Needs Assessment & Project Scope

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Danfoss-Turbocor

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Needs Assessment

Danfoss-Turbocor manufactures state of the art compressors for air conditioning systems, and a crucial part of their compressors is a labyrinth seals that prevents the refrigerant from leaking from the high pressure compression stage into the low pressure portion of the compressor. The company has implemented different labyrinth seal designs, but each design has failed to provide conclusive efficiency results. Danfoss-Turbocor needs a test rig which will be able to provide quantitative results on the amount of leakage that is encountered at this labyrinth seal. The test rig should be adjustable to fit various seal sizes, shaft alignments, and testing conditions (ie different temperatures, pressures etc). It has also been requested that the working fluid of the test rig be air instead of R134A in order to minimize test costs. In addition to the test rig, Danfoss-Turbocor would like us to provide theoretical calculations and mathematical modeling of the leakage rates through this specific seal. Danfoss-Turbocor also inquired about a possible use of a CFD (Computational Fluid Dynamics) analysis of the seal, but this analysis was revoked from the requirements, due to a lack of experience of this type of software use.

Project Scope

Problem Statement:

The focus of this project will be to design and build an apparatus which performs tests on a labyrinth seal. The test performed will quantitatively measure the flow rate of a fluid through a seal. The results of these tests will be used to analyze which seal design is superior. Once these results are collected, they should be compared against the mathematical modeling of the flow rates.

Background

According to Flitney and Brown [1], a labyrinth seal operates on following two methodologies; rotating radial faces cause centrifugal separation of liquid or solid from air and a series of restrictions followed by a clear volume creates expansion of a gas and hence reduces the pressure. These seals use a very small gap in between the seal and the rotating shaft, and then grooves are machined into the seal in order to disrupt the flow. A general design of a labyrinth seal is shown in figure 1 [2]. It can be seen that the fluid is prevented from leaking through the seal, by disrupting its flow through the use of turbulent inducing grooves across a very small clearance area. According to Boyce [2], a labyrinth seal has the following advantages: simplicity, reliability, tolerance to dirt, system adaptability, very low shaft power consumptions, material selection flexibility, minimal effect on rotor dynamics, back diffusion reduction, integration of pressure, lack of pressure limitations, and tolerance to gross thermal variations. Boyce [2] further claims disadvantages associated with this type of seal are the following: high leakage, loss of machine efficiency, increased buffering costs, tolerance to ingestion of particulates with resulting

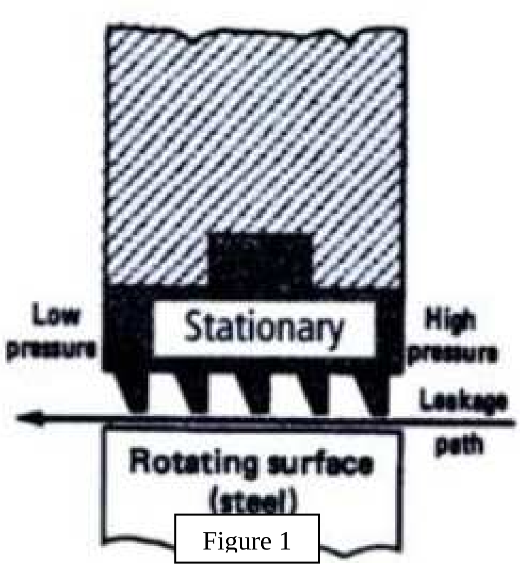

Figure 1

damage to other critical items such as bearings, the possibility of the cavity clogging due to low gas velocities or back diffusion, and the inability to provide a simple seal systems that meets OSHA or EPA standards. The current design of the labyrinth seal in use at Danfoss-Turbocor consists of three steps each with three groves. Much research has been preformed regarding the labyrinth seal, but engineers at Danfoss-Turbocor still question which combination of the following will reduce the amount of leakage: number of teeth, number of steps, tooth thickness, and spacing.

An experiment was conducted at Texas A&M University in order to determine the most effective configuration of teeth in a labyrinth seal. Figure 2 [3] represents the test rig used in their study, but it should be noted that their study dealt with a labyrinth seal and a non-rotating shaft, whereas our experiment will study the leakage rates through the seal while a rotating shaft is present. Nevertheless, the results provided by this experiment should be compared to any theoretical and experimental calculations that are conducted by our team.

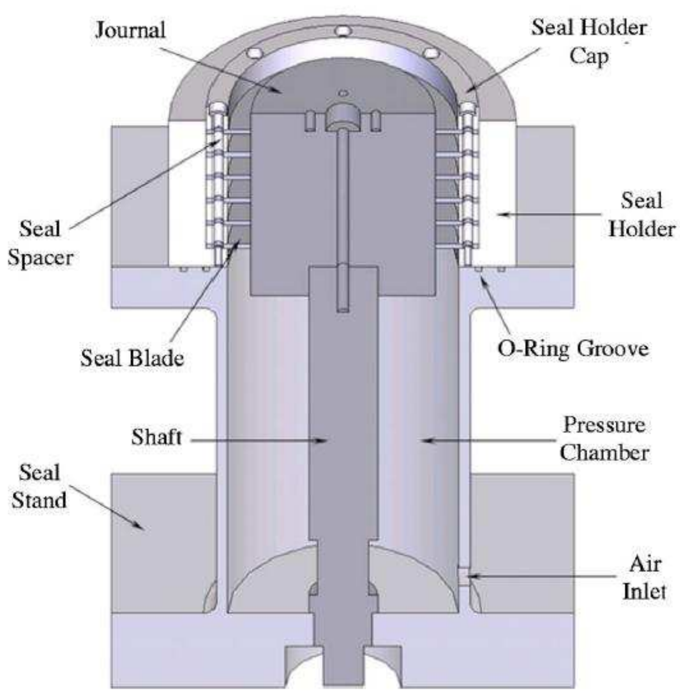

Figure 2

Constraints

There are several limiting factors that will need to be taken into account over the course of this project. The most important constraint is the working fluid. It has been asked that air be substituted for R134A as the working fluid. One of the limiting factors that included with the working fluid is the pressure attainable in the high pressure side of the rig. The substitution was made in order to reduce the cost of testing as well as to decrease the complexity of the test rig. The current design utilizes shop air supplied by Turbocor which has a maximum pressure of 100 psi. It is believed that 100 psi will be sufficient pressure. A budget of $1,500 will also play a limiting factor in that it will affect level of precision in the measurement instruments that are purchased. The budget may also affect the size of the test rig due to material costs. The material selected for the rig body, which is steel, has placed a constraint on the rig construction due to the fact that the FAMU-FSU COE machine shop does not have the capability to work with steel. Because of this, an outside machine shop will need to be found in order to complete construction.

Objective

In order to satisfy the requirements given by Danfoss-Turbocor, our progress will be updated through scheduled design presentations. The main objective for this test rig is to quantitatively measure flow rate through the seal. Having met the fall semester objectives of creating an acceptable test rig design for Danfoss-Turbocor, the focus of the spring will be to build and test the design in order to provide a definitive answer on labyrinth seal effectiveness. To satisfy the overall objective, several milestones must be completed. The first is for the raw material to be cut down and then given to a machine shop for construction and welding. After initial machining and construction have been achieved, the next goal would be to integrate the electronics which will provide data on the fluid flow. The final objective is to successfully run the test rig using different seal designs in order to provide a quantifiable answer as to which labyrinth seal design is most effective. Should all of the goals be completed the project will be successfully concluded by April 9, 2009.

Expected Results

By the conclusion of spring semester a working design will be built and tested. The test results produced by the rig will be used by Danfoss-Turbocor to select which seals will be best for use in their compressors. Based on the preliminary calculations it is suspected that the mid level number of teeth will provide the best leakage prevention.

In addition to the creation of the test rig, several deliverable are required for the completion of the project. Among them is a user's manual with instructions detailing the proper use of the test rig. A final report will also be generated which will contain all of the findings on labyrinth seal effectiveness as well as recommendations as to which seal would be most cost efficient for use in the Danfoss-Turbocor compressors.

Acquisition of Materials

The ordering of raw materials, pre-machined components, various gauges, and electronics began in mid-December of 2008. As of January 10th, 2009, most of the materials required to complete the design of the labyrinth seal test-rig had arrived. The raw materials in this case consisted of a 4-foot by 2- foot, ½- inch thick plate of designation A-36 steel; a 2-foot, 6-inch diameter A-36 steel tube; and a 6-foot long, one-inch thick A-36 steel bar. All of these raw materials were ordered hot-rolled and as such will require the removal of a 1/20th inch thick crust of corroded material. 3-foot sections of threaded rod (screw material) also arrived, and will need to be cut into smaller pieces. In addition to the raw materials, pre-machined components also arrived. The pre-machined components included plumbing connections and a high-pressure safety valve. The sponsor company lent electronic pressure and temperature gauges to the project, and also provided the electronics to acquire data from these devices. The electronics required that the design team order a power inverter/transformer which had also arrived by early January.

Some materials still had yet to be ordered, including o-rings, bolts, nuts, washers, lock-washers, and a tolerance-enabling set of "shim-packs." The shim-packs will enable the axial-distance control of a displacer-cylinder (often referred to as the shaft) surrounded by a labyrinth seal. The axial-distance tolerance becomes critical in the test of a "stepped labyrinth seal," see figure X.

Machining Raw Materials

To the team, it seemed unrealistic in meeting the timeline to give all of the raw materials to the sponsor, or to the University's metal shop, for machining. One of the team members had access to a metal shop and freedom to use the majority of equipment, including band saws, drill presses, and small lathes. Several options were available for machining the materials, and it seemed prudent to spread the work among the options. Machining the raw materials began with moving them to the team member's metal shop.

The large sheet of ½-inch thick steel was cut into squares from which the circle-based parts could be cut. From the large sheet (which weighed close to 160 lb) came several squares ranging from 6 to 13 inches, and 5 to 25 lb. From this point more plans for machining the parts were required.

Planning for Additional Machining and Welding

Some of the parts are either too large to the tolerances are too tight to be machined in the shop provided by the team member. These parts will need to be handed over to the project sponsor companies' machine shop. This includes the complete machining of circular plates over 6 inches radius, and tolerance machining of four spacing legs. Welding of certain components will have to be outsourced after Danfoss-Turbocor completes the machining of such parts. Last, there are a few parts that will need to be machined on a mill. These parts can be machined in parallel to other parts and may be given to either Danfoss-Turbocor or the University's machine shop for such work.

Final Assembly will most likely take place in the team member's provided shop, where required tools are easily accessed. Testing of final dimensions will take place in Danfoss-Turbocor's measurement room. Testing of the labyrinth seals and data acquisition is expected to take place at DTC as well.

References

[1] Flitney, R. and Brown, M., 2007, "Seals and Sealing Handbook", Elsevier, pp. 238

[2] Boyce, M., 2003, "Centrifugal Compressors: A Basic Guide", PennWell Books, pp. 453-455

[3] Gamal, A., Vance, J., April 26, 2007, “Labyrinth Seal Leakage Tests: Tooth Profile, Tooth Thickness, and Eccentricity Effects”, Journal of Engineering for Gas Turbines and Power