MODELING AND SIMULATION OF A CLOSED LOOP BALL MILL GRINDING CIRCUIT

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Abstract - The concept of modeling and simulation in a ball mill grinding process have grown exponentially in recent past owing to the competition in the cement industry. In most of the control applications Linear models have been the front runner for a long time and still a vast majority of controller designed for cement plants are based on these linear models. But as the demand for accurate measurements, cheaper hardware, energy efficiency arose, efforts were put in to designing such models that also incorporates the inherent non linearity associated with the cement process. This paper discusses the designing and implementation of different linear and nonlinear models and its simulation for a closed loop ball mill grinding circuit and advantages of using the non linear models over the linear models in future.

Index Terms— Control, Grinding, Linear model, Modeling, Non Linear model, Simulation.

I. INTRODUCTION

A cement ball mill is a grinder that grinds the clinker to produce fine cement. It works on the principle of impact. The functioning of ball mill is further discussed in this study. Development in the field of science and technology and competition in the cement industry resulted in a steady growth of research for the control techniques used in a ball mill. The PID controllers used initially were applicable only for SISO systems and made plenty of assumptions. The result was plant model mismatch. Considering multiple inputs and multiple outputs, in due course of year modern control techniques were introduced and they replaced the PID based ones. When it comes to modeling and simulation of a grinding process, different types of process models are considered owing to different parameters opted to study and in different levels of complexity. Advanced methods for modeling the ball mill grinding and its simulation using different criteria have been successfully carried out already. They are too complex in nature and simple close loop simulation cannot be carried out. Even modeling based on the specific breakage rate have been done but simple closed loop analysis was unachievable. The closed loop analysis for the linear models in this paper are carried out by using the Model based Predictive control technique with the help of inbuilt MATLAB Model predictive control toolbox and for the non linear differential equation model, a simple PI control based closed loop simulation is carried out. Model Predictive control is a process control technique that represents the complex dynamic behavior of the system. It was preceded by PID Controllers whose usage was restricted to simpler systems. The main features of a complex system are large time delays and higher order dynamics, as PID controllers could not handle this, the alternative of MPC was adopted. Model Predictive controller, as already established, is better suited for such systems that are multivariable in nature, complex in behavior and have input and output constraints. It prevents the input and outputs going out of constraints and also prevents excessive variation in the input. The success of Model predictive control in cement plants is evident by the fact that majority of the cement plants in the world employs MPC technique to control the mill process. During control calculations, the manipulated variable u(k) at the kth sampling instant is found out and is used to minimize the cost function. The cost function is nothing but the sum of squares of deviations between predicted future outputs and the specified reference trajectory. The optimization cost function is given by the equation

$$J = \sum_{I=1}^{N} w_{xi} (r_i - x_i)^2 + \sum_{i=1}^{N} w_{ui} \Delta u_i^2 \qquad (1)$$

x_i = i^{th} control variable
r_i = i^{th} reference variable
u_i = i^{th} manipulated variable
w_{xi} = state weighing coefficient
w_{ui} = Control weighing coefficient

As we have already discussed, linear models are deployed in majority of plants without considering the non linearities associated with the process. The main advantages of developing better models which are inherently non linear in nature are :

- Reduce the power consumption
- Product quality can be improved
- Rate of production can be increased
- Uninterrupted operation of ball mill can be achieved.

In this paper : section II describes the dynamics of the ball mill circuit, Section III deals with types of modeling and its simulation results, Section IV briefly explains the future work of the project.

II. DYNAMICS OF THE BALL MILL GRINDING CIRCUIT

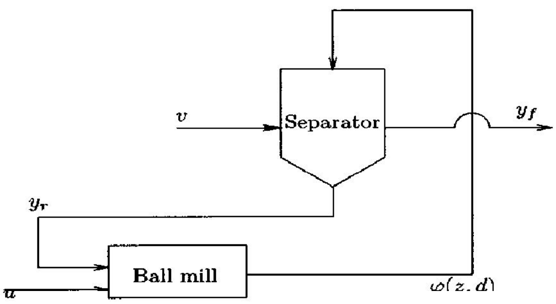

Fig.1

In a continuous ball mill grinding circuit, the ball mill and the separator are interconnected. A ball mill consists of a long hollow cylindrical shell that is fixed at both ends and rotated about its central axis by a prime mover. The prime mover is generally a motor with a clutch. We are considering the ball mill with horizontal axis. The raw material fed to the ball mill is cement clinker. Mill drum is filled with steel balls that grind the cement clinker upon impact. When the ball mill rotates, the steel balls are lifted up and dropped down on the feed material and hence due to the impact, the cement clinker breaks into smaller fragments. Once milling is done, the product is sent to the separator that separates the fine particles from the coarse particles. The coarse particles are recovered and sent to ball mill. Considering the process dynamics of the ball mill grinding circuit, the feed material to the ball mill is cement clinker that is fed at the rate of tonne per hour and denoted by u in the Fig.1. v is the rotational speed of the motor used in the air separator that separates the coarse from the fine particles .The outlet of the ball mill is sent to the separator as input and as the finer particles are separated from the coarser particles , the latter is redirected back to the ball mill via inlet. The finished particles leaves the separator at the rate of Yf. The control variables are the mill load measured in folaphone sound level, rejects flow rate from the separator to that is measured in tonne per hour and the product Blaine, the unit of which is cmÂ²/g. Manipulated variables are the feed flow rate to the ball mill measured in tonne per hour and the separator speed which is measured in percentage. There are plenty of disturbances in this system such as CM bag filter damper opening, mill outlet temperature, mill inlet damper positing, separator bag filter fan power control, separator bag filter fan pressure control, cement outlet temperature. For our convenience, we have selected mainly two disturbances that are mill fan speed measured in percentage and separator fan load measured in kilowatts.

III. MODELING AND SIMULATION

Three cases of modeling and simulation have been discussed in this paper. First one is the closed loop simulation of a simple linear model without any disturbance signal using MPC Toolbox, second one is the closed loop simulation of a much complex linear model with two disturbance signals using MPC Toolbox and the last one is the PI based closed loop simulation of a non linear differential equation model using a MATLAB algorithm. 1. Linear Model without Disturbance (1.1) Modeling System Identification technique is used to build a mathematical model of the cement ball mill grinding circuit using the measured data from the simulator. The control variables considered in this case are the product Blaine measured in cmÂ²/g and the rejects flow rate measured in tonne per hour. The manipulated variables are feed flow rate measured in tonne per hour and the separator speed measured in percentage. Thus we have two inputs and two outputs making it an interactive multivariable system. The two inputs are stored as an array in an input variable and two outputs are stored as an array in an output variable. Using the system identification toolbox in the MATLAB, these two inputs and outputs are imported and tried to fit for different linear time series models. There are different types of models like transfer function models, ARX models, ARMAX models, state space models . When the data is tried to fit for different models, state space model showed better fit . The open loop step response for the state space model is shown in Fig.2

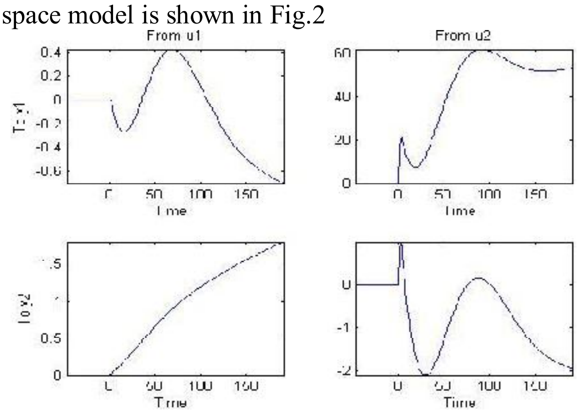

Fig.2

(1.2) Closed loop Response

The closed loop response is obtained using the MPC toolbox. The state space model generated using the system identification toolbox is imported here.

The nominal values of the manipulated variables, feed flow rate and separator efficiency were set to be 120 t/h and 60%. The nominal values of the control variables, rejects flow rate and product Blaine were set to be 120 t/h and 3100 cmÂ²/g. The prediction horizon was set to 300 and the control horizon was set to 50. The control interval was set to be 0.5 time units. As discussed earlier, main advantage of using MPC is that constraints can be set to input and output. Here, the input constraints for feed flow rate was set between 80 and 150, and for separator speed between 40 and 80. The output constraints for product Blaine to be between 2000 and 3300, and for rejects flow rate between 80 and 150. The input weights were set to 1.5 and 5 , output weights were set to 2 and 3. The weights restricts the deviation of the input and output variables from the nominal value. For a step change of 10 for rejects flow rate and a step change of 50 for product Blaine, the control action brings the output to desired setpoint as in Fig.4

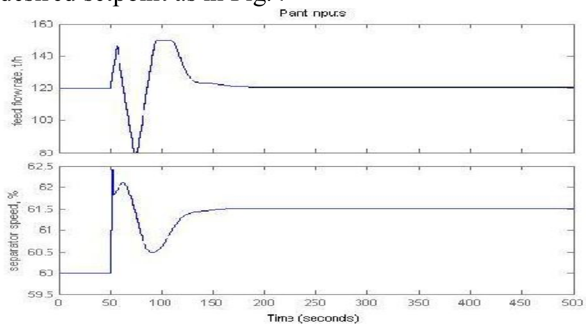

Fig.3

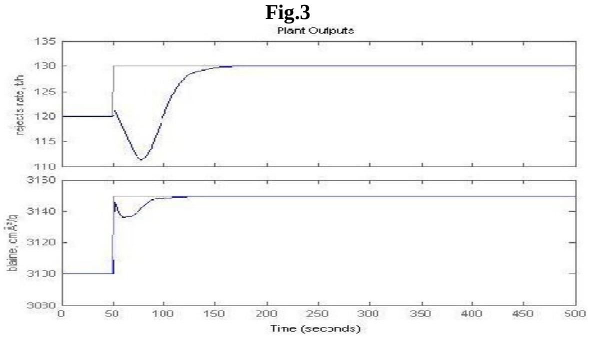

Fig.4 2. Linear Model with Disturbance (2.1) Modeling

System Identification is used here also to build a mathematical model from simulator data. The difference is that , here we consider two extra disturbance variables which are mill fan speed measured in percentage and separator fan load measured in kilowatts. The manipulated variables are the feed flow rate and separator speed. The control variables are product Blaine and rejects flow rate. A state space model is generated with four inputs and two outputs. The four inputs being two manipulated variables and two disturbance variables. The open loop response for the state space model is shown in Fig 5

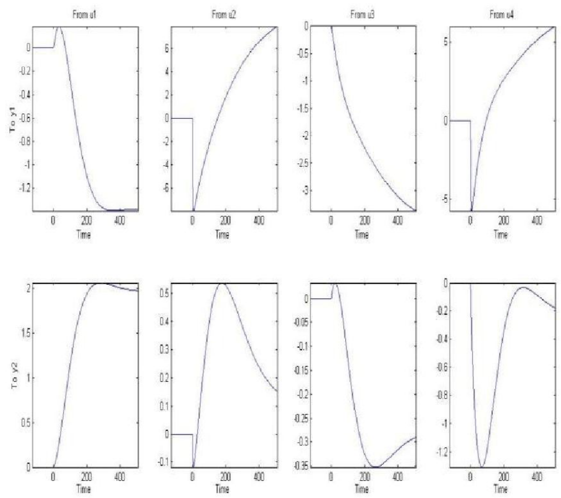

Fig.5

(2.2) Closed loop Response

As in the previous case, closed loop response is obtained using MPC toolbox where the state space model designed with 4 inputs and 2 outputs are first imported here. The nominal values of the manipulated variables, feed flow rate and separator efficiency were set to be 124 t/h and 56% . The nominal values of the control variables, rejects flow rate and product Blaine were set to be 125 t/h and 3150 cmÂ²/g. The nominal values of the disturbance variables, mill fan speed and separator fan load were set to be 80% and 400 kilowatts. The prediction horizon was set to 500 and the control horizon was set to 200. The control interval was set to be 0.2 time units. Here, the input constraints for feed flow rate was set between 110 and 130, and for separator speed between 55 and 60. The output constraints for product Blaine to be between 3100 and 330, and for rejects flow rate between 110 and 130. The input weights were set to 0.1 and 0.1, output weights were set to 1 and 1.

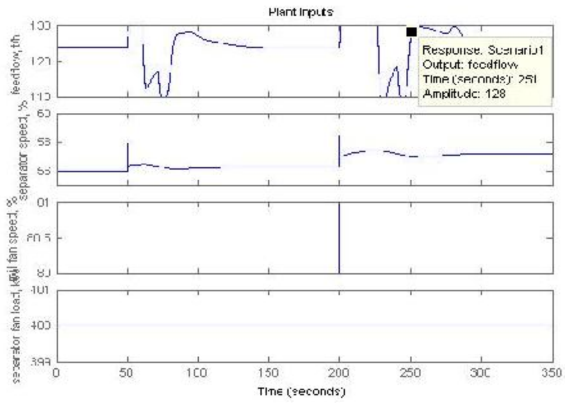

Fig.6

For a step change of 1 for mill fan speed and a step change of 10 for product Blaine as shown in Fig.6,the control action brings the output to desired setpoint as shown in the Fig.7

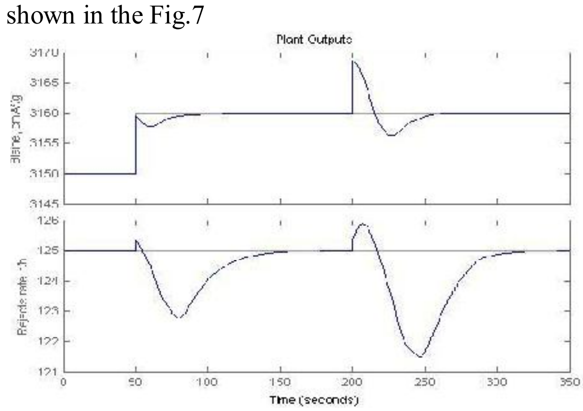

Fig.7

3. Non- Linear Model with Disturbance

A multivariable PI control of a non linear differential equation model is discussed in this section. (3.1) Modeling An already developed non linear differential equation model based on mass balance is considered in this study. Fig.1 corresponds to the process flow diagram. Two control variables under consideration are the mill load measured in folaphone sound level and the rejects flow rate measured in tonne per hour. Two manipulated variables are the feed flow rate measured in tonne per hour and separator speed which is measured in terms of percentage.

$$Tf\frac{dYf}{dt} = -Yf + (1-\alpha(v))\varphi(z,d) \quad (2)$$

$$Tr\frac{dYr}{dt} = -Yr + (\alpha(v))\varphi(z,d) \quad (3)$$

$$\frac{dz}{dt} = Yr - \varphi(z,d) + u \quad (4)$$

$$\varphi(z,d) = 20z\, e^{(-dz/80)} \quad (5)$$

$$\alpha(v) = 9\left(\frac{v}{vmax}\right)^3 - 13.5\left(\frac{v}{vmax}\right)^4 + 5.4\left(\frac{v}{vmax}\right)^5 \quad (6)$$

$$vmax = 200 \quad \alpha max = 0.9$$

Even though there is a third state variable, products flow rate, in the differential equations, we are neglecting it for our convenience of restricting manipulated variables to two and control variables to two. u is the feed flow rate, v is the separator speed, z is the mill load, d is the clinker hardness, Yr is the rejects flow rate, $\alpha\ v$ is the separation function and φ z,d is the grinding function . The time constants are , Tr. Initial values of feed flow rate and separator speed were set to be 126 and 57 .
The initial states were set to be 65 and 400.Using an ODE solver,the outputs were obtained from the state derivatives. Keeping feed flow constant and giving step changes with respect to separator speed , the step response generated is shown in Fig.8

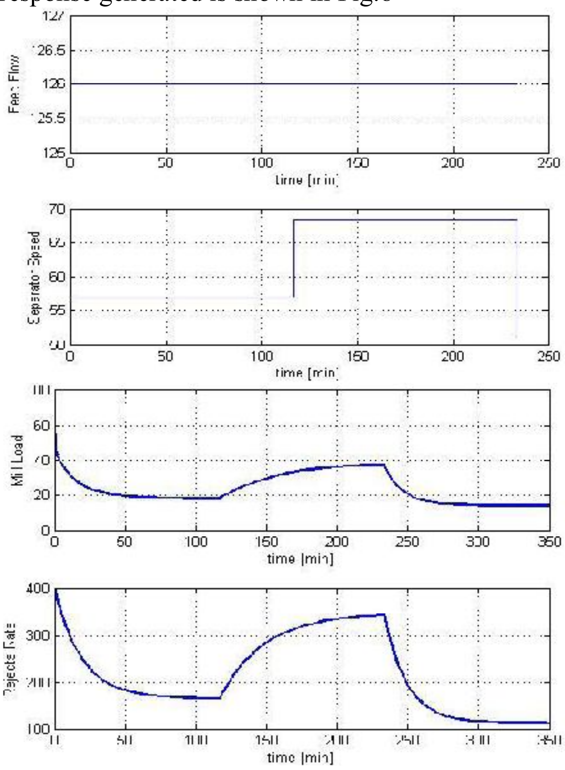

Fig.8

Keeping separator speed constant and giving step changes with respect to feed flow the step response generated is shown in Fig.9

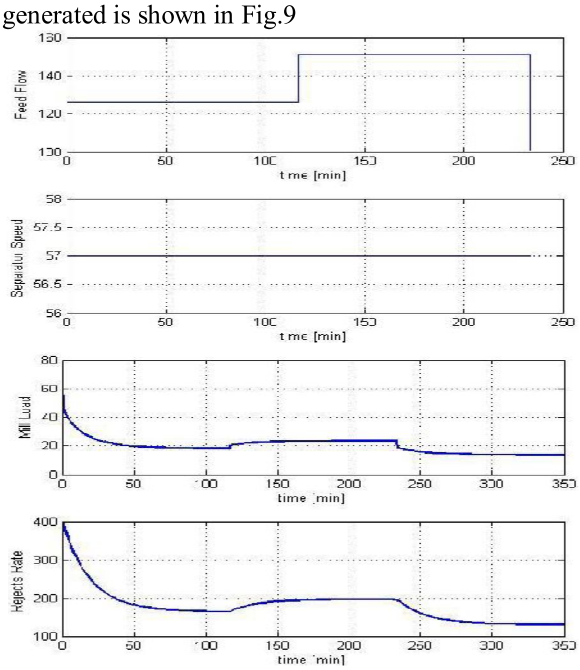

Fig.9

(3.2) Closed loop response
A simple PI based control is used to carry out the closed loop simulation for this non linear model. Initial values of feed flow rate and separator speed was set to be 126 and 57.The initial states were set to be 65 and 400. The nominal values for the mill load and rejects flow rate were set to 70 and 400. Controller gain for first input was set to 0.18 and for the second input,it was set to 0.1 . The integral time for each inputs were set to 70 and 100 . The closed loop response of the model is shown in Fig.10

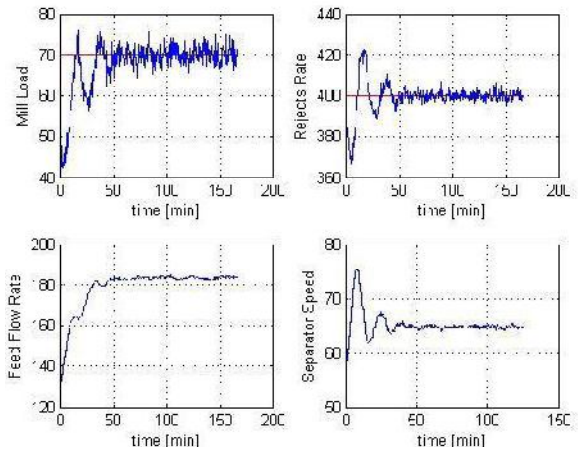

Fig.10

CONCLUSION

In this paper, the simple closed loop simulation for models of different complexities for a ball mill grinding circuit is carried out. It also emphasizes on how the linear models are simpler in nature and are designed with lot of assumptions. As the complexity of the model increases, more plant dynamics it takes into consideration. Hence the controller employing a non linear model takes into account the non linearities associated with the real time plant and reaches the setpoint faster. Linear PI based control was carried out for the non linear model in this paper and is expected to be substituted it with Non linear MPC in future work.

REFERENCES

[1] E.Brinksmeier et al, "Advances in Modeling and Simulation of Grinding Processes",CIRP Annals - Manufacturing Technology Volume 55, Issue 2, Pages 667–696, 2006

[2] Vladimir Monov, Blagoy Sokolo, Stefan Stoenchev,"Grinding in Ball Mills : Modeling and Process Control",Cybernetics and Information Technologies. Volume 12, Issue 2, Pages 51–68, March 2013

[3] D.Q.Maine, J.B.Rawlings, C.V.Rao, P.O.M Scokaert,, "Constrained Model Predictive Control : Stability and Optimality", Automatica , Volume 36, Issue 6, Pages 789–814, June 2000

[4] F. Grognard, F. Jadot, L. Magni, G. Bastin, R. Sepulchre, V. Wertz,"Robust stabilization of a nonlinear cement mill model", IEEE Trans. Autom. Contr,Volume 46 ,No.4 ,Pages 618-623,April 2001

[5] Xi-song Chen, Qi Li , Shu-min Fei,"Constrained Model Predictive Control in Ball Mill Grinding process",Powder Technology, Volume 186, Issue 1, Pages 31–39, August 2008

[6] L.G. Austin, P. Bagga,"An Analysis of fine dry Grinding in Ball Mills", Powder Technology,Volume 28, Issue 1,Pages 83–90, January–February 1981

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