Studies of a Remotely Closed Ultra High Vacuum Flange

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Abstract

This project deals with the creation of a special flange to be used in an ultra high vacuum storage ring system. This flange needs to be free from RF leakage and be opened and closed without physically touching it. To ensure that there is no RF leakage from the flange various seals and seal seats are being tested using a magnetron device. The mechanism used for opening and closing the flange has been designed by another team, however part of this project is to determine the amount of force that will be applied. The mechanical drive can only supply a limited amount of force, therefore it is imperative to maintain a good seal with minimum compression. The amount of force that will be used to close the flange is being determined by an Assembly Force Test. This test provides a relation between the assembly force and the compression of the various seals that seat between the male and female sections of the flange.

Introduction

In the Wilson Synchrotron Laboratory at Cornell University CESR, the storage ring, and CLEO, the detector, are being upgraded. The portion that this project focuses on is the detector/storage ring interaction region. Here the old design for the beam pipe is being modified for easier installation and better focusing. A vital and important part of this modification is a joint called the Magic Flange. The term “Magic Flange” was created by a few skeptics in the Laboratory of Nuclear Studies department who did not believe a gadget such as this was feasible without a little magic behind it. In the original concept, besides being remotely closed the Magic Flange was going to rotate to tip the focusing magnets. It was also to be the joint between the cold side of the superconducting magnets and the warm ring. With these three hard jobs to do it took on the term “magic.” As the superconducting magnets were designed, the Magic Flange lost these last two jobs. The name stuck, however, even though “remotely actuated flange” is probably more accurate.

Background

The section of CESR, the Cornell Electron Storage Ring, that runs through the current detector, CLEO II.5, is one single piece. This created a few problems. The installation of the pipe was very strenuous. Made of thin beryllium, it can break if bent by more than 1 mrad. The silicon detectors were placed around the center part of the pipe and there were 1.5 m extensions of that pipe on either side of them. Special care had to be made not to bend these lever arms that were hanging freely. Another problem with this design has to do with the focusing magnets.

This section of the beam pipe contains the interaction point where the particles collide. The beams are focused to the collision point using four quadrupole magnets, two electromagnetic and two rare earth. The closer the magnets are to the beam, the greater the focusing power. The design of the CLEO II.5 interaction region does not allow the REQ final focusing magnets to get any closer to the interaction point than the support cones. This can clearly be seen in Fig. 1.

The CLEO III interaction region was redesigned to make installation easier and safer and allow focusing magnets to move closer to the interaction point, as shown in Fig. 2. The Magic Flange is part of what makes that possible.

Prototype

The prototype that is being used in these tests is made of copper, as will the actual flange. The only difference between this prototype and the design of the real flange is that it is not a part of a long-extending beam pipe component, see Fig. 3. The prototype being used needs to be adaptable to the RF generator and be easily handled for the Assembly Force testing. The joint of the flange is identical to the original design, including O-ring diameters and grooves, clearance between the male and female pipes, and distances between the O-rings. Any discrepancies between it and the final product are a result of these tests. Though not complete, some needed modifications have already been diagnosed.

RF Testing

In the storage ring electromagnetic fields travelling with the electron and positron beams have a frequency spectrum that ranges from DC up to about 10 GHz. As these bunches travel around CESR they travel with a large peak electric field. This moving E field induces a current along the walls of the beam pipe. If the walls are continuous then the wall current is allowed to flow freely around the storage ring walls. If there is a gap or discontinuity anywhere along the walls, the image current will build up a charge on one side of the gap. As the field passes, the opposite charge will build up on the other side. The difference in charge between the two sides of the gap produces a field of its own by extracting some of the passing bunches energy. This field across the gap then acts as an antenna and emits signals in the RF range (390 kHz to 10 GHz). If allowed to penetrate the chamber and propagate out to the surrounding CLEO electronics these signals will be amplified and interfere with the sensor readings, much the same way as a hair dryer can interfere with a television set. The CLEO electronics are essentially antennas; designed to pick up charge that is liberated when high-energy charged particles pass nearby. If other signals are present they will distort the output of the detector and give false readings on the collisions.

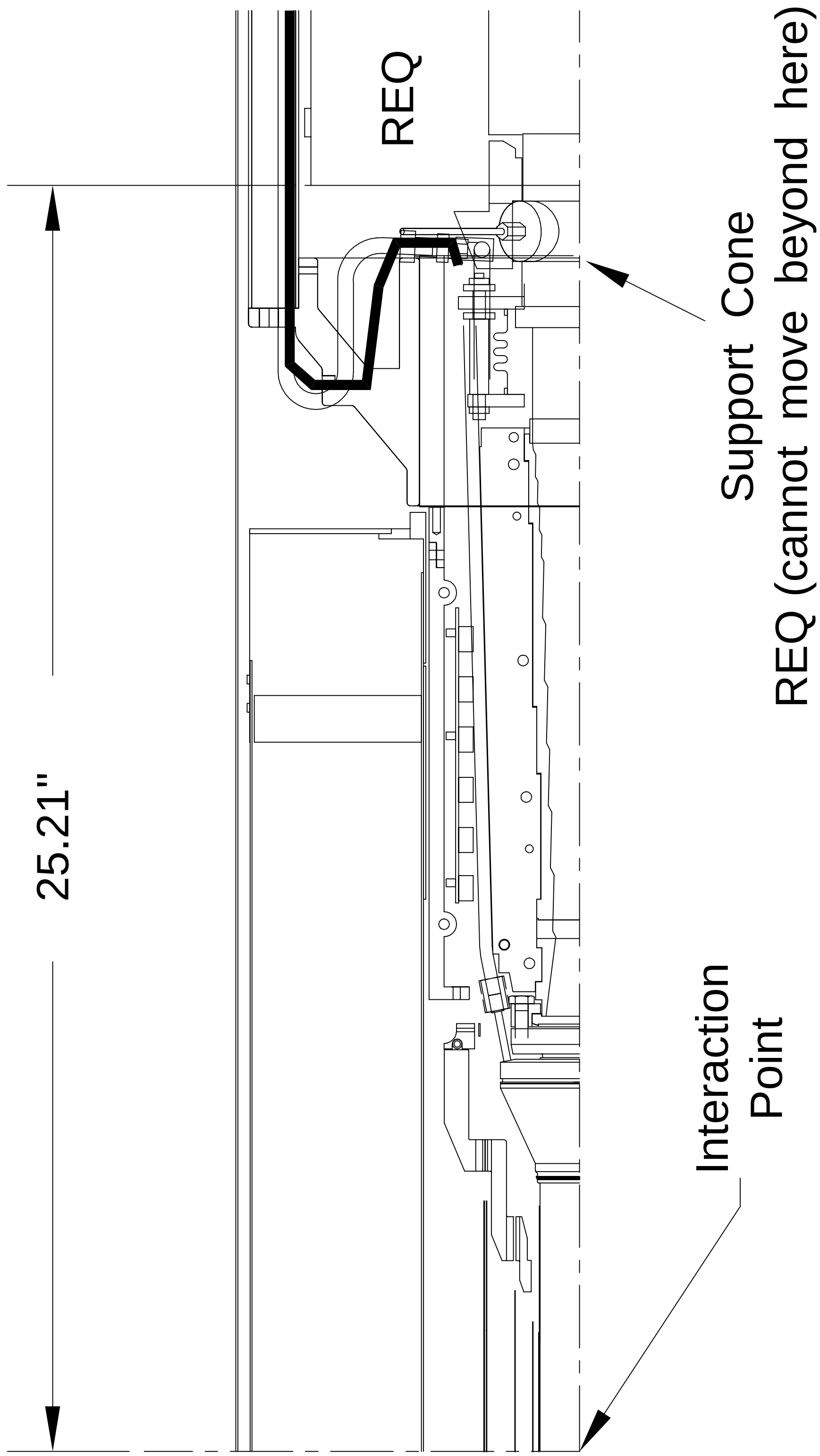


Figure 1. CLEO II.5 Interaction Region

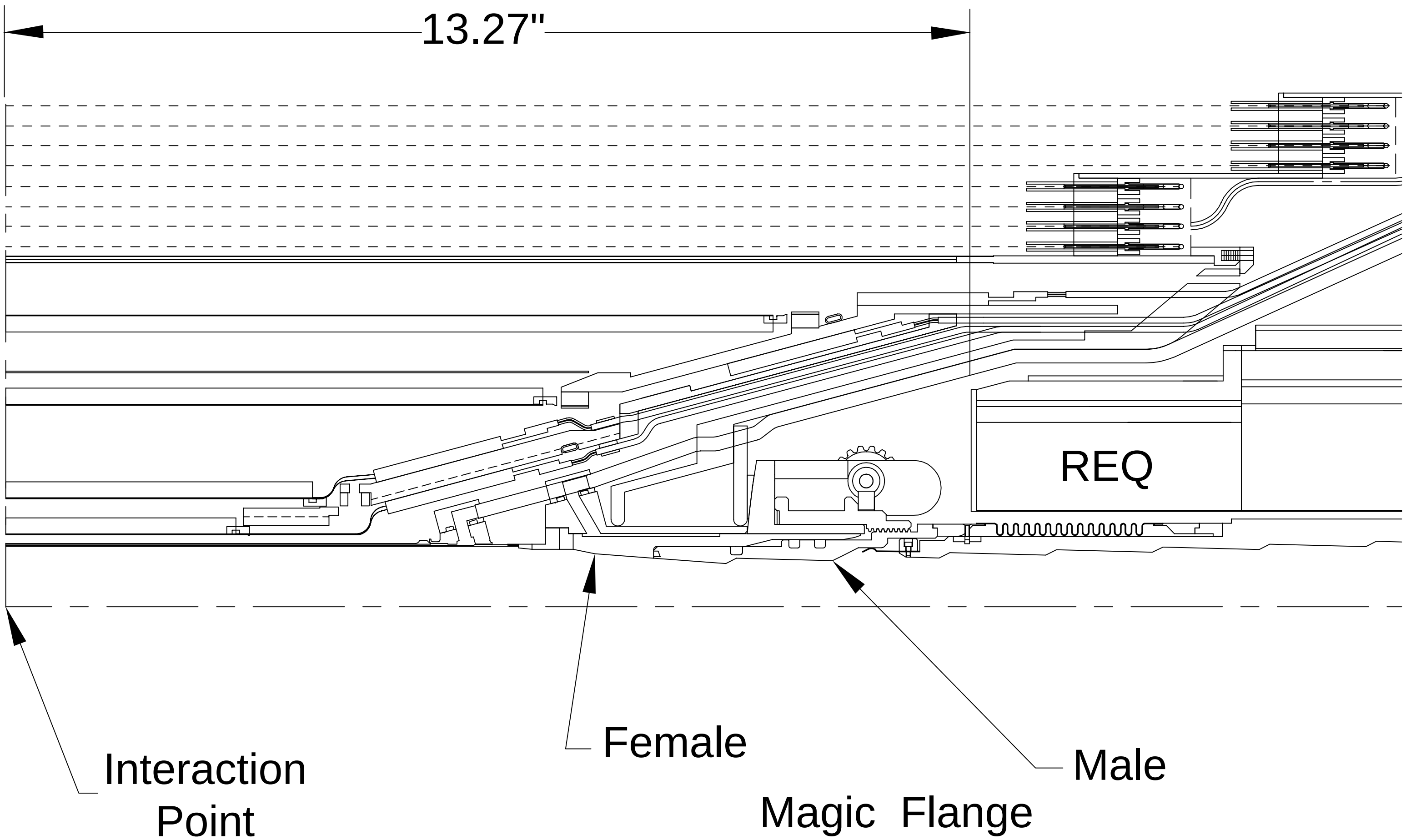


Figure 2. The CLEO III Interaction Region.

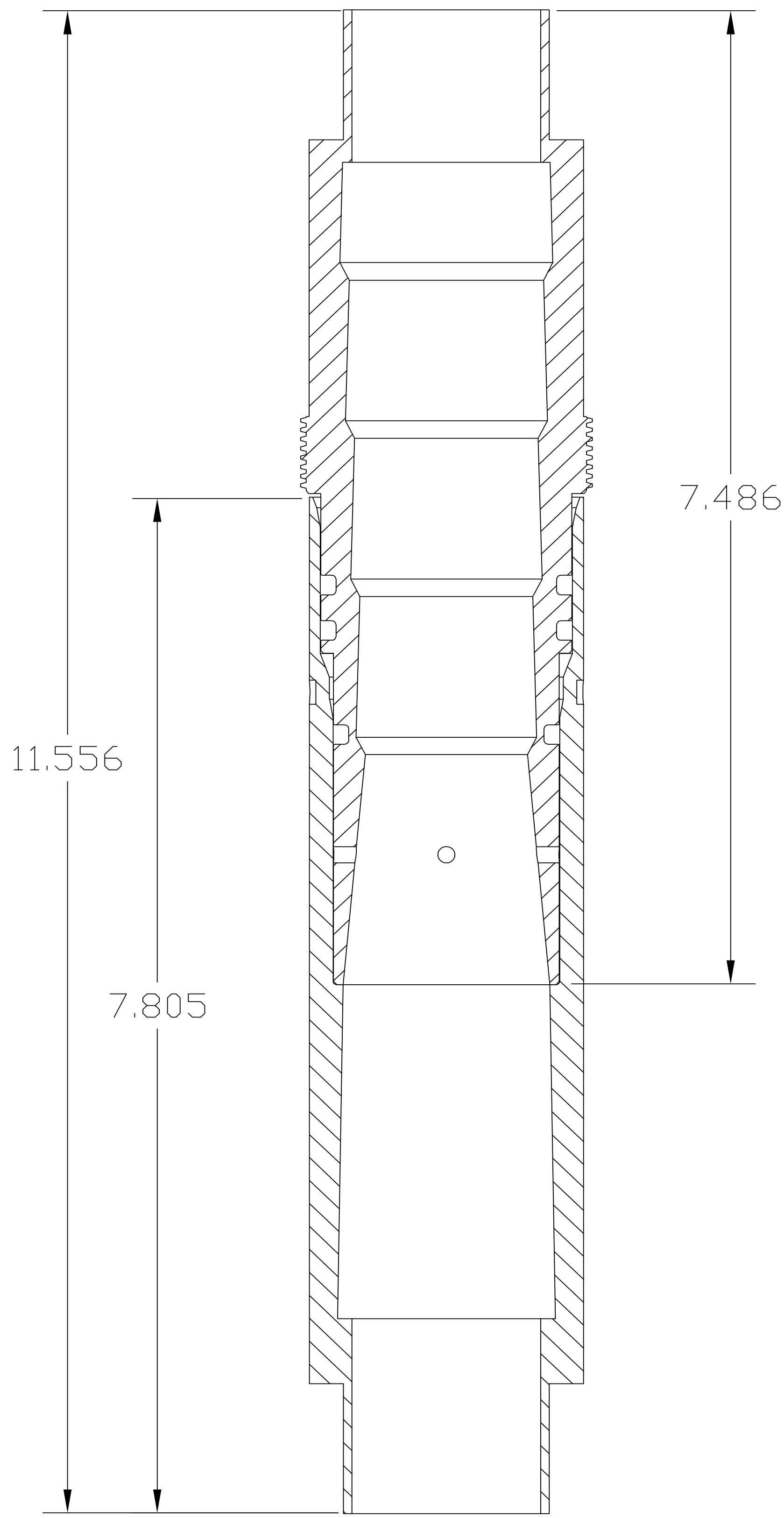


Figure 3. The Magic Flange Prototype.

If the walls of the beam pipe maintain electrical continuity along their outside surfaces then the image currents will continue to propagate along the pipe. This is the purpose of the RF seals. They act as an electrical connection between two conductive objects that are not in direct electrical contact already. The goal of this portion of the project is to determine which type of RF seal works best in the Magic Flange.

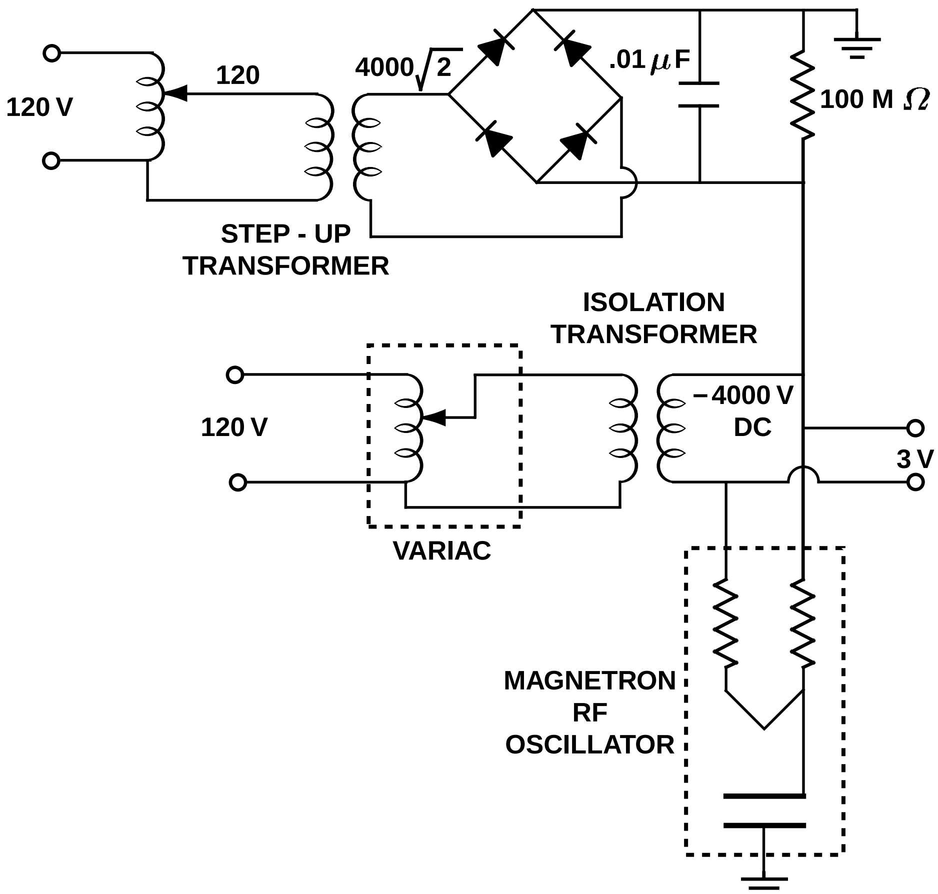


Figure 4. Schematic of the Magnetron Apparatus (circuit).

The apparatus, shown in circuit from in Fig. 4 and in layout form in Fig. 5, is used in testing the Magic Flange prototype for RF leakage. It includes a magnetron for creating the RF, a high voltage source for maintaining the high voltage needed for electron emission, and three power meters, one to read the forward power being pushed through the system, one to monitor the reverse power that may be reflected back, and another attached to a probe loop that is used to detect any leakage outside the flange.

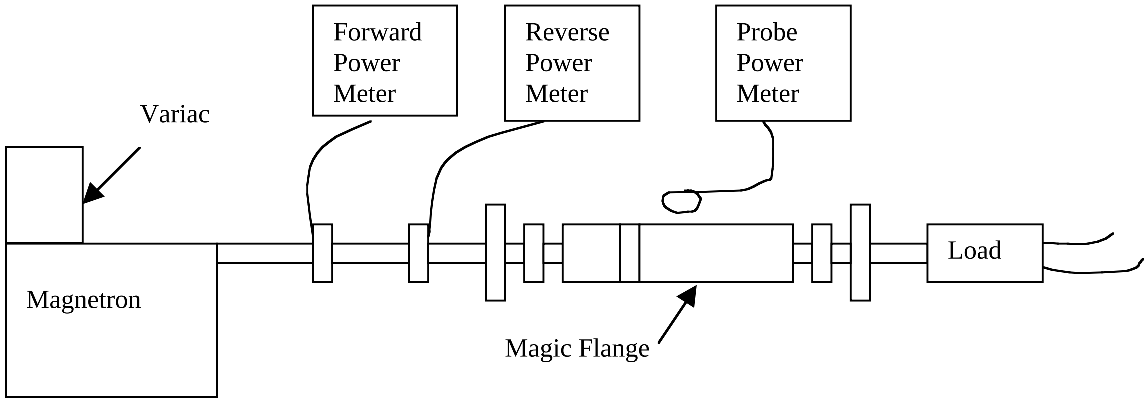


Figure 5. RF Testing Apparatus (layout)

The magnetron generates electromagnetic waves mostly in the radio part of the spectrum. These waves are run through the center of the flange. In the actual CLEO/CESR region the power behind a RF wave can vary anywhere from 0 to 1 000 W. Therefore this apparatus has a variable power supply to simulate the different amounts that may exist inside the flange.

As stated earlier the probe acts as an antenna in search of waves that escape from inside the Magic Flange. As the RF waves pass through the loop they induce a current in the wire. This current is converted into a power reading in the meter and a microwatt value is displayed, P_{probe}. Then, a ratio is created with this information, P_{probe}, and the total input power, P_{in}. As an example of this examine these two equations:

CONNECTION LEAK: $R = P_{probe} / P_{in} = 65 * 10^{-6} / 34.13 = 2 * 10^{-6}$

MAGIC FLANGE LEAK: $= 0.4 * 10^{-6} / 34.13 = 1.17 * 10^{-8}$

During the initial stages of the experiment the flange was not connected properly to the magnetron apparatus. A large leak was recorded, 65 microwatts on the meter, giving a $2 * 10^{-6}$ ratio. In these initial stages the unmodified flange was read with a 0.4 microwatt leak. Its ratio was much smaller at $1.17 * 10^{-8.}$

One problem that must be taken care of before beginning any measurements on the Magic Flange is RF leakage of the magnetron apparatus itself. Referring back to Fig. 5, the load is where most of the trouble was encountered. By wrapping the load area with a wire mesh, steel wool, and aluminum foil, and then sealing the gaps with copper tape, the leaking was eventually stopped; a reading of 0 microwatts on the probe meter. Accurate testing could be performed on the flange.

Once the apparatus is prepared measurements can be taken. A systematic procedure is needed to ensure that the data is compatible.

Magnetron Initiation:

1. Turn water spigot of cooling system on.
2. Check that AC to all instruments is on.
3. Switch on variac to heat the filament.
4. Check that voltage dial is in the 0 position.
5. Switch on the High Voltage Supply.
6. Set meters at their proper ranges for the measurements for that session and begin.

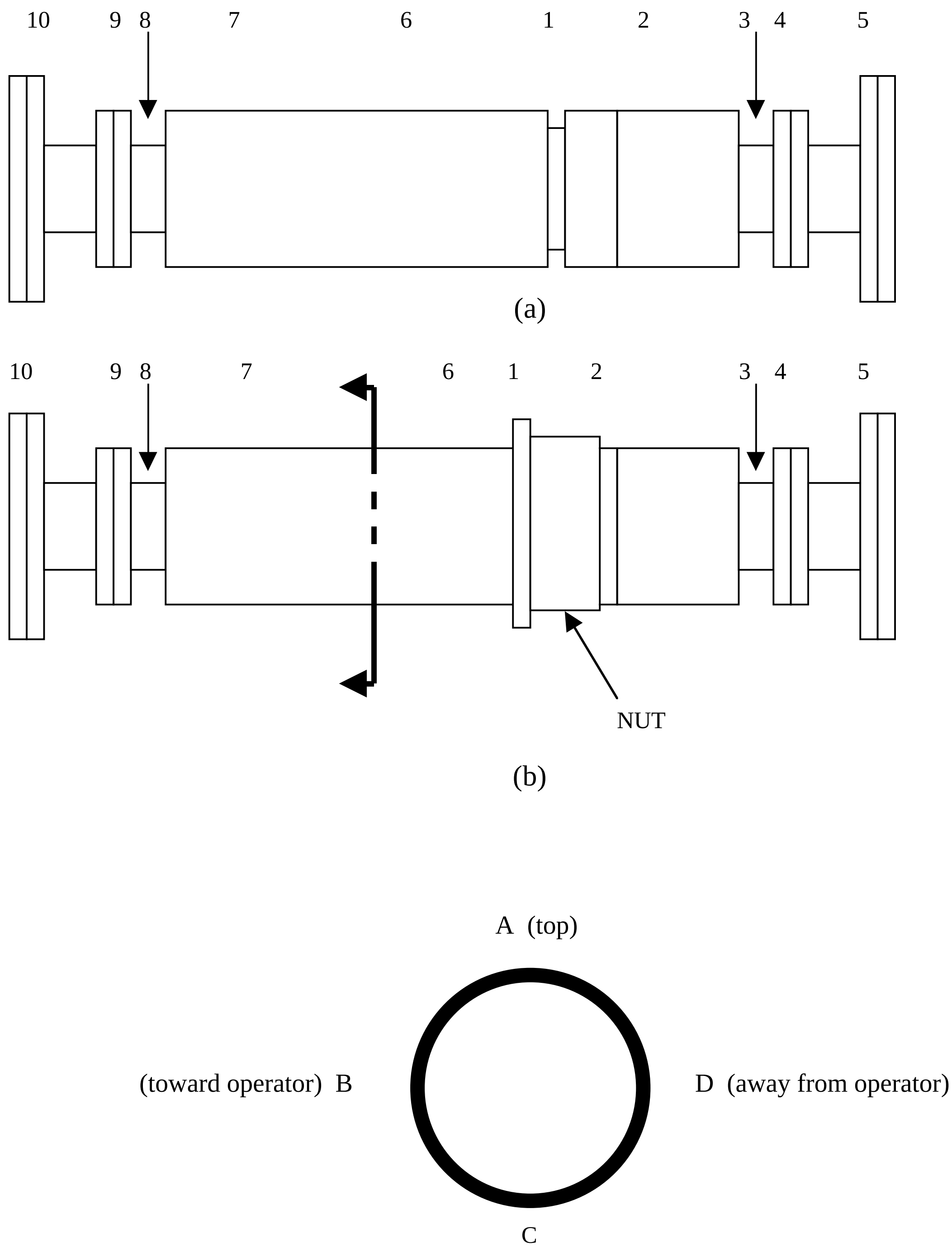
Table 1 is an example of the table used in taking down the data.

Table 1 Example of a table used in recording magnetron test data.

DRY VACUUM SEAL O-RINGS	ENGAGE SYSTEM 9:50AM	
NO SHIM	WATER	On
NO BAL	AC	On
SEAL		
NO NUT	HF	On
TAN RF O-RING	HV	On

Stand Placement (1/2 turn #)	Voltage kV (Current) mA	Forward Power mW (30 mW rng)	Reverse Power mW (3 mW rng)	Probe Power *m*W (3 *m*W rng)	Probe Placement
0	35	5	0	0.025	1AT
	(60)			0.05	R
				0.025	BT
				0	R
				0	CT
				0.05	R
				0.15	DT
				0	R
				0.05	2AT
				0.05	R
				0	BT
				0	R
				0	CT
				0	R
				0	DT
				0	R

A very specific plan is designed for taking readings around the flange. The numbers and letters in Fig. 6 correspond to the far right column in Table 1.



(c) Cross Section of Flange

Figure 6. Probe Placement Diagram

Fig. 6(a) gives the numbering used when testing the flange without the nut, and Fig. 6(b) gives the numbering used when the nut was being used. The measurements are taken at four points around the circumference of the flange (A-D) in Fig. 6(c), and this is done at ten different locations along the flange and its connections to the apparatus. The R and T notation in Table 1 refer to the positioning of the loop with respect to the flange. R stands for radially and T stands for tangential. The standardization of the placement of these measurements led to an important discovery that will be discussed later in this section.

It is very important to remember to keep monitoring the input power. This apparatus is homemade style and was not designed to maintain a constant input.

The results of this experiment as it has been performed thus far are incomplete with respect to the purpose of the testing. Basically, the test itself has been designed. Now it is just a matter of going through the experiment. During the first run of testing a high P_{probe} was discovered on the top (A). That is the reason for the far left column in Table 1. The seals were not under enough compression to keep the joint from bending and the female pipe would hang down from the horizontally fixed male pipe. A lab stand was placed under the female pipe and readings were taken at every half turn of the dial that raised the stand.

The RF O-ring seals work by compression. Two different seals were chosen for the initial testing, a blue, EcE 89 based O-ring, and a tan, EcE 82 based O-ring. There are tiny conductive pieces throughout the O-ring material. As they are compressed they come in contact with each other creating an electrical connection between the two items that are compressing it. When the female end was hanging down it increased the compression on the bottom half of the O-ring, area C, which made its shielding better than at area A where the compression was less.

This effect is also apparent on a side to side basis, perpendicular with the plane of the O-ring. As the pipe hangs down freely, the top leakage is mostly on the side that is hanging down. This is again because of the shifting compression. This example, Table 2 and Fig. 7, shows the side to side effects. Series 1 corresponds to the female side of the nut, 1AR, and Series 2 refers to the male side, 2AR, the side that is fixed to the magnetron apparatus. Referring to Fig. 7, at placement 0 the female side is hanging downward from the horizontal. The leakage is greater on this side of the nut, the female side, while it is hanging. As the male and female sides of the flange become parallel, around placement 6, the leakage is equal on both sides of the nut. And as the female side is lifted above parallel, its leakage is lowered and the leakage on the male side increases. It is clear that the compression on the RF O-ring needs to be constant and continuous.

The next move was to begin shimming the RF groove until the compression was enough to keep the male and female pipes parallel and shield the RF. The testing was cut short, however, due to a transformer burn up on the magnetron apparatus. It has recently been repaired and tests are being run.

Table 2. RF Measurements

NO SHIM	WATER	on
BAL SEAL	AC	on
NUT	HF	on
TAN RF O-RING	HV	on

Stand Placement (1/2 turn #)	Voltage kV (Current) mA	Forward Power mW (30 mW rng)	Reverse Power mW (3 mW rng)	Probe Power *m*W (3 *m*W rng)	Probe Placement
0	32	10	0	0.3	1AR
1	(280)			0.4	
2				0.3	
3				0.25	
4				0.2	
5				0.2	
6				0.3	
7				0.2	
8				0.1	
9				0.2	
10				0.3	
10				0.2	2AR
9				0.25	
8				0.3	
7				0.4	
6				0.2	
5				0.1	
4				0.1	
3				0.15	
2				0.1	
1				0.1	
0				0.2	

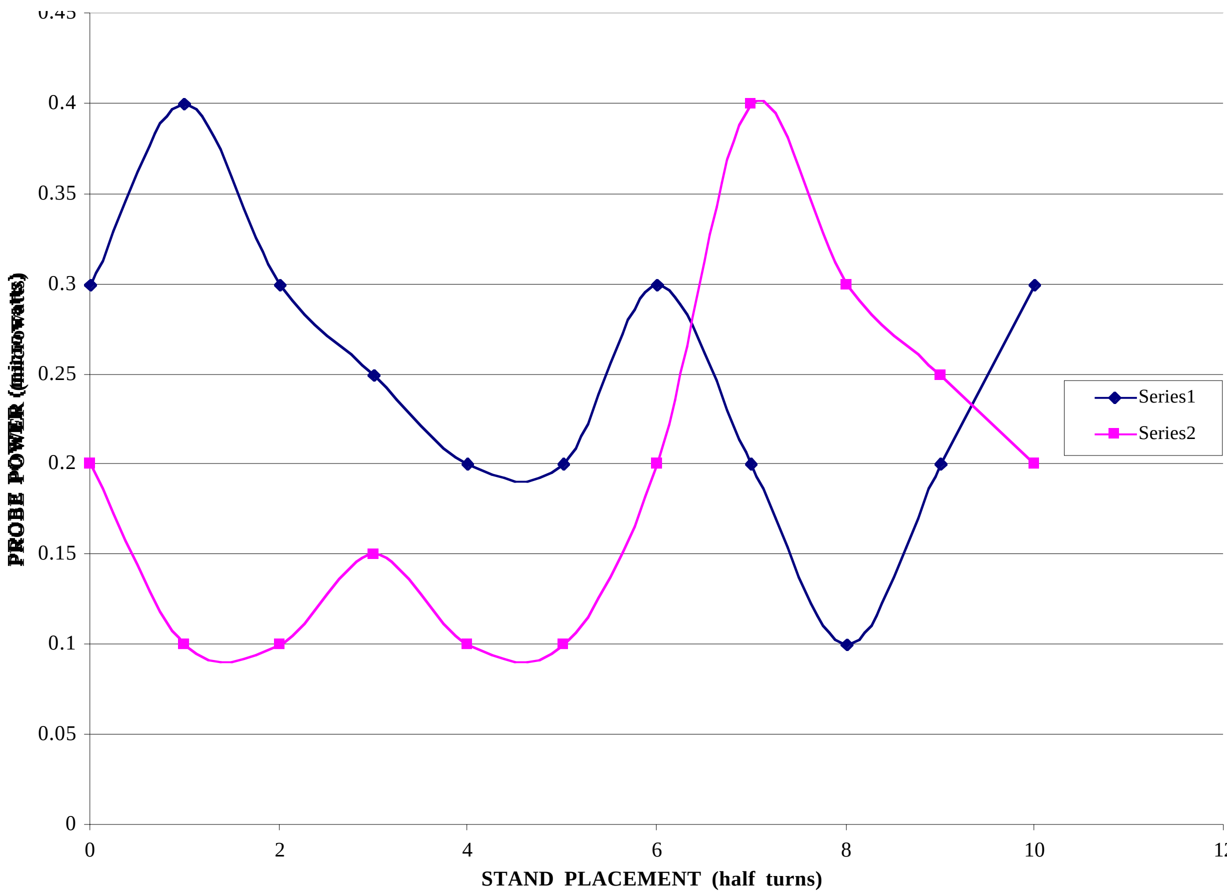


Figure 7. RF test readings

Assembly Force Testing

With the loss of the RF testing apparatus, another line of testing was started. The bending at the joint of the Magic Flange was a definite problem that needed to be addressed. The Assembly Force Test was designed to compare different compressions on the O-ring seals with the closing force applied by changing the O-ring seat depths. If the compression of the vacuum seal O-rings is maintained in the desired range, around 25%, then the RF seal O-ring compression can be varied to meet the assembly force limits and the needs of the RF shielding. After discovering the bending problem this should have been the next logical move, to set standards for the vacuum seals first before trying different RF seals and groove depths. Therefore the magnetron went down at a good time. It moved the project in the right direction unintentionally.

The test is rather simple. The equipment consists of a few pre-weighed lead bricks and plastic jars filled with steel ball bearings, an aluminum stand, six small- and six large-diameter Viton O-rings, copper tape with conductive adhesive, calipers, a tube of Fomblin, disposable gloves, and a wristwatch. The set-up is shown in Fig. 8.

The goal behind the first run of tests was to shim the vacuum O-rings until they required a 50 lb. assembly force. The compression on the seals is directly related to how much space they are confined in. Since the clearance between the male and female pipes is held fixed (.004 on the prototype) the depth of the groove is what determines the compression on the O-ring. The copper tape is used for shimming. One layer was applied at a time to the bottom of the vacuum O-ring grooves. Four trials are done at each groove depth. The weights are applied to a top plate. They are added in one pound increments and sit for ten seconds before the next weight is added. The purpose of the six O-rings is to accommodate the decompression time of the Viton. It takes the O-rings about 20-30 minutes to return to their original form, but it only takes seconds to prepare the next trial. It is important to note that after the Viton O-rings are allowed to decompress the lubricating grease, Fomblin, is reapplied.

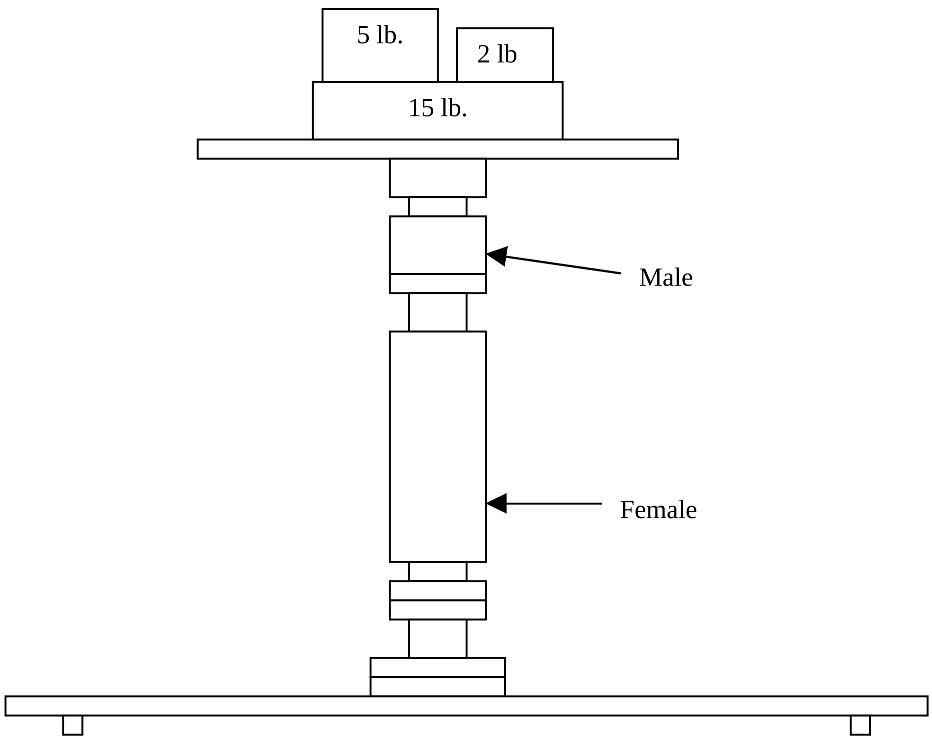


Figure 8. Assembly Force Test

The procedure begins with a wipe-down of the inside of the female pipe with isopropanol. The O-ring grooves are also wiped out, and two newly lubricated Viton O-rings are put in place. The male pipe is set on top of the female, as shown in Figure 8, and the aluminum weight support is placed on top. The weights are added and readings are taken when the male pipe begins to move downward and when the flange is completely closed. The weights and support are removed and the flange disassembled. First the inside of the female pipe is wiped clean. Then the O-rings are removed and allowed to decompress. If it is the middle of a set, the copper shims in the bottom of the grooves are wiped down and uncompressed O-rings are put in place in the grooves. If it is the end of a set, after removing the O-rings and wiping down everything a new layer of copper tape is added. Then the new groove depth is measured and two fresh O-rings are placed on the male pipe. Then the measurement procedure is repeated.

Table 3. Data from the compression experiment.

Groove Depth small	(in.) Large	Shim Size small	(in.) Large	Weight to Move (lb.)	Weight to Close (lb.)	Date
0.111	0.1115	0	0	10.62	18.34	07.14.98
				10.78	18.34	
				9.62	18.34	
				8.3	18.34	
0.108	0.108	0.003	0.0035	12.78	20.34	
				12.1	20.34	
				10.62	20.34	07.15.98
				10.62	20.66	
0.1055	0.1055	0.0055	0.006	14.78	22.47	
				13.1	22.15	
				13.78	20.15	
				11.78	18.34	
0.103	0.103	0.008	0.0085	16.1	28.69	
				14.78	23.89	
				13.78	23.89	
				14.78	22.89	
0.1	0.1	0.011	0.0115	17.34	30.69	07.16.98
				16.1	26.69	
				15.1	23.89	
				16.34	25.37	
0.0985	0.098	0.0125	0.0135	19.34	32.25	07.17.98
				18.34	30.69	
				17.34	30.69	
				17.66	28.69	
0.0955	0.0965	0.0155	0.015	22.89	29.69	
				20.34	28.69	
				21.66	30.93	07.20.98
				20.66	29.69	
0.0935	0.093	0.0175	0.0185	23.89	35.25	
				22.89	32.25	
				24.21	34.25	
				21.21	33.25	
0.0895	0.0915	0.0215	0.02	27.37	38.74	07.21.98
				26.69	36.74	
				25.21	37.74	
				23.89	36.06	
0.089	0.0895	0.022	0.022	34.93	50.79	07.22.98
				29.69	46.78	
				30.93	43.54	
				30.69	43.22	

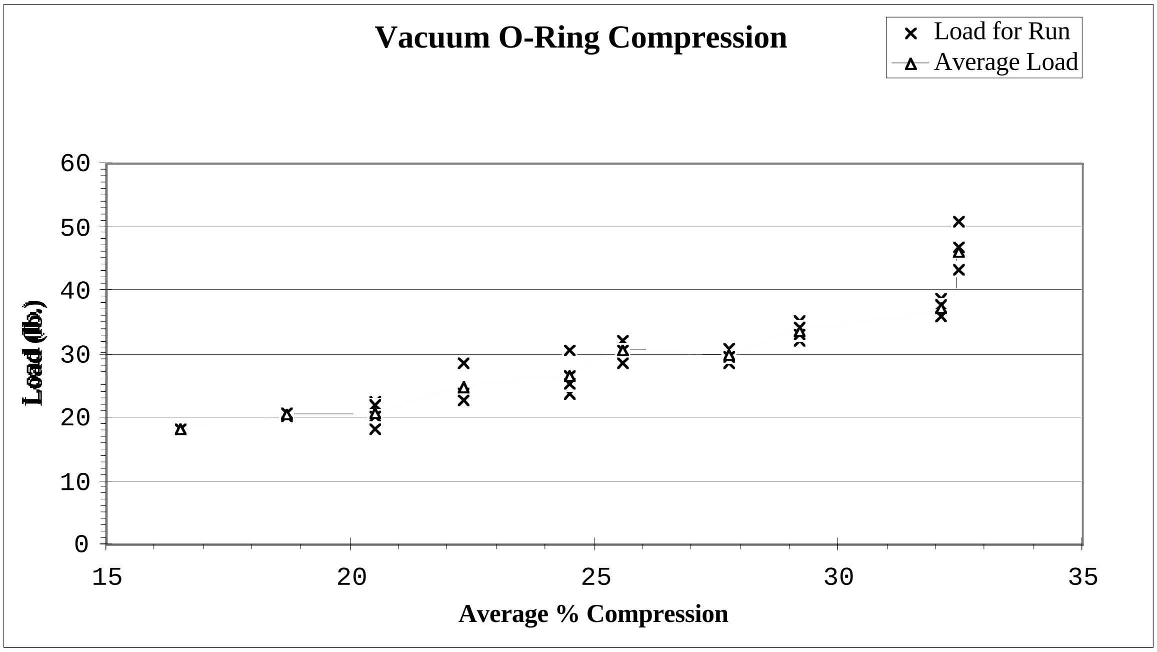


Figure 9. Graph of data from the compression experiment.

Table 3 shows the data table obtained in this experiment. You can see from this chart that even though the O-rings were changed there was still a bit of a decline in the necessary force applied. This is most likely due to the further compression of the layers of copper tape, and the inconsistencies between the O-rings.

As noted earlier, this data was used to determine the proper groove depth for a 25% compression. The data was plotted as Fig. 9. A 25% compression corresponds to about a 26 lb. load, which was recorded at groove depths approximately between 0.0935 in. and 0.1 in. This decreases the current depth by 0.011-0.018 in.

Further testing will follow repeating these same steps with the RF seals (non-lubricated). Once the RF groove depth is established through the RF testing on the magnetron the total assembly force and a method for its installation can be determined.

Conclusions

Several usable discoveries were made during the seven-week duration of this portion of the project. The original design of the flange, that which the prototype was molded from, needs a few modifications. The groove depths of the O-ring seats need to be altered to give the proper compression on the vacuum and RF seals. The depth of the vacuum O-ring groove has been narrowed down to a range of 0.0935 – 0.1 in.

Once the RF testing is complete the depth for the RF O-ring groove can be determined. As well, the total assembly force can be found by completing the Assembly Force Testing. It is the recommendation of this paper that the RF seal be brought up to an adequate compression by shimming during the remainder of the RF testing. Then return to the Assembly Force Test to complete this portion of the project. The force applied to the flange has a limit of 90 pounds, which is probably quite larger than the force that will be required by the two vacuum seals and the RF seal together. Therefore it is the RF shielding that is the driving force behind the RF groove shim.

As long as the Magic mechanical drive system that has been agreed upon does its duty to join the male and female sections of this flange together it should hold up to the conditions of the ultra high vacuum and the sensitivity of the surrounding detector upon completion of this project.

Acknowledgments

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