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"Comparative Analysis of Silicon Carbide Labyrinth Seal with Chromium Molybdenum Labyrinth Seal by using Ansys for Replacement in Gland Sealing of Steam Turbine"

KEYWORDS: Labyrinth seal, leakages, ANSYS, gland, steam turbine.

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ABSTRACT The performance of steam turbine seal is related to many factors. One of the important factors is the degradation and change in turbine seal tooth profile after many hours of operation. This leads to increased flow losses and hence reduction in overall turbine efficiency. The performance of turbine seal can be predicated and improved by using ANSYS. ANSYS is becoming a very important tool for designer engineer and research in improving the performance of component involving steam flows. The reason is that ANSYS effectively replaces the needs to perform expensive experimental measurement and testing of new design and prototype. This study conducts analysis and clearance on the leakage behavior of labyrinth seals. Both ANSYS and an analytical tool were used to predict the leakage flows of two different materials seal configuration with various thermal stress analysis. The advantages of the Silicon carbide labyrinth seal over the chromium molybdenum labyrinth seal become more evident as the clearance gets larger. As the clearance becomes sufficiently small, the advantages of the Silicon carbide labyrinth seal clearances become evident and they reduce steam losses and improved turbine efficiency.

Introduction

Minimizing unwanted leakage between stationary and rotating parts is very important in achieving high performance of rotating machines such as steam turbines. Labyrinth seals remain popular despite the recent development of several advanced sealing techniques. Their main advantages include structural simplicity, reliability, high temperature resistance, a wide operating range in terms of pressure ratio, and so on. They are widely used in various local components of steam turbines, particularly in the turbine seal tip areas. A labyrinth seal is a non-contacting sealing device that consists of a series of cavities connected by small clearances. The flow loses its total pressure while it sequentially experiences acceleration into the clearance due to contraction, friction through the clearance, and dissipation of kinetic energy at the cavity. Recent rapid improvements on the efficiency and power output of steam turbines require enhanced design of every flow component inside the seal area. As the performance improvement becomes marginal, minimization of leakage flows becomes more important. Therefore, labyrinth seals are used more intensively, their clearances are more tightly designed and controlled than before, and their configurations are evolving continuously. Therefore, the requirement for an accurate leakage prediction is becoming crucial. [15]

Labyrinth seal

Labyrinth seals are based on positive, finite mechanical clearances which are sufficiently large to preclude the possibility of contact between the parts in relative motion. They may be used either in the radial or axial flow configurations and are effective by reason of the generation of eddies within the cavities. The spacing of the barriers between the cavities is usually about twenty times the radial clearance. Labyrinth seals are effective for high speed installation. The clearance may vary from 0.25 to 1.00 mm. The seals are produced in wide variety like interlocking, non-interlocking, staggered seals, seals with axial clearance or radial clearance or both. The most critical aspect of labyrinth seal design is the provision for the thermal expansion of the equipment being sealed. The adverse effects of inadvertent contact may be minimized by the use of a relatively soft material, for silicon carbide labyrinth seal for one of the components. Instances of failure of the barrier elements by fatigue are usually due to aero elastic instability which could be avoided by suitable design. There are ANSYS available to design a labyrinth seal. Labyrinth seals can be configured in many ways. Optimizing labyrinth seal geometry depends on the given application and greatly affects the labyrinth seal leakage. Labyrinth seals have been used extensively as turbine interstage steam seals. Performance benefits of labyrinths must be balanced with other design issues. They require more radial space, are more difficult to manufacture, and may produce an undesirable thrust load because of the seal tip area. [14]

Analysis of seal material

The outcomes of the analysis of **silicon carbide** labyrinth seal and **chromium molybdenum** labyrinth seal for various stresses and strain are described here one by one with the help of illustrating the images showing the effect of respective parameters on the labyrinth seal tooth.

3.1 Silicon carbide labyrinth seal

In this section the **total deformation** of labyrinth seal is calculated using ANSYS. For this purpose the modeled labyrinth seal in Pro-Engineer is exported to ANSYS is converted as an IGES file and then an automatic mesh is generated. The result of total deformation of labyrinth seal is illustrated in fig.1 having maximum value as 2.0643 mm. The maximum total deformation lies at the right face of labyrinth seal tooth. The surface location of total deformation can also be seen lying at the face of labyrinth seal tooth in red color shown in figure 1

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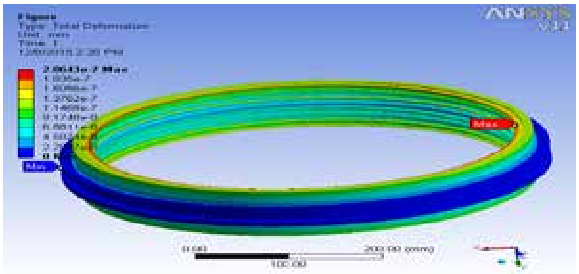

Figure 1 Total deformation of Silicon carbide labyrinth seal

Here the **maximum shear stress** of labyrinth seal is calculated using ANSYS. For this purpose the modeled labyrinth seal in Pro-Engineer is exported to ANSYS is converted as an IGES file and then an automatic mesh is generated. The result of maximum shear stress under the non contact area between labyrinths seal is illustrated in fig. 2 having maximum value as 0.026751. The largest maximum shear stress lies at the edge of the contact zone. The surface location of maximum shear stress can also be seen lying below the surface at the centre of the contact zone in red color shown in 2.

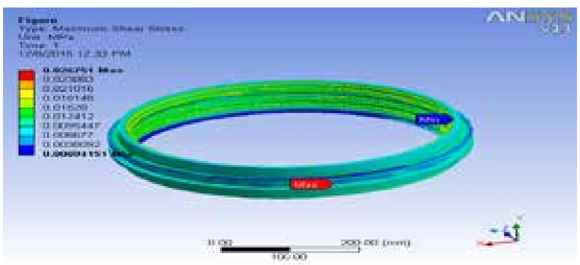

Figure 2 Maximum shear stress of Silicon carbide labyrinth seal

Here the **Equivalent (von-Mises) stress** of labyrinth seal is calculated using ANSYS. For this purpose the modeled labyrinth seal in Pro-Engineer is exported to ANSYS is converted as an IGES file and then an automatic mesh is generated. The result of equivalent elastic strain under the contact area between two mating labyrinth seal is illustrated in fig.3 having maximum value as 0.046335. The largest equivalent elastic strain lies at the top edge of the contact zone. The surface location of maximum equivalent elastic strain can also be seen lying below the surface at the centre of the contact zone in red color shown in figure 3.

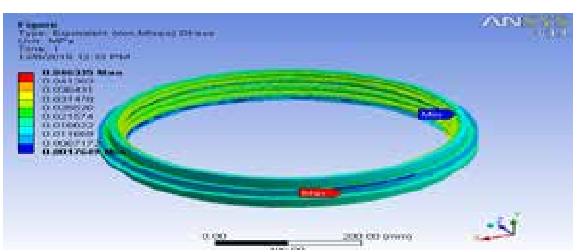

Figure 3 Equivalent (von-Mises) stress of Silicon carbide labyrinth seal

Here the **maximum principal stress** of labyrinth seal is calculated using ANSYS. For this purpose the modeled labyrinth seal in Pro-Engineer is exported to ANSYS is converted as an IGES file and then an automatic mesh is generated. The result of maximum principal stress under the contact area between two mating labyrinth seal is illustrated in fig. 4 having maximum value as 0.039406. The largest maximum principal stress lies at the contact zone. The surface location of maximum principal stress can also be seen in red color as shown in figure 4.

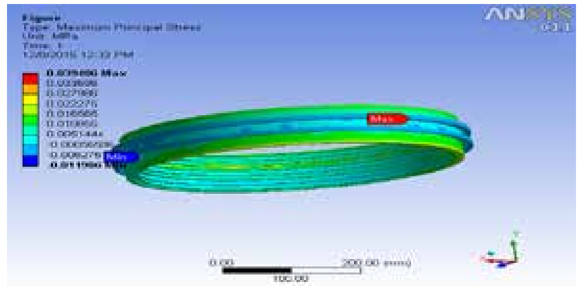

Figure 4 Maximum principal stress of Silicon carbide labyrinth seal

Here the **normal stress** of labyrinth seal is calculated using ANSYS. For this purpose the modeled labyrinth seal in Pro-Engineer is exported to ANSYS is converted as an IGES file and then an automatic mesh is generated. The result of normal stress under the contact area between two mating labyrinth seal is illustrated in fig.5 having maximum value as 0.021518. The largest normal stress lies at the root of pinion. The surface location of maximum normal stress can also be seen lying above the surface at the center of the contact zone in red color shown in figure 5.

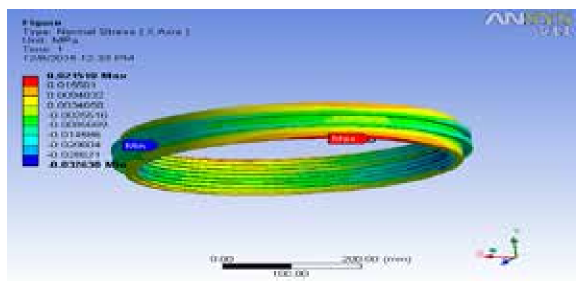

Figure 5 Normal stress of Silicon carbide labyrinth seal

Here the **Total Heat flux** of labyrinth seal is calculated using ANSYS. For this purpose the modeled labyrinth seal in Pro-Engineer is exported to ANSYS is converted as an IGES file and then an automatic mesh is generated. The result of Total Heat flux under the contact area between two mating labyrinth seal is illustrated in fig. 6 having maximum value as 3233.9 W/mm^2. The largest Total Heat flux lies at the top of labyrinth seal tooth. The surface location of maximum Total Heat flux can also be seen lying at the center of the contact zone in red color shown in figure 6.

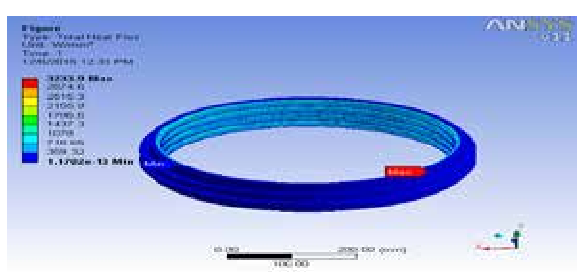

Figure 6.Total Heat flux of Silicon carbide labyrinth seal

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3.2 Chromium molybdenum labyrinth seal

In this section the **total deformation** of labyrinth seal is calculated using ANSYS. For this purpose the modeled labyrinth seal in Pro-Engineer is exported to ANSYS is converted as an IGES file and then an automatic mesh is generated. The result of total deformation labyrinth seal is illustrated in fig. 7 having maximum value as 5.2157 mm. The maximum total deformation lies at the right face of labyrinth seal tooth. The surface location of total deformation can also be seen lying at the face of labyrinth seal tooth in red color shown in figure 7.

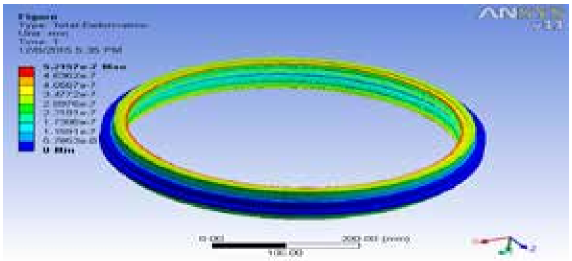

Figure 7 Total deformation of Chromium molybdenum labyrinth seal

Here the **maximum shear stress** of labyrinth seal is calculated using ANSYS. For this purpose the modeled labyrinth seal in Pro-Engineer is exported to ANSYS is converted as an IGES file and then an automatic mesh is generated. The result of maximum shear stress under the contact area between two mating labyrinth seal is illustrated in fig. 8 having maximum value as 0.05727MPa. The largest maximum shear stress lies at the edge of the contact zone. The surface location of maximum shear stress can also be seen lying below the surface at the centre of the contact zone in red color shown in figure 8.

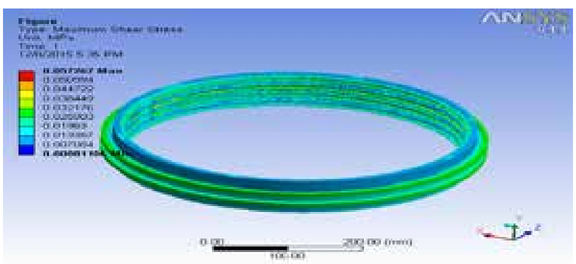

Figure 8 Maximum shear stress of Chromium molybdenum labyrinth seal

Here the **Equivalent (von-Mises) stress** of labyrinth seal is calculated using ANSYS. For this purpose the modeled labyrinth seal in Pro-Engineer is exported to ANSYS is converted as an IGES file and then an automatic mesh is generated. The result of equivalent elastic strain under the contact area between two mating labyrinth seal is illustrated in fig. 9 having maximum value as 0.099733MPa. The largest equivalent elastic strain lies at the top edge of the contact zone. The surface location of maximum equivalent elastic strain can also be seen lying below the surface at the centre of the contact zone in red color shown in figure 9.

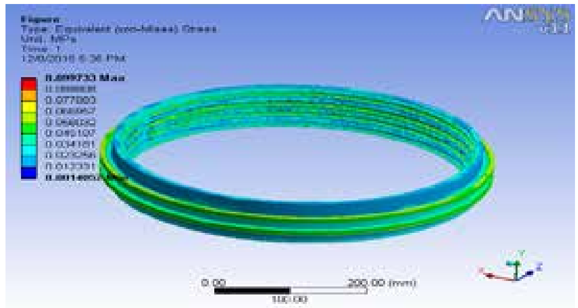

Figure 9. Equivalent (von-Mises) stress of Chromium molybdenum labyrinth seal

Here the **maximum principal stress** of labyrinth seal is calculated using ANSYS. For this purpose the modeled labyrinth seal in Pro-Engineer is exported to ANSYS is converted as an IGES file and then an automatic mesh is generated. The result of maximum principal stress under the contact area between two mating labyrinth seal is illustrated in fig. 10 having maximum value as 0.091953MPa. The largest maximum principal stress lies at the contact zone. The surface location of maximum principal stress can also be seen in red color as shown in figure 10.

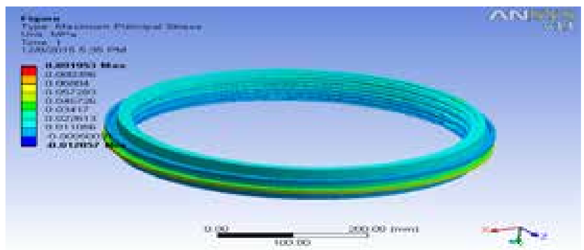

Figure 10. Maximum principal stress of Chromium molybdenum labyrinth seal

Here the **normal stress** of labyrinth seal is calculated using ANSYS. For this purpose the modeled labyrinth seal in Pro-Engineer is exported to ANSYS is converted as an IGES file and then an automatic mesh is generated. The result of normal stress under the contact area between two mating labyrinth seal is illustrated in fig. 11 having maximum value as 0.045398MPa. The largest normal stress lies at the root of pinion. The surface location of maximum normal stress can also be seen lying above the surface at the center of the contact zone in red color shown in figure 11.

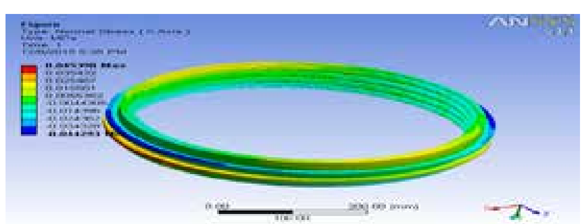

Figure 11. Normal stress of Chromium molybdenum labyrinth seal

Here the **Total Heat flux** of labyrinth seal is calculated using ANSYS. For this purpose the modeled labyrinth seal in Pro-Engineer is exported to ANSYS is converted as an IGES file and then an automatic mesh is generated. The result of Total Heat flux under the contact area between

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two mating labyrinth seal is illustrated in fig. 12 having maximum value as 8310.1W/mm^2. The largest Total Heat flux lies at the top of labyrinth seal tooth. The surface location of maximum Total Heat flux can also be seen lying at the center of the contact zone in red color shown in figure 12.

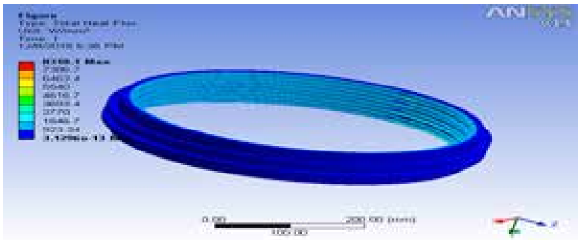
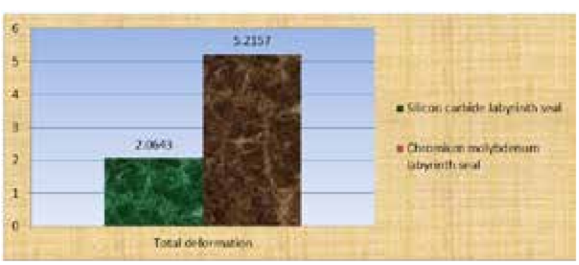


Figure 12. Total Heat flux of Chromium molybdenum labyrinth seal

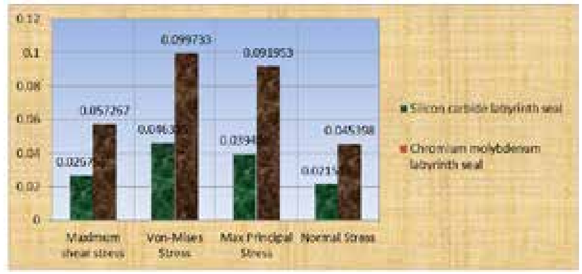
The following table 1 shows the comparison of Ansys result between Silicon carbide labyrinth seal and metallic labyrinth seal. From the comparative study of total deformation maximum shear stress, Von-mises strain, Max. Principal stress, Normal Stress, Temperature and Total Heat flux between Silicon carbide labyrinth seal and metallic labyrinth seal, it concluded that the data obtained for Silicon carbide labyrinth seal is comparative less to the metallic labyrinth seal.

Table 1. Results comparison between Silicon carbide labyrinth seal and chromium molybdenum labyrinth seal.

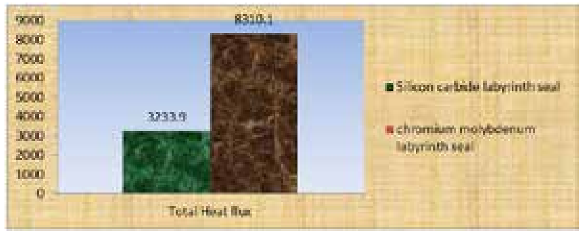
Sr. No	Parameters	Silicon carbide labyrinth seal	Chromium molybdenum labyrinth seal
01	Total deformation	2.0643	5.2157
02	Maximum shear stress	0.026751	0.057267
03	Von-Mises Stress	0.046335	0.099733
04	Max Principal Stress	0.039406	0.091953
05	Normal Stress	0.021518	0.045398
06	Total Heat flux	3233.9	8310.1



Graph A



Graph B



Graph C

The above graph A, B, C illustrates the ANSYS comparison between **silicon carbide labyrinth seal** and **chromium molybdenum labyrinth seal.** The brown shade line in graph shows the outcomes of chromium molybdenum labyrinth seal and green shade line in graph shows the Silicon carbide labyrinth seal. The data obtained from analysis help us to understand about the feasibility of Silicon carbide labyrinth seal material in place of chromium molybdenum labyrinth seal and it also clearly shows that values of various stresses and thermal analysis obtained from ANSYS for Silicon carbide labyrinth seal are lesser than chromium molybdenum labyrinth seal. Finally it is concluded that Silicon carbide labyrinth seal material holds good as substitute material for chromium molybdenum labyrinth seal from technical point of view.

Conclusions

The ANSYS predicted sufficiently well the leakage flows of different seal configurations and flow arrangements for various thermal stress analyses. In the Silicon carbide labyrinth seal, the various thermal stress analysis decreases and also the clearance decreases. This trend was adequately predicted by the ANSYS. In both the converged and diverged flows of the chromium molybdenum labyrinth seal, the clearance dependence was much smaller than that of the Silicon carbide labyrinth seal. The ANSYS results were also sufficiently accurate both qualitatively and quantitatively. The difference in the leakage behavior according to the flow direction in the chromium molybdenum labyrinth seal was well predicted by the ANSYS.

The trends of the variation of the various thermal stress analyses with the clearance size were quite different between the Silicon carbide labyrinth seal and the chromium molybdenum labyrinth seal. The advantage of the chromium molybdenum labyrinth seal is obvious when the clearance is large; the advantage diminishes when the clearance becomes very small. Therefore, since the marginal performance gain over the Silicon carbide labyrinth seal can hardly justify the increased fabrication cost, the application of the chromium molybdenum labyrinth seal does not seem very feasible in instances where the running clearance needs to be very small. Instead, a Silicon carbide labyrinth seal with more teeth (the Silicon carbide labyrinth seal can accommodate more teeth than the chromium mo-

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lybdenum labyrinth seal for a given axial length) seems to be a suitable design alternative.

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