Control Systems for Multiple Tool Heads for Rock Mining

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Riadiace systémy pre viacúčelové raziace hlavice

The paper deals concerns automatic control systems for multiple tool heads for rock mining. The dynamic model of the multiple tool head and models of control systems implemented in MATLAB/Simulink environment as well as results of their simulations are presented.

Key words: *automatic control system, multiple tool head, simulation.*

Introduction

Tool heads in mining machines are equipped with cutting, milling and drilling units. Their operation involves the combination of rotating and forward motion of the machining tools (cutters, discs, drilling teeth). Rotating and forward movements are usually executed by means of separate drives where the loads depends on the rock body to be cut, that is its variable physical and mechanical parameters. The main task of the automatic control system for the machining head is to stabilise the moment of force M_o in the rotating head motion by controlling the velocity v_p in the forward motion. The quality of velocity control will be adequate once the relationship $M_o= f(v_p)$ is known. This relationship is to a great extent indeterminate because of changes in the surroundings, also due to the complexity of electro-mechanical drive systems. The only practical solution available is to apply the real-time identification of this relationship and, on that basis, to calculate the optimal instantaneous velocity in the tool head forward motion.

Dynamic model of the tool head

The cutting head is shown schematically in the form of a block diagram in Fig. 1. Input parameters in the model are: angular velocity represented by v_s and linear velocity in the forward motion v_p. At the output from G_1 these two quantities yield the total depth of the cut $g(t)$. The transmission function in block G_2, taken to be $M_o(t)= f\ [g(t),\ K_o(t)]$, may be treated approximately as the constant transfer function with the variable coefficient depending on $K_o(t)$. The coefficient given as $K_o(t)= K_{oe}+ K_{ov}(t)$ is used to embody the variable properties of the cut rock body. The formula providing the force of resistance in the forward motion $F_p(t)= f[g(t),\ K_p(t)]$ is similar. The block H represents the relationship between the force of resistance and the total cut depth.

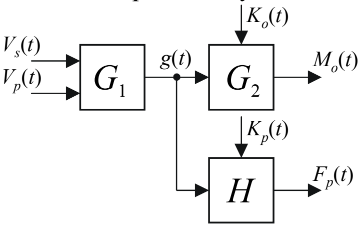

Fig 1. Cutting head - block diagram.

A more detailed description of the cutting head model can be found in (Podsiadło, 1976). The torque in the head acts upon the driving system (an asynchronous motor) through a mechanical gear while the force of resistance in the forward motion F_p acts upon the feed drive system. For the purpose of this study the system is represented as a asynchronous motor supplied from a frequency converter to enable velocity control v_p. Schematic diagram of the model implemented in MATLAB/Simulink environment is shown in Fig. 2. The results of simulation tests are provided in Fig. 3. The power of the rotating motion drive is taken to be 125 kW, the power of the forward motion drive is 50 kW. It appears that simulation results would in satisfactory degree reproduce the industrial processes. This model was further made use of in simulations of automatic control systems for head operation.

Automatic control systems for the cutting head

The automatic control system for the cutting head should implement the following functions:

- stabilisation of velocity in forward motion on a predetermined level when the drives are not overloaded,
- stabilisation of the rotating motion drive load when the velocity of forward motion is too large for the given mining conditions.

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Simulation tests were run on automatic control systems to stabilise the torque of tool loading forces with forward motion drives in which frequency converters were employed.

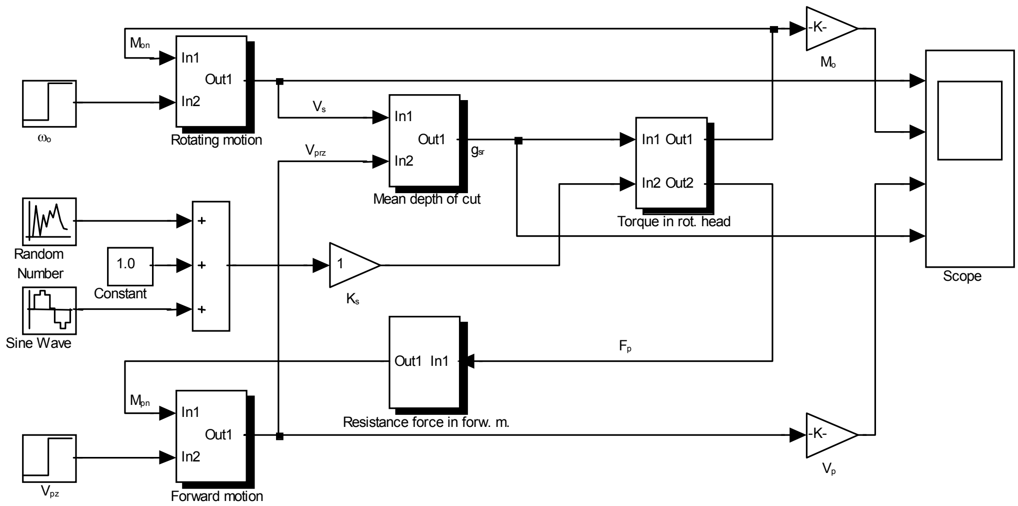

Fig.2. Cutting head - Simulink model.

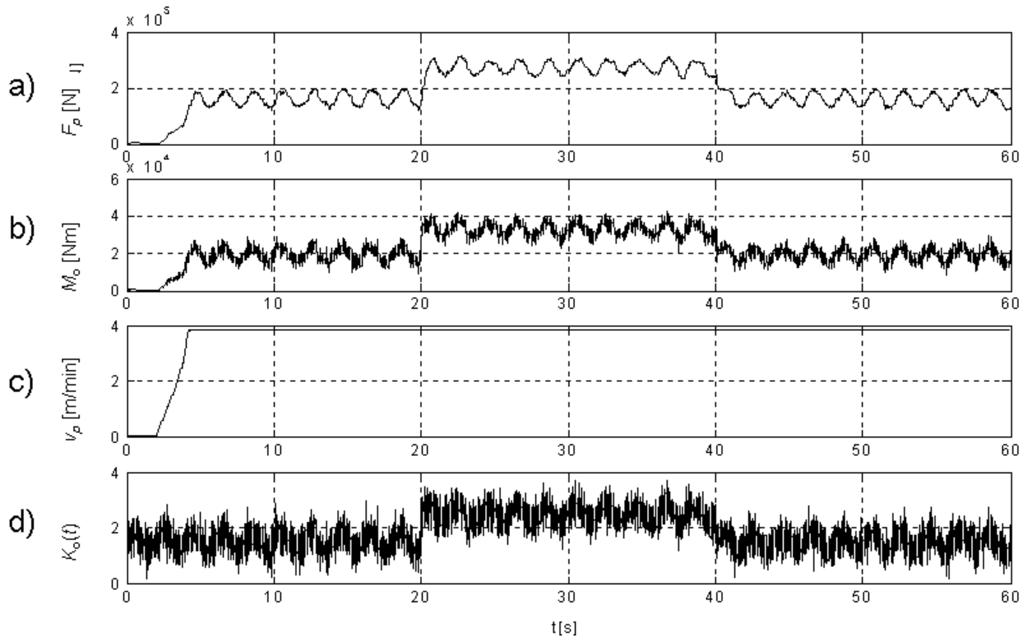

Fig.3. Cutting head operation – time patterns: a) forward force F_p*, b) torque* M_o*, c) forward velocity* v_p*,*
d) rock mass variability coefficient $K_0(t)$.

Velocity stabilisation system with drive loading feedback

A model of a mining machine with the velocity stabilisation systems with the drive loading feedback implemented in MATLAB/Simulink is shown in Fig. 4. The velocity stabilisation system consists of a PID controller. When the cutting tool is overloaded, an additional controller is employed utilising the feedback from the moment of force in rotating motion. When the gain factor in the feedback loop is set v_{p2}=0, the system will implement only velocity stabilisation in forward motion. Simulation results are presented in Fig. 5.

Simulation results clearly indicate that such systems will not help to eliminate instantaneous overloads of the tool drive. Furthermore, the fluctuations of moment of force increase, too. As the load distributions may vary between the drives, as they depend on variable properties of mined rocks, the selection of PID controller parameters may present a major difficulty.

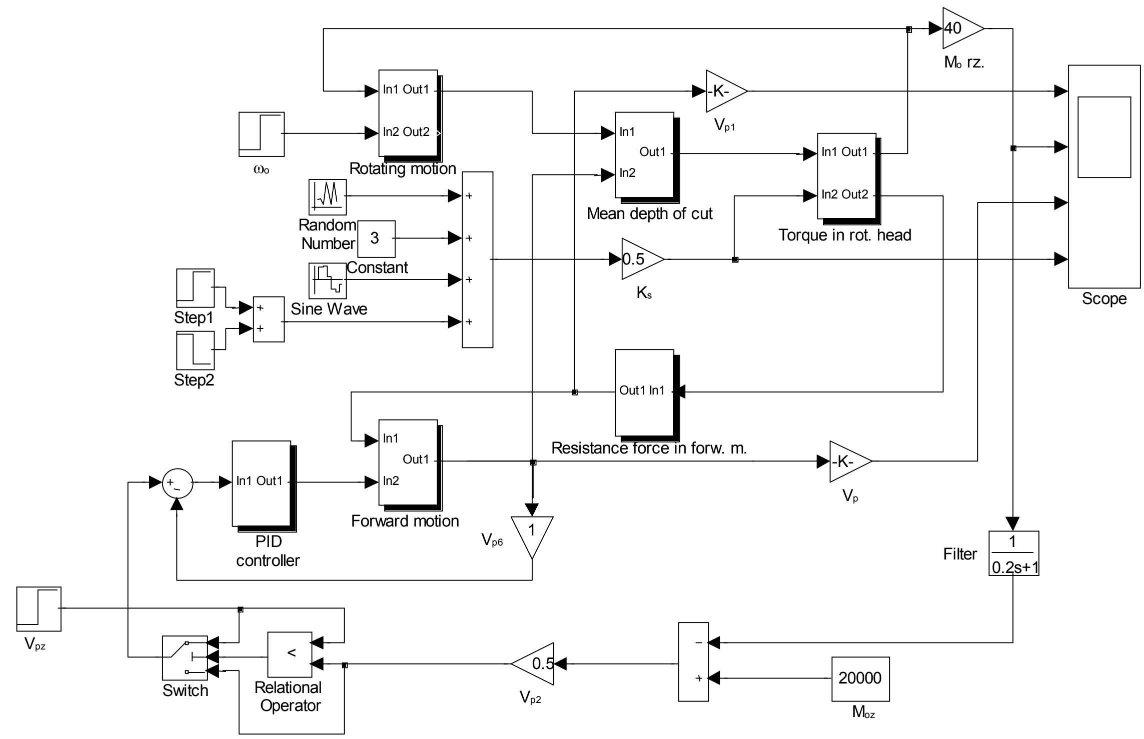

Fig.4. Control system for velocity stabilisation with an additional feedback from the rotating drive loading – Simulink model.

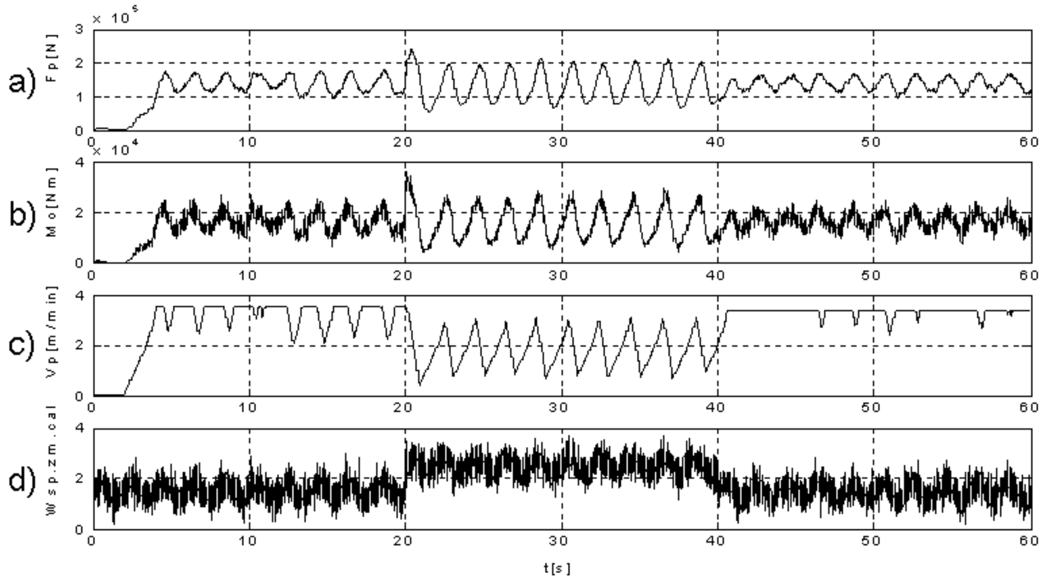

Fig.5. Head operation with stabilisation of the drive and feedback from the moment of the rotating drive loading force for M_{oz}= 20000 [Nm] – time patterns: a) forward force F_p*, b) torque* M_o*, c) forward velocity* v_p*, d) rock mass variability coefficient.*

Adaptive control system

In order to improve the control system performance, tests were run on system wherein the relationship $M_o=f(v_p)$ would be identified on-line and on that basis the optimal head velocity in the forward motion v_p would be calculated (i.e. optimal for the given mining conditions).

In simulation tests the relationship $M_o=f(v_p)$ is written as:

$$M_{o,n} = -a \cdot M_{o,n-1} + b \cdot v_{p,n} \quad (1)$$

where: *n* - the instantaneous time moment.

This formula yields the value of v_p for the subsequent torque. The time of signal sampling was set to be 0.01 s. Coefficients *a* and *b* are identified using the covariance method (also known as a correlation method) (Podsiadło, 1985). Coefficients in the model are found from the following system of equations:

$$\gamma_{MoMo}(1) = a \cdot \gamma_{MoMo}(0) + b \cdot \gamma_{MoVp}(1) \qquad (2)$$

$$\gamma_{MoVp}(0) = a \cdot \gamma_{MoVp}(1) + b \cdot \gamma_{VpVp}(0) \qquad (3)$$

where: $\gamma(k)$ – values of covariance and reciprocal covariance function for the time lag k=0 and k=1 are determined in a recurrent procedure.

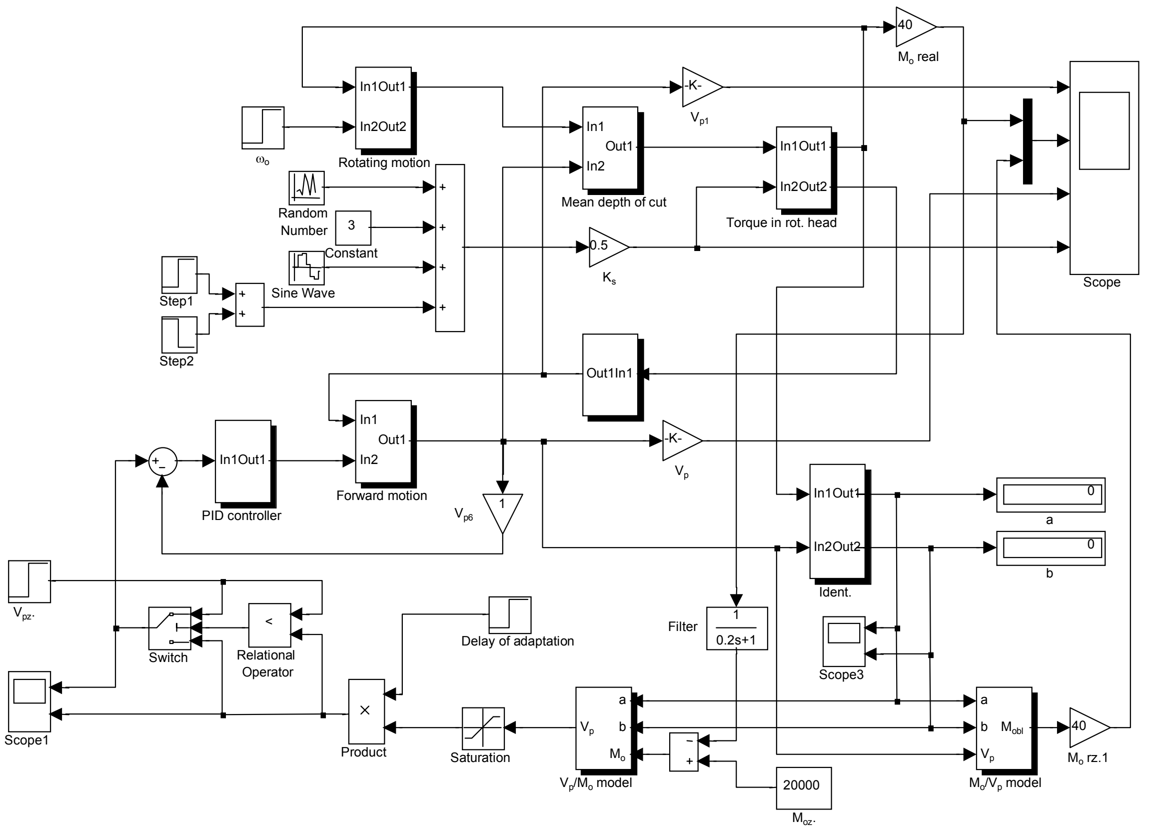

Fig. 6. Adaptive control system – Simulink model.

The model of a mining machine with an adaptive control system for velocity control is shown in Fig. 6. Simulation results are given in Fig. 7. Simulations show that system performance would be improved. Further improvements can be achieved by applying a more complex model of the relationship $M_o=f(v_p)$.

Fuzzy control system

High complexity of the electromechanical systems in the machine and variability of mined rock properties would merit the use of the methods of fuzzy logic (Piegat, 1999). These methods do not require that the mathematical model of the considered process or plant be exactly known. The model of a mining machine with a automatic control system utilising a fuzzy controller (Sugeno method) is shown in Fig. 8. The system utilises the feedback from the torque *Mo* and its derivative. Simulation results are provided in Fig. 9.

A close examination of Fig. 7 and Fig. 8 leads us to the conclusion that in both cases the results are similar. A major advantage of an automatic control system with a fuzzy controller is that it is insensitive to model imprecision and disturbances. A definite drawback is that more elaborate software is required which can prolong the time required for algorithm implementation on a given PLC controller.

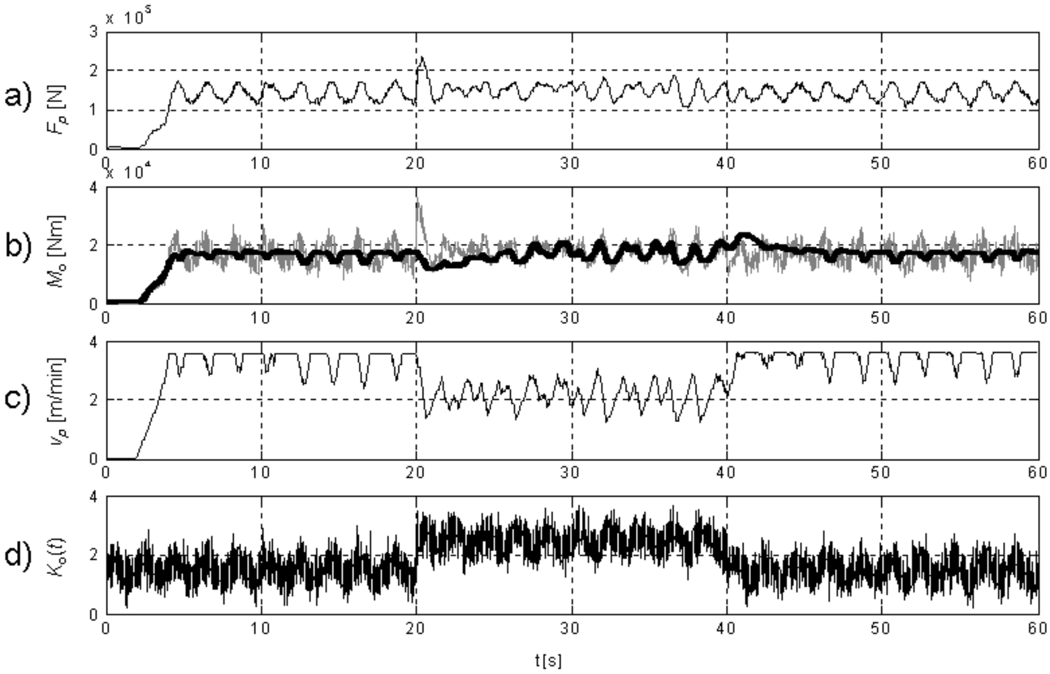

Fig.7. Adaptive control system operation for M_{oz} = 20000 [Nm] – time patterns: a) forward force F_p, b) torque M_o, c) forward velocity v_p, d) rock mass variability coefficient.

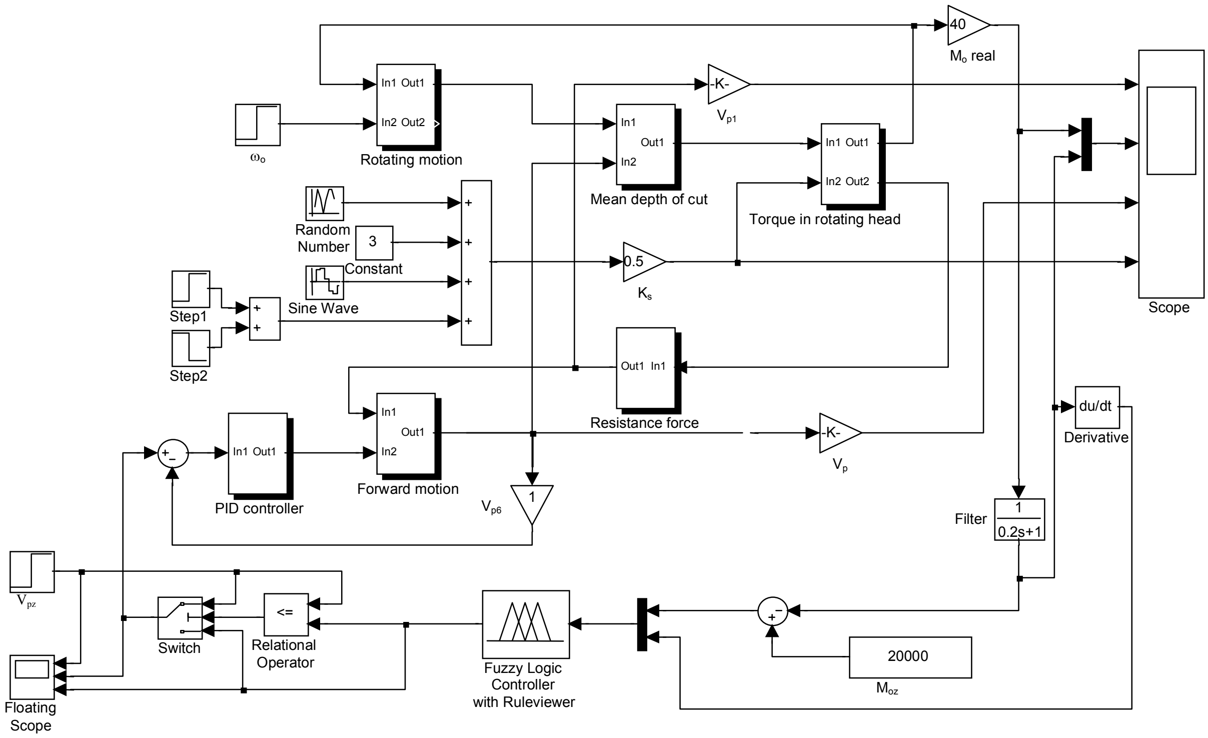

Fig.8. Fuzzy control system – Simulink model.

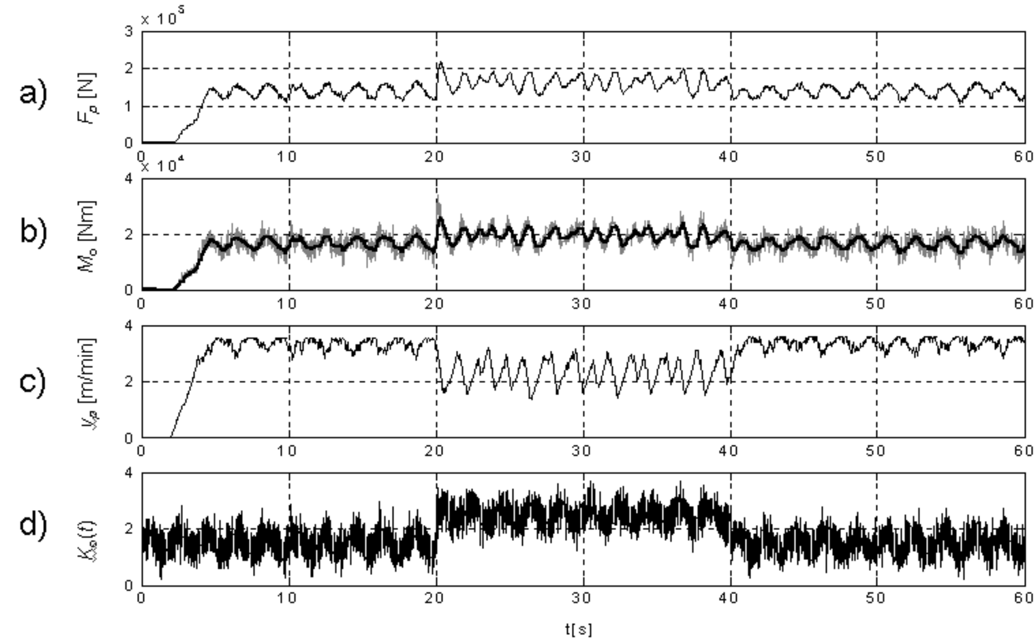

Fig.9. Fuzzy control system operation for M_{oz} *= 20000 [Nm] – time patterns: a) forward force* F_p*, b) torque* M_o*, c) forward velocity* v_p*, d) rock mass variability coefficient.*

Conclusions

The paper reviews selected automatic control systems for the multiple tool head. It appears that adaptive control systems or systems utilising fuzzy controllers are adequate for these applications. The latter system has been lately implemented in an microcontroller with fuzzy capabilities and research work is still underway (Rosół and Sapiński, 2003).

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