UNIVERSITY TURBINE SYSTEMS RESEARCH (UTSR) 2024 GAS TURBINE INDUSTRIAL (GTI) FELLOWSHIP

Prepared by:

Elliot Moore
B.S. Mechanical Engineering, Student
Texas A&M University

FINAL REPORT
UTSR Summer 2024 Fellowship

Prepared for:

Southwest Research Institute

August 08, 2024

Benefiting government, industry and the public through innovative science and technology

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Timothy C. Allison, Ph.D.
Director – R&D
Machinery Department

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ABSTRACT

As turbomachinery technology continues to push the cutting edge in performance and efficiency, individual subsystems must keep up with higher design criteria. Seals must be able to withstand higher temperatures and pressures in modern design applications. With the implementation of supercritical carbon dioxide (sCO2) in state-of-the-art turbomachinery applications, higher temperatures and pressures are needed to meet design requirements. The purpose of this work is to progress the design of a test rig to run seal systems capable of operating at temperatures of 700C and 250 bara spinning up to 21 krpm. The test rig is capable of measuring leakage and estimating drag loss through the seal. Currently, the test rig is designed to test a dry gas seal (DGS) for use in sCO2 applications, but a variety of seal designs and working fluids can be tested with minimal modification. This report discusses the development of the High-Temp Dry Gas Seal (HTDGS) test rig and research progression by the author.

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1. INTRODUCTION

The Gas Turbine Industrial Fellowship (GTIF) Program, under the University Turbine Systems Research (UTSR) Program, provides university research students with the chance to engage in advanced research on the next generation of industrial gas turbines. This initiative aims to bolster U.S. energy security and contribute to a cleaner environment. Managed by the U.S. Department of Energy's Office of Fossil Energy Advanced Turbine Program, the fellowship seeks to enhance American gas turbine technology.

I am honored to be selected to be a part of such a rewarding opportunity. This 10-week research fellowship allowed me to work alongside Southwest Research Institute (SwRI) in San Antonio, Texas to participate in state-of-the-art research rooted in the next generation of turbomachinery technology. My scope of work allowed me to conduct end cap pressure analysis, hydrotesting preparations, problem solving, as well as aiding the overall progression of the project.

2. HIGH-TEMP DRY GAS SEAL (HTDGS) TEST RIG

2.1 BACKGROUND

In turbomachinery, seals serve the purpose of separating process gas from the lubrication system. Seal development has been a major point of research for decades in turbomachinery due to its significant effect on efficiency of the system. Leakage of process gas into the other subsystems (seal efficiency) has a significant effect on the overall machine efficiency [1]. Therefore, there has been extensive research in developing efficient seal designs to limit the seal leakage in rotating machinery.

Dry Gas Seal (DGS) designs have become the primary method for use in high pressure ratio, and high circumferential speed environments. DGS's provides hydrodynamic lift as the rotating and stationary components operate in normal operation. As a result, DGS designs show a clear advantage over throttle seals, with respect to leakage rates, at higher pressures (200 bar) [2].

Previous work has been done to develop a test rig capable of testing various turbomachinery seal designs in high temperature, moderate pressures [3]; and high pressure, moderate temperature [4] environments. There is little literature that shows testing seal designs in both high temperature and high-pressure environments, especially with larger DGS designs. Therefore, there is a need to develop a seal test rig that is capable of operating in high temperature, high pressure, and accommodating larger seal designs, such as DGS's [2].

2.2 TEST RIG

The test rig is divided into three major subsystems comprised of: the motor, the spindle assembly, and the seal test assembly. See Figure 1 for the overall test rig design with three subassemblies including a top view and cross section view.

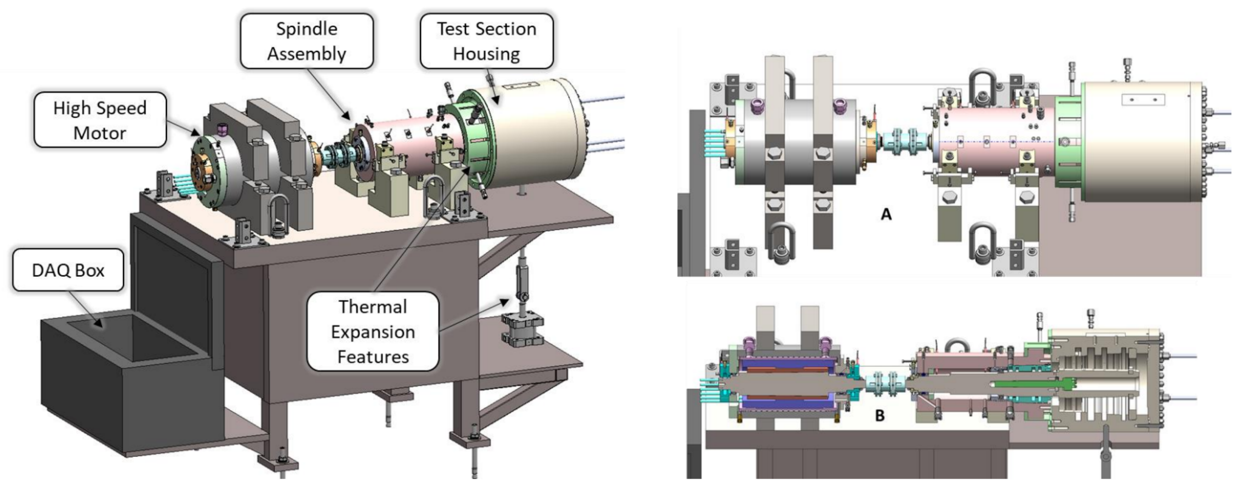

Figure 1: Overview of Test Rig [2]

The motor system comprises of an assembly of a stator, permanent magnet, roller bearings, and cooling passages designed to be cooled with a glycol-water mixture. Figure 2 shows a cross section of the motor assembly. See Kerr and Bensmiller [2] for an in-depth description of the motor specifications and a rotordynamic model of the system.

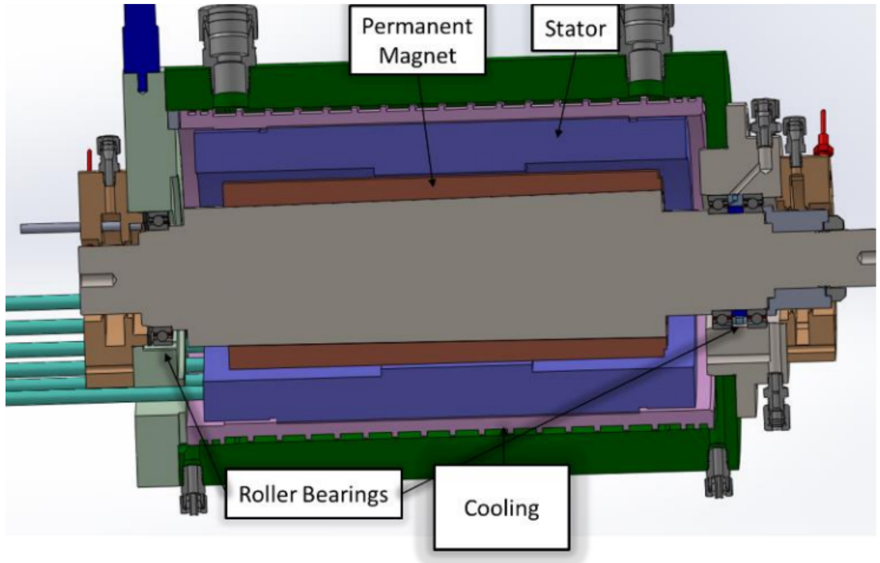

Figure 2: Motor Assembly [2]

The spindle system provides a point of contact for the test rig to connect to ground. An added complexity of the system is managing the large thermal gradient from the seal housing to the rest of the rig. Longer shaft lengths allow for better cooling but lead to increased rotordynamic instability due to an increased overhung weight. Back to back angular contact bearings provide axial and radial support to the system in combination with a squeeze film damper. The lubrication system utilized is a oil-air system that lubricates the ball bearing components. A significant feature of the spindle system is a hirth coupling incorporated into the rotor design which allows the spindle assembly and seal housing assembly to separate. By allowing separation between the two subsystems, different seal configurations can easily be implemented into the test rig for different test points, which provides significant versatility for the rig. See Figure 3 for a cross-sectional view of the spindle assembly

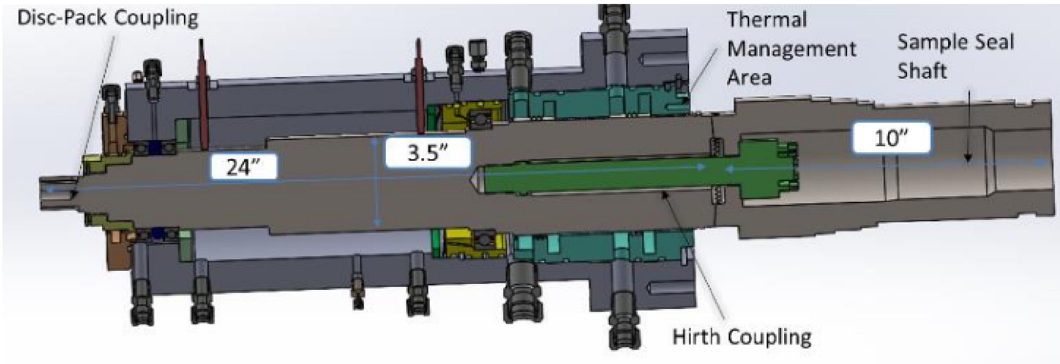

Figure 3: Spindle Assembly [2]

From Figure 3, the thermal management can be seen. As mentioned previously, a combination of high temperature environments and large overhung weight leads to complications with rotordynamic instability. The thermal management area must be large enough to remove adequate heat from the rotor yet small enough to limit rotordynamic instability in the system.

The third subsystem contains the seal housing with accompanying seal shaft. The primary purpose of the test rig revolves around this subsystem and the seals being tested. All components were designed to function in environments of 700C and 250 bara all in accordance with the ASME Boiler and Pressure Vessel Code (BPVC). A finite element analysis (FEA) was done on the seal housing to ensure it meets BPVC requirements. The difficulty in designing this test rig is the high temperature effects on the material. For this reason, Inconel 625 was chosen as the material used for much of the design components to operate successfully according to BPVC criteria. See Figure 4 for a cross section view of the seal housing showing the FEA simulation performed to design loading.

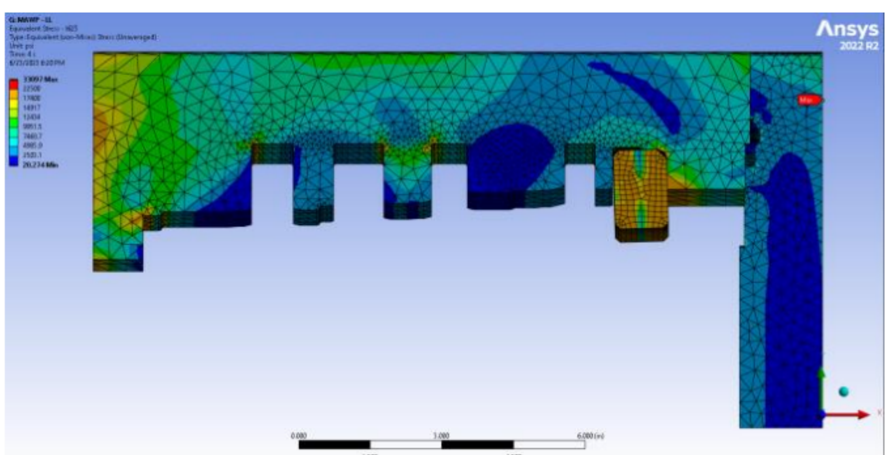

Figure 4: Seal Housing Assembly [2]

2.3 END CAP ANALYSIS

The end cap functions as a pressure containment device that ensures safe pressure containment both in normal operation as well as in seal failure cases. Both of which must be in accordance with BPVC.

2.3.1 DESIGN PROBLEM:

A significant factor in designing the test rig is the design and analysis of the end cap on the seal housing component. Due to the nature of the test rig requirements, significant pressure must be contained in the housing, which results in extreme loads on the end if pressure cannot be mitigated effectively. In normal operation, the load on the end cap is not intended to withstand the entire load exerted by 250 bara of operating pressure. However, in the event of a seal failure, the pressure buildup could result in significant loading on the end cap. In this situation, if careful consideration is not taken, yielding could occur in the end cap which may result in dangerous 'cannon-like' behavior of the end cap. Therefore, careful pressure mitigation strategy must be implemented into the test rig to prevent catastrophic failure of the end cap.

2.3.2 PRESSURE RELIEVING STRATEGY:

The initial pressure mitigation strategy implemented was a burst disk integrated into the end cap. See Figure 5 where the proposed burst disk location is. The burst disk would be configured to rupture at a set pressure in the event of a seal failure during testing. Upon rupture, high pressure gas would be relieved through the burst disk and alleviate load applied to the end cap.

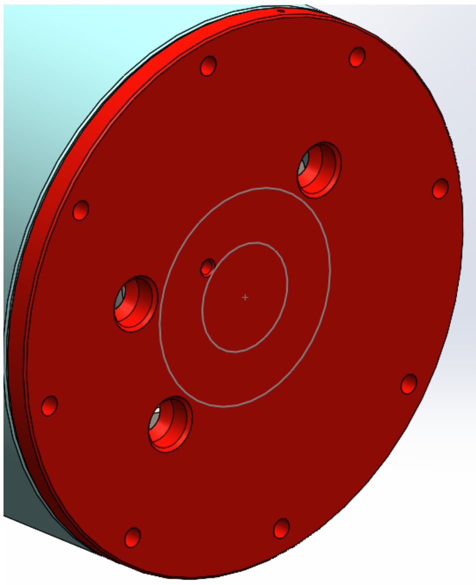

Figure 5: Proposed Burst Disk

2.3.2.1 *Burst Disk Analysis:*

To gain a clearer picture of the back pressure developed upon rupture, a modeling tool was developed in excel to determine the buildup pressure buildup with respect to time. This allowed the design engineers to gain a clearer picture on what size burst disk was needed for adequate pressure load mitigation. Upon further analysis, it became clear that a burst disk alone would not be adequate for the magnitude of the pressure needing to be relieved. Therefore, a new pressure relieving strategy was developed to alleviate pressure before reaching the end cap chamber.

This strategy incorporated a Pressure Safety Valve (PSV) into the secondary chamber of the dry gas seal (See Figure 6). Upon a failure in the primary seal, pressure would build in the secondary chamber of the DGS. At this point, the PSV would actuate at a set pressure of 20 bara, thus preventing further pressure buildup in the end cap. Upon a failure that follows in the secondary seal, the pressure would build within the end cap at which point the burst disk would rupture and alleviate additional pressure buildup. With a combination of the PSV in the secondary chamber and a burst disk in the end cap chamber, pressure buildup on the end cap can remain at a manageable level.

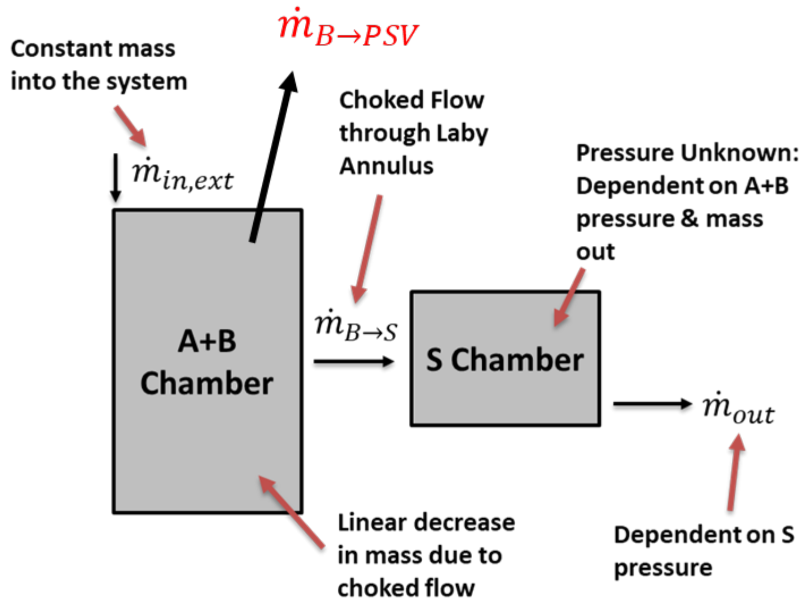

Figure 6: Pressure Mitigation Strategy

Figure 6 displays the propose pressure relieving strategy upon tandem seal failure of the DGS. The A and B chambers represent the high-pressure regions of the DGS with A representing the primary seal chamber and B representing the secondary chamber. The S chamber represents the chamber applied load on the end cap. This is the chamber where pressure mitigation is of concern.

2.4 HYDROTESTING

2.4.1 PURPOSE

The general purpose of a hydrotest is to ensure safe pressure containment within a pressure vessel utilizing a incompressible fluid (water) before a compressible fluid may be used. Since incompressible fluids do not store significant amounts of energy when pressurized, they allow the engineer to safely assess the pressure containment ability of a pressure vessel device. Hydrotesting is also mandatory according to BPVC.

2.4.2 CAP DESIGN

To conduct a hydrotest on the High-Temp Dry Gas Seal test rig, hydro caps were designed to be integrated in place of the DGS. The caps were design in such a way to simulate the thrust loads that would occur in normal operation of the rig. See Figure 7 which displays the hydro caps to be machined and the thrust loads being applied on the seal housing.

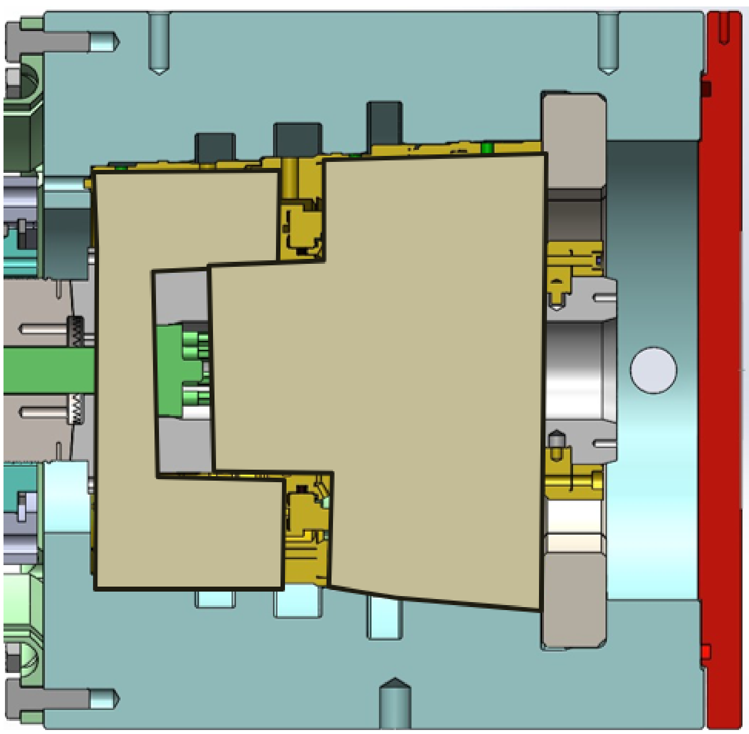

Figure 7: Hydro Caps

Work done included dimensioning hydro caps according to acceptable running clearances between the two parts, dimensioning O-ring clearances, and overall dimensioning of parts according to acceptable geometric dimensioning and tolerancing (GD&T). Once the parts were determined acceptable, quotes were gathered to machine parts for assembly.

2.5 CONCLUSIONS AND FUTURE WORK

This report discusses progression of the High-Temp Dry Gas Seal test rig and the associated work done. The goals for this work was to progress the assembly of the test rig to allow for testing to be done on dry gas seals. Facilitating this progress requires various problems to be researched and designed for. The work this report discusses includes a more in-depth build-up pressure analysis following a tandem seal failure and subsequent pressure mitigation strategy, hydrotesting cap design, as well as general work done progressing the physical test rig.

Challenges faced throughout the work discussed in this report were problems with motor operation not discussed in this report as well as project management challenges that altogether prevented testing of the test rig.

Future work of the test rig includes final design and analysis of the end cap and subsequently quoting for machining. Then, the test rig will able to be fully assembled and ready for testing. Operation of the test rig will include environment conditions up to 700C and 250 bara testing a DGS.

Overall, this report discusses an overview of the test rig and previous work, development of the end cap design, as well as progression and preparations for hydrotesting. Although testing was not able to be accomplished during the duration of this work, significant improvements were made to the development of the project as a whole that will lead to further development in the future. SwRI plans to use the test rig for initially testing dry gas seals, however, preparations are being made to test various seal designs on the test rig.

3. ACKNOWLEDGEMENTS

I would like to thank Southwest Research Institute as well as the UTSR fellowship program for allowing me to participate in the GTIF program to conduct cutting edge research in the realm of turbomachinery. Thank you to Division 18 Machinery Department for hosting me this summer and a special thank you to Jason Bensmiller and Tommy Kerr for their help on my work on the HTDGS test rig.

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