



DESIGN OF A CMM ACTUATION SYSTEM

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Abstract

The article deals with the design of a coordinate measuring machine (CMM) Somet Berox XYZ 464B actuation system. The goal was to transform an existing archaic CMM into a semiautomatic CMM driven by three stepper motors and controlled via the Arduino platform. Within the parametr of maintaining precision, it was not possible to make holes or perform other machining operations on the frame of the CMM. Only existing holes and clamping elements were acceptable to use to modify the machine. The existing holes remained after the disassembly of the old and unnecessary magnetic belt clutches.

Key words: coordinate measuring machine; CMM, actuation design; Arduino; metrology; low-cost.

INTRODUCTION

Nowadays, when the demands on precision, quality and accuracy of produced parts are ever higher, continuous improvement, upgrading and acceleration of CMMs is necessary (Vermeulen, et al., 1998; Kunzmann & Wäldele, 1988). State of the art CMMs can almost eliminate fails which arise from human factor. These fails are inherent in large volume in measurement results (Melichar et al., 2016).

CMM Somet Berox was fully movable only by human power. There was a high percentage of fails deriving from human factor. For this reason the idea of modernizing this CMM located on the department of manufacturing systems and automation on the Technical University of Liberec emerged. A Czech CMM Somet Berox XYZ 464B was used for this purpose of rebuild. His typical bridge structure excelled particularly with quill structure and with the system of magnetic clutch used for micro movement. The aim of this article was to rebuild the actuation system of an old CMM Somet Berox, in compliance with today's required standards of accuracy and at low-cost (Hadač, 2017).

MATERIALS AND METHODS

The decision regarding which new type of positioning system should be used was the initial stage of developing this rebuild. Two variants were considered: Variant A - using three stepper motors controlled by the Arduino platform - low-coast modernization, and variant B - using a commercial system and with DC servomotors and commercial control system from Pantec/Deva company. The decision was made using the multi-criteria evaluation of variants employing the points method (Metfessel's alokation). The more appropriate variant A, realization with three stepper motors, was chosen as the result of these evaluation methods.

A mechanical belt drive was used for the power transfer between the stepper motors and the movement devices. The following mathematic formulas (1) (2), were used to determine the toothed timing belt (Pešík, 2010).

$$\frac{\beta}{2} = \arcsin \frac{D_{w2} - D_{w1}}{2a} \quad (1)$$

where β is the belt contact angle (rad), D_w is the pulley diameter (m), a is the toothed pulleys center distance (m).

$$L = \pi \frac{D_{w1} + D_{w2}}{2} + \frac{D_{w1} - D_{w2}}{2} \beta + 2a \cos \frac{\beta}{2} \quad (2)$$

where D_w is the pulley diameter (m), β is the belt contact angle (rad), a is the toothed pulleys center distance (m).

Design of the clamping elements for axis XYZ

Stepper motor clamping elements for axes X, Z and Y positioning were among the first parts to be designed shown in Fig. 1 and Fig. 2. These parts were drafted using Autodesk Inventor CAD software and subsequently were cut on a CNC laser cutting machine. All elements were designed considering the current holes and spaces which remained after the disassembly of unnecessary parts from the original CMM. Due to insufficient space on the CMM, methods such as design for manufacturing (DFM) and design for assembling (DFA), were used in the designing of the elements.

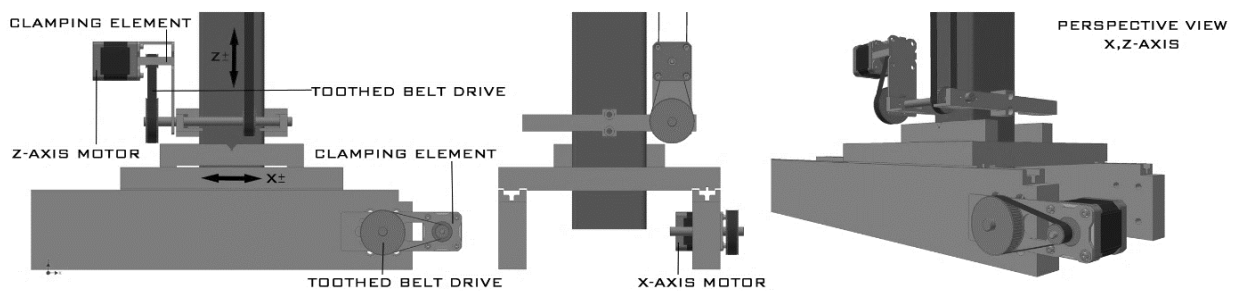


Fig. 1 3D model of X- axis and Z - axis CMM parts

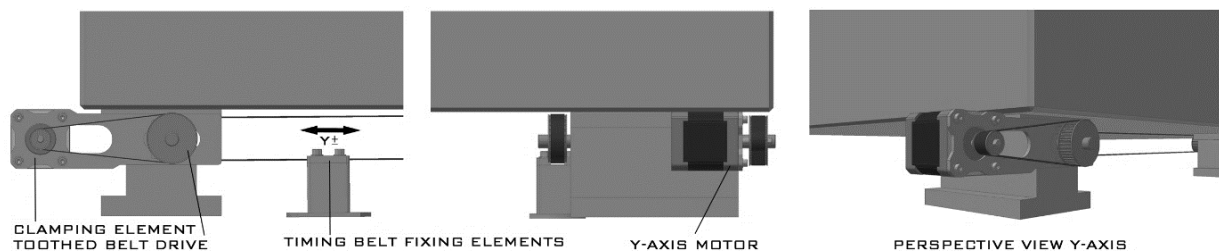


Fig. 2 3D model of Y-axis CMM parts

Arduino hardware connection

Commercially purchased low-coast Arduino platform components were used for this project. The Arduino platform began to emerge in 2005 at Ivrea Institute in Italy as a student project. Arduino motherboards are available for all of the different operation systems, along with a large amount of relevant training information and an intuitive interface IDE (Integrated Development Enviroment), making Arudino a widely-used and very popular platform all over the world (*Candelas et al., 2015*).

The connected of Arduino components shown in Fig. 3.

The list of components used:

- **The microcontroller board Arduino AtMega 2560** - this board is designed for 54 digital input, which is enough for connection to all components.
- **Expanding 3D CNC Shield V3 Printer Expansion Board** - which is especially usable for 3D printers. There exists a large similarity between 3D printers and CMMs and for this reason this expandable board was used for this project as well.
- **Three Arduino motor drivers DRV8825 with microstepping** - these drivers are intended for bipolar stepper motors operating from 8,2V to 45V and can deliver maximal 2,2A with additional cooling. These drivers can be expanded by microstep elements with 1/32 step resolution.



- **Two joysticks PS2** - the first is for controlling motors in X and Y axes, and the second for controlling the motor in the Z-axis.

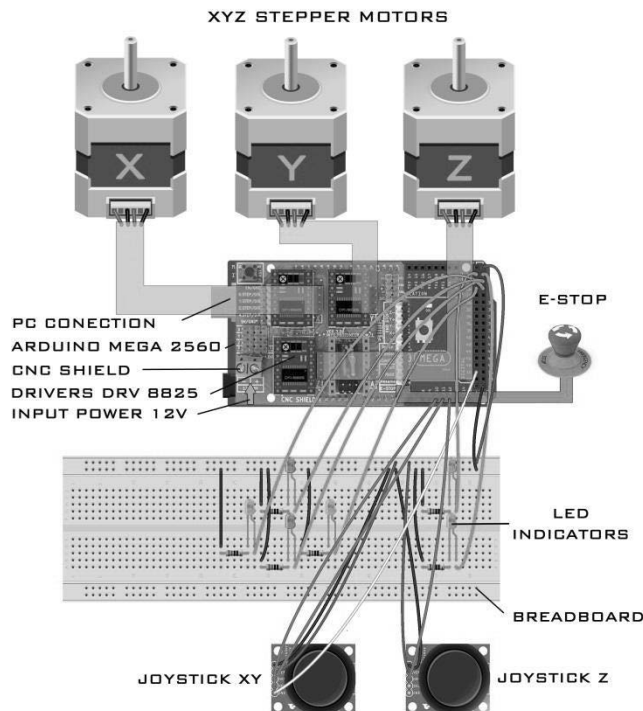


Fig. 3 Connected of Arduino components

Arduino control code to coordinate actual joysticks movements with motors rotations was written in the first step of programming. Three variants for controlling the CMM were considered:

- Var. A – Motor rotation depending on the angle of joystick rotation
- Var. B – Motor rotation depending on pressing of the joystick and adjusting the present speed
- Var. C – A combination of variants A and B.

Variant C was chosen as the most suitable for this rebuild. The reason was simple: the inexperienced personnel will work with the CMM, and the sensitivity of the low-cost joysticks is not sufficient. The potentiometers inside the joysticks are not capable of linear movement during manipulation. It seems clear that potentiometers with linear movement abilities would be more advantageous for this kind of application.

RESULTS AND DISCUSSION

Fig.4 shows the realization of the upgraded CMM with clamped elements mounted, Arduino hardware, toothed pulleys, toothed belts, stepper motor, electric wires and fasteners fully assembled.

The acquisition costs (less than 290€) for the components purchased prove that one of the main aims of this article the low-cost CMM upgrade was achieved. The final price is up to 50 times lower than professional two or three-axes actuators.

Subsequent to this article, there are some future upgrades to recommend on this CMM Somet Berox, which could lead to streamlining of the work processes.

An upgrade of the Arduino control code is especially recommended which will make it possible to work with CMM in a fully automatic mode. This recommended upgrade in cooperation with an optimal algorithm and correct sampling strategy definition could chiefly lead to reduction of a measurement cycle time for CMM that can enhance efficiency of inspection process (*Mian & Al-Ahmari, 2014; Moroni & Petro, 2011*).

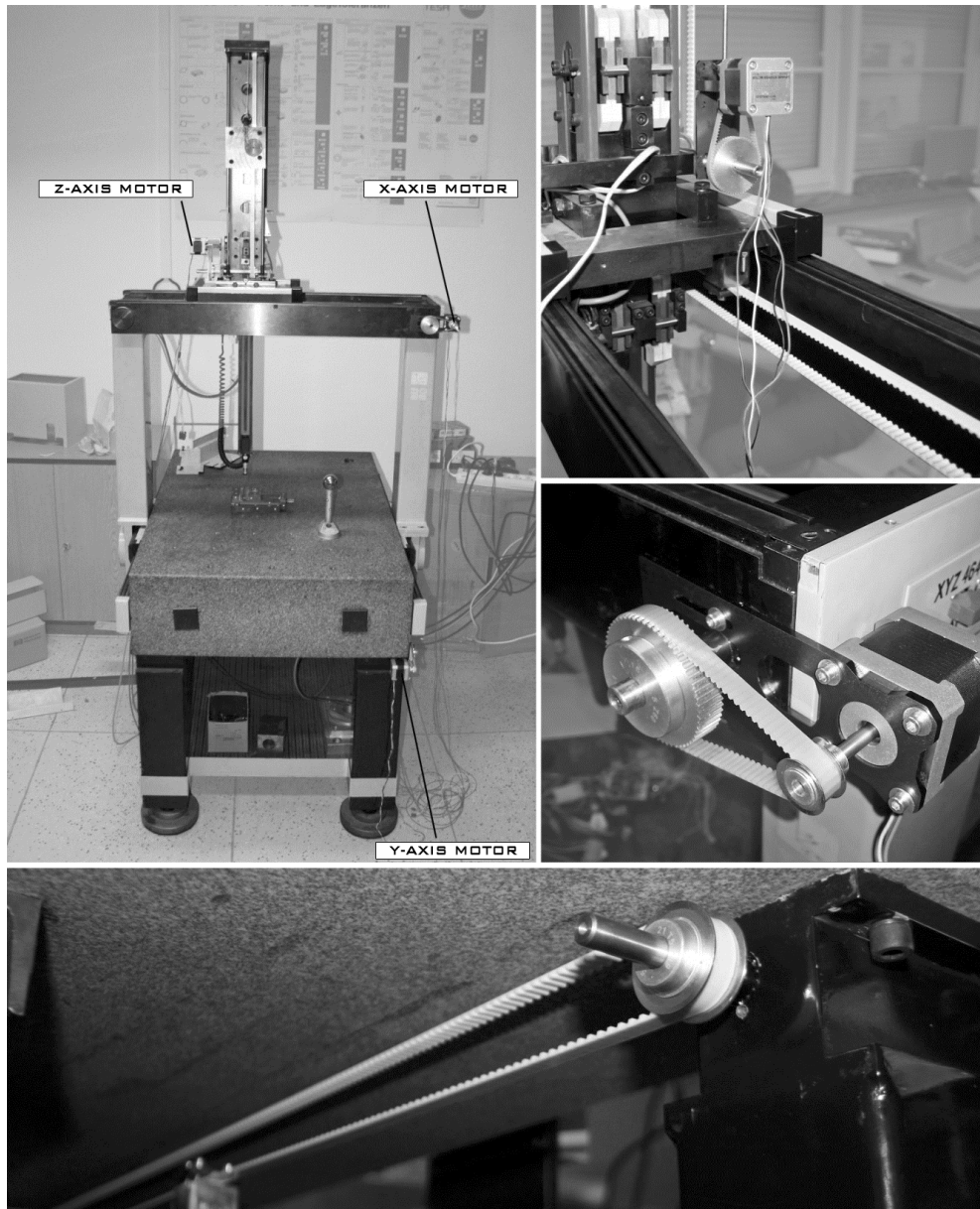


Fig. 4 Final realization of the CMM

A second upgrade regards the connection between touch probe signals and stepper motor signals by which the safety of CMM components will be ensured.

Should these recommended modifications of the CMM Somet Berox be realized, the speed increase, safety, accuracy, general modernization and technical approach to modern CMM of this originally manual CMM will be achieved (*Hocken, 2016*).

At the end of the rebuild measurements was carried out. For this a reason simplified model to estimate uncertainty in CMM could be very beneficial in some cases as reported by (*Arencibia et al., 2015*) but for our project gauge blocks were used for the verification of accuracy of the measured dimensions. Fig.5 shows the measured values for the 80 and 100 mm gauge blocks. (*Bosch, 1995*). Software Tango!3D from Topmes company was used for the verification of the measurements. This software was integrated with the CMM Somet Berox in previous modification. As can be seen, there are no deviations from nominal values of the steel gauge blocks. The results of the measurements with acceptable variations of $\pm 0,01$ mm from the nominal values are affected with several sources of CMMs error such as errors from the axes of the CMM, errors from the probing system etc. (*Nafi, 2011*). Verified by these measurements it can be said, that the rebuild of the CMM Somet Berox was completely successful. (*Hadač, 2017*).






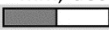

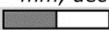

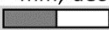
	Actual	Nominal	Hi-Tol	Lo-Tol	Difference	Error	Graph
Distance Plane1,Plane2							mm, dec
 99.99	100.00	0.01	-0.01	-0.01			
Distance Plane5,Plane6							mm, dec
 79.99	80.00	0.01	-0.01	-0.01			
	Actual	Nominal	Hi-Tol	Lo-Tol	Difference	Error	Graph
Distance Plane4,Plane5							mm, dec
 80.01	80.00	0.01	-0.01	0.01			
Distance Planeyz,Plane3							mm, dec
 100.01	100.00	0.01	-0.01	0.01			

Fig. 5 Output from Tango!3D measurement software - Measurement of the gauge blocks

By comparing CMM Somet Berox linear measuring tolerance $MPE_E = \pm (7+L/100)$ (μm) where L is a measured length given in (mm), with modern studies of CMM - $MPE_E = \pm (4.5 + L/100)$ and better) (Sladek, 2016) suggests that the machine is unable to compete with modern CMMs, but is still sufficient for teaching and occasional measurement purposes.

CONCLUSIONS

The main research effort in this article was the exploring of low-cost modernizing possibilities for a 3-axis machine (CMM) and its transformation via open-platform Arduino controlling.

The complete realization of the selected variant included measuring, concept design of stepper motors and their holding elements in Autodesk Inventor software, cutting the holding elements on a CNC machine, purchasing all necessary components, disassembling all unnecessary elements, writing Arduino control code, connecting all electronic components, assembling all new components, and finally testing functionality of the whole system. The result of the project was a low-cost modernization, fully functional, readily modifiable, semiautomatic CMM, moved by stepper motors and controlled by the Arduino platform using a pair of joysticks.

ACKNOWLEDGMENT

This publication was written at the Technical University of Liberec as part of the project "Innovation of the products, equipments and processes in engineering practice" with the support of the Specific University Research Grant, as provided by the Ministry of Education, Youth and Sports of the Czech Republic in the year 2019.

REFERENCES

1. Arencibia, R., V., Souza, C.C., Costa, H.L. & Piratelli-Filho, A. (2015). Simplified model to estimate uncertainty in CMM. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*. 37(1), 411-421.
2. Bosch, J. A. (1995). *Coordinate measuring machines and systems*. New York: M. Dekker.
3. Candelas, F.A., García, G.J., Puente, S., Pomares, J., Jara, C.A., Pérez, J., Mira D. & Torres F. (2015). Experiences on using Arduino for laboratory experiments of Automatic Control and Robotics. *IFAC-PapersOnLine*, 48(29), 105-110.
4. Hadač, O. (2017). Design of the CMM Somet Berox propulsion systém (in Czech) [Master thesis]. Technical university of Liberec, Faculty of Mechanical engineering, Department of manufacturing systems and automation.
5. Hocken, R.J. & PEREIRA, P.H. (2016). *Coordinate Measuring Machines and Systems*. CRC Press. DOI: 10.1201/b11022. ISBN 9780429114229.
6. Kunzmann, H. & Wäldele, F. (1988). Performance of CMMs. *CIRP Annals*. 37(2), pp. 633-640.
7. Melichar, M., Kubatova, D. & Kutlwaser, J. (2016). CMM Measuring Cycle and Human Factor. *Proceedings of the 27th International DAAAM Symposium 2016. DAAAM International Vienna* (pp. 0371-0376).



8. Mian, H.S. & Al-Ahmari, A. Enhance performance of inspection process on Coordinate Measuring Machine. (2014). *Measurement* 47, 78-91.
9. Moroni, G. & Petro, S. (2011). Coordinate Measuring Machine Measurement Planning. In *Geometric Tolerances* (pp.111-158). London: Springer London.
10. Nafi, A., Mayer, J.R.R. & Wozniak, A. (2011). Novel CMM-based implementation of the multi-step method for the separation of machine and probe errors. *Precision Engineering*. 35(2), 318-328.
11. Pešík, L. (2010). *Machine elements* (in Czech). Liberec: Technical university of Liberec. ISBN 978-80-7372-574-7.
12. Sładek, J.A. (2016). Accuracy of Modern Coordinate Measuring Systems. *Coordinate Metrology*. In *Springer Tracts in Mechanical Engineering* (pp. 337-382). Berlin, Heidelberg: Springer. DOI: 10.1007/978-3-662-48465-4_6. ISBN 978-3-662-48463-0.
13. Vermeulen, M.M.P.A., Rosielle, P.C.J.N. & Schellekens, P.H.J. (1998). Design of a high-precision 3D-coordinate measuring machine. Eindhoven University of Technology, Precision Engineering Section.

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