FREMIX: a high power 8 GHz plasma heating experiment

FREMIX: A HIGH POWER 8 GHz PLASMA HEATING EXPERIMENT

by

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ABSTRACT

A survey will be given of the problems encountered in the assembly and the operation of the 40 kWCW 8 GHz equipment used for the FREMIX-experiment. This experiment aims at resonant ion heating in a magnetic bottle at frequencies which are the product of non-linear mixing of electron cyclotron resonance waves.

The problems can be divided into three categories:

1. The requirements for operation of two klystron amplifiers: power supplies with protective equipment, steering circuitry, cooling water.
2. Wave guide system: arc protection, circulators, vacuum window.
3. The construction of the plasma chamber; the introduction of diagnostic tools: 4-mm interferometry, X-ray detection escaping particle analysis, detection of excited radiation and mixing products (1-5 MHz; 16 GHz).

I. PURPOSE OF THE EXPERIMENT

1) Study of non-linear mixing processes of two electromagnetic waves in a magnetic bottle at slightly different frequencies in an electron cyclotron resonance plasma.
2) Study of possible ion heating by choosing the different frequency equal to a typical ion frequency (ω_{ci}, ω_{LH}).

II. EXPERIMENTAL FACILITY

1) The magnetic field, generated by 4 watercooled air coils, has a mirror geometry with mirror ratio R = 1.2. Electron cyclotron resonance occurs at 0.28 T for 8 GHz. By setting the magnetic field the distance between the resonance zones can be chosen between zero and 0.25 m, which corresponds to the length of the plasma chamber.
2) The microwave power sources are two 20 kWCW 8 GHz klystron amplifiers (Sperry SAX 4188) driven by two 2 K39 reflex klystrons The main characteristics are: an electronic bandwidth of 50 MHz (± 1 dB), a mechanical tuning range of ± 100 MHz and a power gain of 50 dB minimum. The installation can be operated CW or, by using a switch diode in the driver circuit, in a pulsed mode. At present the pulse length is 1 msec with a duty rate of 0.1. The two driver klystrons are tuned to two slightly different frequencies. Both frequencies are fed to both klystron amplifiers (Fig. 1); the frequencies ly well within the electronic bandwidth. The difference frequency is accurately controlled in a range of 0.5 to 5 MHz by means of a feedback stabilization (± 10 kHz for short time stability).
3) The plasma chamber is an oversized wave guide 8 × 8 cm^2, parallel to the magnetic axis, length 18 cm with tapered transition to standard wave guide WR 112 (RG 52/U) on both sides. The plasma chamber is provided with holes of various dimensions for diagnostics. The microwave power is fed to the chamber transversally to the longitudinal magnetic field; the tapered sections are connected to the wave guide by precision cast E-bends. Thus, only within the chamber, regions occur where $\omega_{ex} = \Omega_{ce}$ and $E_{\sim} \perp B_o$. Furthermore, the bends prevent the charged particles out of the plasma from reaching the vacuum windows. The VSWR inside the chamber as it is measured on a model proved to be less than 1.5.

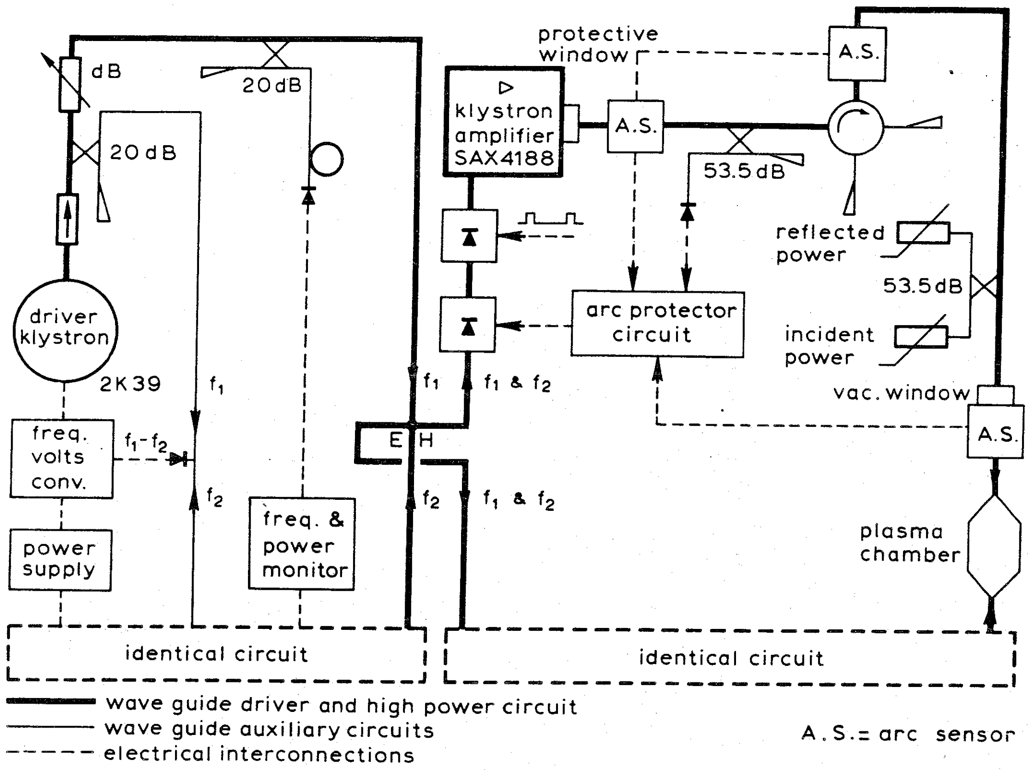

Fig. 1. Microwave circuit

4) The working pressure is 10^{-5} to 10^{-3} Torr H_2 or other gases, e.g. He.

5) Diagnostics:

a) Absorption of microwave power in the plasma chamber: Bolometers for incident and reflected power.

b) 4 mm-interferometer: The measuring wave is reflected by a spherical mirror machined out of the wall of the experimental chamber (Fig. 3).

c) X-ray detection: 2.5"×2.5" NaJ(Tl) scintillator crystal with lead collimator. This crystal receives radiation from the plasma only (Fig.2). Spectrum analysis is performed by

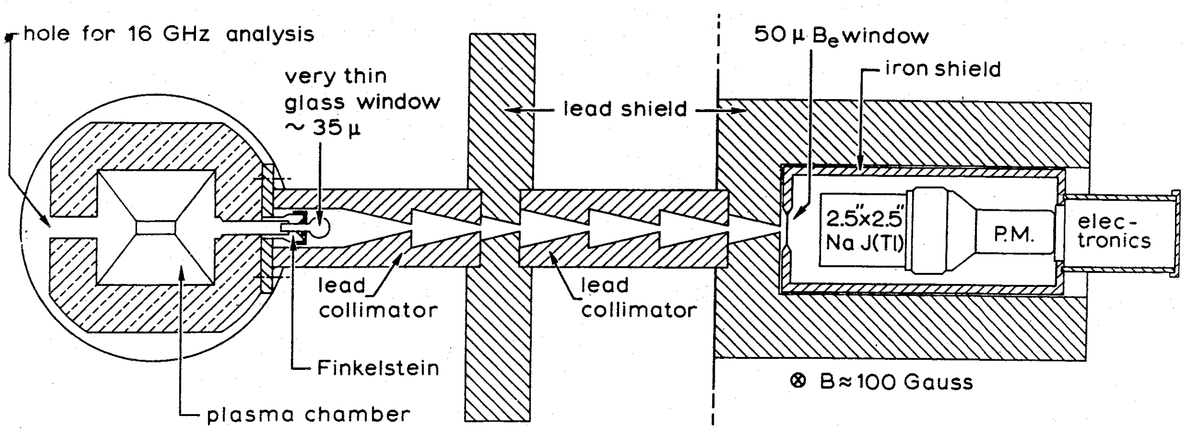

Fig. 2. X-ray detector

a 400 channel pulse height analyzer.

d) Escaping particle analysis: Along the axis through pipes with 2 mm diameter in the 90° bends (Fig. 4).

e) Difference frequency antenna with a coaxial low pass filter having 30 dB suppression of 8 GHz (Fig. 5).

f) 16 GHz antenna: hole with 15 mm diameter with transition to rectangular standard wave guide WR 62 (RG 91/U).

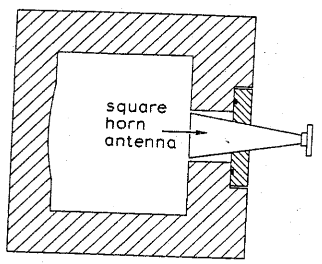

Fig.3. 4-mm interferometer

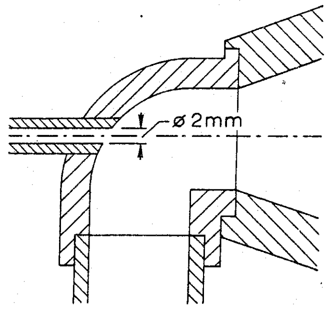

Fig.4. Escaping particle analysis

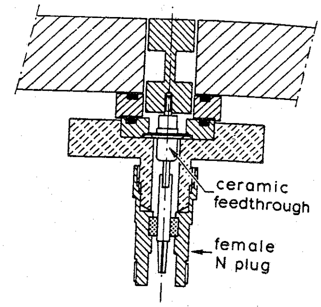

Fig.5. Difference frequency antenna

III. TECHNOLOGICAL PROBLEMS

The major problems concern generation, transport and application of microwave power to the plasma chamber.

1) Installation and operation of the klystron amplifiers. Most protective devices are incorporated in the power supply e.g. the crowbar circuit, which switches off the beam voltage of 20 kV within 4 μsec when an overload occurs. A closed cooling system, using decalcinated water with an anti-corrosion additive (Nalco 39), has a maximum capacity of 150 kW. It provides sufficient cooling of the collectors of the klystron amplifiers (2 × 60 kW dissipation) at a flow rate of 60 l/min.

2) High power microwave system.

Besides the normal precautions in handling CW microwave power, special attention has been paid to the protection against wave guide arcs. The arc protective system consists of several arc sensors, fast acting light sensitive diodes (LS 400), watching the interior of the wave guide system at various positions (Fig. 1). The arc protection is provided at the output windows of the klystron amplifiers, at the circulators and at the vacuum windows. The leading edges of the pulses from the light diodes are amplified and applied to the gates of fast silicon controlled rectifiers (2N 2329). The current through any of the silicon controlled rectifiers can activate the switch diode in the driver circuit to yield an attenuation of 20 dB, which is sufficient to extinguish a wave guide arc. Total switch-off time is 4 μsec. Furthermore the klystron amplifiers are protected against a high VSWR which is monitored by crystal detectors. The output of these crystals is connected to the same protective system. Difficulties have been encountered with the vacuum windows between the pressurized high power wave guide system and the low pressure plasma chamber.

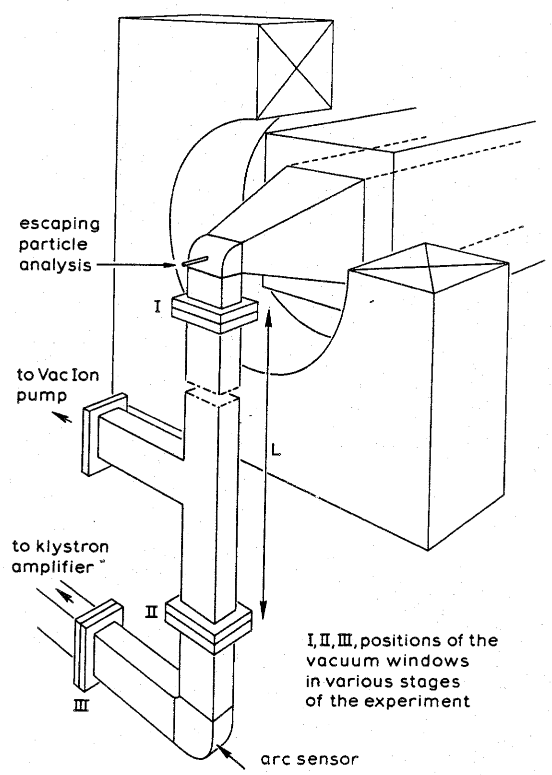

Fig. 6.

At first the windows, of the poker chip type, were located (position I, Fig. 6) within the bore of the magnet system. Both windows broke down when the experiment was operated at 2 × 5 kW peak power (pulse length 8 msec, duty rate 0.5). The damage consisted of a starlike cracking originating from the centre together with some discoloration at the pressurized side. A possible cause of the failure is a multipactor discharge in spite of an anti-secondary emission coating. The presence of the magnetic field, 0.3 T directed parallel to the surface, and possible contamination of the horizontally mounted window by dust particles or an oil film may have facilitated the multipactor discharge.

Because it was thought that the presence of the magnetic field was its dominating cause the windows were moved to position II, where the magnetic field is low (0.01 T). The same type of poker chip windows were used. Again a failure occurred now at a peak power of 2 × 15 kW (pulse length 1 msec, duty rate 0.1); only starlike cracking was found. The probable cause was again a

multipactor discharge in the high electric field strength on the surface of the window due to the combination of high power and high VSWR.
Finally, more rugged 1/2 λ-block windows were installed (position III). Arc sensors facing the window surface were added. An extra bend was introduced so that the windows were mounted vertically now. Possible contamination is further reduced by addition of small getter ion pumps near the windows. So far no failure has occurred at the applied maximum condition: 2 × 1.5 kWCW and 2 × 4.5 kW peak power (pulse length 1 msec, duty rate 0.1). It should be noted that the change of position of vacuum windows (from I to II) to a region of low magnetic field causes the occurrence of new zones where $\omega_{exc} = \Omega_e$, now in the low pressure part of the wave guide system. It has been verified that even under severe conditions (high VSWR, pulse length 100 μsec) no discharge has occurred in those zones. This was expected, since the h.f. electric field there is parallel to the static magnetic field. The connections of the wave guides in the low-pressure part of the system are made by means of a gold wire crushed between thick stainless steel flanges with outer dimensions equal to CPR 112.

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