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Influence of Roundness on Load Carrying Ability of Interference Fits

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Abstract

Interference fits are commonly used to assemble cylindrical parts. Dimensions of the mating parts, roughness and geometrical features are some factors which can influence the strength of such fits. Roundness or circularity is a two dimensional geometrical feature of a cylindrical component which can affect the functional performance of interference fitted assemblies. In this work, the effect of roundness on load carrying ability of interference fits was experimentally analyzed. Interference fits with a grade of H7u6 were achieved between standard deep groove ball bearings and C40 steel shafts with a nominal diameter of 20 mm. Shafts were prepared by CNC turning followed by cylindrical grinding. Measurements were taken for diameter, roughness and roundness parameters. Roundness was measured at three different sections at an engagement length of 10mm for bearings and shafts. Finally, selective assembly was done and specimens tested on UTM to determine the maximum load required for the failure of the joint. The various factors were analyzed against the extraction load. It was observed that, after interference and roughness, the roundness parameter RONt correlates with the extraction load well. However RONq was found insignificant to predict the load carrying ability.

Keywords: Interference fits, roundness, extraction load

1. INTRODUCTION

Interference fits are commonly used to assemble cylindrical parts due to their ability to carry axial and radial loads without fasteners. The load carrying ability of such fits are influenced by factors such as mating part dimensions, surface roughness and geometrical irregularities etc. A brief review of literature, which shows the significance of various parameters on interference fits, is given below.

Russel [1], studied the factors affecting grip on different types of fits and concluded that the machining accuracy of mating surfaces and nature of lubricants applied on the contact surfaces have major influence in axial load carrying ability. Ramachandran et al. [2] analyzed the influence of roughness on interference fits and reported that the performance of the assembly can be correlated with the roughness of mating parts. Thornley et al. [3] studied the effect of dimension and roughness on stiffness of shrink fitted components and found that displacement of specimen took place at lower interference and high roughness value. Ramamoorthy et al. [4] worked on improving the load carrying capacity of interference fits and reported that better surface finish leads to intimate contact thereby increasing load carrying capacity. Yang et al. [5] analyzed the influence of roughness on interference and showed that the asperities played an important role in peak to peak tightening thereby improving the fit strength. Ramamoorthy et al. [6] analyzed the surface deformations in press and shrink fits and reported that the press fits will reduce the profile deformation and thus increase the load-carrying capacity. Sogalad et al. [7] carried out roundness profile analysis for the interference fitted assemblies and found that with the increase in average undulation number, load bearing capacity increases and roundness error alone could not give any definite pattern for the interference fitted assemblies. This may be due to the limited variation (4 microns) in the roundness error of the specimens studied by them.

It is well known that the load carrying ability is primarily influenced by the amount of interference. From the literature cited, it is observed that surface roughness also plays a significant role in controlling load carrying ability. However studies on the effect of geometrical irregularities like roundness is very limited. Also works indicating combined effect of interference, roughness and roundness on load carrying ability were not noticed. Hence it was decided to carry out a comprehensive study focusing on roundness along with other potential factors which can affect the performance of interference fits.

2. METHODOLOGY

Interference fit between solid shafts with ball bearings was considered in this work. The standard fit H7/u6 was chosen with nominal diameter 20 mm. Shafts were manufactured, measured and press fitted into standard deep groove ball bearings. They were disassembled using Universal Testing Machine (UTM) and the extraction load was determined. The variation of maximum load was analyzed with respect to each factor.

3. EXPERIMENTAL PROCEDURE

3.1 Selection of Ball Bearings and Preparation of Shafts

Interference fitted assemblies consist of two mating parts. This may be a combination of hole-shaft, bush-pin, bush-shaft, etc. The shaft may be hollow or solid. For the current work, solid shafts and standard deep groove ball bearings were chosen as this is an important application of interference fits. NBC 6204 deep grove ball bearings was chosen for the study. Shafts were prepared as shown in Fig 1. The material used was C40 steel round bars. The chemical composition was tested and obtained as C 0.39%, Mn 0.83%, P 0.027%, S 0.02%, Si 0.203% with remaining iron. The hardness was measured and found to be in the range of 280–290 HV. The natural variation during grinding process led to variation in shaft diameter covering the full range of u6 grade. For getting variation in roundness values, the shafts were ground in different machines.

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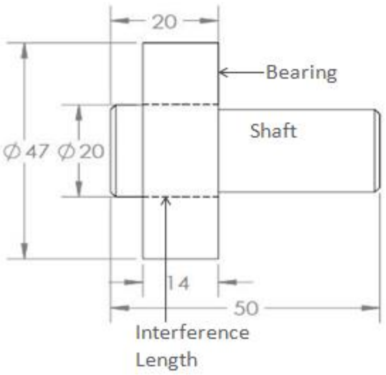

Figure 1. Line diagram of Bearing-Shaft assembly

3.2 Measurements of Shafts and Bearings

Shafts and bearings were measured for dimensions, roughness and roundness parameters. The diameter of the shaft was measured using CMM (Bright A 504, Mitutoyo). Roughness parameters were measured on surface profilometer (SJ-410, Mitutoyo). Roundness data were collected using Mitutoyo Roundtest RA-1600. Roundness parameters were measured by taking three separate sections on the shaft as well as bearings. Least square circle (LSC) strategy was used for evaluation. The parameters used to quantify roundness have been defined in ISO 12180-1: 2011 [8], and are briefly reproduced here for the convenience of readers. With reference to Fig 2, peak-to-valley roundness deviation (RONt) is defined as the value of the largest positive local roundness deviation added to the absolute value of the largest negative local roundness deviation. Root mean square roundness deviation is defined as the square root of the sum of the squares of the local roundness deviations from the least squares reference circle.

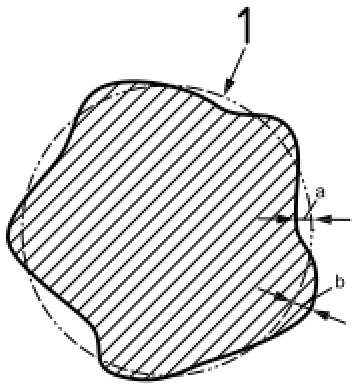

Figure 2. Local roundness deviation of a feature; 1-Reference circle, a-negative local deviation and b-positive local deviation

In this work, RONt and RONq were measured. The total interference length was 14 mm as shown in Fig 1. All these measurements were carried out over a length of 10 mm leaving 2 mm at both ends to exclude the effect of chamfers and rounding. Roundness profiles for a sample of shaft and bearing at 3 different sections on the interference length are shown in Fig 3.

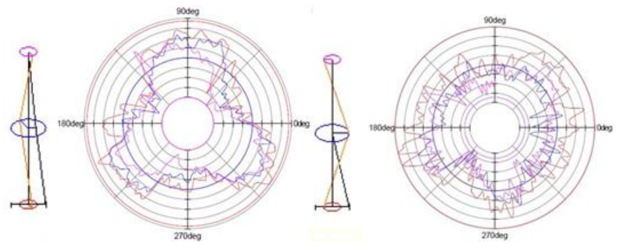

Figure 3. Sample roundness profiles for Shaft (left) and Bearing (right)

3.3 Assembly and Testing of Specimens

After carrying out the measurements, shafts were press fitted on bearings. Load carrying capacity or the 'extraction load' is the maximum load when applied axially on the assembly that causes a micro slip between the shaft and bearing. A compressive load was applied using a UTM with the help of a specially designed fixture, at a constant rate of 0.1kN/s till the shaft was extracted. Load extension graph for a sample is shown in the Fig 4. The maximum load to cause assembly failure can be observed. It can be seen from the graph that with very small movement of the shaft, the applied load suddenly rises to maximum (Fm). Thereafter, it is observed that load decreases with movement of the shaft and finally, it reaches zero when shaft and bearing are completely disassembled or disengaged.

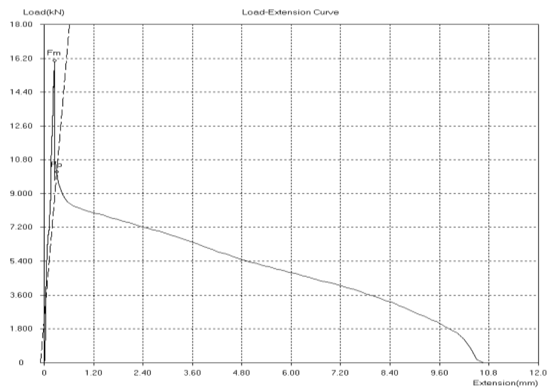

Figure 4. Load-Extension graph for a sample

4. RESULTS

To study the effect of various factors on the load carrying capacity, graphs were plotted between these variables and examined as discussed below.

4.1 Effect of Interference (I)

Interference is a common factor for the bearing-shaft assembly, which is obtained by subtracting the bearing diameter from shaft diameter. The variation of extraction load with interference is shown in Fig 5. It can be seen that with increase in interference level, load carrying capacity increases.

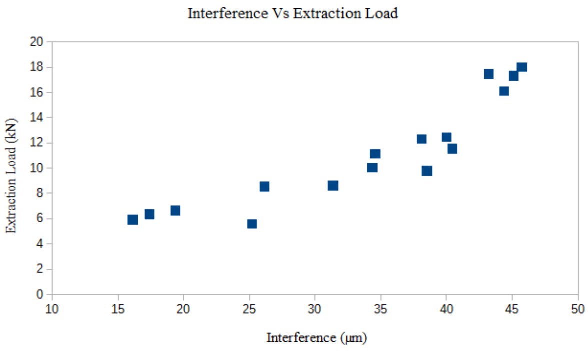

Figure 5. Interference vs Extraction Load

4.2 Effect of Shaft Parameters

4.2.1 Shaft Roughness (Ra):

The variation of extraction load with roughness parameter Ra of shaft was analyzed. No correlation between surface roughness and extraction load was observed. The reason could be the narrow range of average roughness values obtained for the shafts, which is between 0.4 to 2.5 µm.

4.2.2 Shaft Roundness at different sections (RONt):

RONt values for 3 sections along the interference region were plotted separately against the extraction load. But no definite pattern was observed.

4.3 Combined Effect of Interference, Roughness and Roundness

The individual analysis of interference, roughness and roundness reveals that interference was the significant factor which can control the load carrying ability primarily than roughness and roundness. It was decided to analyze the combined effect, as the fit strength can be a function of all the above factors. Hence a linear regression analysis was conducted in MINITAB 17 statistical software to analyze the correlation between the response extraction load and the predictors such as interference, roughness and roundness. The analysis of variance (ANOVA) table 1 is shown below. It can be observed that after interference and roughness, roundness (RONt) of the shaft plays a significant role in controlling the load carrying ability.

Table 1: Analysis of Variance

Source	DOF	SS	MS	F-Value	P
Regression	3	245.99	81.996	37.04	0.000
Interference	1	143.93	143.927	65.47	0.000
Roughness	1	11.39	11.385	5.14	0.043
RONt	1	10.85	10.849	3.90	0.047
Error	12	26.56	2.214		
Total	15	272.55			

SS = Sum of squares, DOF = Degree of freedom, MS = Mean square, P-Value = Probability Value

The results gave R^2 value more than 0.90. Predicted R^2 is found to be more than 0.83. These values show high ability of the parameters to explain the variation in load carrying capacity. The first order model equations derived from the analysis is given by,

$$Load = 0.56 + 353.6\, I + 1.779\, Ra - 0.446\, RONt \qquad (1)$$

4.4 Effect of Bearing Parameters

4.4.1 Bearing Roughness and Roundness:

Bearing roughness and roundness data was also analyzed with respect to the extraction load. It was found that there is no definite pattern visible for both parameters. From the measurement data, it was observed that the range of roughness (Ra) values varied from 0.1 to 0.5 microns and roundness from 1.6 to 2.4 microns. Bearing factors were found insignificant in comparison to shaft parameters may be due to this smaller variation.

This can also be justified by comparing the surface roughness profile deviations before and after UTM testing as shown in Fig 6. It can be observed that the shaft roughness peaks and valleys were reduced. The reason may be plastic deformation i.e. crushing of peaks and filling of valleys. It can also be visible that for bearings there were no significant reductions in the roughness values. The standard bearing NBC 6204 material composition is high chromium steel alloy, which is harder than C40 steel. So the plastic deformation might have occurred primarily in the shaft. Hence the bearing roughness peaks and valley deformation is negligible as compared to shaft.

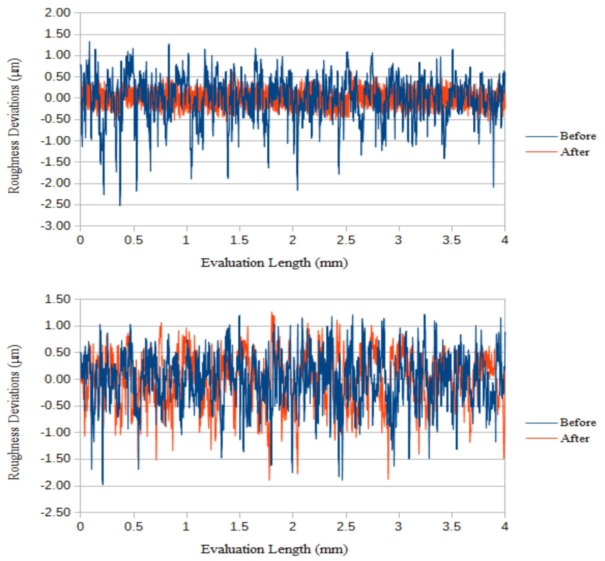

Figure 6. Roughness deviation comparison profiles for shaft (top) and bearing (bottom) before and after UTM testing

5. DISCUSSION

The significance of RONt alone is discussed in the previous section. The individual analysis of RONt reveals that it is not statistically significant as the P value is greater than 0.05. The reason could be the involvement of a single cross section without considering interference and roughness. However, regression analysis showed that all the three factors are relevant in predicting the load carrying ability with the order of significance as Interference > roughness > roundness.

In addition to RONt, the influence of RONq was also explored in this work. Linear regression analysis carried out on this parameter and found it as insignificant to predict extraction load. The variation in roundness value is higher for RONt parameter, ranging from 1 to 10 microns. However the variation for RONq parameter is comparatively less (1 to 2 microns), as it takes the entire profile deviation points into consideration for calculating roundness error.

6. CONCLUSIONS

Effect of roundness and other factors on load carrying ability of shaft-bearing interference fitted assemblies has been experimentally studied. The variations of shaft parameters were found more significant than bearings. It can be due to high hardness of bearings along with low range of roughness and roundness values. Load carrying ability increases with the increase in the interference level of the assemblies. However, roughness as well as roundness independently failed to correlate with extraction load. The combined analysis of all the factors revealed that the load carrying capability of the fits is controlled not solely by the amount of interference. Along with interference, roughness and roundness were found equally significant. Hence it is concluded that roundness have an influence in predicting the load carrying capability of interference fits.

7. SCOPE FOR FUTURE WORK

In this study, geometrical feature roundness was only considered. It is well known that roundness is a cross sectional property of a cylindrical part. Focusing the whole surface can provide better understanding. Hence this work can be extended to study the effect of cylindricity on interference fits, which is a 3D surface feature of a cylindrical part.

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