ECH Mirror Interface Tank for 110 GHz, 1 MW Gyrotron*

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ABSTRACT

A 1 MW, 110 GHz gyrotron is to be installed at General Atomics in 1995. A Mirror Optics Unit (MOU) has been designed and built to connect to the existing 110 GHz transmission line system. The unit reduces and directs a 145 mm diameter beam from the gyrotron to a 19 mm diameter beam which is then injected into a 31.8 mm diameter corrugated waveguide of the transmission line system. The unit operates under vacuum and is able to absorb beam spray from the gyrotron. The tank also contains various diagnostics equipment to protect the gyrotron and to determine the amount of energy loss in the tank, and at the window of the gyrotron output. This paper discusses further the design parameters, assembly and installation of the unit in the transmission line system.

INTRODUCTION

A GYCOM 110 GHz gyrotron has been delivered to General Atomics and is being installed into one of the three existing Electron Cyclotron Heating (ECH) transmission line systems [1]. As the first of the three microwave 1 MW sources, this 2 s pulse length gyrotron generates and projects a 145 mm diameter beam perpendicular to the axis of the gyrotron through a water cooled window (Fig. 1). This beam is focused and reduced to a 19 mm diameter beam by two mirror assemblies mounted in the MOU housing or vacuum tank. The MOU, linking the gyrotron to the existing ECH transmission line, assures proper coupling of the microwave beam to the transmission line and maximizes power delivered to the DIII–D plasma. This is accomplished by the five major components (Fig. 2) of the MOU: MOU housing or vacuum tank, absorber, input and exit bellows assemblies, carriage assembly, and the mirror assemblies.

VACUUM TANK

To maintain a vacuum of 10^{-4} Torr or better, a vacuum tank, 590 mm in length with two 670 mm diameter end flanges, and a turbo pump station are utilized. The tank houses the mirror assemblies, an absorber, vacuum gages and a fiber optic arc detector. Designed to withstand a vacuum load of one atmosphere, the tank is made of stainless steel to minimize the magnet interference with the superconducting magnet of the gyrotron. The two end flanges have several ports to mount and insert the input and exist bellows assemblies, the two mirror assemblies, and instrumentation. One of the ports also is used as an access port to allow thermal paper to be inserted into the tank between the gyrotron window and the first mirror assembly, the first and second mirror assemblies, and the second mirror assembly and the exit bellows assembly. Initial location measurements of 2 ms microwave beam pulse are made in atmosphere to verify proper orientation of the mirror assemblies and the input and exist bellows assemblies. An arc detector is mounted on the access port flange and is positioned to view the gyrotron window. If arcing occurs at the window or else where in the tank, the detector system responds within 10 µs and discontinues operation of the gyrotron to minimize the damage to the gyrotron window and the MOU internal components. To monitor the vacuum pressure of the tank, ion and convectron gages are located on one of the end flanges along with a cold cathode sensor. The cold cathode sensor is used in the fast closing shutter system of the transmission line to protect the DIII–D vacuum in case of a sudden increase of pressure in the system. To assure ease of serviceability to the internal components of the tank, all equipment mounted on the end flanges utilize conflat gaskets to maintain the vacuum.

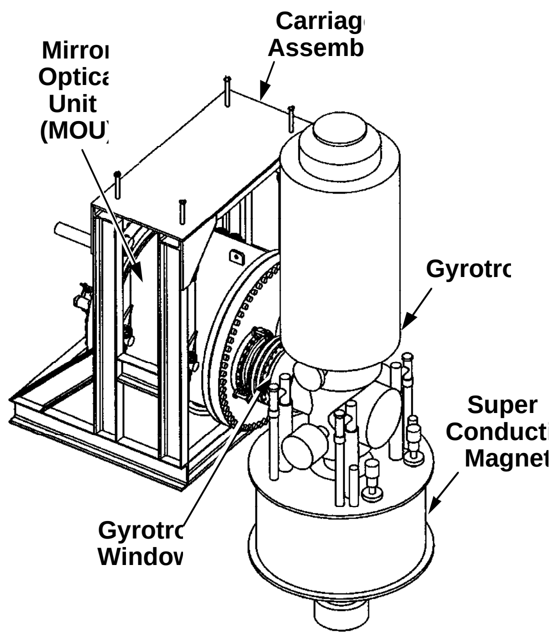

Fig. 1. MOU assembly and gyrotron.

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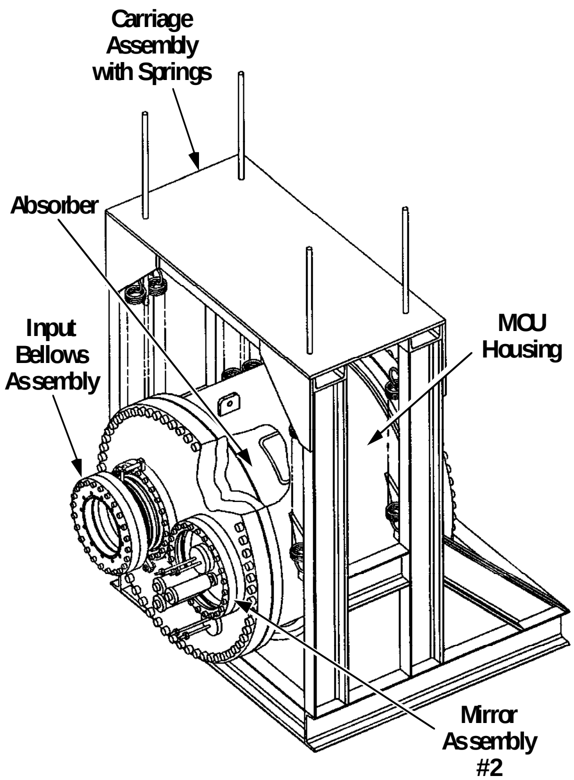

Fig. 2. MOU assembly.

ABSORBER

The absorber consists of a copper sleeve mounted on one of the end flanges and simply supported off of the inner diameter of the MOU housing. It is estimated that up to10% (100 kW) of the power from the gyrotron may exit from the gyrotron window with a wide angle and will not be captured by the first mirror assembly. To absorb this power, the inner diameter of the copper sleeve is coated with titanium dioxide. The power is absorbed by the titanium dioxide and is transferred into the copper. The 0.10 mm thick titanium dioxide coating is designed to absorb 10% of the energy of the beam spray per bounce. This minimizes localized heating on the inner diameter of the sleeve. The outer diameter of the copper sleeve has a 6 mm stainless steel water cooling tube brazed to it in a serpentine pattern. The water flow (see Table I for parameters) in the stainless steel tubing removes the heat from the copper and allows for a calorimetric measurement to be made to determine the amount of power in the microwave beam spray. The end flanges are not water cooled but are of significant mass that the maximum expected temperature of the flanges is 46°C with free convection and radiation to air.

Table I
Absorber Cooling Parameters

Maximum Temperature of Copper	78°C
Water Inlet Temperature	24°C
Pressure Drop	2.5 Bars
Flow Rate	4.7 l/m

INPUT AND EXIT BELLOWS ASSEMBLIES

To position the MOU so that the entrance port of the MOU is aligned with the microwave beam exiting the gyrotron window, a bellows arrangement has been designed. Since it is unknown the exact location and angle of the 145 mm beam exiting the gyrotron window, the input bellows assembly can be varied as much as 2° and shifted 6 mm off center of the window. The exact angle and orientation of the gyrotron beam is determined by observing a liquid crystal sheet (LCS) mounted on the back of a Teflon water load with a camera. The Teflon load is mounted inside a containment microwave absorption box and the gyrotron is pulsed into the Teflon load. The few watts not absorbed by the Teflon load exits the load and produces a visible pattern on the LCS which should be identical to the gyrotron microwave beam. By viewing the heat pattern on the LCS at several locations the angle and orientation of the gyrotron beam can be determined. The input bellows is then properly adjusted via bolts and spherical washers on each of the end flanges of the bellows assembly to match the angle and orientation of the beam exiting the window. Since the bolts of the assembly span from one end flange to the other they also react the vacuum loads. Internal to the input bellows assembly is a copper plated stainless steel insert that protects the convolutions of the bellows from stray microwave power. The 0.6 mm thick bellows convolution will not withstand an estimated 10 kW of direct and/or reflected power so the insert is installed to reflect and any power away from the bellows. To assure bolt circle alignment when the bellows assembly is installed on the MOU, one of the end conflat flanges is rotatable.

As with the input bellows assembly, the exit bellows assembly allows a waveguide to be oriented so that the microwave beam coincide with the center axis of the waveguide. The exit bellows assembly comprises of a 31.8 mm diameter output waveguide, a X-Y translator fixture, a bellows and an insert spool piece mounted on a 203 mm diameter conflat flange. The waveguide is captured in the X-Y translator fixture stage and has a travel of plus or minus 13 mm in the X-Y direction with respect to the MOU end flange. The X-Y translator is mounted on three spherical washer and bolts sets allowing the X-Y translator and waveguide to be tilted 0.05 in any orientation The spherical washers and bolts also react the vacuum load. The waveguide is enclosed by a copper coated stainless steel spool which also serves as a reflective shields for the bellows from the direct and reflected microwaves in the MOU.

CARRIAGE ASSEMBLY

To align the MOU to the gyrotron window and to minimize the mechanical load on the gyrotron, an aluminum carriage assembly positions the MOU tank via four sets of springs and alignment yokes. The springs allow the gravitational load of the MOU to be zeroed by extending the springs via threaded shafts secured to the top of the carriage assembly. The other end of the springs are pinned to tabs welded to the outer diameter of the MOU housing. The springs assure that a minimal load is induced into the gyrotron flange and gyrotron. This is desirable so that the gyrotron is not moved with respect to the super conducting magnet and its magnetic field. Also, during operation of the gyrotron, thermal expansion of the gyrotron will occur(as much as 0.18 mm vertical growth has been experienced with the Varian Gyrotron,) [1] and the springs and alignment yokes of the carriage assembly allow the MOU to move with the gyrotron. The yokes act as guides and only allow movement in the vertical direction. The tabs on the outer diameter of the tank are set in the yokes and have pins to guide the tank in the yokes. The carriage assembly has adjustable leveling feet, to adjust the elevation and angle of the MOU and input bellows assembly with respect to the gyrotron window flange during installation.

MIRROR ASSEMBLIES

Each of the two mirror assemblies (Fig. 3) are mounted on conflat flanges which mount to the 670 mm diameter flanges of the MOU. Each assembly consist of a machined copper mirror, three vacuum linear feedthroughs for control of the location and orientation of each mirror, a copper cooling mounting block, stainless steel cooling line, water feedthroughs, and support blocks and rods mounted on the conflat flange.

The first mirror, 160 mm by 174 mm, is machined to assure the microwave beam, once reflected off the mirror, is primary guassian mode and slightly focused. The second mirror, 135 mm by 147 mm, is machined to further focus the beam to 19 mm diameter. Both mirrors were designed and machined by GYCOM so that the output microwave beam has a 99% coupling coefficient to the HE_{11} mode propagate in the 31.8 mm diameter waveguide.

To position the mirrors in the MOU housing to the prescribed angle and distances, linear feedthroughs are used. The first or center linear feedthroughs of each assembly controls the location of the mirror with respect to each other and the distances from the gyrotron window or the output waveguide assembly. The mirror of the first assembly is required to be located 600 mm from the gyrotron window which is accomplished with the center linear feedthrough of the second mirror assembly. The mirror of the second assembly is positioned a required 400 mm from the first mirror and 400 mm from the output waveguide of the exit bellows assembly with the first linear feedthrough. Also required is a 46° angle of reflection of the microwave beam from the first mirror to the second. The second or side linear feedthrough of both assemblies provides the capability to position the mirrors at this angle. The third linear or top feedthrough of each assembly is to control the pitch of each mirror in relationship to the conflat flange. This allows for correction of the error in pitch caused by assemblies tolerance build up. Once the mirrors are positioned correctly, the feedthroughs are locked to prevent any further adjustment to the position of the mirrors.

Each mirror is estimated to absorb approximately 1% (10 kW) of the source power of the gyrotron. The mirror absorbed power heats the copper mounting block and the heat is removed from the block via the water flow in the stainless steel tubing brazed to the back of the block. The temperature rise and water flow rate to cool each mirror is depicted in Table II.

CONCLUSION

The MOU is designed to convert and focus a 145 mm diameter multiple mode microwave beam to a 19 mm

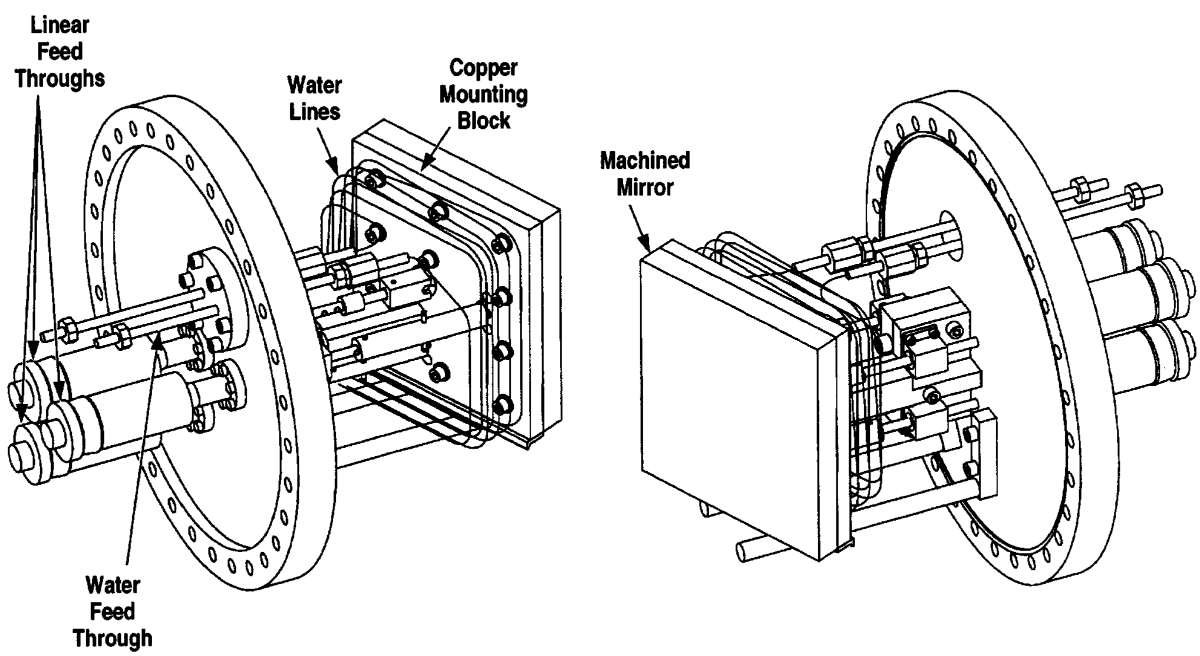

Fig. 3. Mirror assembly.

diameter He_{11} guassian beam for the existing 110 GHz ECH System. It allows for the absorption of the gyrotron microwave beam spray and accomplishes this in an evacuated environment to minimize arcing in the unit. Operations of the gyrotron and the MOU will commence at the end of the of October with power being injected into the DIII–D plasmas at the end of the year.

REFERENCES

[1] W.P. Cary, “110 GHz ECH on DIII–D: system overview and initial operation,” in proc. 14th IEEE/NPSS Symp. on Fusion Engineering, pp. 912-914, 1191, 1991.

Table II
Mirror Assembly Cooling Parameters

Mirror Assembly # 1	
Maximum Temperature of Mirror and Block	30°C
Water Inlet Temperature	24°C
Pressure Drop	1.4 Bars
Flow Rate	4.7 l/m
Mirror Assembly # 2	
Maximum Temperature of Mirror and Block	32°C
Water Inlet Temperature	24°C
Pressure Drop	1.4 Bars
Flow Rate	4.7 l/m