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THE CONTROL SYSTEM FOR A MANIPULATOR WITH TWO DEGREES OF FREEDOM FOR WATER HYDROSTATIC TRANSMISSION DRIVE

Piotr Kucybała, Andrzej Sobczyk

Cracow University of Technology, Institute of Machine Design
Jana Pawła II Avenue 37, 31-864 Krakow, Poland
tel.: +48 12 6283336, +48 12 6283405
e-mail: kucybala@mech.pk.edu.pl
sobczyk@mech.pk.edu.pl

Abstract

The article presents concepts of control of the manipulator with two degrees of freedom, which uses a water hydraulic power unit to drive the actuators. The proposed control system is based on the use of electromagnetically controlled "rosettes valve" and proportional flow control valve. The control system is implemented using a computer equipped with a module for the real-time operating system (XPC Target) working in connection with the environment Matlab/Simulink. Controlled variable of the drive system is the displacement of the individual hydraulic cylinder and after determining manipulator kinematics, any point of the object in operating space. The positioning error of individual manipulator elements will be determined during the test in terms of different control algorithms, using the PID controller and PWM signal. In addition, it analyses the impact of changes in the velocity of the piston rod for the boom mechanism and the arm mechanism. An important aspect of the presented hydrostatic drive system is the use of water as a medium that physical and chemical properties are different from commonly used hydraulic oil, and which is friendly to the environment and meet the high cleanliness requirements for the fluid used to transfer the hydrostatic energy. Therefore, the control system requires a different approach, tied with synchronous control valves ON/OFF and proportional control flow regulators to achieve high accuracy.

Keywords: *fluid power control system, hydrostatic transmission system, water hydraulics*

1. Introduction

Control and monitoring of the position or velocity of actuators such as a robot arm, manipulator accessories machines or working equipment, operating under different conditions is one of the most important goals in the optimization of operation. It is designed to improve or automate the work of individual mechanisms. A decisive impact on these parameters is the construction of the device, actuators and controls system that is used in the instrument, and also the control algorithm.

One of the interesting environmentally friendly devices that are slowly entering the market are devices or machinery that uses water hydraulic power unit to transmit the drive, based on the so-called ordinary tap water [1-3]. Control the position or velocity of devices using water hydraulic power unit to drive is quite troublesome when compared to devices using to drive the oil hydraulics. This is mainly due to the limited range of hydraulic components, which can be used and as well as the high prices of these components [8].

The cause of this condition is the use of materials resistant to the corrosion, by the cooperation of water as a medium, as well as accelerated wear as a result of poor lubricating properties. These also contribute to the reduction of interest systems of this type. Research work on extending the applicable range of water hydraulics is ongoing, resulting in the development of this field. Mention may be working on the use of special anti-corrosion coatings and improved abrasion properties, which are coated typical elements used in hydraulic oil [3, 6, 7].

2. The structure of the test stand

The test stand is built on the model of construction work machine like manipulator with two degrees of freedom working in a coplanar system. The drive manipulator is realized through the use of two hydraulic cylinders controlled independently using to deliver power as a medium of ordinary tap water. Fig. 1 shows a schematic of the test stand and the placement of adopted Cartesian system and the location of the point P, which in the following discussion is an important point of reference.

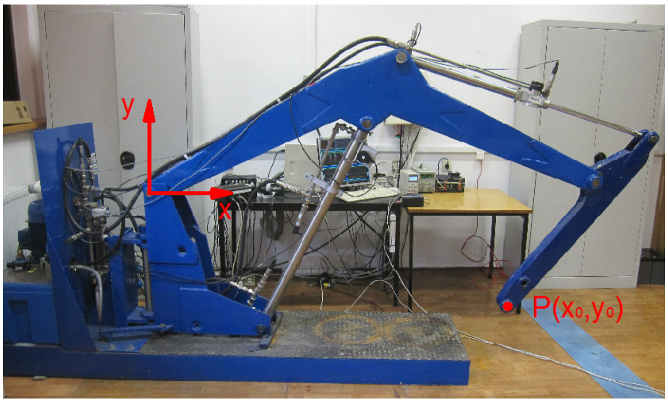

Fig. 1. Scheme of test stand and placement of Cartesian system and the location of the point P

The test stand is made up of a boom mechanism, arm mechanism, and a body frame that is the fixing of the whole structure. The drive mechanism uses two independently controlled hydraulic cylinders, the diagram of the hydraulic system presented in Fig. 2.

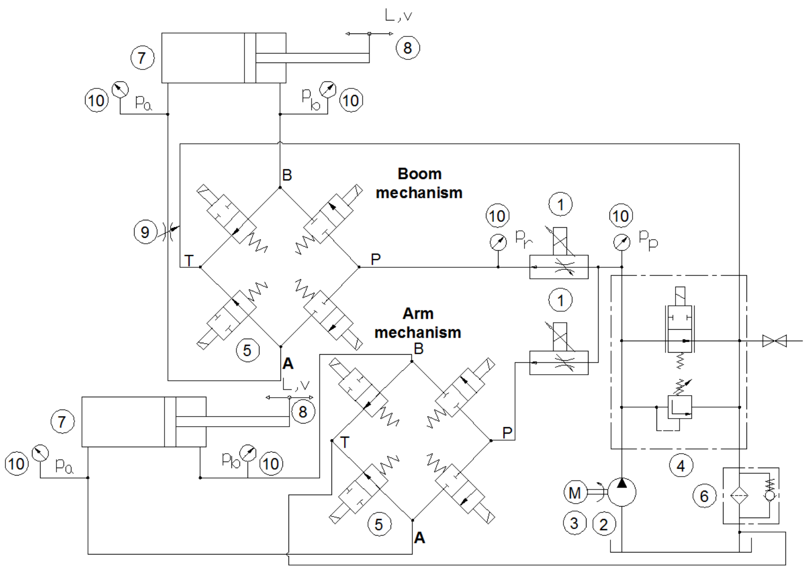

Fig. 2. Diagram of the hydraulic system

The main component of the hydraulic system is a hydraulic pump (2), which task is pumping liquid through two proportional flow control valves (1) and two bridges valve (the valve rosettes – 5) to the hydraulic cylinders (7) of boom mechanism and arm mechanism. Rosette valve handles directing the volumetric flow to the respective cylinder chambers, and a proportional flow controller handles providing the appropriate flow rates to the individual chambers. These two elements constitute the system responsible for the proper positioning of the individual mechanisms and require appropriate controls that will guarantee operation of the system after a set trajectory.

The flow regulator valve and rosette valve have different control structure. Rosette valve is made up of four valves operate on the principle of on/off, while the flow control is an element that acts proportionally. Therefore, to make a forward or retract a cylinder of one of the mechanisms, should be controlled rosette valve and flow control valve, which can be difficult. For the appropriate control apply system, a test stand is equipped with a measurement and registration system. The control system monitors the position, i.e., the displacement piston rod, pressure in the cylinder, the outlet pressure pump. Also recorded a command sent to the individual coils of rosettes valve and also signal that is sent to the flow controllers.

Control of individual mechanisms is done through control valves ON/OFF and the proportional flow controller. The use of proportional hydraulic components can control the size of the flow whereas control valves, execute on/off, eject and retract function of cylinders. Above ensures continuous operation of the system and advantages over conventional directional valves, where you can just completely open the way for the flow or close it completely. As a result, it became possible to control the velocity and positioning of the hydraulic cylinder accurately [4, 10].

Rosettes valve and proportional valves are controlled by output signals generated by industrial computer xPC Target, which is equipped with the inputs and outputs card. Signals to the valves on/off are sent as a digital signal while to the proportional valves as an analogue signal. The control source program is sent to the computer industry XPC is via TCP/IP (Ethernet) with a computer called the Host. The host is, in this case, a laptop installed with Matlab Simulink. In Matlab Simulink is built control algorithm, with the elements that configure the individual signals. The measuring system records values: pressure in the hydraulic system using strain transducers and real displacements of the cylinder with the help of potentiometric sensors. Diagram of the control system shown in Fig. 3.

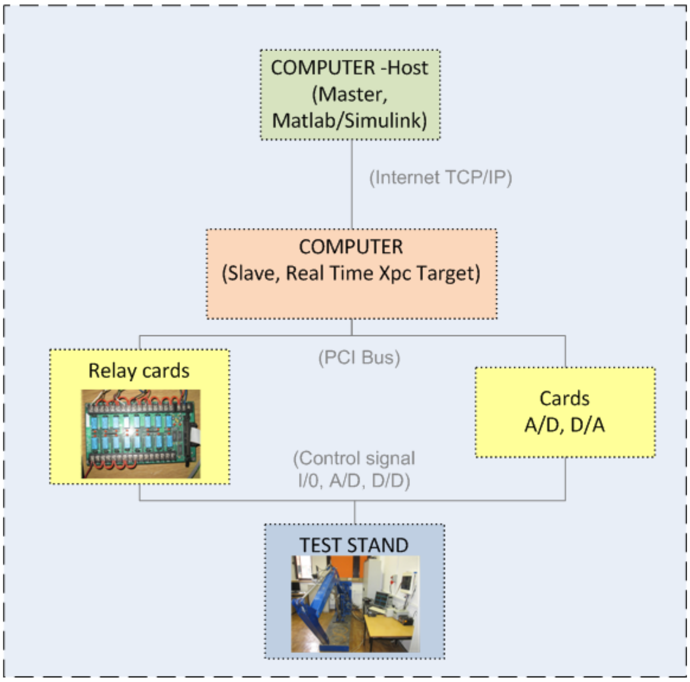

Fig. 3. Scheme of control system for test stand

3. Experimental studies

In the paper, analyse the hydraulic system of the coplanar manipulator, using as a medium of pure tap water, with two degrees of freedom (the mechanism of the boom and arm mechanism of excavators). To determine the position of the end point of the manipulator, as well as to determine the working area and the desired trajectory, it is a necessary analysis of the structure and the kinematics of the manipulator [5]. Apart from the fundamental constants of the geometric dimensions (length and angle values of equipment), you must also take into account the value of stroke and dead zone of hydraulic cylinders. Not taking into account the exact dimensions, and the range of the cylinders, can lead to erroneous results and ultimately damage the manipulator, or an obstacle appears in the work area. In order to achieve the individual mechanisms cylinders set trajectory of the end point manipulator, (which may be the digging mechanism), inverse kinematics can be used for solving the problem, on the basis of coordinates of the point P (Fig. 1) to determine the desired the individual cylinders displacement.

Experimental studies were designed to verify the ability of accurately control trajectory by individual drives using rosettes proportional valve and flow regulators. The research was carried out for one standardized signal made up of a rectangle and a circle inscribed in it, and for three different assumed the velocity of movement of the hydraulic cylinder. Based on the location of the end point of a manipulator from standardized signal calculated the displacement of rods for the boom and arm mechanism using inverse kinematics.

A standardized signal with the displacement of hydraulic cylinders is shown in Fig. 4.

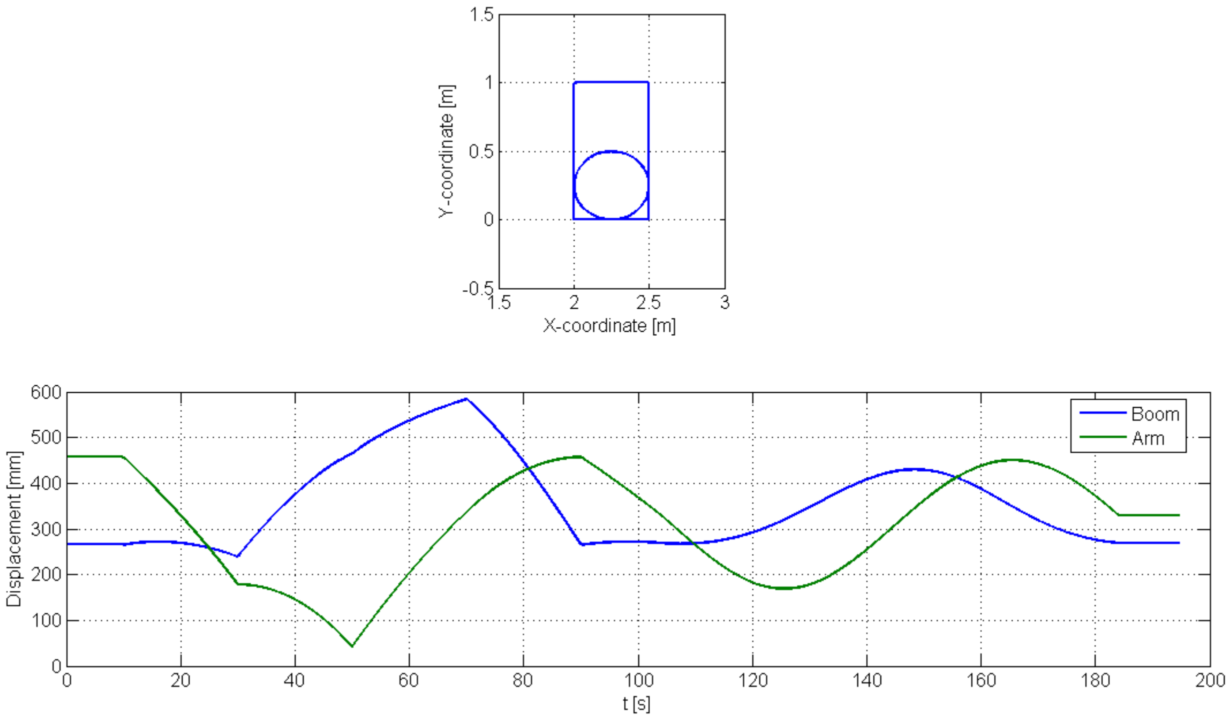

Fig. 4. Standardized signal with the displacement of boom cylinder and arm

This signal causes the simultaneous operation of two mechanisms of the test stand, the boom mechanism, and the arm mechanism and checking the correct work of the control system. Examined two control system, first control system based on PID controller; the second control system has been developed to a PWM controller. Sample characteristics obtained for the selected signal for PID control and PWM controller and boom mechanism shown in Fig. 5 and for the arm mechanism shown in Fig. 6.

By comparing, the signals obtained with the experimental test with set signal it should be noted that the proposed control system is the correct process, which allowing control equipment of the set trajectory. It can be seen minor differences between relative displacement and theoretical displacement and oscillation of this signal, and pulsation of the pump pressure. The differences between relative displacement and theoretical displacement for boom and arm mechanism for the PID and the PWM controller are shown in Fig. 7 and 8. These disparities presented in the form of error displacement appointed as the difference between the set value and the actual value.

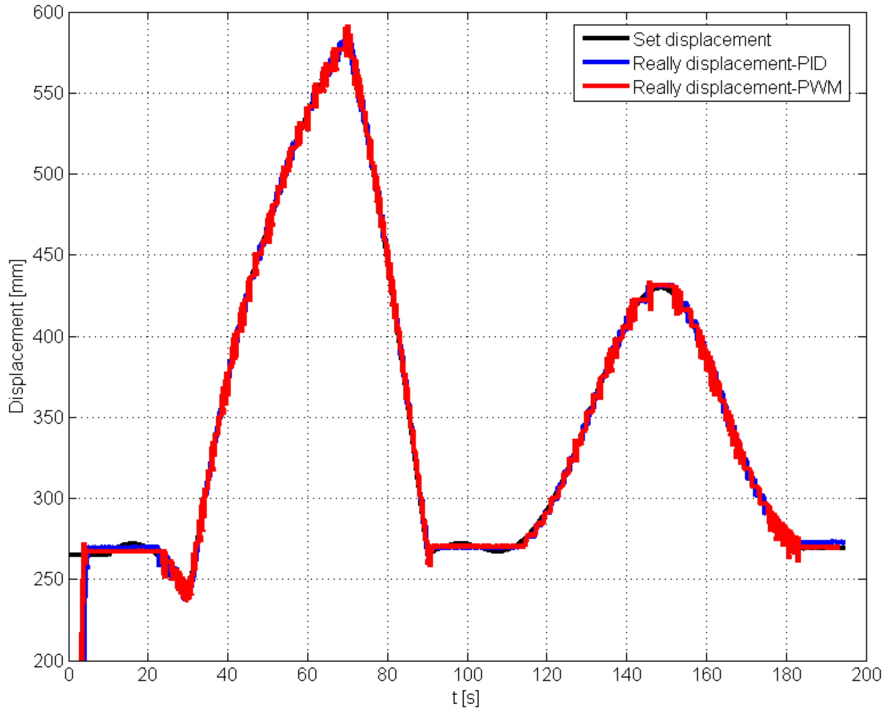

Fig. 5. Comparison of the displacement piston rod for boom mechanism control with PID controller and PWM controller

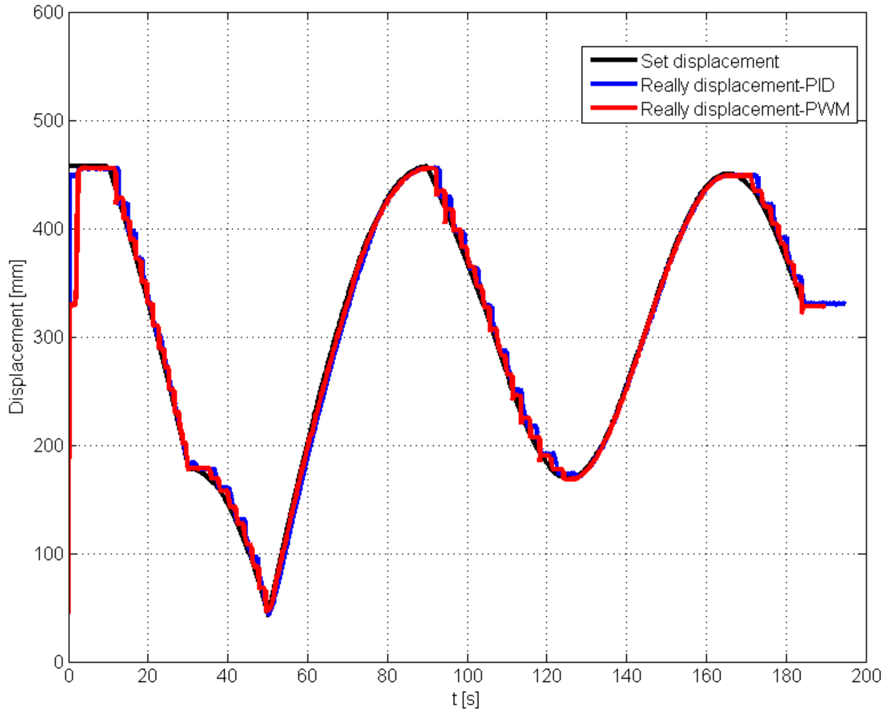

Fig. 6. Comparison of the displacement piston rod for arm mechanism control with PID controller and PWM controller

Analysing the fault displacement diagrams can be seen that the maximum error is the arm mechanism (Fig. 8), is about minus 20 mm and appears for PID controller. This error is upon during retracting of the cylinder. After an analysis of pressures in cylinder chamber and the structure of the test stand has been observed that after set parameter to move rod of the cylinder, first phase followed by a slow increase pressure and only after about 0.5 seconds followed by movement of the rod cylinder. The reason for this fact is probably applicable to the connection rod

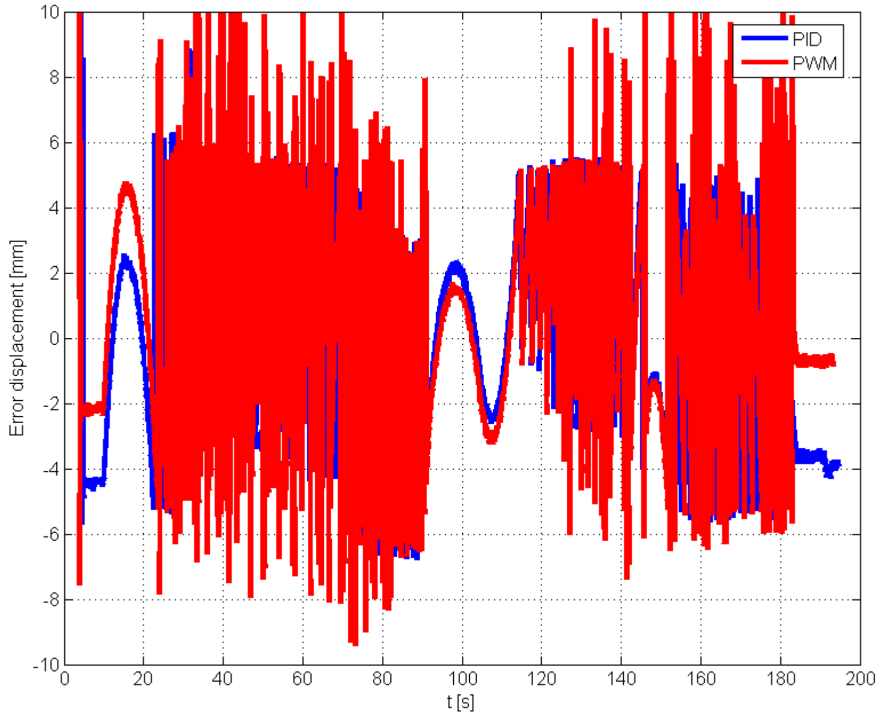

Fig. 7. Comparison of displacement errors for the displacement piston rod for boom mechanism control with PID and PWM controller

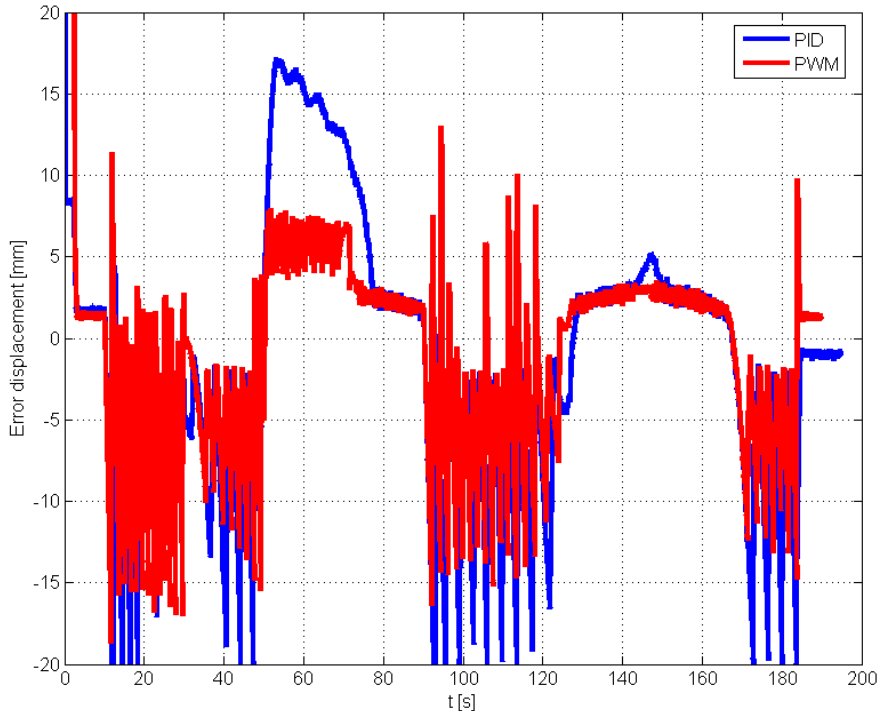

Fig. 8. Comparison of displacement errors for the displacement piston rod for arm mechanism control with PID and PWM controller

side of the cylinder of a long flexible hose which, when increased pressure first increases in volume, causing a delay in the operation of the cylinder move. At the time of forward is not observed this behaviour because the side of the piston a connection is made from stainless steel pipe with a lower susceptibility to deformation. The positioning error forward phase fluctuates in the range of about 8 mm for PWM controller when using the PID controller; the error is much larger especial in the starts moments.

Position error reach of the boom mechanism (Fig. 7) using PWM controller is slightly larger than when using PID control, it shall be in the range of 10 mm. Positioning errors for the two control modes and different velocity of boom and arm mechanisms are shown in Fig. 9, which shows the displacement of the manipulator endpoint (point P in Fig. 1) in Cartesian coordinates.

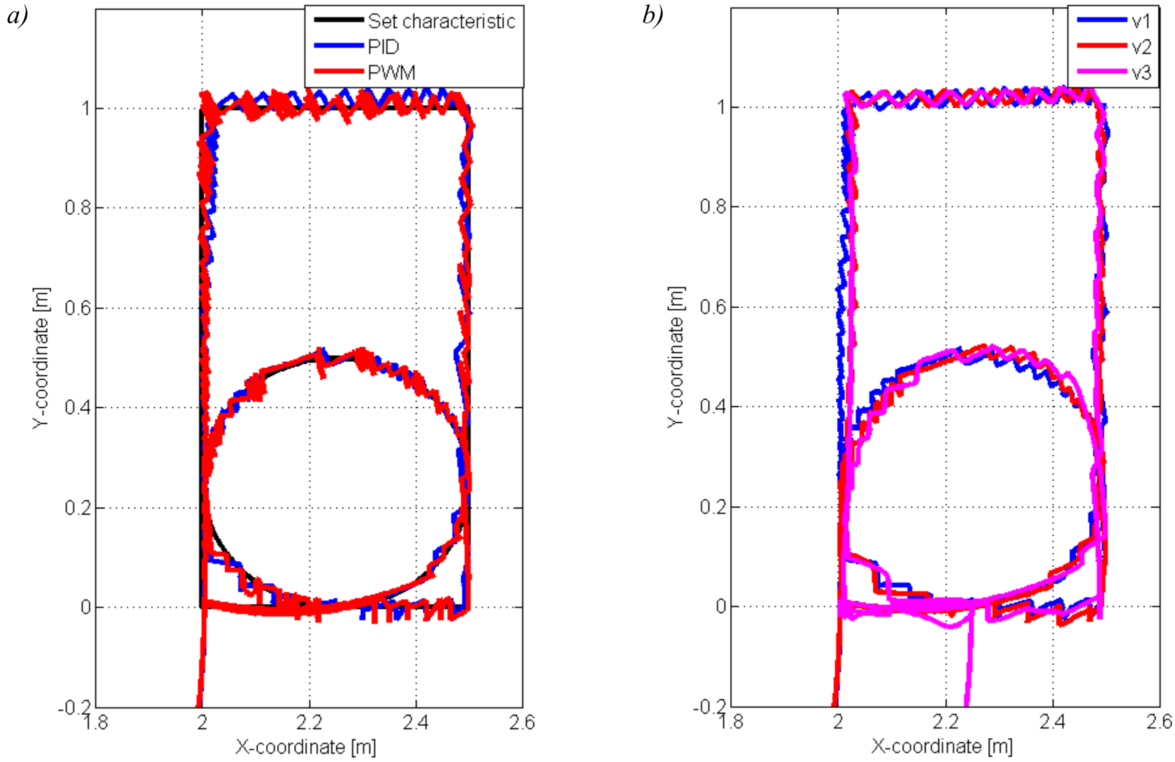

Fig. 9. Characteristics of discrepancies reference signal from a real signal for: two systems of controller (a), three different velocity of mechanisms (b)

Analysing the characteristic differences of the reference signal with a real signal it can be observed that the proposed system allows to perform adjustments manipulator with two degrees of freedom by the defined coordinates. The positioning accuracy is dependent on the type of controller used, the type of mechanism used to operate, elements used for the connection of cylinder. Effects of the velocity of movement of the different mechanisms implemented are negligible.

4. Summary

Presented manipulator control system with two degrees of freedom, using the drive, water as a medium, with two rosettes valve and two proportional valve flow controls, allows for smooth control of any point manipulator, according to the trajectory. The experimental tests conducted confirm the functionality of the system used, but the study did not give answers that the controls allow to get better results in the form of reduced positioning error.

An interesting phenomenon that has been observed is the effect used a hose to increase the positioning error. Noteworthy is also the fact of appearing during control the so-called pulled work it means momentary stops of the cylinder, causing the appearance of large oscillation of the whole manipulator. Their work is mainly manifested in the boom mechanism because it can be a much load in this mechanism.

The proposed algorithm needs to be developed, in order to eliminate pulled work, reflect the impact of the load conditions and broaden its analysis of the wider range of velocity changes as well as analysis of the structure of the tubes used in the system. Good functional characteristics of the proposed control system and the relatively low costs allow us to conclude that elements of this type can be applied to high-pressure water hydraulics, instead of proportional valves and relatively expensive servo valves. Such a solution can be cheaper and can provide a good way for the use of water hydraulics systems, which are placed higher and higher requirements of environmental protection.

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