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Editor of series: Nenad Radojković, e-mail: radojkovic@ni.ac.yu
Address: Univerzitetski trg 2, 18000 Niš, YU
Tel: +381 18 547-095, Fax: +381 18 547-950
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TIME PARAMETERS OF MICROCOMPUTER CONTROL BY THE ACTUATORS IN AUTOMATION TECHNICAL SYSTEMS

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Milan Bukumirović

Faculty of Transport and Traffic Engineering, University of Belgrade

Abstract. *Time parameters of control which characterize action speed of components in automation technical sustem: of power units - actuators and microcomputers (microprocessors) are discussed and defined in this work. On the basis of already known mathematical models for dynamic transitional processes, appropriate duration of these processes in fluid actuators is determined. In this way the required time is defined, i.e. action speed of operating control devices of technological equipment and of automatic control systems of automated processes.*

1. INTRODUCTION

The present state and expected development trend of flexible production systems (FPS) and of their flexible transport systems (FTrS), as well as of other automated and robotized systems, are characterized by application of new technologies; from widely spread use of robots (during the seventies) to production systems integration and communication systems integration (Fig. 1) [2, 6, 7, 14].

In such systems the control over the FTrS and their of operations – the processing control information system (PCIS) represents the core of the entire control system. From the user's point of view and that of designing two basic groups of problems in automatic microcomputer control are solved:

- control of operating mechanisms -actuators, and
- hierarchic arrangement of control of the system, i.e. of the process [1, 2, 6, 8, 13, 14, 15, 16, 19, 20].

The first case refers to the control of a single device or of a number of them, while the second one discusses group control over robots and equipment that realize the designed process of operation. Starting point of the hierarchic arrangement of control is, as in any other type of control, the control of actuators (operating devices). That is the reason for

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discussing the control of actuators in respect to the detailed defining of time parameters - of their operation speed (activation). Integrative observation of actuator operation speed and of operation speed of computer control system, what cannot be found in technical literature but is of a constant need in practice, allows for defining complete automatic control system (of ACS).

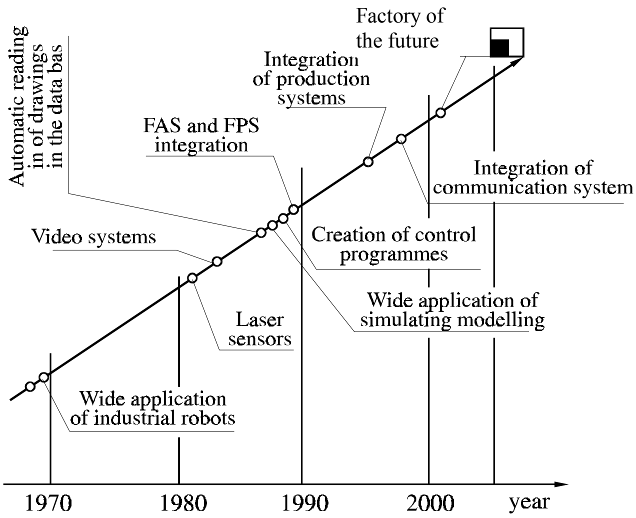

Fig. l. Development trend of flexible production systems to the end of the century
FAS - Flexible automation systems; FPS- Flexible processing systems

2. REALIZATION SPEED OF MICROCOMPUTER CONTROL SYSTEM

Processing control information systems, such as the ACS, are realized by computer technique. In contemporary automatics time systems it is carried out by direct digital control. In the FPS programming comprieses setting of tasks formed according to synchronized-cyclic algorithm of control [2, 8, 13, 15, 16, 17], which in general case of the ACS has the form as follows:

$$M_0 y(t+\Delta t) = M_o A\{u(t) + B\,|\,M_0 y(t)\,|, \xi(\tau)\} \tag{1}$$

where is:

- M_0 – mathematical expectation (mean value);
- y – vector of output values;
- t – current time of the process;
- Δt – time between the start of the ACS action till obtaining response information on this action results;
- A – action operator on the whole;
- u(t) – vector of control calculated by means of a computer and transmitted onto the actuator power unit;

B – controlling disturbances operator;
$\xi(\tau)$ – vector of monitoring accidental (non- controlling) disturbances;
τ – time of control and development of the process.

In fluid actuators (hydraulic or pneumatic ones) with electromagnetic distributor (electrohydraulic or electromagnetic one), with a possibility of braking (damping), and with microcomputer (microprocessor) control (Fig. 2), the change of time parameters *t* and τ [1, 15, 17] occurs in the domain of:

$$t_0 \le t \le t_0 + T, \quad \text{and} \quad t \le \tau \le t + \Delta t \tag{2}$$

where:
t_0 – starting time, and
T – time interval of the course and observation of the process (and of control).

Action speed of the ACS operation with fluid actuators, in respect to the system structure (Fig. 2), consists of:
- action speed of a computer, and
- action speed of electrohydraulic and/or electropneumatic actuators.

During the technological process it is necessary to know the time of actuator executive action and the speed of microcomputer control action. In the ACS, by application of direct digital control, control action speed represents, in fact, delay (τ_{del}) of the control action in relation to the course - condition of the technological process, ($\tau_{process}$) [1, 15, 17].

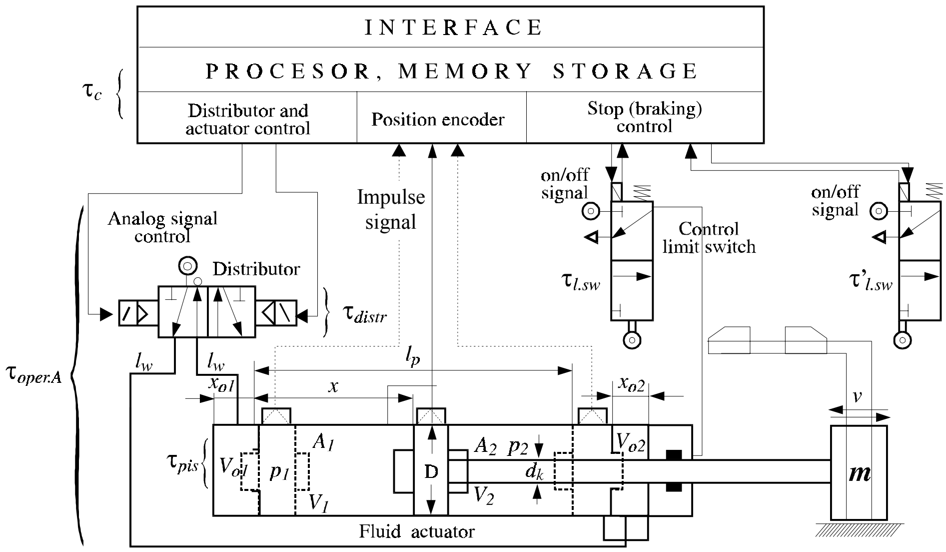

Fig. 2. Fluid actuator (operating mechanism) with microcomputer control (and possible structure and functions of microcomputer system)

For the ACS synchronized control in real time is possible by means of a digital computer (the constant n has the value of $0 < n \le 1$ and it is always $n > 0$), what results into multiple stabilization of processing parameters [15]. In that case the time of control action delay time in relation to the moment of change of the technological process condition amounts to:

$$\tau_{del} = n\,\tau_{process}, \quad \text{for} \quad 0 < n \leq 1 \tag{3}$$

In the processing control information system (PCIS), the time of control action delay is the sum of the computer engagement time required for establishing programmed control (τ_C) , and the time of mechanical motion performed by the actuator ($\tau_{oper.A}$) (Fig. 2), which activates operating device or mechanism:

$$\tau_{del} = \tau_C + \tau_{oper.A} \tag{4}$$

This equation (4) defines the action speed of the automatic control system (ACS) ($\tau_{control} = \tau_{del}$) over the process as the technological object of control (TOC) – ACS TOC. It means that the term action speed of the ACS TOC denotes the time that elapses from the beginning of measurment of the output controlled value to the end of the actuator motion of the operating control device for the purpose of its defined correction, and the time of the computer reception of the electric signal sent from the limit switch designating that the control action (motion, force action, etc.) is performed.

Limit cut-off switch or hydraulic pressure relay activates exhaust cam adjusted at the end of the pistion rod at the point of contact of mechanism with support, or the pistion itself activates contactless limit switch for the position of the piston in the cylinder at the end of the piston braking motion.

3. OPERATION SPEED AND CONTROL ACTION SPEED OF MICROCOMPUTERS

The time of computer engagement in the ACS structure represents summed times of measuring output controlled values and information transmission to the computer ($\tau_{m.t}$), of waiting time before channels for information processing - subsystems of a digital system and selection of the mode of control ($\tau_{w.selec}$), of processing time – of programme realization of control (τ_{prog}), of the time at output, i.e. the time of control signal transmission (information carrier) along the lines to the operating actuator ($\tau_{t,ex}$), and of the time of pure delay ($\tau_{p.del.}$). The time of pure delay represents the time affirmative information transmission - of electric signal designating that control and corresponding operation (motion, force action, action of pressure, etc.) is performed. According to the above said:

$$\tau_C = \tau_{m.t.} + \tau_{w.selec} + \tau_{prog} + \tau_{t.ex} + \tau_{p.del} \tag{5}$$

During the operation in real time when, with the signal selection the conversion of the signal is stimultaneously initiated, as well as reading in of the selects, the time of analog-digital conversion (τ_{cv}) is effectively added to the total time of the transport delay of the processor ($\tau_{tr.del.}$). Then, the time of the total transport delay ($\tau_{tot.\,tr.del}$) is as follows

$$\tau_{tot.tr.del} = \tau_{tr.del.} + \tau_{cv.} \tag{6}$$

It should be pointed out that, when observing the total time of the programme realization (τ_{prog}) which includes the time of transport delay ($\tau_{tr.del}$) and the time necessary for realization of the rest of the programme ($\tau_{0.prog}$); the time of performing the rest of the programme also includes the time of analog-digital conversion. Neglecting these time values ($\tau_{0.prog} - \tau_{cv} \approx 0$), it can be assumed that the total processing time is:

$$\tau_{prog} = \tau_{tot.tr.del} \tag{7}$$

The total time of the programme realization should be shorter than the period of selection, so that the system could operate in real time [14]. The time required for realization of certain programme is, as a rule, very short and depends on the type of computer, programme complexity, the class of objects complexity and the process, and on the TOC dynamics [15, 17].

In digital automatic control systems periods of selection can be of different values. That depends, first of all, on the class of objects complexity and the process, as well as on the TOC dynamics.

For robotic system $\tau_c \leq 20$ ms [13] is recommended, but for simpler automated systems it should be even shorter [1, 8, 15, 20].

4. OPERATION SPEED - ACTION SPEED OF FLUID ACTUATORS

The speed of control and regulating actions of operating actuators (of different kind of power - hydraulic or pneumatic ones) which activate the control device, i.e. its operating computer controlled mechanism means the time that elapses from the moment of control electric signal action on to the electromagnet of coresponding distributor until the end of the planned piston motion (with the piston rod) in the cylinder, and the moment of activating the limit switch which sends the signal designating that the motion is finished. It is the time of relization of one operating cycle of the cylinder and of one control cycle.

In complex ACS with trunk lines where operating fluid is under constant pressure, the total time of fluid actuator operational motion, that of the piston with the piston rod in the cylinder (Fig. 2) consists of the summed up times of switching the distributor on (τ_{distr}) and of the full operation of the piston rod with the piston in the cylinder (τ_{pis}) [3–20]:

$$\tau_{oper.A} = \tau_{distr} + \tau_{pis} \tag{8}$$

Defining of τ_{distr} in the actuator fluid power unit by establishing the model of distributor elements dynamics, of electrohydraulic or electropneumatic ones, and by means experimental investigation for various structural and operational characteristics [1, 7, 10, 11, 12] can be found in numerous books of technical literature, but for the use in practice the following equations can be applied:

$\tau_{dstr.h} = 0.03–0.18$ sec - for electrohydraulic distributors, and

$\tau_{dstr.p} = 0.005–0.170$ sec - for electropneumatic distributors [1, 10, 20].

Piston rod stroke time, from its initial position to its complete drawing out, is structurally complex and consists of the sum of: uniform motion time (τ_u), transitional processes time ($\tau_{t.p}$) and pressure control valve time i.e. of the limit switch ($\tau_{l.sw}$):

$$\tau_{pis} = \tau_u + k \cdot \tau_{t.p} + \tau_{l.sw} \tag{9}$$

where *k* is the coefficient of the operating fluid line structure (for the line without slowing damping *k=1*, and *k=1.5* for the line with slowing down).

For differential cylinder where fast supply of oil can be provided best, related uniform drawing out of the actuator piston rod is:

$$\tau_u = \frac{l_{pis}}{v} = 60\frac{l_p A_1}{1000\,Q} \ \text{(s)} \tag{10}$$

where:

l_p (cm) – piston stroke at constant speed (Fig. 2.);
A_1 (cm^2) – piston face area (Fig. 2.);
Q (l/min) – operating fluid quantity led into the actuator cylinder.

Analysis of fluid actuator dynamic characteristics results in equations of piston motion (at start, during uniform motion and at braking), as well as in defining of outer forces, i.e. of operating fluid dynamics [1, 3, 8, 11, 12, 13]. Mechanical system forces - operating device structures: operational forces in action and mobile masses are reduced at the free outer end of the actuator piston rod. Reduced mobile mass *m* and resulting force do not depend on the law of motion referring to the mechanism of the device, but only depend on the position of the mechanism (Fig. 2).

The time of transitional processes dunetion represents the summed up times (Fig. 3, and Fig. 4) of:

- the time when pressure in the cylinder is raised to the moment of starting piston motion inside the cylinder (τ_{st});
- the time of piston acceleration till the moment of achieving uniform motion speed (τ_a);
- the time of piston slowing down (of "braking") (τ_{stop}) when a uniform linear reduction of speed to about zero is expected; and
- the time of "damped stooping" (or of elastic stopping) ($\tau_{e.stop}$), when the piston stops motion elastically – "moves" in an oscillating way with constant creeping speed (boundary layer speed).

During that period, when the piston stops, the pressure rise occurs up to the pressure value on the control valve.

The equation is now as follows:

$$\tau_{t.p} = \tau_{st} + \tau_a + \tau_{stop} + \tau_{e.stop} \tag{11}$$

The times τ_{st} and $\tau_{e.stop}$ comprise piston motion in chambers – "idle times" V_{o1} and V_{o2}, with lengths of x_{01}, and x_{02}, (Fig. 2, and Fig. 3b).

On ideal diagrams of piston speed change, in cases when an actuator operates only during acceleration and slowing down periods (Fig. 3a), or also with uniform motion at constant speed – the interval ($t_2 - t_1$), the feature of elastic damping of fluid is not taken into account, but the motion finishes at the cutting point $\tau_{cycl.}$ of the linear curve of braking with the abscissa axis of time. That time of ideal ending of braking $\tau_{i.br.}$ is insignificantly shorter than the time $\tau_{e.stop}$ (Fig. 3b). In that case the time of the limit switch activation ($\tau_{l.sw.}$) is not taken into account either. Such diagrams are characteristic for rigid systems and hydraulic actuators.

Real diagram of the actuator piston motion cycle ($\tau_{cycl.A} = \tau_{pis.}$) includes the time of damped stopping ($t_{e.stop}$), as well as the time of activating the limit switch ($\tau_{l.sw.}$). These times overlap significantly, so only the limit switsh time that is not overlapped ($\tau'_{l.sw}$) is included in calculation ($\tau_{l.sw}$) (Fig. 3b). According to this, the total time of one cycle of the actuator action is:

$$\tau_{cycl.A} = \tau_{st.} + \tau_a + \tau_u + \tau_{stop} + \tau_{e.stop} + \tau'_{l.sw}. \tag{12}$$

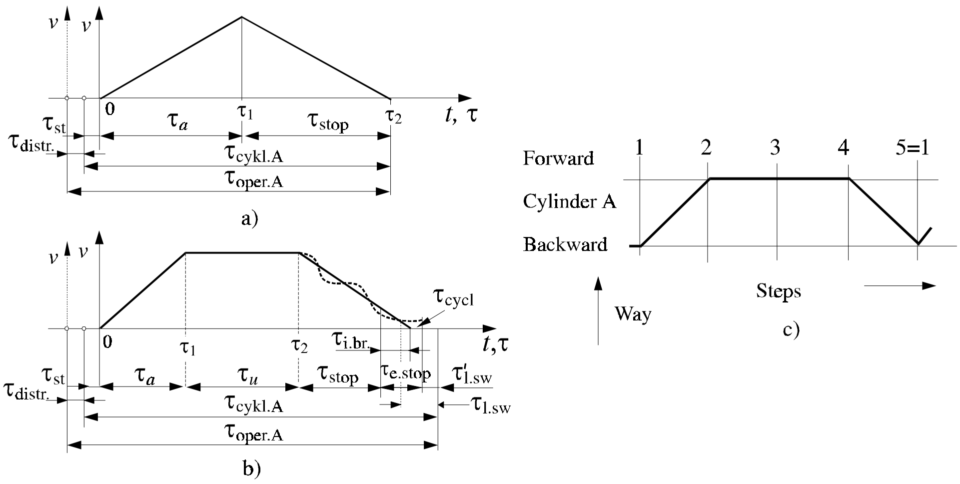

Fig. 3 Ideal diagrams of speed (a, b) and parth-step (c) of piston motion in fluid actuators a) Speed diagram of transitional processes only, b) Speed diagram with the segment of uniform motion and of transitional processes , c) Way-stop diagram (change of piston rod position)

Mathematical modeling of the fluid actuators dynamic processes [1, 3, 4, 5, 10, 11, 12], which in its results contains the systems of differential equations; direct measuring on model installations [3, 10, 12], and process simulation [11] identify characteristic parameters of the actuators processes discussed.

Simulated piston motion speed (v) of the pneumatic cylinder can be rather precisely approximated by means of a diagram of the speed change (v_m) which is analogous to the speed change in hydraulic cylinder (Fig. 4) with nearly all time parameters of the piston motion. In respect to the fact that the speed of piston motion in pneumatic cylinder is conciderably hygher in comparison to the speed in fydraulic cylinder, the differences in time of transitional processes apper. There, also, the time of "damped stopping" and the time of the limit switch are taken separately.

For practical calculations in hydraulic actuators with line length (thrust and return ones) $l_w \leq 10$ m, it can be accepted that $\tau_{t.p} = 0{,}4$ s for $p \leq 10$ (bar), and $\tau_{t.p} = 0{,}25$ s for $p > 10$ (bar) [1].

The time of contact limit switch activation depends on its structure and purpose. That is why this time can range from 5 ms to 75 ms – electricity or pneumatically activated switches. In pressure relay and electromagnetic switches the values of $\tau_{l.sw} = 150$ ms can be used [5, 15, 20].

Contactless inductive limit switches turn on and/or off in a very short time, $\tau_{l.sw} \leq 2$ ms [15, 20]

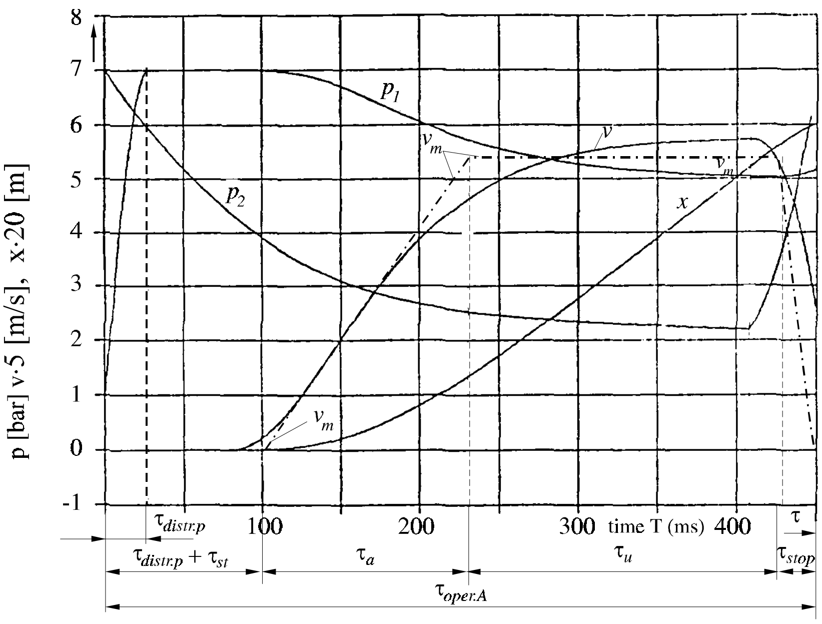

Fig. 4 Dynamics parameters of pneumatic actuators
(D = 50 mm, d = l6 mm, S = 0.3m, F = 600 N, m = 20 kg)
v (t) - piston motion speed from the moment of switching on the distributor,
$p_1(t)$ - operation pressure in the thrust chamber of the cylinder.
$p_2(t)$ - pressure in the retum chamber of the cylinder,
x(t) - piston path in the cylinder
–·–·–· aproximated value of the piston speed (v_m)

Total transitional time with the time of activating the distributor and pressure valve time added, which in control sense are considered integral parts of an actuator, apart from many influencing factors, for calculation in practice the experimental data given in the table 1 can be used [1, 10, 20].

Table. 1

	ACTUATORS	
	HYDRAULIC	PNEUMATIC
Action	$\tau_{distr}+\tau_{t.p}+\tau'_{l.sw}$ (s)	$\tau_{t.p}+\tau'_{l.sw}$ (s)
Without braking	0,55÷1,0	
With braking	0,8÷1,2	≲ 0,20
With fast action	≈0,5÷0,8	

5. CONCLUSION

In the discussion presented time parameters of automation technological systems are defined: of computers and actuators. Fluid actuators are most frequently used as power units of operating control devices of the ACS. More than that, fluid actuators appear in various technical fields as power units of machines or of parts of machines, of devices and installations, of breeches and valves. Hydraulic actuators are irreplaceable for the purpose of overcoming strong forces and considerable lengths of motion.

Applying integrative discussion of time parameters of microcomputer control over fluid actuators, by establixhing corresponding formulae and by presenting real tabular data the basic aim of this work is accomplished. It is obvious that:

– by defining time parameters, action speed of the components and the speed of the whole ACS is defined,
– demands and possibilities of application of appropriate components and of the ACS in technical systems which realize certain processes are dfined in an exact way, and
– the probelem and possibilities of microcomputer control application is explained to a greater number of professionals who have not yet specialized in this field.

In this way, complete discussion of the ACS through investigation of its time parameters of the working process, which has not been carried out until now, allows for complete design of the ACS and application of algorithms and programmes for automatic (computer) designing. By calculating the time of actuator operation, it is possible to make optimum choice of control microcomputer which is the most expensive and the most important component of automation process.

Directors of designing, exploitation and business policy can benefit from this.

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VREMENSKI PARAMETRI - BRZINA DEJSTVA MIKRORAČUNARSKOG UPRAVLJANJA IZVRŠNIM ORGANIMA TEHNIČKIH SISTEMA AUTOMATIZACIJE

Milan Bukumirović

U radu se razmatraju vremenski parametri upravljanja koji karakterišu brzine dejstva komponenata tehničkih sistema automatizacije: pogonskih organa - aktuatora i mikroručunaru (mikroprocesora). Na bazi poznatih matematičkih modela dinamičkih prelaznih procesa, kod fluidnih aktuatora utvrđuju se odgovarajuća vremenu trajanju ovih procesu. Na taj način se određuje potrebno vreme - brzina dejstva izvršnih upravljačkih uređaja tehnološke opreme i automatskih sistema upravljanja automatizovanih procesa.