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CONTROL SYSTEM OF DELTA MANIPULATOR WITH PNEUMATIC ARTIFICIAL MUSCLES

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Abstract: *A project of control system and electro-pneumatic delta manipulator of three degrees of freedom with pneumatic muscle actuators was presented in this paper. Due to the features of the drives applied, the manipulator is characterised by quick action, smooth start and stop, high overload capacity as well as a great number of operating cycles in relation to traditional pneumatic cylinders. A standard PID controller was applied in the control system. The process of tuning PID controller with Ziegler-Nichols method that is based on the evaluation of the system, which is on the verge of stability, was presented herein. An analysis the quality of control for the suggested controller was conducted and the results of experimental research of positioning the effector of the delta manipulator are included as well.*

Keywords: pneumatic muscle actuator, electro-pneumatic manipulator, delta manipulator, PID controller, performance criteria.

1. Introduction

Manipulators and industrial robots with pneumatic drives are applied mainly in the processes of assembling, packing or palletizing (Miko & Nowakowski, 2012a, 2012b). The pneumatic actuators provide sufficiently large operating dynamics, however, they do not provide high positioning accuracy (Takosoglu et al., 2009). It results directly from the functional properties of pneumatic actuators and the working medium, namely compressed air. Friction force in the pneumatic actuators, which introduces huge nonlinearities (S. Blasiak et al., 2013; S. Blasiak et al., 2014a; S. Blasiak & Pawinska, 2015; S. Blasiak, 2015) and thus, prevents obtaining more precise and detailed motions with full trajectory control (Koruba et al. 2010; Krzysztofik & Koruba, 2012), constitutes an additional problem. Pneumatic manipulators are designed mainly as systems with serial kinematics. Rigidity of the structure is the decisive factor that influences the positioning accuracy of the manipulators. Serial kinematic structures of robots and manipulators, in which drive axes are mounted on each other, become deformed under the influence of load masses as well as the weight of the drives themselves. It might lead to a situation, when the deformities are cumulated at the end of the kinematic chain and thus, the positioning accuracy deteriorates. The analysis of the simulative and experimental research of multi-axis pneumatic manipulators with the Cartesian coordinate system revealed that the positioning accuracy of the effector is several times smaller than of a single drive axis. Kinematic structure, thanks to which construction and drives deformities might be decreased, is based on a closed kinematic chain – parallel structure (Laski et al., 2015).

2. Control system

The control system of delta manipulator with pneumatic muscle actuators (Laski, et al., 2014) was built on the basis of the diagram presented in Fig. 1a. Fig. 1b presents the general view of the manipulator. For building the control system the following elements were applied:

- artificial pneumatic muscles DMSP-10-300, diameter of 10 mm and length of 300 mm (Festo),

- piezoelectric proportional pressure valves tecno plus PRE-U2-00-11-21, pressure 0-10 bar, flow up to 1600l/min., voltage controlled 0-10 V (Parker Origa),

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- angle encoders MAB36A, 12-bit, rotation angle of 360°, analog output 0-10V (Megatron),

- real time system for rapid control prototyping and hardware in the loop simulation *xPC Target* (MathWorks),

- laboratory computer system with 16-bit AC and CA cards *education real-time target machine* (Speedgoat).

Control of pneumatic muscles consists in changing the pressured air inside the muscle. That is why, piezoelectric proportional pressure valves were applied to control. The valves used in the control system are equipped with the system of electronic control of the outlet pressure (S. Blasiak et al., 2014b; Takosoglu et al., 2014) and thus, they automatically compensate the overload of working platform of the manipulator, e.g. in case of sudden hit or collision of the platform with an obstacle. The piezoelectric method applied in the valves provides very high dynamics (M. Blasiak & Kotowski, 2009) with a minimum energy consumption (max. power 0,8 W). Thanks to such solution, battery or accumulator power (Nadolski & Ludwinek, 2012) of valves is possible.

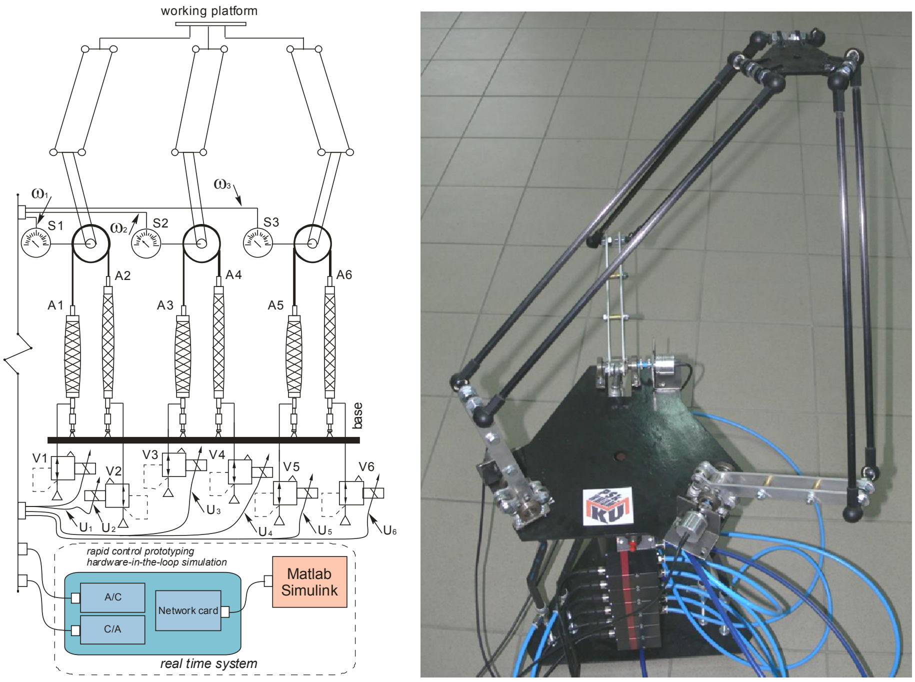

Fig. 1: Diagram of control system a): A – pneumatic muscles, S – angle sensors, V – proportional pressure valves, ω – feedback signal, U – control signal, General view of delta manipulator b)

A typical PID controller was used for controlling the proportional pressure valves. In the control system, three identical PID controllers were used due to the necessity to control three drive axes of the manipulator. The process of tuning PID controller was conducted with Ziegler-Nichols method that is based on the evaluation of the system, which is on the verge of stability (Farana et al., 2014). This method is applied in systems, where it is possible to find some gain, when Nyquist diagram intersects the tipping point or when the first root line intersects the axis of imaginary numbers. Such gain, defined as critical gain might be determined in an experimental way. In the control system, PID controller should be set only for proportional action (action I and D should be turned off), and the gain in action P should be gradually increased until oscillations of constant amplitude appear in the output. The point obtained in that way corresponds to the critical gain kp_{kr} and oscillations with the period T_{OSC}. In some practical applications, such operation might be very dangerous. The control system of the delta manipulator was brought to the verge of stability and the parameters of critical gain kp_{kr}=3.69 and the oscillation period T_{OSC}=0.2 sec. were determined. PID parameters were conducted by means of Ziegler-Nichols tuning rules.

The implementation of PID controller was conducted on the basis of real time system (Wisniewski & Plonecki, 2015) xPC Target of set Matlab/Simulink as well as the laboratory computer system education real-time target machine, taking advantage of the method of rapid control prototyping. The input signals from angle encoders were attached to AC cards, and the output signals from CA cards that were generated on the basis of the control algorithm PID were connected to proportional pressure valves controlling the pneumatic muscles. The control system works in real time with the sampling time of 0.001 sec.

3. Experimental research

The aim of the experimental research was to determine the accuracy and repeatability of positioning of the effector's manipulator in a closed loop with PID controller for particular mass loads. Studies with mass load of the operating platform of the manipulator of 0-3.6 kg, being changed every 0.2 kg, were conducted. Fig. 2a presents dynamic characteristics of first axis of the angular displacement of the manipulator arm for four chosen load masses of a working platform. The studies were conducted for the movement of the manipulator platform along the axis Z. That is why, the remaining two arms make the same movement (Trochimczuk, 2013). The trajectories of manipulator platform for the movement along the axis Z in Cartesian space (Gapinski et al., 2014; Krzysztofik, 2012) for 3 chosen load masses were presented in Fig. 2b.

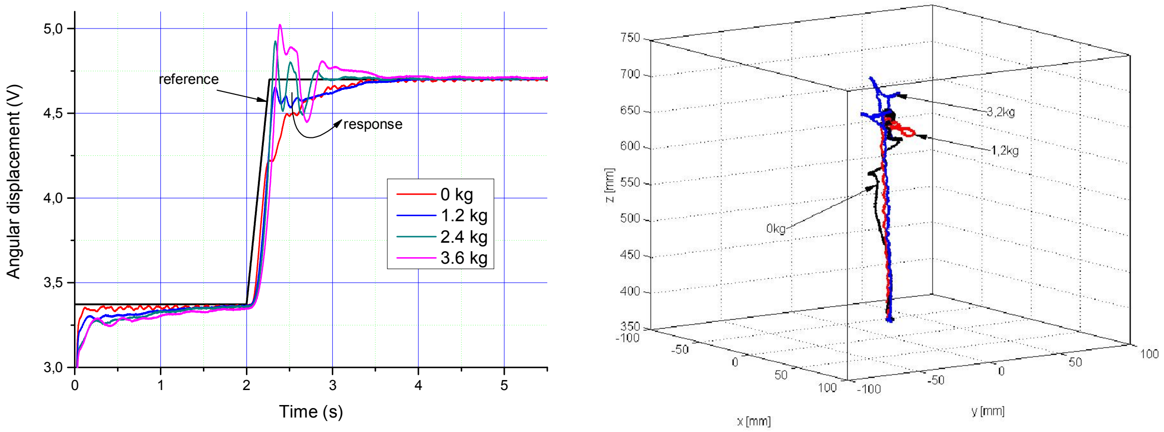

Fig 2: Dynamic characteristics a), Trajectories of manipulator platform b)

An analysis the quality of control in the function of mass load of the working platform was conducted. Fig. 3a presents the results of the experimental research of overshoot, whereas Fig. 3b contains the results of the integral quality indicator ISE (Integral of Squared Error) (Takosoglu et al., 2012).

4. Conclusions

Taking the achieved results into consideration, it was concluded that the manipulator operates well towards load mass of max. 3.6 kg. The positioning accuracy decreases as the load mass of the working platform of the manipulator increases. The integral indicator ISE shows that small load mass influencing the working platform of 0.2-1.4 kg is the most precise in terms of positioning (smaller indicator). In connection with this, the manipulator will operate very well with effector with the weight of 0.2-1.4 kg.

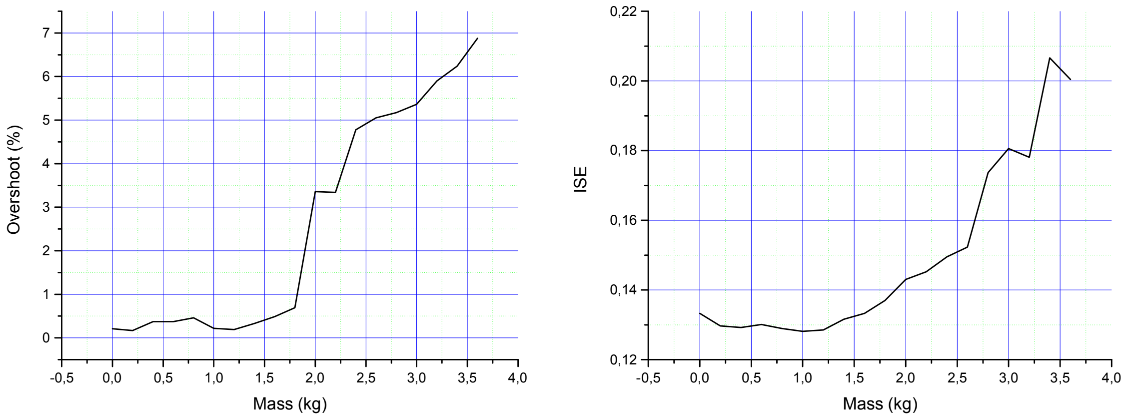

Fig. 3: The influence of load mass on: overshoot a), ISE b)

The designed control system allows changeover, follow-up, and teach/playback control. The manipulator is robust to external loads of the working platform, such as sudden hits against the platform or collisions of the platform with an obstacle. Such cases are automatically compensated due to: the type of drives applied therein (possibility to overload the pneumatic muscles without the necessity to use safety devices), the control valves that were used (proportional pressure valves with electronic control of the output pressure) and the control system applied.

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