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PI Controller Design of Grinding Circuit Based on Frequency Domain

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ABSTRACT:

The grinding circuit can be modelled to design and test different controllers. A represented model is selected from literature to design a controller. A controller design here is based on a frequency method. MIMO PID controller tuning based on gain and phase margins were developed in a way that can be used on the industrial process. A controller based on this method is designed for grinding circuit process. A simple controller is designed and tested numerically with a grinding circuit model. It gives good results compared with other methods. It is recommended to use this method with noise and external disturbances.

Keywords- Multivariable control, PI controllers, frequency control, process control

I. INTRODUCTION

Comminution is the process in which the size particle of ore is progressively reduced until particles of mineral can be separated. Crushing and grinding are the two primary comminution processes and responsible for consuming great deal of energy. Comminution consumes up to 4% electrical energy globally and about 50% of mine site energy. In average for single mine, approximately 6,700 kWh /kiloton of energy consumes on comminution processes [1] and [2].

In a survey study for the grinding circuits control engineers, the authors conclude that 63% of them uses PID control strategy among the various control technologies [2-4].

A study conducted over 11000 controllers used in refining, chemicals, pulp and paper industries found that 98% of all controllers utilized by PID compensators. The uses of PID controller has not affected over time and stay competing the trending of adapting the advanced control. The lower regulatory layer still controlled by PID controller whereas, the setpoints for those layers can be manipulated by other advanced controllers. So, the system highly depends on the behavior of the PID controllers [4].

In the literature many works try to model the grinding circuits (Monov, Sokolov, et al. 2012). In a study to assess the controller of a grinding circuit based on a simulator, particle size and circulating load performance of decentralized PID and predictive control with setpoint and distributes was tested. The decoupled PID accomplishes as well as model-based controllers (MPC), if the delay is small. Moreover, the MPC has difficult to identify when external disturbances exist [5, 6].

The rest of this paper is as follow. Section (2) is to describe the process. Then, define the model which will be used for the simulation. Sections 4 and 5 are bout the simulations methodology. Lastly, results, discussion, conclusion and some recommendation to extend this works

II. GRINDING PROCESS DESCRIPTION

The grinding circuit (GC) in mineral extracting is used to reduce the particle size of the ore. The size reduction measured by the percentage size distribution (SD). The goal of size reduction is to make the valuable mineral composition can be easily recovered in the subsequent beneficiation operation. The schematic diagram of a two-stage GC shown in Fig. 1. It consists of a rod mill in open circuit and a ball mill in closed circuit with a hydrocyclone classifier. So, some of the ore is circulated on the closed-loop until get the required quality to pass the classifier. For this GC, the grinding product size distribution (SD), defined as the fraction or percentage of particles in cyclone overflow passing. It is viewed as the most important quality index. The circulating load (CL), expressed by tons per hour (t/h) of solids entering the ball mill. It is another important index that directly relates to the grinding production efficiency which can be used to affect the throughput. The grinding circuit usually it comes after ore crusher circuit. At first, the ore must be ground to a specified size called the liberation size so that imbedded mineral particles are exposed for effective recovery. During operation, the CL needs to be kept at a desirable setpoint so that the best grinding efficiency can be achieved.
CL need to set to the highest points the closed-loop can handle-the mill, the classifier and the pump, so at fixed SD this operation will be consuming the lowest energy. This is the optimal operation for the GC, However, the SD and CL should be controlled effectively to achieve the optimal process operation. The CL and SD are commonly the measured outputs in some cases the hydrocyclone pressure also an excellent performance measure. The outputs are highly sensitive to various disturbances and plant uncertainties. During the GC operation, disturbances have a significant influence on the operational performance of the open and closed-loop GC operations. The variations of ore hardness and ore feed rate are type of external disturbances. Continuous variation can be caused by the variations of the ore hardness and ore feed rate. Moreover, plant uncertainties may affect the plant dynamics and enhance unstable performances [7].

The rest of this paper is as follow. Section (2) is to describe the process. Then, define the model which will be used for the simulation. Sections 4 and 5are bout the simulations methodology. Lastly, results, discussion, conclusion and some recommendation to extend this works.

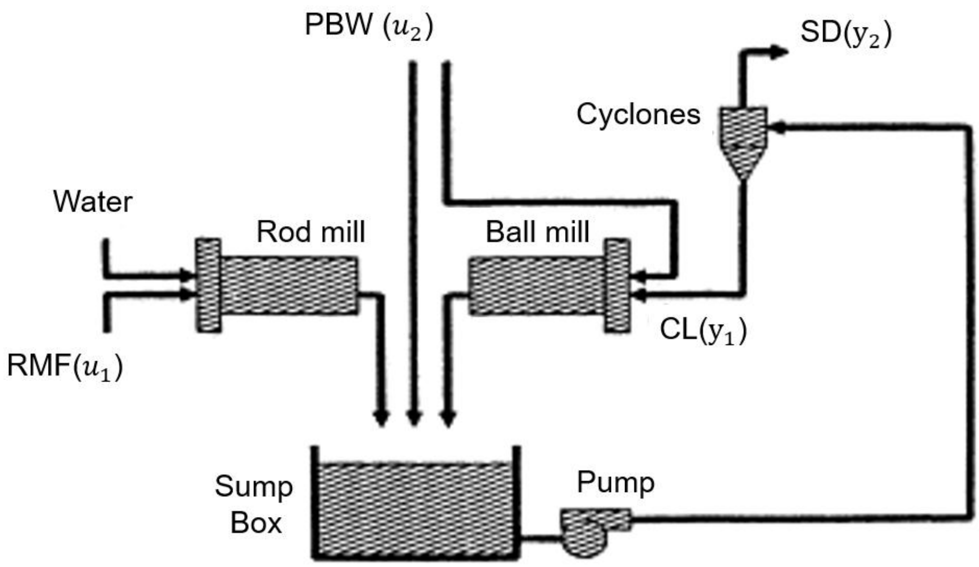

Fig. 1. Grinding circuit layout

III. GRINDING MODELING

The grinding circuit (GC) can be model as two input two output system (TITO). The model in this word was taken from previous work [4]. The two inputs are the pump box water (PBW) and the rod mill feed (RMF). The two outputs are the size distribution (SD) which is the percentage passing 74 \mu m and the circulating load (CL). Note that transfer functions from SD or CL to the input PBW have some more delay time due to the open loop time elapsed. There is no noise signal considered in this work. See Fig. 2 and (1-5).

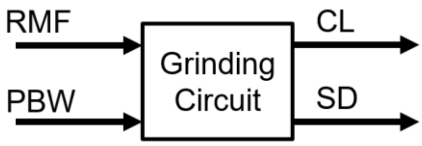

Fig. 2. Grinding Circuit TITO model

$$G_{11}(s) = \frac{CL}{RMF} = \frac{0.6925^{-5s}}{1 + 18s} \quad (1)$$

$$G_{21}(s) = \frac{CL}{PBW} = \frac{0.475(1 - 3.5s)}{(1 + 4.5s)(1 + s)} \quad (2)$$

$$G_{12}(s) = \frac{SD}{RMF} = \frac{-1.63(1 - 2.5s)^{-8s}}{(1 + 28s)(1 + s)} \quad (3)$$

$$G_{22}(s) = \frac{SD}{PBW} = \frac{0.393(1 + 92s)^{-s}}{(1 + 21s)(1 + 2s)} \quad (4)$$

$$G(s) = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \quad (5)$$

IV. DECETRALAZED PI CONTROLLER

PI is commonly and widely used on industry. Frequency techniques not usually applied on grinding circuit control. Frequency can be suitable to design more robust PI controller.

The main control objectives:

Product size distribution should be maintained at fixed set-points and in size less than certain percentage.

Circulating load should be maximized to increase circuit productivity.

V. DESIGN PROCEDURES

The method used in based on the work of many authors [5]. This method is useful to design a system on gain and phase margin requirements. The two input two output system convert to single input ingle output. Fig 3 shown how the g1 transfer function can be obtained. Similar plant can be obtaining for the second loop. (6&7) shown the SISO transfer functions for loop one and two. Fig 4 show the two loop systems.

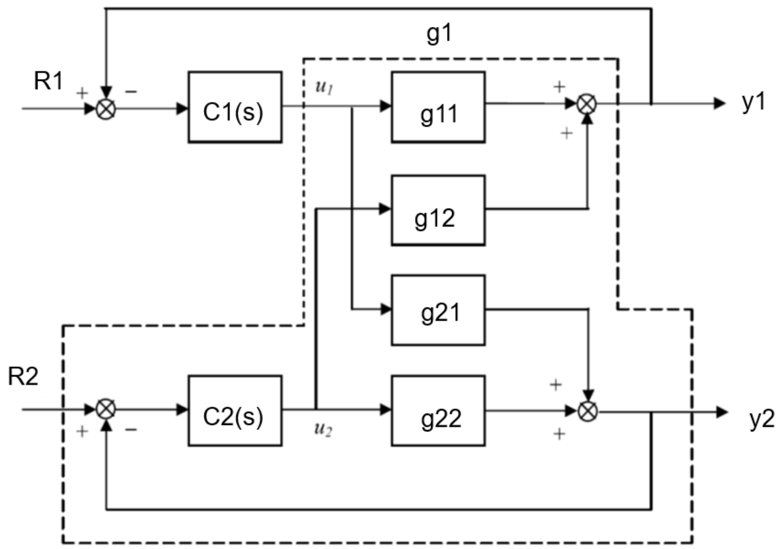

Fig. 3. MIMO closed loop interaction

$$g_2(s) = g_{22}(s) - \frac{g_{12}(s)g_{21}(s)c_1(s)}{1 + g_{11}(s)c_1(s)}. \quad (6)$$

$$g_1(s) = g_{11}(s) - \frac{g_{12}(s)g_{21}(s)c_2(s)}{1 + g_{22}(s)c_2(s)}. \quad (7)$$

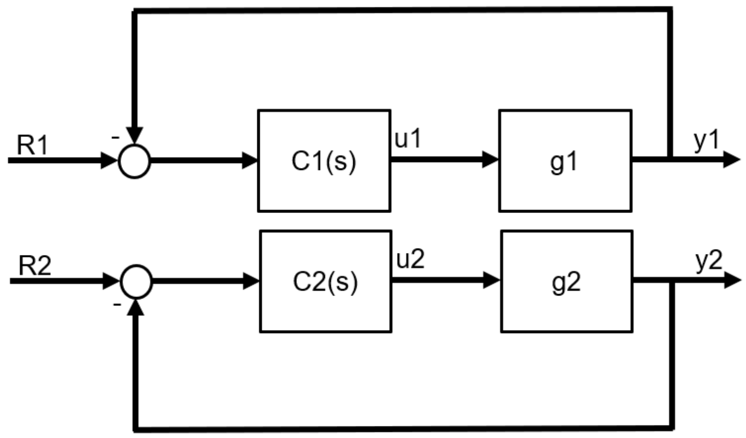

Fig. 4. Realize the TITO as SISO

Now, the task is to design PI controller c1(s) and c2(s) for the plants g1 and g2. The controller should achieve the gain and phase margin on each loop.

The steps as it recommended:

Firstly, we design an initial controller in loop (1) based on some uncertainty estimation due to unknown 2nd loop controller

then design the second-loop controller with the known first-loop controller c_1. Fig 5 shown the PI constants obtained.

Finally, retune the first-loop controller with the known 2nd-loop controller.

In such a strategy, the key problem is how to design an initial controller for loop (1) with an unknown controller in other loop. The details will be given in the next section

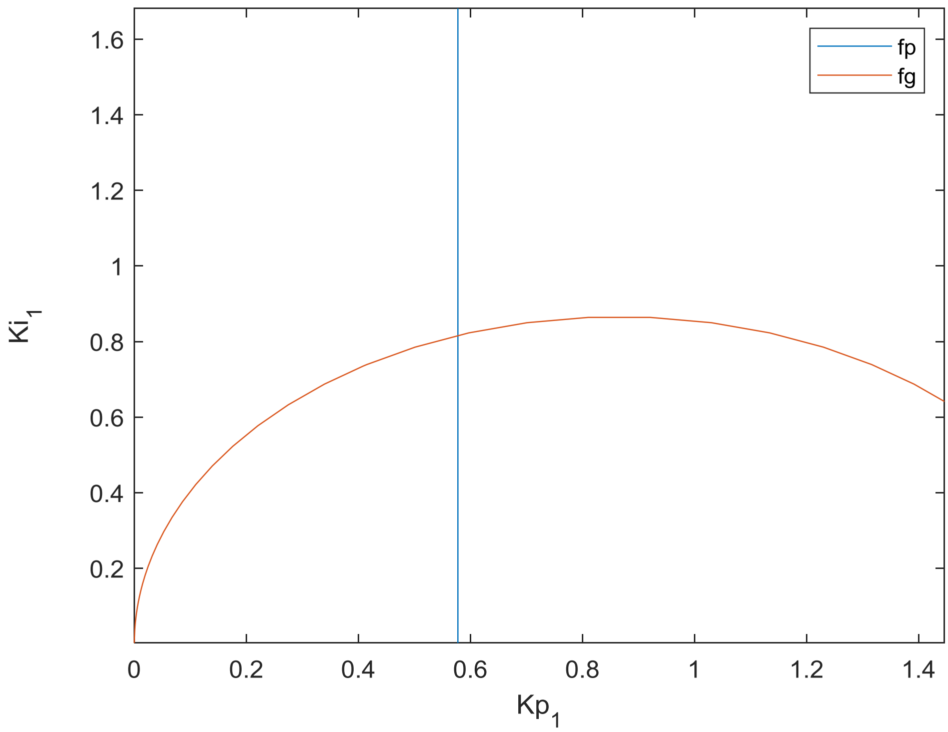

Fig. 5. PI constants for loop (1)

VI. RESULTS AND DISSCUSSIONS

The grinding circuit is modelled by (1-4). The controller obtain by frequency domain analysis is a simple first order controller as shown on (8-9). Plant and controller simulated in MATLAB/Simulink Environment. Fig. 6 shown the block diagram of the controller scheme. The first process input (CL) is a step function from 192 to 208 t/h. The second process input (SD) is fixed at value of 74 \mu m.

The results from grinding circuit controlled by PI MIMO controller are shown in Fig. 7. The first graph is about the rod mill feed (RMF). This is a control variable. It starts at 40 t/h and it jump with the step input function to 58 t/h. This amount is considered appropriate however, it can be increased to achieve more throughput. It can be increased by increasing the circulating load or can put a minimum level on designing PI controller.

$$c_1(s) = 0.58 + \frac{0.8}{s} \qquad (8)$$

$$c_2(s) = 0.1 + \frac{0.097}{s} \qquad (9)$$

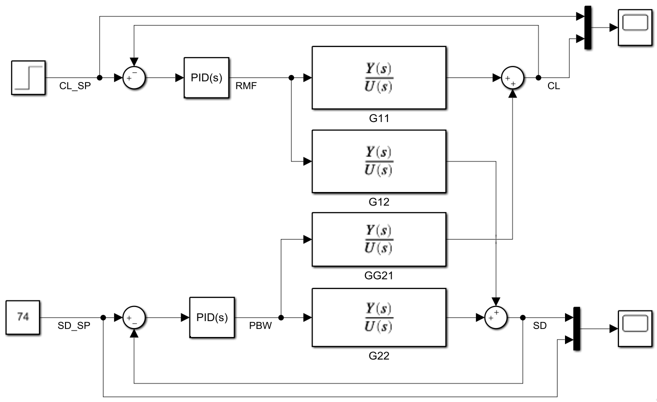

Fig. 6. Block diagram of GC

The second graph, the circulating load used as input. It can be seen the output is tracking the input nicely. The CL is an excellent indicator for the plant efficiency. The third graph is PBW. It jumps from 350 to 380. This amount is considered acceptable, but the total amount needs to be decrease for the system not to consume a lot of water. Last graph is product size distribution SD. The amount of change is 7 %. This is a considerable abut of reduction on the SD. However, the controller helps to recover to the set-point within 3 hours.

I. CONCLUSIONS

In this work, a grinding circuit model used to design a decentralized MIMO PI controller. The design requirement in phase and gain margin can be achieve through tuning procedures on frequency domain. The design can be extended to more realistic model to design a robust controller.

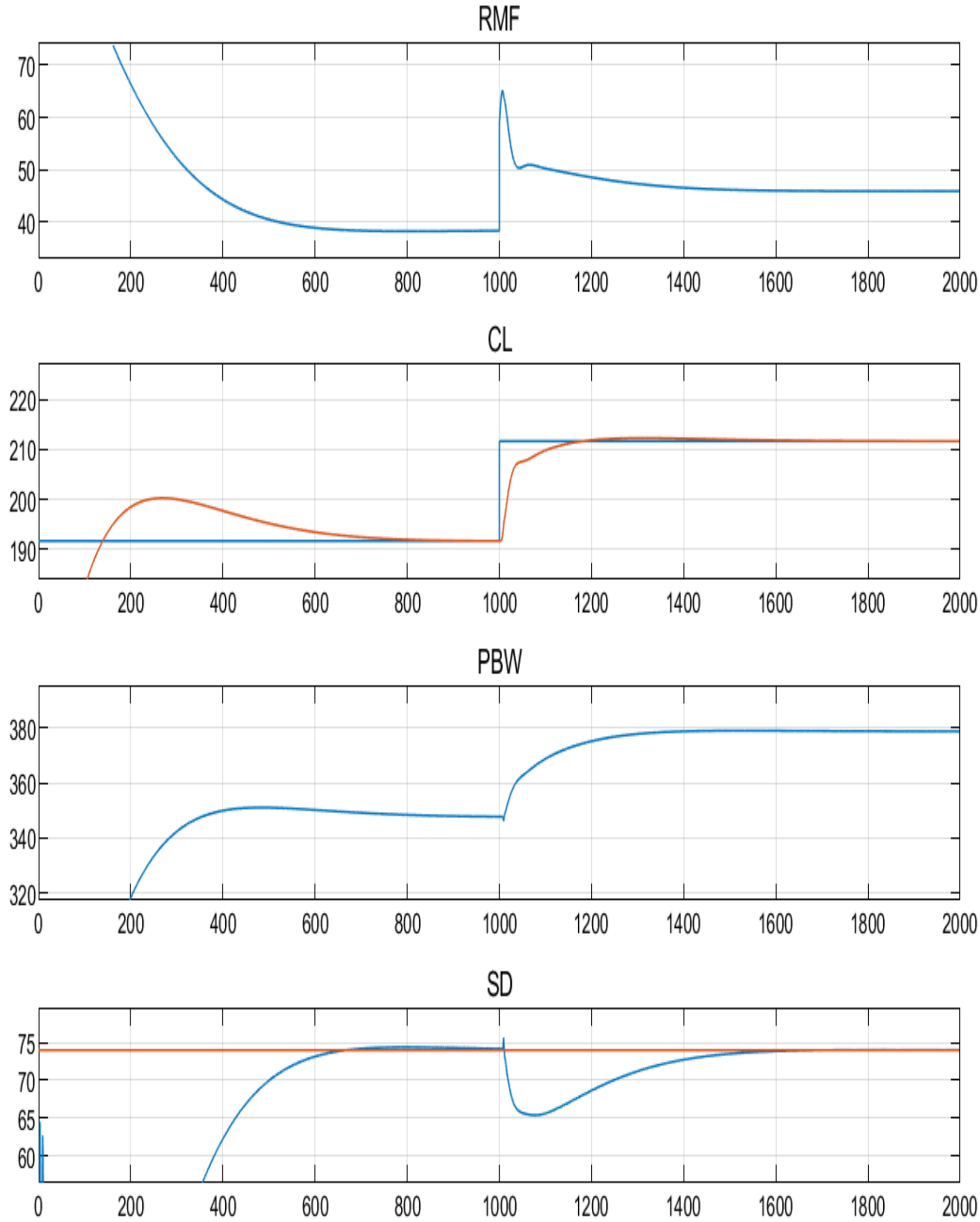

Fig. 7 Numerical simulation results.

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