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ANALOG CONTROL AND PROGRAMMING OF A RTT ROBOT WITH A PLC

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Abstract: *Rotation, translation, translation (RPP) robot on which reference is made in this work is the subject of the patent. This paper presents the possibility of analog programming and control of a structure of industrial robot. The RPP robot is designed and manufactured within the Faculty of Engineering from "Lucian Blaga" University of Sibiu, as a patent no. 112418 CI6.B25J 18/02. Classical systems for programming and control of industrial robots are based on numerical control equipment developed around a PC. Programmable Logic Controllers (PLC) have proven to be viable alternatives to driving machine tools, industrial systems and Robots. PLC is well-suited for industrial environment. The paper highlights the simplicity and ease of configuration control and programming of the robot arm using a PLC with the time required by the mechanical structure. It proposed a method of programming and analog control.*

Key words: *industrial robot, programmable logical controller, analog programming and control.*

1. INTRODUCTION

Control and programming movements of mobile parts of a robot is a matter of great importance especially when the application requires constructive simplicity and is easy to implement. Achievements in the field of robot control and programming show various ways of solving the problem.

The most common achievements are relying on systems configured around the structures of computer. Number of degrees of freedom of movement, as well as linking the rules of these movements, determine the complexity of control and programming of the robot [5, 7, 8].

Various applications of robots in various fields have led to searching for and finding solutions that differ greatly among themselves.

The development of low cost computer has brought the most recent revolution, the Programmable Logic Controller (PLC). The advent of the PLC began in the 1970s, and has become the most common choice for manufacturing controls.

PLCs have been gaining popularity in the domain of factories and will probably remain predominant for some time to come. Most of this is because of the advantages they offer: cost effective for controlling complex systems, flexible and can be reapplied to control other systems quickly and easily, computational abilities allow more sophisticated control, trouble shooting aids make programming easier and reduce downtime, reliable components make these likely to operate for years before failure.

Appearance and development of logic programmable structures in the form of Programmable Logic Controllers has brought the easiness in terms of control and robot programming.

PLC is a digitally operating apparatus which uses a programmable memory for the internal storage of instructions for implementing specific functions such as logic, sequencing, timing, counting and arithmetic to control, through digital or analog input/output modules, various types of machine or processes.

A Programmable Logic Controller is a specialized computer, designed to be used for industrial control [7].

Programmable Logic Controllers are sometime called programmable controllers (PC) but are more commonly called PLCs.

Ladder logic is the main programming method used for PLCs. As mentioned before, ladder logic has been developed to mimic relay logic. The decision to use the relay logic diagrams was a strategic one. By selecting ladder logic as the main programming method, the amount of retraining needed for engineers and technicians was greatly reduced.

Modern control systems still include relays, but these are rarely used for logic. A relay is a simple device that uses a magnetic field to control a switch.

The first PLCs were programmed with a technique that was based on relay logic wiring schematics. This eliminated the need to teach the electricians, technicians and engineers how to program a computer – but, this method has stuck and it is the most common technique for programming PLCs today [4].

There are other methods for programming PLCs. One of the earliest techniques involved mnemonic instructions. These instructions can be derived directly from the ladder logic diagrams and entered into the PLC through a simple programming terminal.

Sequential Function Charts (SFCs) have been developed to accommodate the programming of more advanced systems. These are similar to flowcharts, but much more powerful.

Structured Text programming has been developed as a more modern programming language. It is quite similar to languages such as BASIC.

At "Lucian Blaga" University of Sibiu, in field of robots, there is experience in cinematic structure of robots, work space, as well as in terms of programming and control movements. The model presented in this work, that is the programming and control of movements using a PLC, is the result of a patent of invention.

The robot is relying on cinematic structure with three movements: Rotation-Translation-Translation.

Experimental model of robot was designed and manufactured at the Faculty of Engineering, (patent No. 112418 CI6.B25J 18/02).

2. ROBOT STRUCTURE

The robot is based on a modular structure. Making movements by elastic elements: belts with cable, allows displacement on distance with high dynamic performance. Experimental robot model is manufactured using a structure with cylindrical coordinates, Fig. 1. The kinematics structure allows the robot to realize movements based on wire mechanism. The solution is brevetted as name: Braț telescopic B.I.Nr. 112418/19.08.1997. For each axis movement is necessary a DC servomotors. The type of motor is EVP DC 12V, 120 Watts. Switching between rotation sense is made by an intermediary relays which support 10 Amp on contacts.

The displacement of robot arm, can be achieved independently or simultaneously depending on software and hardware used.

Cylindrically coordinates allows robot arm to move in space under coordinates as is presented in Fig. 1.

The Robot can make a rotation and two translations (rotation, translation, translation - RPP). Mathematically matrix of reference transformation $[A]_{0,n}$ is (OZYX)0 in reference system (OZYX)n, results three operators $[P]_{z0,z}$, $[R]_{z0,\alpha}$ and $[P]_{x,r}$, [1]:

$$[A]_{0,n} = [P]_{z0,z}[R]_{z0,\alpha}[P]_{x,r} \tag{1}$$

Telescopic mechanism of the translation module is the degree of mobility equal to 1, Fig. 2.

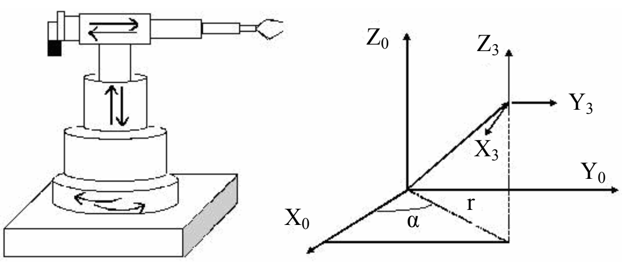

Fig. 1. Structure of RTT robot model.

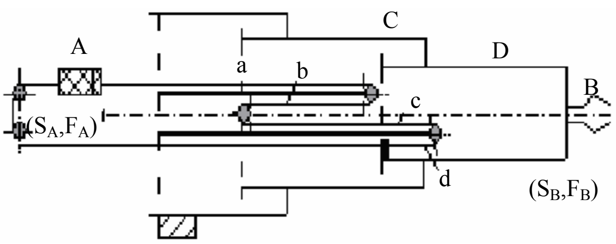

Fig. 2. Telescopic mechanism from robot structure.

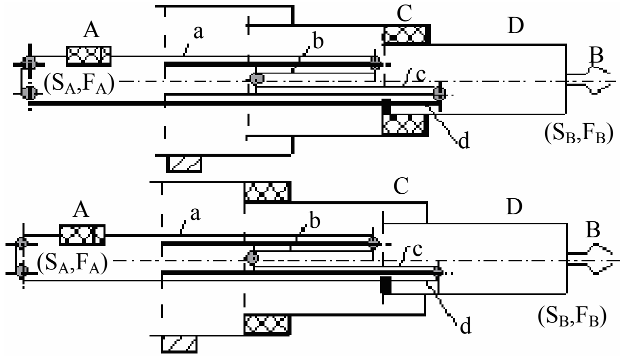

Fig. 3. Speed transfer when the C or D is fixed.

S_A represents input of mechanism, F_A represents mechanical force. Number of external links is equal to 2: an input S_A and an output S_B. Function of transmitting forces depends of S_B and F_B.

S_B depends of S_A. To determine the velocity of movement of the robot arm, we have two situations, when the *C* is fixed, respectively when the *D* is fixed, as is shown in Fig. 3.

Due to construction, module translation movements are fine and can reach high speeds. Because of the elastic structure of transmission of movement, telescopic modules are recommended for use at work that do not exceed 30 N.

3. PLC STRUCTURE AND OPERATING

3.1. PLC structure and modules

A PLC resolves the logic of a ladder diagram (program) rung by rung, from the top to the bottom.

A PLC contains input adjustable level for connecting receiving signals from sensors, switching and so on, output adjustable level for adapting with relays, coils, bulbs. The structure of a PLC is close of a computer structure. The difference consists in executing program. The program is send from a computer (PC), Fig. 4.

Inputs and outputs module from a PLC provide dialog between internal system and external world. Switches represent all digital inputs.

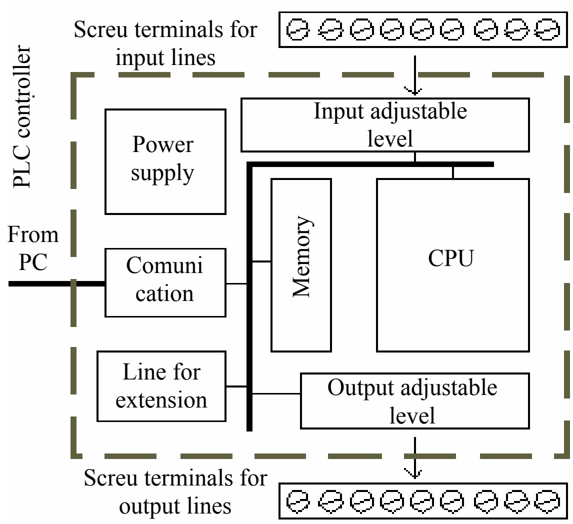

Fig. 4. PLC structure and modules.

The input/output (I/O) system is physically connected to the field devices that are encountered in the machine or that are used in the control of a process. These field devices may be discrete or analog input/output devices, such as limit switches, pressure transducers, push buttons, motor starters, solenoids, etc.

The I/O interfaces provide the connection between the Processor and the information providers (inputs) and controllable devices (outputs).

During its operation, the Processor completes three processes: (1) it reads, or accepts, the input data from the field devices via the input interfaces, (2) it executes, or performs, the control program stored in the memory system, and (3) it writes, or updates, the output devices via the output interfaces. This process of sequentially reading the inputs, executing the program in memory, and updating the outputs is known as scanning.

Figure 5 illustrates a graphic representation of a scan, the control loop [4].

The input/output system forms the interface by which field devices are connected to the controller.

The main purpose of the interface is to condition the various signals received from or sent to external field devices. Incoming signals from sensors (e.g., push buttons, limit switches, analog sensors, selector switches, and thumbwheel switches) are wired to terminals on the input interfaces.

Devices that will be controlled, like motor starters, solenoid valves, pilot lights, and position valves, are connected to the terminals of the output interfaces.

The system power supply provides all the voltages required for the proper operation of the various central processing unit sections.

3.2. PLC versus PC

The architecture of a PLC's CPU is basically the same as that of a general purpose computer; however, some important characteristics set them apart. First, unlike computers, PLCs are specifically designed to survive the harsh conditions of the industrial environment. A well-designed PLC (Fig. 5) can be placed in an area with substantial amounts of electrical noise, electromagnetic interference, mechanical vibration, and non-condensing humidity. A second distinction of PLCs is that their hardware and software are designed for easy use by plant electricians and technicians.

The hardware interfaces for connecting field devices are actually part of the PLC itself and are easily connected. The modular and self-diagnosing interface circuits are able to pinpoint malfunctions and, moreover, are easily removed and replaced. Also, the software programming uses conventional relay ladder symbols, or other easily learned languages, which are familiar to plant personnel.

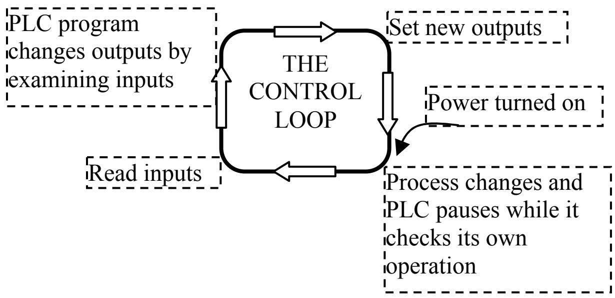

Fig. 5. Steps in execution operations of a PLC.

Whereas computers are complex computing machines capable of executing several programs or tasks simultaneously and in any order, the standard PLC executes a single program in an orderly, sequential fashion from first to last instruction. Bear in mind, however, that PLCs as a system continue to become more intelligent. Complex PLC systems now provide multiprocessor and multitasking capabilities, where one PLC may control several programs in a single CPU enclosure with several processors.

With the proliferation of the personal computer (PC), many engineers have found that the personal computer is not a direct competitor of the PLC in control applications. Rather, it is an ally in the implementation of the control solution. The personal computer and the PLC possess similar CPU architecture; however, they distinctively differ in the way they connect field devices.

While new, rugged, industrial personal computers can sometimes sustain midrange industrial environments, their interconnection to field devices still presents difficulties. These computers must communicate with I/O interfaces not necessarily designed for them, and their programming languages may not meet the standards of ladder diagram programming.

The personal computer is, however, being used as the programming device of choice for PLCs in the market, where PLC manufacturers and third-party PLC support developers come up with programming and documentation systems for their PLC product lines.

Personal computers are also being employed to gather process data from PLCs and to display information about the process or machine (i.e., they are being used as graphic user interfaces, or GUIs). Because of their number-crunching capabilities, personal computers are also well suited to complement programmable controllers and to bridge the communication gap, through a network, between a PLC system and other mainframe computers.

Some control software manufacturers, however, utilize PCs as CPU hardware to implement a PLC-like environment. The language they use is based on the International Electrotechnical Commission (IEC) 1131-3 standard, which is a graphic representation language (sequential function charts) that includes ladder diagrams, functional blocks, instruction lists, and structured text. These software manufacturers generally do not provide I/O hardware interfaces; but with the use of internal PC communication cards, these systems can communicate with other PLC manufacturers' I/O hardware modules [6].

Communication and transmission of the signal within the sensing system are generally processed in digital form after digitization of the analog input signal. The analog transmission of the sensed signal prior to digitization requires special care, as the quality of the signal transmission directly influences the quality of sensing. The analog signal is easily deteriorated by the noise signal surrounding the transducers/sensors and the signal transmission cables.

The high-frequency noise signals coming from the power circuits including the motors, the digital devices, etc., as well as those coming from the power supply can be major sources of noise signals.

The signal transmission requires special techniques when the signal is to be transmitted via relatively moving interfaces without contact. The slip ring, wireless transmission with use of radio waves and optical methods are generally employed in such cases.

4. ANALOG CONTROL AND PROGRAMMING

4.1. Displacement sensor

Sensor used in displacement of robot arm control is analog. The simple analog sensor for displacement may be potentiometer. Potentiometers measure the angular position of a shaft using a variable resistor. A potentiometer is shown in Fig. 6. The potentiometer is being used as a voltage divider. As the wiper rotates the output voltage will be proportional to the angle of rotation [8]

$$V_{out} = (V_2 - V_1)\frac{Q_W}{Q_{max}} + V_1 . \qquad (2)$$

The potentiometer is resistor, normally made with a thin film of resistive material. A wiper can be moved along the surface of the resistive film. As the wiper moves toward one end there will be a change in resistance proportional to the distance moved. If a voltage is applied across the resistor ($V_1 - V_2$) , the voltage at the wiper interpolates the voltages at the ends of the resistor and V_{out} is depending of displacement θ. Potentiometers are popular because they are inexpensive, and don't require special signal conditioners. But, they have limited accuracy, normally in the range of 1% and they are subject to mechanical wear. Potentiometers measure absolute position, and they are calibrated by rotating them in their mounting brackets, and then tightening them in place. The range of rotation is normally limited to less than 360 degrees or multiples of 360 degrees. Some potentiometers can rotate without limits, and the wiper will jump from one end of the resistor to the other. Faults in potentiometers can be detected by designing the potentiometer to never reach the ends of the range of motion. If an output voltage from the potentiometer ever reaches either end of the range, then a problem has occurred, and the machine can be shut down.

Displacement sensor is connected to an input of PLC and energized by external power source $V_1 - V_2$, Fig. 6. Θ_{max} is maximal value of angle of potentiometer cursor, Θ_N is nominal value of cursor displacement.

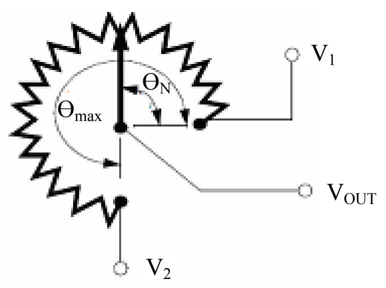

Fig. 6. Displacement analog sensor.

4.2. Wiring analog sensor to PLC and settings

As analog input, potentiometer must be supplied from an external source, PLC used is Moeller Easy 512DC RC, Fig. 7. PLC has analog inputs I7 and I8. In our experiments, I7 receive voltage from sensor circuit. The voltage on I8 represents programmed of displacement. It will be compared with voltage on I7 representing real displacement. PLC will compare the two values of electrical tension from input I7 and input I8, the result of comparison will be switching outputs of PLC in correspondence with Ladder diagram program [9].

The measured value of electric voltage on the analog sensor, corresponding to a cycle of displacement is presented in Fig. 9. The evaluation of electric voltage variation was made by a Voltcraft Multimeter. Data acquisition was made using a PC and software DMM-ProfiLab. The maximum value of electric voltage on the sensor is 10VDC. During a cycle of displacement from 0 to 30, electric voltage increases proportional with displacement. When displacement is finished, electric voltage is constant. Displacement in opposite sense correspond corresponds with increasing electric voltage to "0" value.

I7 and I8 are analog inputs. Displacement potentiometer sensor. If I7 is input for displacement sensor, I8 will receive the value of reference tension which represents desired displacement.

A fusible F will protect PLC power supply. Usually, an analog input is supplied by 12V DC.

The values I7 and I8 can be set so PLC outputs to switch when I7 = I8, or I7 ≤ I8, Fig. 8. The software menu permits to assign function for each input I7 or I8.

Experiments on the robot have been performed aiming to a single displacement of the arm. For other displacement procedure is identical. Each direction of displacement requires the hardware and software alike.

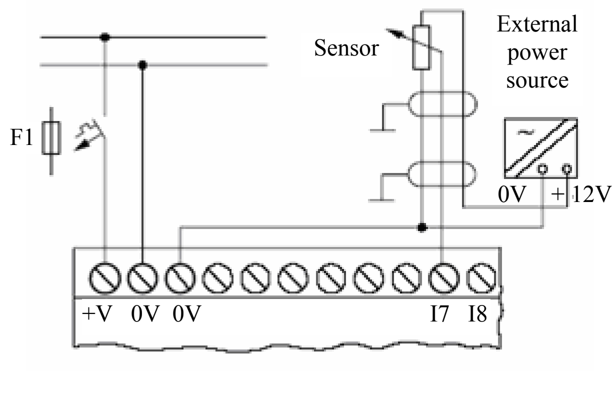

Fig. 7. Wiring analog sensor to PLC Moeller.

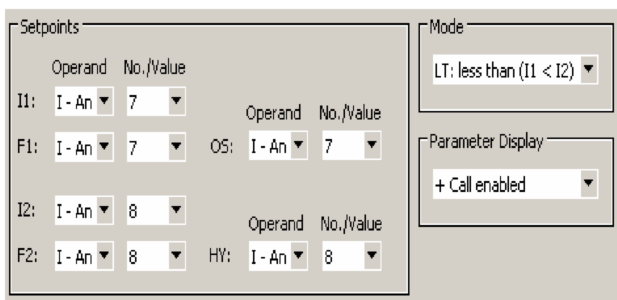

Fig. 8. Setting analog inputs I7 and I8.

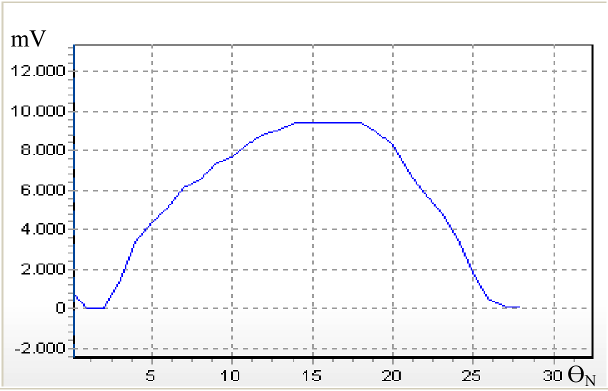

Fig. 9. Electric voltage on the sensor.

PLC as a system for programming and control of robot, permits the development of a number of analog inputs and outputs. For RTT robot are necessary three modules.

4.3. Output configuration and programming

Advantage of using PLC for programming and control of movements is necessity of less switching components such as relays. Internal relays from PLC will establish sense of movement for each motor of robot. Outputs of PLC can be physic such as relays or virtual established from software for example an internal memory. Large number of internal programmable memory available to a PLC can be an image of output or input at any given time.

In our applications, Q01 is an image of output from internal memory of PLC, Fig. 10.

Q02 and Q03 are internal relays from PLC. A normally open contact from Q02 and Q03 close electrical circuit of coils of relays K1 and K2 for switching sense of rotation of DC motor, Fig. 11.

Of course the two relays do not work simultaneously, otherwise they are producing short circuit of supply source (24VDC).

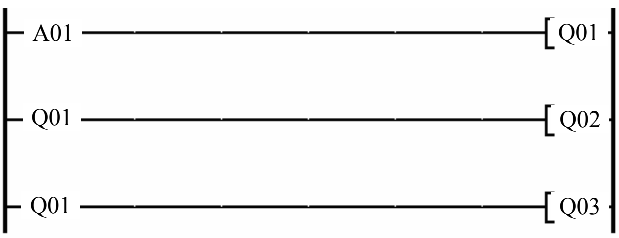

Fig. 10. Software in Ladder diagram.

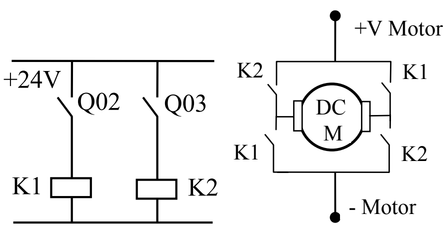

Fig. 11. Connection between PLC outputs and relays.

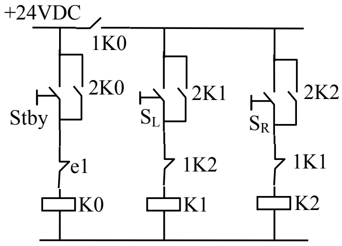

Fig. 12. Hardware external relays configuration.

This situation is avoid, in fact, by using in the software (Fig. 10) an image of Q1 with only two status "0" or "1". This allows elimination of a possible simultaneously of K1 and K2.

For changing sense of rotation of DC motor, from a single supply source is necessary to use two switching relays, K1 and K2.

Relays K1 and K2 are piloted by outputs from PLC, Q02 and Q03. Coils of relays K1 and K2 are wired in electrical circuit of normally open contacts Q02 and Q03.

Electrical circuit of DC motor (DCM) is an H Bridge whose diagonals are normally open contacts of relays K1 and K2, Fig. 12.

As is presented in Fig. 12, hardware configuration of circuit of K1 and K2 contains a normally closed contacts for mutual conditioning.

From Fig. 12 is evidenced that for a sense of rotation will work K1 and for the other sense K2.

Practical working conditions of the system impose the existence of standby function (Stby). Circuit line of K0 will be interrupted by thermal protection of motor e1. The notations from electrical scheme are: S_L-command button for left sense of rotation, S_R-command button for right sense of rotation.

4.4. Testing relation between inputs and outputs

The easy-DC basic units are provided with analog inputs. Inputs I7 and I8, and if present I11 and I12, can be used to connect analog voltages ranging from 0 V to 10 V. A simple additional circuit also allows the analog evaluation of currents from 0 to 20 mA. The analog input signals are converted to 10-bit digital signals.

The following applies: 0V DC corresponds to a digital 0, 5 V DC corresponds to a digital value of 512. 10 V DC corresponds to a digital value of 1023.

For short cable lengths, is necessary a grounded shield at both ends using a large contact area. If the cable length exceeds 30 m or so, grounding at both ends can result in equalization currents between the two grounding points and thus in the interference of analog signals. In this case, only ground the cable at one end.

With easy devices that process analog signals, the device must be fed via a transformer so that the device is isolated from the mains supply. The neutral conductor and the reference potential of the DC power feed of analog sensors must be electrically connected.

"Easy" provides eight analog comparators "A1" to "A8" for use as required.

A comparator can perform six different types of comparison. The relay contact switches if the comparison conditions are fulfilled [9]. The status of inputs can be: $I7 \geq I8$, $I7 \leq I8$; $I7 \geq$ set point, $I7 \leq$ set point; $I8 \geq$ set point, $I8 \leq$ set point.

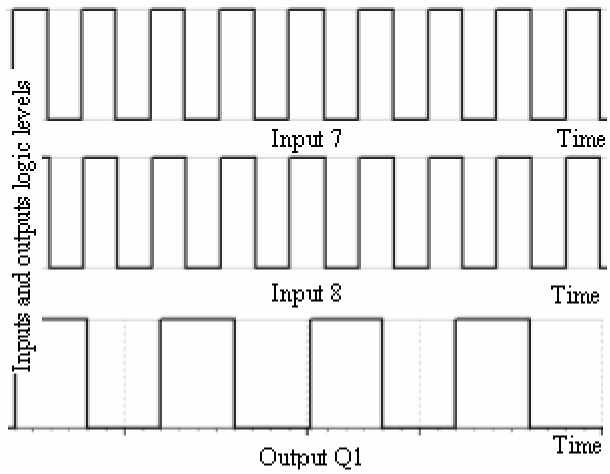

Fig. 13. Relation between inputs and outputs.

Both the set point value and the actual value correspond to the measured voltages.

Resolution of the voltage values: 0.0 to 10.0 V in 0.1 V steps. From 10 V to 24 V the actual value stays at 10.0. It is possible to enter the set point values in order to be compared with the real value.

The PLC offers possibility to view relations between inputs and outputs in oscilloscope modus, Fig. 13.

In top of Fig. 13 is visible variation of electric voltage value of I7 as sensor signal.

Sensor signal is directly depending on value of displacement. I8 represents programmed value of displacement, in electric voltage. Output Q1 will switch status of relays, which commands supply DC motor from a single DC source. The dependence between I7, I8 and output Q1 is visible.

5. CONCLUSIONS

Using PLC for analog programming and control of movements of industrial robots is possible, easy to apply and cheaper than classical numerical control.

Of course, analog programming and control of robot depends on applications. It depends on length of displacement, of complexity of cinematic structure of robot.

As a simple and cheaper solution, analog programming and control can be used in applications when robot works in a large scale of production. Analog programming and control of movements of a robot using a PLC offers possibility of quickly changing software from PLC and setting the value of displacement. The time of interpreting inputs, and switching outputs depends on PLC microprocessor.

PLC Moeller has cycle time between 30 and 300 milliseconds. The number of controlled inputs will divide cycle time. As is shown in Fig. 13, with 300 milliseconds cycle time and an input, speed of switching outputs is over speed of changing electrical voltage from sensor. Analog sensor used in displacement measure is applied as indirect measure. Indirect sensing has the disadvantage that errors of the transmission system are introduced in the measured quantity. These can be, for instance, thermal or elastic deformations of the ball screw or geometric and kinematical aberrations of the transmission system in robots. Therefore, the direct measuring principle should be used if high accuracy and small aberrations are required, such as, for radial positioning in grinding or turning machines. On the other hand, it has to be considered that indirect measurement very often gives a better chance to follow Abbe's principle in machine tools [6]. This principle demands that the probe, in this case the travel of the machine component, and the scale for measuring the travel be in alignment, otherwise errors can occur by non-orthogonally and by tilting effects. It is possible to reach the necessary alignment for indirect measuring systems approximately whereas the direct measuring system is usually placed parallel to the slide and is thus sensitive against tilting errors.

The contribution of the paper consists in idea of applying analog control on a robot with telescopic patented module.

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