accuracy.

Tasks for achieving the goal are as follows:

1) to develop a mathematical model of the operation-to-parametric failures of a woodworking machine tool during the period between repairs;

2) to determine the time intervals between parametric failures of woodworking machine tools;

3) to calculate the reliability characteristics of machine tools during specified periods, considering the alpha distribution of their operation-to-failure time.

The scientific novelty of the article is in solving an important scientific and technical problem of determining rational time intervals for carrying out adjustment work on woodworking machines based on the created mathematical model for assessing the parametric reliability of machines according to the criterion of technological accuracy during the period between repairs.

3 Research Methodology

3.1 Mathematical model of operation time to parametric failure of a woodworking machine tool

According to [9], a mathematical model of the reliability of a technical system is understood as an analytically or statistically represented object that reflects the properties of the system from the point of view of reliability in such a way that its study provides complete information about the reliability indicators and parameters of the system. After considering different speeds occurring in the components and mechanisms of a woodworking machine tool during operation, the change in the accuracy of the machine tool during the period between repairs can be represented by the diagram shown in Figure 1.

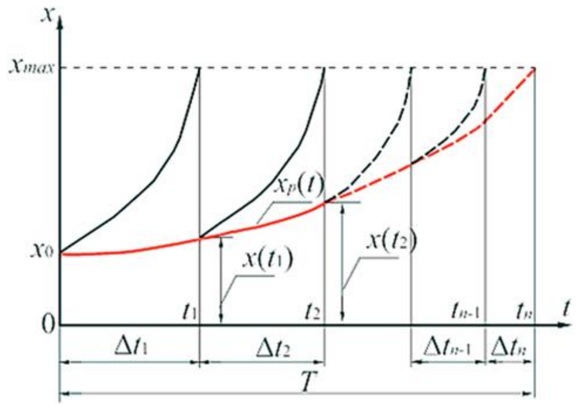

Figure 1 – Diagram of the operating time to parametric failure of a woodworking machine tool

The parametric reliability of a machine tool depends on its technological accuracy, which varies within the tolerance for the size of the batch of parts x_{max} produced by the machine from the lower tolerance limit x_0 to the upper tolerance limit (Figure 1). The period *T* corresponds to the inter-repair period. At points in time t_1, t_2, …, and t_n, the amount of size change $x(t)$ reaches the upper limit x_{max}, when the parts produced on the machine tool do not meet the requirements for the accuracy of the nominal size. Consequently, at the points in time t_1, t_2, …, and t_n, a parametric failure of the machine tool in terms of technological accuracy occurs.

The curve $x(t)$ is obtained by connecting all points on the intervals Δt_i. Adjustments must be performed to eliminate parametric failure to restore the machine's operability.

Adjustment of the machine tool includes a set of measures, the implementation of which allows for improving the technical condition of the machine tool without mechanical processing of its elements and without replacing worn parts. Only gap reduction, lubrication, and tension adjustment are performed when adjusting. It is impossible to reach the initial level of accuracy x_0 using adjustment. Therefore, the value of the tolerance field $x_p(t)$ is reached, which characterizes the accuracy of the adjusted machine tool.

The total loss of accuracy during the operative time *t* of the machine tool is equal to the difference $[x(t) - x_0]$. At a certain point in time, further operation of the machine tool becomes inefficient due to the small value of the difference $\left[x_{max} - x_p(t)\right]$. To determine the duration of the inter-adjustment periods, it is assumed that the difference $\left[x_{max} - x_p(t)\right]$ has a linear dependence on the time interval of each period between adjustments with the same angular coefficient *k* for all time intervals. This coefficient characterizes the speed of machine misalignment per unit of time. Then,

$$x(t) - x_p(t) = k(t - t_{n-1}), \quad (1)$$

where t_{n-1} is the time of the last moment of adjustment before carrying out repairs during the time t_n.

Over time *t*, the rate of change of value $\left[x_p(t) - x_0\right]$ will be denoted as the following time derivative:

$$x_p'(t) = \frac{d[x_p(t) - x_0]}{dt}. \quad (1)$$

At the moment in time t_n, equation (1) takes the form:

$$x_{max} - x_p(t_n) = ktx_n, \quad (2)$$

where $\Delta t_n = t_n - t_{n-1}$.

Equation (2) expresses the relationship between the duration of time intervals between adjustments and the achieved values of technological accuracy for the machine tool after the corresponding adjustment. Assuming that at a given point in time, the rate of change of the value $x_p'(t)$ is proportional to the technological accuracy, the following dependence can be obtained:

$$x_p'(t) = \lambda x(t), \quad (3)$$

where λ is the coefficient of proportionality characterizing the rate of machine tool wear per unit of time.

Taking into account (1) in (3), a linear 1st-order differential equation is obtained:

$$x_p'(t) - \lambda x_p(t) = \lambda k(t - t_{n-1}). \quad (4)$$

The differential equation (4) was solved using the Bernoulli method. To do this, the value $x_p(t)$ is represented as the product of two unknown functions $x(t)$ $u(t)$ and $v(t)$

$$x_p(t) = u(t) \cdot v(t). \quad (5)$$

Then, the rate of change of a value $x_p(t)$ as the 1st derivative of the product of two functions takes the form

$$x_p'(t) = u'(t)v(t) + u(t)v'(t). \quad (6)$$

After substituting expressions (5) and (6) into the differential equation (4), it can be obtained:

$$u'(t)v(t) + u(t)[v'(t) - \lambda v(t)] = \lambda k(t - t_{n-1}). \quad (7)$$

According to Bernoulli's method, the differential equation can be written

$$v'(t) - \lambda v(t) = 0. \quad (8)$$

The differential equation (8) was solved using the variables separation approach. After considering the fact that the constant of integration from the initial conditions is zero, the expression for the function $v(t)$ can be obtained:

$$v(t) = e^{\lambda t}. \quad (9)$$

After substituting (9) into (7), considering the assumption (8), it can be obtained:

$$u'(t) = \lambda k(t - t_{n-1})e^{-\lambda t}. \quad (10)$$

The 2nd unknown function $u(t)$ is determined by the method of integration by parts from expression (10):

$$u(t) = -ke^{-\lambda t}\left(t - t_{n-1} + \frac{1}{\lambda}\right) + C, \qquad (11)$$

where C is the integration constant.

Taking into account the expressions (9) and (11) for functions $v(t)$ and $u(t)$ in the dependence (5), the general solution to the differential equation (4) is obtained:

$$x_p(t) = -k\left(t - t_{n-1} + \frac{1}{\lambda}\right) + Ce^{\lambda t}. \qquad (12)$$

According to (12), at $t = t_{n-1}$, it can be obtained:

$$x_p(t_{n-1}) = -\frac{k}{\lambda} + Ce^{\lambda t_{n-1}}.$$

Hence, the constant of integration equals

$$C = e^{-\lambda t_{n-1}}\left[x_p(t_{n-1}) + \frac{k}{\lambda}\right].$$

Thus, the general solution to the differential equation (4) is as follows:

$$\begin{aligned} x_p(t) = {} & -k\left(t - t_{n-1} + \frac{1}{\lambda}\right) + \\ & + e^{\lambda(t - t_{n-1})}\left[x_p(t_{n-1}) + \frac{k}{\lambda}\right]. \end{aligned} \qquad (13)$$

Dependence (13) is a mathematical model of changes in the technological accuracy of the machine tool during the inter-repair period.

After substituting $t = t_n$ into (13), taking into account the expression for Δt_n, it can be obtained:

$$x_p(t_n) + k\Delta t_n = -\frac{k}{\lambda} + e^{\lambda \Delta t_n}\left[x_p(t_{n-1}) + \frac{k}{\lambda}\right]. \qquad (14)$$

Since condition (2) is satisfied, then from (14), it can be obtained:

$$x_{max} + \frac{k}{\lambda} = e^{\lambda \Delta t_n}\left(x_{max} - k\Delta t_{n-1} + \frac{k}{\lambda}\right), \qquad (15)$$

where $\Delta t_{n-1} = t_{n-1} - t_{n-2}$.

After transforming expression (15) and subsequent logarithmization, a dependence was obtained for determining the duration of the operation-to-parametric failure time intervals Δt_n between machine adjustments

$$\Delta t_n = -\frac{1}{\lambda} ln\left(1 - \frac{\lambda \Delta t_{n-1}}{1 + \frac{\lambda}{k} x_{max}}\right). \qquad (16)$$

The period between repairs **(**inter-repair period), during which the machine reaches a state of inoperability according to the criterion of technological accuracy, consists of successively decreasing intervals of operation to parametric failure:

$$T = \sum_{n=1}^{\infty} \Delta t_n. \qquad (17)$$

For practical use, the time intervals between adjustments are limited to $n = 3$, corresponding to the number of inter-inspection periods of the system of scheduled preventive repairs of woodworking machine tools of complexity group II.

3.2 A model of parametric reliability of a woodworking machine tool in the inter-repair period

According to [24], the operating time t of woodworking machines to failure is described by α-distribution, the differential function of which takes the form

$$f(t) = \frac{\beta \cdot c}{t^2\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\beta}{t} - \alpha\right)^2}, \qquad (18)$$

where α, β, and c – distribution parameters.

Parameter β has the dimension of operating time to parametric failure (the dimension of time) and is the relative durability margin of the machine tool according to the accuracy criterion. Parameters α and c are dimensionless quantities.

The parameter α is the average speed of machine misalignment, the relative average rate of change in technological accuracy. Usually, when parameter $\alpha = 2$ and is greater, parameter $c = 1$.

Taking into account dependence (18), the expression for the probability of failure-free operation of the machine tool according to the criterion of technological accuracy within the intervals Δt_n, determined by dependence (16), takes the following form:

$$\begin{aligned} R(t_1, t_2) &= 1 - \int_{t_1}^{t_2} f(t)dt = \\ &= 1 - \frac{\beta c}{\sqrt{2\pi}} \int_{t_1}^{t_2} \frac{1}{t^2} e^{-\frac{1}{2}\left(\frac{\beta}{t} - \alpha\right)^2} dt. \end{aligned} \qquad (19)$$

The mathematical model is realized using the Maple software.

4 Results

The study of operation-to-parametric failure in the inter-repair period was carried out for woodworking machine tools of complexity group II: the SKTP 505-2 horizontal band saw machine, a circular saw for ortho-sawing of brand Barakuda-2, and the Unimat-17A four-side plano-milling machine. The graphs of the operation-to-parametric failure time intervals are constructed based on the dependence (16) for the specified machine tools and are shown in Figures 2–4.

Exceeding the upper tolerance limit for processing a part, x_{max}, was a parametric failure of the machines. The value of x_0 is taken as the lower tolerance limit.

Calculations of operation intervals to parametric failure for the SKTP 505-2 machine tool (Figure 2) were performed using the following values of the parameters of the mathematical model: the machine's misalignment rate coefficient, $k = 6.15 \cdot 10^{-3}$, which characterizes the rate of wear of the machine per unit of time, $\lambda = 1.05 \cdot 10^{-3}$. The duration of operation intervals and the probability of failure-free operation of the SKTP 505-2 machine tool during these intervals, calculated using dependence (19), are shown in Table 1.

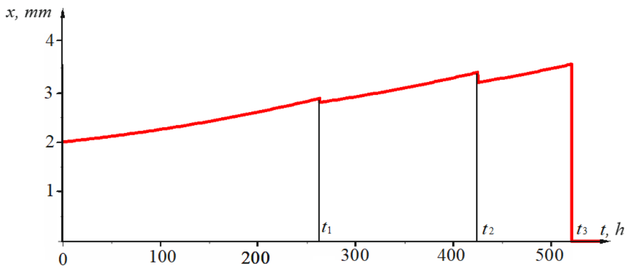

Figure 2 – Duration of the operating time intervals between parametric failures for the SKTP 505-2 machine tool's tolerance field limits: lower x_0 = 2 mm; upper x_{max} = 3 mm

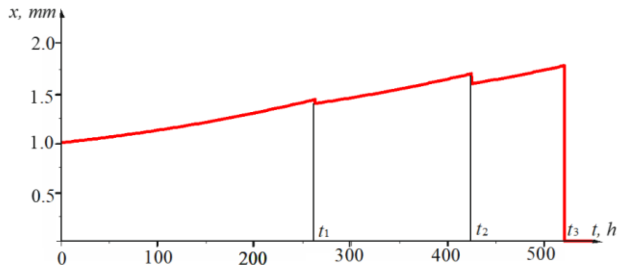

Figure 3 – Duration of operating intervals to failure for the Barracuda-2 machine tool's tolerance field limits: lower x_0 = 1 mm; upper x_{max} = 2 mm

Table 1 – Probabilities of failure-free operation of the SKTP 505-2 machine tool for α = 2, c = 1

Distribution parameter β, h	Duration of operating intervals between parametric failures Δt_i, h		
	Δt_1 = 263	Δt_2 = 162	Δt_3 = 96
	$R(0, t_1)$	$R(t_1, t_2)$	$R(t_2, t_3)$
920	0.933	0.633	0.842
800	0.851	0.602	0.868
700	0.746	0.617	0.893
650	0.681	0.638	0.907
600	0.610	0.668	0.920

Table 2 – Probabilities of failure-free operation of the Baracuda-2 machine tool for α = 2, c = 1

Distribution parameter β, h	Duration of operating intervals between parametric failures Δt_i, h		
	Δt_1 = 470	Δt_2 = 270	Δt_3 = 149
	$R(0, t_1)$	$R(t_1, t_2)$	$R(t_2, t_3)$
2200	0.996	0.839	0.848
2000	0.988	0.772	0.84
1700	0.947	0.670	0.848
1500	0.884	0.628	0.866
1200	0.710	0.643	0.905

For the SKTP 505-2 machine tool, the operating time for the 1st parametric failure is 263 h, the 2nd – 162 h, and the 3rd – 96 h. The probability of failure-free operation to the 1st failure depends significantly on the distribution parameter β. With a decrease in this parameter from 920 to 600 h, the probability of failure-free operation to the 1st failure, $R(0, t_1)$, decreased by 35 %, but the probability value $R(0, t_1)$ is more significant than 0.5. During the operation to the 2nd failure, the probability of failure-free operation becomes somewhat smaller and varies within 10 % when the parameter β changes. The probability of failure-free operation during the operation to the 3rd failure changes by 8.5 %. The duration of the operating time to this machine tool's 1st three parametric failures agrees with the experimentally determined values of the duration of the inter-adjustment intervals in work [23] with an accuracy of up to 17 %.

Calculations of the operating time to parametric failures for the Barakuda-2 machine tool (Figure 3) were made using the following values of the parameters of the mathematical model: the machine misalignment rate coefficient $k = 3.25 \cdot 10^{-3}$; the proportionality coefficient characterizing the wear rate of the machine per unit time equals $\lambda = 0.65 \cdot 10^{-3}$.

The duration of the operating intervals and the value of the probability of failure-free operation of the Baracuda-2 machine tool during these intervals, calculated using dependence (19), are shown in Table 2.

For the Barracuda-2 machine tool, the operating time for the 1st parametric failure is 470 h, 2nd – 270 h, and 3rd – 149 h. With a decrease in the parameter β from 2200 h to 1200 h, the probability of failure-free operating time $R(0, t_1)$ to the 1st failure decreased by 29 %.

During the operation to the 2nd failure, the probability of failure-free operation becomes somewhat smaller and varies within 23 % when the parameter β changes. The probability of failure-free operation during the operation to the 3rd failure changes by 15 %. The duration of operation to the 1st parametric failure of this machine tool is consistent with the experimentally determined duration of the 1st interval between adjustments in the operation [23] with an accuracy of up to 1 %.

Calculations of the operating intervals between parametric failures for the Unimat-17A machine tool (Figure 4) were performed using the following values of the parameters of the mathematical model: the coefficient of the machine's misalignment rate, $k = 1.60 \cdot 10^{-3}$, and the proportionality coefficient $\lambda = 0.40 \cdot 10^{-3}$. The duration of the operating intervals and the value of the probability of failure-free operation of the Unimat-17A machine tool during these intervals, calculated using dependence (19), are shown in Table 3.

For the Unimat-17A machine tool, the operating interval to the 1st parametric failure is 871 h, 2nd – 448 h, and 3rd – 220 h. With a decrease in the parameter β from 4000 h to 2500 h, the probability of failure-free operation in the interval to the 1st failure, $R(0, t_1)$, has decreased by 19 %. During the operating time to the 2nd failure, the probability of failure-free operation acquires slightly lower values and varies within 24 % when the parameter β changes. The probability of failure-free operation to the 3rd failure changes by 3 %. The duration of the operating time interval to the 1st parametric failure of this machine tool agrees with the experimentally determined duration of the 1st interval between adjustments in the operation [25] with an accuracy of up to 3 %.

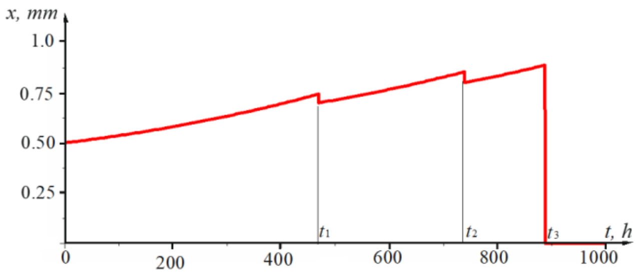

Figure 4 – Duration of operating intervals to failure for the Unimat-17A machine tool's tolerance field limits: lower x_0 = 0.5 mm; upper x_{max} = 1 mm

Table 3 – Probabilities of failure-free operation of the Unimat-17A machine tool for α = 2, c = 1

Distribution parameter β, h	Duration of operating intervals between parametric failures Δt_i, h		
	Δt_1 = 871	Δt_2 = 448	Δt_3 = 220
	$R(0, t_1)$	$R(t_1, t_2)$	$R(t_2, t_3)$
4000	0.995	0.854	0.876
3600	0.984	0.784	0.866
3200	0.953	0.712	0.867
2800	0.888	0.661	0.879
2500	0.808	0.651	0.895

5 Discussion

As the analysis of modern works has shown, the problems of parametric reliability of mechanical equipment, taking into account fast and slow degradation processes in structural elements, require further study.

Since the parametric reliability indicators of woodworking machines are decisive for planning maintenance and repairs, a mathematical model of the parametric reliability of woodworking machine tools was created according to the criterion of loss of wood-cutting accuracy.

For woodworking machine tools, the operating time of which can be described by alpha distribution, with a decrease in the relative durability margin (distribution parameter β), the probability of failure-free operation in the interval to the 1st three parametric failures during the inter-adjustment period is significantly reduced. This is typical for machine tools that have been in operation for a long time (more than 10 years).

6 Conclusions

According to the criterion of technological accuracy, the operating intervals to the 1st three parametric failures of woodworking machine tools in the inter-repair period were determined using the developed model of parametric reliability of woodworking machine tools. The shortest operating time to 1st parametric failure inherent in a band saw is 263 h. For a circular saw machine, the operating time to the 1st parametric failure is 470 h, and for a milling machine – 871 h. The obtained values are consistent with the operational data. This confirms the reliability of the modeling results.

The determined values of the probability of failure-free operation of machine tools depend significantly on the operating time distribution parameter, which characterizes the relative durability of the machine tool. With a decrease in relative durability, the reliability index of machine tools in the inter-repair period can decrease by 35 % for band saw machines. Such a decrease in parametric reliability is due to the rapid wear of the cutting tool - the band saw.

Determining the operating time to parametric failure and the corresponding value of the probability of failure-free operation is the basis for timely adjustment of the machine tool and the development of appropriate adjustment schedules in production. This is especially valuable for machine tools that have been operating for a long time.

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