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AUTOMATED DESIGNING OF MICROPROCESSOR SYSTEM OF TRANSPORT ROBOTS CONTROL FOR ELECTROPLATING LINES

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Abstract: The standard structure of transport robots control system on the electroplating automated production lines is offered. Function and operation features of structural units are considered. The example of the microprocessor control system is shown.

Transport ALE system (electroplating automated production line) consists of 1 – 4 transport robots. Each robot has two degrees of freedom: horizontal – "Forwards" or "Back", vertical – "Upwards" or "Downwards". Simultaneous motions in vertical and horizontal planes are prohibited because of the line equipment design features. Transport robots operation is not dependent from each other, but in definite periods their work is synchronized. The task of each robot includes moving a part on positions (baths) according to the technology and the rules of processing. In upper position of capture the robot is loaded, in lower – is discharged.

Navigation of robots on a line is carried out with the help of inductive discrete sensors which define horizontal location of the robot and fix position of its capture. To transmit a part from one robot to another there exist some zone of joint service. The scheme of sensor, controls and the executive mechanisms of a line location is shown on Fig. 1.

Sensors can be divided into two groups. The first group (poses. *3*, *4*, *10*, Fig. 1) is necessary for positioning the robot, the second group (poses *5 – 9*, *11*) locks operation in case of a crash.

During processing products the line equipment works in one of the two modes – automatic or fixing. In an automatic mode position or current cycle program control is carried out. Fixing mode assumes the equipment control by commands from the button console through microprocessor due circuits of hardware logic.

Since 1972 more than 20 control systems of various ALE types using various generations of computer facilities resources were designed and made by TSTU CAD department. The uniform strategy of control systems structure based on available experience is generated. On Fig. 2 is shown the block diagram of the microprocessor system of ALE control which does not depend on type of resources of computer facilities, is standard and completely meets the requirements of galvanic manufactures. Control systems is placed in a hermetic case containing: the circuit of power supplies; the microprocessor controller (microcontroller); entry signals encoding device; the

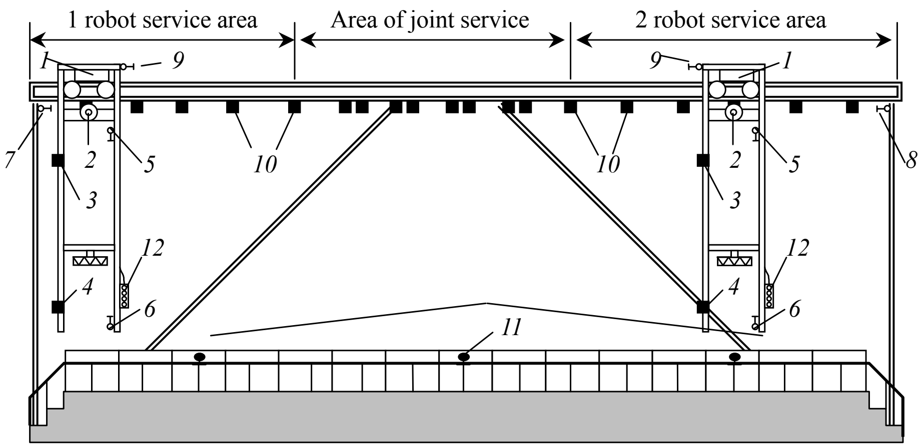

Fig. 1. The electroplating automated production line with transport robots:
1 – electric motor and a reducer of horizontal moving; *2* – the electric motor and a reducer of vertical moving; *3* – the inductive sensor of upper cross-arm position; *4* – the inductive sensor of lower cross arm position; *5*, *6* – mechanical circuit breakers of power supply of movements upwards / downwards; *7*, *8* – mechanical circuit breakers of power supply of movement for limits of a line; *9* – mechanical circuit breakers of power supply of counter movement; *10* – the inductive sensor of a horizontal position; *11* – buttons of emergency turn off of line operation; *12* – button consoles of manual operation

circuit of hardware logic and blocking; drives of electric motors. Operation mode is set by switches on operator's console.

The microcontroller fulfils the program stored in its memory, analyses the state of line sensors, as well as an operator's console and button consoles. The information on a current control object state is transferred for monitoring to the COMPUTER of a top level. The encoding device fulfils coding of signals from sensor positions and eliminates ambiguity of identification. The circuits of hardware logic and blocking, perceives in the automatic mode commands only from outputs of the microcontroller. Taking into account states of mechanical breakers it transfers or does not transfer the command on drives of electric motors. In the control system authors apply drives of Hitachi and Kombivert types permitting to fulfil smooth acceleration or braking of the transport robot, due to wide pulse modulation of phase signals. The absence of electromechanical units and the built – in microcontroller, allow to increase control system reliability and to lower expenses of the consumed electric power. The power circuit filters line interference and carries out power supply of line sensors, the microcontroller, circuits of the hardware logic and blocking (24V direct current). The mode of operation is set by an operator's console: automatic or fixing; through the microcontroller or without it; a number of service functions are also set.

In fixing mode two ways of operation are admitted. The first is carried out with microcontroller. Signals from the button console in this case are processed by the program. The second way requires less control system resources. The following set of devices is applied: the button console – the circuit of the hardware logic and blocking – drives of electric motors. Tracking of positioning accuracy and emergency conditions is assigned to maintenance staff.

Top level computer is housed in special room with office conditions of operation (section foreman, shop superintendent, automatic control system or CAD department). Their main functions are – object monitoring and software developing for line equipment control. In this case program and operation modes are written from top level machine by serial interface into microcontroller memory.

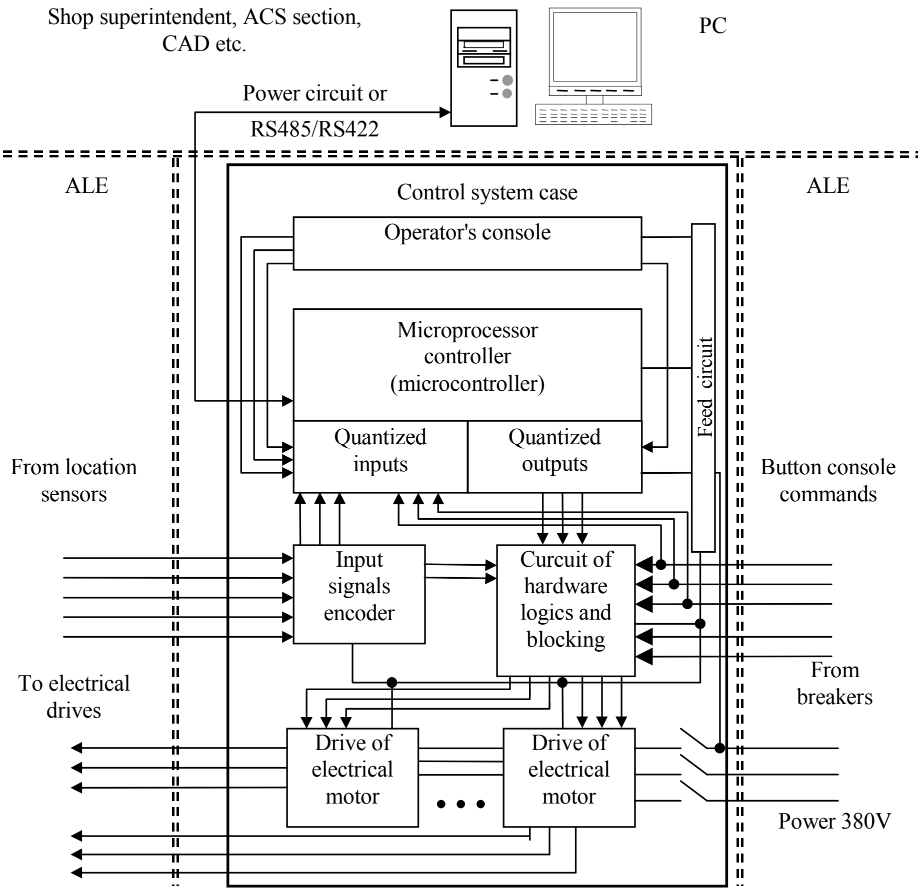

Fig. 2. Structural scheme of transport robot control system

Advantages of such structure are its programming and assembling flexibility apt to control any commercial ALE, as well as its high reliability due to module approach.

The power electronics block does play very important role in the microprocessor control system of transport robots. Its tasks include not only amplification of signals from the microcontroller and their transmission to the executive devices of robots, but also organization of off-line operation in fixing mode. Besides the power electronics block provides control in emergency situations. Long-term experience of control system development and manufacture has shown, that the structure of the block (Fig. 3) consisting of the circuit of the hardware logic and blocking of movements, the circuit of emergency breaking and one or two electric motor drives on one transport robot is optimal. Such structure really provides independent operation of control system in one of two modes – automatic and fixing, eliminates crashes on a line, caused by incorrect robot motions and also has no hardware redundancy.

The circuit of the hardware logic and blocking of movements receives four groups of signals. The first group comes from the microcontroller: MCForward – advance or upward; MCBackward – movement back or downward; MCCK1 and MCCK2 – a binary combination of speed of movement; DriveChoice – choice of the engine of horizontal or vertical movement. The source of the second group signals is the exerciser located directly on the robot. Each signal – ButtonForward, ButtonBackward, ButtonUpward and ButtonDownward, determines movement in an appropriate direction. The third group of signals comes from an operator's console located on

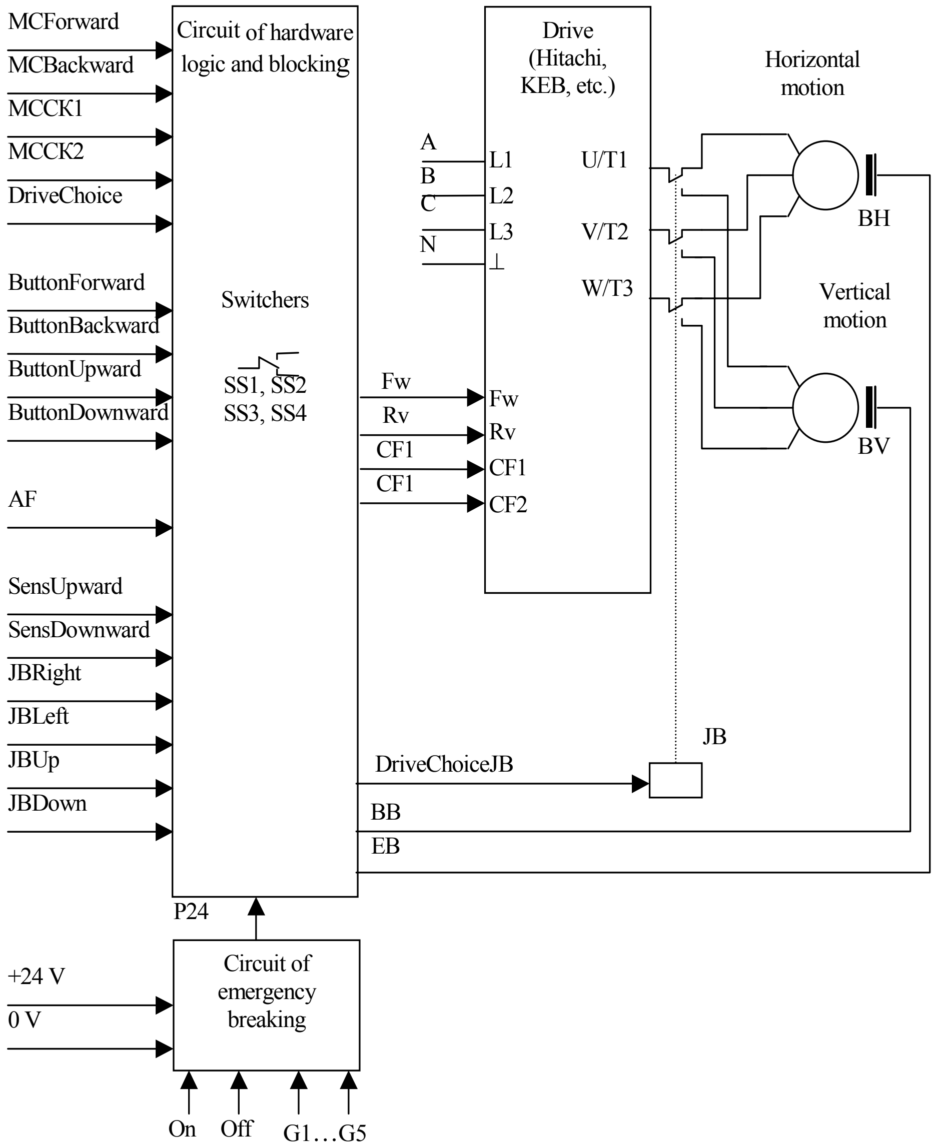

Fig. 3. Structural scheme of power electronic unit

thepanel of a control system. To this group belong: AF – choice of automatic or fixing operation mode; P24 – power supply of circuits with power of 24 V DC; On/Off – switching on/off of power 24 V supply circuits. From sensors (Sens) and junction breakers (**JB**) comes the fourth group of signals: SensUp, SensDown – display accordingly upper or lower position of the robot; JBRight, JBLeft, JBUp, JBDown – inform about extreme allowed positions of the robot; G1…G2 – sequentially connected emergency switches.

On an output of the hardware logic and blocking circuit the following signals are formed: Fw – a direction of advance or upwards; Rv – a direction of movement back or downwards; CF1 and CF2 – a binary combination of motion speed; DriveChoiceJB – amplifies the DriveChoice signal; BV and BH – switching on/off of engine brake of vertical and horizontal movement accordingly.

The group of contacts of magnetic starter (**MS**) in the switched off state transfers control signals from drive outputs to electric motors of horizontal movement. When MS is switched on motions are fulfilled in vertical direction.

The algorithm of the hardware logic operation can be presented as logical models. The level of logical unit corresponds to power of 18…24 B, logical zero to 0…5 B.

In the automatic mode the circuit fulfils a set of equations:

$$A = \begin{cases} \text{Fw} = \text{MCForward}\,\&\,\overline{\text{MCBackward}}\,\&\,\text{JBRight}\,\&\,\text{JBUp}\,\&\,\overline{\text{SensUpward}}; \\ \text{Rv} = \text{MCBackward}\,\&\,\overline{\text{MCForward}}\,\&\,\text{JBLeft}\,\&\,\text{JBDown}\,\&\,\overline{\text{SensDownward}}; \\ \text{CF1} = \text{MCCK1}; \\ \text{CF2} = \text{MCCK2}; \\ \text{DriveChoiceJB} = \textit{DriveChoice}. \end{cases}$$

For example, if it is necessary to move the transport robot forwards on maximum speed from the microcontroller MCForward = 1 command should come, MCCK1 = 1 and MCCK2 = 1. Movement will be carried out up to the moment of the indicated combination removal or by breaking of the right breaker. In fixing the mode the circuit fulfils the following set of equations:

$$F = \begin{cases} \text{Fw} = \left(\text{ButtonForward} \wedge \text{ButtonUpward}\right)\&\,\overline{\text{ButtonBackward}}\,\&\,\text{JBRight}\,\& \\ \qquad \&\,\text{JBUp}\,\&\,\overline{\text{SensUpward}}; \\ \text{Rv} = \left(\text{ButtonBackward} \wedge \text{ButtonDownward}\right)\&\,\overline{\text{ButtonForward}}\,\&\,\text{JBLeft}\,\& \\ \qquad \&\,\text{JBDown}\,\&\,\overline{\text{SensDownward}}; \\ \text{CF1} = \left(\text{ButtonForward}\,\&\,\text{SS1}\right) \wedge \left(\text{ButtonBackward}\,\&\,\text{SS2}\right); \\ \text{CF2} = \left(\text{ButtonForward}\,\&\,\text{SS3}\right) \wedge \left(\text{ButtonBackward}\,\&\,\text{SS4}\right); \\ \text{DriveChoiceJB} = \text{ButtonUpward}\,\&\,\text{ButtonDownward}\,, \end{cases}$$

where SS1-SS4 – states of the speed switchers in fixing mode. Combination SS1и SS2 (SS3 and SS4) defines one of the fixed speeds.

The general algorithm of the power electronics block is defined by the logical equation of two previous equations A and F

$$\text{F}\left(\text{Fw, Rv, CF1, CF2}\right) = \text{P24}\&\left(\overline{\text{AF}}\&\text{A} \wedge \text{AF}\&\text{F}\right).$$

Thus, in the automatic mode only commands of the microcontroller to support accident-free conditions are fulfilled (A system). In fixing mode only commands of the exerciser to support accident-free conditions are fulfilled (F system). Variable P24 has a true value when the circuit of an automatic blocking is switched on and all emergency breakers are in closed position. In case of breaking of one of emergency breakers the circuit of automatic blocking is switched off and signal P24 accepts zero value. From this moment all movements of the robot become impossible.

The device of robots braking is made in such a way that it switches off when power is supplied to windings of electric motors. Accordingly electric motor windings de-energization causes operation of a brake.

The logical equation of braking system operation looks like:

$$\text{BB} = P24\&\text{DriveChice}\left(\text{ButtonUp} \wedge \text{ButtonDown} \wedge \text{MCForward} \wedge \text{MCBackward}\right);$$

$$\text{BE} = P24\&\overline{\text{DriveChoice}}\left(\text{ButtonForward} \wedge \text{ButtonBackward} \wedge \text{MCForward} \wedge \text{MCBackward}\right).$$

It is necessary to notice, that the blocking circuit in systems A and F provides possibility of movement in opposite direction, in respect to disabled. Such organization of blocking, for example, allows to part two collided robots or to return the robot gone across the margin line.

Increased demands are made to microsystems from the point of view of maintenance service. The principal cause is possibility of complex algorithms development and implementation. Let us consider functions of a transport robot control system.

Fixing mode. The operator controls the robot by pressing buttons "Upward", "Downward", "Forward", "Backward". Usually any motion proceeds, while the appropriate button is pressed. The microsystem allows:

1) to fulfil vertical movements from one sensor up to another by single pressing of the button;

2) to fulfil vertical movements with an intermediate stop between sensors and repeated start-by pressing the button;

3) to fulfil automatically vertical movements with an intermediate stop between sensors by single pressing the button;

4) to fulfil vertical movements with automatic control of the motion speed;

5) to fulfil horizontal movement up to the nearest sensor on one pressing the button with minimum speed;

6) to fulfil horizontal movement with automatic control of motion speed mode and stop on the nearest sensor after release of the button;

7) new control program input in memory of the microprocessor system;

8) choice of control program number.

The first function is characteristic for telpher robots. Its implementation program is simple enough and allows the operator not to fix the moment of robot reaching of upper or lower position. The combination of the first and fourth functions is admitted. The second and third functions are characteristic for drum-type robots. At rise the intermediate stop is necessary for draining the electrolyte remains in a bath during defined time period. Then the robot continues movement up to the upper sensor. In case of drum pulling down a stop may not occur, it is enough to reduce speed. Such behavior is stipulated by necessity of smooth imbedding and elimination of drum impact of electrolyte mirror.

On Fig. 4 the diagram of dependence of robot vertical position from time is shown. In point *1* robot acceleration is ended, and movement occurs on maximum speed. In the middle position *2* robot stops. Knowing time t_1, the system fulfils smooth braking. In a time period $[t_1, t_2]$ the robot is in a space-hold, the electrolyte merges in a bath. Further from position *3* robot passes to position *4*. The time period $[t_3, t_4]$ depends on distance up to the following position of necessary to technological process. At this time there is a motion in a horizontal plane. Transition from upper position to lower occurs due to smooth acceleration and reaching of maximum speed in a point *6*. Deceleration and smooth imbedding of a drum starts at point *7*.

The fifth function of system operation can be considered separately or within the sixth. The diagram of horizontal movement speed change is shown on Fig. 5. The main problem here is, that the moment of button release on the console is and accordingly time up to a complete stop is unknown to. Thereof after transition to minimum speed it is necessary to apply sharp braking.

The increase of speed occurs in two stages. At the first stage the transport robot is accelerated up to the first fixed speed, and moves up to the sensor of the next position. Acceleration time t_1 is written in drive settings and is identical to any fixed speed. Time of moving up to the nearest position, $[t_1, t_2]$ depends on distance to it. At the second

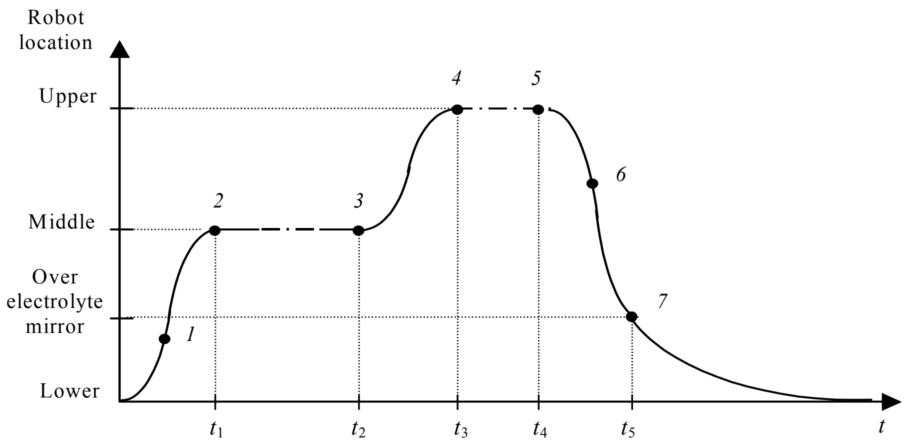

Fig. 4. Diagram of robot vertical movement

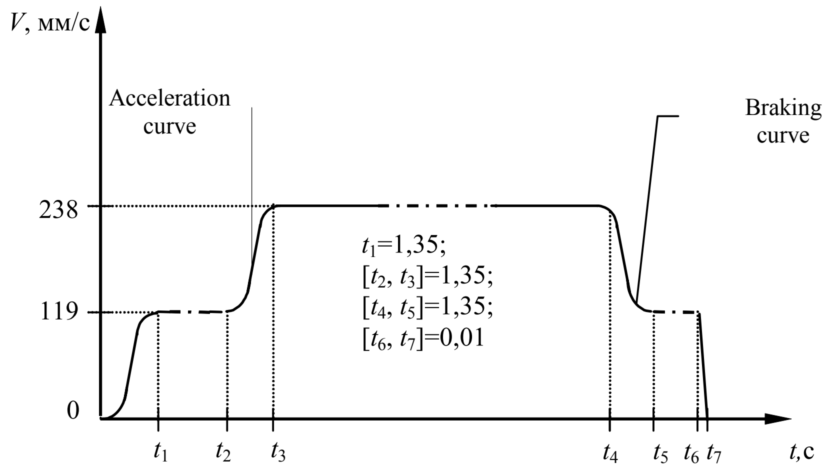

Fig. 5. Robot speed change

stage the transport robot is accelerated up to maximum speed during [t_2, t_3]. Further robot travel to the set position, time [t_3, t_4], depends on paths length. The period t_4 corresponds to the moment of button release on the console. At reaching the given position the transport robot stops. Braking time is rather small, 0.01 s, also it is stipulated by accuracy of positioning.

The automatic mode. In this mode, control is carried out by the microcontroller. The operator, on his own accord, can stop the process and continue it from a stop position or from initial position. Control process must not be affected by de-energization of power supply. The sequence of operations of the robot is set beforehand and transferred to the microcontroller as the control code program. The microcontroller must exactly fulfil control program without operator interference. Hence, software and hardware of microprocessor control system accomplish in the automatic mode following functions:

1) correct and smooth execution of the control program written in memory;

2) non-volatile storage of control programs and current states of the line equipment;

3) automatic control of the robots high-speed mode of movement;

4) synchronization of motions and elimination of emergencies;

5) operative and accident-free system transition in fixing mode and back on demand of the operator;

6) temporal stop of control process and its subsequent continuation;

7) translation of control programs and system circuits to the initial state.

Authors have methodical experience and both algorithms and software accomplishing the listed above functions. It is necessary to notice, that in the automatic mode some functions are easier to fulfil because of expected results predictability. For example, regulation of the high-speed mode can be formalized as follows.

1. To remember current position number of a transport robot P_0.

2. To define position number to which it is required to move P_n.

3. If $|P_n - P_0| < 3$ than to move with on a reduced speed, otherwise to point *4* (Fig. 6).

4. If $|P_n - P_0| \geq 3$ than to move with on a reduced speed to $P_0 \pm 1$, and further up to $P_n \mp 1$ with an increased speed.

This rather simple approach appears to be effective. Braking on a position of a stop is carried out smoothly and necessary positioning accuracy is observed.

The control system microcontroller can have the central processing unit of any type, for example, from i8085 up to single-crystal COMPUTER AT89S51, I/O ports for information in sequential and parallel formats. Microcontroller memory should be of non-volatile type (ROM, PROM on the basis of RAM, Flash-memory). In other words, system hardware should provide input and output of the information on the object, interaction between a top-level computer and an operator. On Fig. 7 is given the circuit of a microprocessor control system (**CS**) unit of two ALE transport robots.

Ports denotation is conventional. The microcontroller receives discrete values of position number as five-bit code and two bits of upper or lower position of the robot. An operation mode (A/F – automatic/fixing) is set from the system console; whether the microcontroller is used or not (MC/MC Not); temporary break of control process (Start / Stop); program or drive errors reset (Reset). In fixing the mode the state of buttons of an operator's console located on the robot (Forward, Back, Upward, Downward) are analyzed. The microcontroller forms signals of motion direction and speed. The total amount of input/output discrete signals of the microcontroller tends to grow with increase of number of serviced robots. Thus, in control systems it is possible to use microcontrollers of any type provide they have appropriate quantity of optically isolated I/O, the timer, an interrupt controller, size of ROM from 4 K, PROM from 2 K, the processor with clock rate from 2 MH.

The most complex part of the system is its software capable of reliable execution of control process. The main problem of hardware-software resources maintenance in galvanic shops – are failures resulted from interference and corrosion resistance of the equipment. The last is solved by applying protective coats and housing of control system units in hermetic cases. Interference's come by power supply lines and are induced on information channels. On Fig. 8 is given the algorithm flowchart of the (monitor) executive program steadily working in high level of interference's. The program works by a principle of time sharing operating systems but with some

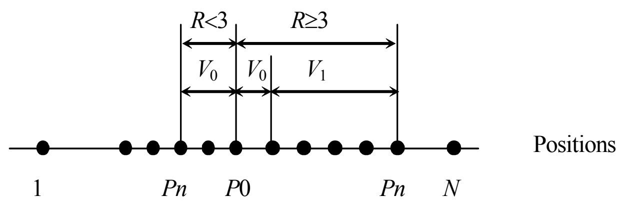

Fig. 6. Scheme of robot motion speed choice:
V_0 – decreased speed; V_1 – increased speed

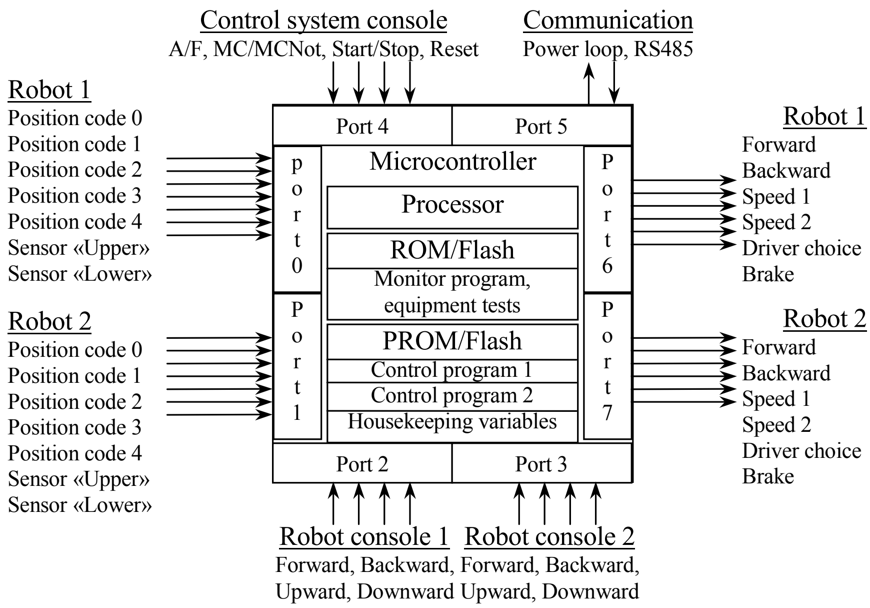

Fig. 7. Sharing of microcontroller technical resources

additions. For the complete analysis of one robot state a time slice is selected. All operations on processing the current situation and making decisions are fulfilled in for the allocated time interval. In the next time interval the state of the second robot is processed etc. Each cycle is completed by translation of the processor in a state of break. Process may proceed on interruption from the timer. Such approach has allowed to eliminate "hang-up" of the program.

Transport robots are slow enough devices, average speed of travel is 0,3 м/s, therefore main attention is given to reliability of system operation as a whole. So, for example, the researches carried out by authors have shown, that the time slice 0.01 s provides execution of the control task and 50…70 % of the processor idle time. Thus it is enough to use processors with clock rate 2…8 MH. The temperature mode of processor operation in such cases is optimal.

The algorithm has one more feature – continuation of operation from the interrupted place after switching power on. The independence from interference's connected with de-energization is thus achieved.

When CS it is translated in fixing mode, all earlier executable motions are interrupted and robots stop. Further operation with/without application of the microcontroller is possible. If operation is carried out with the microcontroller than is possible change of control programs, reset of program counters and execution of service functions by manual control of robot travel. For example, for translation of the robot from lower position in upper, it is enough to press slightly button "Upwards" on the console. The further motion will be fulfilled automatically. In horizontal travel after pressing and the subsequent holding of the button "Back" or "Forwards" the robot will reach the nearest position on an average speed and if the button is still pressed, will proceed to maximum speed. After the button will be released robot will lower its speed and automatically stop on the nearest, on a course of travel, a position.

In the automatic mode commands of the control program are read out from PROM or ROM according to the program counter. Each command is fulfilled not continuously, and is but discretely during a. It is conditionally possible to select three strokes of command execution: reading of the code and the data; decoding, check of equipment

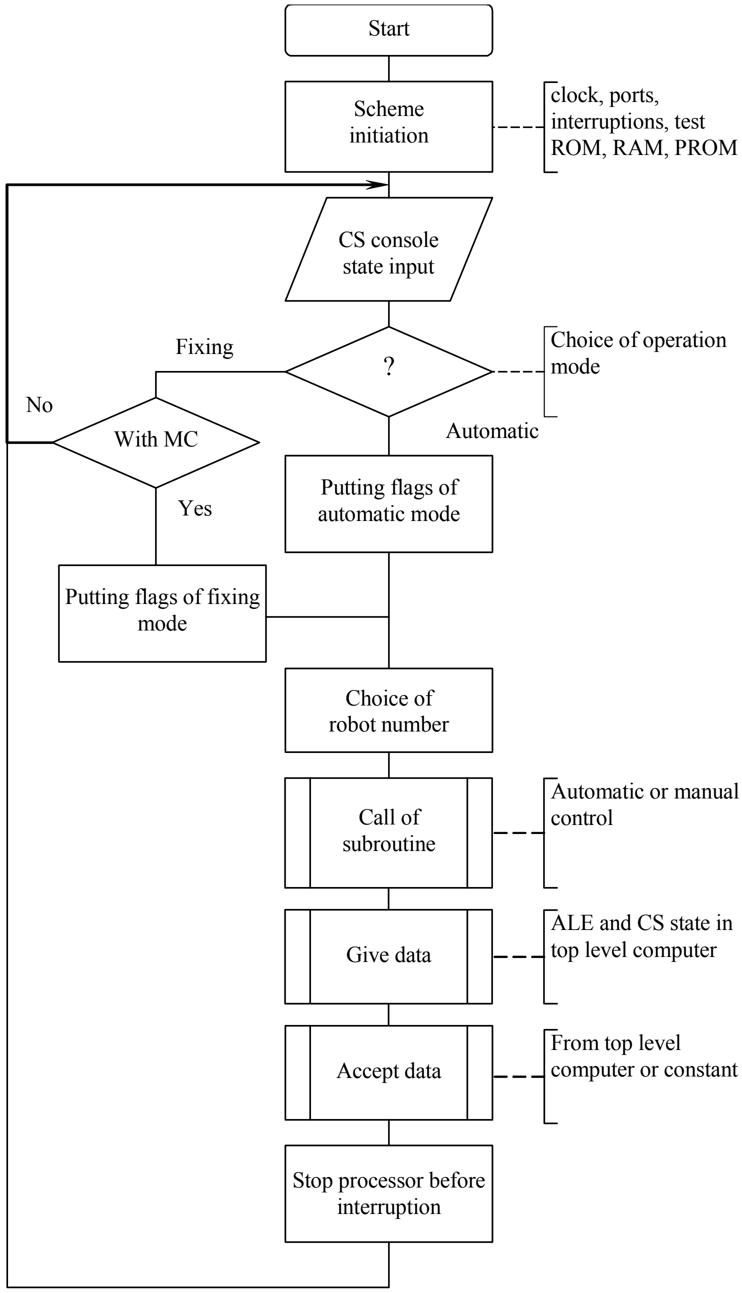

Fig. 8. Flow-chart of main program algorithm

state and creation of instructions; instruction termination. The first and third strokes demand one time slice. The quantity of time slices required for the second stroke is defined by a state of robots and ALE equipment. To define the stroke number in algorithm the flag of command activity is used.

In horizontal travel it is connected with multi-speed mode of operation. In vertical travel having two sensors of upper and lower positions a robot can make intermediate stops. For example, for a drum-type line, the command "Upwards" will have the following steps: to lift up during time t_1, to wait t_2, to raise up to a signal from the sensor.

The given algorithms illustrate completely enough features of program organization of microprocessor control systems of transport robots ALE.

Автоматизированное проектирование микропроцессорной системы управления транспортными роботами линии гальванопокрытий

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Ключевые слова и фразы: автоматизированная линия гальванопокрытий; микропроцессорная система управления; транспортный робот.

Аннотация: Предлагается типовая структура систем управления транспортными роботами автоматизированных линий гальванопокрытий. Рассмотрены назначение и особенности функционирования элементов структуры. Показан пример микропроцессорной системы управления.

Automatisierten Projektierung des Mikroprozessorsteuersystem der Linie der Galvanobedeckungen-Transportroboter

Zusammenfassung: Es wird die typisierte Struktur der Steuersysteme der Transportroboter der automatisierten Linien der Galvanobedeckungevorgeschlagen. Es sind die Bestimmung und die Besonderheiten des Funktionierens der Strukturelemente untersucht. Es ist das Beispiel des Mikroprozessorsteuersystemes aufgezeigt.

Conception automatisée du système à microprocesseur de la commande des robots des lignes des revêtements électrolytiques

Résumé: Est proposée une structure type des systèmes de la commande des robots des lignes automatisées des revêtements électrolytiques. Sont examinées la destination et les particularités du fonctionnement des éléments de la structure. Est montré le système de la commande à microprocesseur.
