Product Specifications
Tentative Schedule

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Concept Generation and Selection

Introduction:

The ongoing objective of this project is to design build and test a device that is able to measure the amount of leakage in a labyrinth seal. The rig must be able to test multiple designs and sizes of labyrinth seals as well as incorporate a rotating shaft whose concentricity with the seals is changeable. The primary objective of this report is to breakdown the test rig into several systems and then analyze all options for fulfilling each systems needs. All options for each component will be weighed so that the best solution can be found. Two possible design concepts have been formed from this process. The first is to design the test rig to be an attachment to a lathe. The second is to use a motor for power generation and create an enclosed system. Both ideas and all aspects of them will be explored in the body of this report.

System Breakdown:

The rig in general can be broken down into several subsystems based on components of the design that have multiple considerations that need to be taken into account. These three subsystems are: shafting considerations, the rig body as a whole, and finally measurement needs and options.

Shafting Considerations

There are two main concerns for the shafting system: achieving the necessary RPMs and the alignment of the shaft. The shaft speed in a typical Turbocor compressor is about fifty thousand rpm. This speed is not realistic for the budget of this project and so a speed of approximately ten thousand rpm will be used (at the request of Turbocor). One of the options to achieve this speed is using a lathe to grasp the shaft inside its chuck. Lathes typically operate at speeds around ninety eight hundred rpm. An added benefit of creating a rig that attaches to a Lathe is that it would save a substantial portion of the budget that would otherwise be allocated towards power generation. It is also suspected that the Lathes dimensional systems will be useful in the task of centering the shaft. After researching prices, it was concluded that motors purchased over the internet would cost roughly half of the total budget of the project. There could also be additional problems in achieving the needed speeds when the rig is set up leading to a very high probability that a gear box would also be needed. Despite these downfalls, using a motor for power generation has an excellent advantage in that it is very versatile and can be used for nearly all possible rig designs. To summarize, the motor provides versatility but would require additional design work while using a lathe attachment would fulfill the power requirements and will cost nothing to use.

The alignment of the shaft is another important factor to consider. At the beginning of the design the shaft must be centered perfectly with the seal so that any variance in concentricity will be accurate. The space between the shaft and the seal in a typical compressor is on the micron level, so proper alignment will require very high precision. Once alignment is initially set correctly, the ability to very the concentricity of the shaft is another goal requested by the sponsor. More attention will be paid to this subject in the discussion of measurement considerations.

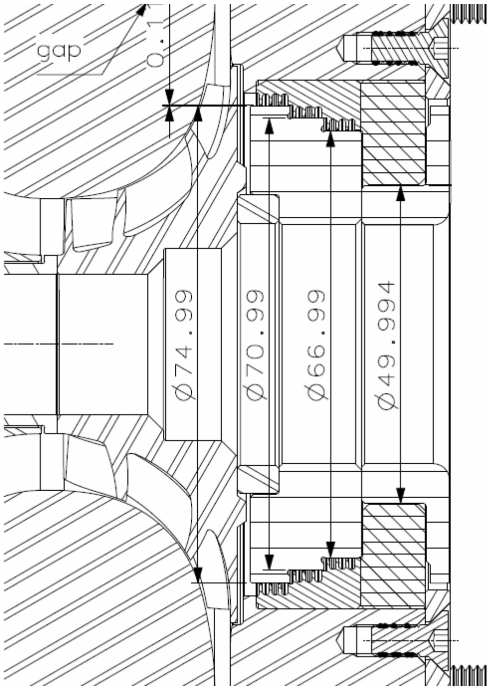


Figure 1: **Drawing of an impeller labyrinth seal. The dimensions refer to the varying diameters of the shaft inside the seal**

Rig Body Considerations

The body of the rig is going to be very important because it will directly determine the conditions in air used to simulate the refrigerant. One of these conditions is that a pressure gradient must be maintained across the seal.

The high pressure side (before the seal) needs to be a specified volume and cannot allow air to leak through anywhere except through the seal. Should there be a leak prior to the air flowing through the seal the data would be compromised and inaccurate. The lower pressure side (after the seal) can either be open to atmospheric conditions or enclosed. By using and enclosed design, the flow through the seal would need to be measured through the pressure change. If the design was open to the atmosphere the flow through the seal would be measured through the mass flow rate. As long as the gradient is the same and the leak is measured through the seal either method will be acceptable

The primary purpose of this rig is to allow Turbocor to test seal designs to select which one is best. To accomplish this, the rig body must be able to accommodate varying seal designs while still maintaining the seal around the shaft with correct concentricity. There are two different ideas for accomplishing this. The first is to use an adjustable chuck to close around the outer diameter of each seal. Unfortunately this idea has several problems associated with it. The most prominent issue would be maintaining and air tight seal around the labyrinth seal so that no air leaks around the seal into the low pressure side. There may also be some manufacturing and implementation issues associated with using the chuck idea. The second idea is to have multiple custom built plates for each seal design and size. Either side of the rig would be on sliders so that they could be moved back to swap out plates to change the seal being tested. While more parts may need to manufactured this gives versatility and ease of use at a fairly minimal cost.

Measurement needs and options:

A very important consideration in designing this project is the choice of measurement equipment. There are two main values that require measurement: the shaft alignment and the flow through the seal. Initially the shaft must be completely centered inside the labyrinth seal. Later the shaft’s concentricity will be varied. In both instances it is important to have a precise system of measurement to ensure accuracy. The two most prominent instrumentation options are high precision calipers or laser sighting equipment. While the laser sighting equipment may be more precise it has the potential to be more costly as well as more difficult to use in comparison to high precision calipers.

The instrumentation for measuring the leakage through the seal deserves great considerations as the choice will most likely affect the entire testing apparatus. There are two main methods of measurement that are being considered, measuring the mass flow rate directly or measuring the pressure and calculating the flow thereafter. To measure the flow rate directly a mass flow meter could be used. The advantage to a flow meter is that it is relatively simple to use, placement is simple, and there would be minimal additional calculations to be made. However, based on product research flow meters have a major drawback, the most affordable ones are not very accurate and the most accurate meters are very expensive. Should the leakage be measured based on changes in the pressure there are several instrumentation options: a pitot-static probe, pressure transducers, or an analog pressure gauge. The transducers and the analog gauge work on the same principle in that they would be located in a closed environment whose pressure would increase as air flowed through the seal. The benefit to the analog gauge is that it is easy to install, cheap, and easy to use. However pressure transducers would be much more accurate than an analog gauge. A pitot-static probe is also an option and has the benefit of accuracy, affordability as well as all group members being familiar in its use. However it would place some limitations on the rig body due to the fact that it must be located in a laminar flow stream to take accurate data. At the present time all measurement options are still under review.

Figure 2: Pressure Gauge

Figure 3: Micron Callipers

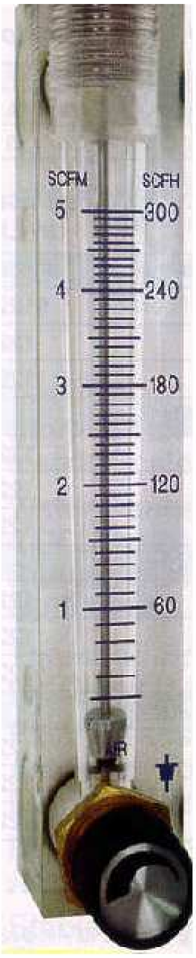
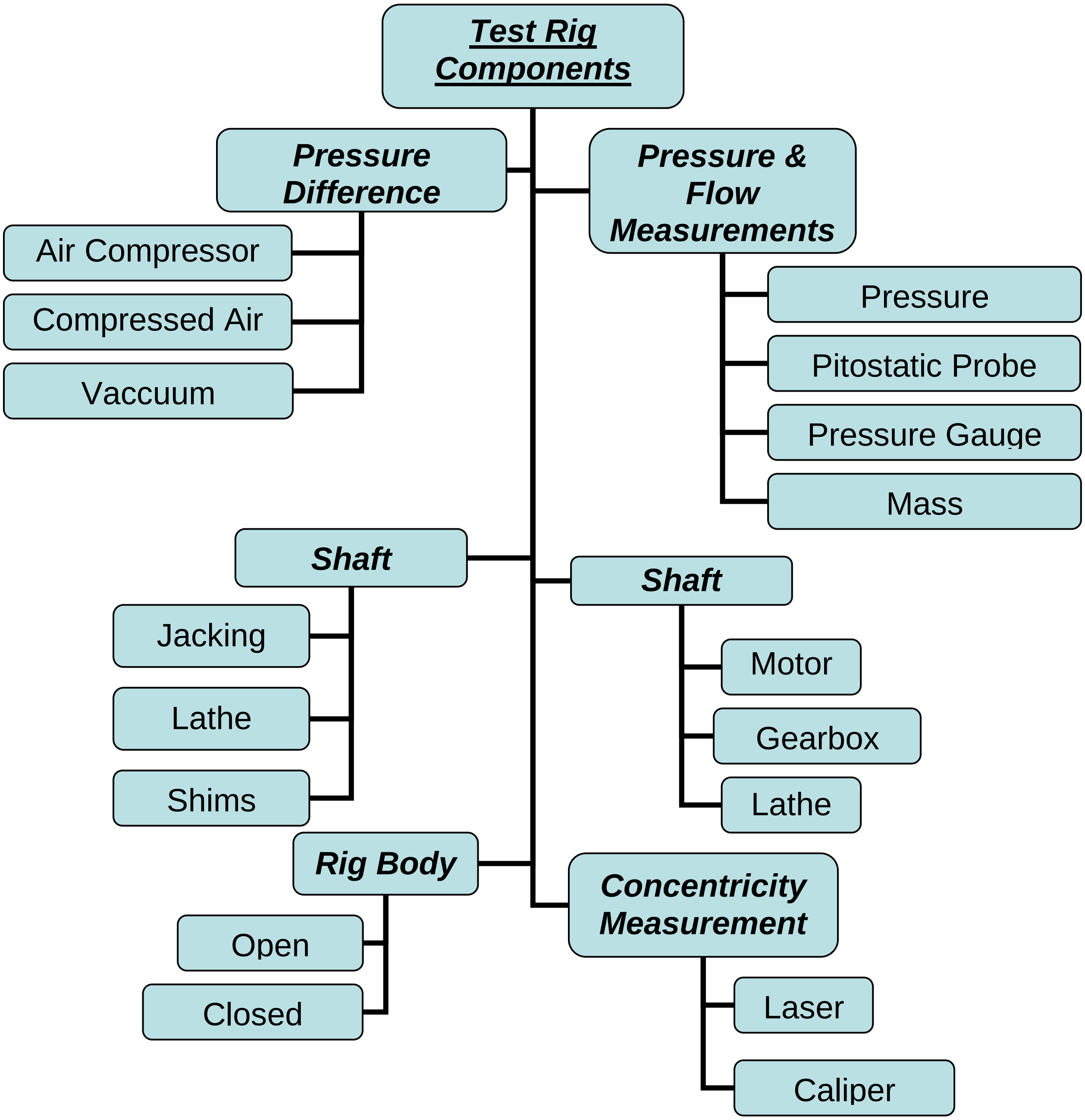


Figure 5: Flow Meter

Figure 4: Pitot-Static Probe

Concept Classification Tree:

Bellow is a test rig that breaks down all of the components of the test rig and then states the options for solving each of the design requirements.



Decision Matrix:

In order to make the best design choices for all aspects of the rig a decision matrix was formed. Each issue that had multiple design options was listed and the subsystem ideas were not compared to one another. There were 6 different criteria on which the evaluation was based as can be seen in the table below. Each criterion was allocated a number (from 1 to 5) based on its importance to the overall project. The ideas were then evaluated on their ability to fulfill each criterion.

Parameters	**Manufacturability**	**Cost**	**Rig versatility**	**Effectiveness**	**Ease of use**	**Repeatability**	**Total**
Idea	5	3	2	4.5	3.5	4	22
Shaft Rotation							
Lathe	4	3	1	4.5	3.5	2	18
Motor	3	1	2	4	3.5	3.5	17
Seal Mounting							
chuck	2	1	2	2.5	3	4	14.5
Multiple custom plates	4	2.5	1	4	2.5	4	18
Pressure Difference							
Vacuum Sealing	2	1	1	2	1	3.5	10.5
Compresed air tank	4.5	3	2	3	3	2.5	18
Air compressor	4.5	2	2	4	3.5	4	20
Measuring Devices							
Pitot Probe	4	2	1.5	4	2.5	4	18
Pressure Transducer	4.5	2	1	3.5	3	4	18
Analog pressure gauge	4.5	3	2	3.5	3	4	20
Rotameter	4.5	3	1.5	3.5	2.5	4	19
Flocat meter	4.5	0	1.5	4.5	3	4	17.5

Parameters	**Manufacturability**	**Cost**	**Rig versatility**	**Effectiveness**	**Ease of use**	**Repeatability**	**Total**
Idea	5	3	2	4.5	3.5	4	22
Body high Pressure side							
Tube directly into seal	3	3	1	3	3	4	17
Control volume box	5	3	1	4	3.5	4	20.5
body Low Pressure Side							
Closed system	5	3	0	4	3	4	19
Open System	5	3	0	4	3	4	19
Shaft Placement							
Multiple load bearings	3	2	2	3	3	4	17
Lathe	5	3	1	4	3.5	4	20.5
Alignment instrumentation							
calipers	5	3	2	3	2	4	19
Laser sighting	5	1	2	4	2	4	18

As can be seen in the matrix above, many of the solutions are ranked very closely. For this reason further evaluation must e performed as well as a review meeting with Turbocor so that the client's input and preferences can be taken into account. However, despite some ambiguity on several of the solution choices two separate conceptual designs were able to be formed.

Conceptual Design 1: Enclosed Seal System

The following conceptual designs will be referred to as the enclosed seal design. There are two variations to the enclosed seal design: the first idea utilizes a closed system which determines the amount of leakage by measuring an increase in pressure with time, and the second design utilizes an open system where a flow is measured through an outlet. The two designs are very similar in nature, and only differ by the type of measurement that is taken on the low pressure side of the seal.

The conceptual design is focused on the incorporation of various seals that will be provided by Turbocor. The main goal of this design is to create a pressure difference across the seal, while maintaining a shaft rotation and concentricity. In order to create the pressure difference, two "pressure vessels" must be created on each side of the seal, and for discussion purposes they will be referred to as the high and low pressure sides. It is necessary to contain the leakage through only the seal, and therefore the respective face of the seal must be incorporated into the design of each pressure vessel. It will be very important to ensure the pressure vessels are constructed in a manner that will be leak proof, and therefore the use of gaskets, O-rings, or some type of sealant must be used.

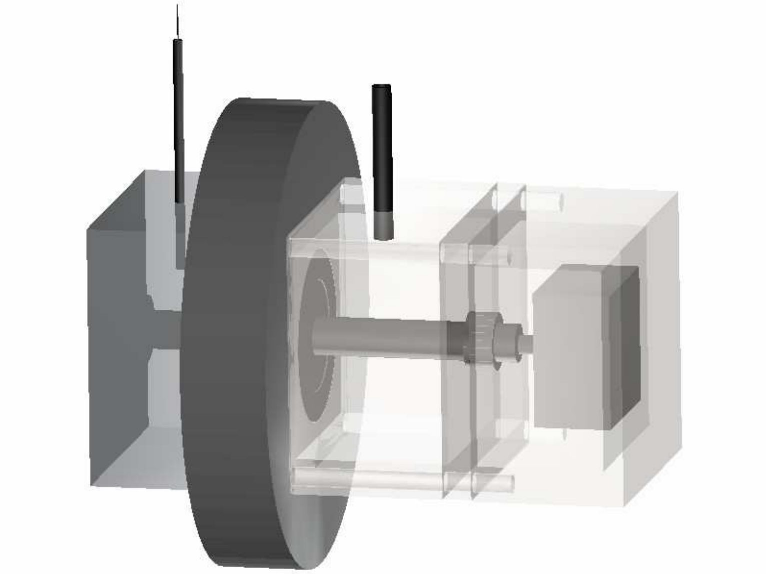


Figure 6: Assembled system drawing of Enclosed Seal System

In order to create the pressure difference needed in the designs, both systems utilize a form of compressed air at an inlet of the high pressure side. The air will be provided to the system by either an air compressor or a compressed air tank, but both options will utilize a pressure regulator prior to the inlet. Using the regulator will be important when ensuring the system has reached a steady state, and will also provide a quantitative measurement of the actual pressure on the high pressure side. The amount of pressure needed from the compressed air will depend on Reynolds number calculations and the requirements of matching the air to R134a.

In order to meet the requirements of Turbocor, this test rig will incorporate a rotating shaft, which should help simulate the flow patterns inside the actual seal. As a part of Turbocors request, our design will include a rotating shaft at a speed of 10,000 rpm, and should likely be driven by an electric motor and gearbox. The labyrinth seal itself is stationary in the application and in our design, but a component labeled as the balancing piston will be connected to the shaft. The leakage that occurs is seen at the gap between balancing piston and the teeth of the labyrinth seal. This gap will need to be maintained and measured during testing, and should also be able to be adjusted to achieve different levels of concentricity. The position of the shaft will need to remain constant, and to adjust the concentricity, the seal position will be varied using some form of jacking bolts. Jacking bolts will allow very small changes to be made to the position of the seal, and therefore allowing concentricity to be adjusted. A measuring system for this component is still needed. Due to the very small clearance size, measuring devices are very limited. The two ideas that are being discussed are laser and caliper type measuring systems. The incorporation of either of these choices still needs to be discussed with Turbocor, in order to determine which is most cost effective.

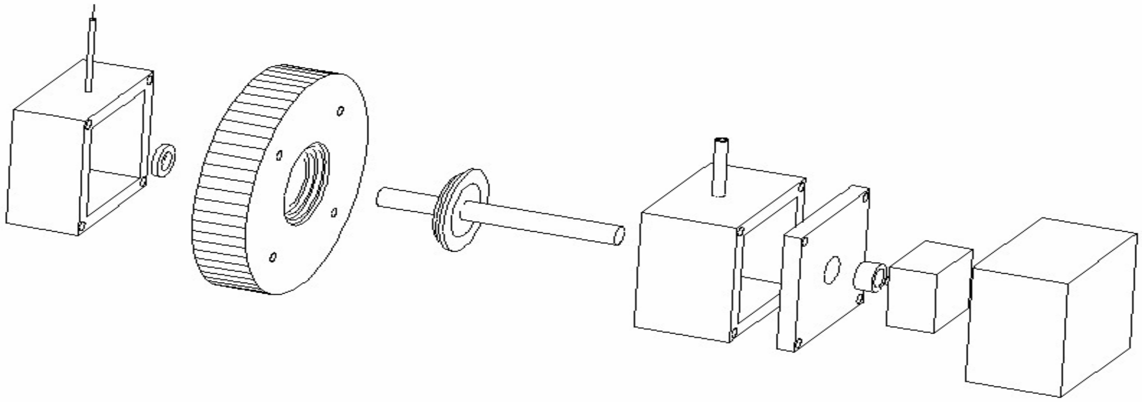


Figure 7: Exploded View of Enclosed Seal Assembly Drawing

The most important portion of this design is the flow and pressure measuring devices. The closed system will use a pressure transducer on the low pressure side to determine the increase of pressure with time, and knowing this increase will allow for calculations of a mass flow rate through the seal. The type of measuring device that will most likely be used in this application is a pressure transducer. This device will be linked to a computer, so that precise measurements can be stored relative to time. The open system will most likely incorporate the use of a pitot-static probe at the outlet of the low pressure side. With the fluid velocity and area of the outlet know, a volumetric flow rate can then be determined from a simple set of calculations. The pitot-static probe will also be linked directly to a computer in order to produce the most accurate readings possible.

Conceptual Design 2: Lathe Attachment System

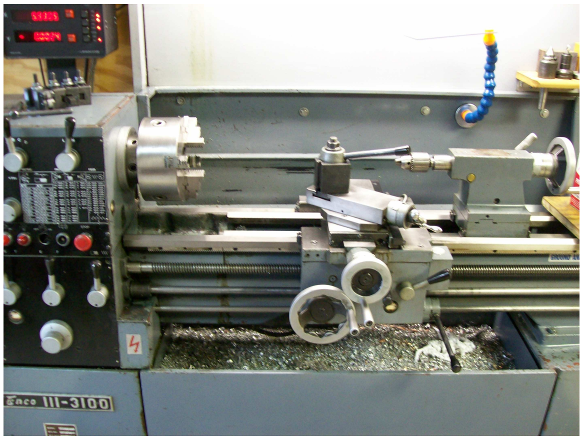


Figure 8: Example of a typical Lathe

Implementing the lathe system would limit the design to using a single-chamber design. It would not be feasible to enclose the entire lathe, which would mean that only the free end of the shaft would be enclosed. This would also mean that the flow would need to be measured on the high-pressure side of the labyrinth seal. In order to measure the flow through the seal, one of two methods would be used. Both methods rely on a steady-state condition being established. The first method uses a fixed-volume reservoir, such as with high pressure gas tanks, and uses a mass balance approach to calculate the flow through the seal. This would require recording the pressure and temperature inside the gas tank once steady-state flow conditions inside the test rig have been established. The Ideal Gas Equation, $PV=mRT$, would be used to determine the mass of gas inside the tank. At that point a timer would be started. Once the pressure inside the gas tank reservoir has fallen to the operating pressure of the test rig, it will no longer be able to sustain that operating pressure and the steady-state condition will end. At that point the timer will be stopped, pressure and temperature inside the gas tank will be recorded and the mass inside the gas tank will be found again using the ideal gas equation. Knowing the mass inside the tank at the beginning and end of the steady-state condition will allow us to find the mass change during the test. Dividing that mass change by the duration of the steady-state test will give an average mass flow rate. It should be noted that the test may require more gas than is available inside the gas tank, and repeating the test will require ordering more pressurized gas.

The other option would be to use an air compressor. In this case, a pitot-static probe will be used to measure the velocity of the flow. A test area, an area of straight tube with constant cross-area, will be created to allow the probe to determine volumetric flow. Knowing the pressure, temperature, and the volumetric flow rate will allow us to use the ideal gas equation to determine the mass flow rate.

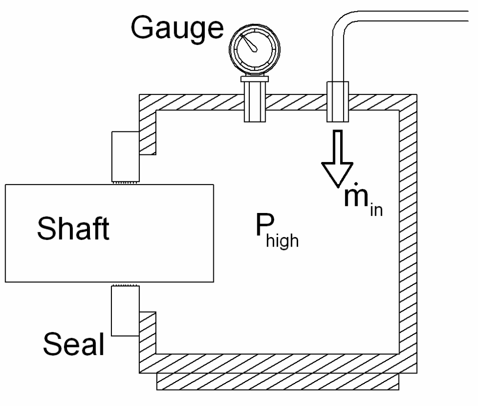


Figure 9: Conceptual drawing of high P side.

Both of the above methods to implement a single-chamber design will require the determination of the steady-state flow condition in order to determine the mass flow through the seal. During a steady-state condition the conservation of mass principle for flow applies. This states that mass flowing into a system is equal to the mass flowing out of the system. During start-up of the test rig, the shaft rotation will begin. Once the shaft is at the desired rpm, the gas flow will be started. As the gas begins to bring the high pressure side of the system up to the operating pressure, a mass of gas will build up inside the main chamber. During this time, the mass entering the chamber is NOT equal to the mass exiting the chamber. As the system pressure reaches the designed operating pressure, the mass flow into the system will begin to near the mass exiting the system. The steady-state operating condition of the system could be defined as the point in time in which constant pressure and constant temperature in the high-pressure side of the system have been established.

References

- Childs, Peter. Technology and Engineering: Machine Design Pg 84 Example 9.2 “Calculating mass flow rate through a labyrinth seal.”

- www.ElsevierMathmatics.com “Calculation of Leakage and Dynamic Coefficients of Stepped Labyrinth Gas Seals”. Department of Mathmatics, Pamukkale Universtiy, Denizli, Turkey.

- Gammel, Ahmed J. Journal of Engineering for Gas Turbines and Power © 2008 “Labyrinth Seal Leakage Test: Tooth Profile, Tooth Thickness, and Eccentricity Effects”.