

DYNAMIC ERROR CHARACTERIZATION OF A SCANNING COORDINATE MEASURING MACHINE

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INTRODUCTION

As the competition for better positions in the market place stiffens, the pressure for more agile and efficient production methods increases. The inspection process is an important and often time-consuming portion of the fabrication of most manufactured goods. The expanding use of coordinate measuring machines because of their flexibility is an attempt to improve dimensional inspection productivity [1]. Specifically the ones with scanning capabilities that can achieve fast measurement speeds are good candidates for the task. However, they still cannot be used to the fullest because measurement accuracy degrades considerably with increasing speed.

With the central objective of improving the performance of a contact scanning coordinate measuring machine (CMM) a project was begun in 1997 at the Center for Precision Metrology - University of North Carolina at Charlotte. Partial results of this research work were previously reported [3,4,5]. This paper contains some further findings of the project.

EXPERIMENTAL PROCEDURE AND RESULTS

For the purpose of this work, dynamic errors are all those which happen or are heightened due to the use of the scanning mode of measurement on coordinate measuring machines capable of it. For the machine used in this study, such errors become more evident at speeds beyond 5 mm s^{-1} on open loop or known path scanning mode [3,4].

Although initial data pointed out the possibility that the analog probe head used by the test machine could be the biggest contributor to the dynamic errors of the measuring system during scanning [3], later results showed that there is a strong influence of the machine moving axes as well [4,5]. Because of that, an approach was devised to investigate these effects and, at the same time, to make it a generic kind of test that could be applied to different configurations of scanning capable coordinate measuring machines. The idea consists on the use of ring gages of different sizes measured on scanning mode at several speeds to provide data for developing a model to account for linear velocity and centripetal acceleration dependence of the observed errors.

In order to remove the ring gage errors from the analysis, the artifacts were measured using a roundness measuring machine (Mahr MFU-7) at several levels and the data were exported digitally for calculation of a Fourier series with fifty terms using procedures written in Matlab. This calculated profile was then removed from the ring gage results obtained with the coordinate

measuring machine. The errors of the roundness machine are very small when compared to the ring gage ones and are not being considered for this study.

The quasi-static errors of the coordinate measuring machine were also removed from the scanning output. The result from a Fourier analysis of a point-to-point measurement on the tested coordinate measuring machine minus the measured profile (Fourier calculated) of the roundness measurement was considered as the "quasi-static" CMM error profile. Some of the factors contributing to this class of errors are residual geometric errors (the machine is software compensated), thermal variations (the experiments were conducted in a controlled environment to minimize such effects), and fixturing [2]. As the point-to-point measurement mode is a quasi-static process, scanning errors should not be present.

The profile for the scanning or dynamic errors is then defined as the Fourier calculated result (with fifty terms) from the scanning trace minus the quasi-static and ring gage errors outlined above.

Three different diameters of ring gages were initially used, 25.4 mm, 112 mm and 164.98 mm. The scan speeds ranged from 5 to 50 mm s⁻¹. The ring gages were scanned with the same test speeds to investigate the impact of varying centripetal acceleration and later with the same acceleration to characterize the influence of scanning speed. The centripetal acceleration is the ratio of the square of the linear speed by the radius traveled by the center of the probe tip (which is different than the radius of the ring gage being scanned).

For all test runs data collection was extended 20° – 30° before and after the analyzed 360°. This was done to avoid transients common to the start and the end of the scanning traces. When unusual outliers were noticed the cause for them was fixed and the test repeated.

The linear acceleration remained unchanged during all the tests although it can vary from machine to machine and some manufacturers allow it to be freely adjusted by the user within

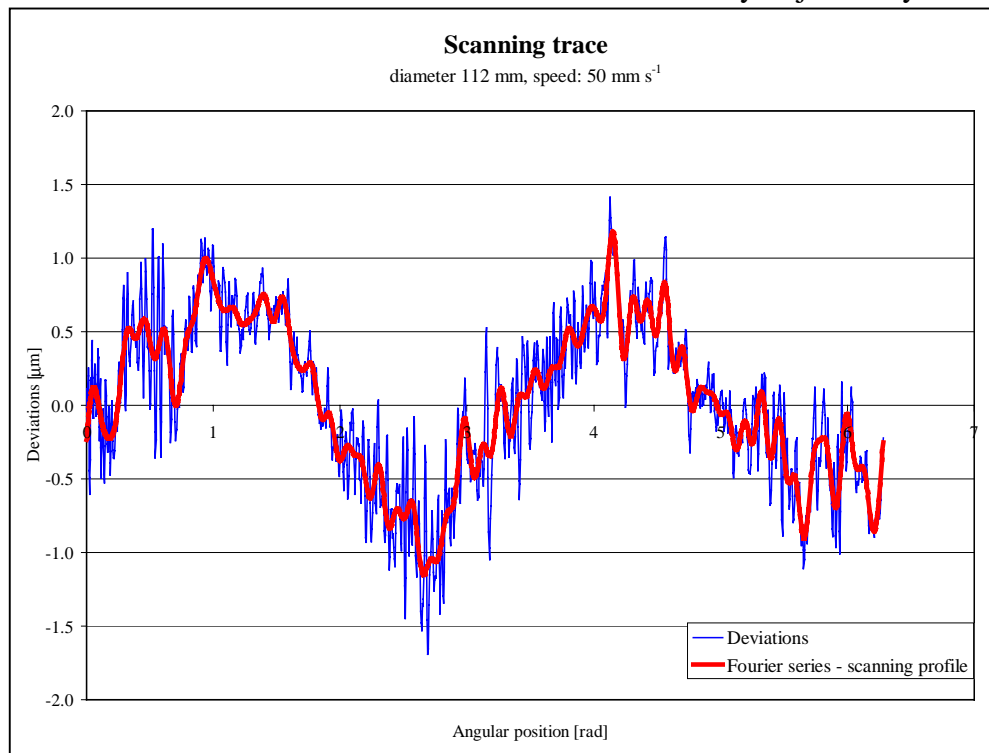


Figure 1 - Scanning trace

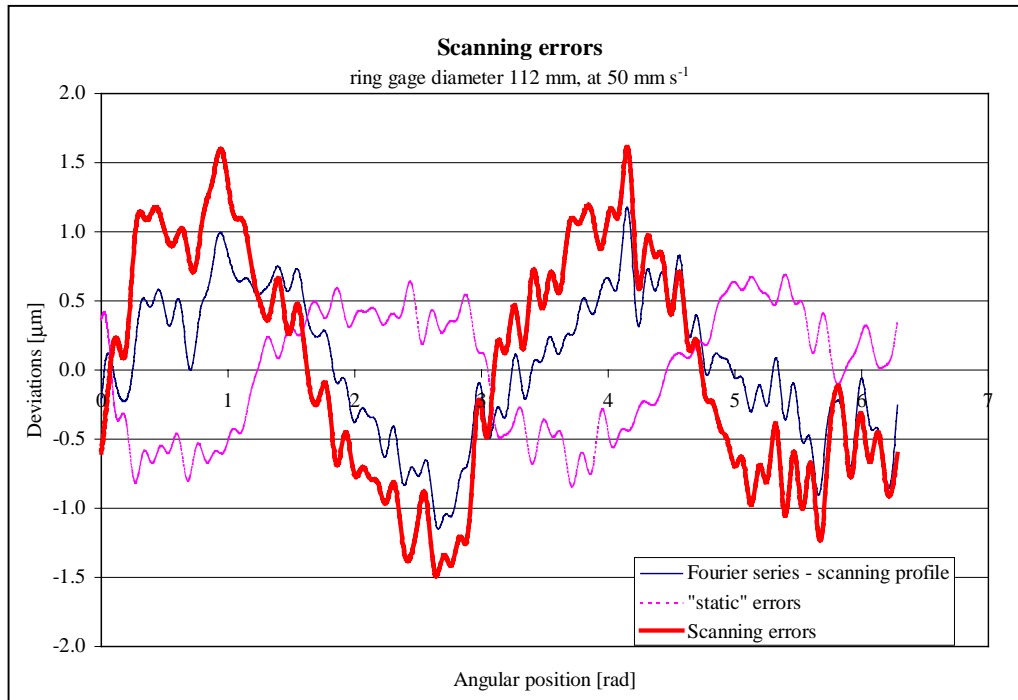


Figure 2 - Scanning errors

certain limits. This model does not make provisions for varying linear acceleration but it still can be applied to situations when a value other than the tested one is applied considering it is maintained constant. Normally, the default setting is the optimal maximum value the machine can still perform within specifications and should be the one chosen for the tests.

On the plot of Figure 1 there is a trace of a scanning measurement. Also, it shows the corresponding contour calculated by Fourier series with fifty terms. For this run, the ring gage used was one with nominal diameter of 112 mm and the scanning speed was 50 mm s^{-1} (the maximum available for this machine on open loop scanning mode). Figure 2 shows a plot with the same Fourier calculated profile plus the trace of the quasi-static errors and the difference between the two, which constitute the mentioned scanning errors.

The depicted example suggests that fewer than fifty terms could be used since the biggest contribution to the total error comes from lower order harmonics. If this trend is proven true after more data have been analyzed, the calculations can be made simpler to allow faster response even with a large number of data points.

Having collected data and performed the described analysis, the next step is to develop the model. This model has to include scanning speed and centripetal acceleration as input variables. It will be possible to estimate the errors for diameters and speeds other than the tested ones.

CONCLUSIONS

A procedure to create a model to compensate for the errors of a scanning coordinate measuring machine when measuring circular features is being described. Further tests and development still need to be carried out in order to fully validate the strategy. Also, the applicability of such procedure to other features will be evaluated. Additionally, by performing

such tests users can identify other scanning related problems particular to their machines that cannot be detected with standardized tests (eventually there will be tests in the proper standards specifically to address scanning performance of coordinate measuring machines).

The final output of this project will be a carefully outlined test procedure as to allow the use on practically any scanning coordinate measuring machine with little or no modifications. First, it will detail the data collection, then the analysis and finally the steps toward the elaboration of the compensation model will be explained.

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