Mill Speed Control Using Programmable Logic Controllers

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Abstract: - This paper presents an application for mill control. In this application a mill is controlled by software running on Programmable Logic Controllers. The paper handle a few topics from cement industry, such are: critical speed, mill speed control. If the peripheral speed of the mill is too great, it begins to act like a centrifuge and the balls do not fall back. Therefore, this application conceived a PID controller for control the mill speed, using Programmable Logic Controllers.

Key-Words: - ball mill, critical speed, operating speed, speed control, Programmable Logic Controllers.

1 Introduction

A ball mill is a horizontal cylinder partly filled with steel balls (or occasionally other shapes) that rotates on its axis, imparting a tumbling and cascading action to the balls. Material fed through the mill is crushed by impact and ground by attrition between the balls. The grinding media are usually made of high-chromium steel.

The smaller grades are occasionally cylindrical pebs rather than spherical. There exists a speed of rotation (the critical speed) at which the contents of the mill would simply ride over the roof of the mill due to centrifugal action [1].

Ball mills rotate around a horizontal axis, partially filled with the material to be ground plus the grinding medium. Different materials are used as media, including ceramic balls, flint pebbles and stainless steel balls. An internal cascading effect reduces the material to a fine powder. Industrial ball mills can operate continuously, fed at one end and discharged at the other end.

Large to medium-sized ball mills are mechanically rotated on their axis, but small ones normally consist of a cylindrical capped container that sits on two drive shafts (pulleys and belts are used to transmit rotary motion). A rock tumbler functions on the same principle[2].

Ball mills are also used in pyrotechnics and the manufacture of black powder, but cannot be used in the preparation of some pyrotechnic mixtures such as flash powder because of their sensitivity to impact. High-quality ball mills are potentially expensive and can grind mixture particles to as small as 5 nm, enormously increasing surface area and reaction rates. The grinding works on principle of critical speed. The critical speed can be understood as that speed after which the steel balls (which are responsible for the grinding of particles) start rotating along the direction of the cylindrical device; thus causing no further grinding [3].

A structure borne sound sensor is attached directly on the shell of the rotating mill. It acquires all sounds
which occur in the metal wall. Noise and sounds produced by other mills or machines are completely ignored by this sensor, as it is totally insensitive to airborne sound. The signals are transmitted wireless to an industrial PC which analyzes them by means of methods of nonlinear dynamics.

Direct measurement at the mill shell enables the recovery of additional information about the current state of balls, liners and diaphragma.

Therefore it is possible to measure simultaneously the level of each chamber of two-chamber mills with high resolution and independent of each other. The third input can be used for an additional temperature sensor, which gains its energy out of the rotation of the mill. This completely avoids regular change of batteries or complex installations.

If air flow cooling is not sufficient, water needs to be injected. The temperature of the material being ground should be kept between 100 °C and 110°C (212 °F and 230°F). To measure its temperature a thermocouple is inserted into the diaphragma.

Fig. 2. The Installation

2 Operating Speed

A ball mill grinds material by rotating a cylinder with steel grinding balls, causing the balls to fall back into the cylinder and onto the material to be ground. The rotation is usually between 4 to 20 revolutions per minute, depending upon the diameter of the mill.

The larger the diameter, the slower the rotation. If the peripheral speed of the mill is too great, it begins to act like a centrifuge and the balls do not fall back, but stay on the perimeter of the mill.

The point where the mill becomes a centrifuge is called the critical speed, and ball mills usually operate at 65% to 75% of the critical speed. Ball mills are generally used to grind material 1/4 inch and finer, down to the particle size of 20 to 75 microns. To achieve a reasonable efficiency with ball mills, they must be operated in a closed system, with oversize material continuously being recirculated back into the mill to be reduced.

Various classifiers, such as screens, spiral classifiers, cyclones and air classifiers are used for classifying the discharge from ball mills.

The critical speed of ball mill is given by:

\[ n_c = \frac{1}{2 \cdot \pi} \sqrt{\frac{g}{R - r}} \]  

(1)

, where:
- \( n_c \) is critical speed ;
- g is acceleration of gravity ;
- R is radius of ball mill ;
- r is radius of balls ;

For a mill diameter \( d=3.64 \) [m] and a radius of mill \( R=1.82 \) [m] and a ball size distribution along the mill, like in the next table:

<table>
<thead>
<tr>
<th>Percent</th>
<th>Ball Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 %</td>
<td>30 mm</td>
</tr>
<tr>
<td>20 %</td>
<td>25 mm</td>
</tr>
<tr>
<td>27 %</td>
<td>20 mm</td>
</tr>
<tr>
<td>41 %</td>
<td>17 mm</td>
</tr>
</tbody>
</table>

We obtain a critical speed of 0.37 Hz. Hence, critical speed in revolutions per minute is:

\[ n_c = 0.37Hz \cdot 60 = 22,2 \text{ rpm} \]

In this case, critical speed is 22 rpm. But ball mills usually operate at 65% to 75% of the critical speed. Hence, operating speed is approximate 16 rpm.

The mill is usually divided into at least two chambers, allowing the use of different sizes of grinding media. Large balls are used at the inlet, to crush clinker nodules.

As a general rule, the size of media has to match the size of material being ground: large media can't produce the ultra-fine particles required in the finished cement, but small media can't break large clinker particles. Mills with as many as four chambers, allowing a tight segregation of media sizes, were once used, but this is now becoming rare. Alternatives to multi-chamber mills are: pairs of mills, run in tandem, charged with different-sized media.

A current of air is passed through the mill. This helps keep the mill cool, and sweeps out evaporated moisture which would otherwise cause hydration and disrupt material flow. The dusty exhaust air is cleaned, usually with bag filters.

Cement mills are normally driven by electric motors. Modern installations draw power of 2-10 MW. The power required to turn a ball mill is approximated by:

\[ P = \frac{a \cdot j \cdot m \cdot n}{d} \]  

(2)

,where:
- P is power in Watts [W] ;
- d is the internal diameter in metres [m];
- a is acceleration \([\text{m/s}^2]\);
- \(j\) is the fraction of the mill volume occupied by media;
- m is the total mass of media in the mill [kg];
- n is the mill speed, in Hertz or \(\text{s}^{-1}\).

3 The Software Application

This application is made in WinCC. In general, WinCC offers three solution approaches for a configuration: using WinCC standard tools, using existing Windows applications with WinCC via DDE, OLE, ODBC and ActiveX or using Visual C++ or Visual basic to develop your own applications embedded into WinCC.

For some, WinCC is the Human Machine Interface system for fast and cost-effective configurations, for others it is an infinitely expandable system platform.

The modularity and flexibility of WinCC gives you completely new possibilities for planning and implementing automation tasks.

WinCC is based on Microsoft’s 32-bit operating systems (currently Windows 95 and Windows NT 4.0). These are the standard operating systems of the PC platform. WinCC offers system modules for the visualization, messaging, acquisition, and archiving of process data, as well as for the coordinated integration of user defined application routines. WinCC is completely open to any user add-on.

This openness is accomplished through WinCC’s modular structure and its powerful programming interface.

The next figure shows the WinCC interface.

Fig. 3. WinCC Interface

Run the application: fig.4 represents the initial conditions, when the mill is empty and the feed bin is full.

Fig. 4. Initial conditions

After the start button is pressed, the mill is loaded with throughput, from the feed bin. After a time, the filling level, from mill, reach at his optimum value.

Fig. 5. The optimum filling level is reached

Using WinCC, it has been designed two controllers: one to control the speed and another to control the current. The controllers interface from WinCC is presented in fig.6.

Fig. 6. PID Controller Interface
Step 7 Lite is an integrated development environment for use by automation specialists to engineer and program solutions to automation problems. In order to understand the design of the Step 7 Lite system and the significance of its performance-centered features, some basic aspects of the processes by which automation systems are programmed need be grasped.

Most modern automation equipment is controlled by software running on specialized computers called Programmable Logic Controllers (PLCs).

The systems controlled by PLCs vary tremendously, with applications in manufacturing, chemical process control, machining, transit, power distribution, and many other fields. Automation applications can range in complexity from a simple panel to operate the lights and motorized window shades in a conference room to a completely automated brewery in which the machinery for everything - from dispensing and mixing ingredients to controlling the brewing process and even filling and sealing of bottles - is under programmed control [7].

In a representative system a Central Processor Unit is combined with a number of input/output modules that connect with sensors and actuators in the automation equipment itself. The programs that run on the PLC are planned, written, and debugged by automation programmers using development software running on conventional desktop or laptop computers or workstations. The programs produced through this development software must be downloaded to the PLC itself to operate the equipment.

Fig. 7 and Fig. 8 show a part from software application, conceived in Step 7 in PLC Programming.

Automation programming is an exacting engineering profession requiring great attention to detail, mastery of specialized concepts and terminology, and thorough and systematic discipline to avoid or eliminate errors. The risks associated with undiscovered errors in PLC code can be enormous. A lurking bug in a PLC program could destroy an expensive piece of material being machined, require the repair of costly equipment, or even lead to injury of personnel.

4 Conclusion

A ball mill grinds material by rotating a cylinder with steel grinding balls, causing the balls to fall back into the cylinder and onto the material to be ground. If the peripheral speed of the mill is too great, it begins to act like a centrifuge and the balls do not fall back. The point where the mill becomes a centrifuge is called the critical speed, and ball mills usually operate at 65% to 75% of the critical speed.

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In this application it has been designed a PID controller for control the mill speed.
References: