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Experimental investigation of steam losses, temperature and vibration in labyrinth seal used in steam turbine

H.G.PATIL	Research Scholars, Department of Mechanical Engineering, BDCOE Sewagram, Dist:-Wardha, Maharashtra – 442001, INDIA.
Dr.V.G.ARAJPURE	Principal, KCES'S college of engineering & Information Technology, Jalgaon, Maharashtra – 425002, INDIA.

ABSTRACT

The Experimental investigation on design of steam turbine labyrinth seal addresses the issue of steam turbine efficiency. A specific focus on labyrinth seal profile for turbine sealing, evaluates the effectiveness of certain Chromium and Nickel in resisting creep and fracture in turbine labyrinth sealing. They are capable of thermal and chemical conditions in labyrinth seal substrate to prevent the corrosion when exposed to high pressure steam. The efficiency of the steam turbine is a key factor in both the environmental and economical impact of any coal-fired power station. To increasing the efficiency of a typical 660MW turbine by 1% reduces steam losses. In this connection an attempt is made on steam turbine labyrinth seal performance. Based on the research presented modifications to steam turbine, the labyrinth seals can be made to increase turbine efficiency. The results and conclusions are presented for a study concerning the durability problems experienced with steam turbine labyrinth seals [17].

This paper addresses the issue of steam turbine efficiency by discussing the overhaul design of steam turbine labyrinth seals. A specific focus has been on labyrinth seal profile, material used in the production of labyrinth seals, and the factors that cause seal failure and therefore the failure of the turbine itself. This prevents turbine failure due to labyrinth seal erosion and cracking. In particular, this project evaluates the effectiveness of certain silicon carbide sealing material and in resisting creep and fracture in turbine labyrinth seals.

KEYWORDS labyrinth seals, steam losses pressure temperature, vibration.

Introduction

Labyrinth seals are the veins of a steam turbine. The efficiency and consistency of a turbine depends on the proper design of the labyrinth seals. It is therefore necessary for engineers involved in the steam turbines field to have an overview of the importance and the basic design aspects of the labyrinth seals. The labyrinth seal design is a multi-disciplinary task. It involves issues like thermodynamic, aero-dynamic, mechanical and material science restraints. The total development of a new labyrinth seal is thus possible only when experts of all these fields come together as a panel. Efficiency of the turbine depends on the parameters like, inlet and outlet steam pressure of labyrinth seal, labyrinth seal materials, labyrinth seal profile, surface finishing of the labyrinth seal etc [17].

The most critical aspect of steam turbine reliability centre on the design of the labyrinth seal. Rotating labyrinth seals are subject to unsteady steam forces during operation, the phenomenon of vibration significance must be measured. Resonance occurs when an exciting frequency coincides with a natural frequency of the system. At timbre conditions, the amplitude of vibration is related primarily to the amount of stimulus and damping present in this system. Labyrinth seal reliability requires design with minimum resonant vibration. The design procedure starts with precise calculation of labyrinth seal natural frequencies in the tangential, axial, tensile, and complex modes, which are verified according to the data. In addition, improved seal teeth shapes and generous stage axial clearances are used to reduce stimulus labyrinth seal. Labyrinth seal covers are used at some of stages or all stages to attenuate prompted vibration. This design practices, and is composed with advanced precision manufacturing techniques, ensuring the necessary labyrinth seal reliabilities. The purpose of this paper is to examine the causes for these seemingly contradictory results. An attempt will be made here to review the previous studies to look into future possibilities of labyrinth seal from the view point of datum and modified design [17].

Design and objective of labyrinth seal

The labyrinth seal was so designed that result of parameter to be measured should be accurate. In this regard the testing platform was selected such that it should not get affected by outside condition or there should be no disturbance during the analysis. Appropriate instruments have been selected for measurement of respective parameter, and the same have been calibrated before measurement. Silence was maintained in the laboratory where measurement has been done. The measurement has been done at room temperature and cycle for testing was decided, the provision has been made for keeping constant Load in MW throughout the cycle, arranging the tool for replacing the Chromium molybdenum labyrinth seal by silicate carbide labyrinth seal. Safety was also taken into consideration during the performance. The sequence of measurement was decided and initially steam pressure was measured as it is a function of vibration and then mass flow rate was measured, lastly followed by temperature measurement.

As per objective of analysis the performance of silicate carbide labyrinth seal is for concurrent the steam turbine. In this regard the analysis investigation has been carried out under the different condition and load on selected steam turbines to examine the performance and to find out data of mass flow rate, vibrations, thermal expansion and temperature of Chromium molybdenum labyrinth seal by silicate carbide labyrinth seal by using instrument like pressure gauge, Load in MW sensor, probe type vibration meter, temperature gun, thermo couple and compared those data between them. Each of the test cycle is of about 12hr. duration. The various results were obtained and performance evaluation is discussed in this research paper.

Procedure of experimentation planning

Experimental planning is made to conduct experiment on steam turbine. The following step are involved in planning the experimentation

Identification of variables Deciding experimental plan, test cycle, test point test sequence.

Selection and calibration of instruments.

3.1 Identification of parameter affecting the performance of operation

The parameters which are considered as basic criterion for improving performance of gland box are discussed here.

Steam pressure: the steam supply during operating condition is measured at a fixed pressure in pipe line. The pressure is measured by pressure gauge in MPa. The steam pressure is recorded in DCS, once the reading fluctuation gets stabilized so as to allow accurate reading of sealing pressure.

Vibrations: The vibrations created during the operation are measured with small piezoelectric accelerometer. The measurement of vibration has been carried out by transducer mounted on the fixed spot at outer surface of casing of gland box and RMS value of acceleration has been recorded.

Heat generated at labyrinth seal: Heat is generated by steam during the operating condition. This is important parameter which helps to understand the performance behavior of seal in gland box of steam turbine. Heat generated is measured on the thermo couple as the temperature of steam increases for various supply of steam pressure and temperature.

Test envelope, test cycle, test point, test sequence

In experimentations planning the test envelop, test cycle, test point and test sequence plays a vital role. The engineering experimentation should be planned in such way that it helps to Load in MW of testing, minimization of error, avoiding wastage of time, thus optimizing the use of resources. Once the different variables affecting the system are identified, a decision is taken about experimentation plan, test cycle, test point and test sequence. In order to determine experimentally the effect of stated parameter on performance of steam turbine, it is necessary to decide the possible range of the corresponding steam pressure. For planning the test range, the test cycle, test point and test sequence is to be decided.

For measurement of seal vibrations the casing of gland box is selected as test point. Steam pressure is measured by keeping pressure gauge centrally at the point on gland steam supply header. The heat generated by steam supply is measured as rise in temperature at outlet header using thermo couple. The test range of all instruments is discussed in respective department of each instrument.

The test cycles consist of load in MW of 60,120,180,240 and 300 MW at 1-3 kg/cm2 pressure running each cycle for ramp rate at temperature of 300 c. The test facility consists of selected labyrinth seal having 12 teeth in the gland ring of steam turbine. It operates at various pressures and at various temperatures as per test cycle. The analysis of labyrinth seal was carried out in ANSYS CFX software. After completion of analysis with chromium molybdenum labyrinth seal as per test cycle for measurement of mass flow rate, temperature, vibration, turbulence kinetic energy on inlet and outlet, viscosity on inlet and outlet of chromium molybdenum labyrinth seal was replaced by silicon carbide labyrinth seal. In this way silicon carbide labyrinth seal were tested along with original seal and mass flow rate, temperature, vibration, turbulence kinetic energy on inlet and outlet, viscosity on inlet and outlet has been recorded for various steam pressure. Prior to starting the measurement of parameters the concerned instruments were calibrated.

Selection and calibration of instrument

Every experimentation contains errors which may be noticeable. Uncertainties should never be ignored lest it should be wastage of time and money. Therefore appropriate instruments should be selected for measurement of the parameters involved in the system. The selected instruments should have specification such that they cover the range of variations in the parameters to be measured at the permissible range of error. There are two basic types of errors that can occur in the measurement of any variable by the instrument. When the numerical average of successive reading deviates from the known correct reading and continuous to deviate irrespective of the number of reading taken it happens due to presence of accuracy error. On the other hand, when successive measurements of a same quantity yield different numerical values, it is because of the presence of precision error. Considering these facts the instruments selected should be calibrated before use.

3.3.1 Selection of the instruments for experimental recording of the response parameters

The following instruments are used for experimentation and measurement

A. Vibration meter

Piezoelectric accelerometer model (CSI 2130) is used for vibration measurement shown in figure. The instrument having resolution depends upon application and having range of 500 m/s^2 .Its measurements provides the following parameters: vibration acceleration, vibration velocity and vibration displacement. The device are usually portable and their readings can be saved partly and retrieve for later use. Vibration meters are an irreplaceable tool for the professional on the job. Vibration transducer is sensitive and gives accurate reading. In this way the vibration is recorded with great precision.

Figure 1 Vibration meter

b. Infrared Thermometer

An infrared thermometer is a thermometer which infers temperature from the portion of the thermal radiation sometimes called blackbody radiation emitted by the object being measured. They are sometimes called laser thermometers if a laser is used to help the thermometer or non contact thermometers from a distance. By knowing the amount of infrared energy emitted by the object and its emissivity, the objects temperature can often be determined. Infrared thermometers are a subset of devices known as **"thermal radiation thermometer"**

Figure 2 Infrared Thermometer

The infrared temperature having operating range -30 c to 650·c (-22 F to 1202 F),operating humidity max 90% RH, power supply of AA battery is required, spectral response 8 to

14 µm (wave length), weight of instrument is 255g, size of instrument is 175x85x75mm, display resolution unit consist of 0.1 c, digit backlit LCD display with function indicators.

C. Pressure gauge

Many techniques have been developed for the measurement of pressure. Instruments used to measure pressure are called pressure gauges. The Bourdon pressure gauge uses the principle that a flattened tube tends to straighten or regain its circular form in cross-section when pressurized. Although this change in cross-section may be hardly noticeable, and thus involving moderate stresses within the elastic range of easily workable materials, the strain of the material of the tube is magnified by forming the tube into a C shape or even a helix, such that the entire tube tends to straighten out or uncoil, elastically, as it is pressurized.

Figure 3 Pressure gauge

When the whole gauge is subject to mechanical vibration, the entire case including the pointer and indicator card can be filled with an oil or glycerin. Tapping on the face of the gauge is not recommended as it will tend to falsify actual readings initially presented by the gauge. The Bourdon tube is separate from the face of the gauge and thus has no effect on the actual reading of pressure. Typical high-quality modern gauges provide an accuracy of ±2% of span, and a special high-precision gauge can be as accurate as 0.1% of full scale.

D. Thermocouple

A thermocouple is an electrical device consisting of two different conductors forming electrical junctions at differing temperatures. A thermocouple produces a temperature-dependent voltage as a result of the thermoelectric effect, and this voltage can be interpreted to measure temperature. Thermocouples are a widely used type of temperature sensor. Commercial thermocouples are inexpensive, interchangeable, supplied with standard connectors, and can measure a wide range of temperatures. In contrast to most other methods of temperature measurement, thermocouples are self powered and require no external form of excitation. The main limitation with thermocouples is accuracy; system errors of less than one degree Celsius (°C) can be difficult to achieve. Thermocouples are widely used in science and industry; applications include temperature measurement for kilns, gas turbine exhausts, diesel engines, and other industrial processes.

Figure 4 Thermocouple

Type K (chromel and alumel) is the most common general purpose thermocouple with a sensitivity of approximately 41 µV/°C. It is inexpensive, and a wide variety of probes are available in its −**200** °C to +1350 °C / -330 °F to +2460 °F range. Type K was specified at a time when metallurgy was less advanced than it is today, and consequently characteristics may vary considerably between samples. One of the constituent metals, nickel, is magnetic; a characteristic of thermocouples made with magnetic material is that they undergo a deviation in output when the material reaches its Curie point; this occurs for type K thermocouples at around 185 °C.

Figure 5 K type thermocouple

E. Magnetic Load in MW pick up sensor

The magnetic Load in MW pickup (MPU) is used to detect the Load in MW of the steam turbine. A Load in MW sensor circuit, either a section on the governor amplifier chasing or a separate unit, is needed to convert the MPU's output signal to one usable by the governor amplifier. The magnetic pickup produces a voltage output when any magnetic material moves through the magnetic field at the end of the pickup. Since most turbines have large gears made of magnetic material (usually iron or steel), magnetic pickups can usually be installed without adding attachments to a gear or shaft. Non-magnetic materials, such as aluminum, brass, and some stainless steels, will not excite the magnetic pickup.

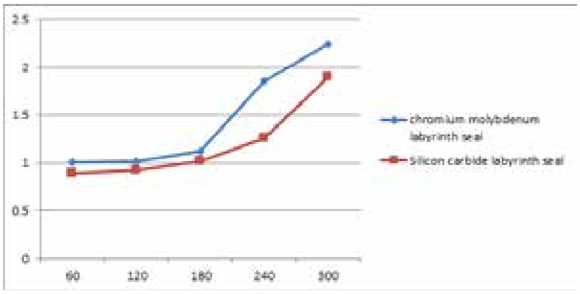
The MPU makes use of a "stray magnetic field" and no provision for return magnetic circuits or paths is necessary. Any device which produces a dynamic discontinuity of magnetic material in the field of the pickup will produce an electrical voltage. The MPU may be excited by a keyway or slot in a wheel, but there is likely to be an unwanted background signal due to varying density or eccentricity of the material. It is better to excite the MPU from a protrusion on the surface. This places the pickup at a relatively great distance from the materials between excitation periods and it is less likely to pick up stray signals.

The output voltage of a magnetic pickup is affected by three factors. Voltage increases with increases of the surface Load in MW of the monitored magnetic material. Voltage decreases as the air gap between the magnetic pickup and the surface of the gear tooth is increased. Voltage waveform is determined by the size and shape of the gear tooth in relation to the size and shape of the pole piece. With any given Load in MW and clearance conditions, a maximum power output will result when the field is filled with a relatively infinite mass of magnetic material at one instant and a complete absence of such material the next. A reasonable approach to these conditions exists when the cross-section of the exciting masses is equal to or greater than that of the pole piece, and the space between is equal to or greater than three times the diameter of the pole piece

4 Procedure of experimentation

4.1 Measurements of steam pressure

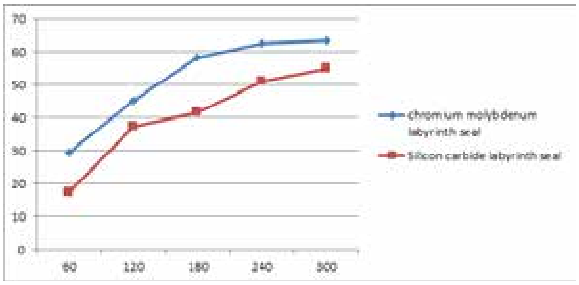
The steam pressure of gland sealing during running was measured by using pressure gauge, as the Load in MW was increased the steam pressure level was monitored by keeping sound lever meter closed to the gland box and the reading was recorded in the instrument. When any interrupted steam pressure level was shown in the screen of the instrument during monitoring, the test was instantly stopped and was started again from initial condition. After running for each test cycle, the reading got stabilized and pressure value in bar was recorded. For each sealing materials of the gland sealing the graphs of the steam pressure were plotted against Load in MW at constant speed for each sealing material. The same are showing in graph 4.1 from this graph it is clear that the steam pressure produced by Silicon carbide labyrinth seal is less as compared that produced by chromium molybdenum labyrinth seal.



Graphs 4.1 of the steam pressure were plotted against Load in MW at constant speed

4.2 Measurements of vibrations

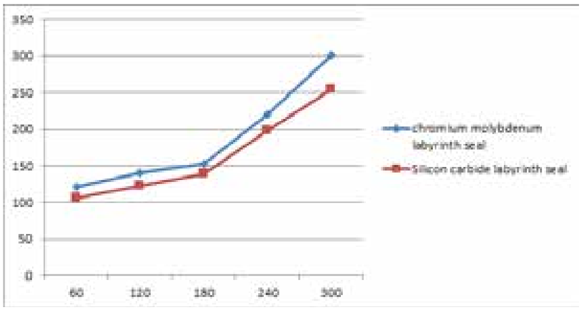
Vibrations produced by gland box were measured during running by using small piezoelectric accelerometer, as the Load in MW and speed of turbine was also increased the vibrations levels were monitored by the magnetic probe of the accelerometer which was attached on gland box casing. When the accelerometer is subjected to vibrations, force is generated which acts on the piezoelectric elements. By Newton's Law this force is equal to the product of the acceleration and the seismic mass. According to the piezoelectric effect, a charge output proportional to the applied force is generated. Since the seismic mass is constant the charge output signal is proportional to the acceleration of the mass. After running for each test cycle, the reading gets stabilized and RMS value is recorded for each sealing materials of the steam turbine. If any interrupted vibration level were shown on the screen of instrument during monitoring, the test was instantly stopped the test and started again from initial condition. Same trend was carried for further future readings and results for both chromium molybdenum labyrinth seal and Silicon carbide labyrinth seal were recorded. The graphs of the vibrations are plotted against the Load in MW and constant speed for each sealing materials is shown in the graph 4.2. From these graphs it is clear that vibrations produced by Silicon carbide labyrinth seal are less than those of produced by chromium molybdenum labyrinth seal.



Graphs 4.2 of the vibrations are plotted against the Load in MW and constant speed

4.3 Measurement of the temperature

Temperature of the seal tooth surface was measured during running using infrared thermometers. For convenience of the measurement of the temperature at the particular seal tooth surface area, a small hole was drilled on surface of gland box casing so that the thermocouple can be fixed it and reading was recorded in the instrument as the Load in MW was increased the temperature level was monitored by keeping the instrument radial to the seal tooth surface area and the reading was recorded in the instrument. After running for each test cycle, the reading got stabilized and temperature recorded for each sealing materials of the steam turbine. Same trend was carried for further readings and results for both chromium molybdenum labyrinth seal and Silicon carbide labyrinth seal were recorded. The graph of the temperature is plotted against Load in MW at constant speed for each sealing material is shown in graph 4.3. From this graph it is cleared that temperature produced by Silicon carbide labyrinth seal is less than that of chromium molybdenum labyrinth seal.



Graph 4.3 of the temperature is plotted against Load in MW at constant speed

4.4 Necessity of experimentation to prove the application & feasibility of Silicon carbide labyrinth seal in place of chromium molybdenum labyrinth seal

In orders to know feasibility and application of Silicon carbide labyrinth seal in place of chromium molybdenum labyrinth seal, it necessary to perform experimentation. During the experimentation we can to know the strength of Silicon carbide labyrinth seal and economics of replacements. The experimentation helps us to find out the accurate results. Considering above experimentation and evaluation of performance, it is agreed to accept application of Silicon carbide labyrinth seal in place of chromium molybdenum labyrinth seals. Silicon carbide labyrinth seal satisfy need of chromium molybdenum labyrinth seal with added advantage. It is proved from extensive performance analysis that Silicon carbide labyrinth seals are flexible for application steam turbine as they withstand the same load as done by chromium molybdenum labyrinth seal and no failure was found throughout the experimentation.

5 Outcomes of experiments

5.1. for Steam pressure

Table 5.1 Results for Steam pressure

Load in MW	chromium molybdenum labyrinth seal	Silicon carbide labyrinth seal
60	1.0061	0.8954
120	1.0132	0.9842
180	1.1170	1.01245
240	1.85479	1.01298
300	2.24556	1.98543

The outcomes of performance for steam pressure in both chromium molybdenum labyrinth seal and Silicon carbide labyrinth seal noted in table 7.1 from these results it is clearly understood that for every cycle of performance the steam pressure produced is greater in chromium molybdenum labyrinth seal than Silicon carbide labyrinth seal. Hence the replace of chromium molybdenum labyrinth seal by Silicon carbide labyrinth seal is feasible.

5.2. For vibrations

Table 5.2 result for vibrations

Load in MW	chromium molybdenum labyrinth seal	Silicon carbide labyrinth seal
60	29.53	17.49
120	45.12	37.34
180	58.24	41.66

240	62.398	51.24
300	68.548	54.95

The outcomes for vibrations produced in both chromium molybdenum labyrinth seal and Silicon carbide labyrinth seal noted in table 7.2 from these results it is seen that for every cycle of performance the vibrations produced are greater in chromium molybdenum labyrinth seal than Silicon carbide labyrinth seal. Hence the application of the Silicon carbide labyrinth seal is feasible and should be used instead of chromium molybdenum labyrinth seals.

5.3. For Temperature

Table 5.3 Results for temperature

Load in MW	chromium molybdenum labyrinth seal	Silicon carbide labyrinth seal
60	120.54	105.24
120	140.21	122.14
180	152.354	139.24
240	219.421	198.20
300	300.54	254.21

The data recorded during experimentation for measurement of temperature for both chromium molybdenum labyrinth seal and Silicon carbide labyrinth seal are noted in table 7.3 from the data it is clearly understood that for every cycle of performance the temperature produced is grater in chromium molybdenum labyrinth seal as compared to that of Silicon carbide labyrinth seal. Hence the application of Silicon carbide labyrinth seal is feasible and if should be used instead of chromium molybdenum labyrinth seal.

6. Conclusions

The implementation of robust turbine labyrinth seals are designed in accordance with the modern material technologies and able to withstand the most of circumstances, in combination with the use of clean and renewable fuel which presents an efficient method of generating substantial amount of electricity. An enhanced labyrinth seal design, focused on resisting the effects of stresses, corrosive agents, and creep-inducing temperatures, will raise the turbine efficiency, consequently leading to an increase in the power plant overall efficiency reduction of the quantity of fuel consumed, and ultimately a decrease in operational costs. Improving efficient labyrinth seal design will help reduce operating costs even further and minimize the environmental impacts of steam turbines. Generally such a combination of technologies would benefit society by providing an effective, viable, and invulnerable means of generating electrical energy [17].

This example demonstrates that under normal operating conditions, stresses are sound and thin acceptable limits. However, what the exemplar also shows are the large forces and stresses involved in such rotating machinery and how important factors such as design viewpoint, manufacture and maintenance strategy are for the sake of ensuring safe operation. The results and conclusions are presented for a study concerning the durability problems experienced with steam turbine labyrinth seals. The maximum operational Von-Mises Stresses are within the yield strength of the material but the deformation is comparatively better for material chromium molybdenum labyrinth seal. Modified solutions for Steam turbine labyrinth seal values to help to maximize efficiency and reduce life cycle costs and improve efficiency and reliability.

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