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THE INFLUENCE OF MEASUREMENT ERROR ON THE RISKS OF THE CONSUMER AND THE MANUFACTURER WHEN COMPLETING CONNECTIONS

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Abstract. The influence of the measuring device error on the consumer's and manufacturer's risks was studied for three cases of the organization of completing: complete interchangeability, selective completing and completing with ranking. The presence of measurement error does not allow to avoid risks; however, their values must be estimated so that they do not have a significant impact on manufactured products. The study was carried out for a "shaft-hole" connection by statistical modeling, the laws of dimension distribution were accepted as normal, as well as the laws of distribution of measurement errors. For the case of completing with complete interchangeability, the accuracy of two-stage control was studied; it is recommended to establish the accuracy of the initial measurements at 20–25 % of the tolerance field, repeated measurements at 10–12 % of the tolerance field, while the manufacturer's risk does not exceed 0.2 %, the consumer's risk is practically zero. In the case of selective completing, the requirements for the accuracy of the measuring device are significantly higher than in the case of completing with complete interchangeability, since errors are possible not only at the limits of the tolerance field but also at the limits of the selection groups. Therefore, the measurement error should not exceed 5 % of the tolerance field width; it is also advisable to limit the number of selection groups. When completing with ranking, the accuracy of the measuring device has the least impact on risks, especially if the number of parts in the batch is large enough and the measurement error complies with the standards in mechanical engineering. It was established that for the number of sets greater than 10, almost complete assemblability is achieved and the risks associated with the measurement error become insignificant. Thus, if it is necessary to increase the accuracy of products at the assembly stage, it is recommended to use completing with ranking instead of selective completing.

Keywords: manufacturing error, accuracy of measurements, consumer's risk, manufacturer's risk, selective completing, completing with ranking.

Introduction

In the production of parts in mechanical engineering, their accuracy is influenced by a large number of factors, as a result of which it is impossible to obtain the absolute value of dimension. As a result of manufacturing, the dimension of a manufactured part is random, subject to a certain distribution law. The tolerance and fit system serves to solve this problem, and if the parts are manufactured within the tolerance, then the resulting connection is considered suitable.

However, no matter how perfect the measuring device can be, it also gives the result with some error. The dimension obtained as a result of the measurement is called actual, and it differs from the true dimension by a random value. Therefore, the actual part dimension sums the true part dimension and the measuring device error. The measurement task is to obtain the value of the actual dimension, which differs from the true one by an amount that does not significantly affect the performance of the product. This is especially important for high-precision parts, since measuring devices with small values of measurement errors are used for their measurements, and special conditions must be created during measurements.

For high-precision connections, it is possible to obtain a fit tolerance within narrow limits both at the manufacturing stage, reducing part tolerances, and at the assembly stage, organizing completing of connections using a special algorithm. Selective completing is widespread, in which parts after measurement are divided into selection groups, and parts that fall into one group are assembled. The author has proposed a special completing algorithm with ranking [1], [2], which is more effective than selective completing.

Problem statement

The presence of a non-zero measurement error leads to the fact that it is possible to transform suitable parts into defective ones and, vice versa, defective into suitable. This phenomenon causes the appearance of the so-called manufacturer's and consumer's risks. The manufacturer's risk refers to the likelihood that suitable products will transform into defective ones. The consumer's risk refers to the likelihood that defective products will transform into suitable ones. The presence of measurement error does not allow to avoid these risks; however, it is necessary to evaluate their values so that they do not have a significant impact on manufactured products.

This is especially important for selective completing and completing with ranking, because high-precision measuring devices are used for them, and the manufacturer's and consumer's risks are associated not only with measurement errors at the limits of the tolerance field but also at the limits of selection groups for selective completing and getting an unsuitable set for completing with ranking.

Review of Modern Information Sources on the Subject of the Paper

In the manufacture of high-precision compounds is important to choice of accuracy of the measuring device [3]. This is due to the need for very accurate measurements, since the accuracy of the measuring device must correspond to the accuracy of sorting. In practical cases, the situation is further complicated by shape geometry errors of the parts and temperature errors of the measurements, which become comparable to the tolerance.

In the most general form – under the normal laws of the distribution of part sizes and measurement errors, the problem of determining the percentage of defects was first posed in [4]. The parameters are calculated through a two-dimensional probability integral. Except in the simplest cases, the solution is made by numerical methods or by approximation.

To reduce the share of defective products, it is proposed to reduce the technological tolerance compared to the constructive one. Such a technological technique will allow to provide higher measurement performance of parts and use simple in design, therefore, inexpensive, devices of certifying the dimensions of parts in automated precision assembly [5].

It is possible to increase the accuracy of measurements both in the direction of increasing the accuracy of measuring instruments, and by increasing the number of measurements themselves. For high-precision compounds, the temperature mode of measurements is of great importance [6].

To determine the size and shape geometry errors of high-precision compounds, it is preferable to use non-contact measuring instruments. This is due to the fact that mechanical measuring instruments leads to deformations, which reduces the accuracy of the results. That is why optical, optoelectronic, laser, and other devices are widely used [6], [7], [8], [9].

Objectives and Problems of Research

An assembly unit may be deemed suitable if the resulting spacing or interference is within tolerance. We will consider the influence of the error of the measuring device on the accuracy of the "shaft-hole" connection.

The problem was solved for three ways of organizing the completing of parts: assembly with complete interchangeability, selective assembly and assembly with ranking. To obtain the manufacturer's and consumer's risk values, statistical modeling was performed. The laws of the distribution of part dimensions and measurement errors were accepted as normal. Errors in the shape of the parts were not considered.

The problem was solved by statistical modeling using VBA in MS Excel.

Main material presentation

Assembly with complete interchangeability. When assembling with complete interchangeability, parts are randomly assigned to sets. Therefore, when modeling, an assembly was recognized as suitable, in which the dimensions of the shaft and holes fell into the tolerance fields. The modeling was performed for fit with a spacing of Ø150 E9/h8, the average values of the shaft and hole dimensions were adopted respectively as $d_s = 149.9685$ mm and $d_h = 150.135$ mm, shaft and hole manufacturing tolerances $T_s = 0.063$ mm and $T_h = 0.1$ mm, errors in measuring shaft and hole dimension δ varied from 0.001 mm to 0.1 mm. As the consumer's risk, the percentage of sets that did not match the connection parameters (the dimensions of one or both parts did not fall into the tolerance field) was determined, but due to the measurement error, they fell to suitable. As the manufacturer's risk, the percentage of sets was determined, the details of which were suitable in their actual dimensions; however, due to the measurement error, they were recognized as defective.

Modeled manufacturer's risk P_{m} in percentage is shown in Fig. 1, consumer's risk in Fig. 2. As expected, the relationship between the manufacturer's and consumer's risks and the error of the measuring device is traced: with an increase in the error of the device, the corresponding risks increase. This is due to an increase in the likelihood of a mutual transition of suitable parts into defective ones and defective into suitable ones. As can be seen from the graphs, the likelihood of the transition of suitable parts into defective ones is much higher with the same error. If the error of the measuring device is $\delta = 0.01$ mm, consumer's risk is $P_{\mathrm{c}} = 0.033$ %, then the relevant manufacturer's risk is $P_{\mathrm{m}} = 0.28$ %.

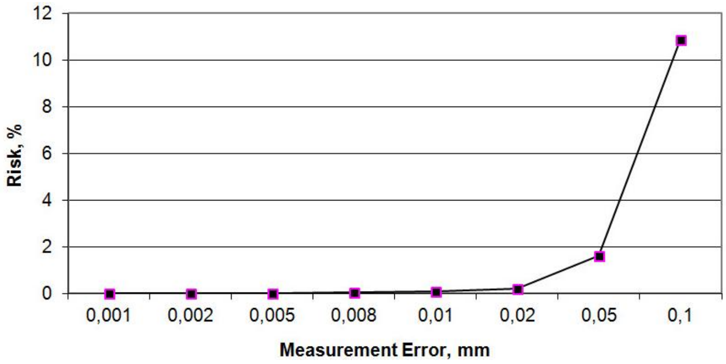

Fig. 1. Manufacturer's risk during assembly with complete interchangeability

Consumer's risk reduction is paramount. At the same time, increasing the accuracy of the measuring device, which allows to reduce the risk, for measuring all parts is economically unjustified; in addition, more precise control requires a lot of time. Therefore, a two-stage control is recommended: at the first control stage, parts that fall into a narrower range of dimensions than it is required for the fit are recognized as suitable, and then the defective parts are re-measured with a more accurate device and some of them are returned to suitable ones.

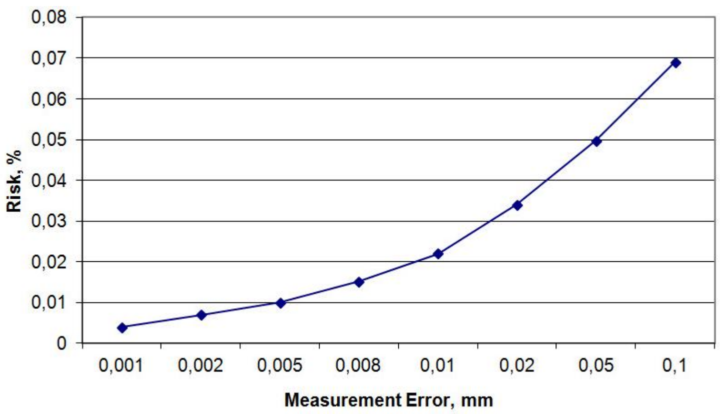

Fig. 2. Consumer's risk during assembly with complete interchangeability

The effectiveness of the two-stage control was verified by statistical modeling. The tolerance field narrowed from 1 μm to 20 μm. The modeling results are shown in Fig. 3 and Fig. 4. As can be seen from the graphs, with the accepted fit, the consumer's risk (Fig. 4) disappears even when the tolerance field is narrowed by 7 μm. However, this increases the manufacturer's risk (Fig. 3). In order to neutralize this, it is proposed to apply the re-measurement of parts that were considered defective using a more accurate device. During the repeated control, the measurements were carried out with an accuracy two times larger than the initial one. The repeated control was carried out with the initial tolerance field. The results of manufacturer's risk are presented in Fig. 5 and as can be seen from the graphs, the manufacturer's risk has slightly increased. The consumer's risk has remaining zero.

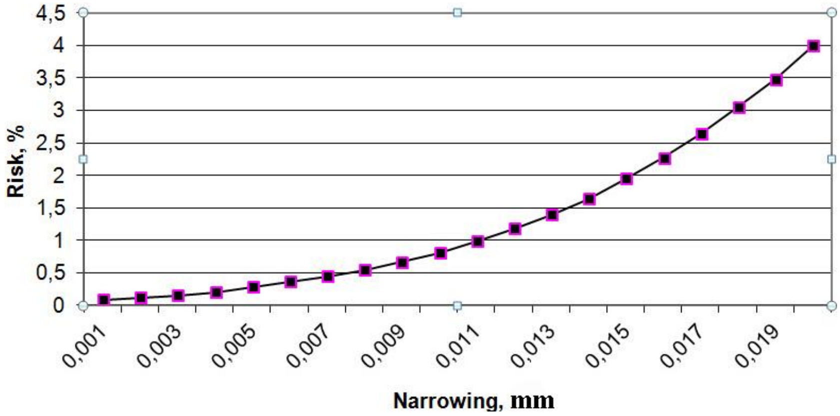

Fig. 3. Manufacturer's risk during narrowing the tolerance field

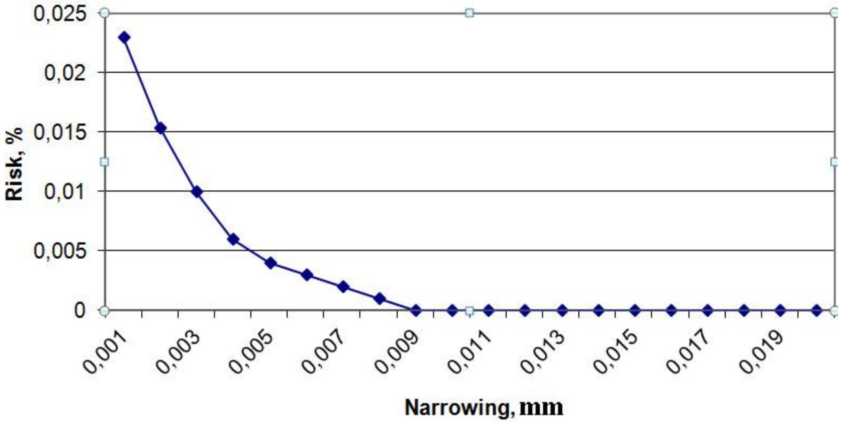

Fig. 4. Consumer's risk during narrowing the tolerance field

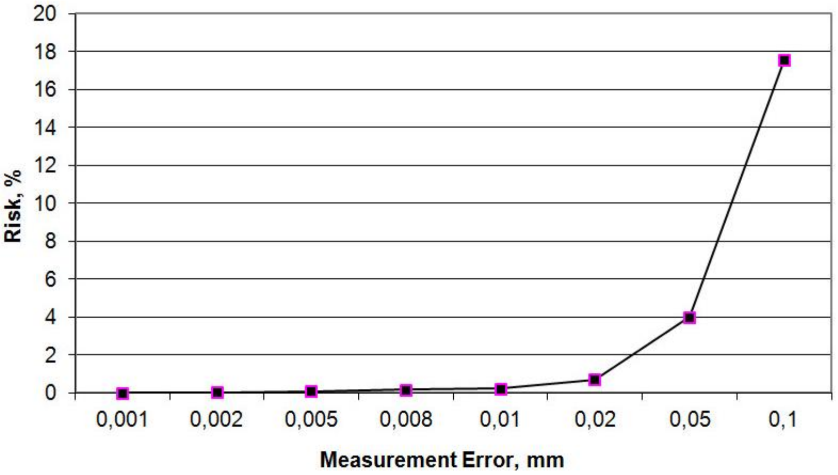

Fig. 5. Manufacturer's risk during assembly with two-stage control

Having examined the relationships in this example with a two-stage control, it can be recommended to establish the accuracy of the initial measurements at 20–25 % of the tolerance field, repeated measurements at 10–12 % of the tolerance field, while the manufacturer's risk does not exceed $P_m = 0.2$ %, consumer's risk is almost zero – $P_c = 0.02$ %.

Selective completing. We shall consider the influence of accuracy of the measuring device for selective completing. As the initial data during the modeling, the same ones were used as during the assembly with complete interchangeability. When sorting into 6 selection groups of the same width, the resulting fit tolerance approximately corresponds to 6–7 quality.

Connections were considered suitable if their shaft and hole were in the same dimension group. The consumer's risk was understood as the likelihood of the transition of one or both parts to dimension groups that do not correspond to their actual dimension, including due to the transition of defective parts into suitable ones. The manufacturer's risk was understood as the likelihood of recognition of one or both parts of the suitable connection as defective.

The modeling results are presented in Fig. 6 and Fig. 7. As can be seen from the graphs, the dependence of the manufacturer's risk on the error of the device (Fig. 6) is comparable to that which we observed in the case of assembly with complete interchangeability. The consumer's risk (Fig. 7) with the same value of the measurement error is much greater than in the case of the complete interchangeability. This is due to the fact that the manufacturer's risk was obtained at the limits of the manufacturing tolerance field, where the density of the dimensions of the parts is relatively low. And the consumer's risk was also obtained at the limits of selection groups, where the density of the dimensions of the parts is much higher and the likelihood of their transition from one group to another is higher.

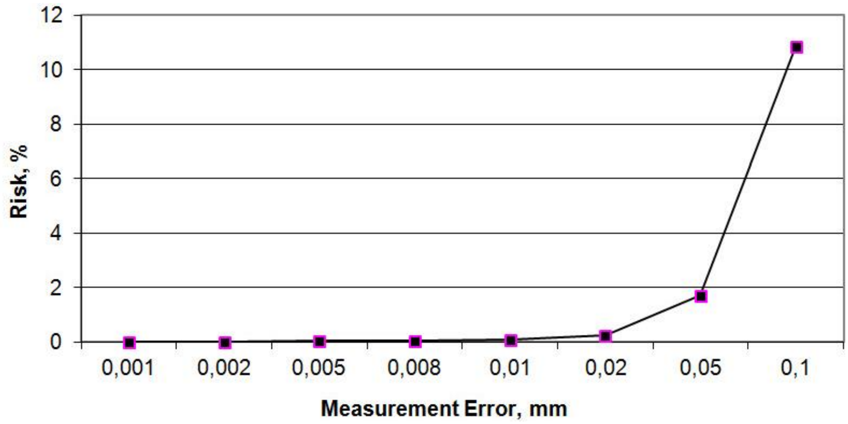

Fig. 6. Manufacturer's risk during selective completing

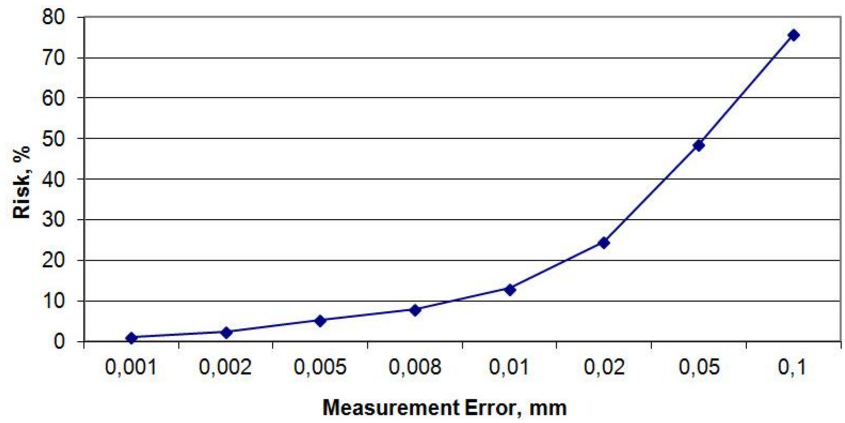

Fig. 7. Consumer's risk during selective completing

In the case of selective completing, the quantity of dimension groups also has a significant effect on the amount of the consumer's risk. The more of them there are, the greater the likelihood of mutual transition of parts at the limits of these groups. To determine how the number of dimension groups affects the amount of the consumer's risk, consumer's risks were obtained depending on the number of dimension groups. The error of the measuring device was 0.002 mm. As can be seen from the graph (Fig. 8), with an increase in the number of dimension groups, the consumer's risk increases, and this dependence is linear.

As the modeling shows, in the case of selective completing, the requirements for the accuracy of the measuring device are significantly higher than in the case of completing with complete interchangeability. Its accuracy should not exceed 5 % of the width of the tolerance field, while the consumer's risk is P_c = 2–2.5 %, manufacturer's risk is P_m = 0.005–0.2 %. The consumer's risk also depends on the number of dimension groups, which necessitates the selection of their optimal number depending on the requirements for the accuracy of the connection.

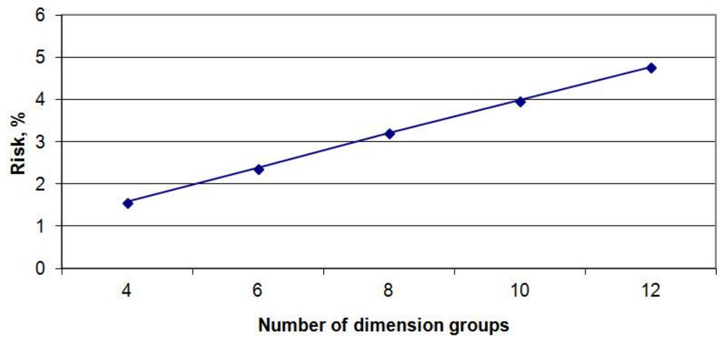

Fig. 8. Risk quantity of dimension groups

Completing with ranking. In this case, the consumer's risk is the completing of a "shaft-hole" pair with parameters outside the tolerance field. There is no manufacturer's risk with this completing method.

As the initial data, a connection with a fit and spacing of Ø150 H7/h7 are taken, whose accuracy corresponds to the accuracy achieved by selective assembly. The arithmetic mean values of the dimensions of the shaft and hole are taken respectively as d_s = 149.98 mm and d_h = 150.02 mm, shaft and hole manufacturing tolerances are T_s = 0.08 mm and T_h = 0.12 mm, errors in measuring shaft and hole dimensions are equal to 0.005 mm, maximum spacing is S_{max} = 0.08 mm, minimum spacing is S_{min} = 0. The number of parts in the batch ***n*** varied from 2 to 50 pcs.

The modeling results are shown in Fig. 9–12. The graphs show the dependence of the assemblability of connections (Fig. 9), consumer's risk (Fig. 10) and a decrease in the proportion of manufacture in progress (Fig. 11) on the number of parts in the batch. As can be seen from the graph in Fig. 9, the assemblability of the batch of connections approaches 100 % already at 10 parts per batch. Similar results are observed for the consumer's risk and the proportion of manufacture in progress: with increasing batch size, they decrease, asymptotically approaching zero. This is due to the fact that with an increase in the number of parts in the batch, the likelihood of successful completing of parts increases, even considering the error.

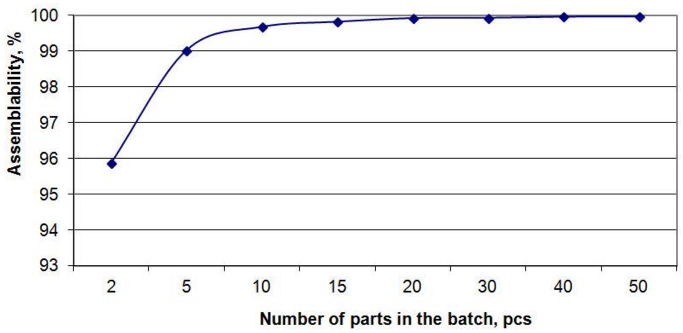

Fig. 9. Dependence of the assemblability
of connections during completing with ranking

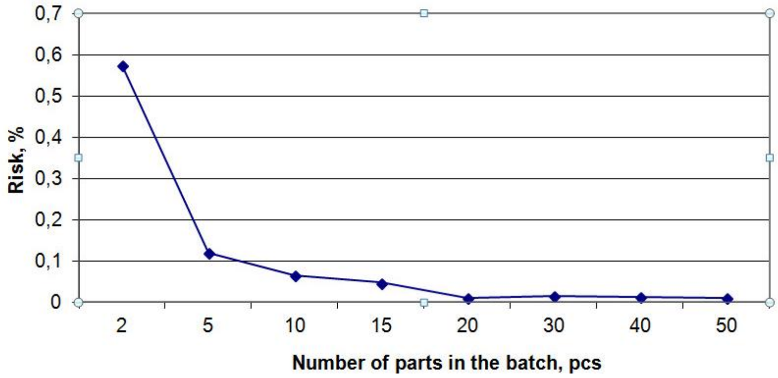

Fig. 10. Risks during completing with ranking

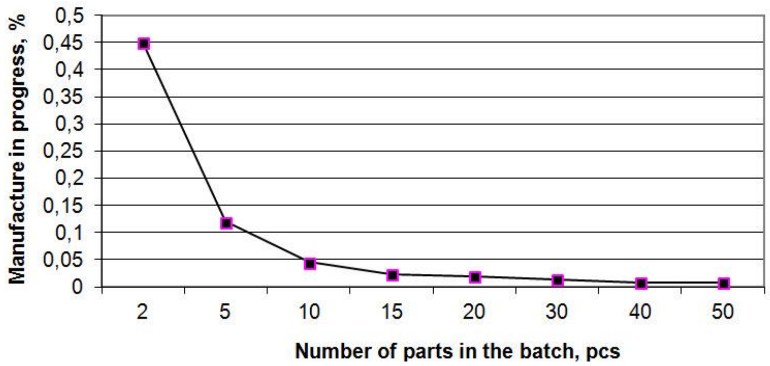

Fig. 11. Proportion of manufacture in progress during completing with ranking

With an increase in the measurement error from 0.001 to 0.1 mm, the consumer's risk begins to grow rapidly with measurement errors above 0.02 mm, i.e. above 25 % of tolerance field. The modeling results are presented in Fig. 12. Consequently, the measuring device for completing with ranking must be selected according to general engineering standards – the accuracy should not be coarser than a fifth part of the tolerance.

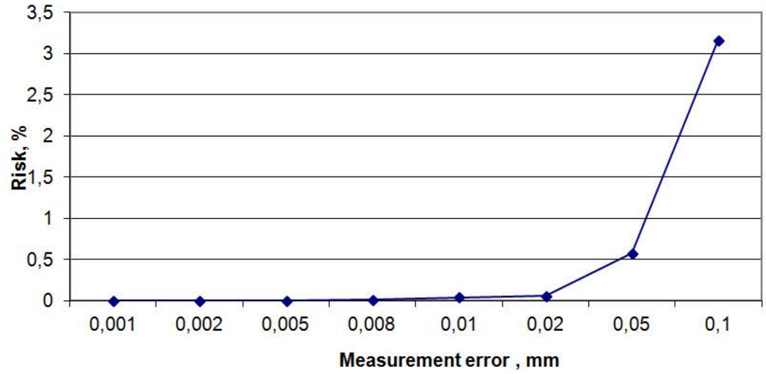

Fig. 12. Risks during completing with ranking

Conclusions

1. For the case of assembly with complete interchangeability, the accuracy of two-stage control was studied for decreasing manufacturer's and consumer's risks. It is recommended to establish the accuracy of the initial measurements at 20–25 % of the tolerance field, repeated measurements of 10–12 % of the tolerance field. Such values can reduce the consumer's risk to almost zero, without increasing the manufacturer's risk.

2. The error in measuring the dimensions of parts has the greatest impact on the percentage of the consumer's and manufacturer's risks during selective completing, where the mutual transition of parts is possible not only at tolerance limits, but also at the limits of dimensional groups.

3. For selective completing, the requirements for accuracy of the measuring device are significantly higher than for the completing with complete interchangeability. The measurement error should not exceed 5 % of the width of the tolerance field. The consumer's risk also depends on the number of dimensional groups, which makes it inappropriate to increase them over 10–16.

4. During completing with ranking, the accuracy of the measuring device has the least impact on risks, especially if the number of parts in the batch is more than 10 and the measurement error complies with the standards in mechanical engineering. Therefore, if it is necessary to increase the accuracy of products at the assembly stage, this completing method is recommended to be used instead of selective completing.

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