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DESIGN OF A QUASI-OPTICAL 120 GHz GYROTRON

Quasi-Optical Gyroklystron Development
Group EPFL/BBC

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I) Introduction

In recent years, various countries have started gyrotron development programs aimed towards high power (> 200 kW) and continous operation in the frequency range 100-150 GHz. One application of these millimeter wave sources is the electron cyclotron resonant heating of plasmas in the present and next generation of fusion machines.
As a first stage of a development program aimed towards a 150 GHz high power gyrotron, the Switzerland-Euratom Association has undertaken the construction of a 120 GHz quasi-optical gyrotron at a power level of 200 kW. This paper will describe the technical development performed by BBC in the frame of the project.

II) Characteristics of a quasi-optical gyrotron

As described in previous papers [1,2] the main difference between a quasi-optical gyrotron (Fig. 1) and a conventional one is the shape of the resonator. The conventional gyrotron uses a cylindrical cavity, whereas the quasi-optical gyrotron uses a Fabry-Perot resonator consisting of two spherical mirrors, hence the name of quasi-optical gyrotron. The advantages of the quasi-optical concept are [1] :

- Thermal wall loading of the resonator wall can be kept at a reasonable value (< 1.5 kW/cm^2) even at high frequencies and high power.
- The decoupling of the spent electron beam and RF-beam gives a large freedom in the design of the high power electron collector.
- The resonator mode TEM$_{00}$ is linearly polarized. If suitably coupled out, the wave can be launched directly towards the plasma without the need of changing the polarization.
- The parasitic transverse modes are suppressed since they have larger diffraction losses than the TEM$_{00}$ mode.
- Frequency tunability of the gyrotron by controlling the magnetic field is possible [3].
- High electronic efficiency is achieved by the use of a prebunching resonator (quasi-optical gyroklystron) [1] .

III. The CRPP/BBC gyrotron development program

In April 1985 the installation of the first components of the quasi-optical gyrotron teststand and its ancillary systems has been started at the new laboratory in Ecublens near Lausanne. A first proof of principle experiment shall be performed before the end of this year. The pulse length of the electron beam will be limited to 50 - 100 µs. This allows for radiation cooling of the resonator mirrors and of the collector. An electronic efficiency of about 30 % is expected for the RF generation. In 1986 the pulse duration will be extended up to 100 ms when a resonator of larger dimension and a new collector, both water cooled, will be implemented. The final step of the testprogram at 120 GHz will be the implementation of a prebunching mirror resonator to investigate the concept of the quasi-optical gyroklystron. An electronic efficiency of about 40 % is predicted.

IV) The technical design

Fig. 1 gives the schematic design of the gyrotron teststand. Emphasis has been put on modularity and flexibility. The vacuum vessel consists of 6 different sections, with a total length of about 5.5 m. For easy modification of the quasi-optical resonator the adjacent parts of the resonator vacuum chamber can be rolled apart on their support together with the pumps, the collector and the collector coils. A gate valve at the entrance of the resonator chamber keeps the electron gun under vacuum while the main chamber is opened. A number of viewports allow the observation of the resonator region. Titanium getter pumps and a 500 l/s turbomolecular pump will maintain a vacuum of 10^{-8} mbar. The magnetic field of about 5T at the resonator region is generated by a pair of split coils having a warm bore of 40 cm diameter [4]. Two bucking coils are provided to shape the field and its gradient in the gun region. All these magnets are superconducting. The cooling is provided by a closed cycle Sulzer liquifier/refrigerator system with a capacity of 12 liter LHe per hour. A pair of Cu coils is used to spread out the electron beam at the collector. The electron gun is energized by a high voltage power supply able to deliver 10 A at 100kV in long pulse (up to 10s). The beam voltage is regulated by a BBC high voltage tetrode CQK 200-4. Based on numerical calculations at the CRPP, the main gyrotron components have been designed and manufactured by the Electron Tubes Department EKR of BBC: the electron gun, the beamducts, the quasi-optical resonator and the beam collector.

1. The electron gun MIG 120-1

The design characteristics of the electron gun are given in TABLE 1.

Beam voltage	- 70 kV
Beam current	$\lesssim$ 10 A
Compression ratio	20
Beam diameter at cavity	2 mm
Beam thickness	0.2 mm
$p_\perp / p_{//}$	1.5
$\Delta v_\perp / v$	3.5 %

TABLE 1 Design characteristics of the electron gun

The gun is of the magnetron injection type with a triode configuration. It will be operated in the temperature controlled mode. The gun head with its M-type tungsten dispenser cathode has been designed as a selfadjusting insert in the gun socket. It can easily be replaced after opening one of the UHV-flanges. The electron gun is housed in its own bakable vacuum chamber closed by a gate valve. A separate pumping system keeps the base pressure below 10^{-8} mbar. The pressure can be monitored even when the high field magnets are energized. Alignment of the gun with respect to the resonator chamber can be performed under vacuum.The grounded anode is provided with a current detector and a thermocouple. The high voltage socket of the gun is insulated by an SF_6-filled hood on ground potential. Fig.2 gives the general design with the operating voltages and the values which have been achieved after conditioning of the gun on the teststand at BBC.

The operating temperatures measured at the head and the socket of the gun are also given. Note that the cooling and electrical insulation are not provided by oil as in existing gyrotrons. Due to the low heat conductance of the cathode supports, a brightness temperature of $1000^{\circ}C_B$ is achieved with a heater power of less than 45 W. To emit 10 A under high voltage condition the brightness temperature will likely be about $920^{\circ}C_B$.

Fig. 3a demonstrates the conditioning effect of the cathode - gun anode gap. At the beginning of the HV-test, cold emission started already at 20 kV. At 32 kV a first arc appeared. After 6 similar conditioning runs, where the cold emission current decreased from one run to the next, the gun stood 42,5 kV for 15 min. without arcing. This corresponds to a fieldstrength at the cathode of about 130 kV/cm. After the conditioning cold emission was no longer detectable at the nominal gun anode voltage of 27 kV. With the cathode heated to $800^{\circ}C_B$ the gun still stood up to 36 kV (Fig. 3b).

2. The electron beam guiding system

Three different types of beamducts are used at the gyrotron test stand. The beamduct section between the gun and the resonator is partly filled with absorbing ceramic (Ceradyne MgO-SiC) in order to damp travelling waves. Surrounding the mirror resonator a delicate grid structure is used on one hand to prevent the growth of the travelling waves and on the other hand to provide a good electrostatic boundary for the beam.

The beamducts downstream of the resonator are partly manufactured from meshed tubes to provide good pumping conductance to the resonator region. To determine the fraction of the beam being intercepted by the ducts, the different beamduct sections are mounted on insulating selfadjusting supports. Critical parts of the beamducts are provided with temperature sensors. Some beamduct sections are equipped with capacitor probes [5] to measure the beam velocity parallel to the magnetic field.

3. The mirror resonator

For the first series of experiments, the gyrotron will operate with a small radiation cooled mirror system mounted on a temperature compensated support structure. The length of the confocal resonator will be about 5 cm with a mirror radius of 9,5 mm. Variation of the mirror separation (± 5 mm) and centering of the resonator with respect to the electron beam axis is possible through a remote controlled adjustment mechanism at a tolerance of a few microns. The RF-power is coupled out through two 2,5 inches diameter waveguides, closed by two alumina, vacuum tight windows. The output power for the 100 μs pulse experiments is detected by an electronic calorimeter (Scientec Model 360401).

BBC is now developing a larger, liquid cooled mirror system for an output power of 200 kW at a pulse duration up to 100 ms. The resonator will be non confocal with a mirror separation of 36 cm. The paek heat load at the center of each mirror will be about 1,5 kW/cm^2 with a total dissipated power of 11 kW. For the RF-power measurement a liquid cooled calorimeter is being developed for operation under vacuum, since the construction of a high power long pulse window is not intended.

In 1984 cold test experiments on quasi-optical resonators were started at the CRPP. Various types of mirrors and coupling structures have been investigated. The RF-source for the experiments is a carcinotron (Thomson CSF model TH 4215) delivering about 0,5 W at 120 to 150 GHz. Fig. 4 shows a typical mode pattern measured at the mouth of the 2,5 inch waveguide at a distance of 1.1 m from the 5 cm confocal resonator. Note that the power of the wave is concentrated in the center of the waveguide.

4. The beam collector

The development of the electron collector is done in two steps. At first a radiation cooled collector has been developed and manufactured at BBC to investigate the beam current distribution on the collector wall in axial and azimuthal direction with 77 probes. The temperature is also monitored at 3 different points. A second collector for long pulse operation at a beam power up to 700 kW will be manufactured beginning of 1986, using the wellproved cooling technique of BBC high power tetrodes.

V) Conclusion

The CRPP/BBC team has sucessfully started the development of a high-power quasi-optical gyrotron for 120 GHz. Based on the know how of the Electron Tubes Department of BBC the main gyrotron tube components could be designed and manufactured within less than 1 1/2 year. First tests on the electron gun look promising . The assembly of the whole teststand is underway and will be completed by the end of October. The first experiments will be performed before the end of 1985.

Acknowledgements

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[3] Hargreaves T.A. et al.Int. J.Electronics 57, 977 (1984)
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[5] Shefer, R.E. et al. MIT Report PFC/JA-83-17 May 1983

Figure Captions

Fig. 1: Schematic design of the 120 GHz-gyrotron test stand

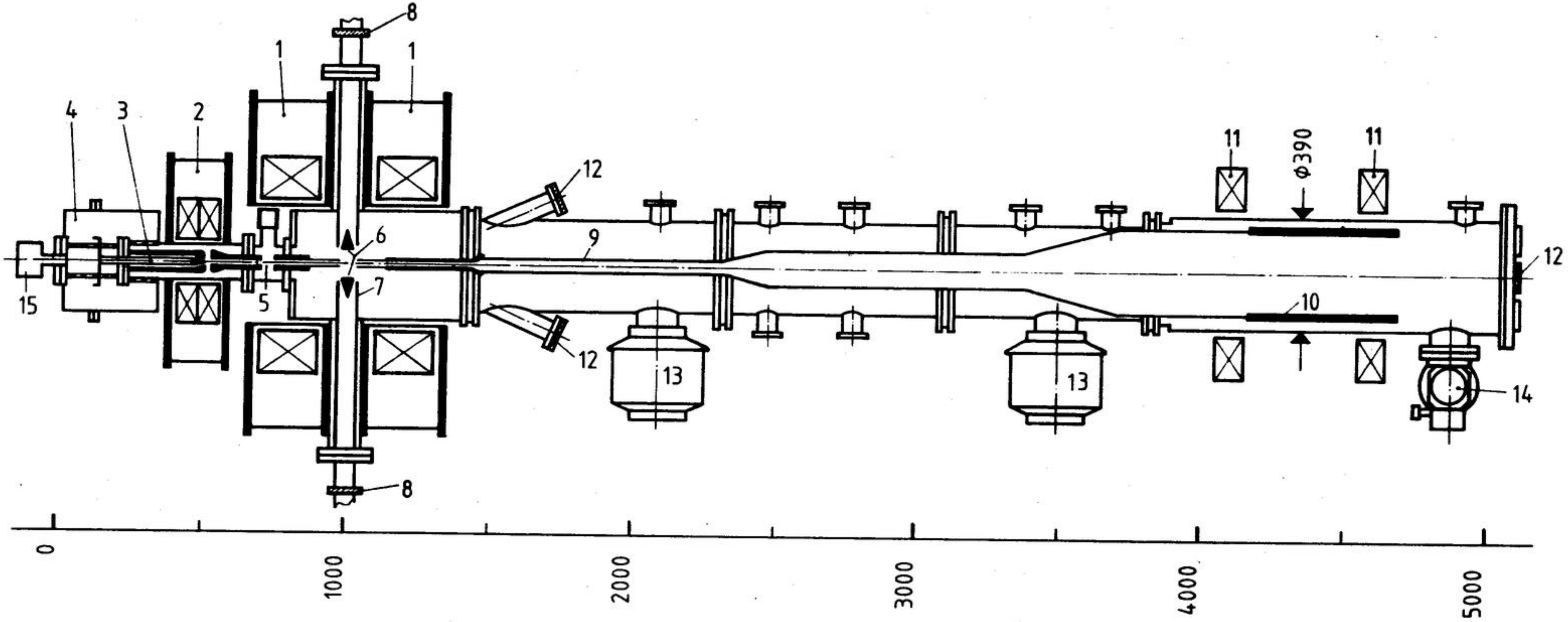
Fig. 2: Schematic of MIG 120-1, including operating voltage, test voltage (in brackets) and temperatures at the critical points of the gun for a cathode brightness temperature of 1000 $^{\circ}C_B$.

Fig. 3: Current-voltage characteristic during the conditioning of the cathode-gun anode gap of MIG 120-1
a) with cold cathode
b) with cathode at 800 $^{\circ}C_B$.

Fig. 4: Rf-mode pattern (power profile) across the coupling tube 1.1 m from the quasi-optical 120 GHz resonator.

DESIGN OF QUASI-OPTICAL GYROTRON TESTSTAND

[f = 120 GHz; $P \leqslant 200$ kW; $\tau \leqslant 100$ µs]



1. main magnet coils (sc)
2. gun magnet coils (sc)
3. electron gun (MIG)
4. SF_6-insulation hood
5. gate valve
6. mirror resonator
7. coupling tube
8. rf-window
9. beamduct
10. collector
11. collector coil
12. viewport
13. Ti-getterpump
14. turbopump
15. ion getterpump

FIG. 1

MIG 120-1

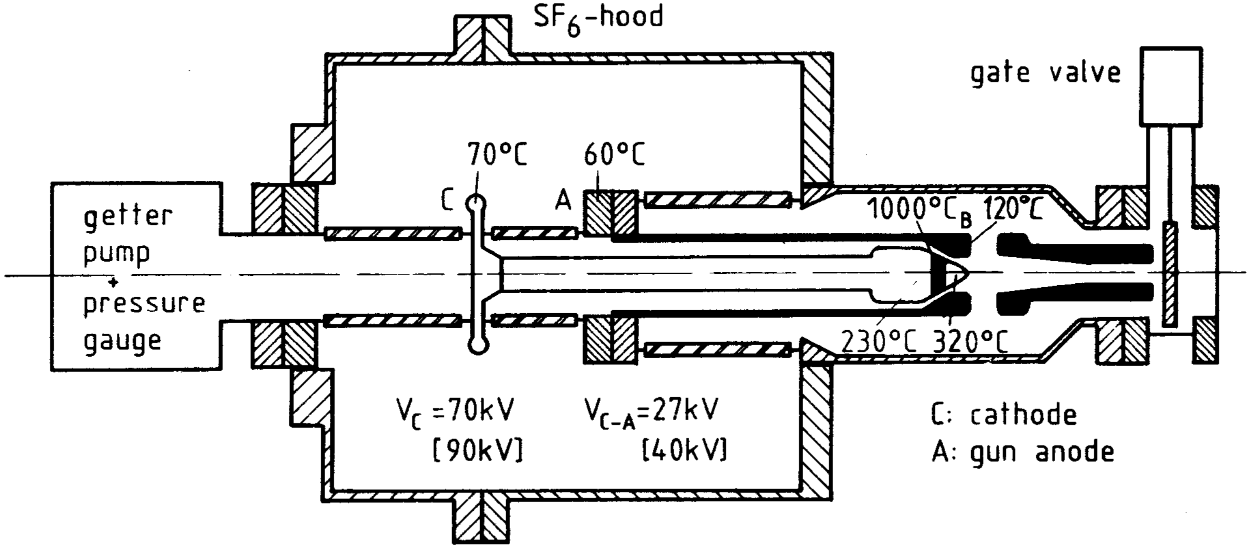


FIG. 2

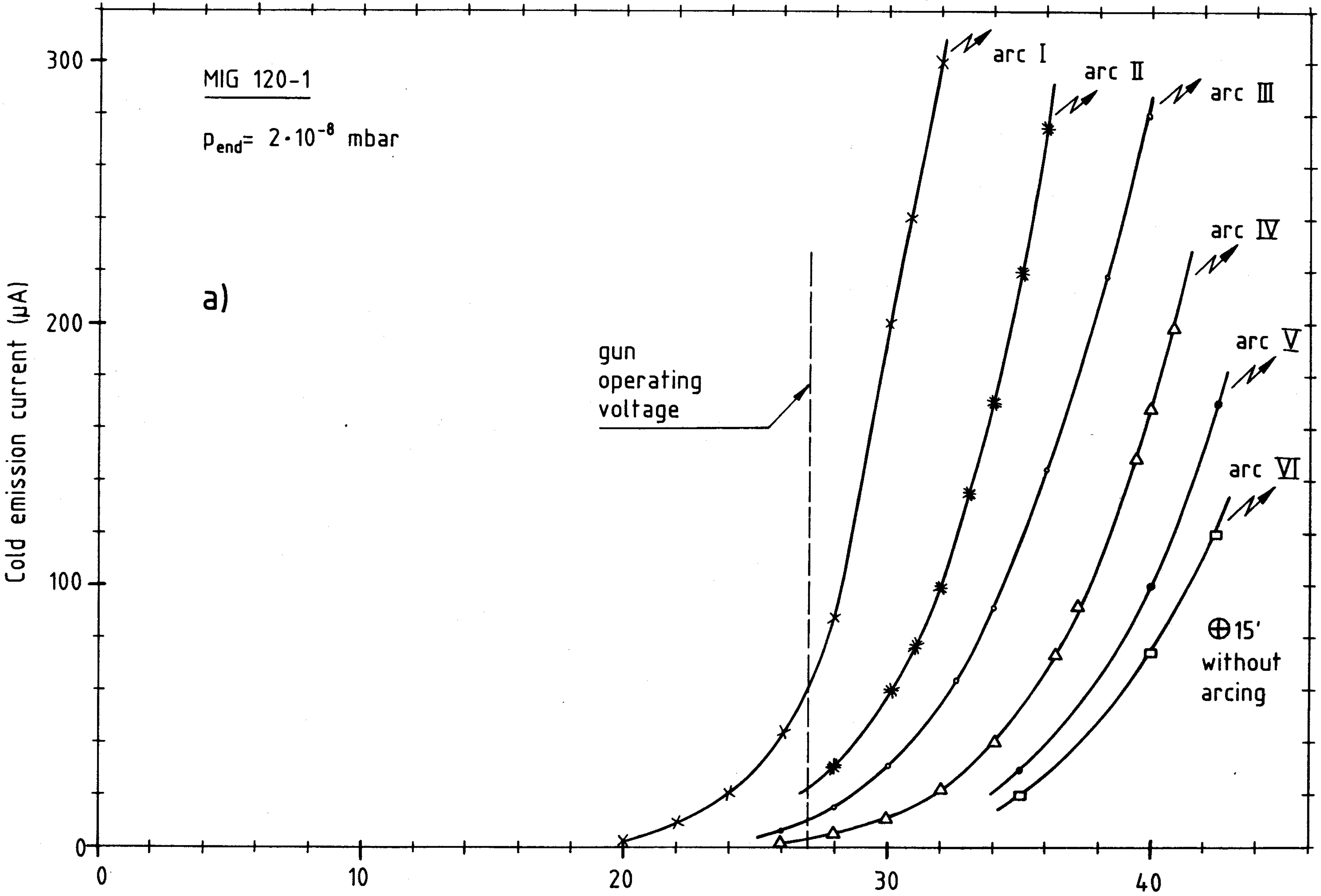

MIG 120-1
$p_{end} = 2 \cdot 10^{-8}$ mbar
a)
gun operating voltage
arc I
arc II
arc III
arc IV
arc V
arc VI
⊕15' without arcing
Cold emission current (μA)
0
100
200
300
0
10
20
30
40

FIG. 3A

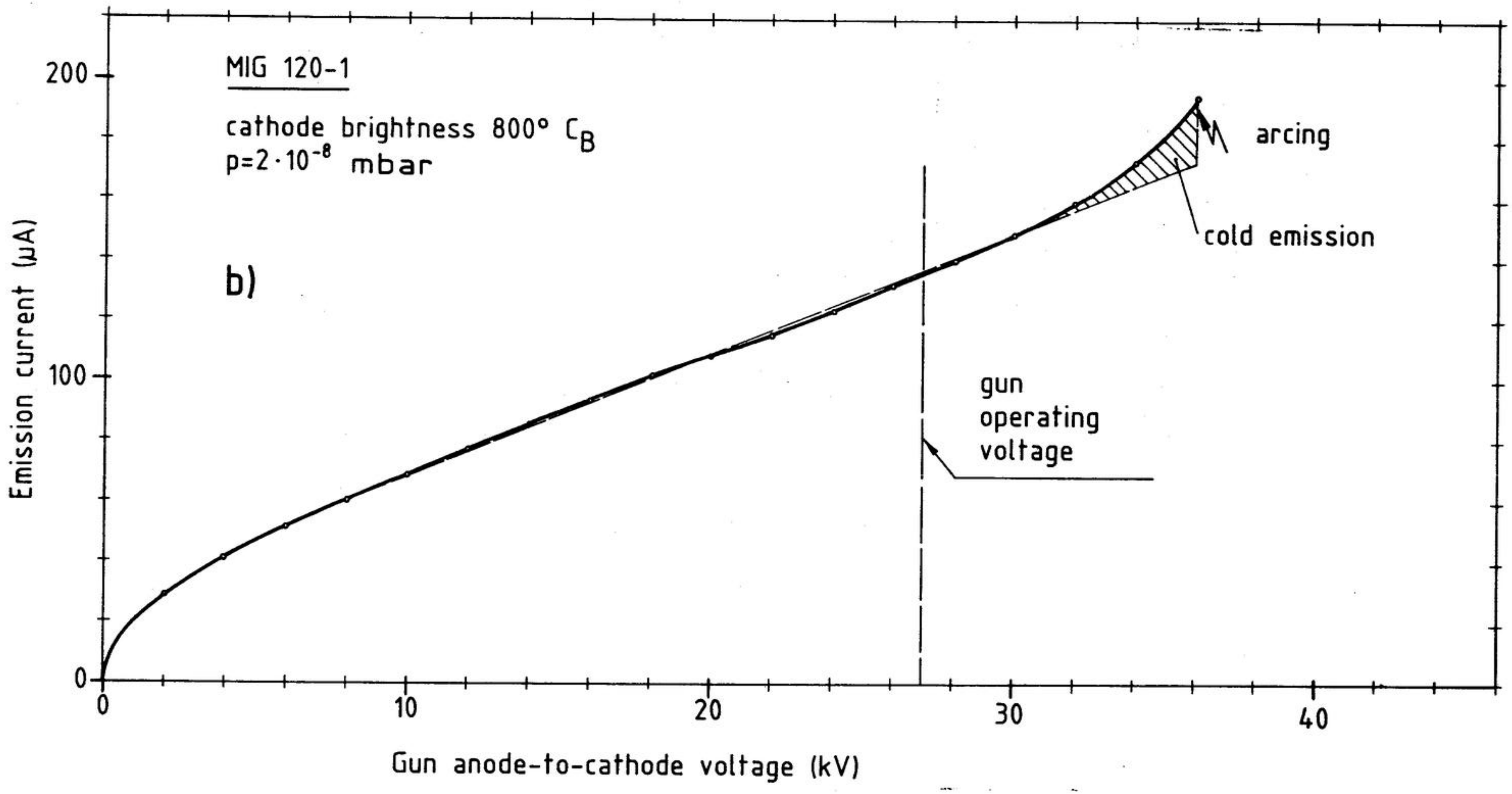

MIG 120-1
cathode brightness 800° C$_B$
p=2·10^{-8} mbar
b)
arcing
cold emission
gun
operating
voltage
Emission current (µA)
200
100
0
10
20
30
40
Gun anode-to-cathode voltage (kV)

FIG. 3B

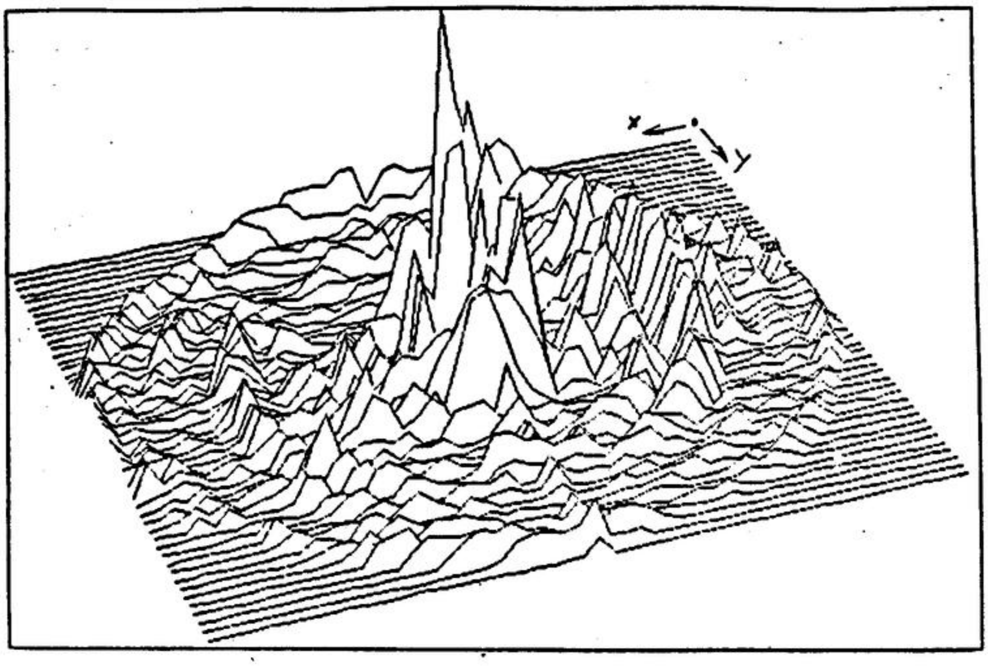


FIG. 4