

Monitoring coordinate measuring machines by calibrated parts

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Abstract. Coordinate measuring machines (CMM) are essential for quality assurance and production control in modern manufacturing. Due to the necessity of assuring traceability during the use of CMM, interim checks with calibrated objects carried out periodically. For this purpose usually special artefacts like standardized ball plates, hole plates, ball bars or step gages are measured. Measuring calibrated series parts would be more advantageous. Applying the substitution method acc. ISO 15530-3: 2000 [1] such parts can be used. It is less cost intensive and less time consuming than measuring expensive special standardized objects in special programmed measurement routines. Moreover, the measurement results can directly compare with the calibration values; thus, direct information on systematic measurement deviations and uncertainty of the measured features are available. The paper describes a procedure for monitoring horizontal-arm CMMs with calibrated sheet metal series parts.

1. Introduction

In manufacturing the continuously increasing demands on geometrical accuracy led to the necessity of testing conformance more frequently. Consequently, the measurement process was shifted from the measuring room to the shop floor and the number of measuring instruments was increased. Besides the requirement that the uncertainty of measurement results must be adequate to the tolerance, traceability must be ensured for all measurement results [2].

In order to fulfil these requirements, also for the production of sheet metal parts, it is necessary to monitor the CMMs where they are applied. Monitoring the accuracy of CMMs requires the application of calibrated artefacts, normally ball plates, hole plates and step gages as defined in standards (e.g. ISO 10360). CMMs with a large measuring volume, such as typical horizontal arm CMMs, checked with ball bars. For all artefacts special expensive fixtures, CNC routines, evaluation programs and training courses for the operators are necessary. Both time consuming positioning and fixing routines for each measurement and the purchase of standardized artefacts is quite expensive. Furthermore, the measurement of artefacts interrupts the regular operation on the CMM.

In contrast to these disadvantages of the regular procedure of acceptance and re-verification tests, the application of the substitution method, where the CMM is used as a comparator, offers an economical procedure to monitor CMMs in practice, but calibrated series parts are required. These parts selected from the mostly measured series workpieces. For the calibration routine the same measurement strategy used as for the series measurements, thus no additional CNC program has to be prepared. However, the main advantage is the fact, that the comparison between measurement and calibration results directly indicates systematic errors of the CMM measurement process. The

recording of the deviations together with the relevant measurement conditions in a database points out the influences. Another benefit is that the experimental procedure to estimate the feature specific measurement uncertainty for measurements on series parts applied, according to the rules of the ISO-Guide to the Expression of Uncertainty in Measurement, sort GUM [3].

2. Determining measurement uncertainty with calibrated parts

To verify the capability of CMMs the feature specific measurement uncertainty has to be known and in an acceptable ratio to the tolerance of the workpiece. In coordinate metrology, the main contributors to the uncertainty are CMM, workpiece, environment and operators including their measurement strategy [4].

The GUM [3] outlines the necessary steps for the correct calculation of measurement uncertainties. The following methods are in accordance to GUM:

- Uncertainty budget [5]
- Monte Carlo Simulation [6]
- Uncertainty estimation with calibrated workpieces [1]

The experimental method, described in [1], characterized by the summarization of all influences on the uncertainty and their superposition during the measurement. It is not necessary to know the separate influences. They are combined in the result of the experiment. Only systematic experiments allow identifying the actual impact of the variable influences. Indeed, this requires a high effort.

To detect the influences of material and manufacturing process the ISO standard foresees that more than one calibrated part has to be measured. The determined roughness and form deviation provide information about the dispersion of the manufacturing process and allow calculating its influence. These characteristics can be gathered more economically from un-calibrated series workpieces rather than a high number of calibrated workpieces.

Based on the measured characteristics of the standard measurement process the measurement uncertainty budget for the series measurement process can be determined. The achieved results, e.g. standard uncertainties, which are due to the individual influence factors, are structured and saved in a database, thus they are easily accessible for further automatic application in different measurement circumstances.

3. Characteristic for a successful interim check

Periodical interim checks build the basis for the decision, if the CMM is capable to measure the workpieces to be inspected. For an interim check, reduced performance verification may be applied to demonstrate the capability that the CMM conforms to specified requirements. The extent of the verification as described for the acceptance test and re-verification tests [7] may be reduced by: number of measurements, location and orientation being performed. In addition, the specifications to be checked can be defined by the operator.

The aim of the interim check is to prove if the measurement instrument has not changed its characteristics and thus its influences on the measurement uncertainty. Since all other components of the extended uncertainty $U(y_m)$ are influenced by other factors than the CMM, only the deviation between calibrated value y_{kal} and measurement results \bar{y}_m in relation to the associated extended uncertainties $U(y_m)$ and $U(y_{Kal})$ have to be checked.

$$E_N = \frac{\bar{y}_m - y_{kal}}{\sqrt{U(y_m)^2 + U(y_{kal})^2}} \quad (1)$$

By an accepted level of confidence of 95 %, the factor $|E_N| > 1$ can be exceeded in 5 % of measurements. It can be assumed that the influence of the CMM has not changed, otherwise the interim check failed and the CMM has to be re-verified.

The feature specific deviations are also stored in the sql-database together with information about significant influences as environmental conditions, selected measurement strategy and operator. By

means of data processing the scenarios, containing deviations and related influences, a knowledge base is created. This knowledge base will subsequently define the pre-conditions for the evaluation of the influences' impact. Automated evaluation routines and a management console were set up based on the acquired knowledge.

4. Monitoring of CMMS with calibrated parts

In order to verify the above mentioned procedure a horizontal-arm CMM for measuring sheet metal parts in series production of a German automotive company has been monitored. As representative part, a shaft collet has been selected. The working standard calibrated at the reference CMM of the measurement centre of the Chair Quality Management and Manufacturing Metrology (QFM).

4.1. Calibration of a shaft collet

The measurement centre of QFM is accredited by PTB4 as DKD5-calibration laboratory (DKD-K-36501) for calibration of standard geometrical features on prismatic workpieces according to ISO 17025. The measuring room (Class 1 acc. guideline VDI/VDE 2627) has almost perfect environmental conditions, e.g. a temperature stability of $20\text{ °C} \pm 0,1\text{ °C}$ all over the year. According to GUM, the measurement uncertainty calculated with the VCMM6 software, which bases on Monte Carlo simulations. The measurement process is modelled by software modules. After the qualification of the relevant influence quantities, an ideal measurement process is computed. The “imperfect” process is repeated computed 200 times for the statistical evaluation of the deviations in the result.

The shaft collet was calibrated at the reference CMM *Zeiss UPMC 1200 CARAT S-ACC* in several positions to get traceable results (Fig. 1). The measurement results y_{kal} are documented in the calibration certificate together with the feature specific extended measurement uncertainties $U(y_{\text{kal}})$.



Figure 1. DKD calibration of a shaft collet with reference CMM

4.2. Segmenting the CMM measuring range

Monitoring of large CMMs with small sheet metal parts reduces the informational value. Even to allow for a statement about the capability of the measurement process of a large CMM like a horizontal-arm CMM, its measuring volume is divided into twelve monitoring fields. The shaft collet was measured at six positions in the x-y-plane and at two z-levels. The results in the individual positions of the workpiece have to be stored in the database. The deviations and uncertainties can be traced back to the machine coordinate system.

4 Physikalisch-Technische Bundesanstalt (PTB), the German national metrology Institute

5 Deutscher Kalibrierdienst (DKD), association of calibration laboratories

6 Virtual Coordinate Measuring Machine (VCMM)

4.3. Calculation of uncertainty budget and evaluation of interim check

The calculation of measurement uncertainty is automatically carried out software assisted by the management console using the current measurement results together with the stored experience values. As illustration of the above-mentioned procedure, an actual measured value for the positional deviation of a flange hole is presented (Table 1).

The factor $E_N < 1$ is not reached in 95% of all measurements on the feature flange hole. It is proved that the monitored CMM is not capable to measure the shaft collet in position 51.

Table 1. Monitoring results of the shaft collet; feature: flange hole, position 51

workpiece:		shaft collet		position on CMM:		POS 51	
feature:		flange hole		tolerance in mm:		0,2000	
nominal size in mm:		0		calibrated value y_{kal} :		0,1795	
tolerance in mm:		0,2		extended uncertainty $U(y_{kal})$:		0,04	
medial temperature T in 癈:		22,6 癈		extending coefficient k:		2	
uncertainty of T in 癈:		0,1 癈		a_{steel} :		11,5	
				u_a :		1	
measurement cycle no.	date:	time:	operator	cal. workpiece m	un-calibrated workpieces		
					m_1	m_2	m_3
1	2004-12-22	07:10	Buchner	0,6208	0,6959	0,2550	0,2584
2	2004-12-22	08:12	Buchner	0,6213	0,6955	0,2559	0,2595
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
20	2004-12-22	02:12	Buchner	0,6208	0,6961	0,2576	0,2686
average value \bar{y} :				0,6210	0,6952	0,2567	0,2632
standard uncertainty u_{prz} :				0,00038	0,00098	0,00092	0,00393
number n of workpieces:				4			
symbol of influences	u_{kal}	u_{prz}	u_T	u_{ws}	$ E_N $	$U(y_m)$	check result
uncertainty	0,0187	0,0021	0,0000	0,0000	8,3300	0,04	Not capable

5. Conclusion

A procedure for monitoring of CMMs with calibrated workpieces was introduced. The monitoring is based on measurements of workpieces with known shape deviations in pre-defined monitoring fields within the measuring volume of the CMMs, wherein all relevant influence factors are considered. All measurement results are stored in a database. All unknown and known systematic deviations of the real process are represented during the experiments.

Based on the gained information the calculation of feature specific measurement uncertainties are already possible an early development stage. So, the measurement uncertainty can be considered during the definition of tolerances.

References

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