GA–A23475

PERFORMANCE OF THE 1 MW, 110 GHz, 10 s GYROTRONS RECENTLY INSTALLED IN THE DIII–D ECH SYSTEM

by
W.P. CARY, R.W. CALLIS, J. LOHR, R.A. LEGG, D. PONCE, and R. PRATER

OCTOBER 2000

DISCLAIMER

GA–A23475

PERFORMANCE OF THE 1 MW, 110 GHz, 10 s GYROTRONS RECENTLY INSTALLED IN THE DIII–D ECH SYSTEM

by
W.P. CARY, R.W. CALLIS, J. LOHR, R.A. LEGG, D. PONCE, and R. PRATER

This is a preprint of a paper presented at the 21st Symposium on Fusion Technology, September 11–15, 2000 in Madrid, Spain and to be published in *Fusion Design and Engineering.*

Work supported by
the U.S. Department of Energy under
Contract No. DE-AC03-99ER54463

GA PROJECT 30033
OCTOBER 2000

ABSTRACT

ECH power has proven capabilities for both heating and current drive in energetic plasmas. For the second phase of ECH power on DIII–D, there will be three 1 MW sources added to the existing three systems for a total power generating capacity of 5.1 MW. This upgrade is based on the use of the single disc chemical vapor deposition (CVD) diamond window, 1 MW diode gyrotron, recently developed by CPI. All gyrotrons are connected to the tokamak via a low-loss, windowless, evacuated transmission line system, using circular corrugated waveguide for propagation in the HE_{11} mode. Each waveguide system incorporates an in-vessel two-mirror launcher. The newest launcher can steer the rf beam poloidally from the center to the outer edge of the plasma and toroidally for either co- or counter-current drive. An overview of the total system, its integration with the DIII–D tokamak, and recent results will be discussed. The various new aspects of the upgrade ranging from building modifications to the use of the new steerable launcher will also be addressed.

1. INTRODUCTION

To further enhance the experimental capabilities of the DIII–D tokamak, funding was made available for the procurement and installation of three additional 110 GHz gyrotrons, which were to operate at pulse lengths of up to 10 s and produce an output power in excess of 850 kW each. The additional power and pulse length capability, provided by these new gyrotrons, will be beneficial in investigating Advanced Tokamak (AT) operating regimes. Of particular interest is the effect of transport barrier modification using the EC systems [1] and the development of methods to control off-axis current in AT plasmas. After completion of this upgrade program there will be a total generating capacity of 5.1 MW of 110 GHz power on DIII–D [2]. Performance of the new gyrotrons as well as significant experimental results will be addressed in this paper.

2. ECH SOURCE DESCRIPTION

Prior to the installation of the three 110 GHz production gyrotron systems there were already five short pulse (~2 s) gyrotrons, operational on the DIII–D tokamak [3]. Two of these gyrotrons were manufactured by Communications Power Industries (CPI) and three were of GYCOM manufacture. The first GYCOM gyrotron has been in operation since 1996, two more were procured from the TdeV program and brought on-line this year, while the CPI gyrotrons were brought into operation in 1997 and 1998. All five of these gyrotrons have a peak power output of ~1 MW but have limited pulse length capability due to their output window design. Only the second CPI development gyrotron has a 10 s pulse length capability due to the use of a CVD diamond window. The nominal parameter of the original gyrotrons as well as the first two CPI production gyrotrons is shown in Table 1.

As mentioned in the introduction, the upgrade gyrotrons were specified to have an operating power of > 850 kW with a pulse length of 10 s. After submittal of bids from several gyrotron manufacturers, CPI was chosen as the supplier. The CPI design incorporates a gaussian rf output and a CVD diamond output window. Based on the recent experience of operating both diode and triode gyotrons, it was decided to require a diode configuration rather then the triode. The primary reasoning for this decision was based on the complexity of operating the necessary electronics at high voltage for the triode case and added expense, in contrast to the relatively simple support electronics and ease of operation associated with a diode design. As will be discussed later, the use of the diamond window allowed a gaussian output to be used for the first time, which allowed for a simplified injection scheme of the rf beam into an evacuated waveguide system.

The rf transmission system is comprised of evacuated, aluminum, 31.75 mm diameter, circularly corrugated waveguide operating in the HE_{11} transmission mode. The diameter was chosen because of the power handling capability and its relative insensitivity to misalignment. The viability of this particular waveguide had already been validated with the operation of the first three gyrotrons and was therefore chosen as the transmission line of choice for the upgrade gyrotrons [4]. With the use of the diamond window permitting the ability to have the rf generated in a gaussian mode rather than the flattened beam of the earlier gyrotrons, the required correction and focusing mirror configuration has been much simplified. The use of only a single focussing mirror has been demonstrated on the first two of the upgrade gyrotrons. Initial power measurements

Table 1
Gyrotron Performance Parameters

	GYCOM 3 Gyrotrons	CPI Development #2	CPI Production #1	CPI Production #2	CPI Production #3
Frequency, GHz	109–110	110	110	110	110
Gun Type	Diode	Triode	Diode	Diode	Diode
Output Window	Single disk	Single disk	Single disk	Single disk	Single disk
Material/Seal	Boron nitride	CVD	CVD	CVD	CVD
Seal		Al diffusion	Al diffusion	Au/Cu Braze	Au/Cu Braze
Cooling	Edge H2O	Edge H2O+inhibitor	Edge H2O+inhibitor	Edge H2O	Edge H2O
RF power (kW) & Pulse Duration (s)	960/2.0	1000/10	1000/10	1000/10	1000/10
Efficiency, %	38	32	32	32	TBD
Beam Voltage, Current	72 33.8	80 35	80 35	80 35	80 TBD

indicate that the power loss associated with the new mirror design is significantly less than the previous two-mirror design. The transmission line layout for the eight-gyrotron systems is shown in Fig. 1, which also shows many of the key transmission system components.

At the tokamak end of the transmission system are four dual launchers (presently three are installed, a fourth dual launcher will be installed in the Summer of 2001). Each launcher is comprised of a pair of focusing mirrors and a flat tilting mirror used to steer the beam. All three installed launchers have the ability to change poloidal direction between successive plasma shots, while only one has the additional capability of between shot toroidal steering. The fourth launcher will have both toroidal and poloidal steering capability. At present, none of the launchers has mirrors capable of supporting pulses of greater than 5 s in length. A new mirror design is currently being investigated which should support the full pulse capability of the CPI production gyrotrons.

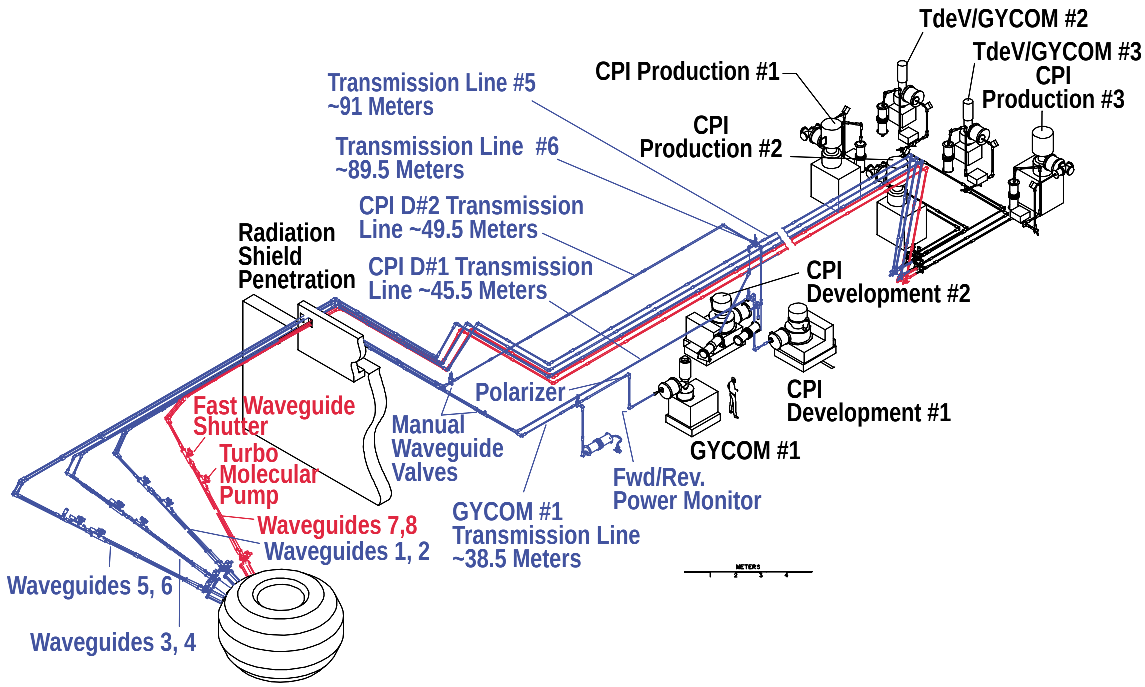

Fig. 1. ECH transmission line layout and configuration.

3. INITIAL OPERATION

Operation of the first CPI production gyrotron began in June of this year and was used to support several physics experiments before a vacuum leak developed. The second of the production gyrotrons has been delivered and was brought online in late July. This tube has a high temperature braze seal on the diamond window, which should minimize the risk of a failure in this area. Despite the setbacks in the initial operation of the production gyrotrons, there have been several significant successes in the program which have validated many of the earlier design decisions. First and probably foremost was the decision to use the diode geometry rather than the triode configuration. These new tubes have come online in much less time and have exhibited a much larger operating window compared to their triode predecessors. The decision to have the rf output beam be generated as a true gaussian beam rather than the flattened beam has also been validated. The single focusing mirror scheme has worked quite well. Since the output beam is rather predictable from one gyrotron to another, we were able to use the same mirror on the second production gyrotron as was cut for the production #1 gyrotron, without any noticeable degradation in the waveguide coupling efficiency [measured power loss in the mirror interface unit (MIU)]. An added feature of this single mirror configuration is the reduction of stray/uncoupled power lost in the MIU. On the non-gaussian gyrotron systems there was ~15% of the output power lost in the MIU. This is in contrast to the ~7% power loss associated with the new configuration.

4. EXPERIMENTAL RESULTS

With the newly acquired ability to steer the rf beam to different locations between shots and the great repeatability of plasma conditions from shot to shot, has come some very interesting information on the transport barrier behavior. Figure 2 depicts the electron temperature (T_e) versus plasma radius (p) associated with the EC power being deposited at various locations. Of particular interest is the sharp drop in T_e when the EC is pointed at the transport barrier location (ρ=0.35). Another interesting observation is in the area of plasma performance enhancements even after the EC power has been removed. Figure 3 shows the measurement of the electron temperature (T_e) and neutron production rate S_N) of the T_e on consecutive shots where EC power is applied to one and not the other. Note the higher achieved T_e and S_N later in the shot with the EC power as compared to the one without.

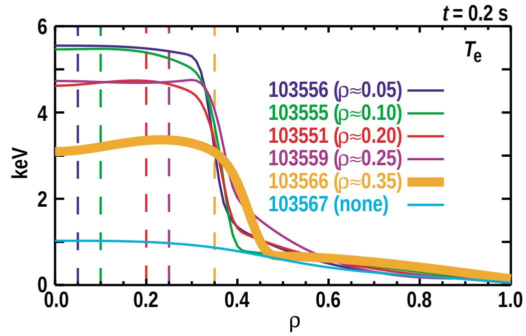

Fig. 2. T_e versus EC target location ρ.

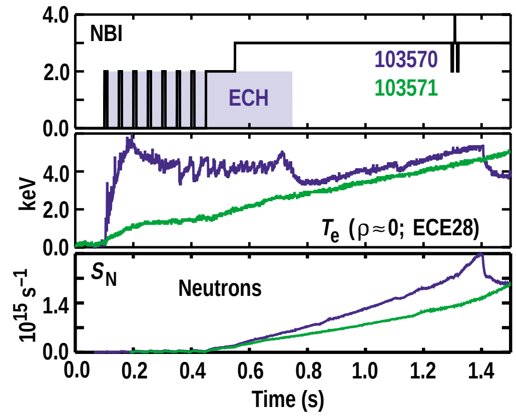

Fig. 3. Enhancements in T_e and S_n after ECH turnoff.

5. CONCLUSION

Even though we have just begun to evaluate the performance of the new gyrotrons, it is already obvious that several of the decisions made early in the design phase of the upgrade have paid off. The diamond window has allowed for not only longer high power pulses, but for almost direct coupling of the rf beam into a waveguide. This alone has resulted in ~5% more power being coupled into the waveguide system. The use of a diode gun gyrotron has made the operation of the gyrotrons much easier and the new gyrotrons have exhibited a much greater tolerance to magnetic field and beam voltage fluctuations. The ability to change out gyrotrons without having to also change coupling mirrors and their associated alignment process has meant that it is possible to replace gyrotrons and have them operational in a much shorter period of time than the previous generation of gyrotrons also used on DIII–D. Further operational time will be needed to validate the robustness of this new design but early indications are that these gyrotrons should be much more robust than any of the previous tubes used at DIII–D.

REFERENCES

[1] C.M. Greenfield, *et al.*, Proc. of 41st American Physical Society Annual meeting, Division of Plasma Physics, November, 1999, Seattle Washington.

[2] W.P. Cary, *et al*., Proc. of the 18th IEEE/NPSS Symp. on Fusion Engineering, Albuquerque, New Mexico, 1999.

[3] R.W. Callis, *et al.*, Proc. of the 20th Symp. On Fusion Technology, Marseille, France, 1998.

[4] H.J. Grunloh, *et al*., Proc. of the 18th IEEE/NPSS Symp. on Fusion Engineering, Albuquerque, New Mexico, 1999.

Acknowledgement

Work supported by U.S. Department of Energy under Contract No. DE-AC03-99ER54463.