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SIX-AXIS CONTROL JOYSTICK BASED ON TENSOMETRIC BEAM

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S u m m a r y

Manual programming of machine tools is realized by buttons located on control panels. Currently used tools allow simultaneous movement in only one axis of the machine resulting in inefficient and unintuitive motion control. In robotics special teaching programing is used which allows the robot to memorize the coordinates and orientations during providing an effector according to defined trajectory. It is necessary to develop a multi-axis sensor with a high rigidity in order to control machines. It could allow control over the movement of group components according to the intention of the operator. This article presents the control system, which takes into account the six-axis control joystick. The paper is focused on joystick design, as well as the calibration procedure.

Keywords: dynamometer, manual control, strain gauge beam, multi-axis force sensor, strain gauge sensor

Sześcioosiowa manetka sterująca zbudowana na belkach tensometrycznych

S t r e s z c z e n i e

Programowanie manualne maszyn technologicznych jest realizowane poprzez przyciski umiejscowione na panelach operatorskich. Stosowane narzędzia umożliwiają jednoczesny ruch tylko jedną osią maszyny. Skutkuje to nieefektywnym i nieintuicyjnym sterowaniem jej ruchem. Obecnie w robotyce stosowane jest programowanie przez nauczanie za pomocą manualnego prowadzenia robota po trajektorii i wprowadzanie współrzędnych punków trajektorii do pamięci. Do sterowania maszyną konieczne jest opracowanie wieloosiowego sensora o dużej sztywności. Umożliwi to kontrolę ruchu zespołów maszyny zgodnie z intencją operatora. W pracy przedstawiono system kontroli, który uwzględnia manetkę sześcioosiową. Przedstawiono także proces projektowania oraz kalibracji urządzenia.

Słowa kluczowe: dynamometr, manualne sterowanie, belka tensometryczna, wieloosiowy sensor siły, czujnik tensometryczny

1. Introduction

Computerized Numerical Control (CNC) machine tools are widely developed. Graphic presentation of machining program simulation has become a standard but machines are still programmed on-line with so-called G-code [1]. Interesting method of programming robot motion used in industry is programing

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robot by teaching it the selected points of the trajectory. Manually moving machine component requires the convenient and efficient movement adjuster such as, for example, joystick [2]. Modern machine tools can be manually controlled by appropriate functions and buttons on operator panel. This method of control is inconvenient, therefore often a mobile remote control connected to the machine by a flexible cable is used (Fig. 1). That remote control enables manual control when operator is near to the workspace. The main disadvantage of this control system is the possibility of changing only one axle position at the one moment. Due to this fact, remote control method has great limitations in manual programming.

Fig. 1. Remote control used in milling machine

To apply the method of manual position control in order to displace CNC machine components it is necessary to develop a suitable joystick for machine control. Osypiuk in his publication presents machines force / position control system [3]. Our idea of the CNC plasma cutter controlling is shown in Fig. 2.

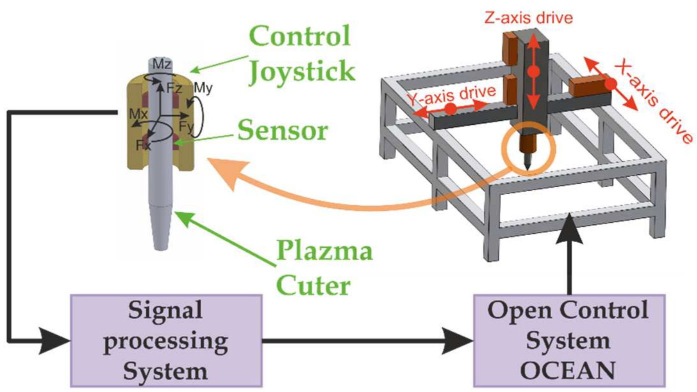

Fig. 2. Scheme of control unit with six-axis joystick

According to Fig. 2, manual control of the machine by the operator is done using a six-axis sensor attached to the end effector. A manual control of the machine drives is implemented by using the sensor coupled to the CNC control system. Several solutions of sensor systems allowing an effective multi-axis machine control were presented in literature. Sensors are based on: tensometric beam designed in the form of a cross [4, 5], optic sensors [6] or fully pre-stressed dual-layer six-axis force/torque sensor based on a modified Stewart platform architecture [7].

2. Design concept of six-axis sensor

As a result of studies conducted over the manual programming system of machines we proposed a sensor consists of 12 beams with strain gauges. Designed sensor has the shape of three-armed star. Conception of sensor's shape and location of strain gauges is presented on Fig. 3.

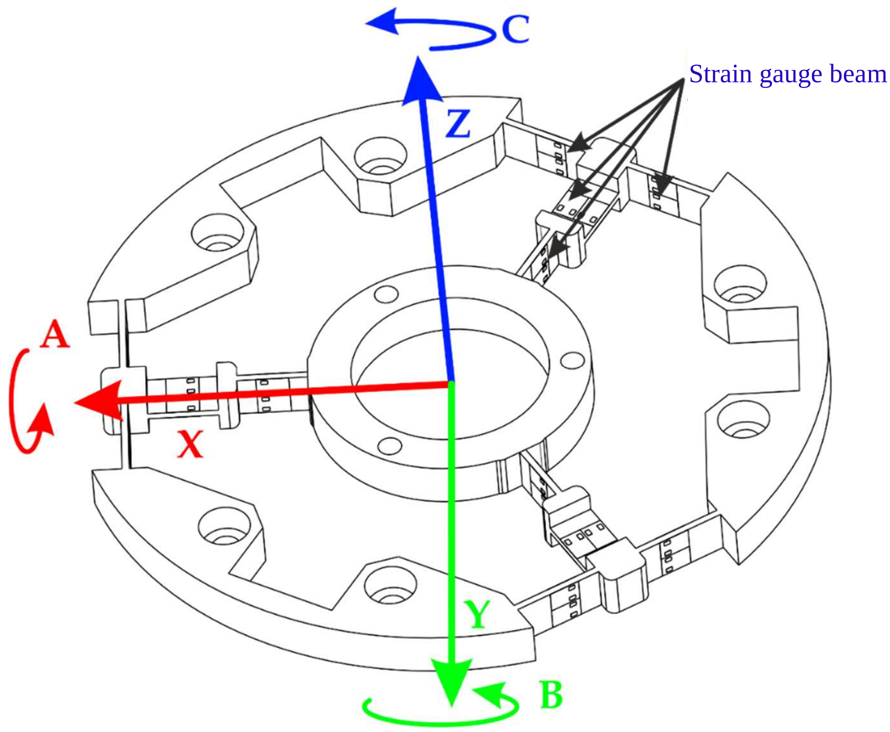

Fig. 3. The construction of designed six-axis sensor and reference system

This structure was designed and simulated in SolidWorks. The dimensions and shape of the sensor have been optimized in order to maximize the deformation of tensometric beams in certain directions. The joystick was designed for the following ranges of forces/torques of interaction with an operator, which are shown in Table 1.

Table. 1. Ranges forces/torques measurement

Interaction	**Range**	
	Max force/torque	**Min force/torque**
Translation X	500	-500
Translation Y	500	-500
Translation Z	500	-500
Rotation A	100	-100
Rotation B	100	-100
Rotation C	100	-100

Geometrical model was divided into finite elements and immobilized with three contact surfaces. The various range of load was applied to the inner ring (Fig. 4).

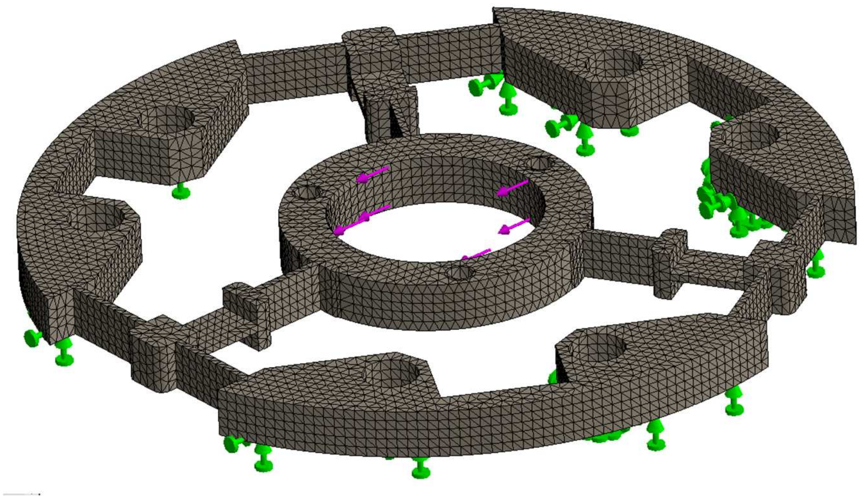

Fig. 4. Discretization of the six-axis sensor with

We carried out a series of simulations taking into account different load values in order to predict the behavior of the sensor during normal operation. The aim of the performed simulations was also to determine the distribution of stresses in the respective beams. Based on the stresses distribution, control procedures of the joystick designate the value and the direction of the forces and torques acting on the sensor. From the interaction force/torque of operator with the joystick, the moving velocity signal of specified drive axes was generated. Some simulation results are presented in Fig. 5-7. The Figures 5, 6 and 7 show the distribution of stresses in designed sensor, created by the action of forces in the *x*, *y* and *z* direction, respectively.

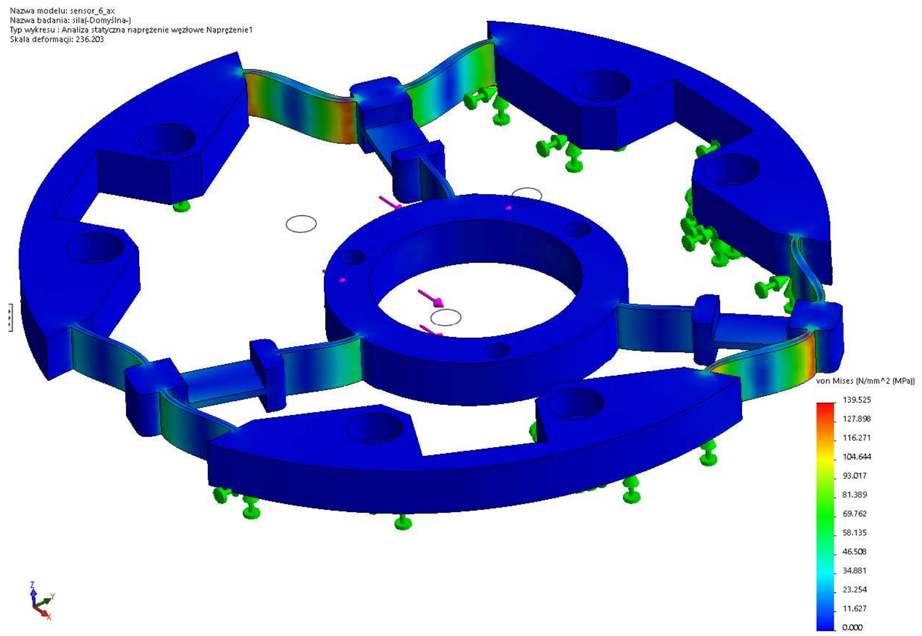

Fig. 5. The distribution of stresses with force load –150 N on direction X

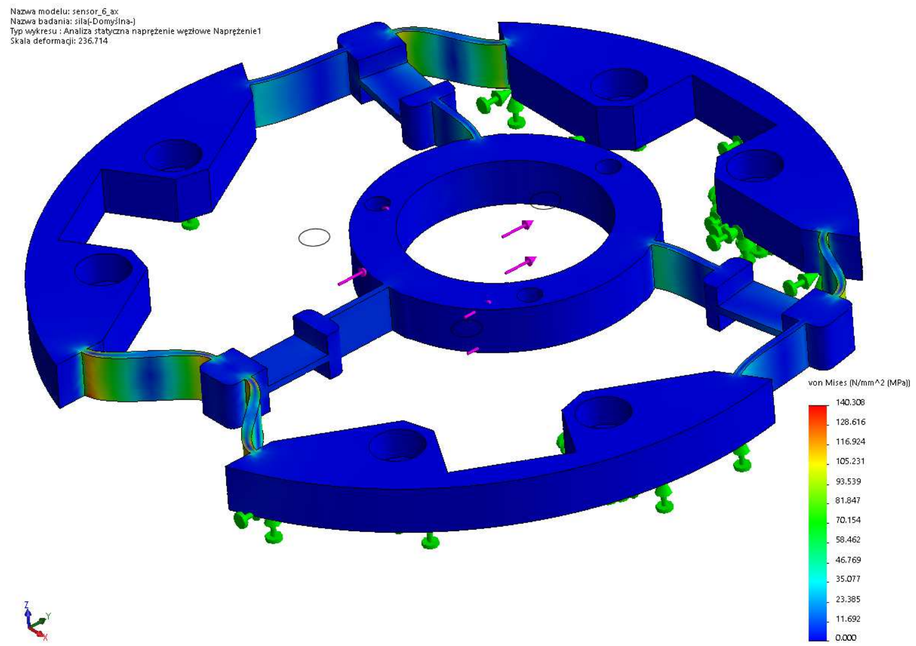

Fig. 6. The distribution of stresses with force load –150 N on direction Y

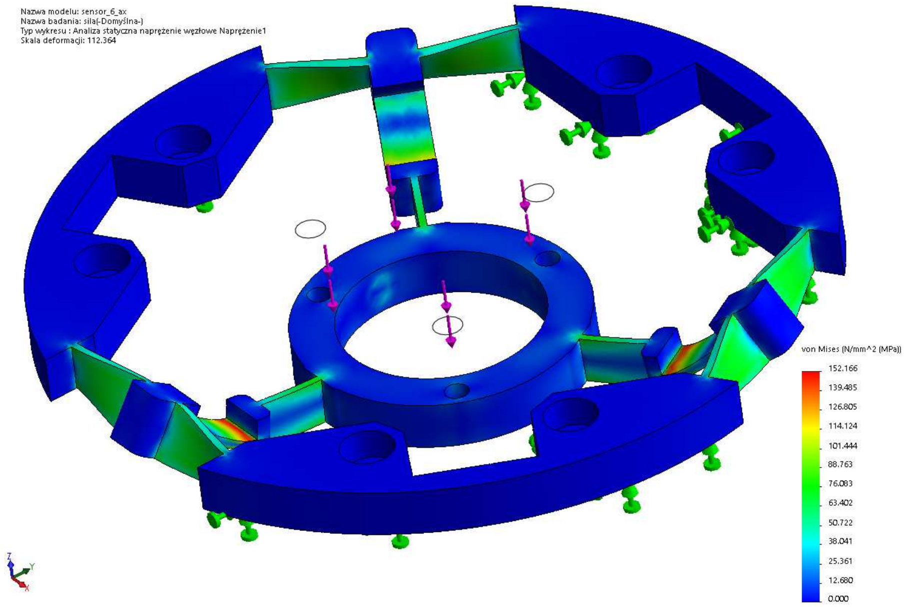

Fig. 7. The distribution of stresses with force load –150 N on direction Z

3. Experimental test and calibration

The program of experimental research has been developed. It included the calibration of the measurement system and the functionality tests of the designed multi-axis sensor. The calibration phase was carried out on specially prepared experimental stand (see Fig. 8).

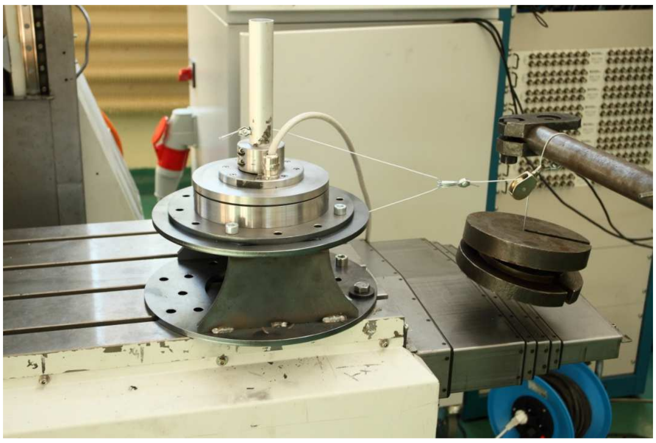

Fig. 8. The experimental stand for calibration of the joystick measurement system

It makes possible to load the sensor of joystick in a strictly defined direction. According to the plan of the experiment, in individual measurement sessions, the joystick was loaded with the forces and torques operating in the different directions of the Cartesian reference system. The system was loaded in sequence with weights of mass 5, 10, 15, 20 kg, operating in both sides (positive and negative) of the given direction in order to calibrate the measurement system. In Figure 9 the results of the sample measurements are depicted. In this case the measurement were conducted on strain gauges adhered to the 6 previously selected beams for Y direction force. We obtained the linear dependence of registered voltage of tensometric bridge as a function of loading force, as it is shown in Fig. 9. Comparing the simulation results described in section 2 with the obtained characteristics of voltage as a function of load, we made the calibration of the joystick measurement system. After performing the calibration, we can determine the value and direction of force relative to the reference Cartesian system.

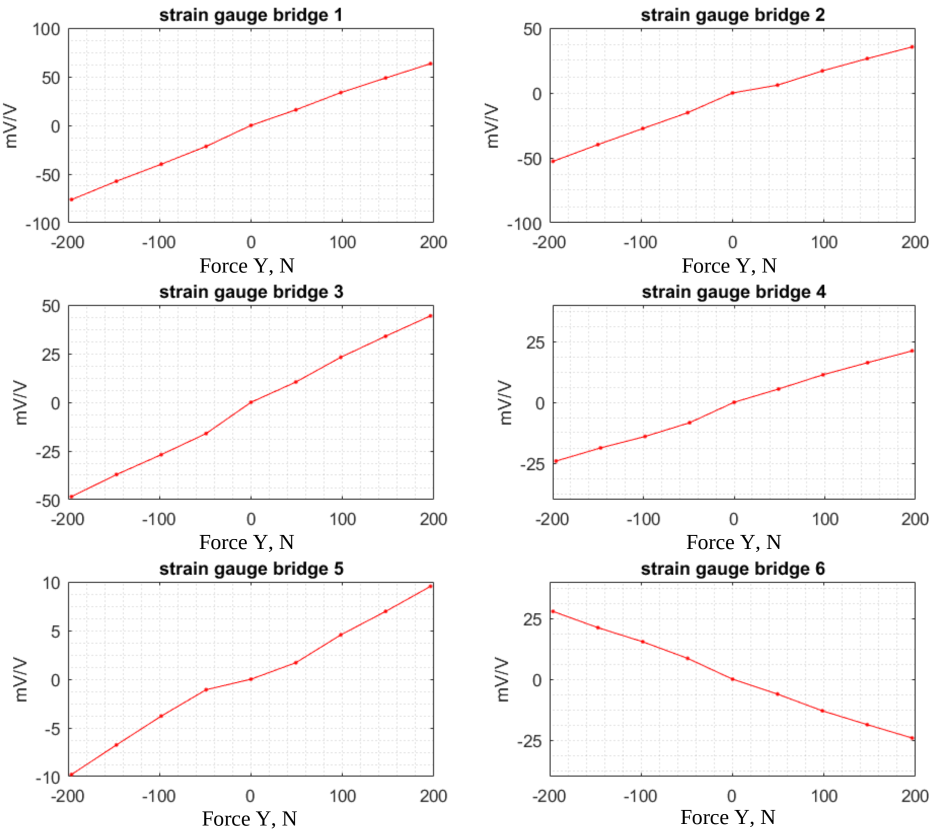

Fig. 9. Result of measured tensometric bridge voltage as a function of loading force in Y direction

With calibrated system it was possible to connect the joystick to the CNC control system and provide functional tests of the machine operation. All functional tests were performed on the three – axis CNC machine with an additional rotary table constituting the fourth axis. The sensor has been connected to the open control system called OCEAN using NI PXI. OCEAN is a CNC system for supervising the movement of the machine, whereas the NI PXI is an interface device used for filtering and converting the measurement force signals into the signal of machine movement velocities. During the functional tests we have regulated the gains of measured force signals to get possible the highest dynamic of the machine movement, while also maintaining also the quality of this motion (Fig. 10). Defining large gains of the force signals, we observed a fast loss of stability of the system: operator – joystick – CNC machine. The operator arm could not keep up with the machine movement and the machine components fell into the oscillatory motion opposing the operator actions. Finally, the amplitude of the machine oscillation increased, resulting in a large degradation of the machine movement quality.

Fig. 10 Designed joystick connected to CNC machine during functional test performed by operator

4. Conclusions

Based on the performed research it can be concluded that the designed multi-axis joystick is an effective tool for manual machine control. However, during the functional tests we have noticed the disadvantages of the presented control system. The sensor is a very sensitive device which does not allow the operator to move machine components in a previously specified direction using only one machine drive. While pressing the joystick in a particular direction, the operator encountered a difficulty in controlling the rotary axes, because he always performed some residual moments, which resulted in a small rotary end effector movements.

Designed sensor may be utilized without described problems in device having the serial kinematic structure with rotary kinematical pairs e.g. industrial robots. In this type of robots the operator arbitrarily moves the end effector without any reference axis. During the operation with machine tools, which have a kinematic structure based on three orthogonal linear axes and two rotary axes, the operator may feel some discomfort trying to move the machine in only one linear axis. For this type of machines it is suggested to temporarily block the drivers of axes which the movement is undesirable. The second solution of the stated problem is to separate the control of the rotary and linear axes.

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