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ABSTRACT

The planned growth in the EC system on DIII–D over the next few years requires the installation of two depressed collector gyrotrons, a high voltage power supply, two low loss transmission lines, and the required support equipment. This new DIII–D EC equipment could be made identical to the ITER EC system requirements. By building the DIII–D hardware to the ITER specifications it will allow ITER to gain beneficial prototyping experience on a working tokamak, prior to committing to building the hardware for delivery to ITER.

1. INTRODUCTION

Electron cyclotron resonance heating and current drive (ECH/ECCD), has a multitude of applications beneficial to improved performance in tokamak plasmas. Localized EC heating can be used to modify or enhance the current density profile, leading to a high fraction of pressure produced bootstrap current (>50%). EC waves can be used to produce and extend internal transport barriers to larger plasma radius. And ECCD can suppress performance robbing plasma-instabilities by driving currents in the zones where instabilities are known to originate.

The DIII–D tokamak has had high power 110 GHz EC systems in use since 1995 (Lohr [1]). The first high power gyrotrons had pulse length limits of 0.6 to 2 s owing to thermal stress limits of the window material. With the availability of CVD diamond windows the pulse length was extended to multiple seconds. The introduction of collector depression has lead to higher efficiency and the possibility to go to even higher output power. The next generation gyrotrons offer power levels to 1.5 MW or higher, at efficiencies as high as 52%.

2. OVERVIEW

The 110 GHz ECH system for the DIII–D tokamak consists of six assemblies (see Fig. 1). Each assembly consists of a gyrotron, a gyrotron superconducting magnet, a gyrotron/magnet supporting tank, a low loss transmission line, a launcher, associated controls and high voltage power equipment. By 2005 all six gyrotrons will be long pulse gyrotrons, manufactured by Communication & Power Industries (CPI), having a nominal rating of 1 MW, 10 s. The US Gyrotron Development Program, funded by the DOE, is in the processes of constructing a 1.5 MW 110 GHz gyrotron with testing using the DIII–D EC facility by the end of 2004. In the next expansion of the DIII–D EC system it is anticipated that two of these new generation gyrotrons will be added bringing the total installed power to 9 MW. However, with the advent of the ITER program (Bosia [2]), there is a possibility that the US Gyrotron Development Program will be redirected to support the development of a 120 GHz gyrotron, in which case it could be beneficial to the DIII–D program to incorporate these gyrotrons into the system as the next EC enhancement step.

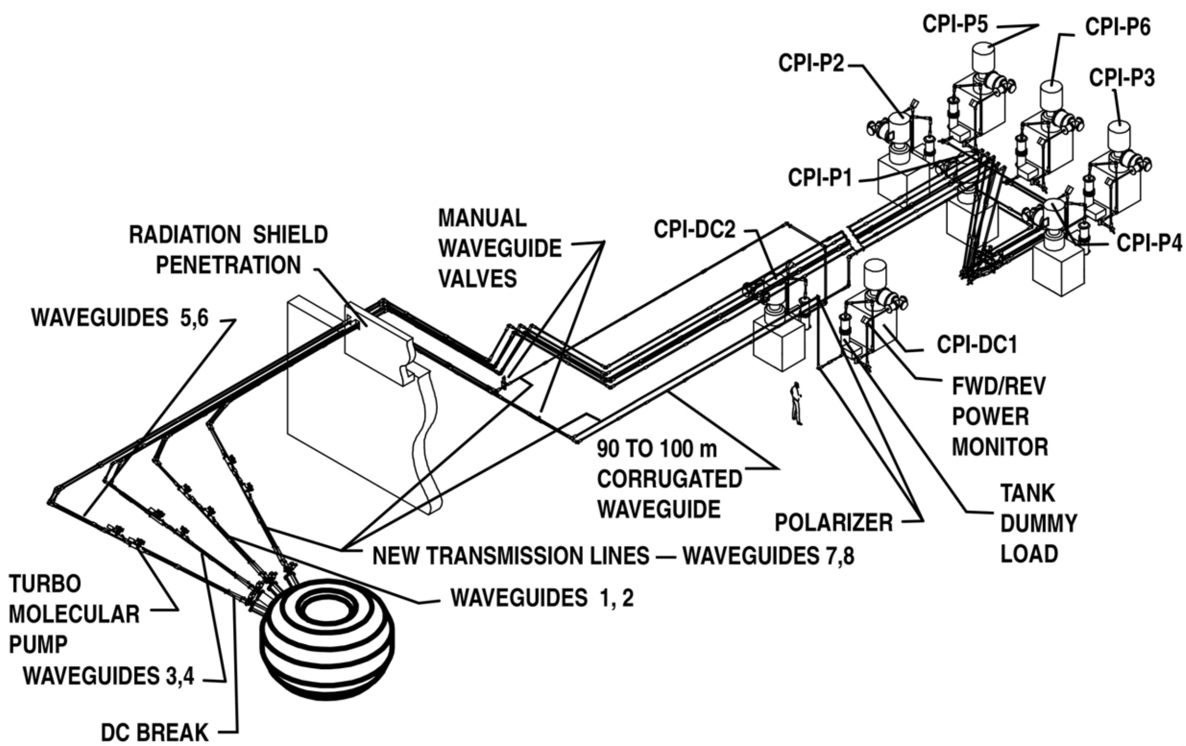

Fig. 1. Schematic of the DIII–D EC system, showing the location of the gyrotrons and the routing of the transmission lines. Key waveguide components are also identified.

2.1. LONG PULSE GYROTRON

The long pulse 1 MW 110 GHz gyrotrons used in the DIII–D ECH system are an internal-mode-converter design with a Gaussian output rf beam (Felch [3]). The 1.5 MW 110 GHz gyrotron is similar to the 1 MW version with the addition of a depressed collector allowing for an increase in power without the need for a larger collector (Blank [4]). To operate at higher powers the electron gun was modified for operations at a beam voltage of 96 kV, and the interaction cavity, although using the same TE22,6 mode, was modified to optimize operation at 1.5 MW (Blank [4]). Another change was that the aperture of the CVD diamond output window was increased from 50.8 mm to 88 mm to reduce the thermal stress in the window, by reducing the thermal gradient. A schematic diagram of the gyrotron is shown in Fig. 2.

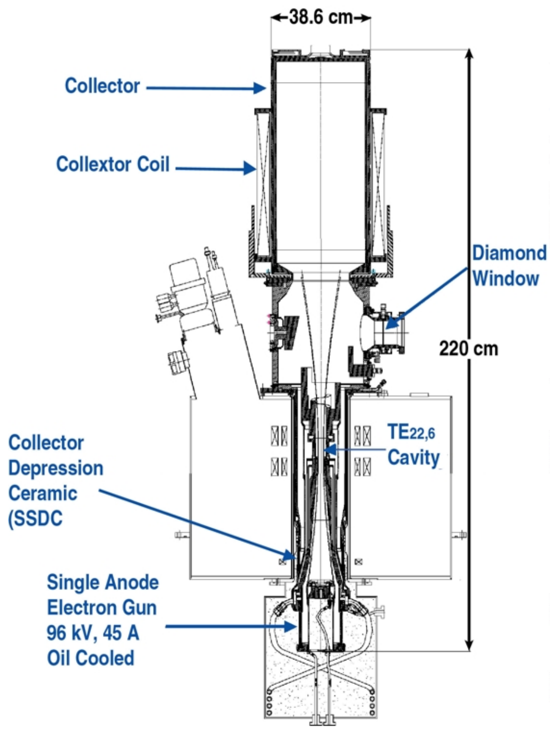

Fig. 2. Schematic view of the CPI 1.5 MW 110 GHz depressed collector gyrotron.

Short pulse testing of the cavity, at MIT, resulted in a power measurement of 1.4 MW (Anderson [5]), with the lower power level being attributed to a lower achieved beam alpha. It is anticipated that when the launcher and mirrors are added the final output power will be reduced to 1.3 MW, thus to increase the power capability the next embodiment of the gyrotron will need a higher mode cavity. It is also anticipated that the US Gyrotron Development Program will be realigned to support the ITER needs, requiring the gyrotron to be higher power (up to 2 MW) and operate at 120 GHz. Thus if DIII–D uses these next generation gyrotrons the DIII–D EC system will get an added boost in power and ITER will get valuable field testing of components prior to use on ITER.

3. TRANSMISSION LINE

Each gyrotron is connected to the tokamak by a low-loss–windowless, evacuated transmission line using 31.75 mm diameter circular corrugated waveguide for propagation of the HE_{11} mode (see Fig. 1). Each waveguide system incorporates a power monitor, a waveguide switch, two grooved-mirror polarizing mitre bends, several flat mirror mitre bends, a pumping section, a DC break, and terminating in a two-mirror launcher in the tokamak. The launcher can steer the rf beam poloidally from the center to the outer edge of the plasma, and can also scan ~±20° in toroidal direction. A poloidal scan across the tokamak upper half plane takes about 2 s

For the two new depressed collector gyrotrons, two new transmission line systems will be installed. In order to handle the anticipated higher power the transmission lines will be assembled from components developed for the ITER EC system (Olstad [6]).

4. POWER SUPPLIES

A new power supply system will be needed for the depressed collector gyrotrons. An advantage that a depressed collector gyrotron has over a standard gyrotron is that the electron acceleration voltage is the additive sum of the cathode voltage and the body voltage, with the body power supply only having to source capacitive currents during turn-on, the gyrotron has a low capacitance of 130 picofarads. Thus the highly regulated body supply operates at relatively low currents (20 – 50 mA) and modest voltages (30 kV). The bulk current is from the cathode supply, which can be fabricated from simple solid state devices, such as Insulated Gate Bipolar Transistors (IGBTs).

The body supply will be a Trek Model PD04013, which is a high-voltage power amplifier designed to provide precise control of output voltages in the range of 0 to +30 kV DC, with an output current range of 0 to ±50 mA, and a slew rate of > 350 V/μs. The cathode supply will use the transformer-rectifier sets identical to those used on the present systems, which are rated 40–100 kV, 100 A. While the voltage regulation equipment will be a solid state pulse-width-modulated regulator using IGBT solid state devices, with an IGBT fast series switch to protect the gyrotron in case of a fault. Where possible the IGBT modules will be identical to those developed for the ITER EC power supply. Figure 3 gives a one-line schematic of the power supply.

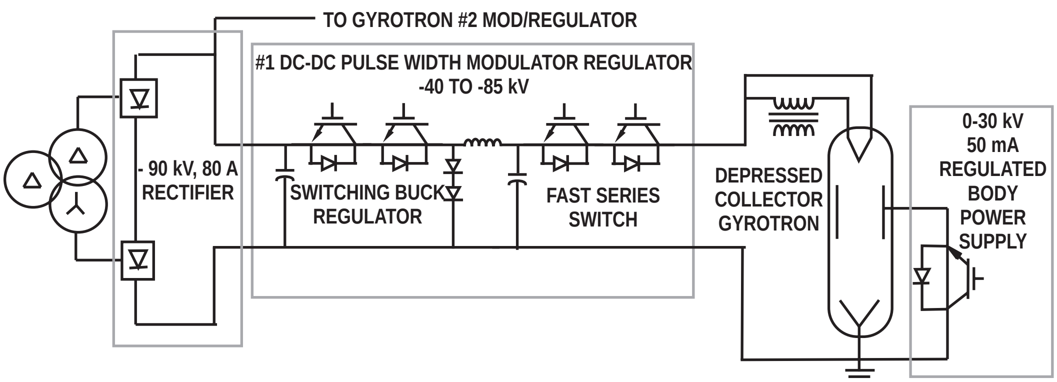

Fig. 3. Schematic of the depressed collector power supply, showing the transformer rectifier set, the pulse width modulated regulator, the fast series protection switch, and the high speed highly regulated body power supply.

5. SUMMARY

The DIII–D program will in the near future be adding two depressed collector gyrotrons to the EC system. Beside the new gyrotrons there will be two new transmission lines and a new power supply. Owing to the anticipated realignment of the US Gyrotron Development Program to match ITER EC needs, the DIII–D EC additions will try to incorporate as much of the ITER hardware as possible, so that the system can produce and handle higher power, more reliably, for longer pulses. And ITER could benefit by getting field testing of these components prior to installation on ITER.

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