TEST RESULTS OF THE 84 GHZ / 200 KW / CW GYROTRON

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Information about produced in 2003 CW gyrotrons is presented. 84 GHz gyrotron is designed for operation in two regimes: 200 kW / CW and 500 kW / 10 s. During tests in NIFS, Japan following regimes was achieved: 200 kW / 180 s and 400 kW / 10 s after MOU. 82.7 GHz gyrotron is intended for operation in IPR, India. During it's factory acceptance tests 200 kW, 1500 s regimes were demonstrated. Besides gyrotrons the systems include magnets, matching optic units (MOU), dummy loads and transmission lines. Main characteristics of this components are shown.

Activity of GYCOM during two last years was connected with production 200 kW CW gyrotrons intended for plasma heating experiments in National Institute for Fusion Science, Japan and in Institute for Plasma Research, India. At the fig.1 the external view and main dimensions of the 84 GHz CPD gyrotron are shown. Gyrotron uses the brazed diamond window disk from de Beers. It's setting diameters in cryomagnet equal 139 / 140 mm. Gyrotron has diode-type electron gun with cathode diameter 69 mm, power depression lens is located after cavity-radiator unit, all mirror of quasi-optic converter are grounded. CPD insulator is placed under the cryomagnet, during CW operation it is cooled by oil. Cavity operating mode is $TE_{12.5}$, the stray radiation inside the tube is absorbed by inner absorbers with developed surface. The gyrotron has 12 circuits of water cooling, for CW operation achievement all elements of tube including the body are designed with one's own cooling. In June, 2003 the gyrotron was finally tested at the GYCOM's site factory in N.Novgorod. The designed output parameters was 200 kW in CW operating regime and 500 kW in 10 s operating regime.

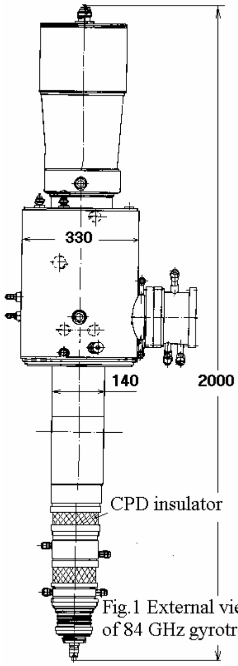


Fig.1 External view of 84 GHz gyrotron

At the Fig.2 the dependencies of gyrotron output power and efficiency on the beam current are shown. The graphs were taken off in long pulse regime. Calculated accelerating voltage equals 68 kV. Output power about 200 kW was obtained at beam current 9 A, cathode voltage U_c=-46 kV, anode voltage Ua=+22 kV with efficiency almost 49.5%. Power 500 kW was obtained at the current 21 A at the same beam voltage with efficiency 52%. Optimum regime of oscillation was 360 kW output power at beam current 13.5 A with efficiency 58%.

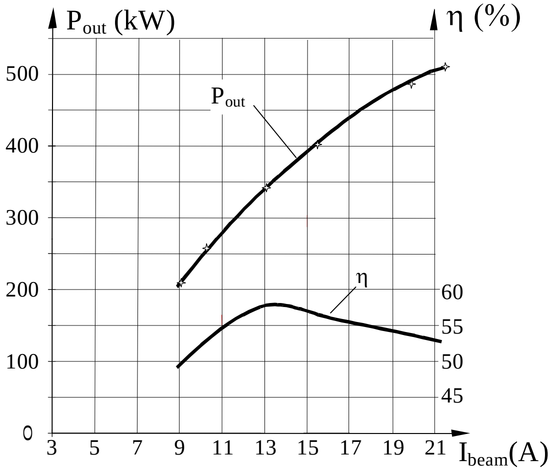


Fig.2 Output power P_{out} and efficiency η vs. electron beam current I_{beam}.

The power losses were measured in different gyrotron system units. The result is: 11% is loosed in inner gyrotron absorbing surface, including gyrotron body, 0.75% is loosed in diamond window unit, not only in the disk. Gaussian wave beam purity after the output window appeared to be about 93%, 9% of penetrated through the window power is absorbed in MOU.

The gyrotron in November 2003 and January 2004 was tested at the customer site in NIFS at the vacuum system conditions. Additionally the system consists of GYCOM's vacuum MOU with pair mirrors for 31.75 mm in diameter wavequide transmission line feeding, magnet without liquid helium filling provided by the NIFS, dummy load and wavequide line, produced by General Atomic. In the Table 1 the demonstrated operating regimes are shown. The system worked as in dummy load and in LHD machine. Operation in machine was more reliable and useful for gyrotron because of power reflection from it was less than from dummy load. But long work in CW regime with waveguide line caused the waveguides overheating and pressure rise as result. This reason limits the gyrotron system operation at the present stage.

Table 1. Demonstrated in NIFS operating regimes (during tests in NIFS the efficiency of operation was less than during factory tests because of the operating regime did not optimized).

n	P_{out}, kW	τ, s	U_c+U_a, kV	U_c, kV	I, A	Note	Reason of operation stop
1	145	690	67	51	9.2	In dummy load	Pressure rise

2	200	240	67.5	51	9.5	In LHD machine	Pressure rise
3	400	10	67	49	19	In dummy load	Arc-detector

At the Fig.3 oscillograms of gyrotron CW operation on the 200 kW output power level are shown.

The oscillorams confirm that stabilization of the gyrotron operation was achieved. Full thermal balance takes place after about 4 minutes, during this time the beam current stops to growth and it deviation does not exceed 5% (about 0.5 A on the 10 A level). The current of ion pump does not growth after about several hundred milliseconds.

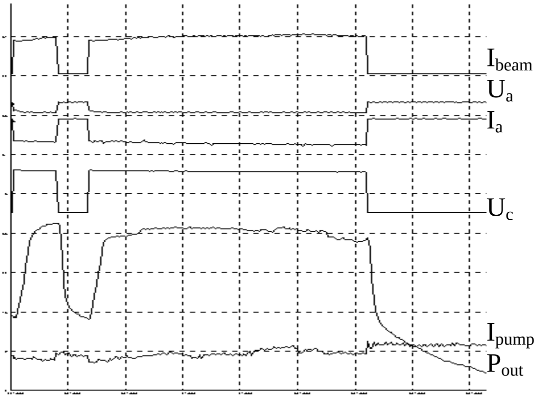


Fig.3 Oscillograms of 84 GHz gyrotron CW operation.

The photos 1, 2 show view of gyrotron lower part prepared for installation into the oil tank and the gyrotron installed in magnet with side view of MOU.

Photo 1. Gyrotron lower part.

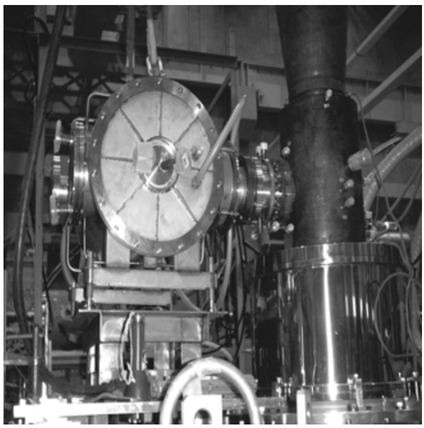


Photo 2. Gyrotron in magnet and MOU.

The design of second produced 200 kW CW gyrotron little differs from the previous description. The main are: 157 / 158 mm setting diameters in the cryomagnet, relief window for stray radiation remove, cavity operating mode $TE_{10.4}$, cathode diameter 51 mm. Designed regime is 200 kW CW operation after transmission line. Testing longevity of operation equals 1000 s. All gyrotron system components - gyrotron, cryomagnet, MOU for waveguide transmission line with diameter 63.5 mm feeding and calorimetric load - were elaborated and manufactured in GYCOM. The system is able for operation with over pressure about 0.5 atm.

The dependencies of the output power and efficiency on the beam current at the optimized regimes are shown at Fig.4. Measured output power losses distribution is: gyrotron inner absorbed surface 6%, relief window 5%, diamond window unit 0.55% (it is less than in 84 GHz gyrotron due to the more narrow output wavebeam), MOU 12% and transmission line 6%.

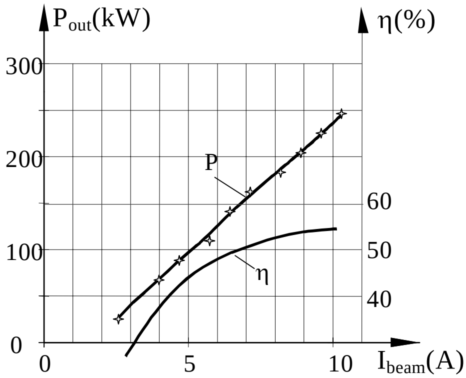


Fig.4 Output power P_{out} and efficiency η vs. electron beam current I_{beam}.

Oscillorams at Fig.5 of the 1000 s gyrotron operation with continues output power measurement by calorimetric load confirm the gyrotron stable and reliable operation. During factory acceptance test the regime with 1500 s continues operation was demonstrated, maximum HF energy in the tube switching on was about 0.3 GJ.

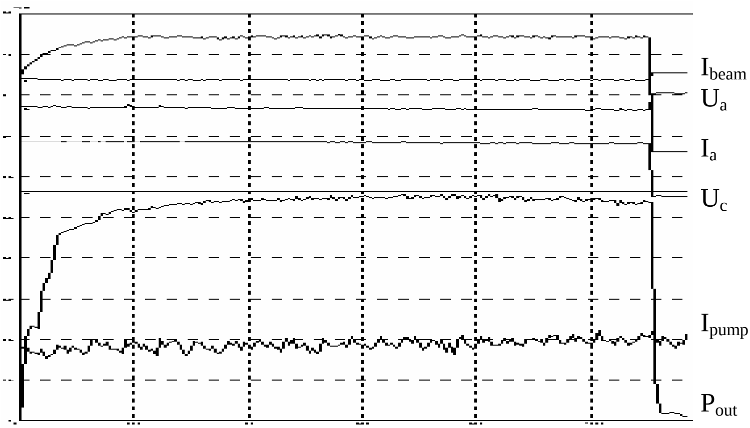


Fig.5 Oscillograms of 82.7 GHz gyrotron 1000 s operation.

Modification of 82.7 GHz CW gyrotron with BN window and lowered up to 30 kV cathode voltage, 15 kV anode voltage operates with output power 35 kW in Guardian Industries company since 2003. The photos 3, 4, 5 show gyrotron in cryomagnet with the relief load, MOU and side view of the transmission line fragment.

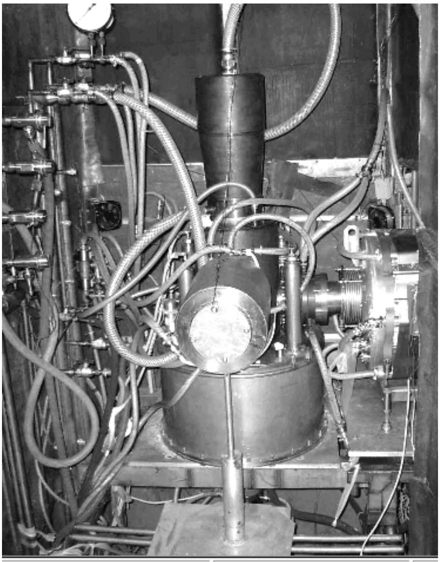
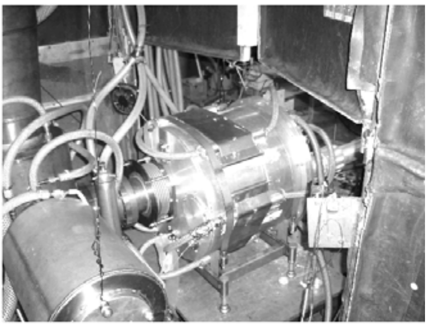
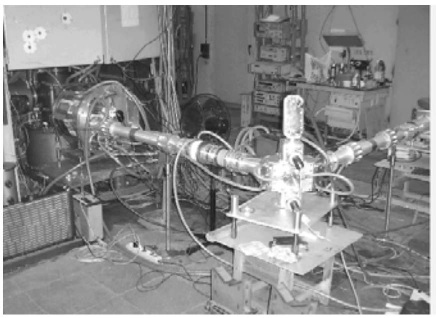


Photo 3. Gyrotron in magnet

Photo 4. MOU

Photo 5. Waveguide line





The conclusions are: two CW gyrotrons with 200 kW output power were produced and tested up to 1500s operation longevity, full thermal stabilization in the gyrotron system was achieved during about 4 – 5 minutes, utilization of relief window and stray radiation absorbers successfully decreases the thermal load in the gyrotron body at mentioned power level. But the rise of CW output power up to 500 kW and more in existing gyrotron design will cause the problems, which can be resolved by launcher utilization. At the present time GYCOM specialists fulfilled cold experiment with cavity operating mode $TE_{12.5}$ launcher, which demonstrated about 95-97% mode converter efficiency. Design of 84 GHz gyrotron is modified for 500 kW CW operation with tested launcher utilization. For purpose of production 170 GHz / 1 MW CW gyrotron the operating mode $TE_{25.10}$ launcher was calculated, manufactured and tested in short pulse experimental gyrotron in IAP. The result confirms 95-97% mode converter efficiency.