Design of landing of assembly machine building units with circulating load rolling bearing rings

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Abstract. The article presents the results of solving the scientific problem of ensuring folding, which is complex and includes the appointment of optimal tolerances, maximum deviations and landings in the design. The authors presented for selection of locally loaded bearing rings the field of tolerances of holes and shafts depending on type of bearings, operating conditions and the nature of load. The authors consider the definition of the dynamic coefficient through the value of the landing on the minimum tension between the circulating load ring and the surface of the connected part. Checking the correctness of the choice of landing involves ensuring the condition of strength at the allowable tension. The authors determined the equivalent dynamic load for the established requirements for design of rolling bearings, taking into account the load variability of 6005 N and calculated the durability of 9500 hours. In article it is established that on diameters of openings of demountable cases under external rings with local loading it is expedient to assign fields of tolerances H6, H7, G6, G7. The article confirms the possibility of periodic rotation of the bearing ring during the operation of the folding unit and reduce the uneven wear of the raceways.

1. Introduction
In today's economy [1], the quality of training of graduates of technical and agricultural higher education institutions are determined mainly by the degree of formation of future specialist’s skills and ability to produce competitive products [2]. Therefore, the higher school should integrate into its educational standards [3], curricula and the structure of the main disciplines [4], the aggregate requirements of production and business [5], and preferably taking into account the peculiarities of staffing of enterprises in the region [6]. In the process of manufacturing any product of all types of machine production, ultimately [7], the problem of ensuring its assembly with the provision of the appropriate type of geometric interchangeability [8]. Typical technological processes of assembling machine-building products [9] and the main approaches to ensuring manufacturability [10] are presented in the literature,
for example, in [11], and taking into account the peculiarities of heavy engineering also in [12], where, however, has no recommendations for training specialists in this field [13].

In the process of manufacturing any product for all types of production [14], the problem of ensuring the manufacturability of assembly with the provision of the appropriate type of interchangeability is solved [15]. In the special technical literature is widely used the term machinability of the part, which means the ability of materials to be processed by cutting or, alternatively, a set of properties of materials that ensure their processing by cutting to achieve optimal values of basic technological indicators (cutting speed, surface quality, cutting force, etc.) [16].

The problem of ensuring the manufacturability of the assembly is complex and includes, above all, the question of determining the optimal tolerances, limit deviations and landings in the design of the product with justification for choosing the type of interchangeability (complete, incomplete, group, fit or adjustable) [17]. The design of design and technological documentation is associated with the choice of the required accuracy of surfaces and their roughness [18], justification of landings taking into account the technological features of processing [19] and, in particular, with reasonable rationing of deviations in the shape and location of surfaces [20].

Researchers need to take into account current standards for the basic norms of interchangeability, as this primarily forms the quality of machine-building products and their competitiveness [21]. Therefore, it is very important that the scientific literature reflects modern ideas and methods of accuracy rationing [22], the purpose of landings in the joints, including, for example, in complex units with standard rolling pads [23], which are most common in engineering products, regardless of their series [24].

The aim of the research is to study the general factors that ensure the accuracy of folding units with rolling mills with the achievement of the desired nature of the connection of the rings with the surfaces of the shaft and the hole.

2. Materials and methods

Despite the fact that the assembly of units with standard rolling mills (general specifications) are the most common in machine-building products, regardless of their series, the process of connecting them with parts is insufficiently studied – comprehensive studies have been conducted only on radial two-row roller rollers type 3182100 with a conical hole, when installing which the radial clearance in the roller is regulated by axial movement of the inner ring relative to the conical neck of the spindle [25].

The problem of ensuring folding is complex and includes, first of all, the question of assigning optimal tolerances, maximum deviations and landings in the design. Landing of rolling mills on the shaft and in the body should be selected taking into account the type and size of the rolling mill, its operating conditions, value and nature of loads acting on it, but, above all, the type of ring load: local, circulating or oscillating. According to the most common guide among practitioners [26], as well as all textbooks and manuals without exception, the landing of the circulating load ring is determined by the so-called intensity of the radial load by the formula:

\[ P_R = R \cdot k_D \cdot k_1 \cdot k_2 \cdot (B - 2 \cdot r)^{-1}, \]  \hspace{1cm} (1)

where \( P_R \) – intensity of radial loading, kN/m; \( R \) – constant radial load in the direction, kN; \( k_D \) – dynamic landing coefficient depending on the load (for overload up to 150% moderate shocks and vibrations \( k_D = 1 \), for overload up to 300%, strong shocks and vibrations \( k_D = 1.8 \)); \( k_1 \) – coefficient that takes into account the degree of relaxation of the landing tension for the hollow shaft and the thin-walled body (for the hollow shaft \( k_1 = 1 - 3 \), solid \( k_1 = 1 \), for the body \( k_1 = 1 - 1.8 \)); \( k_2 \) – coefficient of non-uniformity of load distribution \( R \) between rows of rollers in two-row conical roller rollers or between double ball rollers in the presence of axial load on the support \( k_2 = 1 - 2 \); in the absence of axial load \( k_2 = 1 \); \( B \) – bearing width, m; \( r \) – radius of curvature of the chamfer of the ring, m.

To select locally loaded rings in the mentioned sources the recommended fields of tolerances of openings and shafts depending on type of a rolling mill, working conditions and character of loading are resulted. If the dynamic coefficient \( k_D \) is difficult to determine, the fit can be determined by the
minimum tension between the circulating ring and the surface of the part. Determine the smallest tension of the circulation-loaded ring by the formula:

\[ N_{\text{min}} = 13 \cdot R \cdot k \cdot (B - 2 \cdot r)^{-1} \cdot 10^{-6}, \]  

(2)

where \( N_{\text{min}} \) – the lowest design tension that provides the required strength of the connection of the circulating load ring with the shaft, mm; \( k \) – design factor, which depends on the series of felling (\( k = 3.5 \) for especially light series; \( k = 2.8 \) for light series; \( k = 2.3 \) for medium series; \( k = 2 \) for heavy series).

Choose the required standard fit that meets the condition:

\[ N_{\text{min},s} \geq N_{\text{min}}, \]  

(3)

where \( N_{\text{min},s} \) – the lowest tension of a standard landing.

We check correctness of a choice of landing, proceeding from a condition of durability, for this purpose we define admissible tension:

\[ N_{\text{max}} = 11.4 \cdot d \cdot k \cdot \alpha_p \cdot (2 \cdot k - 2)^{-1} \cdot 10^{-6}, \]  

(4)

where \( N_{\text{max}} \) – the greatest design tension providing necessary durability of connection of a circulating loaded ring of a rolling pin with a shaft, mm; \( d \) – nominal diameter of the connected ring of a rolling mill, mm; \( \alpha_p \) – permissible tensile stress (for steel rolls \( \alpha_p = 400 \) MPa).

Check the strength of the connection, following the condition:

\[ N_{\text{max},s} \leq N_{\text{max}}, \]  

(5)

where \( N_{\text{max},s} \) – the greatest tension of a standard landing.

3. Results and discussion

Determine the landing of the circulating loaded inner ring of a radial single-row bearing № 205 of accuracy class 6 (\( d = 25 \) mm, \( D = 52 \) mm, \( B = 15 \) mm,) on a rotating solid shaft. Estimated radial reaction of the support \( r = 1.5 \) mm, \( R = 3 \) kN. Impact load, overload 200%. There is no axial load. Determine the load intensity by formula (1):

\[ P_R = 3 \cdot 1.8 \cdot 1 \cdot 1 \cdot (15 - 2 \cdot 1.5)^{-1} \cdot 10^3 = 450 \text{ kN/m}. \]

Here we take the values of the coefficients under the specified operating conditions of the bearing: \( k_D = 1.8 \), \( k_1 = 1 \), \( k_2 = 1 \). Under the specified conditions for the shaft corresponds to the tolerance field \( k_6 \), i.e.\( \varnothing 25 k_6 (\pm 0.015) \). The maximum deviations of the diameter of the hole of the inner ring of the bearing are found by: \( EI = -0.01 \) mm, \( ES = 0 \). Then the landing of the inner ring of the bearing on the shaft \( \varnothing 25l_0 k_6 \). Limit tensions: \( N_{\text{min}} = ei - ES = 0.002 - 0 = 0.002 \) mm, \( N_{\text{max}} = es - EI = 0.015 - (-0.013) = 0.025 \) mm. The tolerance field of the hole in the housing under the outer locally loaded bearing ring is assigned a hole diameter of \( D = 52 \) mm for the specified conditions of the rolling mill, we accept the tolerance field \( JS7 \) (for the bearing of the sixth accuracy class), i.e.\( \varnothing 52JS7 (\pm 0.015) \). The maximum deviations of the outer diameter of the outer ring of the bearing are: \( ei = -0.013 \) mm, \( es = 0 \). Then fit the outer bearing ring in the housing \( \varnothing 52l_0 k_6 \). Limit tensions and gaps: \( S_{\text{max}} = ES - ei = 0.015 - (-0.013) = 0.0028 \) mm, \( N_{\text{max}} = es - EI = 0 - (-0.015) = 0.015 \) mm. By formula (2) we find:

\[ N_{\text{min}} = 13 \cdot 3 \cdot 2.8 \cdot (15 - 2 \cdot 1.5)^{-1} \cdot 10^{-3} = 0.0091 \text{ mm}. \]
Tolerance field of the inner ring of the bearing $\varnothing25m6\left(\begin{array}{c}+0.025 \\ +0.009\end{array}\right)$. Then fit the inner bearing ring on the shaft $\varnothing25\frac{10}{m6}$. Limit tensions: $N_{\text{min}} = ei - ES = 0.009 - 0 = 0.009$ mm, $N_{\text{max}} = es - EI = 0.025 - (-0.01) = 0.035$ mm. Condition (3) is fulfilled. By formula (4) we find:

$$N_{\text{max}} = 11.4 \cdot 2.8 \cdot 25 \cdot 400 \cdot (2 \cdot 2.8 - 2)^{-1} \cdot 10^{-6} = 0.1064 \text{ mm}.$$ 

Condition (5) is fulfilled. Determine the landing of the single-row tapered roller bearing №7209 on the shaft. The most loaded is the bearing of the right support. The load on the inner ring is circulating. Radial load 4788 N. The expected difference between the temperature of the furnace and the ambient air 20 °C. The sizes of the specified rolling mill: $d = 45$ mm, $D = 85$ mm, $B = 19$ mm, $r = 2$ mm, $r_1 = 0.8$ mm. Minimum allowable tension according to formula (1): $N_{\text{min}} = 0.0124$ mm. For clarity of the choice of landing we will make the table 1.

**Table 1.** The value of probable gaps and tensions.

| Deviation of an opening of an internal ring, μm | Shaft, μm tolerance field | Probable, μm | Tension |
|-----------------------------------------------|--------------------------|--------------|---------|
|                                               | es/ei                  | clearance    | min     | max     | min     | max     |
| 0                                             | js6                    | +8/-8        | -        | 1.2     | -        | 18.8    |
| -12                                           | k6                     | +18/+2       | -        | -       | 8.8     | 28.8    |
|                                               | m6                     | +25/+9       | -        | -       | 15.8    | 35.8    |
|                                               | n6                     | +33/+17      | -        | -       | 23.8    | 43.8    |

From table 1 it follows that the closest tolerance field of the shaft, which provides the connection with the inner ring of the rolling mill the required tension, is $m6$. Estimated durability under the given working conditions makes 9500 hours. Therefore, the bearing operation mode is normal. The inner ring of the rolling pin has a circulating load mode.

Instead, not only the methodological basis for the purpose of planting ring rings, but also detailed tables for their selection, taking into account, above all, the mode of its operation (depending on the ratio of the current radial load and dynamic load capacity), the type of load, type and diameter and even with numerous examples of machines and folding units. By the way, with reference to this standard in [7] is a compiled table with a simple list of recommended fields of tolerances and landings of rings of different types of furnaces depending only on the type of load, but without examples of sound selection of landings. A comparative analysis of both methods of assigning the considered plantings or tolerance fields shows the following differences. In the tables for the selection of plantings of rings with circulating load according to the method [18] there are no fields of tolerances of shafts, namely p6, r6, r7, recommended for many classes of machines and units operating in difficult conditions and tolerance fields with the main deviation h, provided by the standard for precision machines (hydraulic motors, small electric machines, in-pour spindles, etc.) and rolling mills on fixing sleeves.

Locally loaded rings usually require landings with a gap or transients with a higher probability of a gap – such a landing under the action of starting torque, shocks and vibrations from time to time scrolls relative to the connected surface, thus ensuring uniform operation of the raceway and the possibility of axial movement way of temperature deformations. To select the landings of such rings, in contrast to the materials in [11], specific landings are given, of course, taking into account the required accuracy class of the feller and the mode of operation of the machine. But the disadvantage of the method of selection according to [19] and other above sources is that they do not take into account the peculiarities of the manufacture of folding units with detachable housings.

According to the experience of mechanical engineering, the nominal (estimated) durability of joints with rolling mills in real conditions can be greatly reduced due to deformation of rolling pin rings, insufficient area of their adhesion to surfaces (less than 70…75%) due to unreasonable technical requirements for connection accuracy and surfaces of the connected details, and also deformations of both parts of the case after processing of planes of the socket and apertures (here after their preliminary
assembly). The latter is due to technological heredity associated with deformations that occur during machining of parts, especially non-rigid holes (which are body parts), due to the redistribution of internal residual stresses in the metal thickness.

To minimize this phenomenon in the manufacture and assembly of detachable housings perform a number of measures aimed at ensuring the quality of the folding units under consideration. For example, the displacement \( e \) of the axis of the hole relative to the plane of the connector is limited by tolerances (figure 1, a), and before installing large shafts in semi-holes fit its landing surfaces in areas adjacent to the plane of the connector, performing the so-called collapse, the dimensions of which are regulated by a special normative document depending on the dimensions of the hole (figure 1, b).

![Figure 1. Scheme of installation of the outer ring of the rolling pin in the semi-opening of the housing (a) and fitting the surfaces (b).](image)

It is easy to see from figure 1 and that the condition of assembly of the outer ring of the rolling mill with a semi-finished product can be expressed by the condition:

\[
2 \cdot \sqrt{4^{-1} \cdot D_0^2 - e^2} \geq D_{II},
\]

where \( D_{II} \) and \( D_0 \) – the actual diameters of the outer ring, respectively, the roller and the hole of the housing, respectively, m; \( e \) – eccentricity, m.

After simple calculations we obtain that theoretically the assembly is provided under the condition that:

\[
e \leq 2^{-1} \cdot \sqrt{D \cdot (ES_0 - \Delta D_m)},
\]

where \( D \) – nominal joint diameter, m; \( \Delta D_m \) and \( ES_0 \) – respectively, the lower deviation of the outer diameter of the ring of the roll and the upper deviation of the hole of the housing, m.

Calculations taking into account 6 and 7 qualities for holes and showed that, for example, for the diameter range of 100...500 mm, the most common in large gearboxes, the allowable value of the offset of the hole axis relative to the plane of the housing connector is 1...4 mm, which, taking into account the economically achievable accuracy of calibration of boring rods of boring machines practically does not limit the folding of the folding unit of the feller. To ensure a gap in the joints of the outer locally loaded rolling pin rings in the holes of the detachable housings, it is recommended to assign tolerance fields H6, H7, G6, G7 regardless of the rolling pin type, dimensions and operating conditions. The layout of the tolerance fields of the joints of the outer ring of the rolling mill according to the recommended options is shown in figure 2.
Figure 2. The layout of the tolerance fields of the outer ring of the rolling pin (l0) and the hole (H6, H7, G6, G7) in the housing.

Note that the tolerance fields JS7, K7 and M7, which are given among others in figure 2 and other above-mentioned sources for holes here are generally unacceptable, because, first, with the tolerance fields of the rings l0, l6. They will give transitional, not with a gap, landings, and secondly, do not take into account the described production phenomena of technological heredity.

As modern production experience shows [27], the diameters of the holes of the detachable housings are assigned tolerance fields with the main deviation H. This, in our opinion, is due to the usual traditional principle of assigning tolerance fields to the size of all internal surfaces in the body part, i.e. in this case zero line, which is technologically rational [28]. Despite this, the quality of assembly, especially of large detachable housings, does not always meet the required standards [29]. Production observations have shown that often for the installation of rolling mills during fitting it is necessary to remove a layer 2…3 times larger than the normalized.

The calculations of the average gaps in the joints in the case of using the tolerance fields of the hole H6, H7, on the one hand, and the tolerance fields G6, G7, on the other hand (according to figure 2) showed that in the latter case the gap in joints with nominal diameters of 100…500 mm is 1.2…1.7 times larger. It should be noted that in the case of assigning to the holes of such housings tolerance fields H6, H7 and characteristic due to the psychological factor of the operator negative asymmetry when processing the hole by test passes, gaps in joints (especially taking into account shape deviations and location of connected surfaces) generally close to 0, and in some cases (with unfavourable summation of deviations of surfaces in the process of assembly) instead of the gaps required for operation in such connections, in fact, even tension can be formed [30].

4. Conclusion

The calculations of the average gaps in the joints in the case of using the tolerance fields of the hole H6, H7, on the one hand, and the tolerance fields G6, G7, on the other hand showed that in the latter case the gap in joints with nominal diameters of 100…500 mm is 1.2…1.7 times larger.

On diameters of openings of demountable cases under external rings with local loading it is expedient to assign fields of tolerances H6, H7, G6, G7, and in large folding units – fields of tolerances G6, G7 that will allow to create a backlash in connection with a ring, and, hence, the possibility of periodic rotation of the latter during operation of the folder unit of the rolling mill and reduce the uneven wear of the raceways and the associated increase in the durability of the folding units with rolling mills.

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