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ECCENTRICITY MEASUREMENT SYSTEM FOR ROTATING MACHINES WITH LARGE INDUSTRIAL LOAD

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ABSTRACT

Eccentricity in shaft due to heavy load reduces efficiency of motion transfer between rotating machines. Permissible tolerance levels for shaft eccentricity vary with the type of load and may depend on various parameters as well. Accordingly, to match the permissible tolerance level of eccentricity, sensor and signal conditioning circuits should be designed with utmost care. Eccentricity transducers are used in monitoring steam or gas driven turbine or motors with heavy load. Radial contact between stationary and rotating elements at slow roll speed is measured. Eccentricity measurements indicate whether rotor eccentricity is small enough to allow machine start-up without causing damage. Value of eccentricity should be displayed continuously. Beyond permissible limit audible alarm should be generated. This paper presents the overview of the fundamentals of eccentricity measurement and discusses a system design for the stringent eccentricity criteria considered with reference to an industrial application.

Keywords—Eccentricity, Gap Sensor, Bow, TSI

I. INTRODUCTION

Heavy loads connected with motor, generator and other machines have considerable effects on performance of it. Various stresses and effects like static and dynamic eccentricity, run-out, offset, and vibration must be reduced to improve efficiency of machine performance. Rotating machines operated with an eccentric air gap makes more mechanical vibration, more degradation of insulation because of increased movement of coil and rotor or stator rubbing and damage due to unbalanced magnetic pull.

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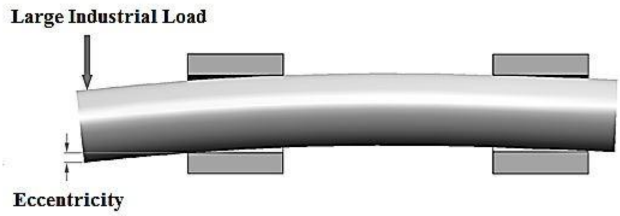

Fig. 1 Shaft Eccentricity [10]

Static Eccentricity[9] strikes when the centerline of the shaft is at a constant offset from the centerline of the stator and it can be removed by proper alignment. Dynamic Eccentricity[9] strikes when the centerlineof the shaft is at an inconsistent offset from the centerline of the stator. Effects of it can be calculated by effective measurement and analysis. Fig. 1 Shows bending of Shaft due to eccentricity and Fig. 2 shows rotational path due to dynamic eccentricity.

Possible causes for eccentricity and gap in rotor- stator path or combination of causes are

- Bending of the shaft due to load
- Aging effects on rotor-stator assembly
- Rotor outer diameter is eccentric to the axis of rotation
- Shape deformation of the shaft
- Rotor and stator are round but do not have the same axis or axis of rotation
- Temporary thermal bow and gravity bow

Due to practical constraints several points must be considered when determining the location of the eccentricity transducers concerning shaft bow[1]. Eccentricity is measured while the turbine is on slow roll. As it is impractical to mount Eddy Probe Transducers Non-Contacting Pickups mid-span on the rotor where the eccentricity measurement would be the highest, the transducers are mounted outside the pressure case as far from the bearing or nodal point practically. The bearing should be avoided as a mounting location because during slow roll operation the rotor is turning in the bottom of the journal bearing and is not dynamic while the eccentricity measurements are being made. This effect forces the bearings to become nodal points.

Shaft Eccentricity plays a very important role in the Turbine Supervisory Instrumentation or TSI System[2] on large steam turbines or gas driven turbines. Due to the increasing complexity of machinery controls and operations, it is essential to fully understand an application before installing a transducer. The most common application for eccentricity transducers is in steam or gas driven turbine & when monitoring these turbines, radial contact between stationary and rotating elements at slow roll speed is measured. Eccentricity measurements indicate whether rotor eccentricity or slow roll bow is small enough to allow machine start-up without causing damage. Shaft bow may be due to fixed mechanical bow, temporary thermal bow or temporary bow due to any sort of sag or bow at standstill, sometimes called gravity bow.

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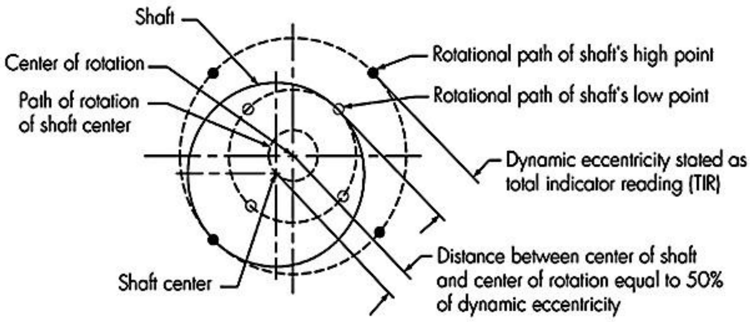

Fig 2. Rotational Path Due To Dynamic Eccentricity

Measurement with eddy current sensors and control method for the rotor radial position control to remove vibration due to rotation and mass-unbalance has been discussed in [4]. Importance and measurement of eccentricity as well as vibration is prime to discuss rotor-dynamic analysis[6] and practical issues. Effects of eccentricity on power balance should be analysed to calculate error in power balance[7] considering it as one of many possible sources of error.

Problem in lateral shaft motion is eccentricity resulting from side loads on the rotary shaft. Side loads can cause the shaft to deflect elastically. Elastic deflection estimates are possible, when side loads are quantifiable, by using Roark and Young type calculations, or finite element analysis. If the angular location of the side load is constant, then the angular orientation of the shaft deflection is also constant. Sometimes such conditions are referred as static offset. Sensor and Eddy current probe details are discussed in [8]. Optical fiber sensor also can be used in similar applications and dynamic strain measurement [11].

Section II discusses overall system for eccentricity measurement with block diagram. Section III discusses sensor, its selection and location Section IV discusses Alarm and display part of the system. Details of work has been summarised and deducted in conclusion section.

1.1 Proposed design for Eccentricity Measurement System

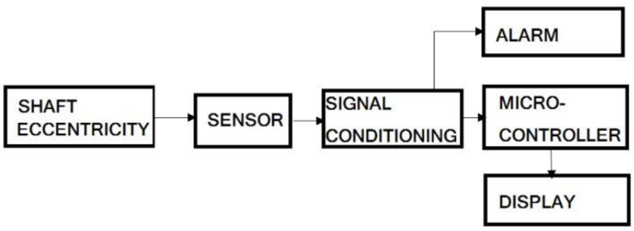

Fig.3 Block Diagram of Shaft Eccentricity Measurement System

As shown in block diagram Fig. 3 eccentricity is detected and measured by an eddy current sensor, followed by small signal conditioning part. Conditioned signal is compared with permissible limit to generate audible alarm

if needed. Output of signal conditioning part also goes to display through ADC and other micro-processing in Arduino-uno board.

Sequence of operation

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- Sense eccentricity using sensor. Sensor selection and sensor mounting is crucial.
- Signal conditioning
- Send conditioned analog signal to
  - Comparator and
  - ADC inbuilt in micro controller
- Turn on audible alarm if permissible limit exceeds indicated by comparator output.
- Send Microcontroller output for a digital display.

1.2 Sensor selection, mounting and Signal Conditioning

A. Sensor Basics and Targets with Conductive Property

An eddy-current sensor generates an alternating magnetic field at the tip of probe. When generated field is near to conductive material, the field induces small electrical eddy-currents in the material.

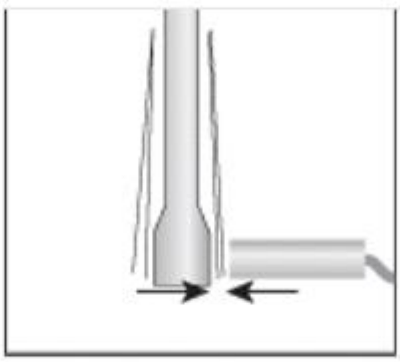

Fig. 4 Gap Sensor for Eccentricity Measurement

It produces a new magnetic field opposing the field from the sensor. The field interaction changes as per change in gap between the probe and target. The sensor electronic assembly measures this field interaction and produces output voltages proportional to the change in the gap. Sensor arrangement is shown in Fig. 4.

The eddy-currents induced in the target are dependent on the permeability and resistivity properties. Thus eddy-current sensor is sensitive to changes in material also. There can be a drastic difference between magnetic materials like iron and steel with nonmagnetic materials like aluminium and copper. The difference between two nonmagnetic materials is also significant. The material and alloy should be specified with specifications and orders to assure an accurate calibration. Targets have minimum thickness requirements because the magnetic field penetrates the surface of the target and it varies with material type.

1.3 Harsh Environments

The magnetic field effects of eddy-current sensors neglect nonconductive materials and is not affected by most contaminants. This helps an eddy-current sensor to operate while immersed in liquids, with machine coolants or other liquids present in the sensing area creating hostile environment.

1.4 Sensor Probe, Ranges and Accuracy

Eddy-Current probes are mainly designed as displacement sensors measuring changes of the gap between the

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sensor and the target. The variation in average distance from the probe to the surrounding material creates a change in output voltage. Larger probe diameter is needed for larger range[3]. Accuracy at the high resolutions created by precision eddy-current sensors may be affected by the environment and measurement setup. Target areas must be at least three times larger than the probe diameter. Probes must be positioned in a stable mechanical system in a stable environment. Even small changes in temperature cause expansions of the target that are detectable by high-resolution sensors. Fig. 5 Shows probe range and gap details for target.

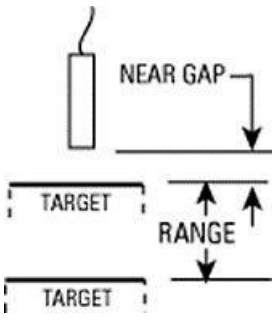

Fig. 5 Probe Range [3]

1.5 Sensor Location

Eccentricity transducer should be located and mounted with both the ease of installation and the ease of understanding the operation. Scaling for both the peak to peak and direct measurement method should be evaluated for proper coverage.

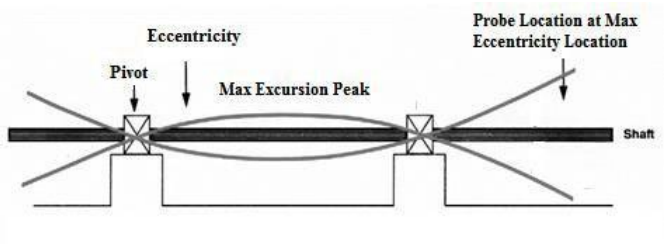

Fig. 6 Sensor Mounting for Typical Eccentricity in Turbine-Generator Set [1]

Transducer selection should be based on the ranges required, recognizing that large gap voltage changes can occur during start-up and during machinery operation. Two Sensors are placed 90 degree to each other. Sensor can be mounted at a .15 mm to .5 mm distance from the shaft periphery in some cases based on application. Here proposed distance is .3 mm from periphery. Fig. 6 shows sensor mounting for typical eccentricity in turbine-generator set

Two monitor operation modes are possible, peak-to-peak or direct. Peak-to-peak is the overall amplitude of the inter low for one shaft revolution. It is an amplitude and is not directly affected by angular orientation. Direct mode is the direct representation of rotor bow based on change in gap voltage when the rotor moves toward or away from the transducer. This is the mode where the mounting configuration will have the most impact. Direct mode is used in

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cases where a large amount of rotor bow is present, the eccentricity information provided assists in determining where to stop the rotor to help eliminate the bow.

If a clock [1] is used for references 12:00 would be top to exact centre. With a probe at top position 12:00, if the gap voltage is lowest the bow is at the bottom 6:00 location. Thus, if a reduction in gap for upscale away indication has been selected, the meter movement is at its maximum point and the bow is at its lowest point.

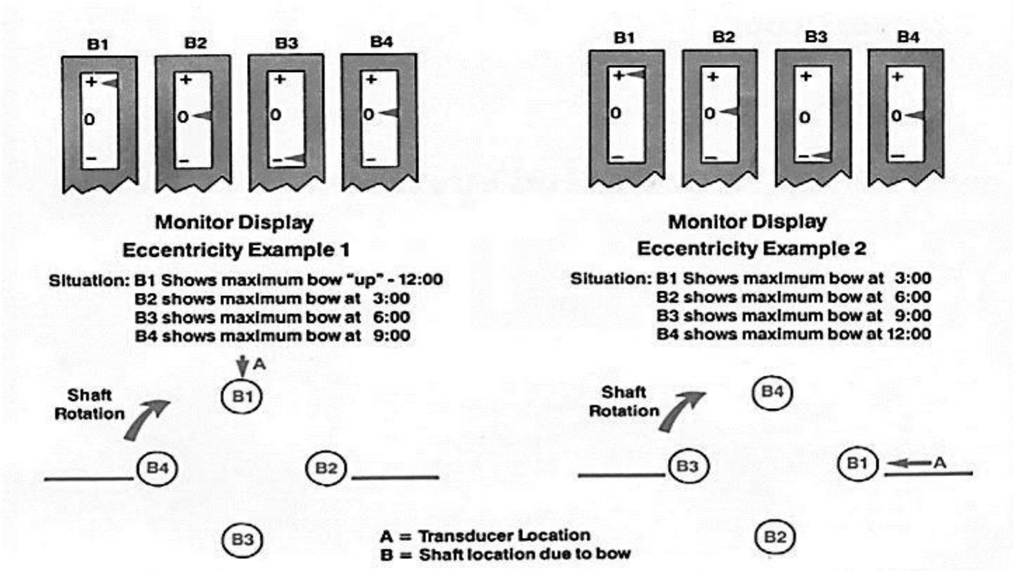

Fig. 7 Sensor Output with Clock Position Reference [1]

Consequently, a probe at bottom 6:00 that measures a reduction in gap for normal indication will show the location of bow at top 12:00 for its maximum meter reading. It is true for all other considerations when deciding for a probe's angular orientation. Include change in gap voltages due to reasons like tube oil, hydraulics of oil pump or turning of gear. This should not be a problem if the scale on the direct mode of the monitoring device has sufficient range. Ease of mounting the transducer is also significant. Most machines are assembled in two halves top or upper and bottom or lower.

Thus, we have a split line which is generally called the horizontal split line. Due to the need for disassembly and reassembly of the machine, it is impractical to mount transducers at the top or upper casing 12:00, It is generally easier to adapt a bracket fitting or fixture to the lower casing and to locate a transducer at the horizontal split line 3:00 or 9:00 clock positions.

In severe cases of eccentricity, It must be verified that the transducer has sufficient linear range. Determine how much bow can be allowed before the machine rubs and set the upper alarm at this point or at a point slightly less. Also consider radial clearances due to shaft rise or run- ning attitude angle, The transducer should be gapped to allow adequate range for maximum excursions both towards and away. Fig. 7 shows sensor output with clock position reference. To share voltage for signal conditioning, voltage divider is suitable choice.

II. ALARM & DISPLAY

Alarm circuit is prepared using Comparator to compare with permissible limit. Output of both comparator

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circuits from sensors goes to OR gate. OR gate output is connected with Buzzer circuit to generate audible alarm. Fig. 8 and Fig. 9 shows comparator and buzzer circuit respectively.

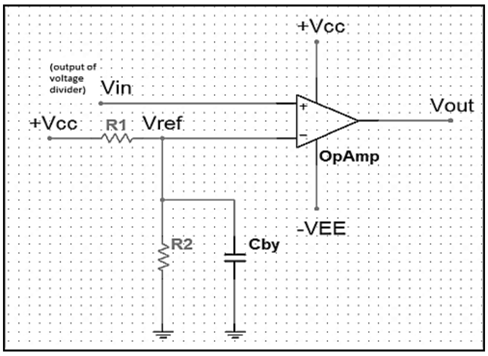

Fig. 8 Comparator Circuit

Display part uses simple circuit using Arduino Uno, a microcontroller board, based on the microcontroller with inbuilt ADC. Major steps for programmable device for display purpose are

- Conversion from analog to digital data (0 to 5 V to 8 bit data)
- Convert to eccentricity value with 19.6 mV resolution using lookup table
- Send data to LCD display through display driver

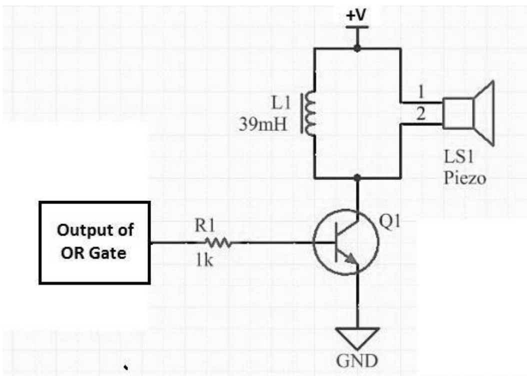

Fig. 9 Buzzer Circuit for Audible Alarm

The Uno is a microcontroller board based on the ATmega328P[5]. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. Fig. 10 shows circuit for LED display indication.

It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. Thus sensor to display and alarm results in complete monitoring and measurement system for eccentricity.

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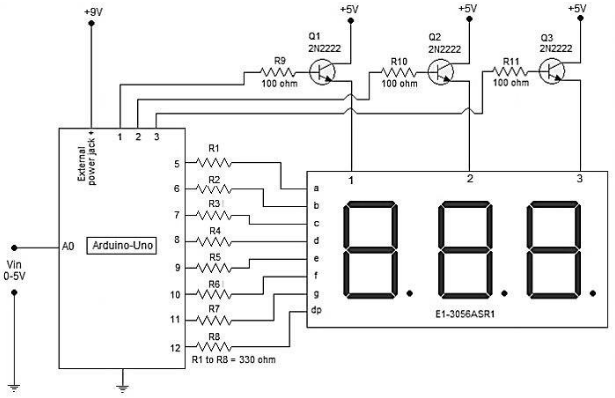

Fig. 10 Circuit to Display Eccentricity

Proposed system is economically viable solution for the problem of shaft eccentricity. It also covers all aspects like sense, signal condition, display and alarm. Thus provided solution addresses practical budgetary constraints also.

III. CONCLUSION

Eccentricity in shaft due to load is a major problem mainly associated with turbine-generator set and other similar applications of rotating machines. Based on application, permissible limit of eccentricity are decided. Sensor selection and design of signal conditioning circuits should be based on the requirements of the particular application. Selection of sensor and mounting of sensor at proper location is crucial. A wide range of eccentricity transducers are used in steam or gas driven turbine or while monitoring these turbines. Radial contact between stationary and rotating elements at slow roll speed plays a vital role in eccentricity measurement and hence is usually measured. Highly accurate and precise eccentricity measurement is essential to ensure that the rotor eccentricity is well within the permissible limits for safe machine operation. Eccentricity measurement system designed and presented herewith incorporates all important aspects of the application and satisfactorily matches the specifications criteria. For the continuous monitoring an LED display is provided and an alarm circuit is also integrated in the proposed system for safety purpose.

REFERENCE

[1] Larry Covino "Proper Eccentricity Probe Location" Orbit, December 1990

[2] Field Application Note on Eccentricity" STI Vibration Monitoring (www.stiweb.com), 2012

[3] ECA110 Sensor Manual & Users Guide", Lion Precision, 2015

[4] Anssi Sinervo, Antero Arkkio " Rotor Radial Position Control and its Effect on the Total Efficiency of a Bearingless Induction Motor With a Cage Rotor" IEEE Transactions on Magnetics, Vol. 50, No. 4, 2014

[5] ATmega328 datasheet", ATMEL, 2015

[6] David R. Gruwell, Fouad Y. Zeidan "Vibration and Eccentricity Measurements combined with rotordynamic analysis on a six bearing turbine generator" Proceedings of the 27th Turbomachinery

Symposium, 1998

[7] B. Silwal, P.Rasilo, L. Perkkiö, A. Hannukainen, T.Eirola, A. Arkkio "Numerical Analysis of the Power Balance of an Electrical Machine With Rotor Eccentricity" IEEE Transactions on Magnetics, Vol. 52, No. 3, 2016

[8] http://www.sensonics.co.uk/pdfs/brochures/TurbineSupervisoryGuide.pdf

[9] [9]. "A Closer Look at Air Gap Eccentricity" on http://reliabilityweb.com/articles, 2016

[10] "Shaft deflection, runout, vibration, and axial motion" Kalsi Seals Hand Book, Chapter D4, 2015

[11] Kleiton Morais Sousa, Uilian José Dreyer, Cicero Martelli, and Jean Carlos Cardozo da Silva "Dynamic Eccentricity Induced in Induction Motor Detected by Optical Fiber Bragg Grating Strain Sensors" IEEE Sensors Journal, Vol. 16, No. 12, 2016