**Light Metals 2012** *Edited by: Carlos E. Suarez*
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## ELECTRODE TECHNOLOGY for ALUMINIUM PRODUCTION

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## ELECTRODE TECHNOLOGY for ALUMINIUM PRODUCTION

## Paste Plant Design and Improvement

*SESSION CHAIR*

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# ADAPTIVE FUZZY CONTROLLER FOR BALL MILL IN ANODE PLANT

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## Abstract

An adaptive controller for keeping a ball mill working stably and efficiently is proposed in this paper. The controller is based on fuzzy logic control strategy by developing a method of adjusting the quantification and proportion factors. The selection of these factors makes a big influence on the static and dynamic performances of the controller. This new control strategy is implemented in Albras Anode Plants. The controller program was developed with ladder language and runs on programmable logical controller (PLCs) from Allen Bradley. Anode plants are operating with ball mills which are being controlled by fuzzy controllers, and the noise, that is the control variable is working around the established operation point. The results demonstrate the effectiveness and viability of the system that hereafter will be implanted for other processes of the anode plant.


## Introduction

The ball mill feed production system is one of the major assistant systems in an anode plant and the mill is a very important mechanism among them. The ball mill is a cylinder containing steel balls and has two ends, one is the inlet of material; the other is the outlet of the mixture of powder and air. When the mill is operating, because it revolves at a slow speed, the steel balls and the material are promoted by the centrifugal force and frictional force, and then fall down by their weight. Under the action of striking, extruding and grinding by the steel ball, the material becomes powder and the powder is carried away by the airflow through the outlet to supply the fine fraction of anode recipe. An important working characteristic of a ball mill is that the relation between its load (quantity of material inside it) and electric power consumption is not proportional. This is because driving the mill and lifting the steel balls consumes vast amounts of electric power. Therefore, it is very un-economical for the ball mill to work light loads. Another working characteristic of a ball mill is that its output has a limit. While the ball mill is un-economical for light loads, the output will decrease if the mill is overloaded. This is because the fall distance of the ball becomes shortened and the effect of the balls striking is weak when the mill is full of material. There are two difficulties in controlling the ball mill. Firstly, it is difficult to measure the quantity of material inside the mill, because it is in a dynamic process and the internal environment is inhospitable while the mill is running. Secondly, the mill is a non-linear object, and its dynamic process is very complex. It is very hard to have a satisfactory control effect with general control strategies. Fuzzy logic control has been successfully used in many industrial applications [1, 2]. In accordance with the characteristics of a ball mill, a control strategy with a double-deck structure of self-optimizing and fuzzy control is developed and presented in this paper. This control strategy uses only input and output signals [3]. The organization of this paper is as follows. In the first section is discussed in detail the proposed fuzzy logic controller. In the second section, an improvement is introduced to the fuzzy logic controller. Real time application results are given in the last section, which demonstrate that the proposed control strategy is practical and efficient.

## Fuzzy logic control for ball mill

The structure of a fuzzy controller in the control loop is shown in figure 1, where F (Fuzzification), KB (Knowledge Base), IM (Inference Machine) and D (Defuzzification). For this SISO (single input, single output) system, a fuzzy controller with two dimensions is suitable, and its input variables are error E and the change of error Ec and the output variable of the controller is the set point to control the speed of the scale [4].

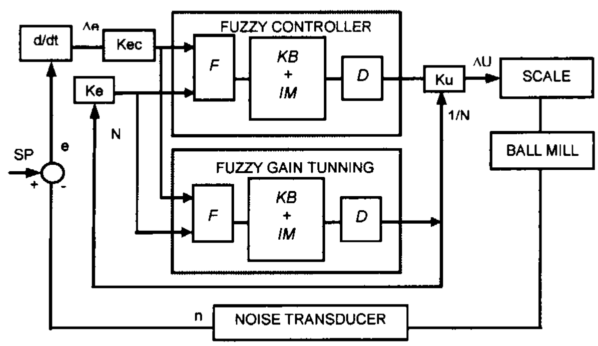
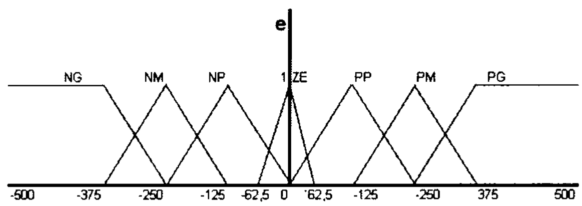
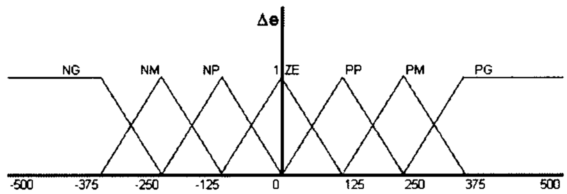



Figure 1. Structure of the fuzzy controller of ball mill

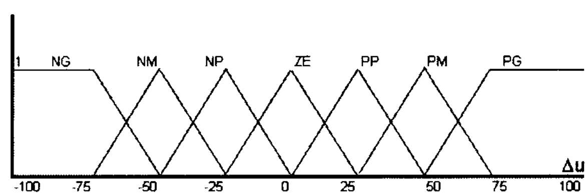
In the fuzzy controller presented above, for error E, change of error Ec and the output, change of control U, are used 7 linguistic values, NB: Negative Big; NM: Negative Medium; NS: Negative Small; ZR: Zero PS: Positive Small; PM: Positive Medium; PB: Positive Big. Next, it is necessary to define the membership function and the domains of the fuzzy sets. The quantity of material inside the ball mill is indirectly indicated by the noise signal (0 – 100%, after transducer). So the basic domain of the error (possible value space) is: $E \in [-100, 100]$, while the basic domain of the change of error is $Ec \in [-200, 200]$. Let Ke = 5, Kec = 2.5, where Ke is the quantification factor of error, Kec is the quantification factor of the change of error. Thus, the domain of error is: $E \in [-500, 500]$; the domain of the change of error is $Ec \in [-500, 500]$. The basic domain of the output variable (0 - 20mA) is: $U \in [0, 20]$; therefore, the basic domain of change of the control variable is: $U \in [-20, 20]$. Let Ku = 5, where Ku is the proportion factor. The fuzzy domain of the change of control is: $\Delta U \in [-100, 100]$. The membership function in the controller is triangular [5], as shown in Figure 2. In order to get a high control precision nearby the set point, a non-even distribution function is used as the membership function of error. A big leaning triangular membership function was used about the zero of error, and its overlap is 25%. In other regions, even distribution membership functions are used and their overlap is 50%.




(a). Membership of the Error




(b). Membership of the Change of Error




(c). Membership of the Output
Figure2. Fuzzy Input & Output variables

For the controller where error and change of error is input, and change of control is output, the so-called Mamdani rule was used as the control rule [6, 7] (see Table 1). The compositional rule is max-min; the center of gravity law is applied in the defuzzification of the output variable.

Table 1. Mamdani fuzzy control rule

| e \ Δe | NG | NM | NP | ZE | PP | PM | PG |
|---|---|---|---|---|---|---|---|
| **NG** | PG | PG | PG | PG | PM | PP | ZE |
| **NM** | PG | PG | PM | PM | PP | ZE | ZE |
| **NP** | PG | PM | PM | PP | ZE | ZE | NP |
| **ZE** | PM | PP | PP | ZE | NP | NP | NM |
| **PP** | PP | ZE | ZE | NP | NM | NM | NG |
| **PM** | ZE | ZE | NP | NM | NM | NG | NG |
| **PG** | ZE | NP | NM | NG | NG | NG | NG |

**Self-adjusting fuzzy logic controller**

A simple fuzzy controller has many shortcomings, such as difficult selection of good fuzzy parameters, so there are many methods to improve its performance [8, 9]. Here some improvements of the fuzzy controller were made, by developing a method of adjusting the quantification and proportion factors. The selection of these factors makes a big influence on the static and dynamic performances of the controller. The following procedure is employed:

1. A bigger Ke will lead to a faster speed of the system reaction, but a bigger Ke will also result in a bigger overshoot. A smaller Ke will make the inverse influence. Furthermore, Ke is also related to the steady state error of the system: the bigger the Ke is, the smaller the steady state error and the control dead zone are.

2. A bigger Kec will cause the system transition time to be longer, and the systems reaction becomes blunt; while a small Kec will give the system a higher overshoot and surge. Another characteristic of Kec is that its value can be selected in a wide range. In other words, the system is not much sensitive to the change to Kec.

3. In the rising stage and steady period of the system response, Ku has different influences. In the rising period, a big Ku can make the system have a quick rising, but also overshoot more easily; while a small Ku will make the system reaction become slower. In a steady period, a bigger Ku will cause a bigger surge. There are many kinds of schemes to improve selection of Ke, Kec and Ku. But all of them follow the same logic: when the error is big, the aim of the system control is mainly to rapidly reduce the error and speed up the dynamic process. A small Ke, a small Kec, and a bigger Ku are sufficient for this purpose. When the error and the change of error are small, and the system is close to the steady state, a fine control action is needed. A bigger Ke and Kec is needed to enhance the system sensitivity and reduce the control dead zone. Furthermore, reducing Ku will make the system to have a small overshoot and a small steady state error.

A conclusion can be obtained from this discussion that the change trend of Ke, Kec and Ku is not the same for each of them, and sometimes the control effects are opposite. On the basis that Kec has less influence on the system, the strategy of parameter adjustment can be obtained, that is, Kec is adjusted off-line and manually; Ke and Ku are automatically adjusted on-line. For convenience, Ke and Ku are reciprocal to each other. Let

$$Ke = Ke_0 * N;\ Ku = Ku_0/N$$

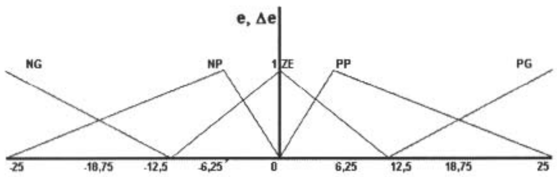
Here, $Ke_0$ and $Ku_0$ are the initial values set up manually; N is the adjustment factor.

Table 2. Modified rules for N

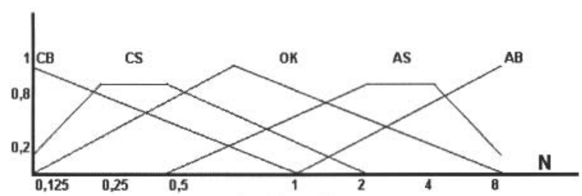
| e \ Δe | NG | NP | ZE | PP | PG |
|---|---|---|---|---|---|
| **NG** | CB | CS | OK | CS | CB |
| **NP** | CS | OK | AS | OK | CS |
| **ZE** | OK | AS | AB | AS | OK |
| **PP** | CS | AS | OK | AS | CS |
| **PG** | CB | CS | OK | CS | CB |

The rule to correct N is shown in Table 2, where input variables are error and change of error, and the output variable is N. These fuzzy variables have 5 values as follows: error and change of error have values NB : (Negative Big); NS : (Negative Small); ZR : (Zero); PS : (Positive Small); PB : (Positive Big).

N has values AB (Amplify Big); AS (Amplify Small); OK (No changing); CS (Contract Small); CB (Contract Big). Let the quantification factors of error and change of error be: K0e = 1/4, K0ec = 1/8; thus, their value domains are: E, Ec ∈ {.4,.3,.2,.1, 0, 1, 2, 3, 4}; the range of N is: N∈ {0.125, 0.25, 0.5, 1, 2, 4, 8}. A small quantification factor is chosen, that makes the error and change of error with a narrow value region. This is because the change of N does not need to be adjusted tenuously. Fewer values of error and change of error will make the query table simple. Fuzzy sets of error E, change of error EC, and factor N are shown in Figure 3.




(a). Membership of the Error and Change of Error




(c). Membership of the Factor N
Figure 3. Fuzzy Input & Output variables

**Results**

The controller designed above was put into service in Anode plant of Albras company last year. The results show that the effect is very satisfying. The summary of the test can be seen in Figure 4 and Figure 5.

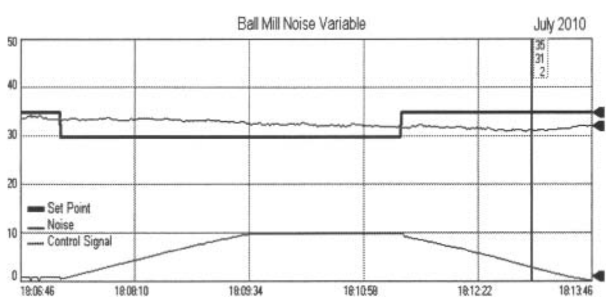



Figure 4 (a)- Signal controller behavior before the Fuzzy Controller

As can be seen in figures 4 (a) e (b), the answer of the traditional PI controller is slower than the fuzzy controller when the set point changes of value.

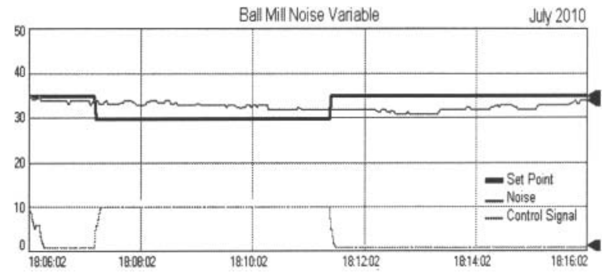



Figure 4 (b)- Signal controller behavior after the Fuzzy Controller

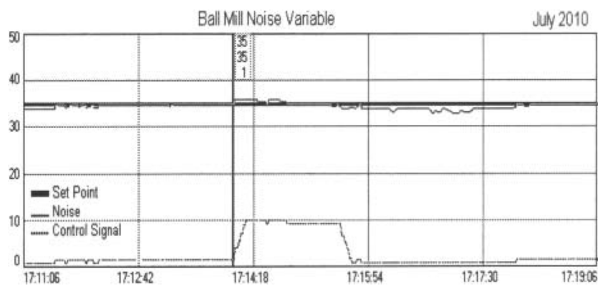



Figure 5.- Noise behavior after the Fuzzy Controller

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