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A CONTROL DESIGN TECHNIQUE FOR GRINDING SYSTEMS WITH FEEDFORWARD UNDERCOMPENSATION AND FEEDBACK CONTROL

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Abstract. *Feedforward and feedback control are new control algorithms used in industrial processes control and very suitable for grinding systems control. The purpose of this paper is to provide a design technique for a control system of a grinding circuit using the feedforward and feedback control. The control scheme is based on the undercompensation of the milling feed flow. The best value of the undercompensation is chosen after analyzing several scenarios. The controller design based on this value proves to provide improved productivity.*

Keywords: ball mill, cement mill, feedforward control, feedback control, undercompensation, milling circuit.

1. INTRODUCTION

There exists a few types of control strategies: open loop control, feedforward control and feedback control. The feedward and feedback control are useful tools in engineering area, when there is available and known the set of deviations between the setpoint and process output [1-6].

Feedback control is always reactive. It seeks to correct the deviation if something goes wrong and it is always too late. Feedforward control is essentially anticipative. It acts according with previous process knowledge and history (i.e., it acts according with a plan) and doesn't wait for happening something wrong and taking actions only after this, [11].

Mainly, feedforward control should be enough to control the system. However, because inevitably there exist disturbances and uncertainty, hence it is neccessary to use also feedback control.

It is important to overcome the limitations of a feedforward scheme which is sensitive to disturbances and uncertainty. But feedback itself has some limitations, the most important one being that it makes the system sensitive to noise.

Here it is provided a design technique for a control system of a grinding circuit using the feedback and feedforward control, based on the undercompensation of the milling feed flow. For this purpose, the paper is structured as follows. The second section provides the necessary theoretical background and the control scheme with undercompensation of the grinding system feed flow. The next section shows the simulation results of the dynamic behavior of the cement mill for several values of the undercompensation. Finally, there are presented the conclusions, followed by the reference section.

2. THE SYSTEM WITH FEEDFORWARD UNDERCOMPENSATION AND FEEDBACK CONTROL

The closed loop circuit of the cement mill embedding the air separator is given in Figure 1. The rotating mill is feeded with the material feed flow (*MF*), consisting of clinker and other necessary raw material components.

This mix is then grounded by a large number of steel balls. After this, the grounded mill product (*MP*) is transfered into the air separator, where it is subdivised into two flows of particles [1].

The first flow is the final product (*FP*). The second flow containes the rejected flow (*RF*) of particles, which is recirculated to the mill inlet for regrounding [1].

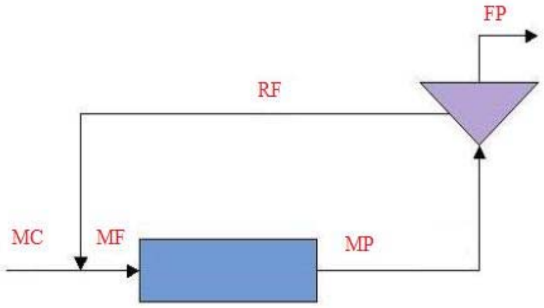

Figure 1. The milling circuit.

The sum of the raw material components (*MC*) flow and of the recirculated flow (*RF*) constitues the total mill feed flow (*MF*):

$$MC + RF = MF \tag{1}$$

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Equation (1) illustrates the flows applied to the mill inlet, while Equation (2) illustrates the flows obtained at the separator outlet:

$$MP = RF + FP \tag{2}$$

The feedforward control is generally agreed to be the single most useful concept in practical control system design beyond the use of elementary feedback ideas [2]. Clearly, if one can measure up-stream disturbances, then by feeding these forward, one can take anticipatory control action which preempts the disturbance affecting the process [3].

The feedforward compensation (see Figure 2) is used to provide the fastest possible response to dynamic changes in the input signal [3].

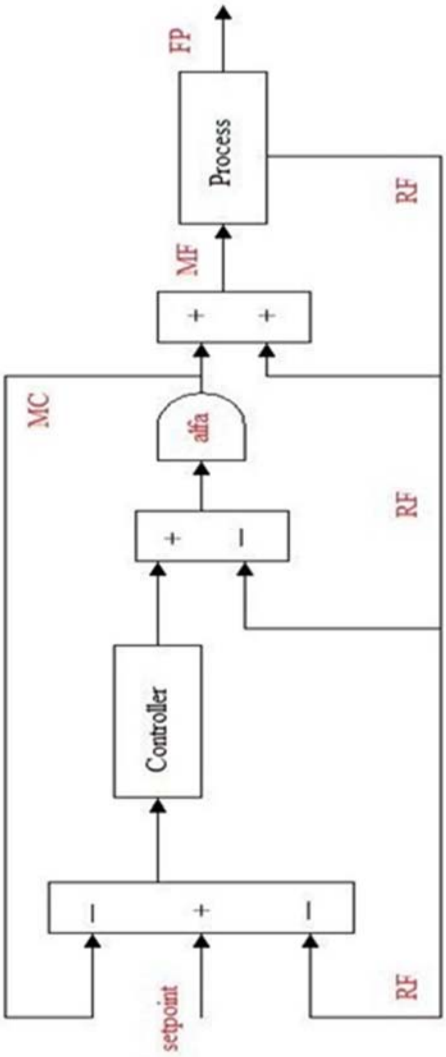

Figure 2. The control scheme with undercompensation of the feed flow.

The control scheme is based on an undercompensation of total mill feed flow *MF*. The basic principle of this scheme is the undercompensation of various feed flow rates induced by the recirculated flow rate *RF* [4]:

$$\Delta MC = -\alpha \cdot \Delta RF \tag{3}$$

where:

$$0 < \alpha < 1 \tag{4}$$

Because feedforward undercompensation does not ensure steady-state error, a control loop had to be implemented, by using the recirculated flow rate *RF* and the mill flow rate *MF* in order to reconstitute the feed flow rate [4].

One of the simplest and advanced control strategies is the PID (Proportional Integral Derivative) control with feedforward undercompensation. The PID controller is described by:

$$u(t) = k_p \cdot e(t) + k_d \cdot \frac{de(t)}{dt} + k_i \int e(t)dt \tag{5}$$

where:
- u(t) is the controller output;
- e(t) is measured error;
- k_p is the proportional gain
- k_i is the integral gain
- k_d is the derivative gain.

3. THE SIMULATION RESULTS

According to Figure 2, was performed the SIMULINK model (Figure 3). To find more details about this model, check [10]. There can be found explanations about the identification step of the process model.

The dynamic behavior of a cement mill is simulated by using MATLAB-SIMULINK. In the subsequent figures we have noted with *CF* the cement flow.

From the conditions given in Equation (3) and Equation (4), it can be infered that there may be several situations, depending on the values of undercompensation α. These situations can be grouped in three cases:
- a small undercompensation value, close to zero: $\alpha=0.1$;
- a medium undercompensation value: $\alpha=0.5$;
- a large undercompensation value close to one: $\alpha=0.9$.

The behaviour of the flows within the cement mill circuit for the considered values of the undercompensation α are presented in Figures 4-12. For example, Figure 4 show the variation of final product and setpoint for $\alpha=0.1$.

It can be seen that the system response tends to 125 [tonnes/hour] and then stabilizes at this value. Thus, the stationary deviation is 0 (zero).

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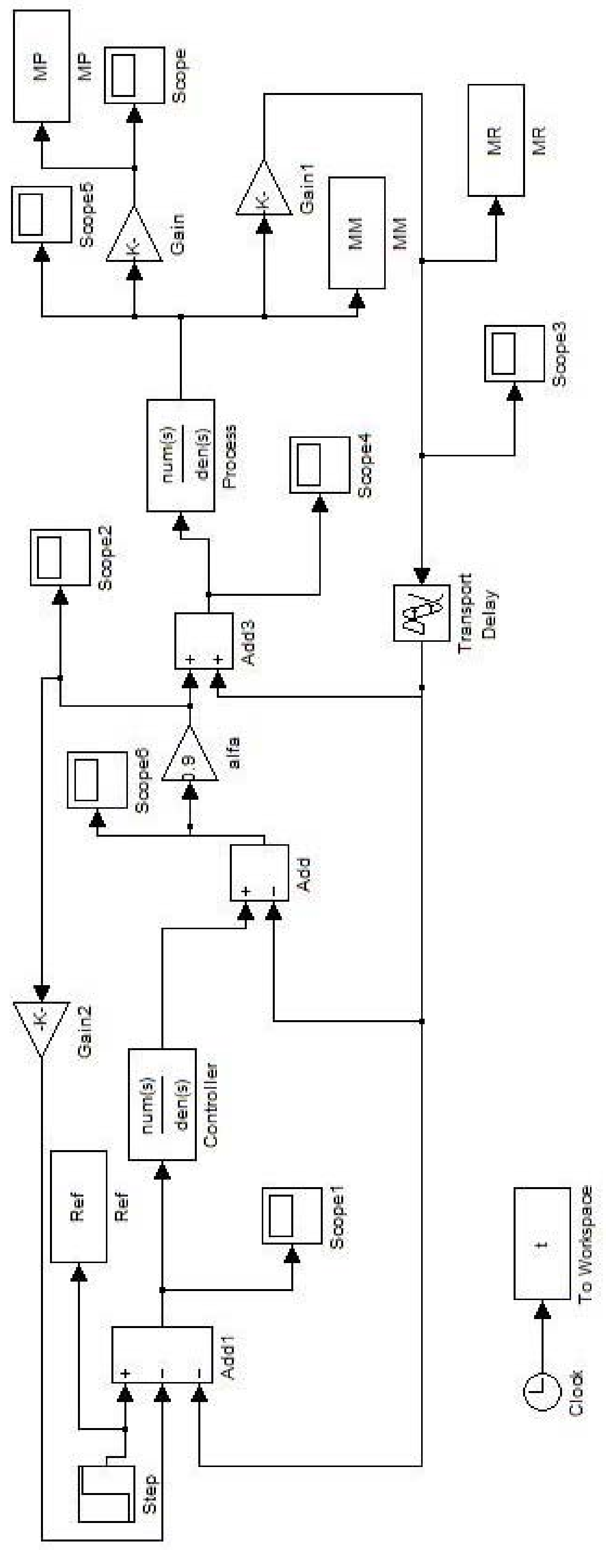

Figure 3. The SIMULINK model of control scheme with undercompensation of the feed flow

Similarly, by analyzing the results given in Figures 4-12, we can conclude the followings:
- the mill product *MP* increases from 90 [tonnes/hour] to 125 [tonnes/hour], after the setpoint is applied;
- the cement product *FP* increases from 72 [tonnes/hour] to 100 [tonnes/hour], after the setpoint is applied;
- the recirculated flow *RF* increases from 18 [tonnes/hour] to 25 [tonnes/hour], after the setpoint is applied.

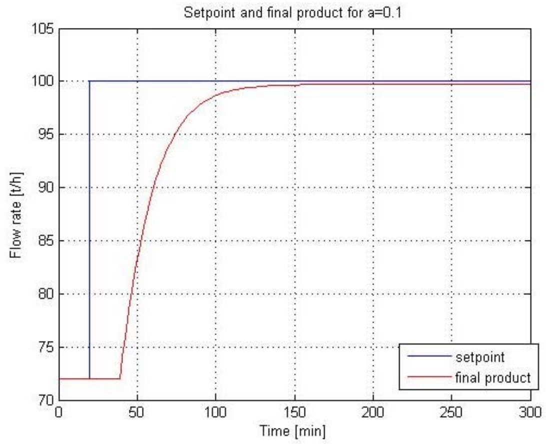

Figure 4. Setpoint and final product for *α=0.1*.

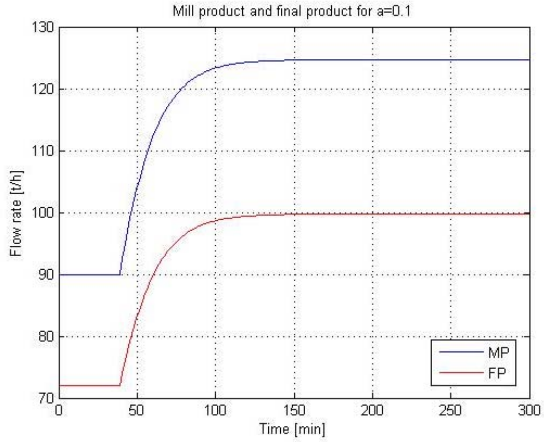

Figure 5. Mill product and final product for *α=0.1*.

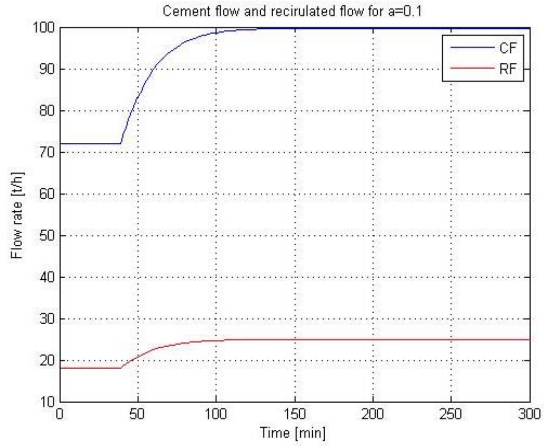

Figure 6. Cement flow and recirculated flow for *α=0.1*.

By analyzing all three cases, it can be seen that the output signal reaches the steady state in all 3 cases, but with some differences.

In the first case, *α=0.1*, according with Figures 4-6, the transient response is 110 [min.] (i.e., 150 [min.] - 40

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[min.]), the step signal is applied after 20 [min.] and the starting point of the signal rising is after 40 [min.]. So, the delay between the time of the application of the step signal and of system output reaction is 20 [min.] and the start time of the steady state is 150 [min.].

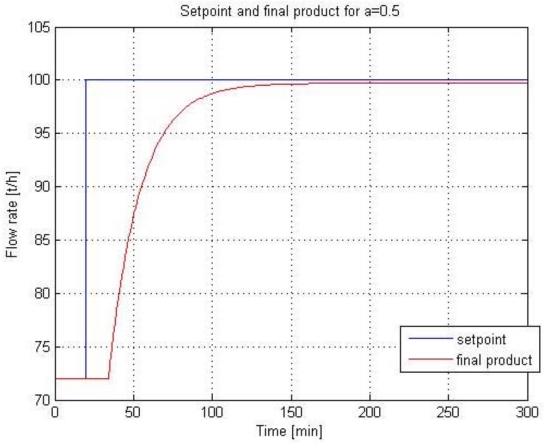

Figure 7. Setpoint and final product for *α=0.5*.

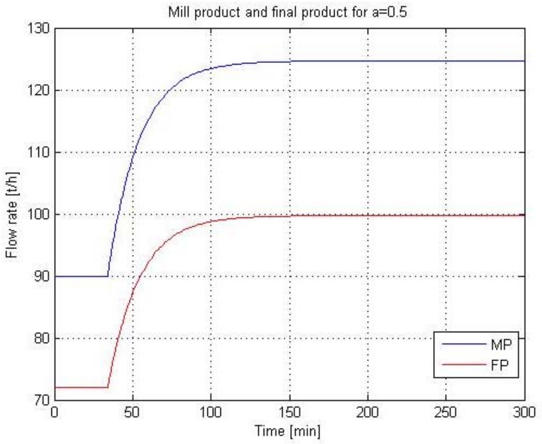

Figure 8. Mill product and final product for *α=0.5*.

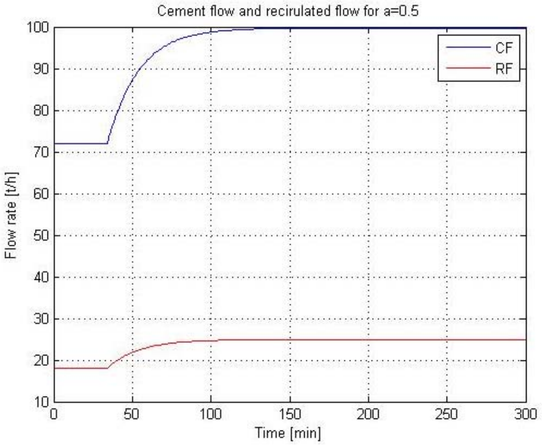

Figure 9. Cement flow and recirculated flow for *α=0.5*.

In the second case, *α=0.5*, according with Figures 7-9, it can be seen that the transient response is 118 [min.] (i.e., 154 [min.] - 36[min.]), the step signal is applied at 20 [min.] and the starting point of the signal rising is after 36 [min.]. The delay between the time of the application of the setpoint and of system output reaction is 16 [min.] and the start time of the steady state is 154 [min.].

In the third case, *α=0.9* (see Figures 10-12), it can be seen that the transient response is 122 [min.] (i.e., 156 [min.] - 34 [min.]), the step time is applied after 20 [min.] and the starting point of the signal rising is 34 [min.]. The gap between the time of application of the setpoint and of system output reaction is 14 [min.] and the start time of the steady state is 156 [min.].

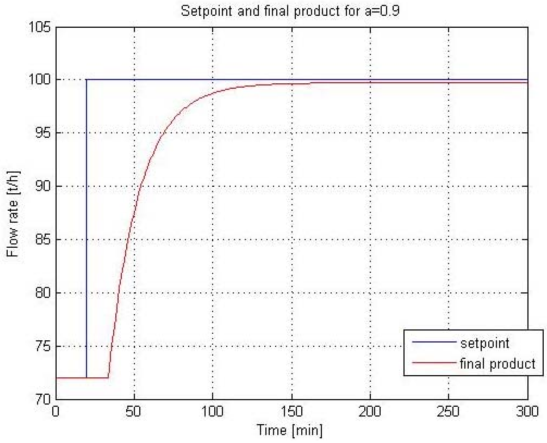

Figure 10. Setpoint and final product for *α=0.9*.

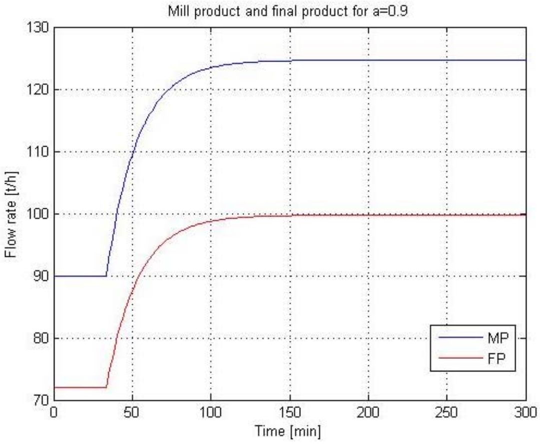

Figure 11. Mill product and final product for *α=0.9*.

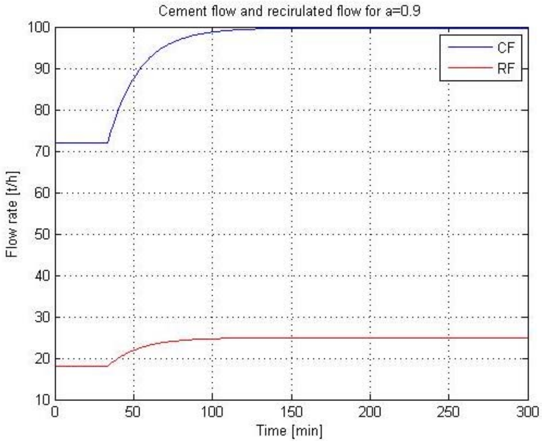

Figure 12. Cement flow and recirculated flow for *α=0.9*.

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This analysis leads us to the conclusion that from the three cases taken into consideration, the first case proves to be the best because it offers the shortest dynamic regime. This value of the undercompensation is used for the control scheme of the cement mill feed flow controller.

4. CONCLUSIONS

The paper presents a design technique for a control system of a grinding circuit for milling operations using the feedforward and feedback control. Mainly, feedforward control should be enough to control the system, but because there exist disturbances and uncertainty, it is neccessary to use also feedback control. The control scheme is based on the undercompensation of the milling feed flow. There are analyzed several scenarios based on several values of the undercompensation. The value which provides the best results is then employed for the controller design. The proposed technique provides the benefit of an improved productivity by shortening the duration of the dynamic regime.

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