



TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 68, Issue Special I, May, 2025

STUDY ON THE MEASUREMENT ERROR ANALYSIS OF AN OMM MEASUREMENT SYSTEM USING A PROBING MODULE CAD-CAM SOFTWARE

Cristian-Eusebiu POPESCU, Aurel TULCAN, Adrian BUT

Abstract: The purpose of this work is to establish and validate an efficient dimensional inspection system by using the On-Machine Measurement (OMM) process with the aid of a measurement module of a CAD-CAM program. In recent years, CAD-CAM software's has introduced modules that allow the measurement of parts executed directly on the machine tool. Through this system, the quality of the executed part can be controlled. To perform this study, an aluminum part was designed and machined by milling on a 3-axis CNC machine. The finished part was dimensionally measured on the milling machine using an OMM system and on a dedicated Coordinate Measuring Machine (CMM), thus being able to compare the accuracy and errors of using an OMM system. According to the measured values, there are no significant differences between the measurement methods of the two OMM, but larger deviations can be observed between the measured values obtained from OMM and CMM methods.

Keywords: OMM – inspection, CMM – inspection, CAD – CAM software, 3-axis milling, geometric tolerances, dimensional inspection.

1. INTRODUCTION

The world economy, including the global manufacturing industry, is going through essential changes, the main factor being globalization but also the climate crisis. The challenges of the manufacturing industry relate to reducing the product life cycle and meeting customer requirements, which are related to the lowest production costs and the shortest possible time to launch the product. In addition to these cost and time requirements, the dimensional accuracy of the manufactured parts is an essential factor, both from a functional point of view and for subsequent assemblies. Accurate measurement is conditioned by the need to execute the parts within the limits of the imposed tolerances. In addition, it is necessary to ensure measurement traceability of the process to guarantee accuracy in any result and analysis in case of measurement errors that could occur [1,2].

To be able to meet customer requirements, reliable control of production systems is necessary. Improving product quality standards

involves deepening control and inspection methods. In this scenario, quality control requirements require strict product inspection standards.

Today, the manufacturing and dimensional validation of parts in the machine tool area are important factors for the development of test assemblies. The certainty that the process is being carried out correctly is the guarantee that a job will be delivered according to the required specifications, without the risk of having to remanufacture because there was incorrect machining or incorrect dimensioning at an early stage, and finally rework parts [3].

In this paper, an actual industrial problem is addressed: how to develop a reliable approach for measuring industrial parts by measuring the milled part directly on the machine, but not with mobile CMM (coordinate-measuring machine) equipment. To achieve this objective, the measurement system integrated into the milling machine and a probing module of a CAD-CAM system will be used. In specialized literature, this type of approach is called OMM - inspection.

2. LITERATURE REVIEW

On-machine measurement is defined as the measurement of workpieces placed in the workspace of the NC (numerical control) machine (without moving it), usually using a probing feature of the machine that also manufactures the part. Standard Coordinate Measuring Machines measure in a separate measuring laboratory. Each measurement method has its strengths and weaknesses that make technicians prefer one over the other [4].

The acronym OMM is also named in the specialized literature: inspection on the machine (OMI) or verification on the machine (OMV). The measurement process can be performed at the end of the final NC machining operation or between partial procedure operations. In the case of manufacturing parts on CNC (Computer Numeric Control) milling machines (2, 3, 4, or 5 axes), the measurement process is carried out by a touch probe mounted in the axis of the milling machine. Relative NC measuring movements between the spindle and the workpiece are programmed to touch the workpiece by the probe in measuring points preselected on the CAD model of the workpiece. The spatial direction of the final approaching movement is controlled to be perpendicular to the workpiece surface in measuring points. This makes it possible to compare the space positions of measured points with corresponding points selected on the CAD model and to evaluate errors of workpiece surfaces in the normal direction to the surface.

Machining centers offer precision milling capable of generating machined surfaces with micrometer precision and surfaces with nanometric roughness. The mechanical parts executed on these centers are used in the leading fields of industry, from the aerospace, medical, optical, and electronic industries. However, there are a multitude of factors that can cause surfaces to deviate from the nominal designed part. In addition to the human factor, we can list several important factors, such as: the rigidity of the technological system (machine tool-tool-device-part), the environment, structural errors of the machine, and vibrations. Based on these facts, the metrology process and the surface compensation operation are defined in the

further development of the technologies for a process that respects the imposed requirements, so a better accuracy of the surfaces and the milled parts [5].

Even if the CMM metrological process remains the only standardized system for the final validation of a machined part, in recent years, the metrological process has undergone a change of approach. In addition to classic solutions (offline solutions), which are based on the measurement of machined parts in dedicated laboratories (functionally regulated) and with specialized equipment, metrology was introduced as a necessity within production departments. This was necessary to further enhance measurement efficiency and intelligent manufacturing [6]. In addition to those listed previously, OMM solutions can avoid errors caused by repositioning the workpieces, use machine axes to extend the measurement range, and improve measurement efficiency [7]. In recent years, OMM solutions have come to be used more and more, there are a lot of reports on this subject. OMM solutions can be classified mainly into 2 categories, by contact and optical methods.

A new direction has appeared in recent years and has been developed by CAD-CAM software companies. This is also the reason behind the realization of this case study. Several CAD-CAM manufacturers have begun to develop and integrate modules dedicated to OMM measurements. This mode can optimize milling processes combined with feedback from part measurements while the part is on the CNC machine. The users can make quick decisions based on the results obtained from OMM measurement.

In most of them, the latest versions of CAD-CAM software have also integrated measurement modules and are defined as a normal working procedure. Measurement procedures have an integrated solution at On-Machine Measurement. This means that the system uses the CNC machines not only to mill the part, but also to use contact probes to measure the result of the machining. Measurement is performed as part of the machining process, providing real-time feedback at specified control points while machining is still in progress.

On-machine measurement validates the machining process while the part is on the machine.

3. MATERIALS AND METHOD

3.1 Workpiece and material used

To achieve the declared objective, it was decided to manufacture by milling a mechanical part composed of primitive geometric shapes, such as a cylinder and rectangular parallelepiped, on a CNC milling machine.

The isometric view of the workpiece that is part of this study can be seen in Figure 1. The workpiece has overall dimensions of 150x80x15mm. According to the 3D definition of the part, the part design considers the inclusion of as many probing cycles as possible (rectangular pocket, rectangular block, hole, boss, etc.).

The aluminum alloy 7075 was chosen as the material for the machined part, having good machinability and dimensional stability. This 7075 material is very well known among fabricators as a high-strength material. It belongs to the 7000 aluminum alloy series. It is widely used in applications that require an excellent strength-to-weight ratio, such as aerospace, military technology and automotive (mechanical parts, injection molds).

The corresponding standards of aluminum alloy 7075 can be seen in Table 1.

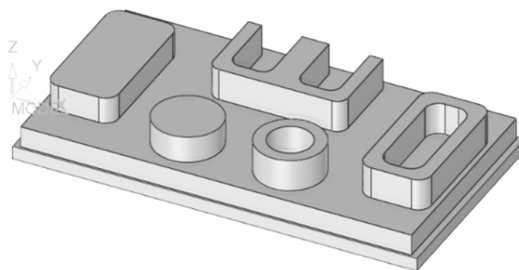


Fig. 1. The isometric view of the workpiece.

Table 1

Material equivalence according to standards.

Standard			
DIN	AlZnMgCu1.5	W. Nr.	3.4365
AFNOR	A – Z5GU	ENAW	AlZn5.5MgCu
ASTM	7075	ISO	AlZn5.5MgCu

3.2 Considerations regarding the milling machine and its OMM system

The experimental work was carried out with the experimental machining system and the milling machine center presented in Figure 2.



Fig. 2. The milling machining center used for experiments.

The experimental machining system is a 3-axis CNC milling center HAAS VF-2YT-EU, with a maximum spindle rotation of 10.000 [rpm] and 22.4 kW maximum rating and Max torque 122 N·m 2000 rpm.

The CNC milling machine is equipped with a probing system for CNC machine tools named WIPS module (The Haas Wireless Intuitive Probing System) from Renishaw Company. WIPS comprises a complete package of templates in the control panel menu that guides intuitive operators in setting the machine, including the rod of probing from the main shaft, the measuring probe tools, and optical interface. WIPS allows easy definition and quick work origins, tool measurement, and in-process verification of the part and broken tools. The system includes the following options: Visual System Programming (VPS), MACRO Functions, Tree Orientation (SO), and Coordinated Rotation and Scaling (COORD) [8,9].

The Renishaw WIPS system is composed of three components which are shown in Figure 3:

1. OMP40-2 optical transmission probe

It is used for workpiece inspection and work set-up on milling machine (small and medium size) and multi-tasking machines.



Fig. 3. The Haas Wireless Intuitive Probing System

The following properties are noted: flexible probing possibility and reliable modulated optical transmission. These lead to excellent performance for less scrap and higher profits.

2. OTS 3D - touch-trigger tool setter

It is used for measuring tools and detecting broken tools on milling machines.

The following properties are noted: rapid measurement of tool diameter and length, cable-free for machine movement, and a direction-adjustable infrared optical module.

3. OMI-2H – optical machine interface

It is mounted in the working area of the milling machine and represents a combined optical receiver and machine interface.

3.3 Considerations regarding the coordinate measuring machine used for measurement

A DEA Global Lite 7.7.5 coordinate measuring machine (Figure 4.a) was used to measure the specific features on the workpiece and compare the results with the results obtained in the milling machine by the OMM system [9]. DEA CMM uses touch trigger probe technology and is certified, with the Maximum Permissible Error for length measurement formula [10]:

$$MPE_E = 1.9 + L/300 \mu m, \quad (1)$$

where L represents the measuring length.

PC-DMIS 2024 R2 metrology software was used to create measurement routines to verify the workpiece geometry [11].

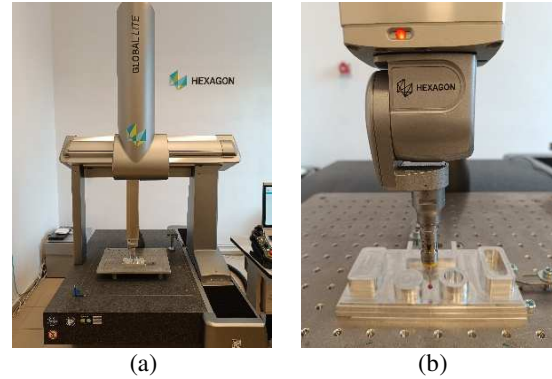


Fig. 4. DEA GLOBAL Lite Coordinate Measuring Machine.

3.4 Method used in the experiment

The method used is based on the following steps:

- Milling of the designed workpiece on the CNC milling machine in 3 copies;
- OMM1: measuring the workpiece using the Virtual Programming System module - VPS probe templates, module integrated into the CNC milling machine;
- OMM2: measuring the workpiece using the CAD-CAM procedure, In Process Measurements;
- CMM: measuring the milled parts in the 3D measuring laboratory.

The part designed for this study was milled in triplicate with the same cutters, machine parameters, clamping system, and lubrication coolant (Figure 5).

Figure 6 shows the features that will be measured: rectangle out (1), boss (2), hole (3), slot width (4), ridge width (5), slot width (6), rectangle in (7) and Z planes (8, 9 and 10).

Regarding the On-Machine Measurement method, both OMM1 and OMM2 use the same contact probe from the CNC milling machine (Renishaw Spindle Probe PN 93-60-0050 - Stylus 6mm Diameter Ruby Ball x 50mm Ceramic Rod with M4 Threads).



Fig. 5. The parts milled for this study.

they only set the parameters that are considered during the post-process operation.

The last step consists of measuring the three workpieces in the 3D Measuring Lab, on DEA CMM. The workpiece is fixed to the machine table using clamps and screws (Figure 4.b). The measurement programme starts with the software alignment of the milled part with the CAD model imported in PC-DMIS and setting the coordinate system origin according to the CAD model.

The features marked in Figure 6 were measured using a straight stylus with ruby ball tip, Ø4 mm, length 20 mm, stainless steel, mounted into a standard force module that is part of a touch trigger probe.

Table 2 presents the probing strategy, and Figure 11 shows the distribution of the probing points to the measurement features and the measurement trajectory.

Table 2

Definition of the workpiece probing strategy.

No	Physical feature	Measured feature	N° of probing points
1	Rectangle out width	Plane	2x 12
	Rectangle out length	Plane	2x 9
2	Boss	Circle	16
3	Hole	Circle	16
4	Slot width	Plane	2x 15
5	Ridge width	Plane	2x 15
6	Slot width	Plane	2x 15
7	Rectangle in width	Plane	2x 15
	Rectangle in length	Plane	2x 6
8	Z1 Plane	Plane	21
9	Z2 Plane	Plane	20
10	Z3 Plane	Plane	45

4. RESULTS AND INTERPRETATIONS

For this study, three types of measurements were performed, two using the OMM method and one using the CMM method. According to the established measurement plan (Figure 6), ten different features (lengths, widths, diameters and Z planes) were measured. In the case of rectangles, the measurement is performed on both axes (Ox and Oy).

The results obtained by applying the OMM measurement method for the measured characteristics of the machined parts are presented in Table 3.

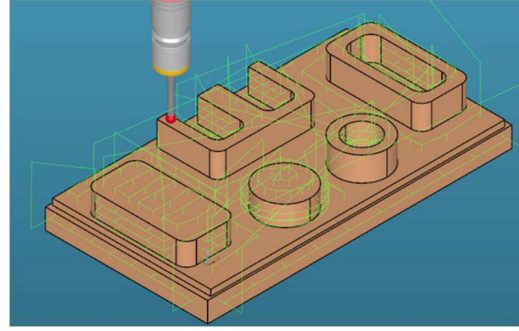


Fig. 11. Probing points distribution and measuring trajectory on CMM.

Table 3

Measurement results obtained using the OMM method.

Measured Features					Measuring method			
No	Feature name	Type	Nominal dimension [mm]	Part no.	OMM1		OMM2	
					Measured dimension [mm]	Deviation [mm]	Measured dimension [mm]	Deviation [mm]
1	Rectangle out	Width	25	1	24.997	-0.003	24.998	-0.002
				2	24.996	-0.004	24.996	-0.004
				3	24.994	-0.006	24.993	-0.007
		Length	50	1	49994	-0.006	49995	-0.005
				2	49995	-0.005	49995	-0.005
				3	49995	-0.005	49995	-0.005
2	Boss	Diameter	25	1	24.994	-0.006	24.995	-0.005
				2	24.995	-0.005	24.995	-0.005
				3	24.997	-0.003	24.996	-0.004
3	Hole	Diameter	16	1	15.993	-0.007	15.994	-0.006
				2	15.994	-0.006	15.994	-0.006
				3	15.994	-0.006	15.995	-0.005
4	Slot width	Distance	15	1	14.997	-0.003	14.996	-0.004
				2	14.998	-0.002	14.997	-0.003
				3	14.997	-0.003	14.997	-0.003
5	Ridge width	Distance	10	1	9.994	-0.006	9.995	-0.005
				2	9.996	-0.004	9.995	-0.005
				3	9.997	-0.003	9.996	-0.004
6	Slot width	Distance	15	1	14.997	-0.003	14.996	-0.004
				2	14.996	-0.004	14.994	-0.006
				3	14.995	-0.005	14.996	-0.004
7	Rectangle in	Width	15	1	14.996	-0.004	14.997	-0.003
				2	14.996	-0.004	14.995	-0.005
				3	14.995	-0.005	14.995	-0.005
		Length	40	1	39997	-0.003	39998	-0.002
				2	39995	-0.005	39995	-0.005
				3	39996	-0.004	39995	-0.005
8	Z1 Plane	Distance	1	1	0.997	-0.003	0.996	-0.004
				2	0.996	-0.004	0.996	-0.004
				3	0.998	-0.002	0.997	-0.003
9	Z2 Plane	Distance	2	1	1.998	-0.002	1.996	-0.004
				2	1.996	-0.004	1.996	-0.004
				3	1.998	-0.002	1.998	-0.002
10	Z3 Plane	Distance	12	1	11997	-0.003	11996	-0.004
				2	11997	-0.003	11997	-0.003
				3	11998	-0.002	11997	-0.003

According to the measured values in Table 3, as expected, there are no significant differences between the two OMM measurement methods. This results from the fact that the same measurement process is used (contact probe, milling machine, and device), the difference is only how the input data for the measurement are entered (VPS system or CAD/Cam software). The deviations resulting from the three measurement methods (OMM1, OMM2, CMM) for the machined parts are presented in Table 4.

Table 4

Deviation values for the 3 measurement methods.

Measured Features					Deviations [mm]		
No	Feature name	Type	Nominal dimension [mm]	Part no.	OMM1	OMM2	CMM
1	Rectangle out	Width	25	1	-0,003	-0,002	-0,003
				2	-0,004	-0,004	-0,004
				3	-0,006	-0,007	-0,003
		Length	50	1	-0,006	-0,005	-0,002
				2	-0,005	-0,005	-0,001
				3	-0,005	-0,005	-0,002
2	Boss	Diameter	25	1	-0,006	-0,005	-0,009
				2	-0,005	-0,005	-0,007
				3	-0,003	-0,004	-0,005
3	Hole	Diameter	16	1	-0,007	-0,006	-0,004
				2	-0,006	-0,006	0,001
				3	-0,006	-0,005	0,002
4	Slot width	Distance	15	1	-0,003	-0,004	0,012
				2	-0,002	-0,003	0,013
				3	-0,003	-0,003	0,014
5	Ridge width	Distance	10	1	-0,006	-0,005	-0,011
				2	-0,004	-0,005	-0,012
				3	-0,003	-0,004	-0,007
6	Slot width	Distance	15	1	-0,003	-0,004	0,014
				2	-0,004	-0,006	0,014
				3	-0,005	-0,004	0,011
7	Rectangle in	Width	15	1	-0,004	-0,003	0,015
				2	-0,004	-0,005	0,014
				3	-0,005	-0,005	0,014
		Length	40	1	-0,003	-0,002	0,008
				2	-0,005	-0,005	0,009
				3	-0,004	-0,005	0,008
8	Z1 Plane	Distance	1	1	-0,003	-0,004	0,04
				2	-0,004	-0,004	0,036
				3	-0,002	-0,003	0,049
9	Z2 Plane	Distance	2	1	-0,002	-0,004	0,01
				2	-0,004	-0,004	0,008
				3	-0,002	-0,002	0,011
10	Z3 Plane	Distance	12	1	-0,003	-0,004	0,009
				2	-0,003	-0,003	0,01
				3	-0,002	-0,003	0,012

Analyzing the values in Table 4, larger deviations can be observed between the OMM and CMM values. Differences can be observed in the following cases:

- Larger measuring distances (1–50 mm and 7–40 mm in length) (Figures 12 and 13).
- Most of the time, machining accuracy and, therefore, measurement accuracy are inversely proportional to the workpiece size.
- External and internal cylinders, boss-2 and hole-3 diameters (Figure 14).

The reasons are related to the NC definition of the tool path and to the measurement accuracy. In the case of OMM methods, the number of predefined points for measurement is 3 in the case of OMM1, respectively, 4 in the case of OMM2. In the case of the CMM method, the number of points and their distribution are much higher, with the possibility of choosing their number (Table 2 and Figure 11).

- Height measurement, Z planes: 8–Z1, 9–Z2, and 10–Z3 (Figure 15).

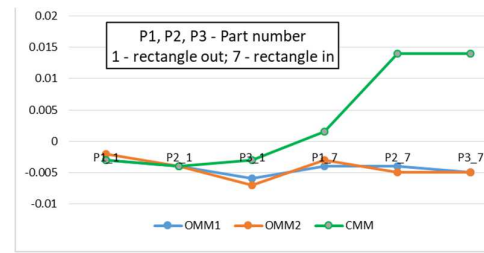


Fig. 12. Width deviations on X-axis

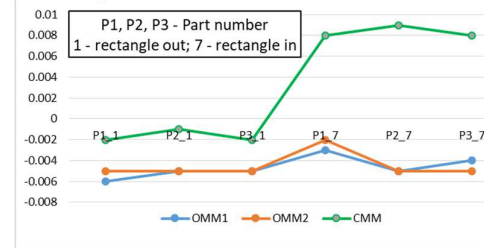


Fig. 13. Length deviations on Y-axis

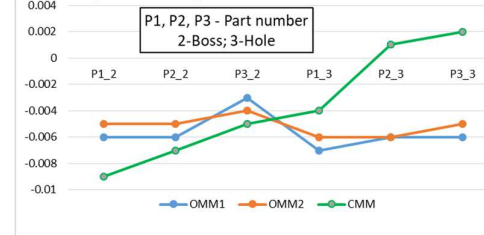


Fig. 14. Diameter deviations on XY-axis

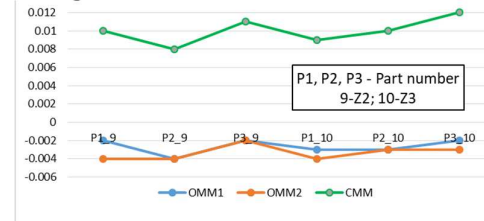


Fig. 15. Distance deviations on Z-axis

5. CONCLUSIONS

According to the values obtained by measurement and their interpretation, there are no significant differences between the measurement methods of the two OMM. However, larger deviations can be observed between the OMM and CMM values.

In addition to the factors listed in the previous chapter, there are of course also those related to the accuracy of the CNC machine, the clamping devices, the measuring system, and, finally, the working environment.

6. REFERENCES

- [1] Aggogeri, F., Barbato, G., Barini, E.M., Genta, G., Levi, R., *Measurement Uncertainty Assessment of Coordinate Measuring Machines by Simulation and Planned Experimentation*, CIRP Journal of Manufacturing Science and Technology, volume 4, pp 51-56, 2011.
- [2] Puertasa, I., Luis Pérez, C.J., Salcedo, D., León, J., Luria, R., Fuertsa, J.P., *Precision study of a coordinate measuring machine using several contact probes*, Procedia Engineering 63, pp 547-555, 2013.
- [3] Jamshidi, A., Maropoulos, P.G., *Implementation of a machine tool performance measurement and diagnostic system and its impact on parts verification*, Second International Conference on Sustainable Design and Manufacturing, 2013.
- [4] *On-Machine Measurement*. Available online: <https://www.keyence.com/products/3d-measure/cmm/applications/on-machine-measurement.jsp> (accessed on 07.02.2025).
- [5] Gao, W., Haitjema, H., Fang, F., Leach, R., *On-machine and in-process surface metrology for precision manufacturing*, CIRP Annals, Volume 68, pp 843-866, 2019.
- [6] Ali, S., H., R., *The-State-of-the-Art of CMM-Coordinate Metrology in Automotive Industry*, SAE Technical Papers, 2017.
- [7] Li, D., Jiang, X., Q., Tong, Z., and Blunt, L., *Development and Application of Interferometric On-Machine Surface Measurement for Ultraprecision Turning Process*, Journal of Manufacturing Science and Engineering 141, 2018.
- [8] *Wireless Intuitive Probing System*, Available online: <https://www.haascnc.com/productivity/probe-system/wips-r.html> (accessed on 02.02.2025).
- [9] *Haas wireless intuitive probing system wips*, Available online: <https://www.renishaw.com/en/haas-wireless-intuitive-probing-system-wips-> (accessed on 06.02.2025).
- [10] *Global Lite*, Available online: <https://hexagon.com/products/global-lite> (accessed on 06.02.2025).
- [11] *PC-DMIS*, Available online: <https://hexagon.com/products/product-groups/measurement-inspection-software/metrology-software/pc-dmis/pc-dmis-2024-2> (accessed on 06.02.2025).
- [12] *Cimatron, Webinars*. Available online: <https://www.cimatron.com/en/webinars/technical> (accessed on 02.02.2025).

Studiu privind analiza erorilor de măsurare a unui sistem de măsurare OMM folosind un modul de măsurare CAD – CAM

Scopul acestei lucrări este de a stabili și valida un sistem eficient de inspecție dimensională prin utilizarea procesului de măsurare pe mașină (OMM) cu ajutorul unui modul de măsurare al unui program CAD-CAM. În ultimii ani programele CAD-CAM au introdus module care permit măsurarea pieselor executate direct pe mașina unealtă. Prin acest sistem se poate controla calitatea piesei executate. Pentru a efectua acest studiu asupra preciziei și limitelor unui sistem OMM a fost proiectată și prelucrată o piesă din aluminiu prin frezare pe o mașină CNC în 3 axe. Piesa finită a fost măsurată dimensional pe mașina de frezat folosind un sistem OMM și pe o mașină de măsurat în coordonate (CMM) dedicată, putând astfel compara acuratețea și erorile utilizării unui sistem OMM. Conform valorilor măsurate, nu există diferențe semnificative între metodele de măsurare OMM, dar se pot observa abateri mai mari între valorile măsurate obținute prin metodele OMM și CMM.

Cuvinte cheie: OMM – inspecție, CMM – inspecție, software CAD – CAM, frezare pe 3 axe, toleranțe geometrice, inspecție dimensională.

Cristian-Eusebiu POPESCU, PhD student, Politehnica University Timisoara, Materials and Manufacturing Engineering Department, E-mail: cristian-eusebiu.popescu@student.upt.ro, Phone: +40726215127.

Aurel TULCAN, PhD, Professor, Politehnica University Timisoara, Materials and Manufacturing Engineering Department, E-mail: aurel.tulcan@upt.ro, Phone: +40751092476.

Adrian BUT, PhD, Assoc. Professor, Politehnica University Timisoara, Materials and Manufacturing Engineering Department, E-mail: adrian.but@upt.ro, Phone: +40726715095.