

ADAM GAŚKA\*, PIOTR GAŚKA\*, MACIEJ GRUZA\*

## I++ SIMULATOR USED TO SUPPORT WORKING WITH COORDINATE MEASURING MACHINE

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### ZASTOSOWANIE SIMULATORA I++ DO WSPOMAGANIA PRACY NA WSPÓLRZĘDNOŚCIOWEJ MASZYNIE POMIAROWEJ



#### Abstract

This paper presents examples of usage of Coordinate Measuring Machine simulator, which facilitate metrological tasks in laboratory and industrial conditions, and constitute a great convenience in Coordinate Measuring Technique learning process.

*Keywords: CMM, simulator, coordinate measurement*

#### Streszczenie

Artykuł przedstawia przykłady zastosowań symulatora Współrzędnościowej Maszyny Pomiarowej, które ułatwiają pracę metrologa w warunkach przemysłowych i laboratoryjnych oraz stanowią duże udogodnienie w procesie nauczania Współrzędnościowej Techniki Pomiarowej.

*Słowa kluczowe: WMP, symulator, pomiar współrzędnościowy*

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\* PhD. Eng. Adam Gąska, MSc. Eng. Piotr Gąska, MSc. Eng. Maciej Gruza, Laboratory of Coordinate Metrology, Department of Mechanical Engineering, Cracow University of Technology.

## 1. Introduction

The development of multimedia technology brings many benefits for both science and industry. Today, one cannot imagine, creating technical documentation using a drawing board and a pencil or writing down complex strength analysis with pen in a notebook. It happens for several reasons. Firstly, computer programs perform their tasks much faster than a human, secondly due to them, possibility of making a wrong decision can be avoided or at least limited. A perfect example of how extremely useful software can be are all kinds of simulators. Simulators are, most often, programs whose task is to restore certain phenomena or behavior of objects, using its mathematical model. In aviation an integral part of pilots training are exercises with simulator. Thanks to them pilots can face extreme situations without risking their lives. They can also practice some routine behaviours without generating costs associated with the operation of planes and fuel consumption. In engineering, as an example programs developed by Dessault Systems like Catia and Delmia can be used. Particular modules are responsible for simulating the machining process or production line simulation. Finding the optimal variant is much simpler with them, they also helps to prevent collisions and downtimes. Simulators are used in many other areas as: medicine (surgery simulations) [1], logistics [2], army, mechanical systems [3], production engineering [4]. They are also used in coordinate metrology, which is nowadays important tool in quality control of automated processes. In most of metrological programs it is possible to simulate probe head behaviour and course of the measurement path. Whereas I++ Simulator described in this article enables simulation of operation of whole measuring station based on virtual model of actual coordinate machine.

This paper presents different aspects of working with Coordinate Measuring Machines (CMM) that can be facilitated by usage of CMM simulator. Cases described in this paper are: usage of simulator for CMM programming in different conditions, the didactic use of simulator for CMM operators training and students lessons, usage of simulator combined with CMM accuracy model in order to build the software allowing determination of the best measurement strategy.

## 2. Coordinate Measuring Technique

In the case of the classical geometrical metrology, typical measuring devices are used to determine dimension of only one type, which in some particular situations could be used to calculate the dimensions of different type (for example, the measured lengths are used to determine the angle). In this way, however, it is difficult to measure object that has a diversified shape, often with complex dimensions. In such cases, each type of dimension should be measured individually, which in turn would lead to increase of the amount of needed tools. It can easily be noted that in a similar situation, automation of any quality control process would be, if not impossible, surely inefficient due to excessive measuring time. Coordinate Measuring Technique (CMT) based on the use of Coordinate Measuring Machines (CMM) has proved to be an excellent solution for this problem. In coordinate measuring technique, data in discrete form are collected from the surface of the measured object, and then they

are the basis for computer determination of dimensions of spatial shaped objects [5]. This technique uses the phenomenon, which for centuries has been used by artists, that is, it reduces the complex shape to the geometric primitives. CMM during the measuring process, locates the coordinates of measuring points and determines the relationship between them. On this basis, geometrical elements constituting the measured object are determined. Software cooperating with the machine, calculates information about the shape of different parts of the object using the collected coordinates (Fig. 1). It is clear that a perfect reconstruction of the measured contour is not possible because it would involve the measurement of an object in an infinite number of points. Therefore, the error of measurement performed on CMM should be understood as the difference between the actual shape of the object, and its substitute representation usually determined using Gauss least squares method. Foregoing errors can be reduced, for example by adopting appropriate measurement strategy (covering the surface of the object by equally distributed measuring points). Coordinate Measuring Technique and the related quality control process automation brings tangible benefits, such as speed and flexibility of measurement tasks.

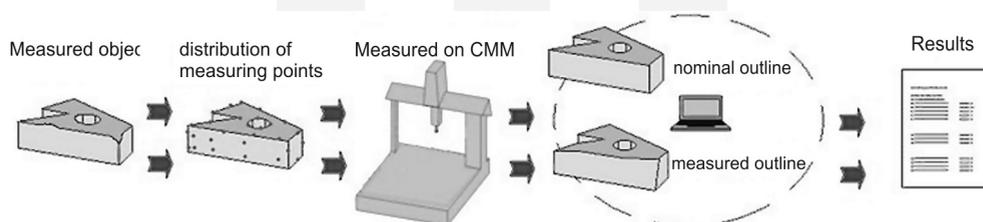


Fig. 1. The essence of coordinate metrology

Rys. 1. Istota metrologii współrzędnościowej

CMM is the most important tool in coordinate measurements. The kinematic pairs shift in mutually perpendicular directions, which determine the Cartesian axes  $X$ ,  $Y$ ,  $Z$  and define the machine measuring coordinate system. Motion between the measuring points identification system and actual measuring point on the surface of measured element is realized by sliding axle system, which movements are measured by standards of the length, and then the values are transferred to the computer and electronic control units. Gathering of measuring point coordinates is done by probe systems, contact or non-contact. This means that in the first case, the measurement is followed by the contact of the probe head with the measuring object, and in the second case, in different manner, for example using the light beam. There are several main programs which work with CMM. Geometric relationships between elements are calculated in them, they also carry out the transformations and constructions needed to determine the indirect dimensions, form errors, location and runout errors.

### 3. I++ Simulator used for machine programming and didactic purposes

I++ Working Group was founded in 1999, made up of representatives of various companies in the automotive industry. The main reason for the creation of the group was an attempt to unify metrology software and provide a platform for future cooperation and ideas exchange.

One of the group's achievements was the introduction of the universal protocol I++ DME, through which it is possible to communicate measuring machine with the majority of existing metrological programs. In practice, this protocol is associated with increased flexibility and machine operators independence from dedicated software, which often affords fewer opportunities, or simply is less comfortable. I++ Simulator also uses mentioned protocol making it possible to cooperate with the most common metrological programs (Quindos, PC-DMIS, Calypso, Modus).

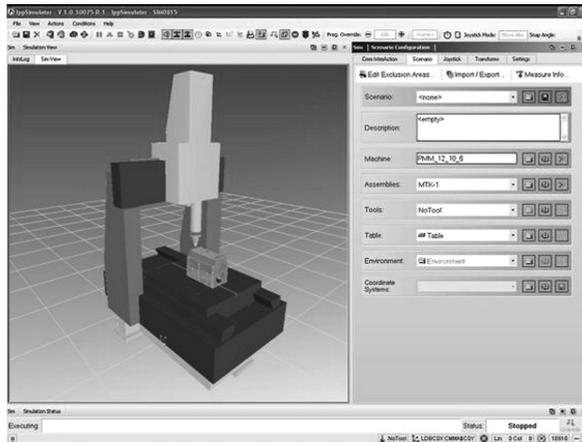


Fig. 2. CMM model loaded into the I++ Simulator

Rys. 2. Model WMP wczytany do programu I++ Simulator

At the beginning of simulation session, models of machine, magazines and probe heads with which the measurement will be carried out, have to be loaded (Fig. 2). Then functions assigned to each button of the gamepad, which is responsible for controlling the machine model, need to be defined. In the next step, the CAD model of the measured part is loaded. After turning on the metrological software, the rest of measurement is proceeded just like on the real machine.

The most convenient way to work with a simulator is using two monitors. One monitor displays the virtual model of the machine when the second one displays measurement software. For controlling the movements of the machine, the pads familiar to the controllers of game consoles are used. The control knobs are responsible for the movement of the machine model in  $X$ ,  $Y$ ,  $Z$ . Furthermore, the virtual machine can be controlled by programming it from the level of metrological applications. It is possible to simulate the measurement of both the manual and automatic mode. There is also camera control option, which allows to observe the machine movement as well as the measuring space. It helps to track the position of the object during the measurement. This makes the machine control becomes much simpler. The operator can also define custom views adapted to the needs, depending on the measurement task.

Extensive database of CMM models offered by leading companies in the industry was built-in the simulator. It is also possible to build unique model of machine using 3D modeling

software. So it can be stated, that the simulator makes it possible to simulate the activities of any existing machine. In addition, there is the option to add to the database models of styli, racks, fixing elements created by the user. The only requirement is to have a proper 3D model of the element.

The undeniable advantage of the simulator is the ability to create and test measurement programs. Although most of metrology software support off-line creation of programs, none of them gives opportunity to verify its correctness during real measurements (collisionless functioning) and thus each of the programs need to be corrected, if not written during the measurements [6]. Thanks to I++ Simulator, having the CAD model of the measured object, there is a possibility to write programs off-line, in “teaching” mode, that was not previously possible. An additional advantage is possibility of checking programs for possible collisions. This can be very useful when the measurement is difficult, for example due to the complex shape of the measured object. Obviously the program created and tested on the simulator can be implemented on a real machine.

Coordinate Measuring Machines are still evolving as well as the range of their applications. Today it can be used in both nano- and large-sized measurements. Still, in some cases programming of CMM using machine itself can be difficult or almost impossible. For example, in measurements of nano elements it is a common situation when one or more dimensions are not visible to the eye. In such circumstances vision systems are used to provide zoom on probe head, measured element and their position. However, this method is cumbersome and it is leaving an operator too much space for making mistakes which can result with damage of relatively expensive stylus. I++ simulator can be also useful when measurements are performed on a high-precision (accurate) measuring machines which work on strictly air-conditioned spaces. The presence of the operator in such room during the programming of CMM could cause an increase in temperature, which in turn could make it necessary to wait some time until conditions stabilize. Any pause during measurements is a waste of money and I++ simulator can be very helpful in preventing it in these situations. It is used in described way in Laboratory of Coordinate Metrology (LCM) which is equipped with one of the most modern air-conditioning systems, giving the thermal stabilization at



Fig. 3. Measurement programmed using I++ Simulator (left side) transferred and performed on PMM 12106 machine (right side)

Rys. 3. Pomiary zaprogramowane z wykorzystaniem programu I++ Simulator (po lewej stronie) przeniesione i uruchomione na maszynie PMM 12106 (po prawej stronie)

level of  $20 \pm 0,05^{\circ}\text{C}$ . The CMM programs are written using I++ Simulator and transferred into real machine (Fig. 3). In this situation, the operator activity in close proximity to the machine can be easily reduced only to the installation of the measured workpiece on the machine table. The costs of machine downtime are also reduced in this way.

Another important aspect of the working with the I++ Simulator which is worth mentioning is its didactic potential. Performing measurements in a virtual environment is a perfect opportunity to learn techniques and strategies used in the real measurements. The system is ideal not only for didactic process at the universities but also in the training of future CMM operators, the system which forgives their possible mistakes and enables their self-correction, without having to pay for imaginable damages. At Laboratory of Coordinate Metrology the system is used at CMT lessons (Fig. 4) giving possibility to work with CMM to all students simultaneously. Before installation of this system in computer laboratory at LCM the lessons of CMM programming were more like a presentation because only one real CMM were available. Through the work on the simulator, operator has direct contact with the CMM measurements in a realistic environment. He has the ability to self-configure workplace (probe head choice - scanning or touch-trigger, styli selection depending on the subject of measurement, configuration of racks, rotary tables, systems of object mounting, etc.) and to determine procedures assigned to the specified machine. Operator learns programming with the simulation of measurement taking into account its specific characteristic of the manufacturer with the possibility of the preparation of measurement programs based on the imported CAD objects prepared in any system and stored in different formats. After the development of measurement strategy the operator has the opportunity to review the decision of the real CMM measurements and the possibility of potential corrections such as a change of stylus approach paths after a collision in the simulator.



Fig. 4. CMM simulation laboratory in Laboratory of Coordinate Metrology

Rys. 4. Laboratorium symulacji pomiarów współrzędnościowych w LMW

Working with the simulator is not limited to a system composed of CMM, the measured object and the equipment but also allows to create the environment that affects the performing of measurement. It is possible to create an entire air-conditioned room with the real machine

and its appropriate equipment with elements such as storages or rotary tables (Fig. 5). Libraries implemented in the simulator are comprehensive enough to precisely reproduce the metrology lab room. In addition, if certain specific equipment is not available it is possible to self-define the missing equipment.

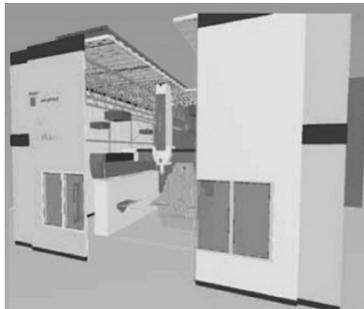


Fig. 5. Example of a real-world scenario with a large bridge CMM and air conditioned room [7]

Rys. 5. Przykład prawdziwego scenariusza z wielkogabarytową WMP w klimatyzowanym pomieszczeniu [7]

#### 4. I++ Simulator enhanced with the CMM accuracy model

The main disadvantage of Simulator is the rudimentary system of measurement accuracy reproduction. In its present form the program does not take into an account the real machine errors and errors introduced by probe head. Variability of the results obtained from measurement simulations depends only on inaccuracy of the creation of CAD models (limited resolution with which they could be saved in digital format) and the accuracy of the point acquisition parameter, which can be defined by user.

Therefore, in Laboratory of Coordinate Metrology at Cracow University of Technology a simulation model called Virtual MC PK was created [8]. It allows to simulate errors of real machines and measuring heads at I++ Simulator. This allows to create a completely virtual measurement system, which can be used to predict the coordinate measurement accuracy and to further research the accuracy of measuring machines under the simulation conditions. Operation of model in conjunction with the I++ Simulator aims in simulation of the residual errors introduced by the kinematics of the machine and probe head errors. As an input quantities it uses the coordinates of the measuring points (simulation of residual errors of kinematic system) and its approach vectors (simulation of probe head errors). The result is the point concluding real errors of simulated machine. In this case, the results of simulated measurements will not only be the random values sampled from the range defined by the user but they will become results containing accuracy of measurements, which can be obtained during measurements performed on the real machines. Model has passed through preliminary tests in the LCM, and proved its correctness for simple measuring tasks. Software created by combining the I++ Simulator and Virtual MC PK model will allow in near future to define optimal measurement strategy and optimal location of measured detail in measuring volume, so that the best possible measurement accuracy could be achieved.

## 5. Conclusions

Coordinate measuring technique is now an indispensable tool of production engineering, creating a basis of quality control systems. CMMs allow quick verification of an object compliance with geometric specifications contained in the technical documentation. Due to the high measurement accuracy and a wide range of possible applications, CMMs are becoming an increasingly popular solution. In some cases, the operator interaction with the machine during its programming may be difficult. In this situation, I++ Simulator can provide invaluable assistance. Basing on results of experiments performed so far, the probability of obtaining good results in programming of micro and nano coordinate measuring machines and machines of high precision using the I++ Simulator is considerably high.

The great advantage of I++ Simulator is also its ability to connect with majority of popular metrological systems by I++ protocol. It allows to program machines using a variety of metrological software types. In addition, Simulator I++ combined with functionality of these software becomes suitable tool used to train new operators of CMM without necessity of wearing out the real machines. Laboratories equipped with I++ Simulator stations are also extremely useful at universities, during machine programming and Coordinate Measuring Technique lessons, which could be confirmed by increasing number of installations at German universities and the feedback from students who state that the CMT lessons become now really interesting and helpful.

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