Examples of the Use of Method of Division of Motions in Practice

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Abstract: **This paper gives the examples of the use of the method of division on motions [1, 2] in practice. The first example is the design of the temperature control for semiconductor laser. Dynamic of this system is difficult to control because this system is sufficiently not stationary. Indeed, the productivity of the cooling with the use of micro-freezing device based on Peltier effect depends on the environment temperature, as well as on the prescribed one, and on the power of the laser light. All these parameters are changing during working operation of the semiconductor laser; hence, the transfer function of the thermal stabilizing loop is not stationary. Adaptive system is difficult to design, and the method of the division of motions provides robustness of the resulting system. The other example is the tracking system for the disk memory. This system has been developed earlier in Institute of Automatics and Electrometry, further the analog system are used in teaching purposes. The speed of the working of the disk memory depends on the accuracy of the tracking systems which stabilize the focusing of the optical lenses in the dynamic processes and allows following of the necessary tracks in the disks. The reason of non stationary features is changing of the loop gain due to the difference light power in the difference modes of the device working. Indeed, when only reading, the system uses small level of the light power, whereas in the writing mode the power is by ten times more. This is the reason for the relevancy of the discussed methods of the feedback control design.**

Key words: **division motions method, localization method, feedback, control, automatics, dynamic error, static error**

INTRODUCTION

Papers [1, 2] propose the method of division of motion. These paper states the results only on the base of mathematical relations. The paper presents results, based on the practice, which was implemented in real project for science and on the training setups for higher education laboratory works.

1. DYNAMICS OPTIMIZATION OF THERMAL STABILIZATION LOOP FOR SEMCANDUCTOR LASER

The progress achieved in optical information technologies require the development of precision systems of automatic control as devices for automatic focusing, track following, drive control, thermal stabilization of active medium of light sources etc. Many questions in this field are already successfully resolved, but the increasing of the dynamics quality is still relevant.

In some cases, the object is described by nonstationary linear differential equations. For example, when solving the problem of thermal stabilization of semiconductor (diode) lasers, one has to take into account the nonlinearity of microfreezer and its dependence on the environment temperature. The temperature is measured with a real probe described by the first order equation, i. e. the object state vector is only partially accessible for measurement.

Let us consider the thermal stabilization system for semiconductor laser [3–26]. The stabilization of temperature is achieved with the use of microfreezer on the base of Peltier element, whose equation has the form

$$\theta + T_1 \frac{d\theta}{dt} = k_1 J \,. \qquad (1)$$

where J, T_1, k_1 are current, time constant and gain of microfreezer respectively, θ is the temperature of working facet of the laser.

There is a limitation

$$J \le J_{\max} = 2.6A \,. \qquad (2)$$

The temperature θ is measured with the thermister connected by the bridge circuit, The bridge equation is

$$\Delta\varphi + T_2 \frac{d(\Delta\varphi)}{dt} = k_2 \theta \,. \qquad (3)$$

Here $\Delta\varphi, T_2, k_2$ are the output voltage, time constant and thermister gain respectively. The characteristic feature of thermal stabilization device is the dependence of parameters k_2 and T_1 on the control current value, air temperature and power of laser emitter. This can be explained by the microfreezer efficiency is defined as a difference between the removed and scattered proper power values. The first one is a linear function of current and the second one is quadratic function. If the prescribed temperature is higher then air temperature, the microfreezer is operating as a heater and these power are added up together.

In Ref. [22] it is proposed the following form of regulator

$$J(s) = \frac{k}{1+Ts}[v(s) - \Delta\varphi(s)]$$

with the current limitation according to (2). In this case, $T \approx 2.3s^{-1}$ being one order of magnitude lower then T_1 and T_2 and the gain $kk_1k_2 >> 100$, therefore, the regulator characteristics are close to the relay ones. The disadvantage of such a regulator is an established oscillatory regime, which, in spite or the filter properties of microfreezer, decreases the emitting stability.

In Ref. [24] for such a system it is proposed the proportional and integral (PI) regulator of the kind:

$$J(s) = \frac{k(1+Ts)}{s}[v(s) - \Delta\varphi(s)],$$

where k, T are regulator parameters selected empirically. It is clear that its speed of response should be found out from the stability condition with all possible values of time constant T. According to the method proposed in this work one can stability of the system with the desired dynamic properties, Let the equation describing the desired dynamic properties for variable θ have the form

$$T_d^2 \frac{d^2\theta}{dt^2} + 2\xi T_d \frac{d\theta}{dt} + \theta = v, \qquad (4)$$

where v is prescribed value, ξ is damping coefficient, T_d is the desired speed of response,

If one take $\xi = \sqrt{2}/2$, the duration of transient process is equal to $3T_d$, and overshooting does not exceed 5 %. Such systems in technical automatic control are considered as more preferable [1].

With the purpose to obtain the equation of the desired dynamics as a function of state $x = \Delta\varphi$ let derivate twice the equation (3) and from this find out the value θ and its derivative whose substitution into (4) yields:

$$T_d^2 T_2 x^{(3)} + (T_d^2 + 2\xi T_d T_2)x^{(2)} +$$
$$+ (2\xi T_d + T_2)x^{(1)} + x = k_2 v.$$

Let us use the relations from [2]. Here, $n = 2$, $m = 3$. The value m is defined by two equations, since the desired dynamic properties for variable θ are described by the second order equation (4) and the probe equation (3) is of the first order. For this case, the characteristic polynomial is

$$N(s) = \mu^2 s^5 + \mu s^4 + Cs^3 + Bs^2 + As + 1,$$

where $\mu = k^{-1}k_2^{-1}$, $C = T_d^2 T_2$, $B = T_d(T_d + 2\xi T_2)$, $A = 2\xi T_d + T_2$.

The regulator equation

$$J(s) =$$
$$= k[-\frac{Cs^3 + Bs^2 + As + 1}{D(s)}x(s) + \frac{v(s)}{D(s)}]. \quad (5)$$

Here $D(s) = k^{-1}k_2^{-1}s^3 + 3s^2 + 2s + 1$. The coefficients $\alpha_1 = \alpha_4 = 1$, $\alpha_2 = \alpha_3 = 2$ in the denominator are selected form the condition of regulator pole location in sector ±60° in the left half-plane. Coeficients A, B, C should satisfy conditions $B^2/(AC) \geq 2$, $A^2/B \geq 2$. These inequalities are satisfied if $T_d \geq 0{,}9\max\{T_2\}$ taking into account $\xi = \sqrt{2}/2$.

Thus, the system maximum speed of responses is limited from below by this of thermister T_2. This is valid only for slight deviations which do not violate the satisfaction of limitation (2). In the case of $x(s), (s)$ are such that value J in regulator (5) exceeds $J_{\max}$, one should limit the control current according (2). Therefore, the speed of response with large deviations is defined by the properties of the microfreezer itself, namely by the value T_1.

This physical limitation produces essential influence only during the compensation of an initial deviation and during the fast (compared to T_1) changing of prescription, i. e. $v \approx const$, the limitation (2) affect only starting period whereas in the established stabilization regime the controllers object behavior is linear and stationary with required dynamic properties.

The diagram of the analog variant of system is shown in *Fig* 1. Digital system based on microprocessor I8051 has been made too. *Fig.* 2 shows the connection diagram of the temperature sensors to the inputs of the microprocessor. *Fig.* 3 shows the recommended construction for stabilizing the temperature of semiconductor laser. The design is particularly important for achieving high accuracy of the temperature control. Operation of thermostabilization systems in conditions of strong pickups from pulsed laser power supplies requires reducing the length of the conductors from the sensor, introducing a galvanic isolation of the input circuits.

High thermal conductivity of the object makes it possible to use the simplest design in which the heat conductor provides thermal contact between the object and the temperature sensor with the working face of the micro freezer. The whole structure is thermally insulated with a casing, and excess heat is diverted from the second surface of the micro freezer through a radiator, cooled by air or water. For better stability, it is also possible to recommend thermostabilization of the casing itself. In this case, the temperature gradient from the sensor to all points of the casing will be more stable, since the temperature of the sensor is stabilized by one circuit, and the temperature of the casing (equipped with an additional sensor) is different.

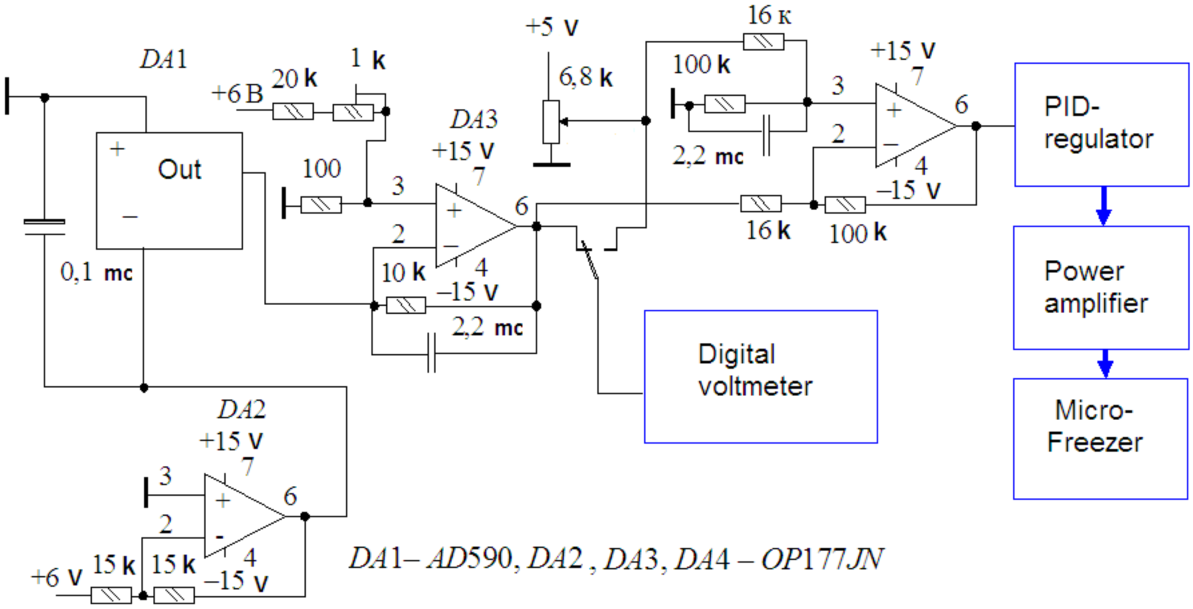

Fig. 1. Thermal stabilization system

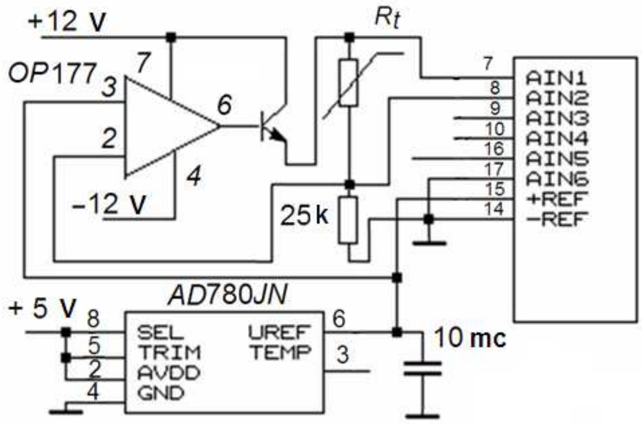

Fig. 2. Circuit for connecting of temperature sensor *AD*780*JN* and thermometric resistor R_t with ADC *AD*7714*JN*

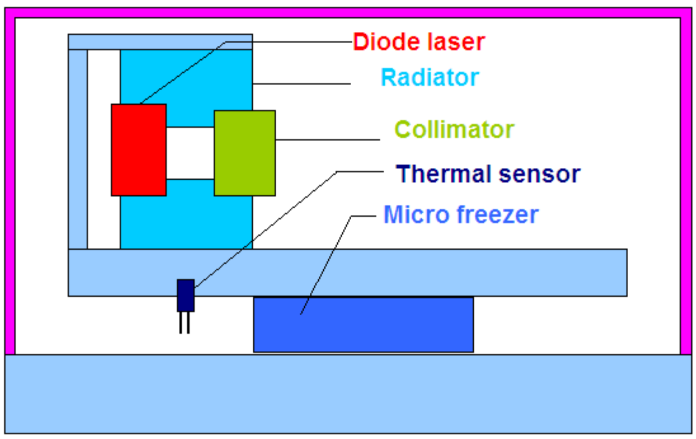

Fig. 3. Construction of the thermal stabilization system

2. THE DESIGN OF TRACKING SYSTEMS FOR FOCUS AND TRACK FOR MAGNETO-OPTIC MEMORY

The reading and writing in the systems of magneto-optic memory (MOM) [27–29] is performed by the contactless method with a sharply focused light beam of semiconductor laser of about one micrometer in diameter. The inevitable disk run-outs both for the focus and those along the rotating axis require the development of precise and reliable automatic tracking system both for the focus and for the writing-reading track carved on the disk.

There are many difficulties in the design of such systems. First of all, the controlled object , which is micro objective with electromagnetic drive (actuator) and optical-electronic probes of position all together are nonstationary. The static gain of the corresponding object is proportional to the disk reflection coefficient which is depending on the requirements of standard can vary from 0.1 to 0.9. In addition, the gain of the controlled object is proportional to the power of laser light which is changing from the reading to the writing modes by the order of magnitude, Second, the controlled object can have nonlinear properties (dry friction, for example). Third, due to specific features of optical detection of weak signals the position probes introduce considerable value of a noise into system. Fourth, because of high speed of the disk rotation (up to 250 rotations per second) and substantial inertia of actuator compared with the speed of response required, the regulator should provide high quality tracking within the broad frequency range: up to frequencies corresponding to substantial damping of the object transfer function and large phase shifts.

The purpose of control in the focus tracking channel is to reduce to zero the defocusing $y(t)$ being equal to the difference between signal $x(t)$ and disturbance $h(t)$, which is vertical motions of the disk surface cased by the beatings. Value $x(t)$ is an increment of corresponding coordinate of focusing lens due to motion of rigidly connected actuator. In the channel of the track tracking the disturbance $h(t)$ it the track radial deviation because of eccentricity, and the radial component of objective motion corresponds to the signal $x(t)$. The transfer function of control object is given in the form of product of transfer function of the actuator and error probe. On the error probe output there is a measurement noise $g(t)$ as *Fig*. 4 shows, where $u(t)$ is control signal. Signal $z(t)$ is accessible for measurement. The influence of light power on the error probe sensivity bk^{-1} is especially strong concerning the rewritable and single-writing disk memory, since the writing and rewriting modes are executed at different power of the laser light. Therefore, the system dynamic properties are required to be invariant with respect to the light power.

For the tracking system for the track and for the focus, the removal of oscillations by reducing of the order turns to be efficient in the MOM devices as the controlled object (actuator) is described by the second order deferential equation (oscillation element).

The probe transfer function is non-linear element with typical gain in the linear field bk^{-1}, which without restriction of generality can be referred to the object and further we assume $bk^{-1}=1$. As shown above, the object equation is the second order one:

$$(a_0+a_1s+s^2)x(s)=bu(s), \quad (7)$$

where a_0, a_1 are dynamic parameters of the object, $x(s)$ is the Laplace transform of the system output signal $x(t)$ (here the equation is given in the operator form), b/a_0 is a gain of the object (including the error probe), proportional to the light power and disk reflectance coefficient.

The desired equation is given in the form of the first order equation

$$(1+\tau s)y(s)=v(s). \quad (8)$$

Here, τ is a parameter characterizing the system speed of response. So, if the time of transient process is given, evaluated by the time necessary for achieving of the level of 95 % of the prescribed one, for the stepwise input action, it is equal to 3τ. For this case, the regulator has the form:

$$k^{-1}b_0(1+k^{-1}s)u(s)= \\ =-(1+\tau s)z(s)+v(s). \quad (9)$$

Here, $c_0=1$, $c_1=\tau$, $b_0=\chi b$ is an estimation of b, i. e. $\chi\approx 1$ and $(1-\chi)$ is relative error due to instability of b; $z(s)$ is Laplace transform of the output signal $z(t)$. The system “object + regulator” equation we can get by substitution of (9) in (7):

$$[(1+a_0k^{-1}\chi)+(\tau+\chi k^{-1}a_1+a_0k^{-2})s+ \\ +\chi k^{-1}(1+k^{-1}a_1)s^2+\chi k^{-1}s^3]y(s)=v(s) \quad (10)$$

and with the growth of k in the characteristic polynomial of equation (10) one can separate a group of fast (two roots) and slow roots (one root). The later behaviour is not substantially influences by the control terms (10) containing factor $\mu=k^{-1}$ in powers higher then those similar terms (i. e. terms with the same power of s) and with the growth of k their influence is arbitrarily reduced. Within the accuracy of up to these negligibly small terms the equation (10) is equivalent to the following one:

$$(1+\tau s)+(1+\chi k^{-1}\tau^{-1}s+\chi k^{-2}\tau^{-1}s^2)y(s)= \\ =v(s). \quad (11)$$

For the analysis of the influence of the disturbance $h(t)$ and measurements noises one should substitute $z(s)=y(s)+g(s)$ into regulator equation (9) as follows from *Fig*. 4 of one takes into account that $bk^{-1}=1$ is referred to the object, and in the object equation (7) one has to substitute $x(s)=y(s)+h(s)$, where $g(s)$,

$h(s)$ are transforms of noise $g(t)$ and $h(t)$. Then the system (10) equation gets the form

$$d(s)y(s)=k^{-1}\chi[a_0+(a_1+a_0k^{-1})s+$$
$$+(1+k^{-1}a_1)s^2+k^{-1}s^3]h(s)+(1+\tau s)g(s)+$$
$$+v(s).$$

Hence, with $|k^{-1}|<<1$ we get

$$y(s)=W_v(s)v(s)+W_h(s)h(s)+W_g(s)g(s),$$

$$W_v(s)=\frac{1}{d(s)},$$

$$W_h(s)=\frac{\chi k^{-1}(a_0+a_1s+s^2)(1+k^{-1}s)}{d(s)},$$

$$W_g(s)=\frac{1+\tau s}{d(s)}, \qquad (12)$$

where

$$d(s)=(1+\tau s)(1+\chi k^{-1}\tau^{-1}s+k^{-2}\chi\tau^{-1}s^2)$$

From the form of $W_h(s)$ (12) it follows that transient process to the step variation of disturbance $h(t)$ is of oscillatory character because of the third power polynomial in the numerator. For better suppression of disturbance $h(t)$ one should increase k, though, in this case, the filtering of noises $g(t)$ is decreased. i.e. with the affects of $v(t)$, $g(t)$ and $h(t)$ one should take care in the choice of τ and k. If $v(t)=0$, as it is in the case of tracking systems for focus and tracks, it is seems reasonable to increase τ for better suppression of disturbance $h(t)$ and noise $g(t)$.

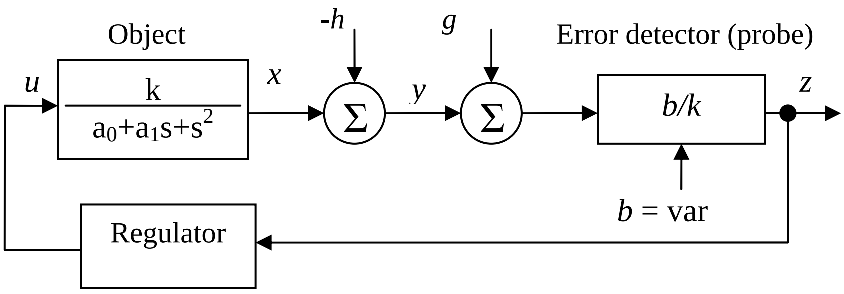

Fig. 4. System structure

Fig. 5 shows transient processes with the regulator according to equation (9) at stepwise input action. These processes were obtained by the computer simulation of equations for the object (1) and regulator (9). In this case, the object parameters are $b=80\cdot10^6$, $\chi=1$, $a_0=0.5\cdot10^6$, $a_1=2.25\cdot10^3$ and regulator parameters are $\tau=10^3$, $k=2\cdot10^4$ (line 1). The change of parameter by the factor of 2 (line 2) and of 0.5 (line 0.5) case the change in the time constant system. The transient processes in the system at action like $h(t)=\cos\omega_0 t$ ($t>0$, $\omega_0=2\pi\cdot250\ s^{-1}$) are shown in *Fig.* 6.

For the regulator realization according to equation (9) let us transform it to the form:

$$u(s)=-k^2\tau z(s)b_0^{-1}+s^{-1}[-ku(s)-$$
$$-k^2b_0^{-1}z(s)+k^2b_0^{-1}v(s)] \quad (74)$$

Introducing notations $A=k$, $B=k^2\tau b_0^{-1}$, $D=k_2b_0^{-1}$ one can get

$$u(s)=-Bz(s)+$$
$$+s^{-1}[-Au(s)-Dz(s)+Dv(s)] \quad (75)$$

With $\tau=10^3$, $k=10^6$ the values A,B,C are $A=10^6$, $B=1.25\cdot10^4$, $D=1.25$.

The regulator structural diagram corresponding to (75) is shown in *Fig.* 6.

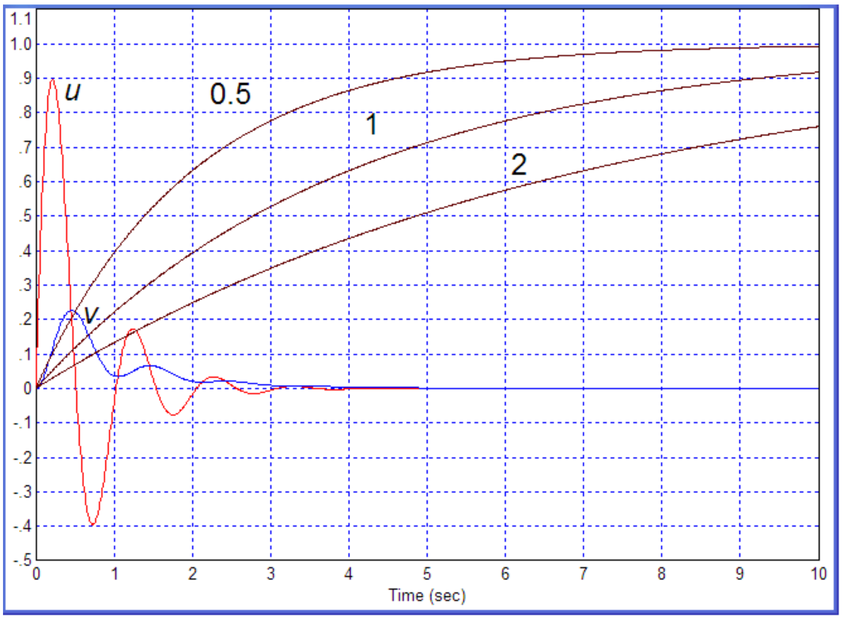

Fig. 5. System reaction on stepwise action: one unit is 0.1 *ms*

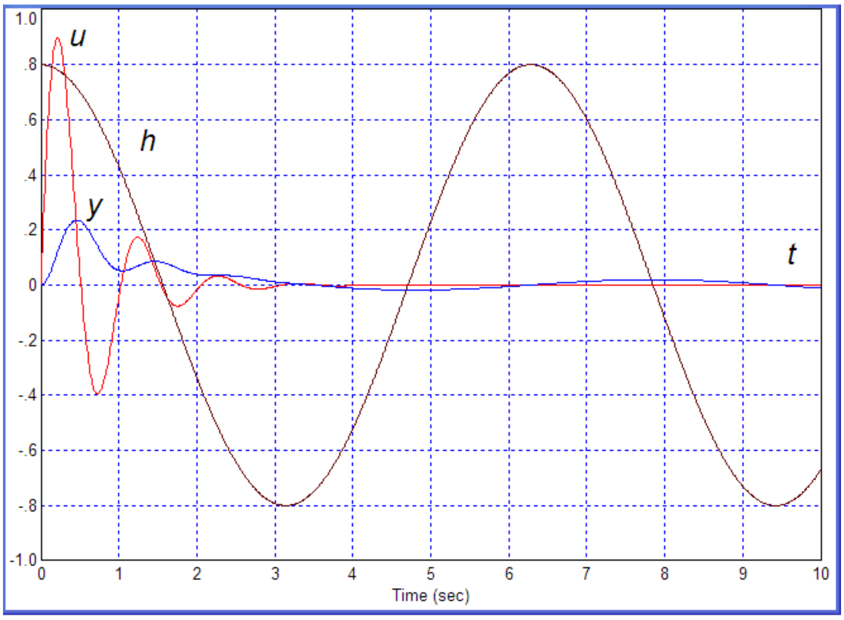

Fig. 6. System reaction on harmonic action: one unit is 0.1 *ms*

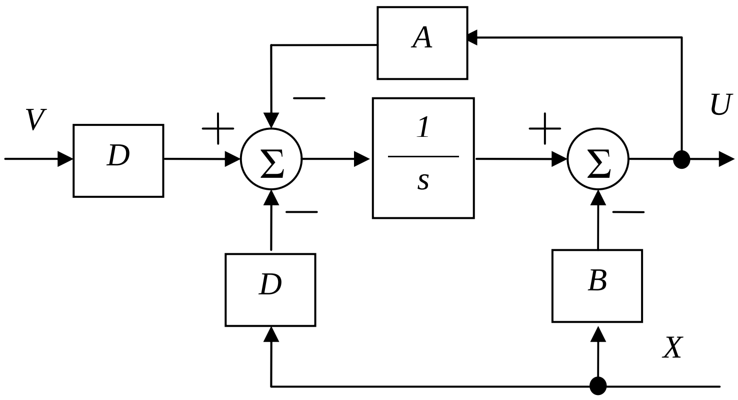

Fig. 7. Regulator structure

The above system has been successfully developed and used in science researches in Institute of automatics and electrometry of Siberian Branch of Russian Academy of Sciences.

CONCLUSION

The discussed examples are very relevant. The results are tested in real setups for science purposes and in training setups for laboratory works in the technical university.

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