# Operation Manual

## Team 1

## Sealing Ring Testing and Characterization


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# Abstract

The circular seal ring can be designed by using the amount (or percent) of crush to estimate the sealing pressure created by mating parts. This project applied a similar method to sealing rings of different cross sections taking steps to simplify the sealing ring selection process, allow research into the relationship between sealing ring geometry, percent crush, and sealing pressure, and ultimately reduce the time and cost of designing or selecting sealing rings. The Team used an MTS machine to test a range of circular, rectangular, and irregular sealing ring cross sections selected by Cummins, Inc. The rings were all composed of the fluoroelastomeric material commonly used in critical applications. The team tested the designated sealing rings at percent crush increments ranging from 5%-40% with increments of 5%. Software controlling the machine also recorded data, which was displayed as load versus displacement. An Excel spreadsheet was then exported as standard software for analysis. A pressure sensitive film was used to measure sealing pressure. The sealing pressure, percent crush, and the load applied are recorded for analysis. The effects of high temperatures, pressures, and corrosive chemicals on the material will not be taken into consideration and the group will be testing straight samples that are assumed to be under no stretch. The Aluminum testing device comprised of, the load piece, the interchangeable groove plate, and the base that the groove plate is mounted in. The load piece is lowered down to compress the pressure sensitive film upon the sealing ring that is inserted into the groove plate. The groove plate is inserted into the base, which is pinned into the base receiver of the MTS machine very much like the load piece into the crosshead. Adjust film sensitivities as needed and maintain the status of the test fixture.

# Acknowledgements

Senior Design Team 1 would like to acknowledge and thank Cummins, Inc. for making this project possible, particularly Terry Shaw and Parker Harwood for being our liaisons and providing guidance along the way. We would also like to thank Dr. Alvi and Dr. Oates for acting as faculty advisors and being available to meet and discuss the project whenever the need arose. We would like to thank Danny, a teaching assistant of Dr. Kalu, for volunteering his time to help the team access and use the facilities. Furthermore, the team thanks Dr. Kalu for letting the group use his lab and equipment. Team 1 would additionally like to acknowledge Dr. Gupta and his teaching assistants Sam Botero, Ricardo Aleman, and Yuze Liu (Liam) for all the time and effort put into the Senior Design class. Last but not least Team 1 thanks Dr. Shih, for without whom all this would not be possible.

# 1. Introduction

Each Cummins, Inc. (and non-Cummins) engine currently being produced contains a variety of elastomeric sealing rings. Each engine contains multiple types of rings that vary in cross sectional shape and thickness, as seen in Figure 1 and 2. They are implemented in order to create leak free joints between engine parts that may contain a range of fluids from coolant and lube oil to compressed air. Many of these fluids are subjected to high pressures with internal parts reaching relatively high temperatures during operation. These high temperature and high-pressure

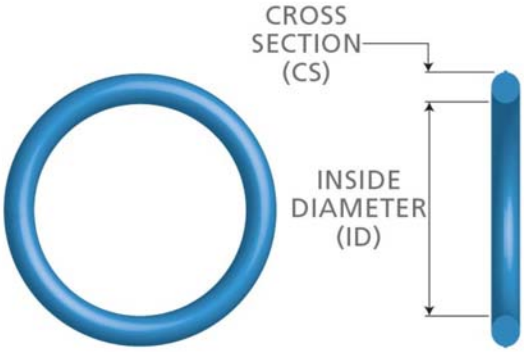


Figure 1: Typical Circular Sealing Ring Profile [3]

environments require the joint to be designed with the best quality elastomeric sealing rings available. Depending on the working environment, the rings must also have the capability to function while exposed to the elements and harsh chemicals. In response to these conditions, sealing rings are made from a variety of materials; such as silicon rubber, which is resistant to weathering [1], and fluorocarbon, which can be used in the presence of petroleum based chemicals [2]. In order to produce longer lasting, low maintenance engines, the need for better-designed joints

Figure 2: Sealing Rings with Irregular Cross Sections [5]

containing elastomeric sealing rings is increasing. Because of this and specifications determined by the sponsor, the team tested sealing components of varying cross sections in order to understand the advantages of varying the cross sections on sealing rings.

A typical elastomeric sealing ring is circular in cross section and is referred to as an “O-ring”, as seen in Figure 1. Although these will work for most joints, Cummins, Inc. has found that using an elastomeric ring with a rectangular or irregular cross section, like the ones shown in Figure 2, can increase sealing pressure while using less material. However, the current procedure for determining the best type of seal ring for a specific joint requires multiple iterations of finite element analysis, which is costly both in time and money.

# 2. Background and Literature Review

Due to its simplistic shape, the circular seal ring can be quickly and cost effectively designed by varying the clearance gap between mating parts that would define a percent crush and result in a sealing pressure. Percent crush is defined as a ratio between the compressed height (or radial dimension) under loading and the original sealing component height (or radial dimension) times 100, as seen in Equation 1.

$$Percent\ Crush = \frac{Compressed\ height}{Initial\ Height} \times 100\% \quad (1)$$

Sealing pressure is defined as the pressure generated between the elastomeric sealing component and the mating parts due to the crush of the sealing component [6]. When the sealing is crushed, a force is being applied by the mating parts onto the seal, causing it to deform and create an equal and opposite force. Depending on the force applied by the mating parts, and the cross section of the sealing ring, the contact area where the force is being applied will grow to match the force, creating the sealing pressure. In Figure 3, one can see how sealing rings are used between mating parts and how their performance varies depending on the pressure applied. When a fluid is trying to escape, it applies pressure on the sealing ring and if the sealing pressure is not greater, then the sealing ring will fail and the fluid will escape.

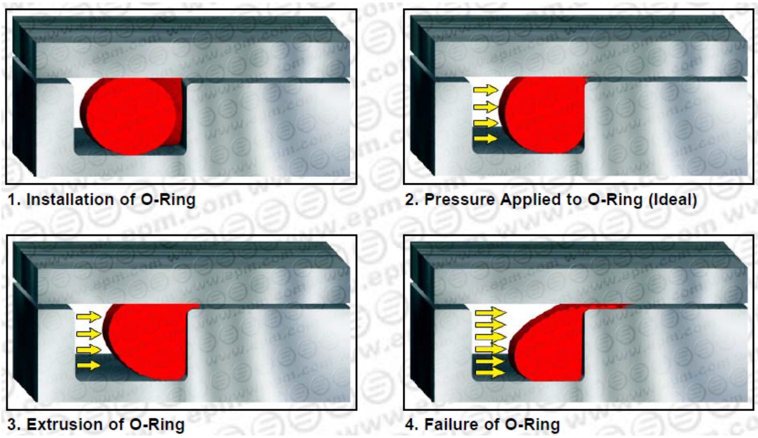


Figure 2: Application of Sealing Rings [8]

The goal of this project was to apply a similar method to measure sealing pressures and understand how varying the cross section affects their performance. This method would simplify the sealing ring selection process, allow research into the relationship between sealing ring geometry, percent crush, and sealing pressure, and ultimately reduce the time and cost of designing or selecting sealing rings. In order to apply the data to practical use, this method will involve parameters such as a shape factor, percent crush, and sealing pressure. This is a crucial step for the project sponsor, Cummins, Inc., such that costs will be reduced in the form of time saved during the design process and less material will be required.

Currently, there are some existing ASTM standards for testing elastomeric seal rings' performance capabilities. The ASTM D1414-19 - Standard Test Methods for Rubber O-Rings is conducted on rings with contrasting cyclic loads and working temperatures in order to give insight into how the different properties of an O-ring will be affected by age [4]. Although standards for testing sealing rings with a general cross section already exist, standards specific to non-circular cross sections do not exist. Therefore, testing beyond circular rings currently has no standards. Also, the sponsor requested testing a percent crush of up to 40%, which is beyond the industry standard of 30%, since damage can occur to the seal beyond 30% crush due to the limitation of space in a mating groove. To be able to reach 40% crush, the depths of the grooves used in testing had to be decreased from the standard dimensions so that the load piece applying the load did not bottom out on the top of the groove plate before reaching 40% crush. The ASTM D395 - Standard Test Methods for Rubber Properties in Compression was also consulted but had to be adapted to testing seals in grooves whereas the standard calls for the test fixture being two parallel flat plates

[7]. During testing, the team dealt with the differences in data with assistance from sponsor and faculty advisors to create the test method used.

# 3. Functional Analysis

The project requires the use of a MTS machine, shown in Figure 4, capable of applying compressive loads on selected sealing rings. For this project a representative sample of rectangular, circular, diamond and double ribbed sealing rings were selected. These sealing rings were composed of fluoroelastomeric (FKM) material and this selection along with the selection of the cross sections were based on the fact that they are the most commonly used in Cummins, Inc. critical applications. The team tested the designated sealing rings at percent crush increments of 5% from 5% to 40%. Software controlling the MTS machine also recorded the load, or force, applied to the sealing ring as the crosshead displaced downwards and compressed the seal. From the software, an Excel spreadsheet can be exported which was the standard software for analysis. For each individual percent crush, the sealing pressure will be measured using a Fujifilm PreScale pressure sensitive film placed between the sealing ring and the mating face. When a pressure is applied to this paper, it creates a pink stain, as seen in Figure 5, and the intensity of the color will tell the tester the amount of pressure applied. The method for analyzing the pressure sensitive film consists of scanning the film and using a software that converts the pink stains into a larger array

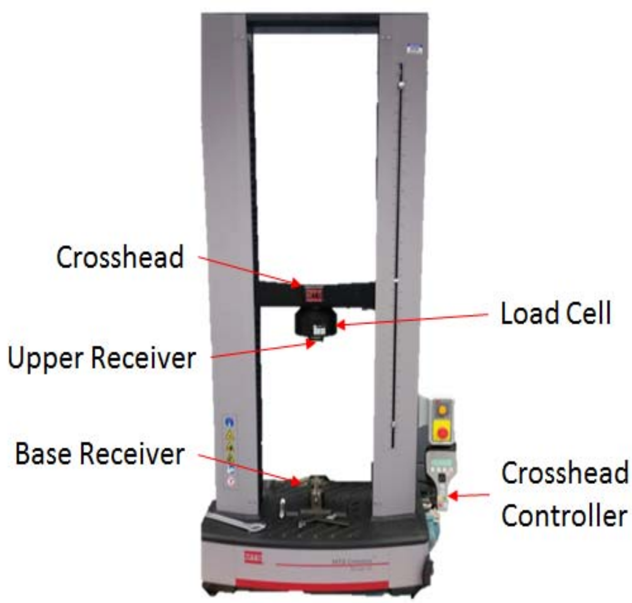


Figure 4: Photo of MTS Machine in Dr. Kalu's Lab

of colors, as seen in Figure 5, in order to visually inspect the sample and derive a sealing pressure. The maximum continuous pressure of each seal is then collected. These three values, the sealing

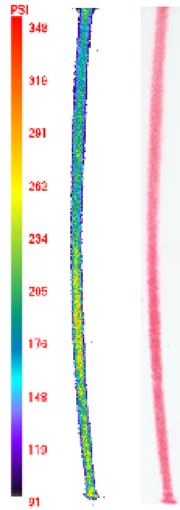


Figure 5: Fujifilm after (left) and before scanning (right)

pressure, the percent crush, and the load applied, will be analyzed in order to identify any correlations that may lead to the development of a shape factor.

There are several delimitations associated with this project that simplified the data collection and analysis processes. The effects of high temperatures and pressures on the material properties will not be taken into consideration. Data collection can be affected by the cut ends of the sealing ring, but these effects will be negated by testing a length of sealing ring that is ten times the diameter of the cross section. The effects of corrosive chemicals on material properties of FKM material will also not be taken in to consideration, as the project does not call for such conditions. Sealing ring properties are slightly affected when the ring is stretched for installation in some designs, however, the group will be testing straight samples that are assumed to be under no stretch.

To accomplish the project, a test procedure was devised to gather data in a controlled, reproducible manner. A test fixture was designed to be used with an MTS Testing Machine that could receive the seals requested for testing by the sponsor. For expected results from the tests, a data analysis method was formulated that was used on the data to find the correlation needed.

# 4. Product Specifications

The project required a testing device comprised of three main Aluminum parts: the load piece, the interchangeable groove plates, and the base that the groove plate is mounted in. The fixture material was chosen to be aluminum 6061 for its rigidity, machinability, weight, and price.

## 4.1 Test Fixture Crucial Dimensions

The test fixture was designed to be used with MTS machines that have cylindrical receivers with interior diameters of 1.25 inches. The load piece has a circular shaft with a through hole so it can be mounted with use of a pin in the MTS machine receivers. The critical dimensions for the fixture can be shown in Table 1. Both the load piece and base must have the pin hole diameter, mounting shaft diameter and length in order to fit into the MTS machine. Also, the MTS machine is capable of closing to a gap between both crossheads of approximately 2 inches, and therefore the overall height must be defined in order to ensure the capability of the full compression of a specimen.

Table 1: Fixture Mounting Dimensions

| Dimension | Measurement (in.) |
|---|---|
| Mounting Shaft Diameter | 1.24 |
| Mounting Shaft Length | 1.75 |
| Pin hole diameter | 0.50 |
| Overall Width | 3.00 |
| Overall Height | 5.72 |

## 4.2 MTS Machine Specifications

The MTS machine used during these experiments was the C45.105. The test fixture was built to fit on the crossheads of this model and the full list of specifications for this model can be seen in Appendix A.

# 5. Product Assembly

Below is the three dimensional model of the testing fixture designed for the MTS machine. The model is complete with groove plate and sample to simulate a testing situation assembly. The load cell is attached to the crosshead, which is connected to the top of the load piece by a pin through

The load piece is lowered down to compress the pressure sensitive film upon the sealing ring that is inserted into the groove plate. The groove plate is inserted into the base, which is pinned into the base receiver of the MTS machine very much like the load piece into the crosshead.

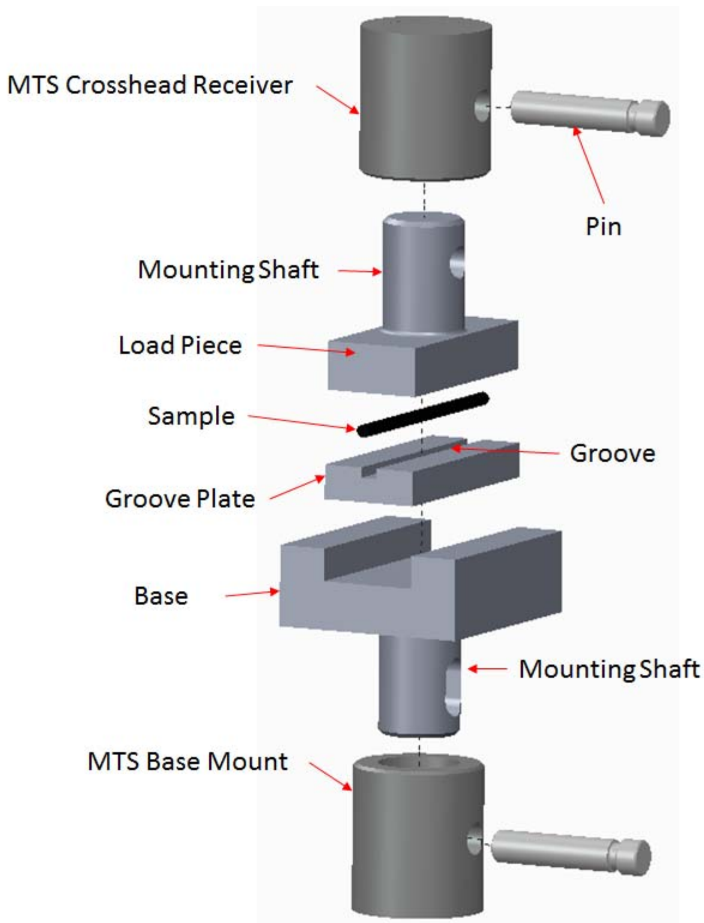


Figure 6: CAD Model of Test Fixture Design

# 6. Operation Instructions

## 6.1 Testing Procedure

1. Load the base and compression piece into the MTS machine.
2. Insert the desired groove plate and secure with small vice.
3. Bring the crosshead of the MTS machine down using the manual controller (very slowly) until contact is made with the base plate. (This is defined when the software shows a spike in load, which implies contact between groove plate and compression piece)
4. Zero the software while the base and compression piece are in contact.
5. Input an upward displacement of 1 in.
6. Zero the software when the crosshead has raised 1 in.
7. Place sealing ring into groove and lay Fujifilm on top of sealing ring.
8. Input a downward displacement designated by the desired percent crush value. (This is an important step, check and recheck before imputing a command to the MTS machine)
9. Once the test has been completed, select “return to zero” on the computer and the crosshead will return to the zero position (1 inch above the groove plate).
10. Remove the Fujifilm and label it accordingly.
11. Export the properly labeled test data to a designated Excel file.
12. If the specimen was tested at a crush value $20\% \leq CV \leq 40\%$, replace specimen and return to step 7.
13. If the specimen was tested at a crush value$< 20\%$, simply return to step 7 and test the same specimen again.
14. After testing a specimen at 40%, return to step 2.

## 6.2 User Interface Procedure

1. If the sealing ring cross-section and desired sealing pressure are known, enter these values into their appropriate boxes under the “option 1” label.
2. If the sealing ring cross-section and recommended percent crush are known, enter these values into their appropriate boxes under the “option 2” label.
3. If the required sealing pressure is known, enter this value under the “option 3” label.

4. “Option 1” will return a recommended percent crush to achieve the desired sealing pressure using the sealing ring cross-section provided.
5. “Option 2” will return a sealing pressure estimate given the sealing ring cross-section provided and desired percent crush.
6. “Option 3” will return 3 different sealing ring cross-sections (circular, rectangular, and irregular) and their corresponding percent crush to reach the desired sealing pressure.
7. When closing the program, DO NOT save changes (This could alter the inputted equations and cause the program to output wrong data)

# 7. Troubleshooting

During testing, there could be potential problem with the Fujifilm and the orientation in which it is placed in the groove. If the imprint on the Fujifilm appears to be a darker shade of pink than the darkest value on the visual scale provided, a higher sensitivity range (used for a higher pressure range) Fujifilm is needed. Likewise, if the imprint on the Fujifilm appears to be very faint, a lower sensitivity (used for a lower pressure range) Fujifilm is needed. If the imprint on the Fujifilm does not correlate with the expected shade of pink, check the displacements, and run the test again. Sometimes when the tests are ran, there is no imprint on the Fujifilm. When this occurs, check that both rough surfaces of the Fujifilm are in contact and run the test again.

# 8. Maintenance

Maintenance for the test fixture is very minimal. It must be occasionally checked for scratches on the base, load piece, and groove plates between tests since this will affect the pressure readings by creating stress concentrators and voids. If imperfections are found, one must use fine sandpaper to polish the surface as needed or if deep scratches or gouges exist, grinding of the contact surface may be necessary. For all MTS machine maintenance, the MTS service department must be contacted.

# 9. Key Components & Spare Parts

Prepare Fujifilm by cutting into thin strips that cover the entire contact area before beginning testing. Prepare multiple sensitivities of film to reduce downtime between tests. Prepare extra sealing rings before testing by cutting them into sample size sections. Have the sealing rings on hand so the person placing them into the groove plate can reach them when/if they are needed.

# References


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# Biography

Richard Edgerton - Team Leader

Richard is a senior Mechanical Engineering student at Florida State University with a focus in Mechanical systems. He recently interned for Cummins, Inc. as a product validation engineer for the QSK 23L engine family in Seymour, IN but will be working as a Product Development Associate Engineer in the Engineering Rotational Development Program at Caterpillar in Peoria, IL after graduation.

Emilio Kenny - Project Analyst

Emilio is a senior Mechanical Engineering student at Florida State University with a focus in Thermal Fluids. Emilio recently interned for Eli Lilly and Company as an Automation/Process Engineer in the injectables sector in Indianapolis, IN. After graduation, he plans to get a Master's Degree in Thermal Fluids.

Kenneth McCloud - Financial Coordinator, Webmaster

Kenneth is a senior Mechanical Engineering student at Florida State University with a focus on Thermal Fluids. He is interested in working on the research and development of renewable energy sources.

Tawakalt Akintola - Project Support

Tawakalt is an exchange student at Florida Agricultural and Mechanical University from Federal University of Technology Akure, Nigeria. Her main focus is in Materials Engineering. She obtained a Diploma in Metallurgical and Materials engineering and had an industrial training at Tower Aluminum Roofing Company, Nigeria. She plans to get a master's degree in Materials Engineering after graduating with a B.S. in Metallurgy and Materials.

Erin Flagler - Project Planner

Erin is a senior Mechanical Engineering student at the Florida State University with a mixed focus in Energy Systems and Materials. Erin interned for Black and Veatch this past summer as a Mechanical Engineer in the Energy Division in Overland Park, KS. After graduation, Erin plans to pursue an engineering career in the energy sector.

# Appendix A: MTS Machine Specifications

| **Product Specification** | **Value** |
|---|---|
| Maximum Rated Force Capacity | 1 kN, 2.5 kN, 5 kN, 10 kN, 20 kN, 30 kN, 50 kN |
| Maximum Test Speed | 750 mm/min |
| Minimum Test Speed | 0.005 mm/min |
| Position Resolution | 0.000047 mm |
| Power Requirements | 200 – 230 V AC, 22 A, 50/60 Hz, 4400 W, 1-phase |
| Space Between Columns | 600 mm |
| Vertical Test Space<br>*Standard Length*<br>*Extended Length* | <br>1200 mm<br>1520 mm |
| Crosshead Travel<br>*Standard Length*<br>*Extended Length* | <br>1000 mm<br>1300 mm |
| Frame Height<br>*Standard Length*<br>*Extended Length* | <br>2269 mm<br>2569 mm |
| Frame Width | 1315 mm |
| Frame Depth | 957 mm |
| Frame Weight<br>*Standard Length*<br>*Extended Length* | <br>1195 mm<br>1265 mm |