DEVELOPMENT OF 170 GHZ/ 1MW/ CW GYROTRON FOR ITER

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Recent test results of 170 GHz/1MW/CW gyrotron being developed in Russia within the ITER program are presented. At pulse duration of 0.1 s, power of 1.15 MW in the output Gaussian beam was attained. In the experiments on pulse extension, output power was not so large considering performance capabilities of high voltage source. At output power of 0.85-0.9MW, the gyrotron pulse could be extended to nearly 20 s. It turned out that transmission line elements rather than gyrotron itself were responsible for pulse limitation.

To provide gyrotron reliable CW run, present level of stray radiation is to be sufficiently lowered. Denisov converter designed to reduce the stray radiation fraction from 11% to less than 3% of generated power will be used in modified gyrotron. New converter was embedded in short-pulse gyrotron mock-up and tested. Long-pulse gyrotron test is planned to the end of the year.

Searching ability to have higher power design of 2MW/170GHz/CW gyrotron has been started. Short-pulse mock-up will be tested in the current year and long-pulse gyrotron prototype will appear in 2005.

Introduction

Gradually approaching ITER requirements, Russian specialists intensively develop 170GHz gyrotron capable to produce above 1MW CW output power at 50% efficiency. Large experience accumulated in the recent years was used to modify sequentially gyrotron design aiming at improvement of cooling, rise of efficiency, reduction of internal losses and stray radiation. Present design [1,2] of 170GHz/1MW/CW gyrotron, which is shown in Fig.1, stipulates usage of following main components and principles:

- Depressed-collector with longitudinal sweeping of worked-out electron beam
- Main output window with 88-mm CVD diamond disk complemented by relief window with 102-mm BN disk
- Built-in quasi-optical converter with four mirrors– three mirrors under beam accelerating voltage and the last adjustable mirror – under ground potential.
- Retarding voltage isolator placed above the cryomagnet (the gyrotron body must be isolated from cryomagnet housing) and provided by flexible cuffs for welding, outside ceramic supports to remove any mechanical stress and inner copper shield to protect ceramic from overheating by scattered RF power.
- Cavity designed for $TE_{25.10.1}$ mode operation.
- Diode type electron gun designed for beam current up to 50A.
- Copper solely used as a material for all inner surfaces with intense water-cooling adequate to CW operation.

Two gyrotrons of this design with few intermediate modifications, which were fabricated and tested, demonstrated stable reassuring results.

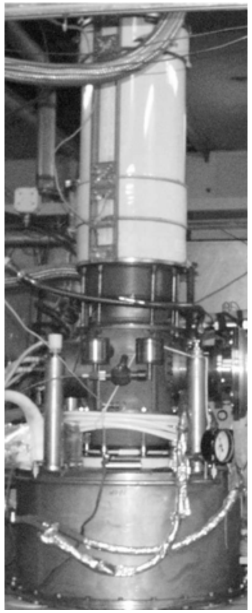

Fig.1 Gyrotron in the test facility

Experimental Results

Gyrotron features are illustrated by Fig.2 where behavior of power transported by output Gaussian beam along with oscillation power and corresponded efficiency are shown as functions of electron beam current at beam voltage of 84 kV. Measurements were made at 0.1s pulse duration acceptable for used calorimetric load.

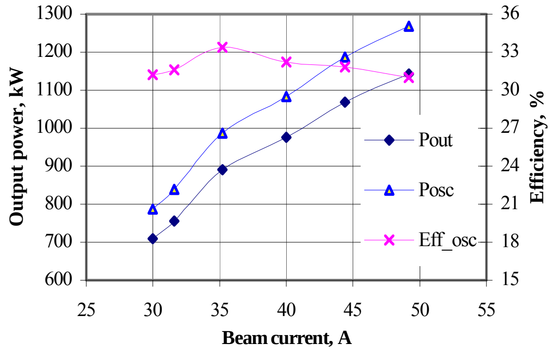

Fig. 2 Gyrotron output power & efficiency vs. beam current

Considering ability to run high voltage power supply with available 120-s pulse duration, regime with 900-kW output power attainable at lower voltage and current was primarily chosen for pulse extension.

Table 1 given below shows the summary of test results ranged following attained power of output Gaussian beam, P_{out}, and pulse duration, τ. Operating regimes are illustrated by values of beam current, I_{beam}, beam voltage, U_{beam}, and efficiency at correspondent recuperation voltage, U_{rec}.

Table 1 Summary of test results

P_{out}, MW	*Eff.*, %	I_{beam}, A	U_{beam}, kV	U_{rec}, kV	Pulse duration	
					τ, s	Limited by
1.15	42	49	84	29	0.1	Load capacity
0.9	44	38	81	28	19	Load arcing
0.7	44	30	80	28	42	MOU arcing
0.5	40	26	76	22	80	Load arcing

Arcing arisen in terminating load or elements of mirror transmission line prevented from either reaching named source limit even at further reduced power level or disclosure of gyrotron serious intrinsic shortcomings. Low drift of operating frequency (~50 MHz) instilled confidence in efficient cavity cooling. Problem with long-term instability of beam current was managed to solve by step tuning of heater current as it is illustrated on Fig. 3. Body current, which looked too high and had tendency to rise during the pulse was managed further to make much lower by application of coating suppressing secondary emission on inactive cathode surfaces.

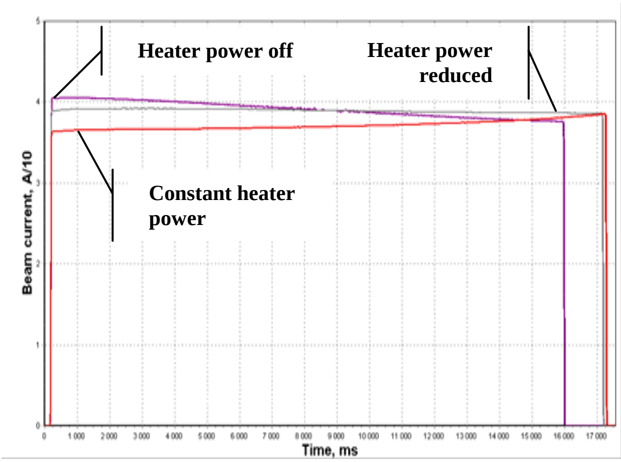

Fig.3 Behavior of gyrotron beam current under heater power step tuning at the pulse start

Table 2 illustrates gyrotron power balance composed basing on plenty measurements carried out in similar regime at various pulse durations.

Table 2 Gyrotron power balance

Power components	Value			Method
	Abs, kW	% to P_t	% to $P_{g.b}$	
Total power input, P_t	2009	100		$U_{beam} \times I_{beam}$
Total generated power	1015	50.5		
Gaussian beam power, $P_{g.b}$	875	44.2	100	calorimetry 0,1 s
CVD diamond window dissipation	2		0.2	calorimetry
Cavity+mirrors dissipation	43		4	calorimetry
Total stray radiation	95		11	
Absorbed in the MOU	50		6	calorimetry 0,1 s
Absorbed in the relief load and BN relief window	41		4.6	calorimetry
Radiated through DC break	4		0.4	calorimetry
Collector power dissipation	990	49.3		estimation
Anode power dissipation	4	0.2		calorimetry

Gyrotron with upgrade mode converter

Most important shortcoming inhere in present gyrotron design is relatively high fraction of stray radiation, measured as 11% of output power. This radiation could cause overheating of DC break ceramic insulator and BN relief window. Temperature monitoring of these ceramic parts allowed to forecast that the retarding voltage insulator under forced air-cooling will not actually impede 1MW/CW operation

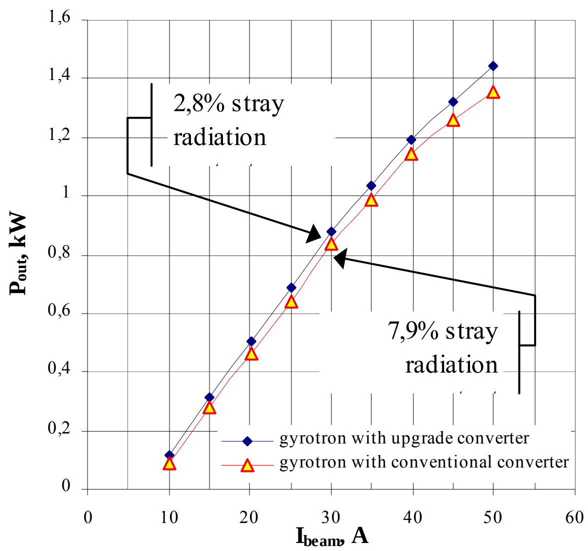

Fig.3 Output power at U_{beam}= 80 kV vs. beam current of gyrotrons with conventional and upgrade mode converter

whereas window overheating will be the potential reason of pulse duration restriction. Limit pulse duration for the gyrotron of given design is estimated as 60s at 1MW power. Pulse duration of 1000s could be available at 0.7MW power.

For elimination of the found out potential restrictions development of new quasi-optic gyrotron system with pre-shaping is conducted now. An upgrade internal converter consisting of a dimpled-wall waveguide launcher (so called Denisov launcher) and four mirrors produces an output beam with theoretical Gaussian mode content of 99,5 % and diffraction losses as little as 2,3 %.

To verify the proper behavior of the converter, a short-pulse gyrotron mock-up has been built and tested. Power measurements made for gyrotron with conventional and upgrade mode converters are compared in Fig.3

The measured power of stray radiation has decreased from 8 % to 3 %. At the first experiment, rather simple quadratic mirrors were used and radiation quality appeared not ideal. For improvement of the wave beam form and additional decrease of stray radiation to a level of 2 %, phase correcting mirrors of synthesized shape are now designed. After design verification on short-pulse model, new converter will be used in the following prototype of ITER gyrotron, which is planned to assemble at the end of this year. If the opportunity of stray radiation reduction to a level of 2-3% will be proved, all known for the present moment restrictions on the pulse duration except for external factors will be eliminated.

Rising of gyrotron power

Capacity of CVD diamond output window estimated at 2-3MW and progress recently achieved in development of 170GHz/1MW/CW gyrotron specifically due to usage of such windows permits to think about further rising of gyrotron power. Actual aim is increasing of output power of 170GHz gyrotron up to 1.5-2MW. Set of works involved in solving of main problem have been started:

- Working out cryomagnet with 190-mm diameter bore and magnetic induction of 7.3 T
- Building of power supplies providing beam voltage of 100-120kV at beam current of 50-70 A in CW regime
- Calculations essential for proper choice of operating mode with azimuthal and radial indexes laying correspondingly in the range of m=25…31 and n=12…19
- Design of diode or triode type electron gun capable to produce stable3-4MW electron beam
- Development of internal mode converter with diffraction losses less then 3 %
- Design of collector capable to withstand up to 3-MW power

Summary

The design of 170GHz/1MW/CW gyrotron with depressed collector and CVD diamond window was developed for ITER. Two gyrotrons of this design have been made and tested.

0.1s/1.15MW, 19s/0.9MW, 42s/0.7MW and 80s/0.5MW were attained last year. Imperfection of terminated load and mirror transmission line limited further progress of output power and pulse extension. Potential limitation of these gyrotrons is estimated as 60s/1MW due to relief BN window overheating by stray radiation. 1000-s pulse could be available at 0.7MW power.

For the purpose of stray radiation considerable decrease, upgrade converter for $TE_{25.10}$ mode was developed, manufactured and tested in short-pulse mock-up. Stray radiation near 3% of radiated power was measured. The gyrotron with upgrade mode converter is planned to be made this year. The design objectives are 1.2MW/50%/CW. RF load and mirror transmission line are improved now to withstand named power.Project of 1.5-2MW gyrotron meaning new cryomagnet with 190-mm bore and new 120kV/70A/CW power supply is under development.

References

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