How to Avoid Errors When Measuring Step Gears

Think of a cookie cutter and a broomstick...

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There are problems in dimensional measurement that should be simple to solve with standard measuring procedures, but aren't. In such cases, using accepted practices may result in errors of hundreds of microns without any warning that something is wrong.

One such problem is the accurate measurement of the dimensions of the three-dimensional track, or the motion surface, around a cylindrical cam, or step gear (Fig. 1). Step gears are used to index a number of different devices such as tool changers, transfer line mechanisms and parts handling systems—virtually any apparatus that must accurately locate workpieces or tools for subsequent operations.

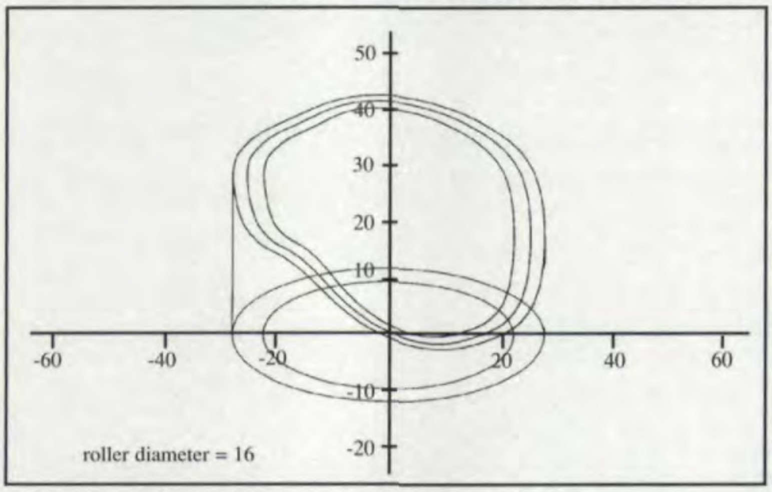

Fig. 1 — Three-dimensional track or cylindrical motion surface.

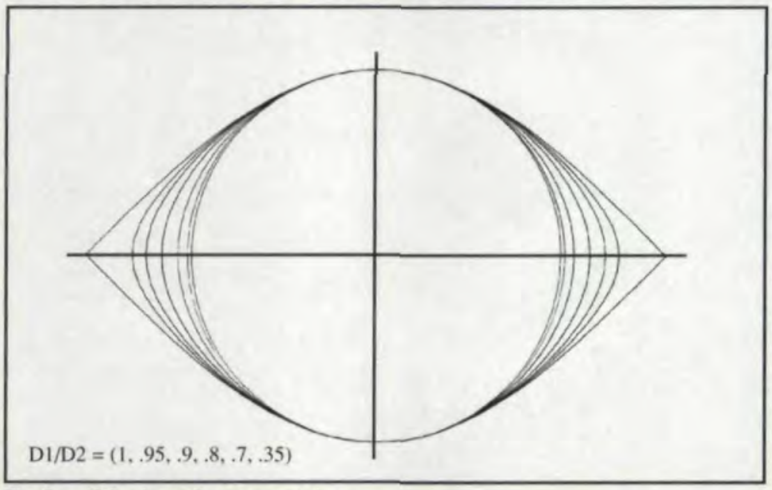

Fig. 2 — Effective roller cross section.

The three-dimensional track forces a cylindrical roller to move parallel to the axis of the cylinder. The relationship between the track and the roller is critical to the operation of the step gear. The challenge is to correctly measure the dimensions of the track with a coordinate measuring machine to determine the axis position of the roller as it moves on the track around the circumference of the cylinder. The position of the roller axis is important since it determines where indexing will begin and end for each "stop."

The standard procedure to determine the position of the roller axis is to measure two parallel lines at the top and bottom of the track around the cylinder at a predefined distance from its axis. This circular measurement is "unwrapped," and a track radius correction is made to compensate for the radius of the roller in order to determine the roller's "center" position.

The error in this procedure is hidden in the roller radius correction. To find the error, it is important to understand the contact characteristics of the roller as it travels the length of the track.

Typically, the roller is tapered so that it fits snugly into the tapered open side of the track. As the track "rises" during the rotation of the cylinder, the curve of the track around the cylinder presents changing surface characteristics to the static surface of the roller. Due to the taper of the track, the slope increases on the inside of the track, causing the line of contact of the roller to shift off axis. When the track descends, the line of contact on the roller swings back past perfect alignment with the cylinder axis to the mirror image of what it was on the ascent curve. The point of contact between the track and roller scribes an oval rather than a perfect circle.

Traditionally, to find the contact point of the roller/surface at a specific radius from the center of the cylinder, the roller and track would be mated and then "cut" with a phantom coaxial cylinder having a diameter sufficient to intersect the roller at that specific radius from the center. This results in two plotted curves on the coaxial cylinder which may be "unwrapped" into a plane. One is a line created by the circumference of the coaxial cylinder, which traces the full path of the track. The second is a point on the axis of the roller where the coaxial cylinder cuts through the cylindrical roller.

The oval shape of the unwrapped, curved intersection plane of the roller is determined by the proportion of the roller and cutting diameters (Fig. 2). As an example, if a broomstick is cut with a circular cookie cutter, the cut end may appear to be a perfect circle. Because the cookie cutter is round, however, it creates an arc-shaped cut through the broom handle which will appear ovoid when viewed off-axis. The shape of the oval depends on the size of the broom handle and/or the size of the cookie cutter. In the case of a step gear, the contact points on both unwrapped curves represent the contact characteristics of the roller on the track at a specific radius. The center point on the oval represents the roller axis.

When using a coordinate measuring machine to find the roller axis position for all measured points along the track, follow standard procedures to create an unwrapped plane using the phantom coaxial cylinder approach. The resulting oval's orientation on that plane must then be mathematically determined. The path of the axis center point on the oval, not a circular cross section of the roller, gives the true position of the roller axis.

The difference in resultant accuracy between using the ovoid shape of the roller and the circular shape of the roller averages 200 microns. Slope characteristics as well as the relative diameters of the coaxial cylinder (the cookie cutter) and the roller (the broom handle) will affect the total error. Maximum discrepancies will appear at the area of maximum slope and at the inner diameter of the motion surface (Fig. 3).

Between the inner and outer radius of the track, the "oval effect" is different. Larger deviations belong to the inner radius where measurements are rarely carried out because of the limitations imposed by the radius of the CMM probe. Conversely, measurements are not carried out at the outside edge because of varying chamfer, which only adds to the problem. The rotating roller may contact the track only at or near one edge. This lack of full length support caused by faulty manufacturing procedures results in high surface pressure and possible catastrophic part failure.

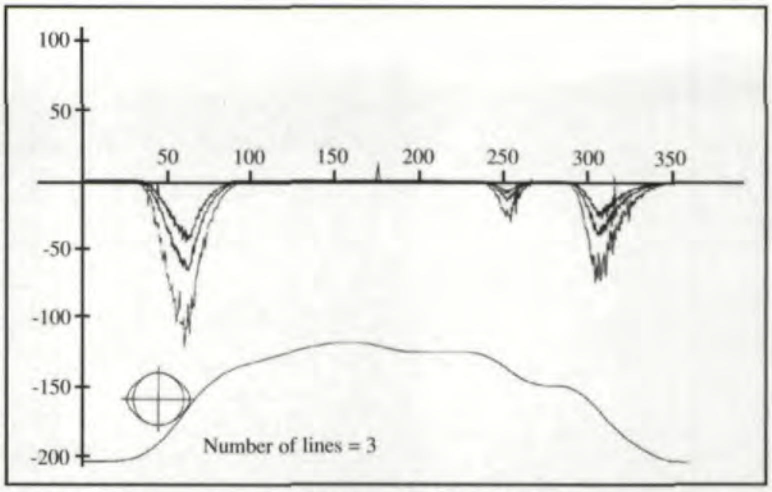

Fig. 3 — Difference between exact solution and simplification.

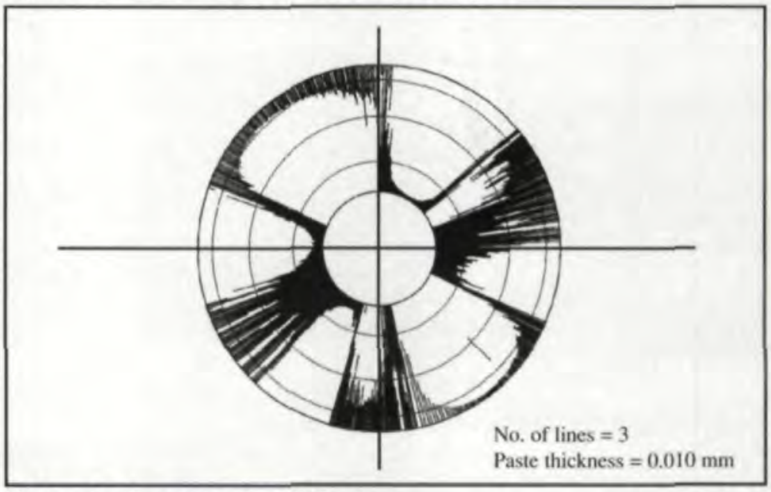

Fig. 4 — Bearing pattern for cylinder curve.

The mathematical relationship between the track and the roller is a complex one. The advantage of using a CMM in this type of measurement is that it can express that complex relationship in terms of *X*, *Y*, and *Z* coordinates, which makes the measurement easier to perform. Special software packages such as the STEPGR option for QUINDOS® metrology software from Leitz take the problems out of step gear measurement, making the radius correction automatically and assuring the correct calculation of the roller position. A bearing pattern can also be generated using this software package if more than one line is measured (Fig. 4). The bearing pattern shows the distribution of areas with high pressure as well as a displacement of the whole shape. ○

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