THE TOLERANCE DESIGN MANUFACTURE AND RELIABILITY①

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ABSTRACT The allocation of proper production tolerances is a vey important task if the finished design is to achieve its intendend purpose. In view of tribodesign optimizing the tolerance of fit is helpful for the production costs and the characters of slider fricition pair. To obtain the great assembly clearance by reducing the accuracy is neither reliable nor economical and will lead to the loss of the machine reliability. Based on ISO standard system, a set of mathematic models were built in cooperation with the tribodesign software. This program can facilitate the tolerance of fit design and selection process.

Key words: tolerance fit reliability service probability distribution machining precision tribology design CAD

1 INTRODUCTION

A very important fact of the manufacturing science is that it is almost impossible to obtain the desired nominal dimension when processing a workpiece. This is actually caused by the inevitable, though very slight inaccuracies inherent in the machine tool as well as by various complicated factors like the elastic deformation and recovery of the workpiece and the fixture, temperature effects during processing, and sometimes the skill of the operator. Since it is very difficult to analyze and completely eliminate the effects of these factors, it is more feasible to establish a permissible degree of inaccuracy or a permissible deviation from the nominal dimension that would not affect the proper functioning of the manufactured part in a detrimental way.

2 TOLERANCE AND FITS

According to the ISO system, the nominal dimension is referred to as the basic size of the part. The deviation from the basic size to each side(positive or negative) determines the high and the low limits, respectively, and the difference between those two limits of size is called the tolerance. The magnitude of the tolerance is dependent upon the basic size and is designated by an alphanumeric symbol called the grade. There are eighteen standard grades of tolerance in the ISO system, which can be obtained from the formulas or the tables published by the ISO.

Before two components are assembled together, the location of the zero line to which deviations are referred must be established for each of the two mating surface. In all cases of clearance fit, the upper limit of the shaft is always smaller than the lower limit of the mating hole. The location of the tolerance zero with respect to the zero line is indicated by a letter, which is always capitalized for holes but small letters are used for shafts, whereas the tolerance grade is indicated by a number, as previously explained. Therefore, a fit designation can be H_7/h_6. The quality of fabricated machines is of great economic importance. In attempts to integrate tribology and tribodesign into mechanical engineering design is advantageous to start by visualizing the engi-

① Received Nov. 7, 1994; accepted in revised form Mar. 20, 1995

neering task of mechanical engineers in general and of designers in particular. In view of tribodesign, there is an optimal clearance of the best tribological behaviours obtained for the sliding friction pair. For a hydrodynamic slide bearing, high values of diametral clearance could lead to excessive damage due to cavitation erosion even where bearings have been designed with a reduced vertical clearance, but a high horizontal clearance, in an attempt to induce a cooling oil flow through the bearing, so-called eccentric wall suction cavitation erosion has occurred in the centres of the bearing hands in the high clearance regions. Theoretically, low level of clearance is required for good load carrying capacity and generation of the hydrodynamic oil film, but the oil flow through the bearing is restricted, leading to increased oil film which in turn results in a thinner film. Thus, clearance has to be a compromise of several factors. Theoretical calculations, based on a heat balance across steadily loaded bearings, point to a standarized minimum clearance of 0.000 75 Journal diameter[1], which has been verified by satisfactory hydrodynamic, cavitation-free operation in a whole range of different engine-types under normal, varied service conditions. The same order of clearance has also been confirmed theoretically in computer simulation of minimum film thickness with due allowance for the variation in viscosity as a consequence of a clearance change. The clearance of hydrodynamic slide bearing can be obtained by[2]:

$$\Psi = \sqrt[4]{U/2.5} \cdot 10^{-3}$$

where U —The velosity of sliding surface, m/s; Ψ —relative clearance S/D, %.

For grease lubricated slide bearing, Ψ may be taken greater than those of the hydrodynamic beraing[3]:

$$\Psi = [(0.050/D) + (2.5 \sim 4)] \cdot 10^{-3}$$

For the plain bearing, the radial clearance and axial play of the shaft should be held with the admissible limits. When joining together shafts and other elements with bearings it is essential to assure a minimum clearance between the bearing working surfaces, and the established positional accuracy of the axis of rotation relative to the mounting surfaces. The allocation of proper production tolerances is therefore a most important task if the finished design is to achieve its intended purpose[4-6].

3 EFFECT OF THE PROCESSING

The reason for the variation in a chosen dimension on parts all made by the same process can usually be grouped into two general classes: assignable causes and chance causes. Assignable causes can usually be located and rectified. Chance causes occur at random and are due to vague and unknown forces which can neither be traced nor rectified. They are inherent in the process and occur even though all conditions have been held as constant as possible. It is not always possible to make a strict and fast distinction between assignable causes and chance causes. If the variations due to assignable causes have been located and removed one by one, the desired state of stability or control is attained. The process is then called a constant-cause system and is said to be in statistical control. Experience in production has indicated that the error distribution can be represented with Gaussian curve, more generally called the probability or normal curve.

For instance, a fit designation of slide bearing is $d400\ H_7/C_7$. The shaft, hole and assembly curves are shown in Fig. 1, where $x_1 = 399.4915$, $x_2 = 400.0285$, $x_2 - x_1 = 0.5365$, $u_1 = u_2 = 0.0285$, $\sigma_1 = \sigma_2 = 0.0095$.

3.1 *Truncation Effect*

In order to compensate for tool wear, production equipment is frequently adjusted so that the parts first formed will lie near the low limit of the tolerance zone for an external dimension and near the high limit for an internal dimension. The distribution of errors would resemble a truncated normal curve on the tolerance of $\pm u_1$ (see Fig. 2). The curve would have a standard deviation σ_t of ku where k is a constant depends on the shape of the curve, which depends on the amount of truncation.

For normal distribution $x = 2$, $\sigma_t = 0.33u$; for $x = 1.5$, $\sigma_t = 0.4u$; for $x = 1$, $\sigma_t = 0.44u$; *for* $x = 0.5$, $\sigma_t = 0.67u$. Fig. 2 shows a symmetrical truncation x equal 1, the constant k would have the value of 0.44. An assembly made from shaft and bearing will have the clearance's variance and standard deviation.

$$\sigma_a^2 = \sum_{i=1}^{n} \sigma_{ti}^2 = \sum_{i=1}^{n} (k_i u_i)^2$$

3.2 *Account of Reworking*

The operator learns that maximum material tolerances have a production advantage. For an external dimension the worker should aim at the fundamental or largest value. For an interanl dimension the worker should aim at the list value and form something smaller and then the parts may be reworked to bring them within acceptable limits. So that the reject rate would be reduced. Suppose that the production equipment forms parts with a smaller dispersion of u' rather than u and that the equipment is adjusted to form parts at the high end of the tolerance for an external dimension, and the equipment is adjusted to form parts at the low end of the tolerance for an internal dimension. The error distribution curve has the standard deviation $\sigma' = ku'$, where k is the same as originally anticipated. The difference between the means of the anticipated and actual production piece part curves is $u - u'$. The normal curve for the assembly of shafts and bearings as actually produced has the variance σ_a^2 or σ_{ti}^2. The natural tolerance $u_a' = 2\sigma_a'$ (see Fig. 3). The mean of actual assembly curve has shifted, and this shift causes the actual bearing clearance smaller than that expected.

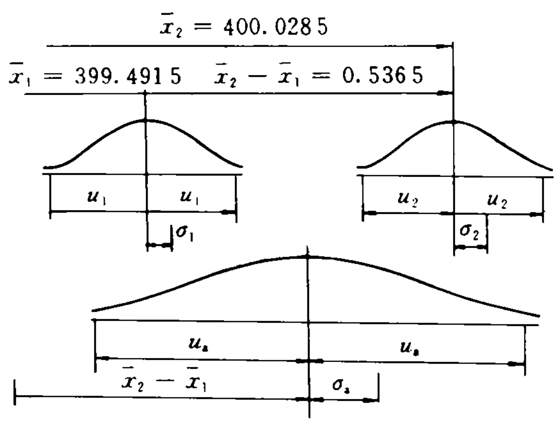

Fig. 1 Assembly curve for d 400 H_7/C_7

$\sigma_a^2 = \sigma_1^2 + \sigma_2^2 = 0.00952 + 0.00952$,
$\sigma_a = 0.013435$; $u_a = 3\sigma_a = 0.040305$;
$S = 0.594 - u_a = 0.553695$

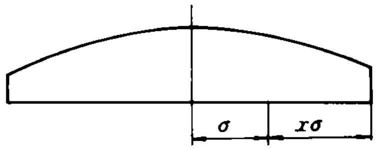

Fig. 2 Truncation effect

4 ACCURACY GRADE

To obtain great sliding bearing clearance, some handbooks and teaching books advise reducing accuracy grade to IT9, IT10 or lower. Table 1 provides a comparison of the results.

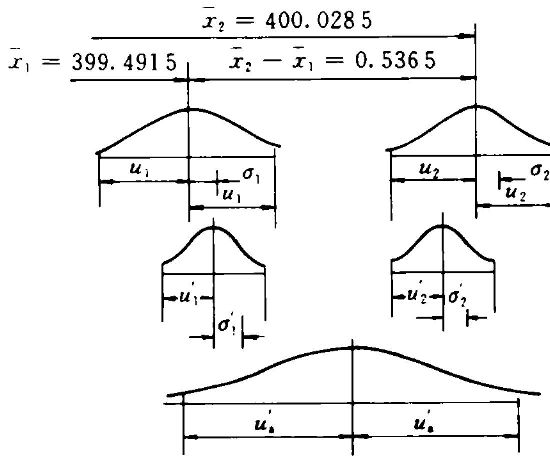

Fig. 3 Shortening of assembly different from the anticipated clearance by using parts fabricated near low limit of shaft's tolerance and high limit of hole's tolerance

$x_1 = 399.4915 + 0.0095 = 399.501$; $x_2 = 400.0285 - 0.0095 = 400.019$; $S_{max} = 0.518$; $S_{min} = 0.48$; $u'_1 = u'_2 = 0.019$; $\sigma_1 = \sigma_2 = 0.441 - 0.019 = 0.00836$; $\sigma'_a = 0.0118$; $u'_a = 0.03547$; $S = 0.48 + 0.03547 = 0.5154$

Table 1 Assembly curve character of various fit qualities(400 diameter)

fit quality	S_{min}	S_{max}	S_{aver}	σ_s	Ψ‰
400 H_7/c_7	0.480	0.594	0.5536	0.0134	1.3840
400 H_7/c_7	0.480	0.518	0.5154	0.0118	1.2885
truncated, $k = 0.44$					
400 B_7/c_7	0.998	1.010	1.0168	0.0134	2.5420
400 H_9/c_8	0.480	0.780	0.5789	0.0330	1.4473
400 H_9/c_8	0.048	0.667	0.5672	0.0290	1.4180
truncated, $k = 0.44$					

5 ECONOMY

A designer is well aware that the cost of a finished product can increase rapidly as the tolerances on the components are made smaller. Designers are constantly admonished to use the widest tolerances as much as possible. Fig. 4 shows the relationship between accuracy and poduction cost. It is obvious that smaller tolerances require the use of high-precision machine tool in manufacturing the parts and therefore increase production costs. Very small tolerances necessitate very high production cost but the increasing of the tolerance will not reduce the production cost remarkably.

Nomal lather's machine capacity is IT7. Grinding machine capacity is IT6, There is no point in reducing the grade to deviate the processing economical accuracy range. Inversely holding the accuracy grade, and varying the fit will result in optimal tribological behaviour of sliding friction mating. If the variations due to chance causes are too great, it is usually necessary to move the operations to more accurate equipment rather than spend more effort in trying to improve the process.

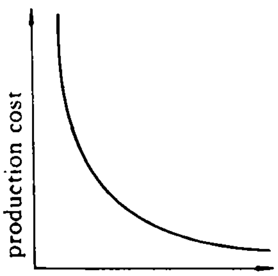

Fig. 4 The relationship between tolerance and production cost

6 CONCLUSIONS

The quality of fabricated machines is of great economic importance. It is the quality that determines the effectiveness of new technology in various fields of industry and the entire country's economy. The quality of industral product implies a totality of properties which stipulate for its ability to satisfy the needs in agreement with its purpose. The most important criteria of quality are the performance characteristics such as ergonomic aesthetic and reliability features. The tribological characters of sliding friction pair are very important for the reliability of machines.

It is an obvious and fundamental fact, that the ultimate practical aim of tribology lies in its successful application to machine design. Tribodesign is regarded as a branch of machine design concerning all machine elements where friction, lubrication and wear play a significant part. It is hoped that the procedures and techniques of analysis in this article will be found helpful in applying the principles of tribology to the design of machines.

REFERENCES

1 Stolarski, T A. Tribology in machine design. Oxford London: Industrial Press Inc, 1990. 218－220.
2 Georg Vogelpohl. Betriebssiche Gleit-Lager. Berlin and Heidelberg: Springer-Verlag, 1967. 177.
3 Göttner, G H. Einführung in die Schmier-Technik. Düsseldorf: Karl Marklein Verlag, 1961.
4 Loges, J. Schmierungstechnik, 1979, (9): 45.
5 Jiang, J C. Journal of Central-South Institute of Mining and Metallurgy, 1992, 23(6): 733.
6 Jiang, J C. Mining Machinery, 1991, (7): 16.