

SCANNING ON COORDINATE MEASURING MACHINES

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Abstract: Single point detection has established itself in the past for the measurement of geometrical features with tactile coordinate measuring machines (CMM). Ongoing development in the field of control engineering has led to the so-called scanning technique as an alternative. Unlike single point detection, this technique allows measuring tasks to be accomplished with coordinate measuring machines which were previously restricted to dedicated measuring instruments. This article presents selective test results for the use of the scanning technology for size and form testing with coordinate measuring machines.

Keywords: CMM, scanning, size and form testing

1 INTRODUCTION

In industrial practice, the testing of standard geometric features is one of the most important quality assurance measures which can be accomplished with the aid of the scanning technique. Moreover, this modern scanning method is used increasingly in digitization and measuring of free form surfaces.

For optimum use of the scanning technology in coordinate metrology, detailed knowledge of the relationships between measuring deviations, scanning parameters and other factors specific to measuring tasks is very important. With this in mind, the Chair of Metrology and Quality Management (Aachen University of Technology) has conducted comparative investigations between single point detection and the scanning technique on coordinate measuring machines (CMM). These investigations showed in numerous measuring jobs that the scanning technique has advantages over single point detection.

However, the changeover from single point detection to scanning may have effects which increase the unreliability of the measuring result. Therefore various influences need to be taken into account which can have an effect on the measuring result particularly in the course of interaction with the scanning velocity. However, the large number of recorded measuring points enables an effective reduction in errors due to modern measured value processing methods such as averaging or filtering [1], [2].

This report shows some interesting relationships between the detected influencing variables, the scanning parameters and the measuring deviations. Special attention is paid to influences and effects which are important in the scanning of standard geometric features.

2 TEST STRATEGY AND TEST PARAMETERS

A carefully conceived and extensive planning phase was crucial for the reliability of the conclusions drawn from evaluation of the tests. The essential emphasis here was placed on the composition and selection of factors to be investigated as well as an estimation of the interaction which represents an important prerequisite for reducing the test rate [3].

Various test methods were applied in the investigations depending on the respective aims. They were all based essentially on the comparison of two process statuses, the single factor method and on an appropriately adapted factorial test method.

The long established single factor method in particular has proven very effective here because, despite its simplicity, it is a great improvement on any unplanned procedure and represents a reproducible method [4].

Owing to the complex relationships in scanning, it was not possible to give consideration to all the potentially influencing parameters in the tests we conducted. Therefore, we determined the most important influencing factors first in a series of preliminary tests and then defined the parameters relevant to the tests (figure 1).

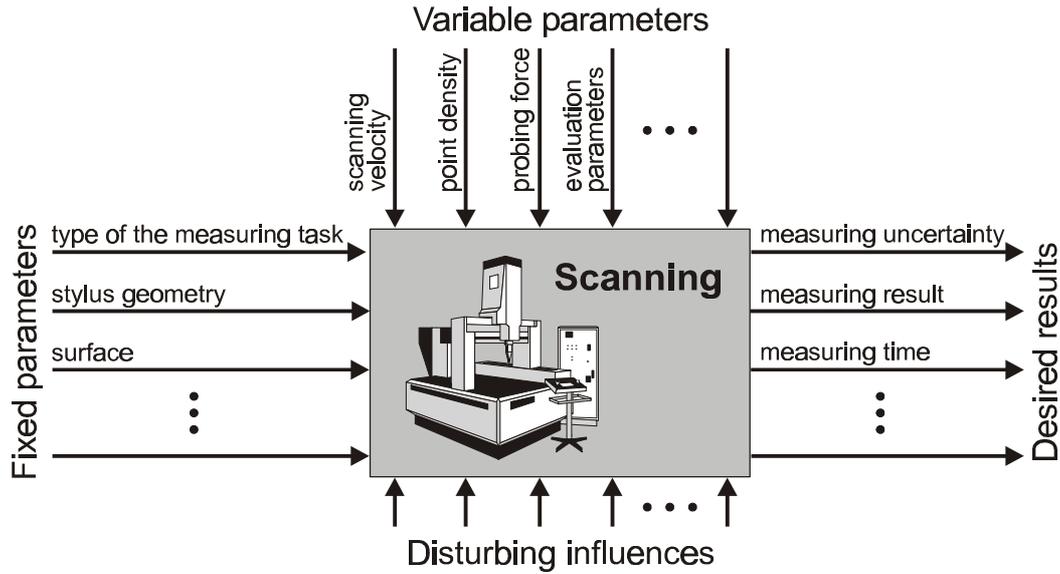


Figure 1. Main parameters influencing the scanning process

3 SELECTED TEST RESULTS

Some of the effects found in the metrological tests are presented below. The influence of the surface, the probing force and the stylus properties are studied in detail in particular. Most of these influences are closely related to the influencing variable of scanning velocity. The result is that the influencing variables concerned need to be evaluated as a function of the selected scanning velocity. Furthermore, this distinct interaction of the scanning velocity with the other influences is made clear by selected test results.

3.1 Influence of the Surface Structure and the Detection Force

To analyse the effect of the surface topography on the measuring result, comparative measurements were made on two test cylinders which exhibited marked differences in surface quality. One of the test objects has a very smooth surface structure due to fine grinding in the finishing phase. The other test object was made by a process of rough turning and therefore has a fine-wave, high frequency surface structure.

A closer look at the diagrams in figure 2 reveals that there is a triple interaction of the individual parameters in this case.

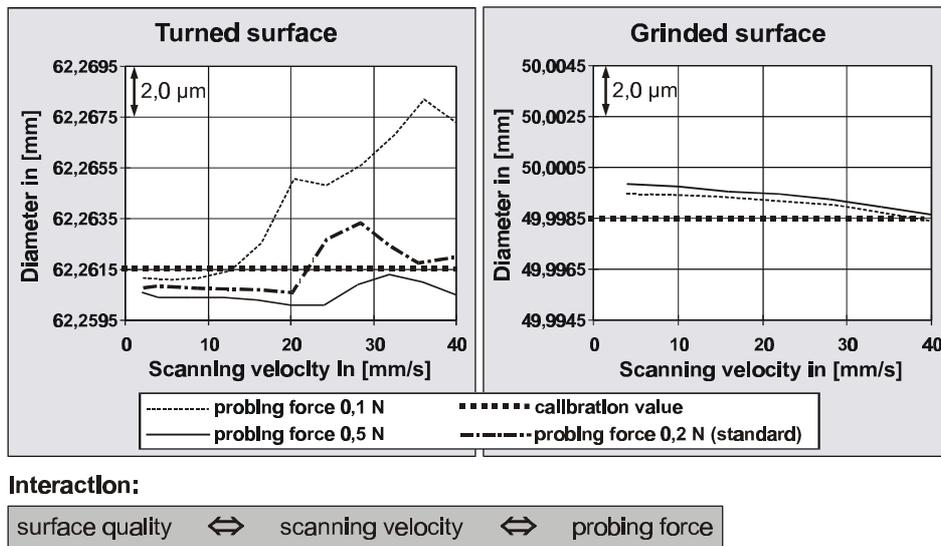


Figure 2. Influence of the surface finish and the probing force on the accuracy of size measurement

This interaction causes differences in the measured diameters of up to 8.5 μm. At the same time it is shown that the size measurements on the smooth surface (right diagram in figure 2) are hardly affected by the set probing force in the relevant speed range. The values of the size measurements made on the fine-wave surface (left diagram in figure 2) are additionally dependent on the set probing force. It should be pointed out that the axes of the two diagrams were scaled identically (graduation: 2 μm).

The effects which can be seen here are largely due to the occurrence of “micro-jumps” of the stylus. These are primarily caused by the surface structure of the measuring object, the scanning velocity and the probing force. This should also be taken into account when applying the scanning technique to the measurement of form deviations on workpieces with an unknown surface structure. In such cases, an appropriate increase in the probing force or a reduction in the scanning velocity is to be recommended.

In this way reliable measuring results can be achieved for the detection of wavy, short periodical surface structures with the scanning technique. Detailed metrological tests would have to be carried out in future in order to be able to make more accurate, quantitative statements.

3.2 Influence of the Stylus Characteristics

To analyse the effect of different stylus properties on the measuring results, tests were run with several different styli under otherwise identical conditions. The characteristics for size measurement derived from the relevant test results show a very distinct dependence of the measured value on the respective stylus, figure 3. The great difference in the trajectories of these curves are almost exclusively due to the different bending strengths of the styli used.

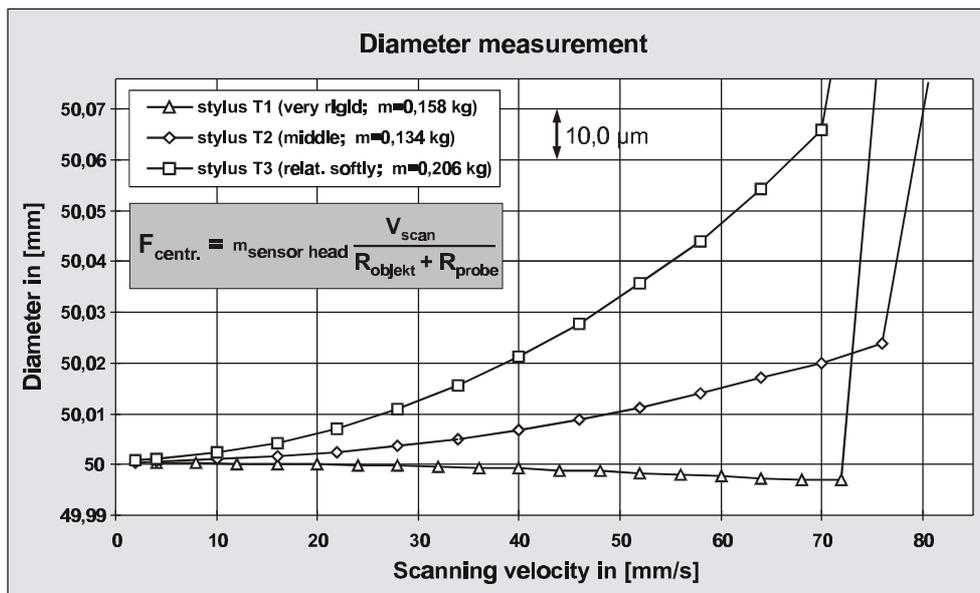


Figure 3. Influence of stylus characteristics on the accuracy of size measurement

With the relatively flexible T3 stylus, the measuring error increases overproportionally with the scanning velocity up to a value of 67 μm. At the same time, a clear influence on the measuring results can be observed for this stylus at relatively low measuring velocities. In comparison with the T3 stylus, the characteristic of the much more rigid T1 stylus has a very stable trajectory with only a slight downward trend. Two characteristic influences can be identified here by the use of the two extremely different T1 and T3 styli as far as their bending properties are concerned. The dynamic-related influence of the elastic stylus deformation (visible in T3) and the equally dynamic-related influence of elastic object deformation (visible in the case of T1). Since the characteristics shown in figure 3 have a very systematic curve, these influences can theoretically be compensated for. Suitable stylus qualification specially designed for scanning circle contours could contribute considerably to a future improvement in the performance of the scanning technique.

Another recognizable effect, shown in figure 3, is the lifting of the stylus. This always occurs at a certain scanning velocity. This critical velocity is device-specific and can be determined theoretically as a function of the bending radius of the scanning path (related to the centre point of the stylus tip), the set probing force and the respective probe mass.

4 POTENTIAL FOR FORM MEASUREMENT ON COORDINATE MEASURING MACHINES

Form measurement on coordinate measuring machines has only been able to establish itself after new developments in sensor, control, and software technology [5]. Wide practical experience now allows technical assessment, but also segregation from dedicated instruments. The great advantage of coordinate measuring machines is in the possibility of measuring the size, form and location of the workpiece in one chucking, on one measuring instrument and in an automatic measuring process. This opens up new areas of application and enables optimized processes in measuring technology. Particularly the throughput times and the number of manual interventions can be reduced considerably [6], [7]. The total machine occupation times are reduced due to much shorter tooling times. There is no need to chuck the workpieces several times. In addition, alignment takes place mechanically on a form tester and takes a relatively long time. This procedure is unnecessary on the coordinate measuring machine due to the one-time mathematical alignment and scanning in the workpiece coordinate system. This reduces the idle times of the machine tools [5].

With this in mind, the Chair of Metrology and Quality Management at the University of Aachen is running tests with the aim of determining the present form measuring potential of coordinate measuring machines. These tests were focused on the unique CMM property, in other words on the measurement of forms on geometries in arbitrary spatial alignment. In this context, the theoretically achievable measuring uncertainty of form measurement can be determined on a high precision coordinate measuring machine.

To compare the form measurement of a cylinder on a form tester and on a coordinate measuring machine, a suitable cylinder and holder were designed and built. The hardened, ground cylinder can be fixed vertically for measuring on a form tester at any time, figure 4. At the same time it is possible to measure the cylinder in an inclined position on a CMM with the aid of the holder shown below. Here, the angle of inclination of the cylinder is approx. 30° . Repeated roundness measurements were made with the scanning technique at four different heights of the cylinder. The measuring conditions and evaluation techniques were the same for both measuring devices as far as possible. The diameter of the stylus tip was 8 mm in both cases (mechanical filter effect). The same Gaussian filter according to DIN ISO EN 11562 with 15 U/R was used for the evaluation with units. Under these conditions, the results were comparable. In addition it was possible to compare the individual roundness plots of both measuring devices by superimposing the form plots (after adjusting the display scales).

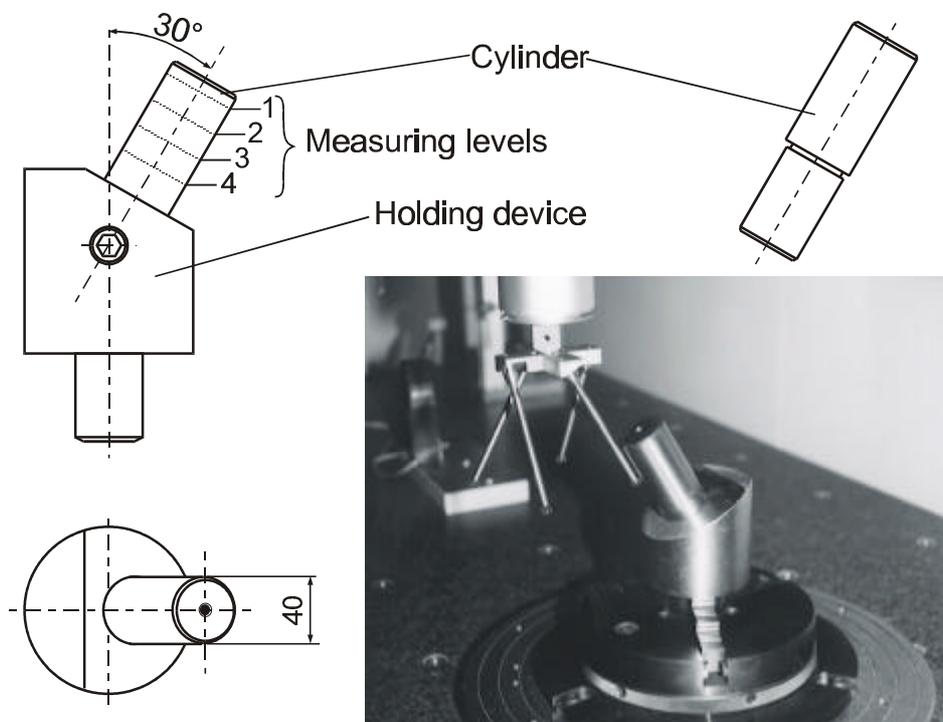


Figure 4. Cylindrical testpieces and holder

The investigations showed that the maximum difference between the values measured on the coordinate measuring machine and the form tester was only $0.2 \mu\text{m}$ in all tests. This even applies for a

cylinder with a spatial inclination. In addition, a high contour fidelity of the relevant roundness plots (except for a slight phase shift) was established, figure 5. It should be pointed out here that these results must be seen as device-specific and that they were achieved under lab conditions.

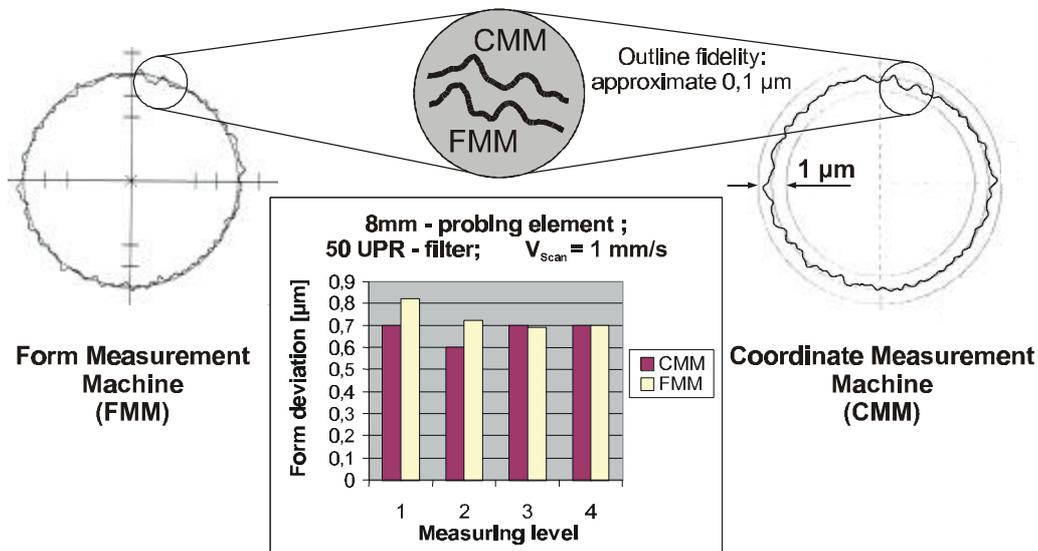


Figure 5. Potential for form measurement on CMM

5 CONCLUSION

In the course of this research project, the necessary technical investigations were conducted to obtain knowledge of the relationships between the scanning parameters and the measuring deviations. The analysis of the test results showed that the effect of the individual influencing variables on the respective target variable (size, form or location) may be very different. Therefore the measuring results of size, location and form measurements were looked at separately and in relationship to the relevant influences.

It became evident that location measurement can be classified as a relatively insensitive target variable in comparison with all the investigated influences. Therefore much greater scanning velocities and shorter measuring times can be achieved in many measuring jobs (e.g. coaxiality, parallelity). This applies for geometric features which can be measured symmetrically.

For size measurement it showed that it is mainly the influence of the stylus characteristics, the surface structure, the feature distinction and the dynamic probe and machine behaviour in connection with the scanning velocity which must be accounted for. Some of these influences lead to systematic deviations and processes which can be approximated by mathematical models. By additionally determining the appropriate "key data" obtained by empirical means, it will be possible to largely compensate for the influences concerned in future. The first solutions for measuring job-specific compensation of these influences are part of the measuring software of the Carl Zeiss Industrial Measuring Technology Business Group in options as so-called VAST technology [8, 9].

The essential influences identified in form measurement in addition to scanning velocity include dynamic machine behaviour, surface structure, feature distinction, probing force and the evaluation. Contrary to expectations, the influence of the stylus characteristics in form measurement proved to be much less than in size measurement. In addition, it was ascertained that above all the choice of a suitable filter in the evaluation and a relatively low scanning velocity can contribute to reliable information on the form. The necessary filter settings should be adapted primarily to the actual form of the geometric element to be measured and to the stylus tip diameter [10, 11].

The results of the tests made show that the scanning velocity can be seen as the main influencing variable in the scanning of standard geometries. At the same time it became evident that the interaction of the scanning velocity with other influences needs to be taken into account when determining the scanning or measuring parameters. In addition, it was established that the potential performance capability of coordinate measuring machines for form measurement tasks has not yet been fully exhausted. By using the scanning technology, form deviations of 3 μm upwards can already be detected reliably on some coordinate measuring machines.

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