§3. Development of Vacuum Corrugated Transmission Line Components

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Eight gyrotrons with six 3.5 inch and two 1.25 inch corrugated waveguide transmission systems are routinely used in LHD. The length of each transmission line is almost 100 meters and has 10 to 20 miter bends. Among the six 3.5 inch waveguide systems, two of them had been evacuated and operated for the use of the high power long pulse operation up to 500 kW, 3s. A new 77 GHz gyrotron that had been developed under the collaboration between University of Tsukuba and NIFS is connected to one of the 88.9 mm evacuated waveguide systems. The specification of this gyrotron is 1MW/3s, and 300 kW/CW. In accordance with this gyrotron, several modifications to the waveguide system are performed.

The miter bend is one of the critical components for the high power long pulse transmission system. To improve the heat removal capability, water cooling channels on some of the miter bend block are fabricated in addition to those on the reflecting plates. The method to make perfect corrugation up to the 45° cut waveguide is developed. The fabrication of the miter bend block with this corrugation and with the cooling channels became possible in the NIFS machine shop. The o-ring seals at the connection between the miter bend block and the straight waveguide are replaced by those of metal gasket in order to attain higher vacuum condition, to be less absorption for the leakage power and to be safe for higher temperature. Several miter bends are already replaced by those of this new type and used during the experimental campaign in the fiscal year of 2007.

Originally the 3.5 inch corrugated waveguide system is designed to allow 1 MW/CW transmission at atmospheric pressure for HE_{11} mode, but it became clear that the higher order mode contamination at the power coupling at the waveguide inlet or the generation due to the mode conversion at miter bends or waveguide connection can enhance electric field inside the waveguide and therefore can trigger the arcing as well as increasing the transmission loss due to the higher loss rate of the higher order modes. This is the main reason why the systems are evacuated to reduce the chance of arcing. The loss of the waveguide, however, inevitably higher than that expected from pure HE_{11} mode due to the mode conversion at the miter bends. The heat generation due to the loss, in particular in the high power CW operation become severe problem for the waveguide system. In order to accommodate with high power CW operation, copper plates with water cooling channels are attached all along the 3.5 inch waveguide system used for the 77 GHz new gyrotron.

The window used at the LHD antenna is replaced to that of CVD diamond. This window is similar to that used at the gyrotron output window, but with the corrugated waveguide inserted just near the surface of the CVD diamond from both LHD and transmission line sides so to minimize the gap in the waveguide. The connecting waveguide at this window is also upgraded. Two observation cut-off holes at the sides of the corrugated waveguide are drilled in 45° to the waveguide axis to see the center of the window. The mounts for the arc detection fiber optic and infrared (IR) temperature monitor are installed on these holes (Fig. 1). This system worked well up to the 640 kW/3.6 s injection which was the maximum power and pulse width injected into LHD during the experiments in the fiscal year of 2007. In Fig. 2 are shown the time evolution of the window and some other parts of the transmission line. The IR temperature monitor shows a reasonably fast response with the rising time scale of about 10 s to the transmitted pulse and the surface temperature is kept well below the safety. The comparison between the temperature rises at the back side of miter bend mirrors with and without water cooling channels indicates that the water cooling at the reflecting plate is effective and necessary for the high power CW operation.

Similar upgrades are planned for an existing 3.5 inch waveguide system to transmit the power from one more new 77 GHz gyrotron that is developed in FY2007.

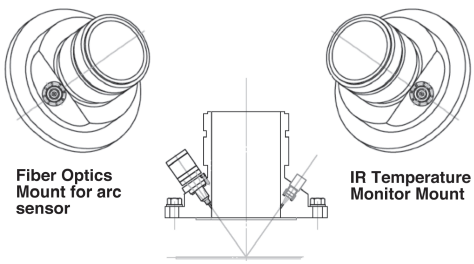

Fig. 1. Corrugated waveguide connected at the vacuum window equipped with the ports for arc sensor and IR thermometer.

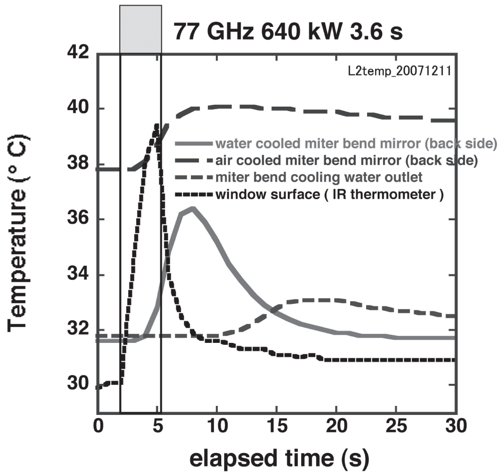

Fig. 2. Temperature evolution at several transmission components during 77 GHz/640 kW, 3.6 s injecton.