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Proportional Integral Speed Controller for Apron Feeder of a Limestone Crusher in a Cement Factory

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Author Details

Omar H Abdalla, Abdel Ghany M Abdel Ghany, Osama AA Tahoon, Ahmed AA Hamda and Mahmoud MA Khattab*

Department of Electrical Power and Machines Engineering, Helwan University, Egypt

*Corresponding author

Prof Omar H Abdalla, Department of Electrical Power and Machines Engineering, Faculty of Engineering, Helwan University, Cairo, Egypt

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Abstract

The paper describes types of limestone crusher properties and comparison between different types of crushers with respect to reduction ratio and feeding material. The type which we deal with in this paper is hammer impact crusher with apron feeder speed control system. The old conventional speed control system, which was depending on relay logic and timers, has been recently replaced by a new advanced system using PLC and SCADA system. The main advantages of the new control system are: increasing production rate, saving time in fault detection, monitoring and data logging. The ability of Proportional Integral Derivative (PID) controllers to regulate many practical industrial processes has led to their wide acceptance in industrial applications. This paper presents the application of the Ziegler-Nichols tuning method to design and testing a PI controller for an apron feeder speed control system of a practical limestone crusher in a cement factory. After tuning the speed PI-Controller of the apron feeder of the limestone crusher, it has been noted that the crusher production rate has increased from 879 ton/hour to 964 ton/hour, i.e. the production rate increased by 85 ton/hour. The crusher is running 12 hour per day and 300 days per year, thus the annual crusher production will increase by 306,000 ton/year.

Keywords: Tuning of PID controllers; Cement industry; Limestone crusher; Apron; PLC; SCADA

Introduction

Limestone crushers are considered to be the backbone of the cement plants, as it is the second step in the processes of the cement industry after the quarry process. In the cement factory investigated in this paper, a hammer impact crusher type O&K (Orenstein & Koppel Mammoth 84/135) [1] was installed 30 years ago. Its original control system was based on conventional control techniques, and lacks essential requirements of modern cement plants operation. So, this system has been replaced by a new operating and control system which consist of a PLC and SCADA system, thus providing more flexibility and stable operation of the crusher. The apron feeder speed control system has been upgraded from conventional control system to a PI-controller and AC-Drive system.

Proportional-Integral-Derivative (PID) control systems [2] have been at the heart of control engineering practice for several decades. In the process control, more than 95% of the control loops are of the (PID) type. A survey conducted by Honeywell [3,4] of 11,600 regulator controllers in 18 industrial plants, have shown that the PID control system was used almost exclusively. The site median for the PID control algorithms use exceeded 97% [3,4].

A PID controller is a three-term controller that has a long history in the automatic control field, starting from the beginning of the last century. The PID control method is most flexible and simple method. This method is more popular among all control methods. The determination of proportional (K_p), integral (Ti) and derivative (Td) constants are known as tuning of the PID controller.

Although the PID controller is the black horse of many industrial processes and does not require much maintenance, it needs to be properly tuned. There are many methods for tuning PID controllers; some of them are experimental like Ziegler-Nichols method [5] and Chien-Hrones-Reswick method [6]. Tuning method of PI/PID controllers based on the Internal Model Control (IMC) and direct synthesis approaches are presented in [7]. The IMC-PID strategy has only one tuning parameter; which is the closed-loop time constant. Simulation studies were presented in [8] for tuning different PID controllers: (i) a super-heated steam temperature control system of 500MW boiler and (ii) a mean arterial blood pressure system. Simulation studies for the design of PID load-frequency controllers (LFCs) for a hydro-thermal power system were explored in [9]. I&PID LFCs for a multi-area power system were studied in [10]. Other methods depending on system mathematical models are available.

If a system mathematical model can be derived, then it is possible to apply various design techniques for determining parameters of the controller that will meet transient and steady state specifications of closed loop control system. However, if the plant is so complicated that mathematical model cannot be easily obtained, analytical or computational approaches to design controllers might not be possible. Then the control engineer can use experimental approaches to tune the controller parameters. Proper controller tuning affects system stability, accuracy and speed of response which will reflect on process productivity.

A method for tuning PID controllers for higher-order oscillatory systems to achieve improved system performance was described in [11].

Methods based on identification techniques to derive a model from measurements are available [12] and [13]. In [12], the experimentally identified input/output model was used to design an optimal output feedback controller for a laboratory power system. In [13], an identified model of a practical electrostatic precipitator was obtained using least-squares method. Based on the identified model an optimal PI controller was designed and tested on the real precipitator in a cement factory. In [14], a genetic algorithm was employed to design a coordinated PID secondary voltage controller for a power system.

This paper presents the application of the PID Ziegler-Nichols [5,15] tuning method to design and testing a PI controller for an apron feeder speed control system of a practical limestone crusher in a cement company.

The paper is organized as follows: Section I presents an introduction to the apron feeder speed control of the limestone crusher. Section II concerns with description of the crusher system, principal of operation, components, old and new apron feeder speed control systems. Section III reviews industrial PID control systems, block diagram and performance. Section IV presents tuning of the PI-controller of the practical crusher apron feeder system and practical test results. Section V summarizes the main conclusions of the paper.

System Description

Principles of operating crushers [1]

The crushers are used in the mining industry works on two different principles: Compression and Impact.

Compression

- The material is pressed between two crushing surfaces which move closer.
- Speed of application of the force = 0.2 m/s to 0.5 m/s.
- Primary gyratory crushers, jaw crushers and cone crushers.

Impact

- The material is subjected to impacts given by rotating pieces (rotor equipped with hammers), or rammed by crushing weights (rods or bowls).
- Speed of application = 8 to 100 m/s.
- Horizontal impact crushers or vertical, rodmills or bowlmills.

Types of crushers

1. Hammers: as shown in Figure 1 & Figure 2.
2. Blow bar impactors
3. Jaw
4. Gyratory
5. Cone crushers
6. Roller
7. Roller/Jaw
8. Toothed roller crushers

Figure 1: Hammer impact crusher.

Figure 2: Basket of hammer impact crusher.

The type of crusher in this paper is hummer crusher: Mammoth 84/135.

84 represents the number of hammers

135 represents the weigh of the hummer.

These two factors determine the dimensions and design of every mammoth crusher. Figure 3 shows an overview of the crusher system.

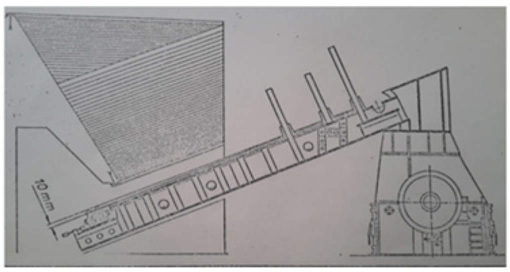

Figure 3: Crusher system overview.

Old control system (Conventional control system): The old system was controlled through mega-watt apparatus by taking a sample of current and voltage from the main drive to control the speed of the apron feeder and to prevent the load exceeding its limit as shown in Figure 4. There are two selection of operation: manual mode and automatic mode.

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In the manual mode: The operator is the person who allows the speed of the apron feeder to increase or decrease according to his/her experience and conditions of operation. In this case when the load reaches 1.6 MW; the MW-apparatus takes the action to stop the apron feeder and it returns to the operation after the load decreases less than 0.75 MW. This action takes few seconds causing waste of time and production due to acting as open loop.

In the automatic mode: When the load is less than 0.75 MW the control action is to increase the speed of apron feeder after 3 sec and when the load exceeds 0.75 MW the classic control makes the apron feeder speed to decrease after 1.5 sec. The apron feeder is stopped when the load inside the reaches 1.6 MW. The load inside the crusher is varying according to the dimensions of the lime stones hardness and mechanical condition of crusher and behavior of operation. The hummers are reversed when being eroded to minimize time of grinding and decreasing the load.

Disadvantage of old the control system: The old crusher control and operation system shown in Figure 4 has a classic control system (conventional control system), which lacks satisfactory essential requirements such as:

1. Operating parameters trends
2. Alarms logging
3. Event logging
4. Possibility for displaying system faults
5. Operator permissions
6. Flexibility to modify control and operation parameters

Figure 4: Old control and operation system.

New control system (PLC & SCADA System): In modern cement plants, where several million tons are produced per year, the control system must be robust and flexible in order to help achieving plant annual production plan rate. Modern cement plants are planned to run the production line up to 300 days/year. Therefore, there should be no time to waste for searching faults such as a bad contact in the conventional relay control systems. That is why the old control system has been replaced by a modern PLC and SCADA system.

Advantage of PLC and SCADA system: The main advantage is to increase the system efficiency and productivity by:

1. Minimizing fault detection time
2. Reducing manpower requirements
3. Trends and statistical analysis help in maintenance decisions
4. No need to regularly visit remote sites
5. Reducing operation costs
6. The PLC system provides control function blocks, such as FB 41, FB 42, and FB 43 [16] where these can be used to control many cement production processes
7. Small size, due to significant reduction in wiring
8. Easy to troubleshooting

The PLC and SCADA system provides the needed requirements to ensure continuous operation with required level of stability. The new control and operation system is shown in Figure 5. The crusher operator is simple and user friendly. The new operation and control system provides alarm logging and trends for operation and control parameters as shown in Figure 6.

Figure 5: Crusher operator station.

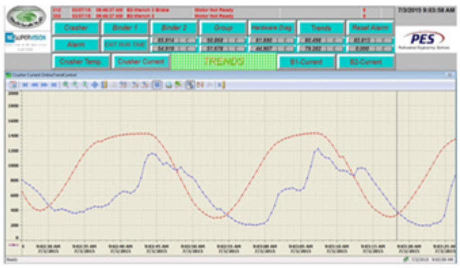

Figure 6: Trend & alarm logging system.

Apron feeder speed control: The old control system for apron feeder speed was depending on a special mega-watt meter. The mega-watt apparatus has a standard analog input signal 4-20 mA which reflects the crusher motor power (1700 kW rated). It has three output free contacts: one for increasing the apron feeder motor speed, while the second is used for decreasing the apron feeder motor speed. The third contact is for stopping the apron feeder if the crusher power exceeds a certain limit. The control of the apron feeder motor speed depends on mega-watt apparatus contacts and two timers for delay action for a short time.

The new control system for the apron feeder speed depends on a Siemens function block FB42 [16]. It acts as a PI controller having an analog input signal 4-20 mA. This signal reflects the crusher motor power (1700 kW rated). Also, it has two output free contacts; one for increasing the apron feeder motor speed and the other is for decreasing the speed as shown in Table 1. The control of the apron feeder motor speed depends on the action taken by the PI-controller according to the crusher motor loading.

Table 1: Limits Apron feeder speed control actions.

Crusher Motor Power	Apron Feeder Motor Speed Action	Notes
<730 kW	Increase	
730:750 kW	Dead Band	
>750 kW	Decrease	
>= 1600 KW	Stop	Protection for crusher motor

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Industrial Controllers

Main characteristics

The main characteristics of a good industrial control system are:

Stability: The controlled variables do not change without limits.

Accuracy: The controlled variables reach the desired values with zero or minimal error between the reference value and measured value.

Speed of response: The controlled variables reach the desired values within an acceptable time.

Cost: The cost of the control process should not be too high.

PID Controller

Figure 7 shows a block diagram of a control system with a PID controller [15]. It is commonly used in industrial processes as it is considered the most powerful controller. Kp is the proportional gain, K_I is the integral gain and K_D is the derivative gain. Figure 8 shows the input and output signals of PID control systems [15].

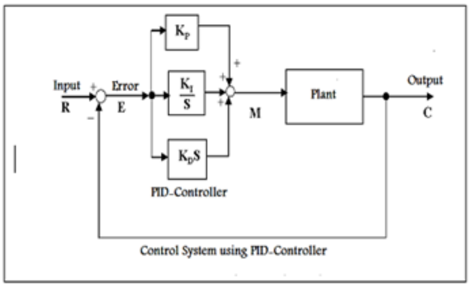

Figure 7: Control System using PID-controller [15].

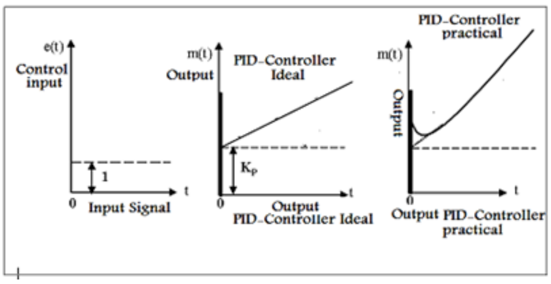

Figure 8: Input and output of signals of the PID-controller [15].

Advantage of the PID-Controller

1. It is robust in operation
2. Provides fast response
3. Remove steady state errors form the controlled system due to its integral action
4. Can be tuned in practical systems

Experimental Tuning of PID-Controllers

There are many methods to tune PID controllers; some of them are experimental like Ziegler-Nichols method [5] and Chen-Horns-Reswick method [6]. Other methods depend on system mathematical models. If a system mathematical model can be derived, then it is possible to apply various design techniques for determining parameters of controller that will meet acceptable transient and steady state specifications of the closed loop control system.

However if the plant is so complicated that mathematical models cannot be easily obtained, an analytical or computational approach to design PID controllers might not be possible. In this case, the control engineer can use experimental approaches for tuning the PID controllers.

PID-Controller Tuning by Ziegler-Nichols Method

The Ziegler-Nichols design methods [5,15] are the most popular methods used in process control to determine the parameters of a PID controller. Although these methods were presented in the 1940s, they are still widely used in practice. There are two methods of Ziegler-Nichols for tuning a PID controller.

The step response method which is based on an open-loop step response test of the process. Then, the method is used to tune the PID controller, i.e. to find the set values of the control parameters based on the step response. The closed-loop method which is based on determining the values of the critical gain Kcr and the period of oscillations Tc which results in marginal stability when only proportional control action is used. Both methods can be performed experimentally or by simulation. The second method is performed experimentally in this paper. It is explained as follows.

Closed loop design steps (single input single output)

- Insert a PID controller with gain K_P in the control loop, the input of controller is the error and output of the controller is connected to the plant input as shown in Figure 9.

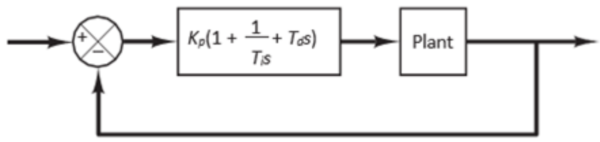

Figure 9: PID control of a plant [15].

- Assume an initial value of the proportional controller gain Kp say 1. Set Ti = infinity, and Td = 0, i.e. using proportional control action only.
- Apply a small disturbance to the system, record the controlled output and see if the system makes continuous oscillations.
- Continue increasing the proportional gain Kp, until obtaining continuous oscillations with constant amplitude as shown in Figure 10. The gain corresponding to this case is called the critical gain Kcr and the period of oscillations is donated by Tc. The value of Tc equals the period between two peaks.
- Determine the optimum adjustments of the required controller parameters in the control loop as illustrated in Table 2.
- Apply the obtained PID parameters to the controlled system and evaluate the system response.

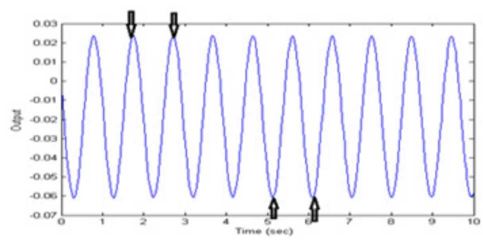

Figure 10: Determination of the period of oscillation Tc.

Note: If the output does not exhibit sustained oscillation for whatever value Kp may take, then this method does not apply.

Table 2: Parameters of controller using Z-N method [15].

Controller	Optimum parameters		
	Kp	Ti	Td
P	0.5 Kc	∞	0
PI	0.45 Kc	Tc / 1.2	0
PID	0.6 Kc	0.5 Tc	0.125 Tc

PI Controller for the Apron Feeder Speed Control

Design of a PI Controller using Z-N Method

- Insert a PI controller with gain Kp in the control loop.
- Assume an initial value of the proportional controller Kp say 1. Set Ti = infinity, i.e. using proportional control action only.
- Continue changing Kp, until obtaining continuous oscillations with constant amplitude. The critical gain corresponding to this case is found to be Kcr = 2.01 .
- Otabin Tc = period between two peaks, the value is found to be Tc = 40 sec as shown in Figure 11.
- Determine the optimum adjustments of the required PI controller parameters in the control loop from the Ziegler-Nichols illustrated in Table 2:

$$K_p = 0.45 \times 2.01 = 0.9045$$

$$T_i = 40 / 1.2 = 33.33 \text{ sec}$$

- Apply the obtained PI parameters to the controlled system and check for system response as shown in Figure 12.

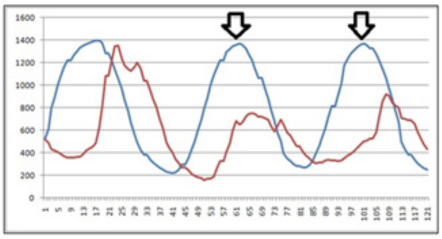

Figure 11: Determine period of oscillation Tc.

Blue: Apron feeder speed **Red:** Crusher power

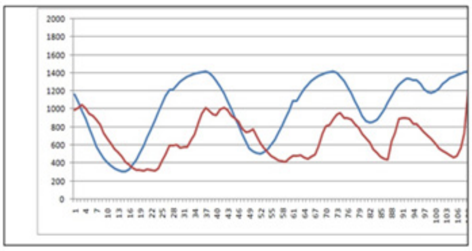

Figure 12: System response with tuning by Z-N method (Kp = 0.9045 & Ti = 32 sec).

Blue: Apron feeder speed **Red:** Crusher power

Comparison of Ziegler-Nichols Method and Trial and Error Method

In some cases, a trial and error method may be employed for tuning PID controlles in practice. This method depends on the experience of the control engineer. It may give acceptable closed-loop control performance but does not gurantee an optimal solution. By comparing between the system response with the controller tuned by Ziegler-Nichols method and system response with a controller tuned by (trial and error method), we have found that the system tuned by the Ziegler-Nichols method has better performances than the system tuned by the trial and error method. It is important to note that the crusher production increased to 964 ton/hour after applyig the Ziegler-Nicholes PI controller for the apron feeder speed control compared to 879 ton/hour with the trial and error method for tuning the PI controller.

Conclusion

Limestone crushers are considered the backbone of the cement plants, as it is the second step in the processes of the cement industry after the quarry process. It is particularly distinctive that when giving more energy to the particle to be crushed, equivalent of having a higher speed would create finer product. While getting fine product increase hammers wear, and with time of operation the hammers should be reversed. To overcome the lacks of conventional control system, the operation and control system has been upgraded to a PLC and SCADA system which provides the essential requirements for flexible and stable operation.

The new control system was first tuned by a trial and error method, but it was noted that the crusher productivity did not achieve its desired performance. Therefore, the new PI-controller system has been re-tuned by using the Ziegler-Nichols techniques described in this paper. Then, it is noted that the crusher production increased from 879 ton/hour to 964 ton/hour after applying the Ziegler-Nichols tuning method to the PI speed controller for apron feeder of the limestone crusher. The production rate has increased by 85 ton/hour. As the crusher runs 12 hour per day for 300 days per year, the annual crusher production increased by 306,000 ton/year.

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