Advanced metrology enables greater profitability for bearing manufacturers

Sen Han, Kongmin Zhu, and Jie Tang

A novel 3D noncontact profiler can accurately measure the roughness and shape of high-precision bearing assemblies, vastly improving on 2D stylus techniques.

Automobiles, metallurgy, mining, and petroleum machinery have been driving significant demand for high-performance, high-precision, and high-technology bearings, with increases of over 30% annually for the past five years. Development, process control, and failure analysis require advanced metrology to examine the full bearing and obtain the details necessary to cost-effectively fabricate quality products. Here, we introduce high-speed 3D noncontact metrology capable of replacing the stylus profilers currently in general use, by highlighting results compatible with the recently developed International Standards Organization areal-surface parameters that enable a far greater understanding of bearing form and finish characteristics.

Recently, our company has been collaborating with ZYS and other manufacturers of high-performance bearings as regards qualification and adoption of interference microscopes for rapid and accurate 3D metrology of bearings, races, and lubricating films. The advanced 3D analyses yield improved detail for grading and process control. This, in turn, leads to greater profitability for bearing manufacturers that require the highest performance because of the applications or environments in which they operate.

A typical ball-bearing assembly consists of a ball, retainer, inner race, and outer race. Different applications use different geometries, such as deep-groove or angular-contact ball bearings, or roller, needle, taper-roller, joint, pillow-block, or constant-velocity bearings, among others. These bearings are widely used in aircraft, automotive applications, gyroscopes, fuel systems, locomotives, wind turbines, and machine tools.

\[ \text{ZYS is the former short name of Luoyang Bearing Science and Technology Co. Ltd.} \]

The overall market for bearings is large and growing, with the fastest growth occurring in high-end precision bearings. In China alone, there are 1900 bearing companies with an overall revenue of US$11.3 billion, and with an annual growth of over 15%. To remain competitive among so many players, industry leaders are turning to cost-effective 3D metrology to design and verify more advanced products that best fit the end applications.

For bearing inspection, one needs to know the overall surface form and roughness characteristics on microscopic scales and identify defects. Understanding the wear mechanism of the bearing design is also critical to predict component lifetimes. Key metrology parameters include roughness, flatness, roundness, diameter, defect count and volume, sphericity, and a number of critical dimensions.

Measuring methods have traditionally been based on 2D stylus and bright-field optical inspection. Figure 1 shows a

Figure 1. 2D stylus system.

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Figure 2. 3D noncontact profiler.

Figure 3. G5-grade steel-ball measurements. (a) 3D topography, (b) 2D cross-section, and (c) roughness. VSI: Vertical scanning interferometer. Ra: Average roughness. Rq: Roughness rms. Rz: Difference between the average of ten maxima (peaks) and ten minima (valleys) in a given region. Rt: Peak-to-valley difference.

Table: G5-grade ball bearings. The uncertainty, $\sigma$, is calculated from the results of ten repeat measurements. Only the G5 ball meets the published specifications.

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<th></th>
<th>G5</th>
<th>G10</th>
<th>G16</th>
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<tbody>
<tr>
<td>Ra (nm)</td>
<td>18.16</td>
<td>26.00</td>
<td>37.85</td>
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<tr>
<td>$\sigma$</td>
<td>0.27</td>
<td>0.60</td>
<td>1.32</td>
</tr>
<tr>
<td>Ra specification (nm)</td>
<td>&lt; 20</td>
<td>&lt; 25</td>
<td>&lt; 32</td>
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Defect evaluation of a ball is described by the maximum dimensions, depth, and total volume of the defect based on 3D metrology. From 3D topography, machining marks are clearly seen and their directionality can be quantified. 2D results, on the other hand, will simply vary based on scan direction with no indication of why this might be occurring. Figure 4 shows a large bearing race of $80 \times 23\text{mm}^2$, measured by stitching multiple fields. Another application not available using 2D stylus is film measurement, where studying lubrication adhesion to different surfaces is currently impossible in 2D. Such a 3D measurement is shown in Figure 5, where the thickness of the residual lubrication varied based on the grade of the bearing tested.

Because of increasing demand from precision-bearing manufacturers, we recently introduced a bearing-specific configuration of our 3D optical profilers. These systems provide all of the software, automation, analyses, and part fixturing for Continued on next page
Figure 4. Larger bearing race of $80 \times 23\text{mm}^2$ measured by stitching multiple fields. S-S cross section: Random cross section as indicated.

Figure 5. Measurement of lubricating-oil thickness.

rapid, accurate 3D metrology of bearing assemblies for development, process control, and failure analysis. Such systems are expected to rapidly become the new standard for bearing-assembly metrology. We will continue to collaborate with bearing manufacturers to develop more inspection parameters for use with 3D noncontact profilers.

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References