Influence of tightening fitting accuracy for resource connection

O A Leonov and N Zh Shkaruba
Department of Metrology, standardization and quality management, Russian State Agrarian University – Moscow Timiryazev Agricultural Academy, Timiryazevskaya, 49, Moscow, 127550, Russia

E-mail: metr@rgau-msha.ru

Abstract. A dependence have obtained for determining the design tolerance of fit, as one of the characteristics of the model of parametric failure of a joint with an interference fit, the calculation is carried out taking into account the wear rate and the parameters of its dispersion at a certain resource and a given probability of failure-free operation. On the example of calculating a connection with an interference fit, it have shown that the choice of a fit without a margin of accuracy cannot ensure the operational reliability of the connection, but only guarantees the absence of failures at the initial stage of work – during the warranty period. It have proven that with the right choice of fit accuracy, it is possible to achieve a significant increase in the resource of failure-free operation.

1. Introduction
Connections with guaranteed tightness are often used in the design of assembly units in mechanical engineering. Plain bearing bushings and rolling bearing rings are pressed into the bores of body parts, valve guides - into the bores of the cylinder head, gear rings on the seating surfaces of shafts, etc. [1]. Fittings of joints with interference in most cases are assigned by the methods of precedents and similarities, which leads to the transfer of old fit to new joints without taking into account loads, geometric parameters, properties of materials of parts and working conditions [2]. Calculation methods are used quite rarely, because they are rather complicated and require an individual approach, such as the calculation of fit for keyed joints of agricultural machinery [3], or the calculation of the smallest preload according to the criterion of the onset of leaks for rubber reinforced cuffs [4]. In most cases, during the operation of machines, there is a decrease in the tightness in the joint, this is due to corrosion-mechanical wear, fretting corrosion, aging of materials, the ingress of abrasive and dust into the joint joint, which significantly accelerates the processes [5].

Under an alternating load, the deformations of the contacting cylindrical surfaces of the materials of the tight joints change cyclically and dynamically, and microshears and microdisplacements of surfaces are formed. Short-term overloads are also possible. This, the most common type of loading, gradually decreases the strength of the joints. Improper fit (when the tightness is low), overloads of the connection during operation, disassembly and assembly work affecting the connection during repair also lead to an increase in the speed of the wear process.

In the theory of accuracy and in the theory of dimensional analysis, there is the concept of functional parameters [6]. Two limits can be distinguished for calculating interference fits. The lower limit of the
functioning of the joint with an interference fit characterizes the smallest functional interference $N_{F_{\text{min}}}$, when crossing the border of which there is a shift of the surfaces of the parts and the failure of the joint. Exceeding the boundary of the highest functional interference $N_{F_{\text{max}}}$ leads to the transition of the material of one of the parts from the elastic zone to the zone of plastic deformations, which significantly reduces the strength of the joint and can lead both to the shift of the parts relative to each other and to the opening of the joint joint. In both cases, it is a failure to work.

2. Problem statement and solution

In modern science, which studies the processes of degradation of the initial parameters of products during storage, operation and repair, the processes of wear can be described by various models and have different types [7]. To construct and describe the wear characteristics of both clearance fit and interference fit, the model of a strongly mixed Gaussian process is most often used, since it more realistically describes the essence of the process [8, 9].

The mathematical model of parametric failure of an interference joint is shown in figure Errors in the processing of parts that form the joints form the scattering of structural interference, which can be characterized by the standard deviation $\bar{C}_N$, and the mathematical expectation. During operation, the aging process begins - from sewing and there is a gradual decrease in the tightness, which in general form can be described by the equation of the dynamics of the tightness, taking into account the change in the average wear function depending on time $\bar{U}(t)$:

$$\bar{N}(t) = \bar{N}_k - \bar{U}(t).$$

(1)

Going beyond the limit of the smallest $N_{F_{\text{min}}}$ or the largest $N_{F_{\text{max}}}$ of the functional interference leads to a failure.

A parametric failure model in the form of a highly mixed Gaussian process for tight joints is described by the expression

$$P(t) = \Phi\left(\frac{\bar{N}_C - \bar{U}(t) - N_{F_{\text{min}}}}{\sqrt{\sigma_C^2 + \sigma_U^2(t)}}\right);$$

(2)

where $P(t)$ is the probability of fault-free operation; $\Phi$ – the Laplace function; $N_{F_{\text{min}}}$ – the smallest functional tightness; $\bar{N}_C$ – mathematical expectation of dissipation of constructive interference; $\sigma_C$ – standard deviation of structural interference dissipation; $\sigma_U(t)$ – is the standard deviation of the scattering of the wear process parameters.

When using a symmetric distribution law, after mathematical transformations in formula (2), we get

\[\end{align}\]
the expression:

\[ T_e = \left[ \left( T_F - \bar{U}(t) \right)^2 - H_U \cdot \sigma_U^2(t) \right] k \cdot \left( T_F - \bar{U}(t) \right) \]  

(3)

where \( T_F \) is the he functional tolerance in fitting; \( H_U \) is the quantile of the wear process distribution law for a given probability of fault-free operation; \( k \) is the coefficient of relative scattering [10].

Using the obtained dependence (3), at a given value of the resource \( t \) and the corresponding PNFO, it is possible to determine the design tolerance of an interference fit. The peculiarity of using the obtained dependence in accuracy calculations is the use of a mathematical description of the dynamics of the wear process – the speed of the wear process and the dynamics of the standard deviation depending on the operating time.

3. Calculation example

Let us calculate the design tolerance and determine the fit of the gear on the shaft of unified gearboxes H 090.20 plant name of the Mosselmash. For the compound under study, the calculation of functional interference was carried out according to the classical method [11], the results of the calculation of the operational and design tolerance of fit, the safety factor of accuracy, for the given parameters of the wear function and for various values of the resource, are presented in the table.

| Table 1. The results of calculating the fit tolerance to ensure a given resource. |
|-----------------------------------------------|
| Parameter                                      | Value                  |
| Functional parameters                         | the greatest interference, \( N_{\text{Fmax}} \), \( \mu m \) | 122 |
|                                               | the smallest interference, \( N_{\text{Fmin}} \), \( \mu m \) | 15  |
| Functional tolerance of fit, \( T_b \), \( \mu m \) | 107                    |
| Probability of fault-free operation, \( P \)  | 0.95                   |
| Quantile probability of uptime, \( H_{C2} \)  | 1.96                   |
| Aging process function, \( \mu m/h \)         | \( \bar{U}(t) = 8.012 \cdot 10^{-3} \cdot t \); \( \rho > 0.9 \) |
| Change in standard deviation of wear scattering over time, \( \mu m/h \) | \( \sigma_u(t) = 1.978 \cdot 10^{-3} \cdot t \); \( \rho > 0.9 \) |
| Specified resource of work, \( t_6 \), h       | 1000 3000 5000 7000 9000 |
| Constructive tolerance of fit, \( T_c \), \( \mu m \) | 97 80 61 40 9          |
| Operational tolerance of fit, \( T_o \), \( \mu m \) | 10 27 56 67 98        |
| Coefficient margin of precision, \( K_p \)     | 1.1 1.5 1.7 2.6 11     |
| Fit Ø40                                       | H9/x8 H8/x8 H7/y7 H6/z5 H4/z3 |

Fits were chosen according to the requirements of the international system of tolerances and fits ISO [12].

Analysis of the data obtained, presented in the table and in figure 2, makes it possible to evaluate the dynamics of the decrease in the design tolerance of landing depending on the required connection resource, provided that the specified probability of failure-free operation is 0.95. The magnitude of the predicted wear is expressed by the operational fit tolerance \( T_o \). With an increase in the resource of work, this tolerance increases. It takes more materials of the parts forming the joint to spend on wear. It is quite logical that in order to provide a greater reserve of materials for wear, the design tolerance of the fit should be less and less. In principle, if you look at the data in the table, the \( K_p \) accuracy safety factor will actually reflect the amount of the wear margin. In turn, the design tolerance of the fit is equal to the sum of the tolerances of the hole and the shaft that form the connection. Thus, the smaller the fit tolerance, the more accurately it is required to make the surfaces of parts of the «hole» and «shaft» type.

Consider the dynamics of changes in landings and separately the quality of shafts and holes.
Figure 2. Relation of the working life $t_c$ of the joint to the constructive tolerance in fitting.

It can be seen from the data in the table that it is most rational to apply the $\varnothing 40H6-z5$ fit, since the sixth hole quality and the fifth shaft quality are technologically achievable during mass production in mechanical engineering, and the landing will provide a guaranteed connection resource of 7000 hours. To achieve a resource of 9000 hours at With the same probability of failure-free operation, a very high precision $\varnothing 40H4-z3$ fit is required, or the use of methods of incomplete interchangeability - selective assembly, fitting, or percentage interchangeability [13]. Technologically, such a fit can only be achieved by using high-precision finishing on expensive equipment. With less work resources, you can use a medium precision landing $40H7-y7$. Landing $\varnothing 40H9-x8$, which is indicated on the working drawing, cannot provide a safety margin for the connection; when using this landing, it is possible to ensure only the absence of failures in the initial period of operation - the warranty period.

With a given probability of no-failure operation of 0.95, it is impossible to achieve a greater resource than 9000. For the conditions of reaching a fifty percent resource (with a probability of no-failure operation of 0.5), when using landings 40H9-x8 and $\varnothing 40H8-x8$, this resource will be 8000 ... 8300 hours, and for landing $\varnothing 40H6-z5$ it will already be 11000 hours.

4. Conclusion
As a result of the analysis of the relationship of the elements included in the dependence to determine the probability of no-failure operation when modeling the parametric failure of joints with interference at the lower limit, a theoretical dependence was obtained for calculating the design tolerance of landing at a given resource value at a certain probability of no-failure operation and known or simulated wear parameters. Using the example of a real interference fit, it has shown that without a margin of accuracy, provided there is fretting, the fit used cannot provide the specified reliability of the connection. Only an increase in the accuracy of the connection parts and an increase in the structural interference make it possible to create the required stock of materials for wear and increase the connection resource by 2.0 ... 2.5 times.

References
[1] Erokhin M N 2005 Machine Parts and Design Basics (Moscow: KolosS) p 462
[2] Bulatov V P et al. 2001 Calculation of the Accuracy of Machines and Devices (Moscow: Polytechnic) p 495
[3] Erohin M N et al. 2019 Calculation of fits for cylindrical connections with key for reducers in agricultural machinery Engineering for Rural Development 469-74
[4] Erokhin M N 2019 Tightness and leakage in applying reinforced rubber sleeves to shafts Russian Engineering Research. 39(6) 459-62
[5] Bondareva G I 2012 Extending the life of concrete-mixer components Russian Engineering Research 32(3) 229-36
[6] Pastukhov A G 2014 Methodology for assessing the quality of assembly units by functional parameters All Materials. Encyclopedic Reference 3 9-16
[7] Pronikov A S 2002 Parametric Reliability of Machines (Moscow: Publishing house of the Moscow State Technical University named after N.E.Bauman) p 560
[8] Leonov O A and Shkaruba N Zh 2019 A Parametric Failure Model for the Calculation of the Fit Tolerance of Joints with Clearance Journal of Friction and Wear 40(4) 332-6
[9] Leonov O A, Shkaruba N Zh and Vergazova Yu G 2019 Determining the tolerances in fitting for joints with interference Russian Engineering Research 39(7) 544-7
[10] Erokhin M N et al. 2006 The relationship between the accuracy and reliability of connections in the repair of agricultural machinery Vestnik FGOU VPO MGAU 2 22-5
[11] Belov V M et al. 1990 Calculation of the Precision Parameters of Agricultural Machinery (Moscow: Publishing house MIISP) p 125
[12] Bondareva G I et al. 2016 Changes in the standard of a unified system of tolerances and landings Tractors and Agricultural Machines 12 39-42
[13] Erokhin M N et al. 2020 Assessing the relative interchangeability in joints with preload Russian Engineering Research 40(6) 469-72