Traceability of CMM Measurements

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The need for traceability

In current measurement technology, traceability is of great importance. It can be required by a purchaser in a contract, or by standards such as ISO 9000-9004 and the relatively new standard ISO 14253. These standards are made to guarantee measurement quality and to protect the purchaser. The demand for traceability strongly influences measurement practice. Traceability of a measurement requires that the measurement uncertainty is stated.

Traceability of a measurement on a Coordinate Measurement Machine, CMM, is very difficult to obtain for most measurements, because the measurement uncertainty can't always be established. This is due to the complex error structure of the CMM.

How to obtain traceability?

In general, there are two approaches to obtain traceability on a CMM:

- Comparator Approach:

The CMM is used to compare the product with reference artifacts that have known uncertainties.

- Error Synthesis Approach:

The separate error sources are combined to an uncertainty on a specific measurement.

The comparator approach requires a reference artifact with approximately the same dimensions and shapes as the product to be measured. This is a great reduction in the versatility of a CMM.

With the error synthesis approach one should be able to achieve traceability for an arbitrary measurement. An important tool for this method is the Virtual CMM (VCMM).

This paper deals with the measurement uncertainty induced by geometrical errors, probing errors and measurement strategies. We combined these errors using a VCMM, which we developed ourselves. This is a model of a CMM that simulates the errors of a CMM and combines them using a Monte Carlo method.

In this paper, first we will show some possibilities of the method of the virtual CMM, next we will point out the existence of some gaps in current methods. These gaps have to be filled to make sure we can apply the method of the virtual CMM without the risk of faulty results.

Modelling Error Sources

The guideway of the carriage is not perfect, i.e. the path of the carriage deviates from its nominal movement. This causes errors in the determination of the coordinates of a measured point. At first, we assumed that we could model these errors as if they were “random”. This means that the error plotted against the position of the carriage is modelled as a white noise signal. If a systematic error of the guideway is measured, one may or may not correct for this error and assume the remaining error “random”. In this case the error of the

CMM is modelled as this systematic error, with a white noise added. Thus, there is no essential difference in the applied method for corrected or uncorrected machines.

Effect of Measurement strategy

Using the method of a virtual CMM, it's quite easy to evaluate the effect of measurement strategy on the measurement uncertainty. We did this for different measurement task, some of which we will demonstrate here. The first example is measurement of angles on an object. In figure 1, three different measurement strategies are shown. Each measurement involves twelve measurement points, six on each side. These points are arranged in a rectangle. The stars in the picture show a simulated measurement point, simulated with a 1000-fold magnification of the random error. The plane is an estimated least-squares plane through six simulated points. From left to right, the horizontal dimension of the rectangle is made larger. The pictures give an idea of the effect of the variation of this measurement strategy parameter. For the machine we investigated, a Zeiss UMC 550, the measurement uncertainty was calculated. The dimension of the long side of the rectangle proved to be the relevant parameter. For instance, with a length of 50 mm, the measurement uncertainty was 12 seconds of arch, for a length of 100 mm, it was 6 seconds of arch.

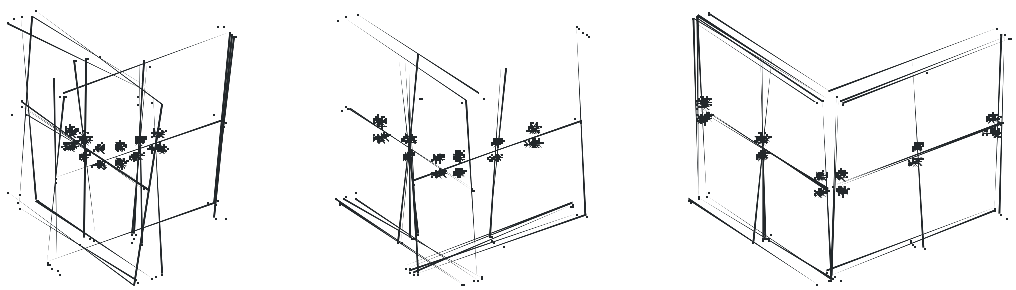

Figure 1: calculated LSQ-planes for angle measurements, 3 diferent measurement strategies

A similar exercise was done to investigate the influence of the measurement strategy on the measurement uncertainty of the diameter and position of a circle. In figure 2, some results are shown. The stars are simulated measurement points, again with 1000-fold magnified random error. The circles are estimated least-squares circles, the dots are the centers of these circles. This picture makes clear that the position of the measurement points on the circle is an important parameter in evaluating the measurement uncertainty

Figure 2: calculated LSQ-circles for diameter measurements, 2 different measurement strategies

Effects to be investigated in the future

So far, proposed and implemented methods for describing and simulating these errors assume that errors can be described as if they were “random”. If we look closer, we see that these errors are not indeed random, but we call them random because we have no accurate way to describe them. If one wants to apply software correction, this approach can give satisfactory results. In software correction, we describe errors, and we correct for them. Errors that we cannot describe, can’t be corrected for. Errors that are random by nature, can’t be corrected for, but errors that are not random but unknown, can’t be corrected for either. If we presume unknown errors “random”, the correction for the known errors still works fine.

If we want to evaluate the measurement uncertainty according to the GUM [1], correct statistical representation of the errors is needed. Therefore, it is important that we develop a method that can describe all errors, known systematic errors, unknown systematic errors as well as “random” errors.

It may not be necessary to describe in detail all error sources, but it is sufficient to describe all statistical properties of these errors. If we want to use a Monte Carlo method, we must generate simulations that have the same statistical properties as possible real measurements. These statistical properties are not only standard error of a certain point, but also auto correlation of one error, and cross correlation between different errors.

In [2], the method of the virtual CMM is used to evaluate the measurement uncertainty of different measurement strategies when measuring a circle. Here, the measurement uncertainty is calculated for different numbers of measurement points, varying from 4 to 1000. In the case of 1000 measurement points, a very small measurement uncertainty is found (0.13 micrometer). This would only be true if all assumptions that were made would be true. One of the assumptions is that all errors are random and normal distributed. In fact, this is not true, this will be demonstrated below.

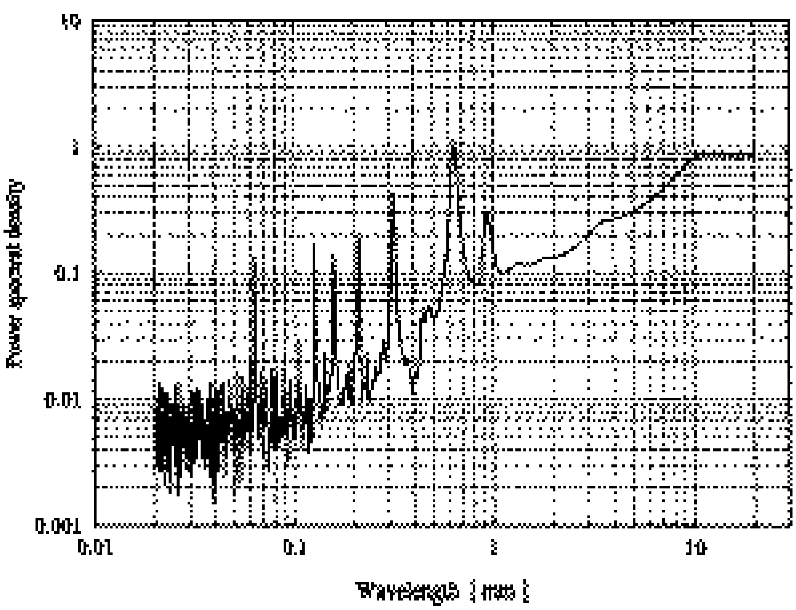

Figure 3: esitmated power spectral density of xTx error of a multi-axis machine (MAHO 700)

In [3], measurements of the error of a multi-axis machine are made, and the power spectral density of this error is estimated, see figure 3. This estimated power spectral density shows clearly that this signal can not be considered as white noise, this means that a series of measurement points can not be considered "random". If we simulate measurements points, using a random number generator, that generates points that are governed by a normal distribution, faulty results will occur. In particular, the expected "cancelling out" of errors when measuring many points will not occur. This means that the measurement uncertainty in the example with 1000 measurement points on a circle is probably not correct, and will in fact be larger.

The generation of simulated measurement points should be done in such a way that the preservation of relevant statistical quantities is assured. The method of surrogate data, as described in for instance [4], may be a good way to do this. This method is not yet implemented in current VCMM implementations, but the principle of this approach is a an essential step in the direction of a satisfying solution of the problem.

Conclusions

The VCMM method is a powerful tool to investigate the effect of measurement strategy on the measurement uncertainty. Current VCMM methods don't use correct assumptions, which may result in faulty results. Further research regarding the use of methods that preserve power spectrum and auto correlation behavior, like the method of surrogate data, is needed.

References

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