Identification of bearing assembly defects using Finite Element Analysis and Condition Monitoring Techniques

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Abstract

Industrial fans are integral components of many industrial plants, particularly Steel plants, power plants, paper and printing, automotive, Air conditioning, petro chemical plants. Fans are normally mounted in bearing-housing assembly, where fan failure can cause expensive unscheduled plant shutdowns. Early detection of faults in these systems allows the user to initiate repairs and it can prevent costly maintenance. Fan problems result from impeller unbalance, misalignment of shafts, cracks, resonance, looseness, bearing problems etc in this paper, fault detection techniques which are based on vibration signals that are acquired from accelerometers, are proposed. Bearing fault detection is conducted by signal processing methods, based on the vibration signature of the rolling elements of bearings. In addition, infrared Theromgraphy technique is proposed as an integrated condition monitoring system with the existing monitoring system to increase the performance of fault detection and to know the degradation of bearings and also theoretical and numerical analysis of the heat conduction process of the bearing to its housing is presented and discussed.

1. Introduction

Preventive maintenance (PM) is an effective approach for reliability enhancement. Time-based and condition-based maintenance are two major approaches for PM. In contrast, condition-based maintenance can be a better and more cost-effective type of maintenance than time-based maintenance. However, irrespective of the approach adopted for PM, whether a failure can be detected early or even predicted is the key point.

In thermography, thermal camera is in the form of temperature values. Thermal camera manufacturers usually have their own software to read this data and display them as a thermal image [1]. When converting temperature values into thermal image, a pseudo-coloring or false-coloring technique [2] is used. The difference in temperature can be imaged and measured using an infrared camera. The recorded visual image is a thermogram or thermal scan. Essentially this device captures electromagnetic spectrum within infrared bands (0.74 – 1000 μm), a thermal image is a function of radiated energy of an inspected object [3].The energy emitted by a surface at a given temperature is the spectral radiance and is defined by Planck's Law [4]. Surface temperature distribution can thus be used to detect thermal anomalies. A thermal anomaly is defined as a thermal pattern of a surface that varies from a uniform color or tone when viewed with an infrared imaging system.

In IRT, numerical modeling is a precious tool. The need for defect characterization has promoted research in quantitative infrared thermography. Information on fundamental parameters affecting the heat transfer are needed to develop the foundation for quantitative thermography and hence analytical studies are needed to determine the capabilities and limitations of IR thermography with out the expense of making and testing the corresponding specimens [5]. Other purpose of numerical modeling in IRT is to simulate the real situation in order to obtain the simulated thermogram [6]. Thermogram can be used to test the developed algorithms (mainly related to image processing) in the case of unavailability of the thermogram from the real object, for instance due to the difficulties to obtain such thermal data. The informative parameters in thermography [7] are any parameters that can be used to characterize the properties of subsurface defect based on their behavior on the other side of the outer surface. These parameters can be a time constant or any magnitudes such as temperature values that can be related with the defect existence. Most investigations for informative parameters derivation were devoted to active IRT.

Plotnikov [8] has discovered that time of peak slope t_{ps} is an informative parameter for defect depth estimation.. Plotnikov and Winfree [9] focused their research on defect depth estimation in composite aircraft components using transient thermography

Numerical simulations have been done to study the influence of material and geometrical parameters on impulse thermography for buildings materials [10]. Three parameters were studied: concrete cover, void size, and thermal properties of materials. These parameters influenced the thermal signature behavior (maximum temperature difference), therefore they were informative parameters in this study. FEM has been used to investigate the behavior of temperature in a concrete slab in terms of impulse thermography [11]. Numerical simulation results using FEM had good compromise with experimental results of the physical problem.

2. Equipment set up and its description:

While charging takes place in furnace plenty of dust and fumes will be expelled from furnace top. All the dust and fumes will be held in the canopy hood situated at the roof, flow through the ducting, and pass through the baghouse for the removal of pollutant and then expelled into the atmosphere. It is an induced draught fan situated between baghouse and chimney. Vibration monitoring revealed that fan drive end bearing has high vibration in axial direction and the maximum temperature on the surface of the housing is 90^0C. ID fan is simply supported in bearings and the arrangement, operating load and speed details are shown in Fig.1

when the fan was in service it experienced high vibrations in axial direction for Drive end bearing and gradually in increasing trend and Fan Drive end bearing housing surface temperatures started to increase and it was non uniform around the outer surface of the bearing

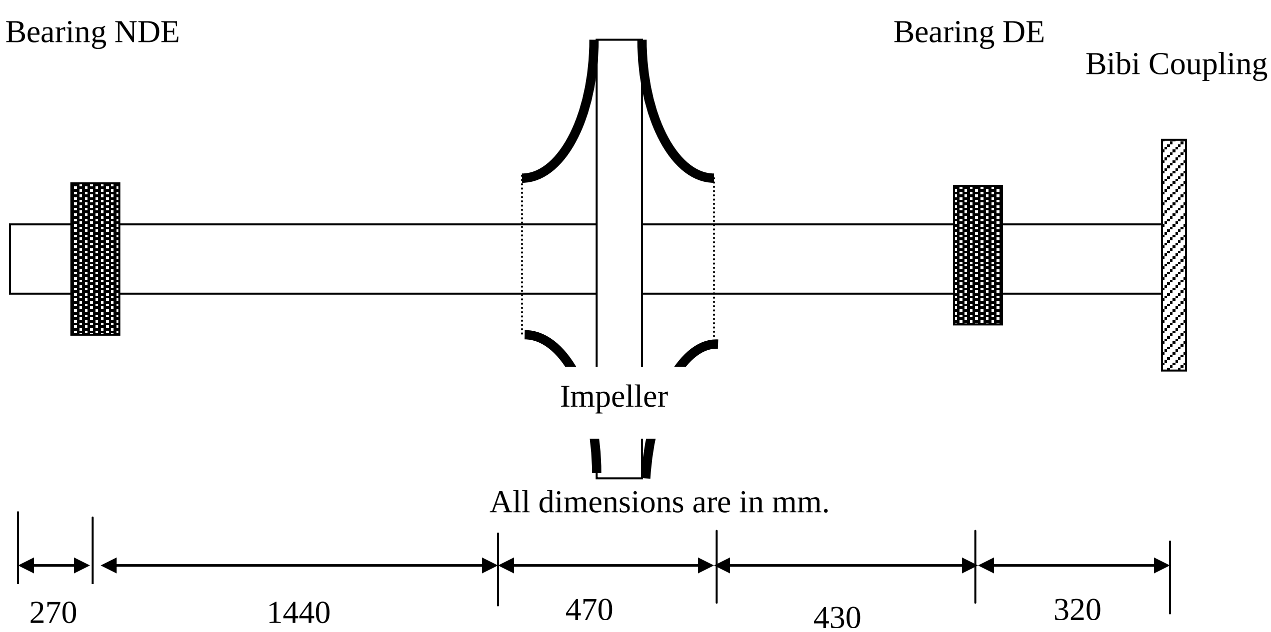

Fig.1 Industrial ID Fan Arrangement

No. of Vanes = 10, Wt. of the Impeller 1750.0 kg., Dynamic Load = 2225.0 kg,

Fan Bearings on both sides = 22328 CCK

Shaft Dia = 150.0 mm, Bearing seating Dia = 140.0 mm, Housing fit = +/- 0.02mm

Bearing clearance = 0.15mm,

Lubricant : Servogem 2,Lubricant Quantity = 2.2 kg approx.

2.1 Theory

As asperities in contacting surfaces rub against each with the frictional contact, the dissipated energy transforms into heat. The thermal energy thus produced subsequently diffuses into the bulk of the contacting materials. The resulting heating affects the mechanical properties of the materials as well as their micro structural characteristics. Thermal analysis of the heat conduction process allows determination of resulting temperature excursions during friction contacting. Heat is generated by frictional processes at contact areas. At low loads and/or for rough surfaces consisting of fairly isolated peaks, the real area of contact is restricted to asperity contacts and is usually much smaller than the apparent area of contact. In contrast, at high loads and/or for smooth surfaces (or even rough surfaces with small peaks and valleys) the apparent and real areas are almost the same. Thermal models must be developed to account for the two extreme cases as well as the intermediate regime. The elementary frictional interaction consists of the transient contacting of two asperities under load L and in relative motion with velocity V. As the asperities slide past each other, work is done by the friction force $Ff = \mu L$ and the rate of thermal energy generation at the interface is given by

$$Q = \mu LV \qquad (1)$$

This energy is subsequently partitioned and diffuses into the bulk materials. If the contact area is Ac the resulting heat flux at the interface is

$$q = Q/Ac = \mu LV/Ac \qquad (2)$$

If the contacting materials are say (Spherical roller bearing) 1 and (bearing housing) 2 and the fraction of the thermal energy going into material 1 is called r then the flux into material 1 is q1 = rq and that into material 2 is

$$q2 = (1-r)\ q. \text{ ----------------} \qquad (3)$$

If a hard material with a single asperity slides over the smooth surface of a softer one, steady state conditions may be quickly established and estimates of the resulting thermal effect can be readily obtained from the theory of moving sources of heat. The analysis yields values of the steady state maximum temperature achieved at the interface. Notice that steady state conditions refer to a coordinate system which moves with the asperity.

Alternatively, if one considers instead two asperities which briefly come in contact with each other, the result is a sudden thermal excursion (spike) leading to the concept of flash temperature, this being the maximum temperature achieved during the brief contact process. More elaborate numerical methods can be used for the estimation of these flash temperatures.

3. Model and Governing equation:

A Shaft and bearing-housing assembly is shown below

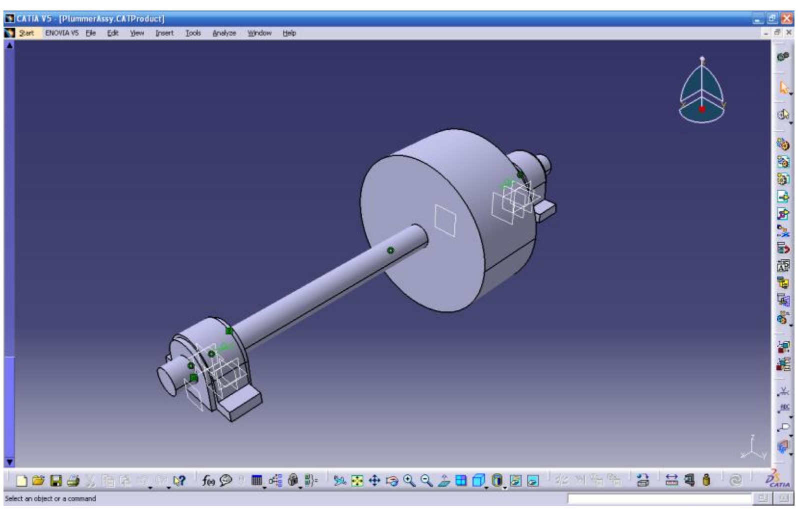

Fig.2 A shaft and bearing-housing assembly

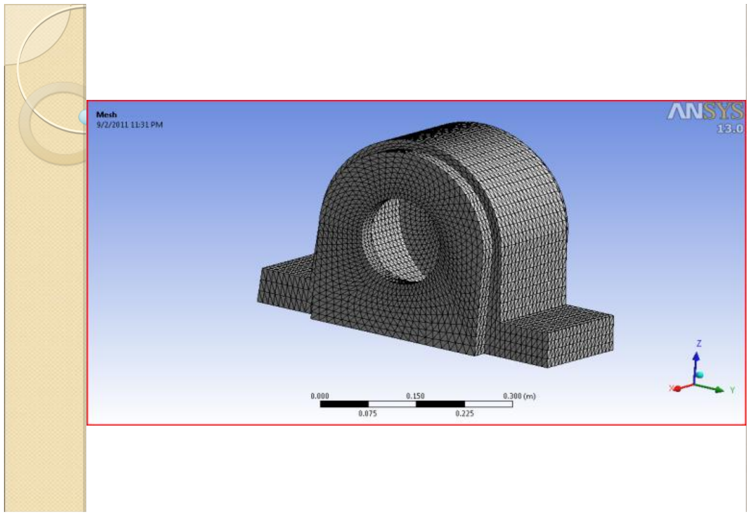

Fig.3 Meshing of bearing housing

A shaft along with the bearing outer race oscillates (due to loose fit between bearing outer race and bearing housing) on the inner surface of a stationary bearing block under the applied load. As the shaft oscillates, heat is generated in the contact region due to friction between the asperities.

Governing equations:

The general governing equation for the transient heat conduction in the shaft or the bearing housing is

$$\frac{\partial^2 T}{\partial r^2} + \frac{\partial T}{r \partial r} + \frac{\partial^2 T}{r \partial \theta^2} + \frac{\partial^2 T}{\partial z^2} + q / k = \frac{\partial T}{\alpha \partial t} --------(4)$$

Assuming steady state heat conduction without heat generation and by neglecting the variation in z direction

The governing equation becomes

$$\frac{\partial^2 T}{\partial r^2} + \frac{\partial T}{r \partial r} + \frac{\partial^2 T}{r \partial \theta^2} = 0 --------(5)$$

Boundary conditions:

Heat flow rate at inner surface of the bearing housing at inner radius i.e. at r=r is estimated by the formulas [] from bearing catalogue approximately it is q=100W, And if the fit of bearing-housing is loose an additional heat which is generated at portion of the inner surface which is predicted from equations 1, 2 and 3 as approximately 40 W

$$q = -k\frac{\partial T}{\partial r} - - - - - - - - (6)$$

At outer surface of bearing housing is considered as free convection

$$-k\frac{\partial\ T}{\partial r} = h(T - T_{\infty}) - - - - - - - - - - - - -(7)$$

4. Numerical model

We are interested in determining the spot temperatures on the surface of bearing housing. For this purpose, we used software based on the finite element analysis

The modeling hypotheses are the following:

• We suppose that the contacts between bearing and housing are imperfect and it is loose fit;

• The rotation speed of the outer race of the bearing in the bearing housing is momentarily and not continuous.

• Heat generation is uniform due to normal running of bearing

Meshing of the experimental device

The computing conditions are as follows:

• Ambient temperature: 22°C

• Boundary conditions as specified in section 3.2

• Internal and external side convection exchange coefficients5.7 W/ m^2/K

• Convection exchange coefficients on the lower and upper faces: 5.7 W/m^2/ K

• Speed of rotation of the axis: 1000 rpm

• The bearing housing is made of Gray cast iron with thermal Conductivity: = 52W/m. K

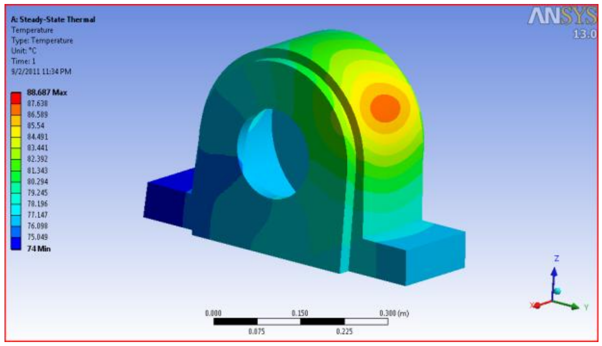

Fig.4 Numerical simulation results of bearing block

5. Vibration analysis:

The bearing analysis was carried out for the defects mentioned below and the spectrum analysis gives the looseness

All possible defects were inspected.and at last predicted the possible looseness is between bearing outer race and housing assembly

Table1: Bearing defects and its fault frequencies

Location of bearing defects	Frequency spectrum	Observations
Good condition	F_S,F_{BPO},F_{BPI}	Good condition can have F_S,F_{BPO},F_{BPI} and its harmonics, the amplitude is small and even, no salient frequency stands out.
Bearing looseness	F_S	Looseness can condition can have F_S and its harmonics.
Rolling elements	$2F_B$,F_{BPO},F_{BPI}	For sever case these frequencies Can be modulated $2F_B$,$F_{C,}$ and the natural frequency can be also excited.
Bearing race way	F_{BPO},F_{BPI}	Increased severity of the defect results in higher order harmonics being produced, the frequency for the raceway with defect will stand out .if the clearance is small $2F_B$ Can also be presented.

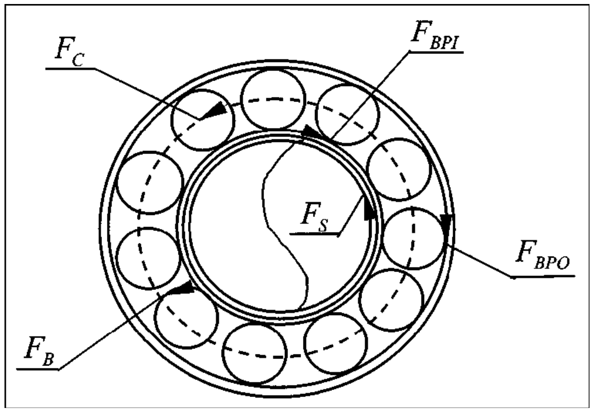

Fig.5 Fundamental basic frequencies

Ball Pass Outer Raceway Frequency (F_{BPO})

Shaft Rotational Frequency (F_S)

Ball Pass Inner Raceway Frequency (F_{BPI})

Fundamental Cage Frequency (FC)

Ball Rotational Frequency (F_B)

Vibration analysis spectrum is shown below

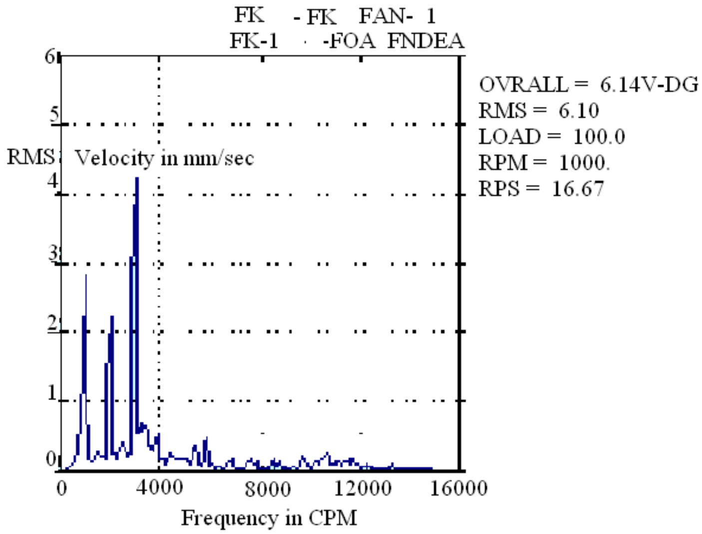

Fig.6 Vibration signature of defective bearing

6. IR Analysis:

Infrared thermography is an excellent condition monitoring technique for diagnostic of equipment and machine. This technique allows monitoring thermal pattern of the equipment in the operating condition, running in full load condition. As a general rule all the equipment has an operating temperature limit which is suitable to use as a base line for detecting thermal changes and variations. This method of detecting thermal anomalies has a wide range in diagnostic and has application in different equipments and machines like, bearings, gear box, conveyor system, drivers, motors, electric generators etc. Such application of infrared thermograph is recognized as one of the most versatile and effective condition monitoring tools.

A thermal imaging infrared camera is an effective technique to scan, monitor and detect the infrared emissions from the surface and generate thermal patterns or uneven heat distribution of the scanned area. These scanned images are very useful in detecting incipient fault and deterioration in the equipment caused by overheating due to defect in the bearing, wear and tear in the machine, distortion in current and voltage, uneven friction and various other deviations from the normal operation of the mechanical system. This method of thermal imaging improves the ability to predict abnormality in the machines

Thermal image of abnormal bearing-housing is shown below

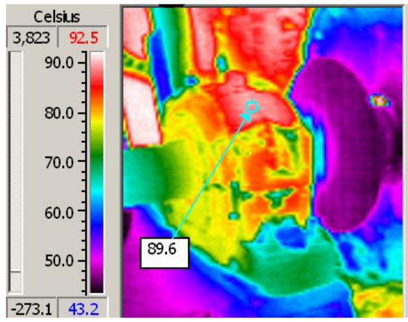

Fig.7 IR Image of abnormal bearing housing

7 Results and Discussion:

The presence of a provoked defect leads to a characteristic vibration level transformed into abnormal heating of the system, and thus the generation of a heat fluxes adding to the nominal heat production. We wish to verify whether this phenomenon induces a rise of the surface temperature that can be detected by infrared thermography, subsequently bearing housing outer surface temperatures are measured with the help of IR Cam

The modeled part analysed with the help of Finite element analysis and modeling hypotheses are as mentioned below:

• We suppose that the contacts between bearing and housing are imperfect and it is loose fit;

• The additional heat flux between the outer race with the bearing housing at contact surface only.

• Heat generation is uniform due to normal running of bearing.

The predicted heat fluxes applied at the contact surfaces of bearing housing and bearing to measure the distribution of the outer surface temperatures of bearing housing. The obtained spot temperatures on outer surface of housing is validated with the available temperatures by infrared thermography and the results are shown in Table2

Vibration analysis further confirms the looseness. Finally the abnormality in bearing housing is identified as a result of loose fit between bearing and housing.

Table: 2 Comparison of spot temperatures of FEA and IRT

s.no Location	Spot temperatures on outer surface of housing measured by Infra Red Thermography(^{0}C)	Spot temperatures on outer surface of housing obtained by Finite Element analysis(^{0}C)
1	76	76
2	89.6	89
3	82	82
4	75	76
5	72	73

8. Conclusion:

Infrared thermography is applied to measure the temperature distribution on the outer surface of the bearing housing and is used as a technique for the validation of the present numerical model for the simulation of improper fit of bearing-housing assembly. The analytical approach using FEM substantiated that the bearing assembly defects can be identified with measurement of bearing housing temperature. The integration of thermography, vibration analysis and FEM strengthens the abnormality detection and aids repair process. Further, vibration analysis strengthens in detecting the mechanical looseness of the bearing -housing assembly. Similar such FEM, Analytical models can be developed and generalized mechanical abnormalities occurred during operation of the equipment. Integration of CM technique helps in detecting incipient fault that is developed in the system before it becomes worst and leads to catastrophic failure and also aids in developing solution to the root cause of failure.

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