DESIGN OF INTELLIGENT CONTROL SYSTEM USING ACOUSTIC PARAMETERS FOR GRINDING MILL OPERATION

Sonali Sen[1] and Arup Kr. Bhaumik[2]

[1]Asst. Prof. St. Xaviers, College (Autonomous), Kolkata
sonalisen_2004@yahoo.co.in
[2]Member IEEE, Principal GIMT, India
arup_bhaumik@yahoo.com

ABSTRACT

This paper utilizes acoustic parameters such as FS,NC, N, P, INC, FL, FH, W for acoustic signals S of different running conditions of a ballmill to deriveout the acoustic signatures and hence control signals, which is to be used for designing the control systems of the mill. The parameters FS, NC, N, P, INC, FL, FH and W are represented by sample rate in Hz, number of cepstral coefficients, length of frame in samples, number of filters in filter bank, frame increment, low end of the lowest filter, high end of highest filter and the window over which the analysis is to be performed respectively. The work establishes an appropriate theoretical background that helps to predict dynamic breakage characteristics with respect to particle size distribution of materials, adequately supported by experimental data. The signatures of different running conditions of grinding mill have been extracted from the captured signal in time frame these have been used as feedback signal to monitor the grinding operation. Condenser based microphones have been used for capturing acoustic signals in time domain directly in computers and stored for further analysis. Matlab R2010b has been used for different analysis of the experiment. On analyzing the signatures, it has been observed whether the fines are produced progressively to attain the desired size range or the mill producing undesired products. Thus, the approach has been used in this paper has the ability to arrive in the stage of optimum grinding by tuning parameters of the mill in real time, and also it can prevent the mill to enter into an erroneous state. Moreover, on study it has found that the present scheme can be used more accurately in comparison to the earlier work of the author. This paper presents an implementation scheme to use acoustic signal as the control signal to regulate the operation of a grinding mill.

KEYWORDS

Ballmill, Acoustic signatures, Intelligent system, Ceptral Coefficients

1. INTRODUCTION

In this work we have proposed a novel technique for optimizing the operation of a grinding mill in real time. To conduct experiment a ball mill (see, Fig.1) has been employed in our work, which grinds the particles into smaller sizes to arrive at a desired range within a certain time. In the existing system of the mill [1], dozers are used to prepare the input mix (feed) with different

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particle size. Each dozer corresponds to a particular size range while varying the speed of the dozer motor controls the amount of dozing of each range. On preparation of input mix of the mill, the mill motor is allowed to start the crushing operation for some specified time (particle residence time) beyond which the mill is stopped manually and the crushed materials are fed into a stack of screen for classification of particles in different size ranges. The desired particle size ranges are collected from the classifier while others are fed into the respective input stack where further dozing prepare the input mix for the next stage of grinding. Thus, the stack of screen or classifier used in tandem with the mill seems to provide a closed loop condition. But the process is purely off-line where the exact state of breakage of particle is unpredictable since each particle breaks in different manner.

The ball mill is a reactor, which implicates a vessel of fixed geometry and kinetics to arrive at desired output with given input. Moreover, the crushing is done with metallic balls, which are collided within the closed inner surface of the mill along with the materials and thus grinding continues. But there is no way to look into the vessel, how generation of fines being produced and to achieve the desired size, whether the speed of the motor to be increased or decreased or even the mill to be stopped. That is to install an optical sensor is next to impossible. Moreover, the breaking process does not generate an amicable amount of heat to use temperature sensor for controlling the operation. But on study it has found that sound changes on changing of product sizes and as well as abrupt changes occur when undesirable situation arises. Moreover, to install sound sensor is very easy, since installation is done on the outer surface of the mill.

Researchers working in this area suggested several mathematical relationships such as Rosin-Rammler [2], Gaudin-Schuman [2], Benette & Colleman [2] equations, which to some extent can forecast how the broken particle vary with different size range. These equations have been tested in early part of our simulation work [3] but none of them found good enough to interpret results at coarse or fine particle size range. The bottleneck involves mainly due to lack of methods of measuring important state variables, ambiguity in the determination of the model coefficients used for prediction and porting to different particle size. Moreover, the existing equations are not suitable enough to fit in an autonomous system where control can be imparted using information transaction only, casting aside the common concept of utilization of screen/cyclone where the overflow/underflow can determine the circulating load in close circuit grinding [4]. More specifically, such equations can be solved only after conducting tests over different real life situations. Finally, till date no scheme has been developed, to regulate the milling parameters when the output deviates from the desired particle size range (product) in real time mode. The similar work has been published in [5] by the same authors described a scheme how acoustic signature can be used to regulate the mill and the product in off-line mode of operations. This work utilizes the **Mel Frequency Cepstral Coefficients** (**MFCC**) for analysis of acoustic signals. In the proposed method the analysis has been done on continuous signal for a sample of 1 second in 30 seconds gap and it has been observed from the graphs whether the grinding takes place to generation of fines or not. The entire method has been described in the following sections 2, 3 and conclusion has been drawn in section 4.

2. USE OF ACOUSTICS

This section explains the reason of employing radiated energy sound to control the grinding process of the ball mill. The method of capturing the acoustic signal using sensors and circuits are described here. In addition, the importance of acoustic signal to recognizing different types of mills has been presented with experimental results.

2.1. Radiated Energy Sensors

Among the various kinds of radiated energy sensors like heat, magnetic, light etc., the acoustic sensor [5] is used in the work for the following reasons:

a) It works on radiated energy and its pattern of change is proportional to the change of sensory response.
b) The change of operational condition of the mill does not require any hard real time system.
c) With the help of the sensory response the machines are identified based on the operating state and load conditions. Sophisticated microphones with the following specifications are used as sensors to capture the acoustic signal:

Type Dynamic

Sensitivity 1.8 mv
Impedance 600 ohms
Frequency range 100-12000 Hz.

Nearly, 16 sets of data are recorded from the mills when they are fully operational and it has been found that the difference of frequency is of the order of 0.4 KHz to 3 KHz. Sampling done for a duration of 0.5 second in 30 seconds gap for testing purpose.

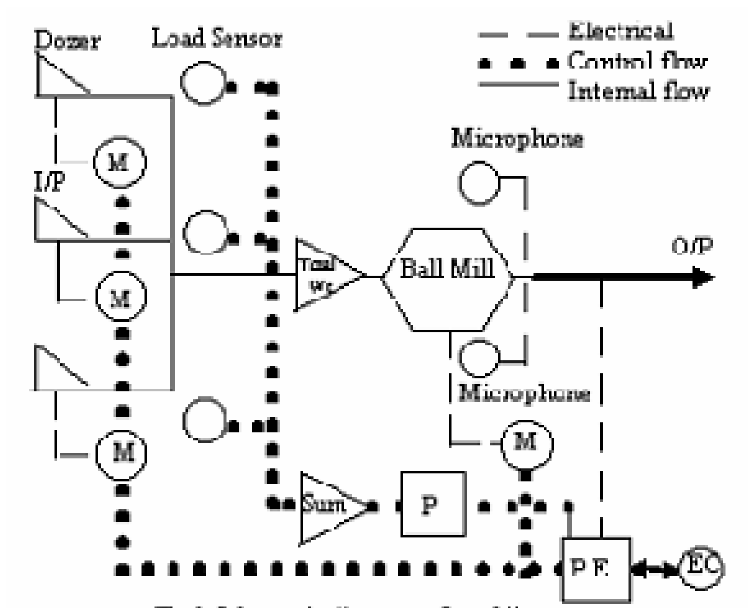

Fig:1 Schematic diagram of tumbling mill with expert controller

P: Microcontroller, Digital Signal Processor/Microprocessor
P.E: Processing Element, E.C: Expert Controller, M: Motor

2.2. The New Approach for Recognition and Analysis of Sound

While studying the nature of sound spectrum for designing the on-line control system, we have found some interesting properties of sound in time domain. The following experiments have been conducted on recorded sound (samples of one second) of various operation modes like empty and loaded ball mill.

i. From the time domain spectrum of empty or loaded ball mil, the corresponding digitized data are read into a matrix.
ii. The short-term power spectrum of that sound, based on a linear cosine transform of a log power spectrum on a nonlinear mel scale of frequency produce a matrix of 256 X 12.
iii. From each column find the mean and plot in a graph.

3. THE EXPERIMENT

The experimentations have been done in two modes such as in off-line mode and in on-line mode. Several publications [3][5][6][7][8] have already been done to design and development of a hybrid control system for operations of grinding mill. In all of these works starting from prediction of grinding process, finding of acoustic signatures, building of Knowledge Base, and finally stability analysis have been described. Whereas, in recent publication [5] the acoustic signatures have been analyzed by finding modal values at various operations and have come to conclusion that mode varies with respect to generation of fines. In this work main concentration has been given to process and to analyze acoustic signals in real-time mode of operation of ball mill.

3.1 The Voice Box and the Acoustic Signal

VOICEBOX is a MATLAB toolbox for acoustic processing. In this toolbox, main emphasis is concentrated on MFCC.

3.2. Mel-frequency Cepstrum coefficients processor

A block diagram of the structure of an MFCC processor is given in Figure 2. The acoustic input is typically recorded at a sampling rate above 10000 Hz. This sampling frequency was chosen to minimize the effects of aliasing in the analog-to-digital conversion. These sampled signals can capture all frequencies up to 5 kHz, which cover most energy of sounds that are generated by ball mill.

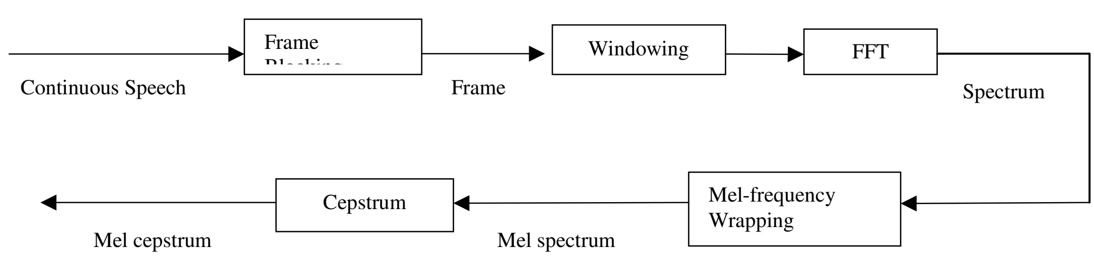

Fig. 2 Phases of MFCC Processor

3.3 Phases of MFCC

3.3.1. Frame Blocking

In this step the continuous sound signal is blocked into frames of N samples, with adjacent frames being separated by M (M < N). The first frame consists of the first N samples. The second frame begins M samples after the first frame, and overlaps it by N - M samples and so on. This process continues until all the mill sound is accounted for within one or more frames. Typical values for N and M are N = 256 (which is equivalent to ~ 30 msec windowing and facilitate the fast radix-2 FFT) and M = 100.

3.3.2. Windowing

The next step in the processing is to window each individual frame so as to minimize the signal discontinuities at the beginning and end of each frame. The concept here is to minimize the spectral distortion by using the window to taper the signal to zero at the beginning and end of each frame. If we define the window as $w(n),\ 0 \leq n \leq N-1$, where N is the number of samples in each frame, then the result of windowing is the signal

$$y_i(n) = x_i(n)\, w(n),\ ),\ 0 \leq n \leq N-1$$

Typically the Hamming window is used, which has the form:

$$W(n) = 0.54 - 0.46 \cos(2\pi n/ N-1),\ ),\ 0 \leq n \leq N-1$$

3.3.3. Fast Fourier Transform (FFT)

The next processing step is the Fast Fourier Transform, which converts each frame of N samples from the time domain into the frequency domain. The FFT is a fast algorithm to implement the Discrete Fourier Transform (DFT), which is defined on the set of N samples {xn}.

3.3.4. Mel-frequency Wrapping

For each tone with an actual frequency, f, measured in Hz, a subjective pitch is measured on a scale called the 'mel' scale. The mel-frequency scale is a linear frequency spacing below 1000 Hz and a logarithmic spacing above 1000 Hz.

One approach to simulating the subjective spectrum is to use a filter bank, spaced uniformly on the mel-scale. That filter bank has a triangular bandpass frequency response, and the spacing as well as the bandwidth is determined by a constant mel frequency interval. The number of mel spectrum coefficients, K, is chosen as 20 by simulation. Note that this filter bank is applied in the frequency domain, thus it simply amounts to applying the triangle-shape windows as in the Figure 4 to the spectrum. A useful way of thinking about this mel-wrapping filter bank is to view each filter as a histogram bin (where bins have overlap) in the frequency domain.

3.3.5. Cepstrum

In this final step, we convert the log mel spectrum back to time. The result is called the mel frequency cepstrum coefficients (MFCC). The cepstral representation of the speech spectrum provides a good representation of the local spectral properties of the signal for the given frame analysis. Because the mel spectrum coefficients (and so their logarithm) are real numbers, we can convert them to the time domain using the Discrete Cosine Transform (DCT).

3.3.6. Output Matrix

A matrix of 256 x 12 with MFCC coefficients has derived out after commutation of step 5. Then, for each column since there are 256 different values, now to calculate the mean of those 256 values for each 12 column. So at the end we get an 1-D array containing 12 columns, which has been used to draw graphs.

3.4. Result

The result of analysis for sound of empty ball mill is shown in Fig.4, wherein Fig 3 is the sound waveform in time domain recorded in empty condition of ball mill. The same procedure is repeated for the spectrum of loaded ball mill and the result is shown in Fig5 -Fig.7.

The following conclusions can be drawn from the graphs.

(i) From fig.4 and fig.5 we can easily differentiate the empty and load situation of the mill.

(ii) There is a substantial difference present in between the graphs. The experiments have also been conducted on different samples extracted from the time domain spectrum at intervals of 1s, and the same observations have been found for empty ball mill. The variations have encountered for the graphs of load varying mill also. The similar and small deviated figures of load varying mill suggest the mill is running under loaded condition and continue to produce fines respectively. Thus, we conclude that the acoustic signal can be used to find an efficient solution to design a dynamic control system for any kind of grinding mill.

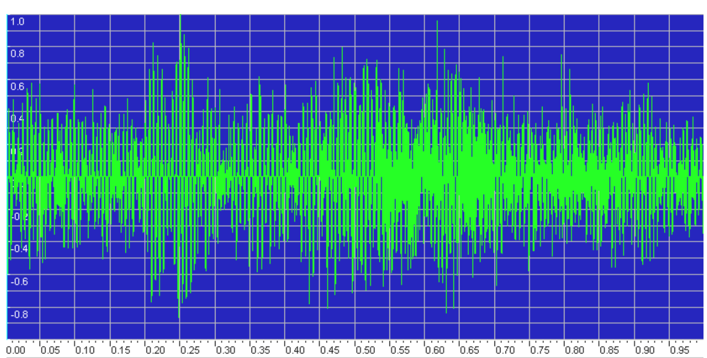

Fig.3 Time Domain Waveform for Empty Ball Mill

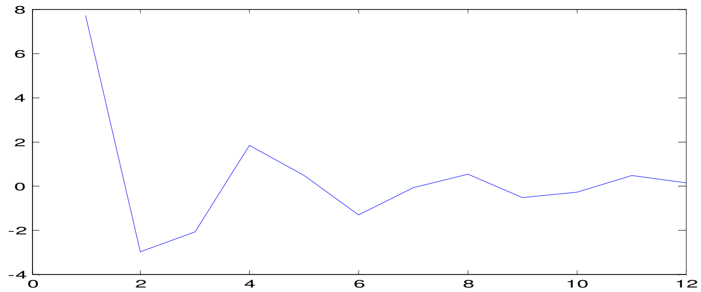

Fig.4 plot after MFCC analysis on Empty Condition Ball mill

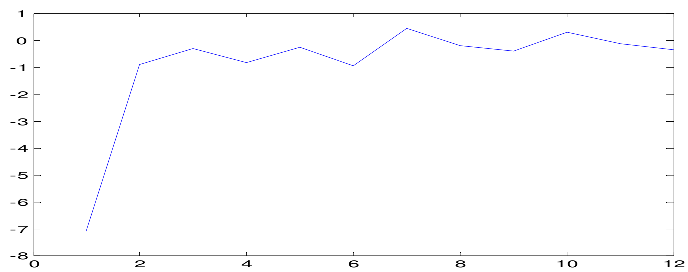

Fig. 5 plot after MFCC analysis on Load Condition First 2 minute

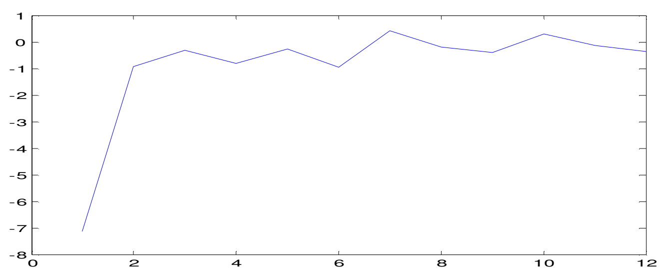

Fig .6 plot after MFCC analysis on laod condition for 1sec after 5 minutes

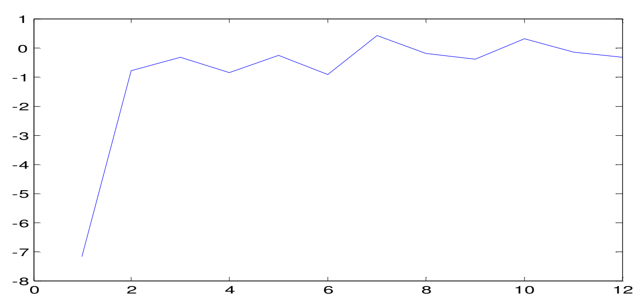

Fig.7 plot after MFCC analysis on laod condition for 1sec after 8 minutes

4. CONCLUSIONS

The intelligent expert control system proposed in the paper provides closed loop grinding in open loop condition utilizing the effect of particle size distributions where random distribution scores fairly well within a limited size band. It has been concluded that the particle size distribution varies with the mass fraction (see, Fig.5) and a multiplication factor (*K*) can de facto give an idea about the change of particle size distribution within a limited size band using which one can obtain predictive grinding and particle size distribution through simulation. Acoustic analysis is an integral part of the work. Its importance basically lies with the formation of the knowledge base of the proposed expert controller and generation of feedback signal that is the key factor in close loop information system. It has also been observed that the proposed method is more suitable towards implementation in system on chip compared to the earlier work of the authors. The model is not only valid for the ball mill but also expected to work well with other different kind of reactors/crushers/compound machines. Under different training conditions convergence of error in acoustic signature has been investigated and obtained satisfactory results.

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AUTHORS

Sonali Sen currently working as an Assistant Professor in the department of Computer Science of St. Xaviers' College (Autonomous), Kolkata. She received her M.Tech in Computer Science and Engineering from university of Calcutta. She is pursuing her Ph. D.

Prof.(Dr.) Arup Kr. Bhaumik, Principal, GIMT did B.Tech & M.Tech in Computer Sc. & Engg. From C.U. and PhD in Computer Technology from BESU, Member IEEE, Life Member ISTE, FOSET & IEI Patent holder on Acoustic Controller for Grinding Mill, Served academics in different Capacities from Lecturer, Asst. Professor, Professor to Principal in Different Organizations starting from NERIST (Govt. of India), Haldia Institute of Technology, MCET, Gurunanak Institute of Technology Published several Papers in reputed Journals & conference proceedings and a book Dr. Arup Kumar B