DEVELOPMENT OF A DEVICE TO MEASURE THE BLADE TIP CLEARANCE OF AN AXIAL COMPRESSOR

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Abstract

Axial compressors, used in gas turbines, jet engines and also small scale power plants, are rotating, airfoil based compressors in which the working fluid flows parallel to the axis of rotation. There has been continuous struggle to maximize the efficiency of these compressors. One of the many ways to achieve the same is to minimize the tip clearance i.e. to reduce the distance between the blade tip and the housing. Experiments need to be conducted to measure the changes in the tip clearance while the compressor is operating. Conventional devices to measure this tip clearance have proven to be costly if a small scale application is under consideration. Our aim in this project is to develop a device which will measure the blade tip clearance of an axial flow compressor economically. The literature review, development of the device, its working and results will be discussed in this paper.

Keywords- Tip Clearance Measurement, Eddy Current Probe, Data Storage Oscilloscope, Eddy Current Technique

I. INTRODUCTION

Minimizing the tip clearance reduces the amount of fuel burned, it lowers the rotor inlet temperature; thus improving turbine efficiency. The reduction of emissions results in extended service life of the compressor and also enhances the mission range capabilities in jet engines. The various methods available to measure this tip clearance include:

A. Optical Fourier Domain Reflectrometry (OFDR)

OFDR is a method used to measure back reflections from optical fiber networks and components. The signals reflected from the device under test interfere with the reflections from a fixed surface; OFDR detects these interfering signals and generates a Fourier transform of the same, thus allowing visualization of multiple reflections [1] of the same, thus allowing visualization of multiple reflections[1].

B. Laser Doppler Velocimetry (LDV)

In an LDV, two coherent laser beams are brought to an intersection under a small angle, such that inside the volume of intersection an interference fringe system with nearly parallel fringes of uniform spacing is generated [3]. An object passing perpendicularly through this measurement volume (i.e., here the turbine blade tip) scatters light that is amplitude modulated with the Doppler difference frequency. A wavelength sensitive detection of this frequency results in axial position of the moving object.

C. Capacitive Sensor Method

The capacitive sensor method works on the principle of capacitance. The main components of the capacitive proximity sensor are plate, oscillator, threshold detector and the output circuit. The plate inside the sensor acts as one plate of the capacitor and the target as another plate and the air as the dielectric between the plates [2]. As the object comes close to the plate of the capacitor, the capacitance increases and as the object moves away the capacitance decreases. The capacitive sensor can detect any targets whose dielectric constant is more than that of air.

Though the above methods are widely used, they have their respective disadvantages which are stated below:

- The optical methods i.e. OFDR and LDV are sensitive to contamination and are not suitable for compressors subjected to heavy vibrations.
- Capacitive sensors are affected by humidity and temperature variation; they are also difficult to design for practical applications.
- Optical devices are costlier than other devices available to serve this purpose and they are also very delicate and need extra care while in use.

II. EDDY CURRENT TRANSDUCERS

The process of Electromagnetic Induction is responsible for the production of eddy currents. In this process an alternating current when applied to a conductor, such as copper wire, develops a magnetic field in and around the conductor. When this alternating current rises to maximum, the magnetic field expands and vice versa. Now, if a second conductor is brought in close proximity of this changing magnetic field, the current will be induced in the second conductor. Eddy currents are these induced currents which flow in a circular path.

An eddy current transducer uses the principle of Electromagnetic Induction and generates eddy currents which can be used to detect the distance between the two conductors. The only constraint with this method is that the second conductor is to be metallic in order to generate eddies i.e. the blade of the turbine should be a metal, if in case a ceramic or plastic blade is used for a small scale application they can be given a metallic coating to make the blades suitable for this application.

A typical circuit which can be used to generate eddies and to measure the tip clearance is shown in Fig.1.

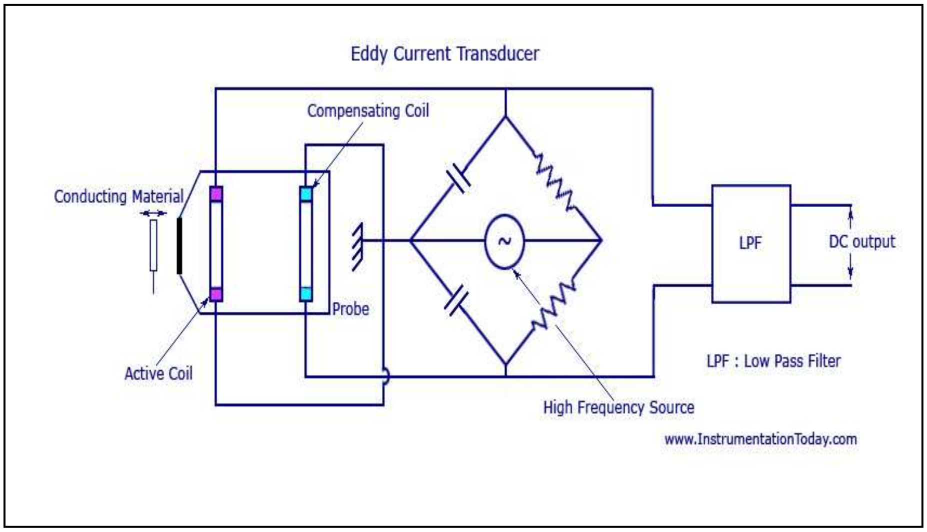

Fig.1 Eddy Current Transducer [5]

In the above figure, the probe is used to generate the eddy currents. It consists of an active and a compensating coil. The magnetic flux is induced in the active coil and is passed through the conducting material (second conductor) to produce eddy currents. The compensating coil is given to provide temperature compensation; hence it is on the adjacent arm of the bridge circuit. The eddy current is detected with the help of an analog meter through which the output can be visually seen.

A. Advantages:

- Sensitive to small distance variation.
- Equipment is portable.
- Minimum part preparation is required.
- Economical method.
- Can work in arduous environmental condition.

B. Disadvantages:

- Only conductive elements can be inspected, but non-conducting elements can be given a metallic coating.
- Range of the eddy probe is limited to 4 to 5 mm, but the tip clearance ranges between 3 to 4mm.

III. DEVELOPMENT OF THE TIP CLEARANCE MEASURING DEVICE

The components required to successfully implement the circuit and to conduct the testing are:

***A. Eddy Current Probe*:**

In order to generate the eddy current, eddy probes are used. There are many such probes available for a variety of applications but choosing the appropriate probe to suit the application is important. The types of probes available are:

- Differential Probes:

  These probes have two active coils wound in opposition and are used to detect surface defects[8]. When both the active coils are over a smooth surface they do not show any differential signal, however if one of the active coils is over a defect then a differential signal is produced. Hence these probes are used for flaw detection.

- Reflection Probes:

  These probes have two coils similar to differential probes but one coil is used to excite the eddy currents while other is used to sense the changes in the testing material [8]. These probes are the most advantageous as both the coils can be optimized for the desired purpose.

- Absolute Probes:

  These are simplest type of probes; they incorporate the basis of eddy current generation and have as active coil which produces the eddy current and a compensating coil[8]. Such probes are widely used because of their wide range of applications.

Though the reflection probes are more accurate and can be optimized according to the application, they are costly. After comparing the reflection and absolute probes, it is found that the absolute probes are apt for this particular application.

Fig. 2 Eddy Current Pencil Probe

Figure 2 shows the surface type pencil probe. The diameter of this probe is 5mm and its length is 4cm. Since the testing range of these probes is 4 to 5 mm they ensure accuracy in measurement.

B. Resistance:

The resistance shown in Fig. 3 is to be chosen depending upon the peak to peak voltage (which is 1 to 2 Volts) as specified by the manufacturer of the eddy probe. This resistance is finalized by trying out various set of standard resistance values and a value of 1k ohms is chosen.

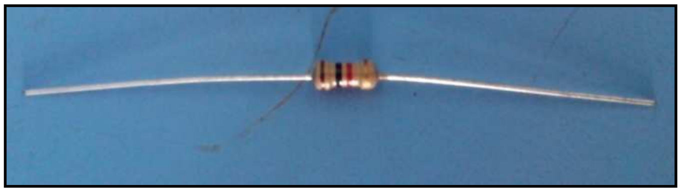

Fig 3 Resistance(1000Ω)

C. Function generator and Two channel Data Storage Oscilloscope:

A function generator acts as an input device, wherein the values of frequency and input voltage can be set for the circuit. The value of limiting frequency is specified by the manufacturer of the probe and is 50 to 500 kHz. An input of 59 kHz is thus given to the circuit. A Two Channel Data Storage Oscilloscope (DSO), as shown in the Fig. 4, acts as an output device and also gives the waveforms related to the input as well as output values. Since the obtained readings from the DSO can be stored, accuracy is ensured.

Fig. 4 Two Channel Data Storage Oscilloscope.

IV. PRECAUTIONS

The following precautions are taken into consideration before testing the probe:

- Meeting the specified voltage/current constraints of each component used, failure of which may result in severe damage to those expensive components.
- Working out the circuit on paper, making sure it is a closed circuit, before attempting it on the bread board.

V. EXPERIMENTAL SETUP

Initially the testing of the probe is done with a metal plate and the entire setup is as shown in Fig. 5.

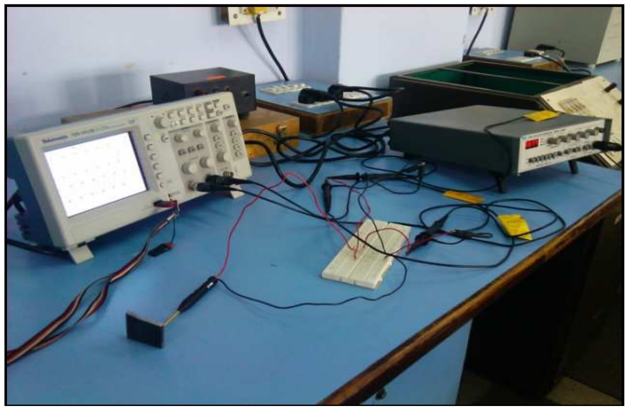

Fig. 5 Circuit Used to Test the Probe.

Two wires of input from the function generator are taken, one of which goes to the bread board and the other goes to the DSO. Output from the breadboard goes to the DSO and hence we get the input-output waveforms. The metal plate is kept at varying distances from the probe tip and the corresponding change in the voltage is noted. The metal plate kept with respect to the probe is shown in Fig. 6.

Fig .6 Positioning of the Probe with Respect to the Conducting Plate.

Waveforms of each of the readings were obtained with the help of the DSO as shown in Fig.7:

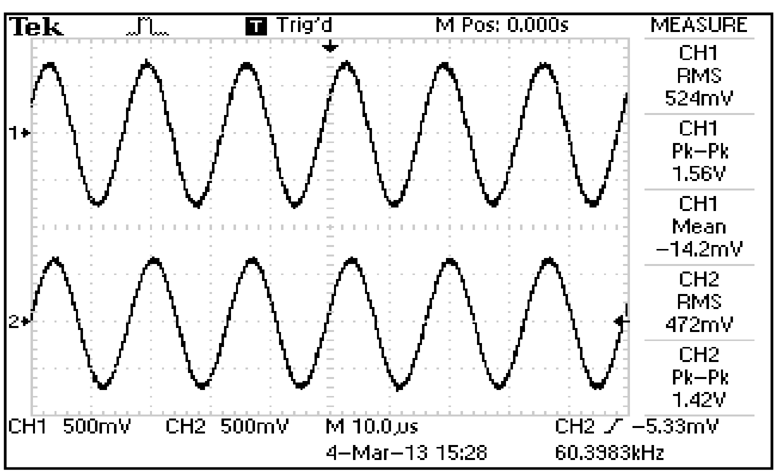

Fig.7 Waveform generated at different distances

Since the output voltage is in millivolts, there is a need for an amplification circuit.

For amplification, the value of resistance is decreased to 470 Ohms and in order to get precise readings the distance between the metal place and the probe tip is varied in steps of 0.2mm using a micrometer and the corresponding voltage values are tabulated below in Table 1.

Table. I

Variation of voltage readings with deflection of conductor plate from probe tip.

Distance	Voltage (mV)
0	110
0.2	100
0.4	98
0.6	94
0.8	96
1	94
1.2	92
1.4	92
1.6	90
1.8	90
2	89

A graph was plotted with the help of the readings obtained, in order to get an overall idea about how the voltage varies with respect to the change in distance. The graph obtained is as shown in Fig. 8.

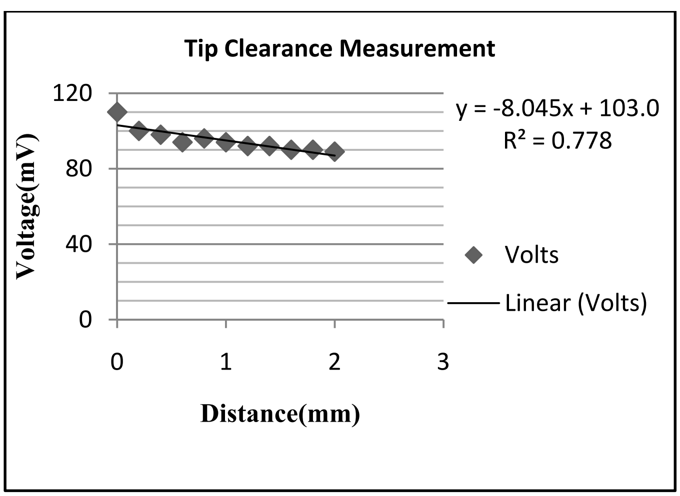

Fig.8 Calibrating graph giving relation between the distance and voltage

As observed, the voltage varies inversely with the distance between the metal conductor and the probe tip given by the Eq. 1 .

$$y = -8.045x + 103.0 \qquad (1)$$

Thus, for a given value of voltage (y), we can calculate the distance (x) using the above equation thus giving us the value of the tip clearance in this case.

The above values obtained are checked for accuracy and hence the percentage error is calculated. The following table shows the calculated error.

Table. II: Error calculation

Actual Distance	Voltage (mV)	Distance obtained	Error
0	110	0	
0.2	100	0.37	46.73%
0.4	98	0.62	35.72%
0.6	94	1.11	46.73%
0.8	96	0.87	8%
1	94	1.11	9.91%
1.2	92	1.36	12.30%
1.4	92	1.36	-2.90%
1.6	90	1.616	0.90%
1.8	90	1.616	-11.38%
2	89	1.74	-14.93%

According to the values obtained it is seen that the average error is 13.11%, since the value is below 20% it can be said that the error is within acceptable limits.

VI. RESULTS

- The Eddy probe is tested successfully and the readings as obtained are tabulated as shown in Table 1.
- The readings show that if the distance between the probe and the conducting plate is varied then the voltage changes along with it with an inverse proportion.

VII. CONCLUSION

The entire experiment proves that the Eddy current Transducer method is apt to measure the tip clearance change and the entire setup can be mounted on a test rig to measure the same.

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