MEASUREMENT OF TRUE POSITION OF THREADED HOLES

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INTRODUCTION

The use of threaded holes for fastener applications is common place in manufacturing. The location and orientation of the threaded hole is crucial in assuring that the fastener is properly engaged, so that failure of the fastener does not occur. However, measurement of the threaded hole "true position" is something that is taken for granted by many in industry. Often the techniques used make incorrect assumptions and or take shortcuts to save time and money.

Related Reference for Threaded Holes

Tolerances for threaded holes using the principles stated in the American Society of Mechanical Engineers (ASME) Y14.5M-1994 "Dimensioning and Tolerancing" preferably use the positional tolerancing method (Section 2.1.1.1). Section 2.9 of the standard states "Each tolerance of orientation or position and datum reference specified for a screw thread applies to the axis of the thread derived from the pitch cylinder." If required the tolerance can be specified to either the major or minor diameter of the thread, however the default condition is the pitch cylinder.

Motivation for Interest in Issue

Interest in the techniques used and the results obtained came about when the measurement of threaded holes on a cylinder surface was required (See Figure 1). In this example the location of the threaded holes was determined using threaded location gages.

The use of these gages is common in dimensional metrology when using coordinate measuring machines (CMM) to determine position. There are various manufactures of these gages and designs vary. Basically the gages are made up of a cylindrical section, of known size and form, which is co-axial to the pitch cylinder axis of the threaded section. The standard gage has a seating face which is perpendicular to the pitch cylinder axis. When inserted into the threaded hole the cylindrical section is probed to establish the axis of the cylinder which in turn establishes the pitch cylinder axis. Using CMM software the position of the hole over the entire length of the feature is determined.

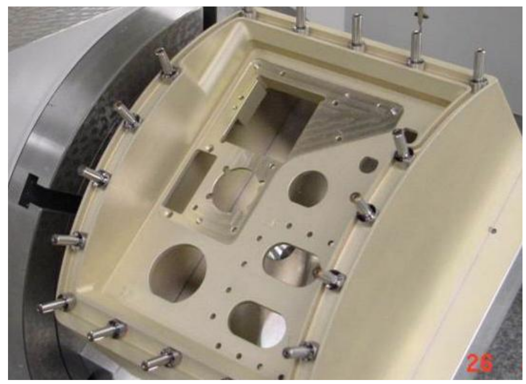

Figure 1. Threaded holes on a curved surface

PROBLEM

The standard threaded location gage when fully engaged contacts the part surface at the seating face. Because the seating face is perpendicular to the pitch axis, on a nominally flat surface, one might not see any apparent problem, but in the case of a curved surface only "line contact" is made which allows for the gage to rotate or rock (see Figure 2).

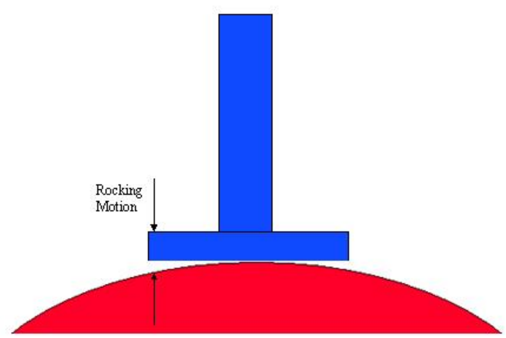

Figure 1. Rocking motion of device

The mating surface of the threaded location gage should not influence the position or orientation of the cylindrical feature. A measurement technique is needed that is not influenced by the gage seat or the part surface.

APPROACH

Evaluation of various threaded location gages was made along with evaluation of a position determination technique in which the thread form itself is probed by the CMM.

Threaded Location Gages

A survey of commercially available products was made and four various designs were acquired for testing. The first gage (See Figure 3) is a standard threaded gage. The second gage (See Figure 4) has a thread form which has been cut to allow expansion of the threaded portion. This expansion provides constant compliance with the thread form and there is no contact of a seating face. The third gage (See Figure 5) utilizes a tapered thread form similar to a standard pipe thread. When inserted into the threaded hole the gage is rotated until compliance is felt. The last gage (See Figure 6) is a rather unique in that a series of six balls located on the thread form are pushed outward to make contact with the flank of the thread form. The manufacturer has determined that the contact point on the flank is at the pitch cylinder of the thread. Once the balls are engaged the gage is aligned and ready for the CMM measurement.

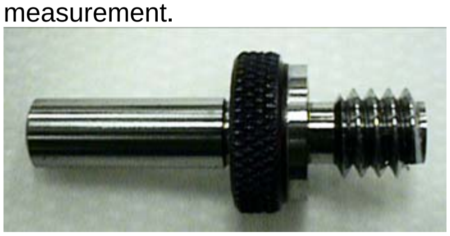

Figure 2. Standard Straight Plug Gage

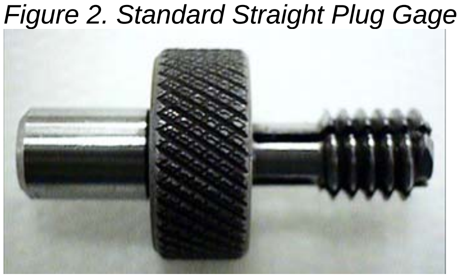

Figure 3. Split Thread Gage

Figure 4. Tapered Thread Gage

Figure 5. Expanding-Ball Gage

Thread Form Probing

The final technique evaluated was to directly probe the thread form. This technique is used by many in industry to avoid the cost and time involved when using the threaded location gages. Direct probing of the threaded hole is performed using a helical path. This helical path is determined using the lead (linear distance traveled in one rotation of the fastener) of the thread. This method will insure that all the CMM probing points are made at the same location on the thread form, although not necessarily on the pitch cylinder (See Figure 7).

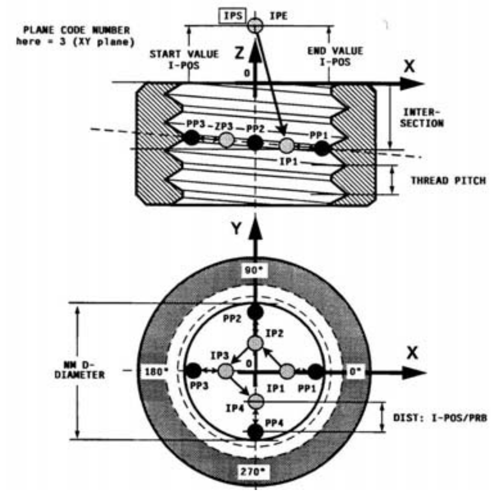

Figure 6. Direct Probing of Thread

Test Pieces

Suitable test pieces were fabricated to use in evaluation of the gages and techniques. For the purposes of this project a thread size of ¼"-20 UNC-2B was selected, as this is a common fastener size used in industry. The first test piece was made of steel and the thread form was lapped to produce a gage quality surface (See Figure 8). The top surface (datum A) and outside diameter (datum B) were ground surfaces. The second test piece was fabricated from aluminum and the threaded hole was formed using a standard tapping operation (See Figure 9). The remainder of the part was turned using a conventional lathe. Both test pieces had a through hole located near the outer edge of

the part which would serve as a tertiary datum C.

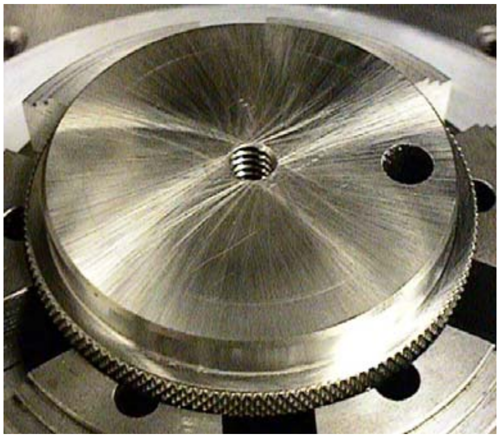

Figure 7. Steel Test Piece

Figure 8. Aluminum Test Piece

Evaluation Procedure

Thread Location Gages

A datum reference frame (DRF) was established using the top surface, outside diameter and through hole. Each threaded location gage was inserted into the test piece and the CMM was programmed to take a total of thirty two points (eight equally spaced points at four different levels) over the length of the cylinder portion of the gage. Due to the short length of the split thread gage a total of twenty four points (eight equally spaced points at three levels) were taken. The measured cylinder axis was used for evaluation.

Direct Probing of Thread

The CMM program measured two circles (8 equally spaced points) at both ends of threaded hole. A line was constructed through the centers of both circles to serve as the axis in evaluation.

Data Collection

The CMM part program was executed a total of ten times for each test piece on three different CMM's, each of different accuracy. The thread location gage was removed between each run and the DRF was re-established with each run. The test piece was not removed from the fixture between runs. The typical setup for the tests is shown in Figure 10.

Figure 9. Typical CMM Run

The CMM evaluated the position of the threaded hole over the length of the feature. The length was from Datum A (Z zero) to -0.5 inches (thickness of test piece). The difference in the two Z axis locations is an indication of the tilt or orientation of the threaded hole axis.

RESULTS

Results for the steel test piece are listed in Table 1 and in Table 2 for the aluminum test piece. The results listed for Z = 0.0 inches (Datum A) and Z -0.5 inches include deviations in the X and Y axes, standard deviation of the data set and the true position result (TP).

A complete uncertainty analysis will be provided during the presentation and in the full paper submitted.

Assumptions

An initial assumption was made that the test results would show a significant range of results between the gages and between the gages and the direct probing method. This was not proven in the results, although the range was greater between the gages and the direct probing method. For the steel test piece the TP range for the gages was 0.0003 inches and for the aluminum test piece the TP range was 0.0006 inches. The TP range between the gages and

the direct thread probing was 0.0015 inches for the steel test piece and 0.0024 inches for the aluminum test piece.

CONCLUSION

Initial indications were that the surface of the threaded hole would influence the range of results. However these tests used a nominally flat surface as Datum A and this fact may have influenced the test results. Although the difference between the gages and the direct probing method are slightly greater, one would need to evaluate if the results justify the cost of the gage. The savings in time spent for insertion of the gage and the gage cost could make direct probing a preferred method.

This project has motivated efforts to conduct further tests to address the issues with threaded holes to yield a minimal uncertainty.

ACKNOWLEDGEMENTS

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TABLE 1. Average of All CMM's – Steel Test Piece (Results in Inches)

		Datum A - Z Axis Zero			**Projected -0.5 inches Z Axis**		
	Axis	**Deviation**	**Std. Dev.**	**TP Result**	**Deviation**	**Std. Dev.**	**TP Result**
Standard Straight Gage	**X**	**-0.00011**	**0.00002**	**0.0003**	**-0.00017**	**0.00003**	**0.0005**
	Y	**-0.00011**	**0.00001**		**-0.00017**	**0.00006**	
Split Gage	**X**	**-0.00016**	**0.00002**	**0.0003**	**0.00029**	**0.00037**	**0.0006**
	Y	**-0.00001**	**0.00002**		**-0.00011**	**0.00007**	
Tapered Gage	**X**	**-0.00017**	**0.00013**	**0.0004**	**-0.00029**	**0.00007**	**0.0009**
	Y	**-0.00010**	**0.00007**		**-0.00037**	**0.00030**	
Expanding Ball Gage	**X**	**0.00004**	**0.00002**	**0.0004**	**0.00029**	**0.00021**	**0.0006**
	Y	**-0.00019**	**0.00005**		**-0.00001**	**0.00021**	
Direct Thread Probing	**X**	**0.00043**	**0.00103**	**0.0009**	**0.00094**	**0.00059**	**0.0020**
	Y	**-0.00017**	**0.00001**		**0.00034**	**0.00045**	

TABLE 2. Average of All CMM's – Aluminum Test Piece (Results in Inches)

		Datum A - Z Axis Zero			**Projected -0.5 inches Z Axis**		
	Axis	**Deviation**	**Std. Dev.**	**TP Result**	**Deviation**	**Std. Dev.**	**TP Result**
Standard Straight Gage	**X**	**-0.00082**	**0.00002**	**0.0027**	**-0.00088**	**0.00007**	**0.0033**
	Y	**0.00110**	**0.00002**		**0.00141**	**0.00063**	
Split Gage	**X**	**-0.00018**	**0.00004**	**0.0027**	**-0.00061**	**0.00039**	**0.0031**
	Y	**0.00132**	**0.00005**		**0.00140**	**0.00010**	
Tapered Gage	**X**	**-0.00047**	**0.00004**	**0.0024**	**-0.00106**	**0.00053**	**0.0031**
	Y	**0.00113**	**0.00018**		**0.00112**	**0.00019**	
Expanding Ball Gage	**X**	**0.00029**	**0.00016**	**0.0024**	**-0.00061**	**0.00087**	**0.0027**
	Y	**0.00117**	**0.00006**		**0.00120**	**0.00016**	
Direct Thread Probing	**X**	**0.00080**	**0.00005**	**0.0016**	**0.00002**	**0.00064**	**0.0003**
	Y	**0.00004**	**0.00010**		**0.00014**	**0.00015**	