iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 3 **Issue:** VI **Month of publication:** June 2015

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Crack detection and crack propagation through vibration monitoring in sugar mill roller shaft

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Abstract: The effects of vibration in mill roller shaft during sugar cane crushing which is one of the crack possibility phenomena were analysed. Inducer tests under various unbalanced conditions performed to clarify the effect of mill roller shaft vibration. By using ANSYS software Dynamic analysis has been done for existing roller mill shaft. So, the natural frequency has obtained. By Fracture analysis the variations in natural frequency has concluded. Being different from other failure classification problems, this paper is concerned with determining the probability of normal condition based on current observations describing the condition of a mill roller shaft. Moreover, this problem can be translated to estimate the conditional probability of current observations given normal mill roller shaft condition using a Hidden Markov Model. From this point, a novel probabilistic health description index called Average Probability Index is proposed for mill roller shaft health evaluation. For automatic crack detection, a semi-dynamic threshold is presented to detect an early fault in a mill roller shaft. If the current API is lower than the corresponding threshold at the first time, we conclude that an incipient fault has occurred.
Keywords: Dynamic analysis, Hidden Markov Model, API.

I. INTRODUCTION

In the sugar industry there are four roller mills are exist. In each roller mill the crushing of sugar cane has been done stage by stage. One crushing mill has four roller mill shafts. These are two Feed rollers, one top roller, and one discharge roller. Totally sixteen mill roller shafts are exist. Each roller mill is run by separate 500 HP motor. One trash beam is picked up the top roller. Cane is fed between the top roller and discharge roller. All rollers have one shell with V-thread for crushing the cane [1]. Due to the crushing of cane the top roller will be a formation of gap because of the feeding of cane the roller shaft will rise. To avoid the rising a 'hydraulic accumulator' is held under pressure of 200kg/cm^2 to 220 kg/cm^2 used by a compressed gas. Hydraulic accumulator rams used each end of top mill roller shaft to avoid the rising.

II. EXPERIMENTAL

A. Shaft description

The following figure shows the one sugar mill roller shaft.

Power transmitted = 500HP
Rotating speed = 4rpm
Shaft length = 4440mm
Shaft material = Forged steel
Shaft weight = 5.6tonne
Density = 7800kg/m^3 [1], [2]

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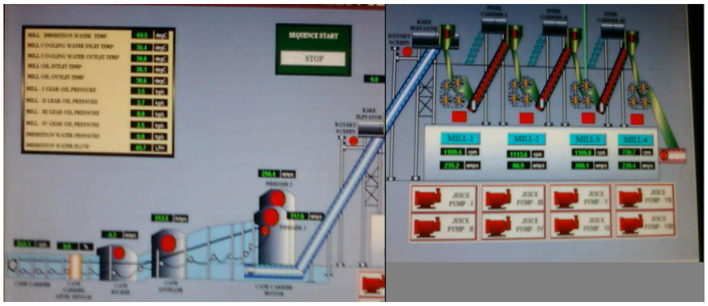
B. Crushing mill control

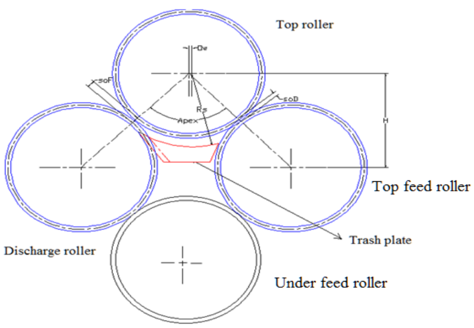


Type	= Four mill tandem
Mill size	= Ø 865 x 1730mm
Drive	= Individual D.C. motor
Speed	= 5 rpm
Crushing capacity (TCH)	= 125 tons / hr
Juice output (including water)	= 131.25 tons / hr
Roller material	= Forged steel
Conveyor type	= Rack carrier type
Rack carrier speed	= 24.5 m / min [1], [2]

C. Mill and Trash Plate Setting

Setting a mill includes the calculation of the openings between the various mill rolls as well as the shape and position of the trash plate [1]. The work openings are calculated first. The work openings are the gaps between the top roll and the feed roll on the one hand and the opening between the top roll and the discharge roll on the other, when the mill is in operation. The next step is to calculate the set openings, that is, what the gaps should be when the mill is empty. The positions of the mill rolls and the trash plate are adjusted until the set openings are achieved [2].

D. Geometry of Mills



E. Modal analysis and Harmonic analysis of uncracked mill roller shaft in Ansys

Modal analysis is the study of the dynamic properties of structures under vibrational excitation. In structural engineering, modal analysis uses the overall mass and stiffness of a structure to find the various periods at which it will naturally resonate [6]. Although modal analysis is usually carried out by computers, it is possible to hand-calculate the period of vibration of any structure. Harmonic analysis is a branch of mathematics concerned with the representation of functions or signals as the superposition of basic waves [4]. Here Ansys software is used to make those modal analysis and harmonic analysis.

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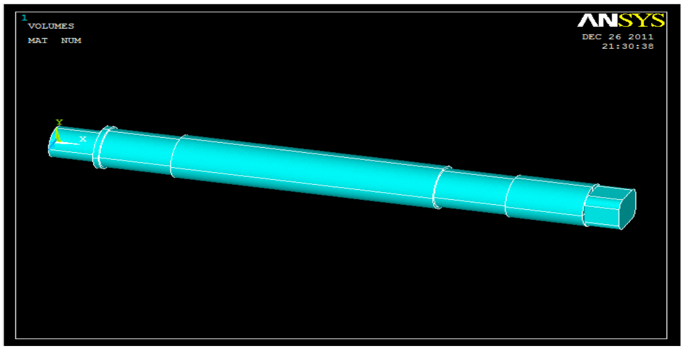
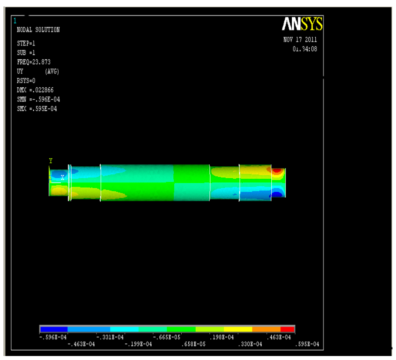
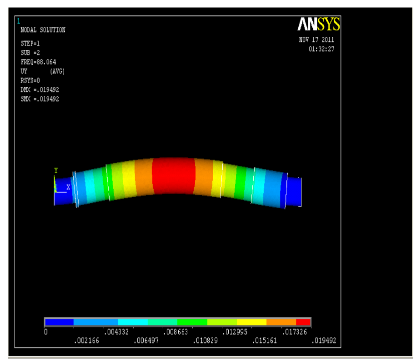


Mill roller shaft model in Ansys

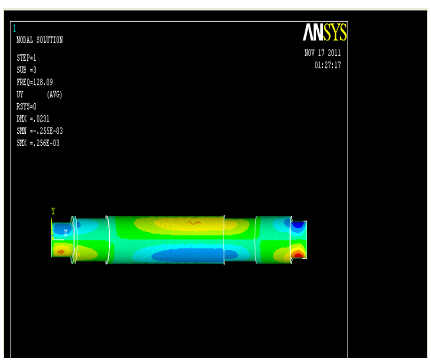
The first four mode shapes should look like the following:



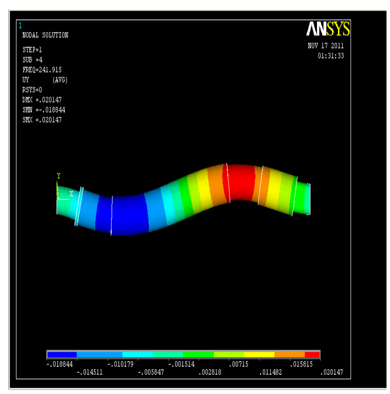
Mode shape-1



Mode shape-2



Mode shape-3



Mode shape-4

F. Frequencies of uncracked shaft

***** INDEX OF DATA SETS ON RESULTS FILE *****

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	0.0000	1	1	1
2	0.29166E-04	1	2	2
3	15.475	1	3	3
4	27.764	1	4	4

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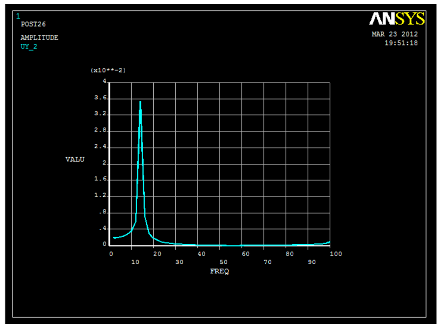


Amplitude and frequency result in ANSYS

G. Fracture analysis of the roller mill shaft:

Initial crack length:

At which fatigue crack growth starts for the given stress range is called initial crack length [5]. Existing failure of the roller mill shaft was around 15mm. We cannot mesh the small curve such as 15mm cracked shaft in ANSYS software. So, here I assume that the initial crack length is 15mm and make the model in hyper mesh software and mesh the cracked shaft in the same software.

Critical crack length:

Critical crack length is defined as at which instantaneous fracture will occur. Griffith crack theory is used to find this critical crack length.

According to Griffith theory:

Critical crack length = $a_{cr} = \left(\frac{K\sqrt{\pi}}{2\sigma}\right)^2$ [4]

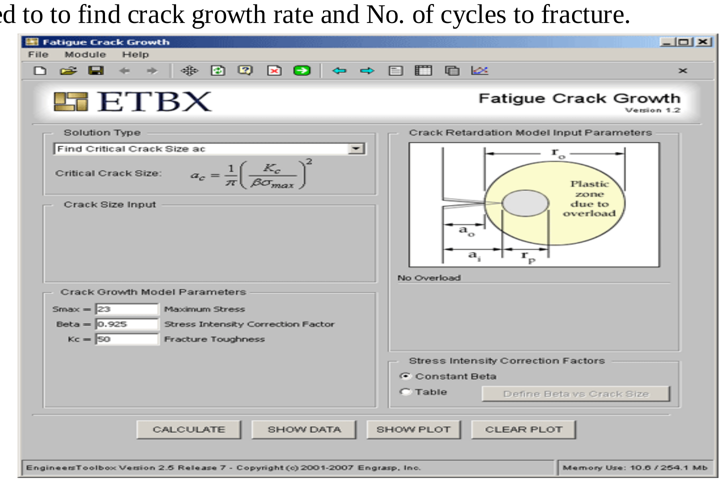
Hydraulic pressure acting on roller mill shaft is 200 kg/cm^2 to 220 kg/cm^2. Here 'K' is Stress intensity factor. It is dependent to initial crack length. So, I assume the initial crack length as 15mm, because of the existing roller mill shaft initial crack length was 10mm to 15mm.

Hydraulic pressure acting on shaft= σ = 200kg/cm^2 = 19613300N/m^2

Stress intensity factor = K = $\sigma\sqrt{\pi a}$ = $19613300\sqrt{\pi X 0.015}$ = 4257662.5 [4]

critical crack length = a_{cr} = 37.011mm

This fracture analysis may be extended to crack growth rate this theoretical fracture analysis can be checked by Engineers tools box software. This software also used to to find crack growth rate and No. of cycles to fracture.



Engineer's tools box software

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ISSN: 2321-9653

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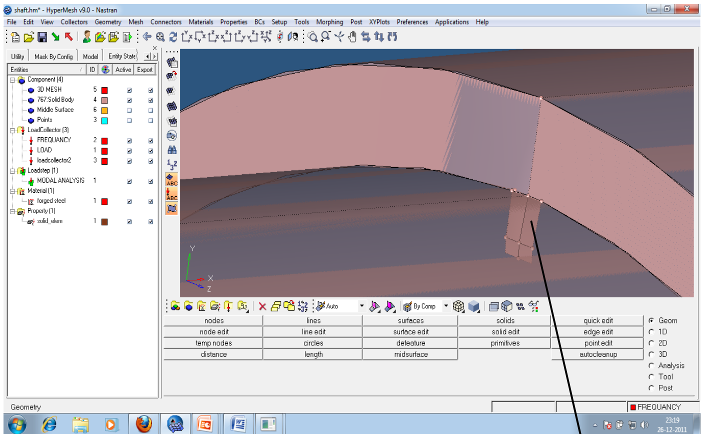
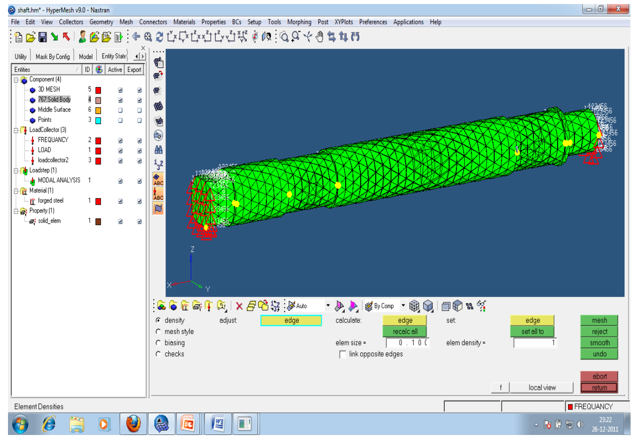
H. Modal analysis and Harmonic analysis of cracked mill roller shaft in Ansys

In ANSYS small cracked areas are cannot be mesh. So we can use Hyper mesh software for mesh the cracked shaft. The following figure shows the cracked shaft model in Hyper mesh model.



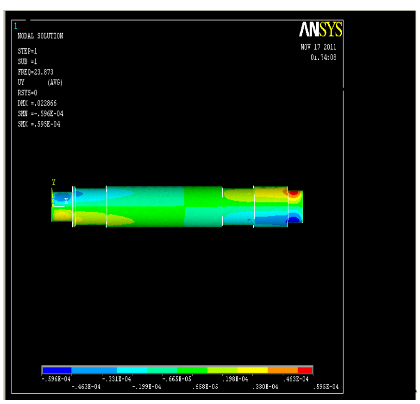
Cracked mill roller shaft model in Hyper mesh software



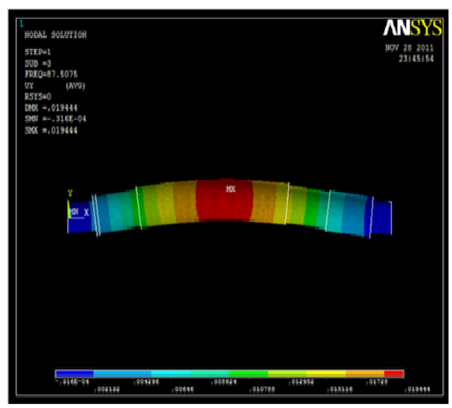
Meshed shaft in hyper mesh software

Crack

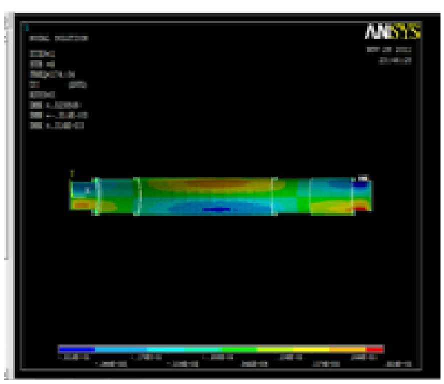
The first four mode shapes of cracked shaft as shown in below:



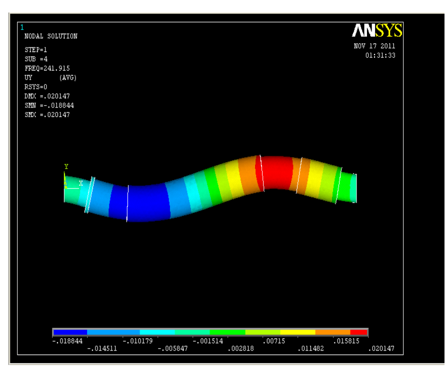
Mode shape-1



Mode shape-2



Mode shape-3



Mode shape-4

I. Frequencies of cracked shaft

***** INDEX OF DATA SETS ON RESULTS FILE *****

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	0.11009E-03	1	1	1
2	41.647	1	2	2
3	87.508	1	3	3
4	174.04	1	4	4

Frequency differences of uncracked and cracked shafts shown in below table.

SET	FREQ for without crack	FREQ for with crack 15mm
1	0.0000	0.11009E-03
2	0.29166E-04	41.647
3	15.475	87.508
4	27.764	174.04

From this analysis cracked shaft frequency will be more when compared to an uncracked shaft [5], [6]. While the increase of crack length obviously the frequency also increased. So, roller mill shaft vibration monitoring is essential because of failure prediction [6], [7].

J. Vibration monitoring

Every half an hour once the displacement reading of the roller mill shaft has been taken by using vibration meter. These are 8.30pm to 6.00pm of 20files. The displacement unit is micron PK-PK. The reading has been taken on drive sides and non-drives sides with two set of the four crushing mill unit. Using this experimental reading first the average value has been determined then the probability of each file can be determined. These reading were input to the Hidden Markov model [7].

K. Average Probability index

When features have been extracted, the proposed health index can be defined using Hidden Markov Model (HMM). Markov said that the future value is dependent to the present value [7]. The HMM is a doubly embedded stochastic model that has been widely applied in pattern recognition, including fault classification. However, the work with HMM in this paper is different from others, since we utilize HMM for the definition of health index rather than fault classification. Generally, an HMM can be represented by a compact notation $\lambda = \{A, B, \pi\}$. To define API, assume that the hidden states are governed by a homogeneous Markov chain of order 1. The purpose of HMM training is to estimate the model parameters $\lambda = \{A, B, \pi\}$ and the training process is realized by fitting the observation probability distribution [7]. Therefore, a novel index called the Average Probability Index (API) is proposed as follows: Since the proposed health index is a statistic of probability, we call it a probabilistic scheme for machinery health evaluation. Furthermore, since the lifetime shaft vibration data used in the case study are collected and numbered sequentially at a certain time interval (e.g., once half an hour) along with the running of the test, time j is consistent with the file number and is represented by the file number (1,2,…,20) [8].

L. Dynamic threshold

In order to detect the occurrence of a gear fault, a semi dynamic threshold $Th(t)$ is defined as below, based on the principle of a 3-sigma limit of time series data [8]. Here, semi-dynamic means that the proposed threshold changes with the historical value of API before the occurrence of an early fault. If the current API is lower than the corresponding threshold at the first time (t_{early}), we conclude that an incipient fault has occurred. Then, the semi-dynamic threshold becomes a fixed value [9].

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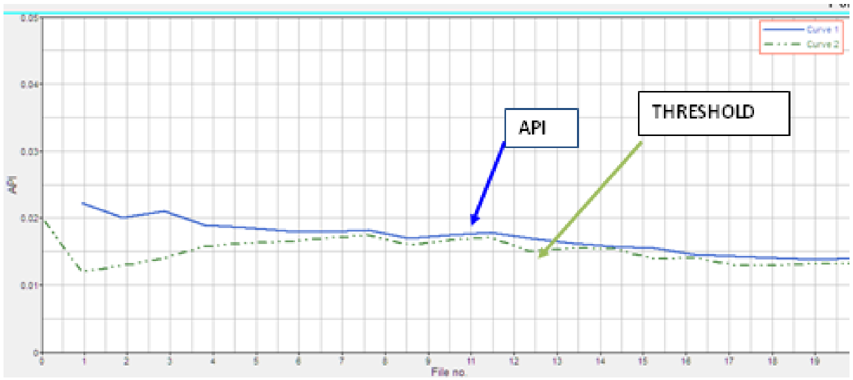
III. RESULTS AND DISCUSSIONS

A. If the current API is lower than the corresponding threshold at the first time, we conclude that an incipient fault has occurred. Fault in the sense it was crack. Below the graph represent relation between the API and threshold. When fault has been occurred, the threshold curve was across the API curve. At the time we conclude that fault has occurred. This graph was plotted in hyper mesh software [8], [9].



B. Critical crack length = 37.011mm at which instantaneous fracture will occur

C. Crack growth rate = $8.26721 X 10^{-8}$

D. No. of cycles to fracture = 1842214 cycles

IV. CONCLUSION

From the results we can conclude that the natural frequency of mill roller shaft has been changed due to crack. The natural frequency of mill roller shaft is 30Hz in normal condition. It is proved from the above experimental vibration parameters readings. The 15mmcrack length of mill roller shaft is 175Hz. obviously the natural frequency of mill roller shaft was change.

We can identify the crack in initial stage itself. If the current API is lower than the corresponding threshold at the first time, we conclude that an incipient fault has occurred. If this crack propagate then the number of cycles at which crack occurs can be found. If the 15mm crack length occurred the final number of cycles to fracture is 1842214.

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