

OPERATOR TRAINING SIMULATOR AND ITS SUBMODEL OF COAL-PULVERIZED MILL.

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Abstract: This Operator Training Simulator is based on technology object oriented model library called “EnergySIM” developed in the simulation packages MATLAB-SIMULINK.

The practical Real-Time coal-pulverized mill model is developed on the base of mathematical-physical analysis (so called “first principles” method). This model is one of the separate technological subsystems of the drum steam boiler and also whole Power Plant. Operator Training Simulator consists complex thermal power unit, i.e. two steam boilers working into one section of the common steam collector and two units steam turbines-generators. The process model describes the standard and abnormal operation regimes in the range of 0 % - 100 % of Maximum Continuous Rate, with implementation of individual disturbances by the instructor of Operator Training Simulator.

The “distributed control system”, which is implemented in the real boilers, is also emulated in packages MATLAB-SIMULINK. The Human Machine Interface is realized in standard software package InTouch and the real desks and panels MOZAIC are also connected through the PCI slots and I/O cards. The communication between MATLAB-SIMULINK and InTouch is based on standard DDE protocol. This Operator Training Simulator belongs to “replica - partially stimulation types”, because Human Machine Interface is realized in the InTouch package and MOZAIC equipments as in the real control room of power plant. The OTS is fully acceptable for engineering tasks, learning and training of engineers and operators.

1. INTRODUCTION

The mill plants were modelled as a simple time delay component (Dolezal and Varcop, 1970), for a long time period, because the main attention of power plant control engineers was concentrated on the boilers and turbines. Until the last few decades, the modern power plants were required to operate more efficiently and economically to meet not only today's intense market competition but also the requirements of environmental protection. Therefore many authors are interested in detailed mill models (Cai, Li and Wang, 1997), (Cai, Lu and Wang, 1999), (Chai, Yue and Yan, 1999), (Fan, Rees and Parker, 1997), (O'Kelly, 1997) and (Hasselbacher, Lang and Lausterer, 1992).

In long time ago some mill modelling experimental tests based on operational experiences with shaft mill combustion were performed (Suchanek, 1960) in Czech Republic.

In these time the theory of shaft Kramer mills was developed (Kopchenov, 1961), and practically implemented (Pavlita, 1963). It is necessary to announce that this type of shaft Kramer mills were used in sixtieth years, later the different type were applied, e.g. fan mills. The original shaft Kramer mills are in operation in Opatovice Power Plants up to this time, of course with many modifications and repairs, therefore this paper deals to this „old“ type of mills.

2. OPERATOR TRAINING SIMULATOR CONFIGURATION

The differences between Operator Training and Engineering Simulators were explained (Neuman, 1997). The models of steam boilers (Neuman, et al., 2002) and power and heat plants (Neuman, et al., 2003) were successively developed.

The details of the simulator layout can be seen in Fig.1. The process and the control system are modeled in MATLAB-SIMULINK. The InTouch mimics and the operator control panels (Mosaic) are used as such in real plant. Three PCs are used, one for the operator, who is in training on the simulator and the second PC is used for the instructor who produces some disturbances and who monitors the performance of the operator. MATLAB models and all the InTouch mimics are placed on instructor PC and are coupled together via DDE protocol. DDE is one of several mechanisms of inter process communication supported by OS Windows. It is an extension of the messaging scheme around which OS Windows is designed. Of the two applications involved in the data exchange, one is known as the server and the other as the client. The client application is the consumer of the data and the server is the provider. The data communication via DDE is possible only between Matlab and

InTouch. The model has been created in Simulink so it was necessary to program special S-functions in order to establish DDE communication between Simulink model and InTouch mimics.

Also operator control panels (Mosaic) are connected to the instructor PC where the connection with MATLAB model is carried out. Only the operator can manipulate with the operator control panels (Mosaic). All the InTouch mimics can be seen on both instructor and operator PCs with the exception of disturbances windows, which are available only to the instructor. The InTouch mimics on both PCs uses in mutual communication “Suite Link” protocol. The operator training simulator is under full control of the operator by means of InTouch mimics and operator control panels (Mosaic).

3. SUBSYSTEMS MODELING IN OPERATOR TRAINING SIMULATOR

The base information for creating structure of an OTS represents a process diagram. It can be demonstrated on an example of a coal mills and feeders subsystem. This part is depicted in Fig.2. The standard type of diagram, which represents so called Process Instrumentation Diagram (P&I D) is little more complex and therefore it is not include in this paper. In P&I D diagram are depicted all the objects which are either manipulated by control or where some measurement is performed. For the operator training simulator is typical that all the information, which is available in monitoring and control system, must be available also in the models used in OTS. Only in this case the operator can manipulate with all the valves, fans, switches etc. as if he would do it in the real plant. This specific requirement invokes a need to have technology object-oriented models of all such elements, which are depicted in P&I D diagram.

In the coal mills and feeders technological scheme, which is depicted in Fig.2, such process elements are mentioned in the following description of its function.

- | | |
|--------------------------------|---------------------------|
| V1 Total air control valve | V5 Cold air control valve |
| V2 Primary air control valve | PA Primary air |
| V3 Secondary air control valve | SA Secondary air |
| V4 Core air control valve | CA Core air |

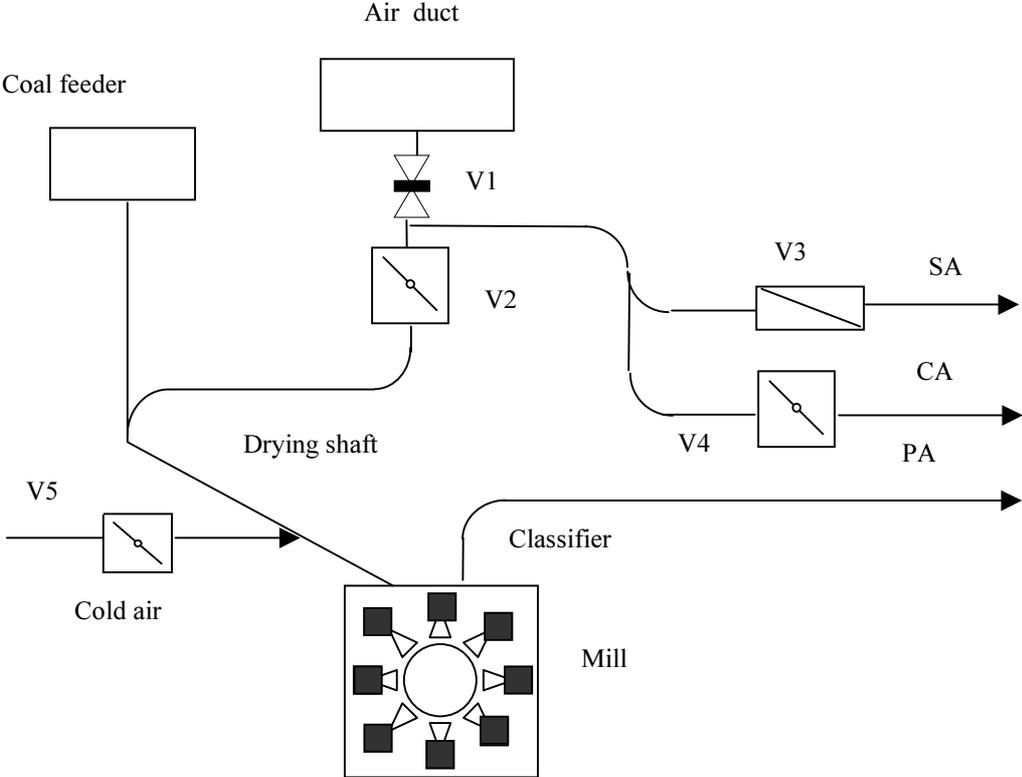


Fig.2 The coal mill and the adjacent equipment

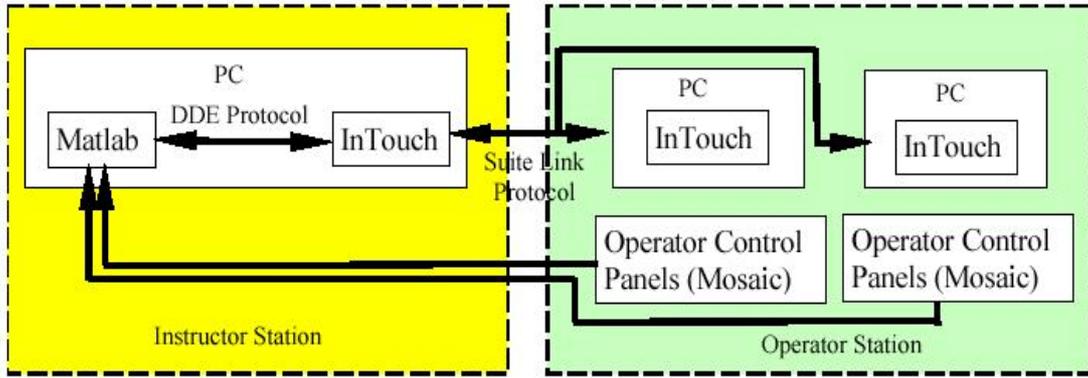


Fig. 1 Layout of Instructor and Operator Stations of Training Simulator

4. MATHEMATICAL DESCRIPTION OF THE MILL

The basic coal accumulation equation in the mill is

$$\frac{dG}{dt} = M_E - M_A \quad (1)$$

The pulverised coal delivery from the mill suits the formula (Kopchenov, 1961)

$$M_A = K_M Q_V^{1,2} \sqrt{G} \quad (2)$$

The mill motor power demand one can characterize by

$$N_M = N_{MO} + b.G^2 \quad (3)$$

The primary air flow rate equation used is

$$Q_V = \Delta P_C / R_C \quad (4)$$

The total aerodynamic resistance in the primary air duct is

$$R_C = R_M + R_K \quad (5)$$

where for the resistance of the mill is

$$R_M = R_{MO} + K_R.G \quad (6)$$

and for the resistance of the primary air flow control valve is

$$R_K = 1/(K_V.\alpha) \quad (7)$$

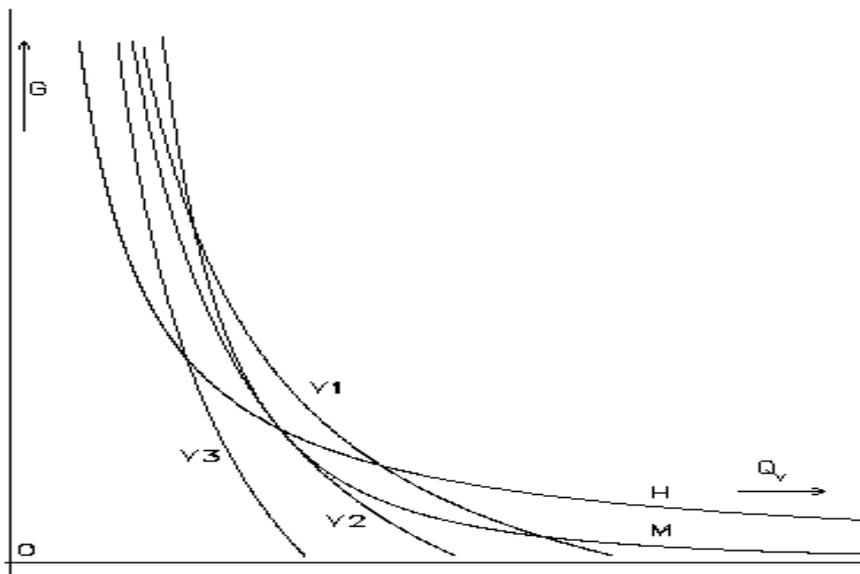


Fig. 4

In the Fig. 4 are characteristics of the coal mill.

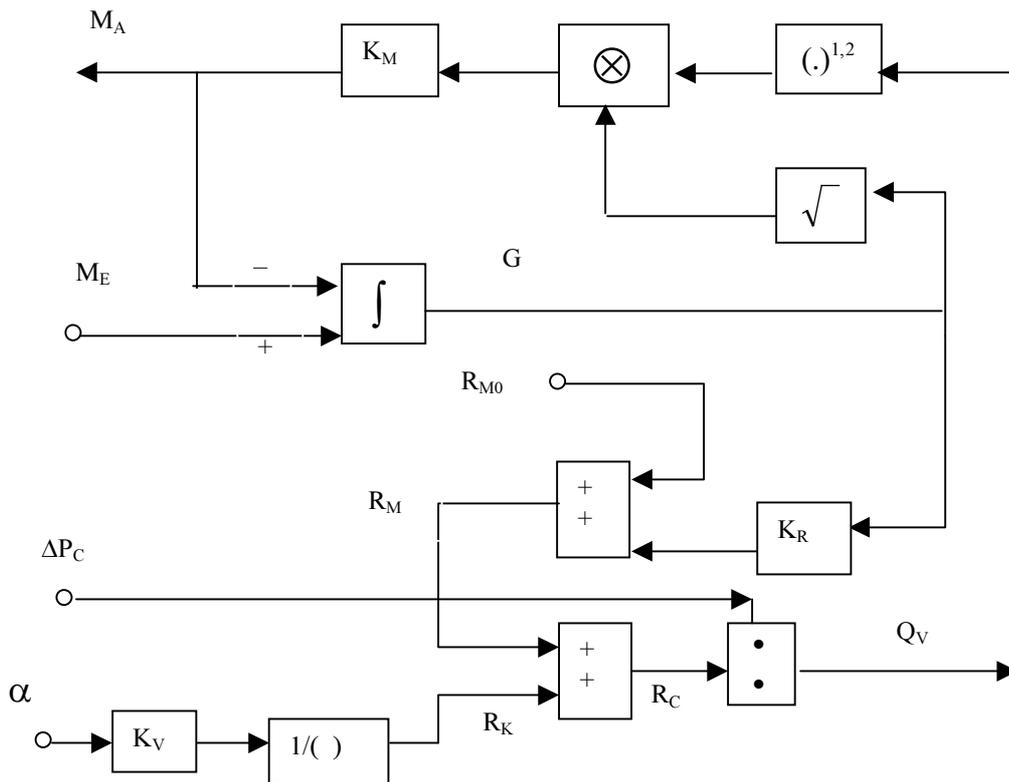


Fig. 3 Scheme of mathematical model of coal mill

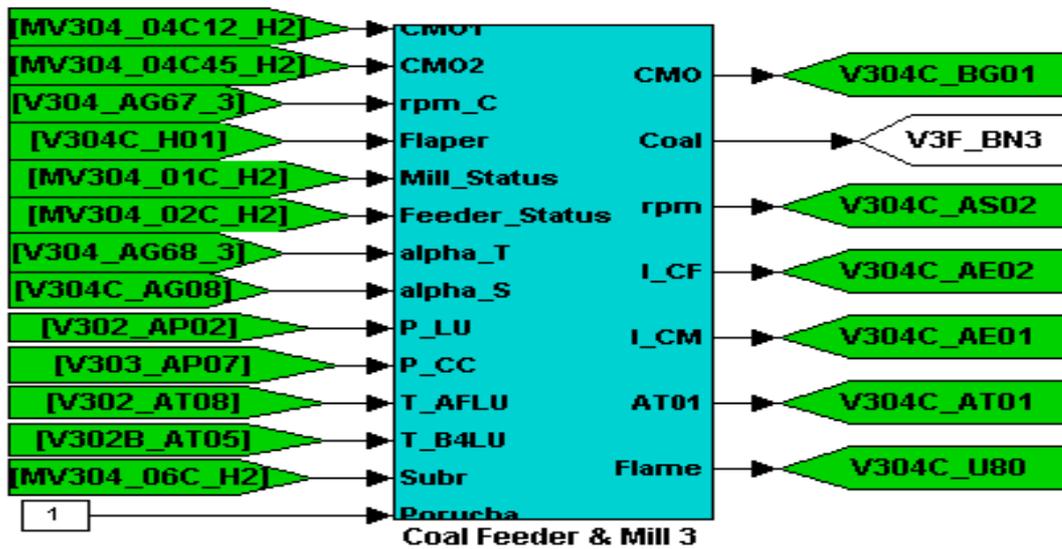


Fig. 5 MATLAB-SIMULINK diagram of Coal Mills and Feeders

$$Q_V = f(G, \alpha) = \frac{\Delta P_C K_V \cdot \alpha}{K_V \cdot \alpha \cdot (R_{M0} + G \cdot K_R) + 1} \quad (8)$$

between Q_V and G when $\alpha = \text{konst}$, as well as the relation (see eq. (2))

$$Q_V = F(G, M_A) = \left(\frac{M_A}{K_M \sqrt{G}} \right)^{1/2} \quad (9)$$

between Q_V and G when $M_A = \text{const}$ are the hyperbolas.

In the Fig. 4, there are three hyperbolas V1, V2 and V3 for three different air control valve positions

$\alpha_1 > \alpha_2 > \alpha_3$ (see eq.(8)) and one hyperbola M for $M_A = M_E = M_0 = \text{const}$ (see eq.(9)).

For $\alpha = \alpha_1$ the hyperbolas V1 and M have two intersection points.

For $\alpha = \alpha_2$ the hyperbolas V2 and M have one common tangent point

For $\alpha = \alpha_3$ the hyperbolas V3 and M have no common points

For a given $M_E = M_A = M_0$, there exist the minimum α_{MIN} for which the working condition of the mill reaches the stability limit.

The linearisation of the problem leads to the characteristic equation

$$s.T_O + 1 - K_O K_R \Delta P_C / (R_K + R_{MO} + K_R \cdot G)^2 = 0 \quad (10)$$

$$\text{where } T_O = \frac{2\sqrt{G_O}}{K_M \cdot Q_{VO}^{1,2}} \quad (11)$$

$$\text{and } K_O = 2,4 \cdot G_O / Q_{VO} \quad (12)$$

The equation (10) gives the condition on the limit of stability

$$(R_K + R_{MO} + K_R \cdot G)^2 = \Delta P_C K_O K_R \quad (13)$$

For a given M_A one obtain the minimum

$$\alpha_{\text{MIN}} = 1 / (K_V \cdot R_K^L) \quad (14)$$

for which the stability limit is reached. In eq. (14) is

$$R_K^L = 0,31 \cdot (K_M / M_A)^{10/7} \cdot \Delta P_C^{12/7} \cdot K_R^{-5/7} - R_{MO} \quad (15)$$

The corresponding air flow is

$$Q_V^L = 1,868 (M_A / K_M)^{10/7} \cdot (K_R / \Delta P_C)^{5/7} \quad (16)$$

and finally the mass of coal accumulated in the mill is

$$G^L = 0,2229 (K_M / M_A)^{10/7} \cdot (\Delta P_C / K_R)^{12/7} \quad (17)$$

For a given position α of the primary air flow control valve to which corresponds the the resistance

$R_K = 1 / (\alpha \cdot K_V)$ on obtain on the limit of stability the pulverized coal delivery from the mill

$$M_{A,MAX} = 0,442 K_M \Delta P_C^{6/5} \cdot (R_K + R_{MO})^{-0,7} \cdot K_R^{-0,5} \quad (18)$$

the primary air flow rate

$$Q_V^L = 0,583333 \cdot \Delta P_C / (R_K + R_{MO}) \quad (19)$$

and the mass of coal accumulated in the mill

$$G^L = (R_K + R_{MO}) / (1,4 K_R) \quad (20)$$

The curve H in the Q_V, G diagram on Fig. 4 gives the boundary of the area of stabil working conditions of the mill.

Symbols used

- b coefficient in mill motor power demand equation
- G mass of coal accumulated in the mill
- K_0 auxiliary coefficient for working conditions of the mill
- K_R coefficient in mill resistance equation
- K_V specific capacity of the primary air flow control valve
- M_A pulverized coal delivery from the mill

- M_E coal supply in the mill
 - M_0 auxiliary coal flow
 - N_M mill motor power demand
 - N_{M0} basic mill motor power demand
 - ΔP_C pressure difference on the air flow duct
 - Q_V primary air flow
 - R_C total aerodynamic resistance in the primary air duct
 - R_K resistance of the primary air flow control valve
 - R_M resistance of the mill
 - R_{M0} basic resistance of the mill
 - s complex variable
 - t time
 - T_0 auxiliary time constant
 - α relative position of the primary air flow control valve
- Upper index L refers the variable to the limit of stability of working conditions

The block diagram of this coal mills and feeders subsystem is depicted in Fig. 5.

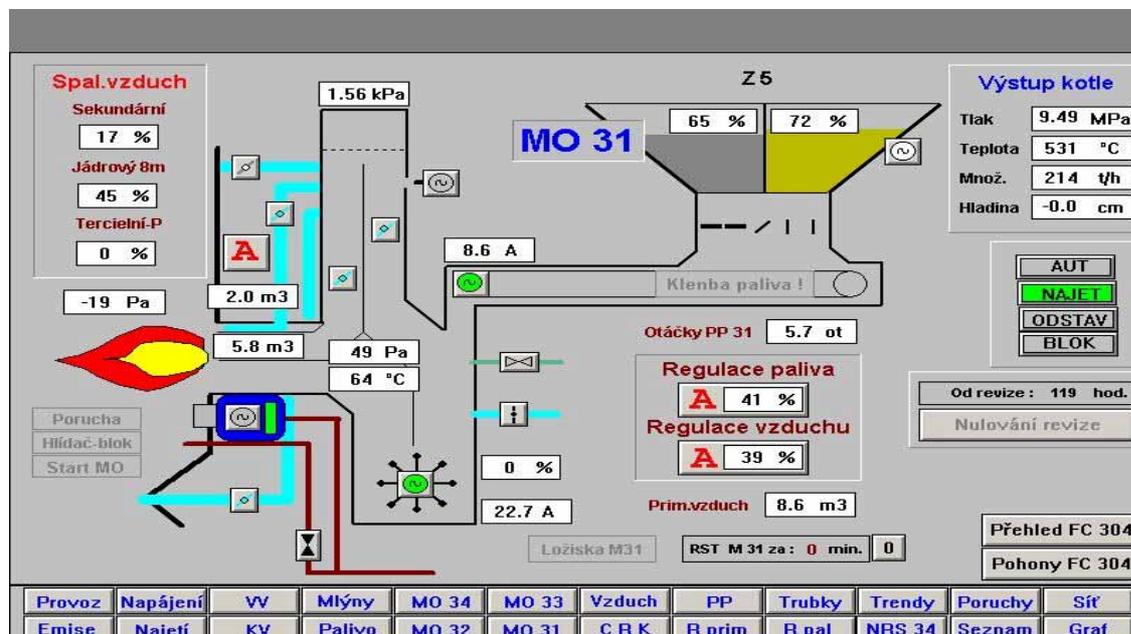


Fig. 7 InTouch mimics of Coal Mills & Feeder

The model of coal mill described in this chapter consists of basic part of its. There are only coal feeding and one “hot” air (PA) going through the air duct into mill. The real model of mill (it is encapsulated in macroblock “Coal Feeder & Mill 3” – see Fig. 5) is able to include also splitting into hot core air (CA), hot primary (PA) and secondary air (SA), and also directly suction cold air (V5). Besides the coal feeders, temperature branch of the mill model, closing valves (e.g., V1) and control flaps (V2, V3, V4, V5) must be also modeled.

In connection with above mentioned fact the final version of the SIMULINK coal feeder & mill model is very large and hence it is not providing an easy survey for readers.

5. OBJECT ORIENTED LIBRARY “EnergySIM”

Object oriented modeling describes each part of the model as an object with certain behaviour; therefore the own-built library called “EnergySIM” was partially developed up to this time.

It is a modular system, a model is obtained by assembling instances of general-purpose models taken from libraries. The system is open, a user is free to expand the default libraries with its own models. The library “EnergySIM” includes the models and modules of many typical components to be found in thermoelectric power plants. Some examples: Gas and Steam Turbine Units, Two Phase Units (HRSG, boiler-evaporator, condenser,

deerator tank), Single Phase Units (economiser, superheater), special Drum and Once-through Evaporator Units, Water Storage, Media Flow Resistance Unit, Heat Flow Resistance Unit, Burner Units, Combustion Chambre Units, etc.

Each module is formulated from basic three conservation physical laws (first principles) and it needs few parameters. However the description of all modules is out of scope of this paper.

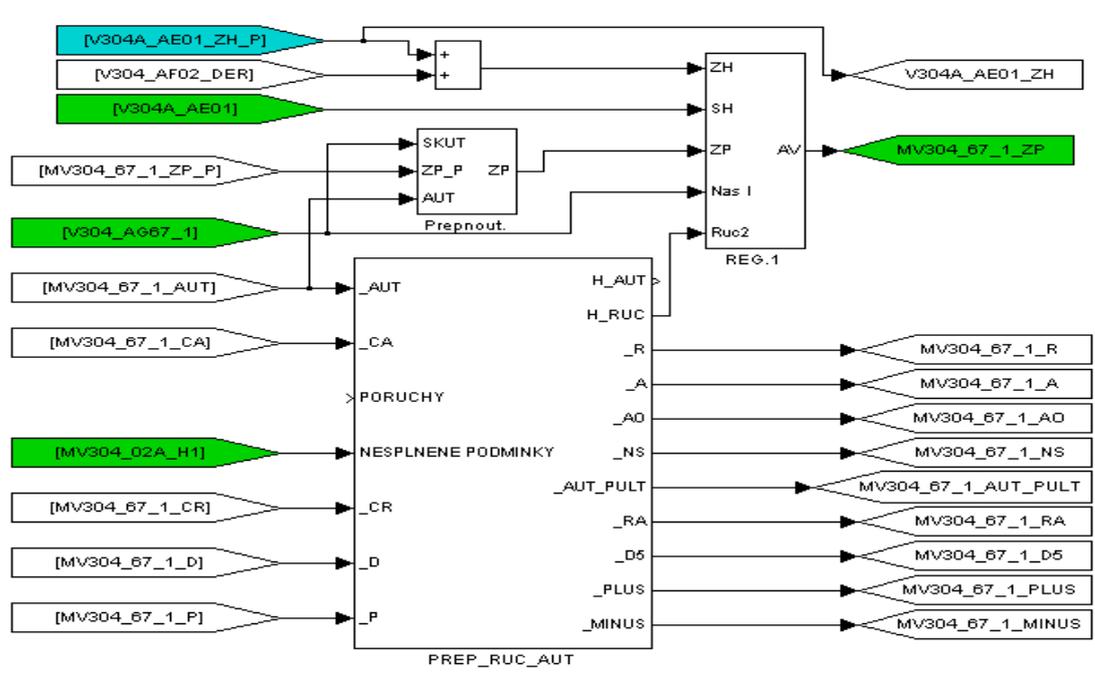


Fig. 6 One example of control loop of coal mills

The final goal is to develop moderately complex non-linear models that capture the key dynamical properties over a wide operation range. All the modelling has been performed in software package MATLAB-SIMULINK. Building a model from this library is very easy and during modelling one can feel that he is constructing an AutoCAD drawing of the model. In this way every one is able to build a model of his own choice very easily without deep knowledge of modelling. The modelling of all the modules is based on the three-conservation laws, Mass, Energy and Momentum balances (Dolezal and Varcop, 1970).

6. EMULATION OF DCS AND REALIZATION OF HMI

The Distributed Control System (DCS) consists of manual control from operator control panel (MOZAIC), control from InTouch mimics and control from standard industrial PID controllers, which has been modelled (emulated) in MATLAB-SIMULINK. The one of many control loops is shown on Fig. 6.

The Human Machine Interface (HMI) is realized in standard SW InTouch and the real descs and panels MOZAIC, which are connected through the PCI slots and I/O cards. The communication between MATLAB-SIMULINK and InTouch is based on standard DDE protocol.

As an example of a mimics in HMI, is the coal mills and feeders scheme, which is displayed in operator training simulator (OTS), in the same form, as it is available in the control room in real plant, is shown in Fig. 7. This InTouch mimics (with operator control panel, Mosaic) is available to operator and instructor, and they can manipulate different variables from the Operator Station or Instructor Station.

7. CONCLUSIONS

This OTS was developed, delivered and commissioned for customer, i.e. Czech Opatovice Power Plants. The parametrization and verification of simulator's features were performed during two months before commitment, every time with participation of minimally one of selected very experienced operators. The condition for

commitment of this OTS to customer was the official written confirmation, signed by three the most experienced active operators, that fidelity of OTS is very high and fulfil the customer requirements.

On the base of our done experiences it can be said that the described type of Operator Training Simulators, based on MATLAB-SIMULINK and InTouch packages, are suitable for full scope replica simulators of smaller energy units (e.g. with capacity less or equal of 110 MWe) and acceptable for customers especially in Central and Eastern Europe and Underdeveloped Countries (Neuman, et al., 2004). The OTS is also fully acceptable for engineering tasks, training of managers, engineers and operators, and especially for control education of students.

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