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Control Systems in Optical Fibre Industry

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Abstract

The shortage of basic raw materials for production of metallic communication cables on one hand and constantly growing demand for increased density of the communication network and for higher transmission rates on the other hand, stimulated the design engineers to look for new media suited for the data transmission. One of the substitution for metallic transmission lines are optical cables.

Key words

Control systems, real time execution systems, micro computers, optoelectronics optical fibre technology, system modellig.

1. Introduction

The shortage of basic raw materials for production of metallic communication cables on one hand and the constantly growing demand for increased density of telecommunication network and for higher transmission rates on the other hand, stimulated the design engineers to look for new media suited for the data transmission, common telephone calls and TV programmes. One of the substitutions for the metallic transmission lines are optical fibres. The transmission of information in these fibres is implemented by means of light. The light source used are high luminescent semiconductor diodes which are capable of operation at transmission rates over more then 10 Gbit/s when transmitting the digital data.

2. The principle of technology of the optical silica fibre and preforms

In the transmission of optical signals by lightguides over long distances the loss is the most important parameter. The quality of optical fibres very much depends on their production process. Four types of optical fibres have been developed :

a) PCS fibres (Plastic Clad Silica) - the total light reflection is provided by the boundary glass - plastic cladding.
b) All-glass fibres with step refractive takes place on the boundary between the glass core and the glass coating whose indices of refraction slightly differ.
c) Graded-index fibres in which the refractive index varies in the transverse direction parabolically. In this case the optical

paths (product of refractive index and geometric path) of all beams (centre and refracted) are theoretically identical. Then the transmitted pulses are stretched very little and the maximum transmission bandwidth is cca 1 GHz km. The manufacture of gradient fibre preform, however, is much more demanding; it is based on deposition of silica in gaseous phase inside the quartz tube, e.g. by the MCVD method (Modified Chemical Vapour Deposition). There the vapours $SiCl_4$ and SiO_2 at temperature of 1600° C form many thin layers on the internal surface of a quarz tube. The layers are deposited in the reaction zone where there is very high temperature created by a microwave resonator, oxygen-hydrogen burner or a resistance heating device. The heat source slowly moves along the quartz tube and each longitudinal passage creates a new internal layer. The refraction index of each deposited internal layer is influenced by admixtures of $GeCl_4$ or P_2O_5 or by the change of GeO_2 concentration. By such procedure it is possible to create up to several hundreds of layers with varying indices of refraction. Finally, the remaining internal channel is sealed.

d) The latest type of fibre are the single mode fibres. There the light impulses propagate axially without reflection in a very thin core (diameter cca 8 μm). Such fibres have high transmission bandwidths - more than 10 GHz km.

3. The principle of the CNC system developed in the institute of radio engineering AVCR in Prague

The fibre F is drawn (*Fig. 1*) from a preform P the bottom end of which is heated up to 2000 °C. The number and the order of the glass layers in the preform is preserved in the drawn fibre. The ratio of thicknesses of the individual layers remains also the same as in the preform

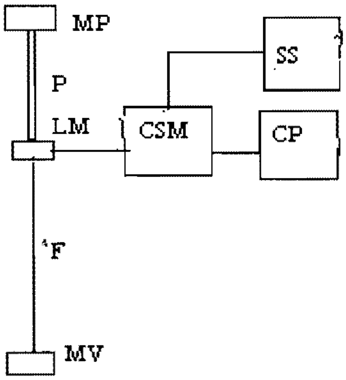

Figure 1: Block diagram of control of technological process for optical fibre drawing.

The drawing servomotor MV is controlled by the control system CSM so that the diameter of the drawn fibre F is equal to the required diameter set by an attendant through the control panel CP. The control system controls yet another servomotor MP which governs the feed of preform P into the furnace. The data on the fibre diameter is fed to CSM from a laser measuring device LM.

The main control computer CSM is interconnected through the internal bus system with a slave computer (microcomputer) SS. The master computer controls also the line recorder enabling to record the value of the fibre diameter or its deviation along its entire length. In the latter case the sensitivity of the recording may be increased to 5:1.

The slave computer SS controls a terminal which has two screens for displaying logical information. On the first the parameters of the control system set by the attendant are presented, on the second all the data computed by the system are displayed. To facilitate handling of the system it is possible to call for instructions by means of push-button HELP for correct selection of control parameters. The instructions appear on the screen.

For elimination of geometrical deviations of the preform from its longitudinal axis the system is equipped by another two servomotors by which the preform is positioned in the plane perpendicular to the direction of drawing so that the fibre passes through the centre of the diameter measuring device LM.

The servomechanisms are, from the computer point of view, connected as peripheries through double parallel duplex interface to the bus system of the microcomputer. The positioning feedback brought from the photoelectric impulse optical encoder of angular displacement is implemented by means of unit DI outside the computer (*Fig.* 2). For on-line measurement of the length of the drawn fibre a photoelectric impulse encoder IRC has been used in the positioning loop. It also defines the positioning accuracy (1/5000 revolution). The speed feedback is brought to the regulator PIR from tachodynamo.

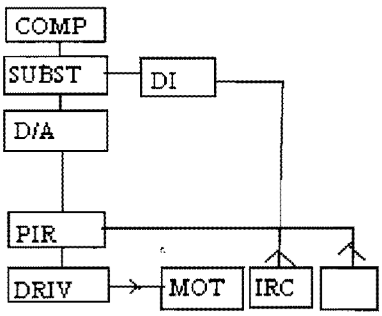

Figure 2: Analog and position loop for the servomotor.

The output data from the microprocessor arranged in fixed time sequence are lead into the digital subtraction in which the output of encoder IRC preprocessed in the unit DI, is subtracted from its contents. The remaining contents in the subtractor represents the regulation deviation of the servosystem converted to voltage in the D/A converter. This voltage is, in the unit PIR, brought with the speed feedback to the regulator PI and to the motor drive.

The unit PIR in *Fig.* 2 is connected to the analogue D/A output of the unit D/A and controls the motor drive. In *Fig.* 3 a simplified diagram of the PI regulator is presented.

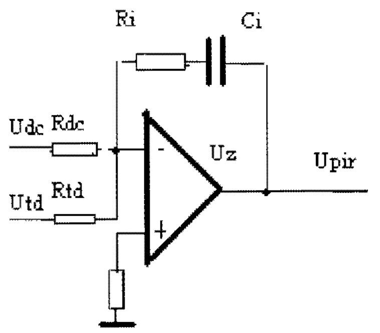

Figure 3: PI Regulator.

Since an infinite amplification is assumed, then

$$(1) \quad \frac{U_{TD}}{R_{TD}} + \frac{U_{DC}}{R_{DC}} = U_Z \frac{1}{R_i + (\frac{1}{pC_i})}$$

$$(2) \quad U_Z = (U_{TD} + \frac{R_{TD}}{R_{DC}} U_{DC}) \frac{pC_i R_i + 1}{pC_i R_{TD}}$$

Where

U_{DC} is the voltage corresponding to the regulation deviation in the subtractor, U_{DT} is the negative feedback voltage from the tachodynamo.

Transmission function in zero initial conditions

$$(3) \quad G(P)' = (\frac{U_Z}{U_{TD}}), \quad U_{DC} = 0$$

$$G(P)_0 = \frac{i + pR_iC_i}{pR_{TD}C_i}$$

4. The matematical model of motor control

Investigation of the system regulator-motor, namely of its dynamic characteristics, is carried out with the aid of its mathematical model and computer simulation. In *Fig.* 4 is a block diagram of the system, which consists of motor, regulator, subtractor with the position and speed feedback. Pulses (f_{IME}) generated by the photoelectrical position sensor IRC are subtracted from pulse sequence f_i . The difference f_{ER} is brought to the 15-bit subtraction where it is converted to voltage U_{DC} from which the output voltage from tachodynamo U_{TD} is subtracted. U_{TD}
realizes the speed feedback.

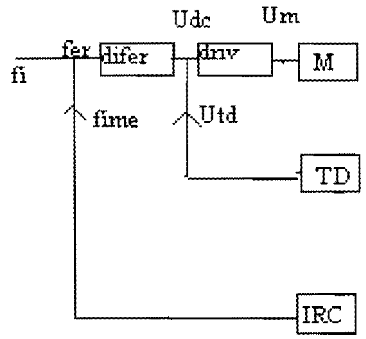

Figure 4: Model of the motor - regulator system.

The resulting voltage is lead to the regulator and a unit whose output voltage U_M drives the servomotor M. In *Fig.*4 also the interface between the numeral position and the analogue speed feedback is shown.

The transmission function of a PI regulator (*Fig.* 3) is represented by equation (3).

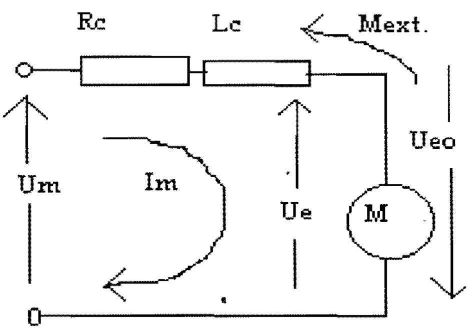

Figure 5: An equivalent diagram of a DC motor.

A linearized model of a DC electromotor is presented in *Fig.* 5. By the law of energy conservation the following relation holds:

$$(4) \qquad U_M \omega_M = (U_e - U_{e0}) i_M$$

where U_M is the voltage at the motor terminals, U_e is the electromotoric force, U_{e0} is the voltage drop due to the armature reaction, M_M is the moment in the shaft of the rotor, M_{EXT} is the external moment in the shaft of the rotor, R_C is the armature resistance, L_C is the armature inductance, i_M is the current flowing through the motor, ω is the angular speed of the rotor, K_M - is the motor constant.

For a motor with permanent magnets it holds:

$$(5) \qquad U_e = K_M \omega_M$$

In case we neglect the armature reaction ($U_{e0} = 0$) we derive from equations (4), (5) the following relation:

$$(6) \qquad M_M = K_M i_M$$

The motion equation is then:

$$(7) \qquad K_M i_M = J_M \frac{d\omega_M}{dt} - M_{EXT}$$

where J_M is the rotor inertia moment.

The voltage across the motor terminals

$$(8) \qquad U_M(t) = U_e + R_C i_M + L_C \frac{di_M}{dt}$$

By substitution from the equation (5) we get:

$$(9) \qquad U_M(t) = K_M \omega_M + R_C i_M + L_C \frac{di_M}{dt}$$

The linear differential equations (7) and (9) represent the state model of the mechanical system. For computer modelling of the system regulator-motor it is convenient to apply the Laplace transform on the state equations and to partition the overall transfer function to parts representing individual blocks. From equations (6) and (7)

we get:

$$M_M = J_M \frac{d\omega_M}{dt} - M_{EXT}$$

and by utilization of the Laplace transform, with the initial conditions set to zero, we

obtain

$$M_M + M_{EXT} = J_M p$$

and the transfer function of the machanical part of the motor is

$$(10) \qquad \frac{\omega}{M_M + M_{EXT}} = \frac{1}{J_M p}$$

From equations (5) and (8) we may derive the following relation

$$U_M - U_e = R_C i_M + L_C \frac{di_M}{dt}$$

and by applying the Laplace transform with zero initial conditions we get:

$$U_M - U_e = R_c i + L_C p i$$

The transfer function of the electrical part of the motor is then

$$(11) \qquad \frac{i}{U_M - U_e} = \frac{1}{R_e p L_C}$$

Using equations (3), (9), (10) we may set up a linear model of the regulator-motor system as shown in *Fig.* 6.

This model has been tested whit MATRIX-X program on the SUN computer.

5. The control algorithm

The system for control of the process "drawing optical fibres" employs a close feedback regulation loop.

As the change in fibre diameter is according to relation (12) proportional to the drawing velocity change and because the drawing process takes place in the conditions of the equilibrium state, the proportional, integration and differentiation type of regulator (PID) was chosen for the process control.

The mathematical representation of the algorithm describing the PID regulator is

as follows:

$$(12) \qquad u = K\{e(t) + \frac{1}{T_i} \int_0^t e(\tau) d\tau + T_d \frac{de(t)}{dt}\} + M_r$$

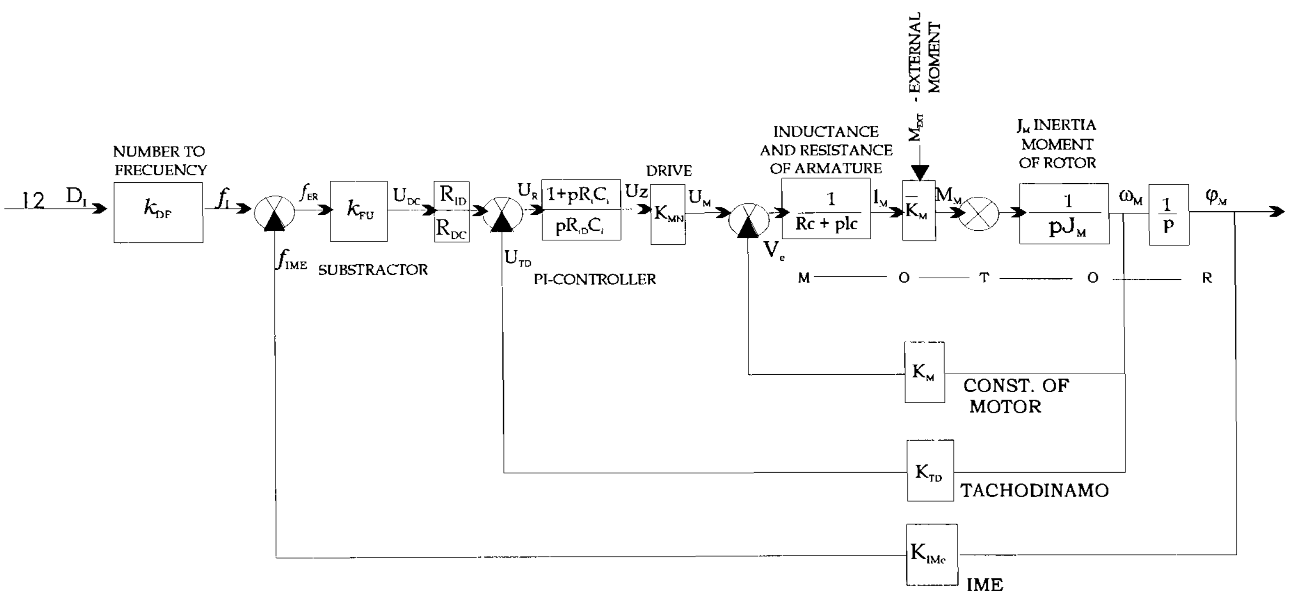

Figure 6: A linear model of the regulator-motor system.

where K is the proportionality constant, T_i is the integration constant, T_d is the differentiation constant and M_r is the regulator output at the beginning of the regulation activity.

The control algorithm before its implementation on a microcomputer must be converted to a form suitable for discrete numerical processing. An integral of a sequence of discrete samples with small time intervals between them may, according to the Euler relation, be substituted by the sum of the samples and the subtractor by its numerical equivalent. The following relation results:

$$u_n = K\{e_n + \frac{T}{T_i}\sum_{i=0}^{n} e_i + \frac{T_d}{T}(e_n - e_{n-1})\} + M_R \tag{14}$$

where u_n is the output corresponding to the n-th sample of the fibre diameter, e_n is the error in the n-th sample, T is the period of sampling, M_R is the output at the beginning of the regulation process.

The calculation of the regulation output u_n is carried out by means of fast floating point arithmetic. The regulator constans K, T_i and T_d can be adjusted even during the drawing process. The values of the constans must be determined for the process experimentally.

6. Concept of the control system

For the control of drawing machine a special operation system (operating in real time) was devised. The system enables us the setting of the process constant parameters such as the preform feed velocity, required fibre diameter and the numerical processing parameters of the fibre diameter laser measuring device signal. The system then operates in real time. After every interruption of the programme execution from the time generator, the execution of the uninterruptable foreground programmes, the purpose of which is the numerical processing of data generated by the fibre diameter laser measuring device and the regulation of the drawing process.

After execution of the foreground programmes the generally interruptable background programmes are run which enable the attendant personnel to communicate with the machine during the drawing process and also allow for registration of parameters of the regulation process. If it will be needed, all parameters eithers of the numerical processing of the signal from the fibre diameter measuring device, or of the regulator proper, can be changed.

8. Conclusion

The digital microcomputer system has, in comparison with the analogue control systems, the advantage of the direct control of speed over a wide range without utilizinga gear box which is a must for the devices controlled by the analogue method.

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Frantisek Kostka. *He completed university studies in 1967 at the Czech Technical university (CVUT) in Prague. After that he had been working at the Resaerch Institute of Tool Machines on control systems for these machines. He obtained the PhD degree in 1980 (Thesis title: «Interpolators in CNC control systems»).In the same year he began to work in the Institute for Radioengineering and Electronics of the Academy of Sciences of the Czech Republic. Here he designed the real time control systems for technology equipment, mainly for manufacturing of optical fibres. At present he also participate at the teaching activities at the Technical University in Plźen.*