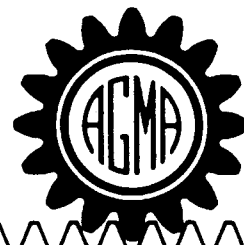


Measurement Uncertainty for Pitch and Runout Artifacts

by: B. Cox, Lockheed Martin Energy Systems, Inc.

American Gear Manufacturers Association



TECHNICAL PAPER

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Bruce Cox, Lockheed Martin Energy Systems, Inc.

[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Primary-level calibration of pitch and runout artifacts require quantifying the measurement uncertainty on the artifact being calibrated by a method that does not rely on a transfer comparison. The measurement decomposition method, developed jointly by National Institute of Standards and Technology (NIST) and Oak Ridge Metrology Center (ORMC) personnel, is used to determine the uncertainty of each component of the measurement task. Once quantified, these components are added in quadrature according to *NIST Technical Note 1297, 1994 Edition*¹⁾. Verification of this method was accomplished by inter-comparison between ORMC and NIST using high precision coordinate measurement machines and rotary tables. The results were also compared with data obtained using the circle closure principle.

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Index and Runout Artifact Measurement Decomposition

In the case of an index and runout artifact, the uncertainty determination consists of checking pitch error using a rotary table and a 1440 Divider by the closure method; checking radial runout of the rotary table; and checking repeatability using an index artifact.

The pitch test which involved repeated measurements on three balls mounted so that a line through the first and second ball centers and a line through the first and third ball centers formed a 15° angle. In the pitch test, the balls were mounted on a 1440 divider, which was also mounted on the rotary table, see Figure 1. When the divider was rotated 15° , the rotary table was rotated 15° in the opposite direction. The angle positions were analyzed by using the circle closure method, where all angles must add to 360° . The angle results are summarized in Table 1.

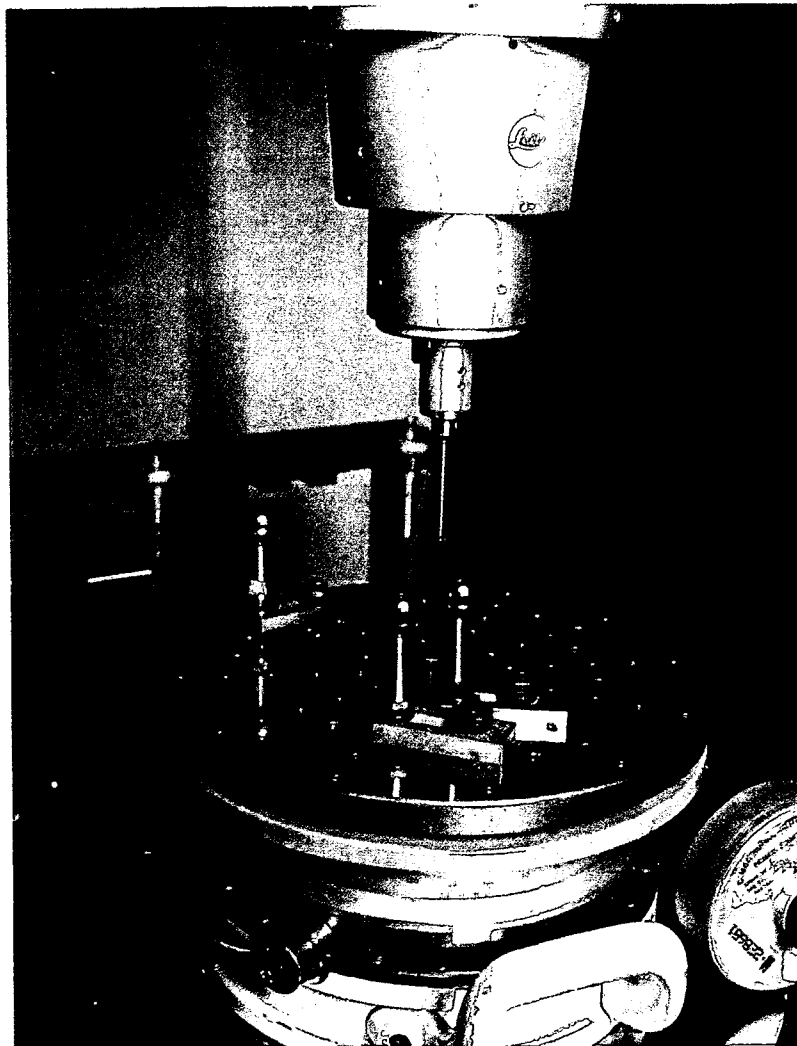


Figure 1 Checking rotary table error using 3 balls and 1440 divider by circle closure

Table 1. Pitch test with 3 balls using closure (arcseconds)													
Nom. ang.	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Run 11	Run 12	Run 13
0	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
15	0.18000	0.21600	0.18000	0.25200	0.21600	0.25200	0.25200	0.18000	0.14400	0.25200	0.14400	0.28800	0.43200
30	0.36000	0.32400	0.25200	0.28800	0.36000	0.28800	0.28800	0.28800	0.18000	0.28800	0.18000	0.36000	0.32400
45	0.43200	0.43200	0.14400	0.28800	0.25200	0.21600	0.21600	0.18000	0.10800	0.28800	0.18000	0.43200	0.21600
60	0.18000	0.28800	-0.21600	-0.07200	-0.14400	-0.14400	-0.14400	-0.21600	-0.25200	-0.03600	-0.07200	0.14400	-0.07200
75	0.07200	0.10800	-0.36000	-0.25200	-0.36000	-0.36000	-0.32400	-0.36000	-0.43200	-0.25200	-0.21600	0.03600	-0.39600
90	-0.03600	0.03600	-0.32400	-0.25200	-0.43200	-0.43200	-0.39600	-0.39600	-0.46800	-0.36000	-0.25200	-0.07200	-0.46800
105	-0.03600	0.07200	-0.32400	-0.21600	-0.36000	-0.36000	-0.36000	-0.39600	-0.39600	-0.36000	-0.32400	0.00000	-0.54000
120	-0.10800	0.03600	-0.39600	-0.21600	-0.39600	-0.39600	-0.46800	-0.43200	-0.50400	-0.28800	-0.43200	-0.10800	-0.68400
135	0.07200	0.18000	-0.21600	-0.10800	-0.25200	-0.28800	-0.32400	-0.28800	-0.39600	-0.21600	-0.25200	0.00000	-0.46800
150	0.03600	0.10800	-0.32400	-0.21600	-0.36000	-0.36000	-0.43200	-0.39600	-0.46800	-0.39600	-0.32400	0.00000	-0.28800
165	-0.03600	0.18000	-0.39600	-0.25200	-0.46800	-0.39600	-0.54000	-0.54000	-0.54000	-0.50400	-0.36000	-0.07200	-0.21600
180	-0.14400	0.18000	-0.68400	-0.50400	-0.72000	-0.61200	-0.72000	-0.72000	-0.68400	-0.68400	-0.50400	-0.25200	-0.32400
195	-0.21600	0.07200	-0.79200	-0.54000	-0.75600	-0.72000	-0.82800	-0.79200	-0.82800	-0.79200	-0.46800	-0.36000	-0.43200
210	-0.28800	-0.03600	-0.86400	-0.64800	-0.82800	-0.82800	-0.90000	-0.90000	-0.86400	-0.90000	-0.57600	-0.43200	-0.54000
225	-0.39600	-0.14400	-0.97200	-0.57600	-0.90000	-0.86400	-0.93600	-0.97200	-0.82800	-0.90000	-0.61200	-0.46800	-0.54000
240	-0.39600	-0.07200	-0.90000	-0.57600	-0.72000	-0.82800	-0.90000	-0.86400	-0.75600	-0.90000	-0.57600	-0.39600	-0.61200
255	-0.32400	-0.07200	-0.86400	-0.54000	-0.72000	-0.72000	-0.86400	-0.79200	-0.75600	-0.82800	-0.57600	-0.43200	-0.68400
270	-0.32400	0.00000	-0.79200	-0.46800	-0.61200	-0.54000	-0.72000	-0.68400	-0.72000	-0.75600	-0.57600	-0.43200	-0.57600
285	-0.28800	0.00000	-0.61200	-0.46800	-0.43200	-0.50400	-0.61200	-0.61200	-0.57600	-0.64800	-0.39600	-0.36000	-0.50400
300	-0.39600	-0.10800	-0.68400	-0.57600	-0.50400	-0.54000	-0.64800	-0.64800	-0.61200	-0.68400	-0.46800	-0.43200	-0.57600
315	-0.28800	-0.03600	-0.50400	-0.43200	-0.39600	-0.43200	-0.50400	-0.43200	-0.46800	-0.54000	-0.39600	-0.32400	-0.36000
330	-0.14400	-0.03600	-0.25200	-0.25200	-0.21600	-0.18000	-0.28800	-0.21600	-0.21600	-0.32400	-0.25200	-0.21600	-0.18000
345	0.00000	0.03600	-0.10800	-0.07200	-0.07200	-0.03600	-0.10800	-0.10800	-0.07200	-0.10800	-0.18000	-0.14400	-0.03600
360	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

The results of 13 runs of the pitch test, in arcseconds, were a maximum deviation of 0.432 a minimum deviation of -0.972. Using a rectangular distribution the standard deviation is calculated below (in arcseconds):

$$u_p = \frac{0.432 - (-0.972)}{2\sqrt{3}} = 0.405$$

Next, a test was conducted, which involved a known ball mounted in the center of the rotary table at two heights to determine the radial runout of the table. A ball was mounted on the centerline of the rotary table and the radial runout was measured at two heights above the table, 9 7/8" and 2 1/2", see Figure 2. The results are shown below in Table 2:

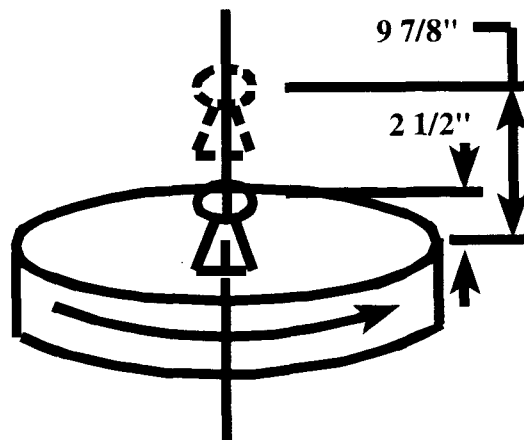


Figure 2 Radial runout test

Table 2. Radial Runout Test (mm)		
Number	Radial Runout High 9 7/8"	Radial Runout Low 2 1/2"
1	0.00028	0.00018
2	0.00031	0.00014
3	0.00032	0.00016
4	0.00028	0.00018
5	0.0003	0.00017
6	0.00031	0.00022
7	0.00031	0.00015
8	0.00031	0.00019
9	0.00029	0.00015
10	0.00034	0.00014
11	0.00032	0.00021
12	0.00031	0.00015

The maximum deviation of the radial runout test at two heights was 0.000340 mm. Taking the arctan of the maximum deviation times $\sin 20^\circ$ divided by the base radius of 57.15 mm (simulating a 4.5" base circle diameter) and multiplying by 3600 to convert to arcseconds gives a total range of ± 0.420 arcseconds (see Figure 3).