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Modeling of Ball Mill Pulverizing System and Research of Support Vector Machine Generalized Inverse with Internal Model Control

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Abstract: As the common equipment of coal power plant, ball mill pulverizing system with double inlets and outlets, which is difficult to get the mathematical models precisely for the nonlinear, multivariable, strong coupling and time-varying characteristics. In this study, mathematical differential equations of the ball mill are deduced based on the mechanism analysis and support vector machines generalized inverse with internal model control is applied in this model. The support vector machine is used to identify the generalized inverse of original system, which in series with original system can be an approximately linearized pseudo-linear system, then combine with internal model control to increase the robustness of the system. To verify the accuracy of the model, simulation was carried with a 1000 MW unit in Hubei Huarun group. Results show that the data from models are in line with the actual operation data. Furthermore, comparison control method in the study with internal model control method was carried, it is proved that the former not only has strong robustness, but also has good features of dynamic responses and decoupling results.

Key words: Ball mill with double inlets and outlets, mechanism modeling, support vector machines, generalized inverse system, internal model control

INTRODUCTION

At present, ball mill with double inlets and outlets equipped with positive pressure direct blowing pulverizing system has been mainly adopted by more than 300MW generating units. For the nonlinear process with multivariable, strong coupling, large time delay and numerous uncertain interference factors, it is very difficult to build up the precise mathematical models. With the gradual developments of thermal power plants and the worse current situations of quality of the coal, ball mill with double inlets and outlets equipped with positive pressure direct blowing pulverizing system has been used by most of the power plants nowadays(Wei *et al*., 2009). However, the studies in this aspect are few and the actual problems are a lot.

Inverse system method is a direct feedback linearization decoupling control method, which is developed in recent years and then formed into generalized inverse system (GI) (Liu *et al*.,2013). Support Vector Machine (SVM) is considered as a kind of new machine language, which has good identification ability in the study of small samples. Combing with GI can form into an approximate linear and not completely decoupled system (Chen *et al*., 2010).

This study is mainly focused on ball mill with double inlets and outlets equipped with positive pressure direct blowing pulverizing system. Mechanism modeling is used to build up the mathematical model, then support vector machine generalized inverse combined with internal model control is used as the control strategy.

MATHEMATICAL MODEL AND GI SYSTEM OF BALL MILL WITH DOUBLE INLETS AND OUTLETS

Working principles of ball mill: Ball mill with double inlets and outlets has two completely symmetrical powder loops, the working principles are shown as follows. Firstly, the raw coal dropped out from coal bunker by coal drop pipe of coal feeder mixed with hot air. Secondly, the mixture is dried into the ball mill, which is crushed in it. Pulverized coal is brought by hot air into the separator, which is on top of the ball mill. Last, the qualified pulverized coal together with drying medium forms into the mixture between wind and powder (primary wind pulverized coal), which is sent to the burner to burn from pulverized coal piping. Therefore the unqualified pulverized coal is needed to back to the ball mill to mill again. As shown in Fig. 1.

Mechanism model of ball mill: Mathematical model of output temperature: Outlet temperature of mill is influenced by many factors, such as air volume, coal volume, specific heat of coal, hot air and cold air. According to energy-balance equation, the following equation can be derived:

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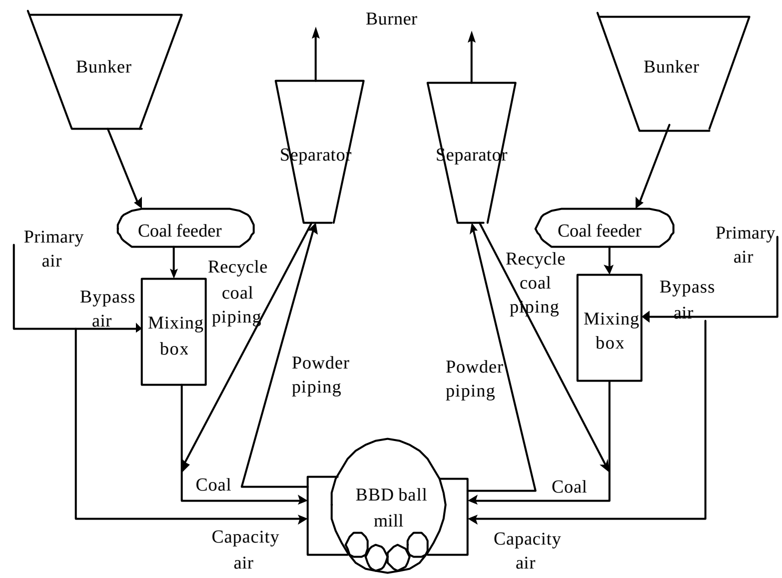

Fig. 1: Schematic of ball mill pulverizing system with double inlets and outlets

$$\frac{d(MH)}{dt} = \sum (F_{IN}H_{IN}) - \sum (F_{OUT}H_{OUT}) + \sum Q_{IN} - \sum Q_{OUT} \tag{1}$$

$$\frac{d[(C_{gq}w_{gq} + C_m w_m)t_m]}{dt} = C_r G_r t_r - C_{lf}(G_r + G_1)t_m + C_1 G_1 t_1 + \frac{B_{gm} C_{gm} t_c}{3.6} - \frac{B_m C_m t_m}{3.6} + Q_o - Q_c \tag{2}$$

$$Q_0 = 41.57 B_{gm} / 3.6 = 11.55 B_{gm} \tag{3}$$

$$Q_c = B_{gm} \Delta w \cdot C_w \cdot t_m / 3.6 \tag{4}$$

Mathematical model of inlet and outlet differential pressure: Differential pressure of ball mill reflects height of coal level, namely:

$$\frac{d\Delta P}{dt} = 3(1 + 0.8\mu) v k_\xi (Q_2 / Q_{20})^2 (G_r + G_1) / V \tag{5}$$

$$Q_2 = (G_r + G_1)/1.283 * (273.15 + t_m)/273.15 + G_w / 0.804 \tag{6}$$

Mathematical model of inlet wind pressure: Inlet wind pressure reflects the air volume of ball mill. From the empirical equations:

$$\frac{dP_{in}}{dt} = R(t_m + 273.15) k_\xi (Q_2 / Q_{20})^2 / V \tag{7}$$

Generalized inverse system of ball mill: Solving the inverse of a system is to solve the mapping relationship from output to input of the system. That is, if the desired output $y_d(t)$ viewed as the input of the inverse system, then the output of inverse system is just the control variable u(t) needed by output y_d (t) generated by the original system. Inverse system in series with original system can be called the pseudo-linear system, which can realize the ability of input and output identity mapping under ideal conditions, shown in Fig. 2. The original system in series with generalized inverse system can realize the linearization and decoupling control of the original system, shown in Fig. 3.

SVM GENERALIZED INBERSE WITH IMC METHOD OF BALL MILL

SVM regression algorithm: The basic idea of SVM regression is that it classifies data by mapping the vector from low-dimensional space to high-dimensional space using nonlinear function mapping (Xu and Rong, 2011). The nonlinear regression function can be expressed as follows:

$$f(x) = (\omega, \phi(x)) + b \tag{8}$$

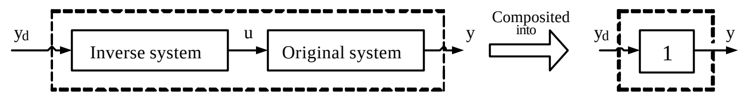

Fig. 2: Linearization of unit of inverse system and unit of pseudo-linear combined system

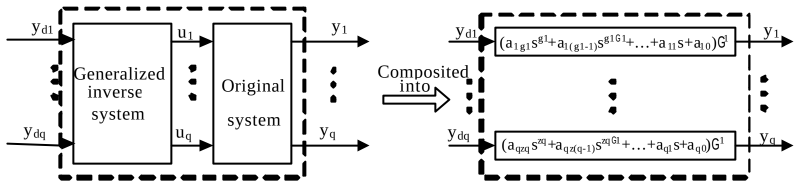

Fig. 3: Linearization of generalized inverse system and generalized inverse pseudo- linear combined system

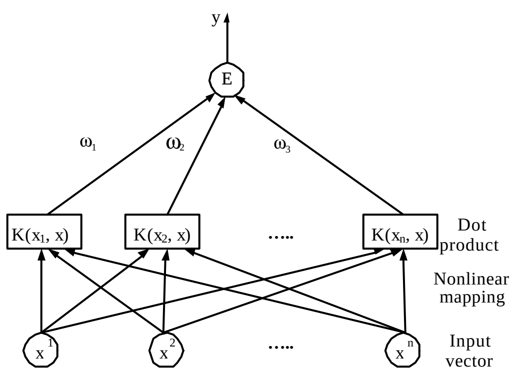

Fig. 4: Structure diagram of SVM

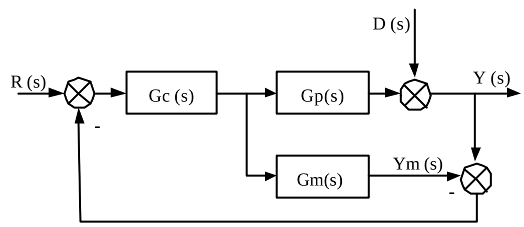

Fig. 5: Structure diagram of internal model control

where, weight vector $\omega \subset R^n$, offset $b \subset R$, ϕ is the nonlinear mapping from low-dimensional space to high- dimensional space, (,) is the inner product.

Through using Lagrange algorithm, duality principle and kernel trick, the output of SVM:

$$y = \sum_{i=1}^{n} (\alpha_i^* - \alpha_i) K(x_i, x) + b \quad (i = 1, 2, ..., n) \tag{9}$$

where, $K(x_i, x)$ is the kernel function, x_i is the support vector, x is the output vector, n is the numbers of support vector. The structure of SVM is shown in Fig. 4.

IMC algorithm: Internal model control has a feature of good robust stability, which is first proposed by Garcia and Monari (Jin and Huang, 2010). Therefore, by introducing IMC closed control to the pseudo-linear combination system better control effect can be obtained. The structure of IMC is shown in Fig. 5.

SVM generalized inverse with IMC algorithm: The specific algorithm is given as follows, according to the fundamentals above those methods:

- **Step 1:** According to the working principle of the original system (controlled system), some relative mathematical differential equations are written to build up the model of the ball mill
- **Step 2:** Analyzing the generalized inverse system of the original system to verify the existence of generalized inverse. If it exists, using SVM to identify the model
- **Step 3:** Because one SVM can only identify one controlled variable, the ball mill system needs three SVMs. Repeat Step 2 twice
- **Step 4:** Design a IMC controller of the closed loop, that is to design the only parameter λ of the filter. To regulate the parameter of the filter will get a more stability of the closed loop system. Thus the schematic diagram of the algorithm is shown in Fig. 6

SIMULATION ANALYSIS

Verification of mechanism model: Ball mill with double inlets and outlets MGS4060 equipped in a unit power plant in Huarun is chosen as an example to study. Mathematical models of ball mill can be derived by organizing data into the Eq. 1-7:

$$\frac{dt_m}{dt} = 0.104G_r + 0.005G_1 + 0.02B_{gm} - 140t_m \quad (10)$$

$$\frac{d\Delta P}{dt} = 0.05*(G_r + G_1)\{[(G_r + G_1)/1.283 + 8438] *(273.15 + t_m)/273.15/134000\}^2 \quad (11)$$

$$\frac{dP_{in}}{dt} = 0.15*(273.15 + t_m)\{[(G_r + G_1/1.283) + 8438] *(273.15 + t_m)/273.15/134000\}^2 \quad (12)$$

Ball mill pulverizing system is simulated to build the model by Matlab/Simulink, which is shown in Fig. 7.

In order to verify the accuracy of the model, 100 sets of data taken by the model to compare the measured data by model MGS4060 in Hu Bei Huarun power plant. The result is shown in Fig. 8(a-c).

The comparison results show that the error of mechanism modeling is very small. In the 100 groups of comparisons, the relative error of the outlet temperature is 0.29%, the relative error of the inlet air pressure is 0.61% and the relative error of the inlet and outlet differential pressure is 0.34%, all within the margin of error, which proves the accuracy of mechanism modeling.

Simulation on IMC with SVM generalized inverse: Simulating by the steps of SVM generalized inverse with IMC. RBF kernel function is chosen in this study, that is:

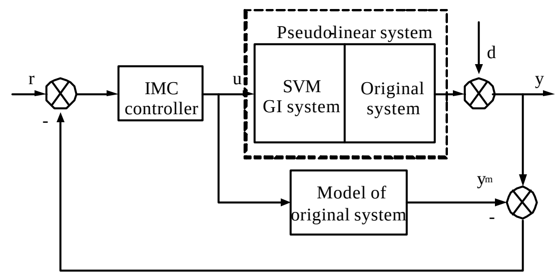

Fig. 6: Principle diagram of support vector machines generalized inverse with internal model control

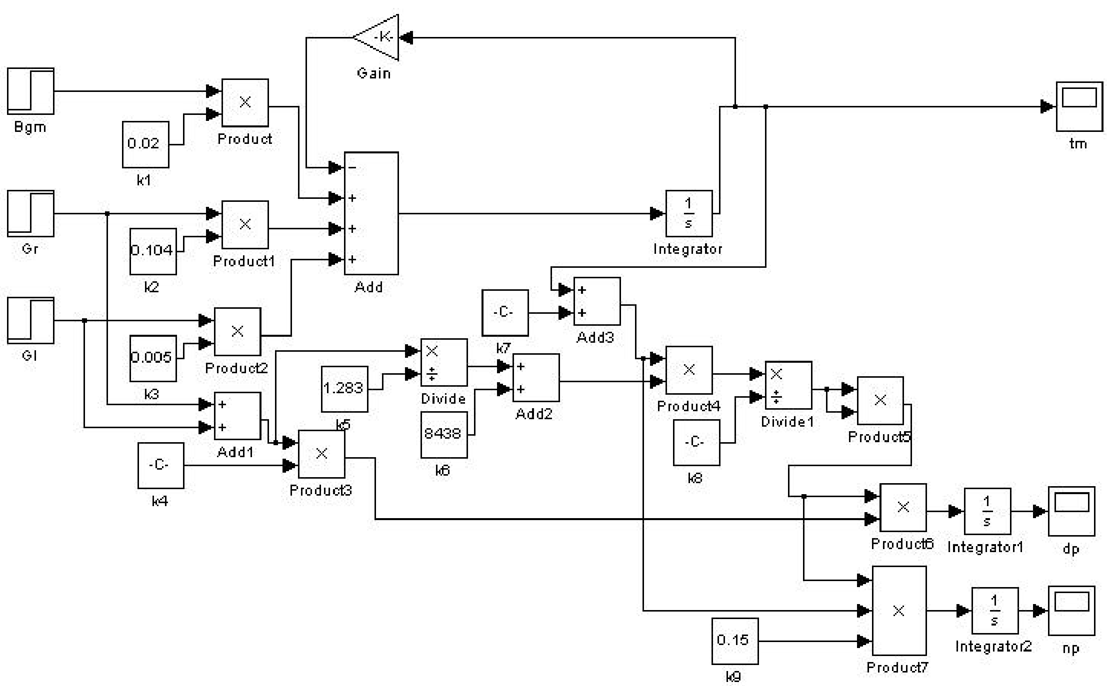

Fig. 7: Simulation of dynamic mathematical model of MGS4060 ball mill

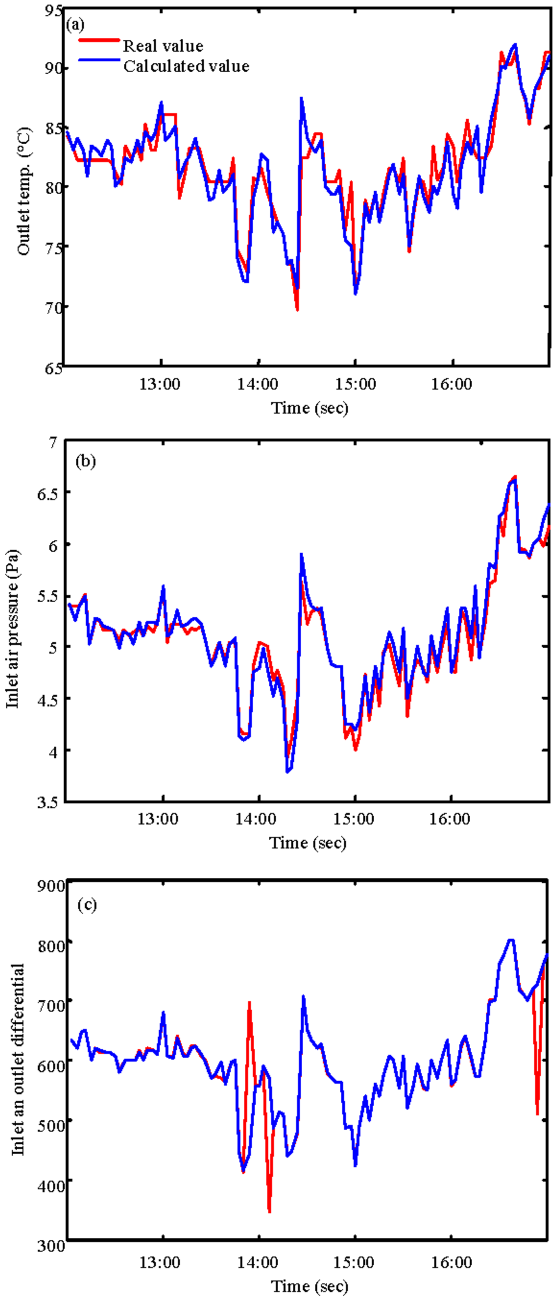

Fig. 8(a-c): Comparison of outputs between mechanism modeling and actual power plant of ball mill with double inlets and outlets, (a) Outlet temperature, (b) Inlet pressure and (c) Differential pressure

$$K(x_i, x) = \exp\left[-\|(x_i - x)\|^2 / 2*\sigma^2\right]$$

The parameter values of SVM identified generalized inverse system are chosen respectively as follows: the penalty factor for the coal is C = 2.2974, the width of

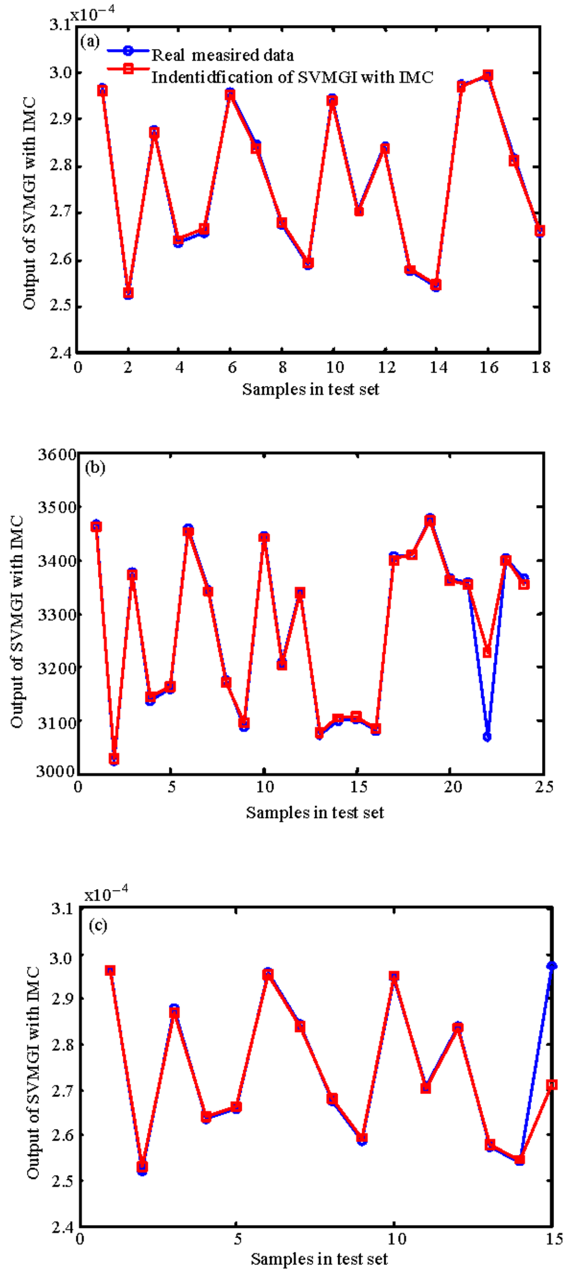

Fig. 9(a-c): Comparison between SVM identify generalized inverse system and test values, (a) Output tm, (b) Output dp and (c) Output np

kernel function is σ = 588.1336, the offset is b = -0.4787, the penalty factor for the hot air is C = 4, the width of kernel function is σ = 377.794, the offset is b = -0.5777, the penalty factor for the cold air is C = 1.3195, the width of kernel function is σ = 588.1836, the offset is b = -0.4875. The result of identification is shown in Fig. 9(a-c).

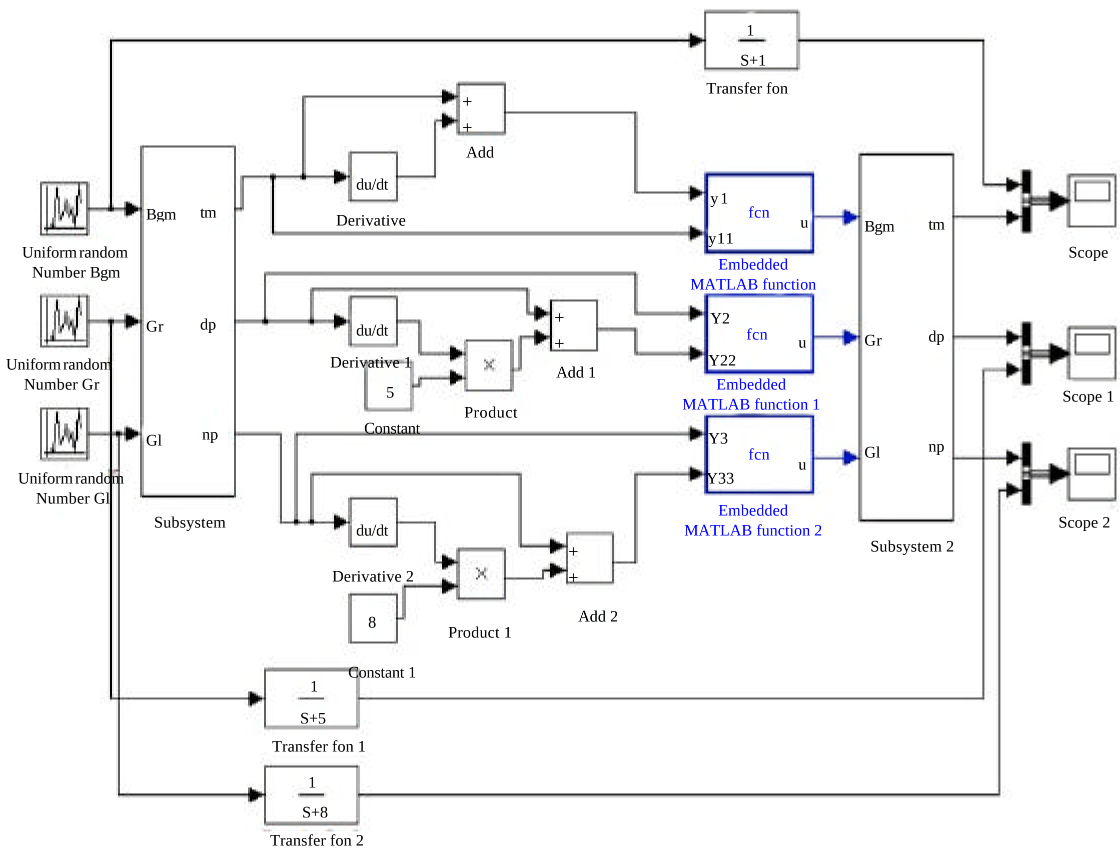

Fig. 10: Simulation of SVM generalized inverse open loop control system

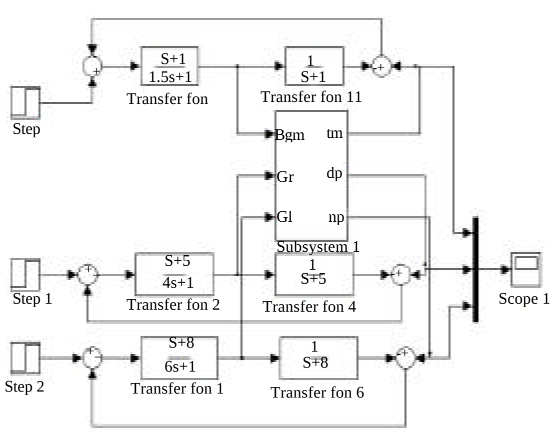

Fig. 11: Simulation of SVM generalized inverse of ball mill with internal model control

It can be seen that the training effect has kept broadly in step with the actual test values, which shows SVM has good identification effect to the generalized system. By using the identified generalized system in series with the original system the decoupling control of original system can be realized. Where, Embedded MATLAB Function module is compiled by M files, which uses SVM to train the generalized inverse model. The inputs object of training are:

$$y_1, \dot{y}_1; y_2, 5\dot{y}_2; y_3, 8\dot{y}_3$$

respectively. But the open loop control effect is not stable, therefore the internal model closed control is introduced. Then setting the parameter of the filters are $\lambda_1 = 1.5$, $\lambda_2 = 4$, $\lambda_3 = 6$, shows in Fig. 10 and 11.

In order to verify the advantages of SVM generalized inverse with IMC, the method used in this study compares with the solo IMC decoupling control, which is set tm to reach 80°C, dp to reach 50 Pa, np to reach 30 Pa, respectively, shows in Fig. 12(a-c).

The simulation result shows that the control algorithm used in this study can realize the decoupling among outlet temperature, inlet and outlet differential.

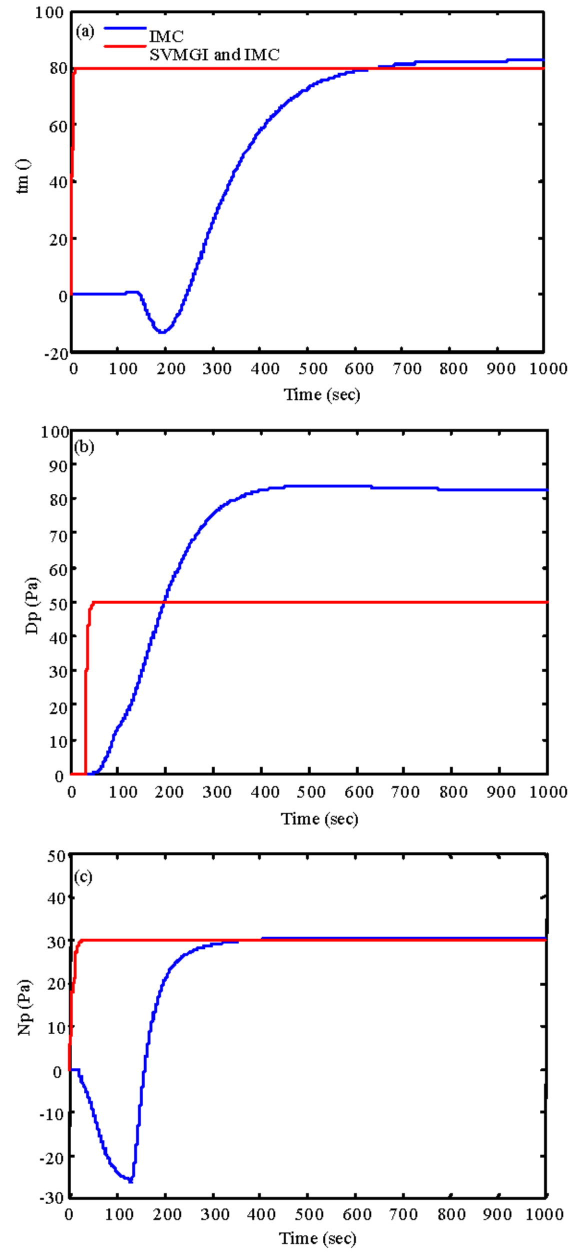

Fig. 12(a-c): Comparison between SVM generalized inverse with internal model control and internal model control, (a) Output tm, (b) Output dp and (c) Output np

CONCLUSION

Through mechanism modeling to analyze the working principles of ball mill with double inlets and outlets, the mathematical differential models are deduced. Then using SVM to identify the generalize system of the model, which in series with the original system to be a incomplete decoupling pseudo-linear system. Last, through introducing IMC makes the closed system stable. From the simulation by Matlab/Simulink, the modeling method adopted in this study has a relatively higher accuracy and the adopted control algorithm has good dynamic responses, decoupling effect and robust stability. It provides a solution to the control problems such as the high order, complex, nonlinear and hard to build up the models of system, which should have a good prospect.

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