INJECTOR LINAC STUDY FOR JAPANESE PROTON SYNCHROTRON PROJECT

H. Baba, S. Fukumoto*, S. Inagaki**, M. Kobayashi,
T. Nishikawa**, S. Okumura and J. Tanaka

Institute for Nuclear Study, University of Tokyo
Tokyo, Japan

ABSTRACT

The Japanese Proton Synchrotron Project will be financed from this fiscal year. The original plan was changed to a 8 GeV slow cycling machine with a 500 MeV booster and a 20 MeV linac as the injection scheme. In this paper we describe results from the design study for the injector linac; i.e. study on the ion source, development of the electroplating tanks, and experiments on the half-size model which was also tested by electron beams. Electron beam as large as 100 μA, which is equivalent to about 180 mA of proton beam, can safely be accelerated. The result is consistent with the previous study on the longitudinal space charge effect.

Introduction

After a long discussion for past ten years, the Japanese Government authorized to build a proton synchrotron of about 8 GeV. The machine will be installed in a new National Laboratory for High Energy Physics at about 40 miles north-east of Tokyo. Researchers in universities and other institutions collaborate with the Laboratory and can use the facilities. A part of the construction money is financed from this fiscal year and the buildings for the accelerator research including the preinjector room are under construction.

The machine is a slow-cycling separated function type proton synchrotron with a 500 MeV fast-cycling booster and a 20 MeV linac as the injection scheme. Table I and II show parameters and structures of the main ring. Parameters of the booster are shown in Table III and those of the linac in Table IV. For financial reasons and man power problems, the machine will be operated at about 8 GeV and at a moderate intensity at the first stage. The energy can be raised up to 12 GeV with an addition-

---

* Permanent address: College of General Education, University of Osaka.

** Permanent address: Department of Physics, University of Tokyo.

al fund for power stations and the intensity to 10^{13} p/s by successive improvements.

The design study of injector linac started in 1966. At that time, the energy of the machine considered was 40 GeV and the injector linac was 125 MeV.[1] Since a big change was made in this plan, the injector linac has been considerably scaled down. However, the efforts at the design study stage are still usefull.

Model Cavity Study

After the last Conference, we continued half-size model cavity experiments on the first 10 MeV stage.[2] The field and phase measurements were carried out. In Fig. 1 and Fig. 2, steady and transient phase shifts along the cavity are compared with the calculations based on the normal-mode theory.[3]

Then, electron beams were injected and accelerated in this model cavity. To pump out the cavity, it is put into a larger vacuum vessel with an electron gun and measuring devices.

If the electron energies and other kinematical parameters are decreased by a mass factor ($m_e/m_p = (1836)^{-1}$) compared to the design values for protons, dynamical problems can be simulated by electrons as in the actual proton linac. For the model cavity is a half-size of the actual one, the r.f. field and the gradient of the focusing field have to be multiplied by the scaling factor 2 and 4, respectively. To get the required quadrupole field for focusing, the wires are turned around the drift-tubes as shown in Fig. 3. The μ-metal sheets are attached around the inner side of the vacuum vessel for shielding the terrestrial magnetic field. The accelerated beam is collected by a Faraday cup, which has an auxiliary magnet to suppress secondary electrons. Retardation potential is given between the Faraday cup and the cavity for measuring electron energies. The block-diagram of the electron model is shown in Fig. 4.

The main purpose of this experiment is to study space-charge effects since the effects in proton linacs are realized at a current lowered by a factor of the mass ratio. An electron gun of a TV tube was used as the electron source, which provices beam currents of 0.5 mA (max.) at 400 V with the diameter of about 4 mm. Experiments were made by using the first 12 or 24 cells of the model cavity. The design values of proton energies corresponding to these cases are 1.6 MeV or 2.8 MeV, respectively. Without a buncher about 20 % of the injected beam can be accelerated at a lower current as expected from phase motions. The ratio gradually decreases by the space charge effect as the current increases. The solid curve in Fig. 5 shows a typical result, in which an electron beam as large as 100 μA can safely be accelerated: the maximum value corresponds to 180 mA of the proton beam. The result can be compared to the previous theoretical studies on the longitudinal space charge effect. Nishikawa and Okumura,[4] and Benton, Chasman and Agritellis[5] reported in 1967 their results of numerical calculations. The calculation is transformed into the present case by dotted curves in Fig. 5, where the beam radius is given as parameters. The agreement between the theory and the present experiment is excellent. In Fig. 6, the energy spectra of accelerated electron beams are shown for various r.f. field levels. The experiments are going on, and a higher current study including the use of a prebunching system, r.f. phase measurements due to beam loading effect, and the emittance measurement of the accelerated beam are being undertaken.

Study on Accelerator Parts

The design study on the accelerator parts has also been proceeding as follows:

1) Ion Source and Preinjector

A model stand for the ion source is used to study duoplasmatron characteristics. A cross section of the duoplasmatron under study is shown in Fig. 7, where the expansion cup with a two stage expander is used. The photograph and the analysis of slit images in the emittance measurement are shown in Fig. 8 and Fig. 9, respectively. The normalized brightness of 7 X 10^8 mA $(\text{cm rad})^{-2}$ is obtained at a 70 mA of the proton beam. A prototype high gradient accelerating column for 750 KV acceleration is now under construction.

2) Accelerator Tank

Electroplating method was developed for fabricating accelerator tanks. A uniform, smooth and thick copper layer was obtained by using a copper bath with an organic brightening agent, U.B.A.C. R-1* and improving the plating techniques. The mechanical, electrical and vacuum properties of accelerator tanks are much improved by the newly developed method. Measured Q values as large as 90 % of the values calculated by using d.c. conductivity of copper are obtained. The surface roughness is less than 0.3 μ and almost independent of the roughness of the base metal surface. The excessive deposition on edges and the lack of the deposits in deep grooves are also eliminated, so that stem holes, r.f. and vacuum ports, and flanges, and the other parts can be machined and welded before plating. After copper plating, no final machining or finishing is necessary. A unit of 94 cm in dameter and 2.5 m in length was fabricated. Drift-tubes and other parts are made by the same method with combining the electron beam welding techniques. A photograph of a prototype 1 m unit is shown in Fig. 10.

3) Q-magnet System and RF Source

Field measurements on the prototype focusing magnets have been made and the field gradient as high as 10 kG/cm can be obtained. Fringing fields and harmonic contents are measured and analyzed by a harmonic analyzer.[6] These quantities has also been measured at pulsed operations by means of a peak-to-d.c. comparison method and a Fourier analysis of the azimuthal field distributions.

The FTH-516 tubes will be used for the RF source and were tested at about a 2 MW power level. The block diagram of RF system is shown in Fig. 11 where a double power feeds at 1/4 and 3/4 of the total length will be used for compensating phase shifts due to the beam loading

---

* made by Ebara-Udylite Co.

effect.[3]

References

1. S. Suwa: The Japanese 40-GeV Proton Synchrotron Project; Proc. of the Sixth Int. Conf. on High Energy Accelerators, Cambridge, 1967, p. 9.
2. H. Baba, H. Hirakawa, T. Nishikawa, S. Okumura, J. Tanaka and Y. Tao : Model Cavity Studies for Tank Design and on Tank Fabrication: Proc. of the 1968 Proton Linear Accelerator Conference, BNL 50120, p. 543.
3. T. Nishikawa: Normal Mode Analysis of Standing Wave Linacs: Field Excitation and Beam Loading in Linac Cavities, BNL Report AADD 87. See also P. M. Lappostolle and A. L. Septier, ed., Linear Accelerators, North Holland Pub. Co., 1970, p. 809.
4. T. Nishikawa and S. Okumura: Longitudinal Space Charge Effect in Proton Linacs; Proc. of the Sixth Int. Conf. on High Energy Accelerators, Cambridge, 1967, p. 162.
5. A. Benton, R. Chasman and C. Agritellis: Computer Calculations of Effect of Space Charge on Longitudinal Beam Dynamics in Proton Linear Accelerators, IEEE Trans. NS-14, 1967, p. 577.
6. D. C. Cohen, W. Myers, R. Stockley: ZGS Linac Quadrupole Measurements; ANL Rept. DC-WM-RS-1, 1963.

Table I MAIN RING PARAMETERS

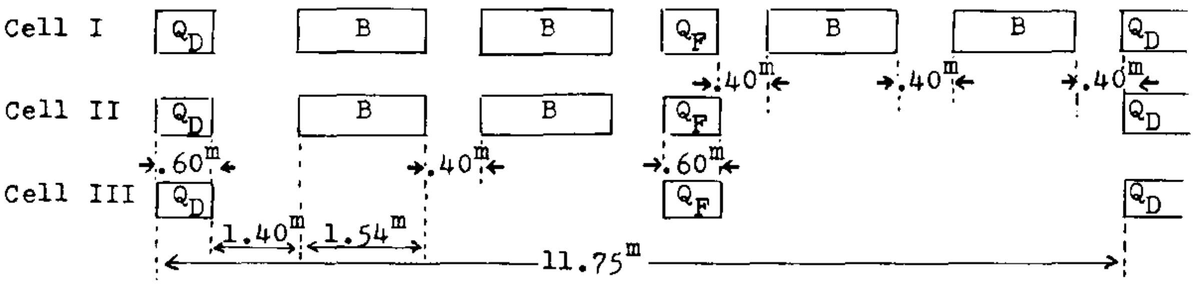
Max. Kinetic Energy	12 GeV *
Type	Separated Function
Radius of Curvature	21.52 m
Mean Radius	52.35 m
Number of Betatron Oscillations	7.25
Max. Bending Field	20.0 kG
Max. Quadrupole Gradient	1.87 kG/cm
Gap and Useful Width of Magnet	5.6 X 10.0 cm^2
Space Charge Limited Intensity	2 X 10^{13} p/pulse
Repetition Rate	1 pulse/2 seconds
Injection Energy	0.5 GeV
Magnetic Field at Injection	1.69 kG
Number of Injected Beam Pulses	9

* 8 GeV at the first stage

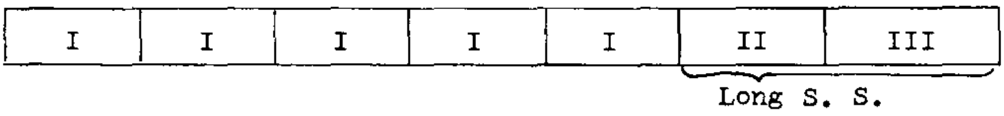
Table II STRUCTURE OF MAIN RING

Number of Superperiods	4
Total Nämber of Cells	28
Number of Cell I	20
Number of Cell II	4
Number of Cell III	4

Structure of Cells



Superperiod



Number of Bending Mag.	88
Number of Quadrupole Mag.	56
Useful Length of Long. S. S.	6.28^m, 4.28^m

Table III BOOSTER PARAMETERS

Max. Kinetic Energy	0.5 GeV
Type	Combined type
Radius of Curvature	3.30 m
Mean Radius	5.82 m
Number of Betatron Oscillations	1.75
Max. Mag. Field	11.0 kG
Number of Cells	8
Structure of Cells	$\frac{1}{2}$ODFFD$\frac{1}{2}$O
Gap and Useful Width of Magnet	6.6 X 12.0 cm^2
Injection Kinetic Energy	20 MeV
Magnetic Field at Injection	1.97 kG
Revolution Frequency	1.67 ~ 6.22 MH$_z$
Harmonic Number	1
Repetition Rate	20 cps
Space Charge Limited Intensity	3 X 10^{12} p/pulse

Table IV LINAC PARAMETERS

Max. Kinetic Energy	20 MeV
Type	Single Tank D-T Linac
Total Length	20 m
Cavity Length	16 m
Number of Cells	90
Frequency	201.25 MH$_z$
Peak Power	3 MW
Injection Kinetic Energy	0.75 MeV
Peak Current	100 mA
Beam Pulse Length	20 μs
Repetition Rate	20 cps
Mean Current	40 μA
Preinjector	Cockcroft-Walton Type
Ion Source	Modified Duoplasmatron

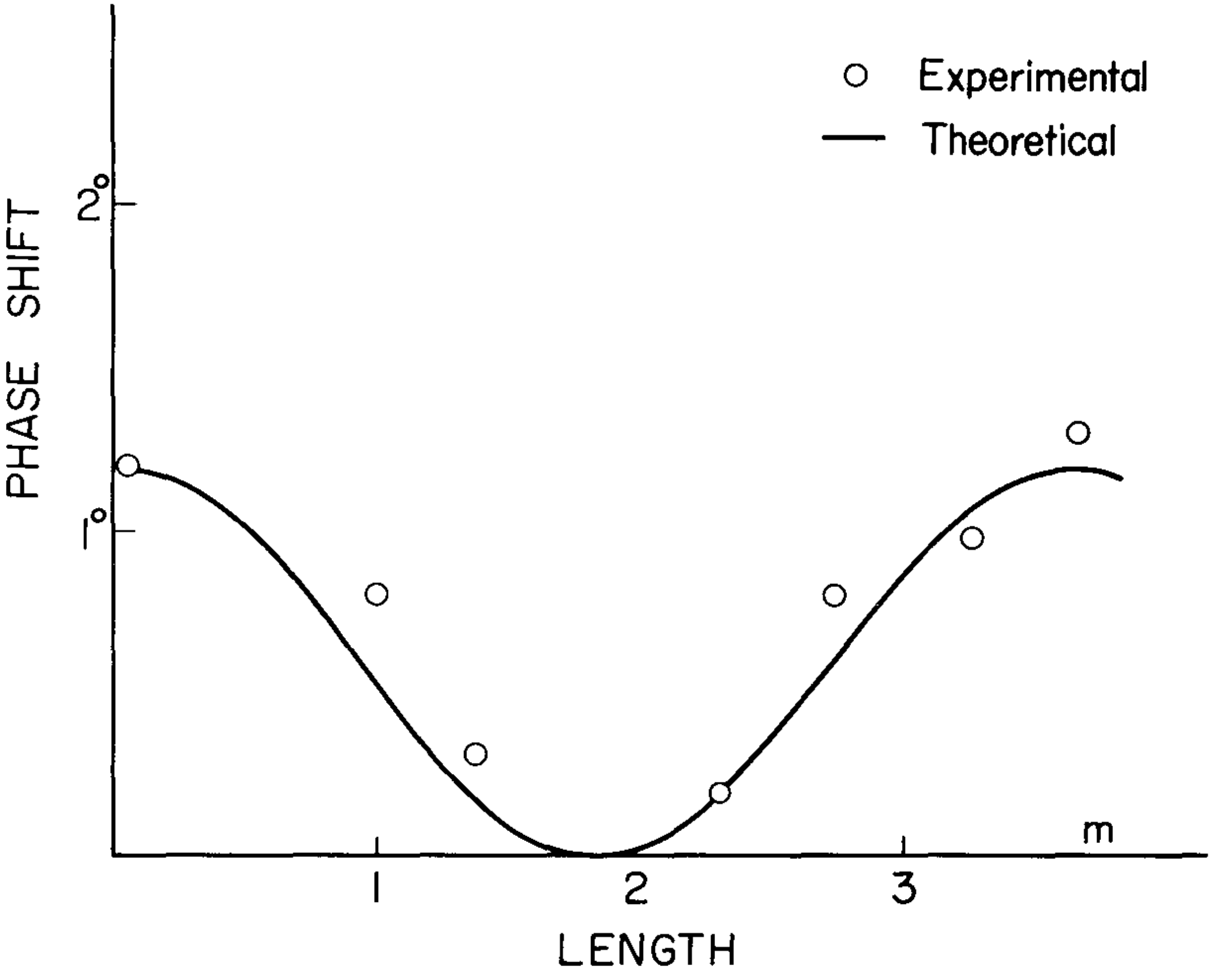


Fig. 1. Steady state phase shift along the cavity length. The cavity is fed at a middle point.

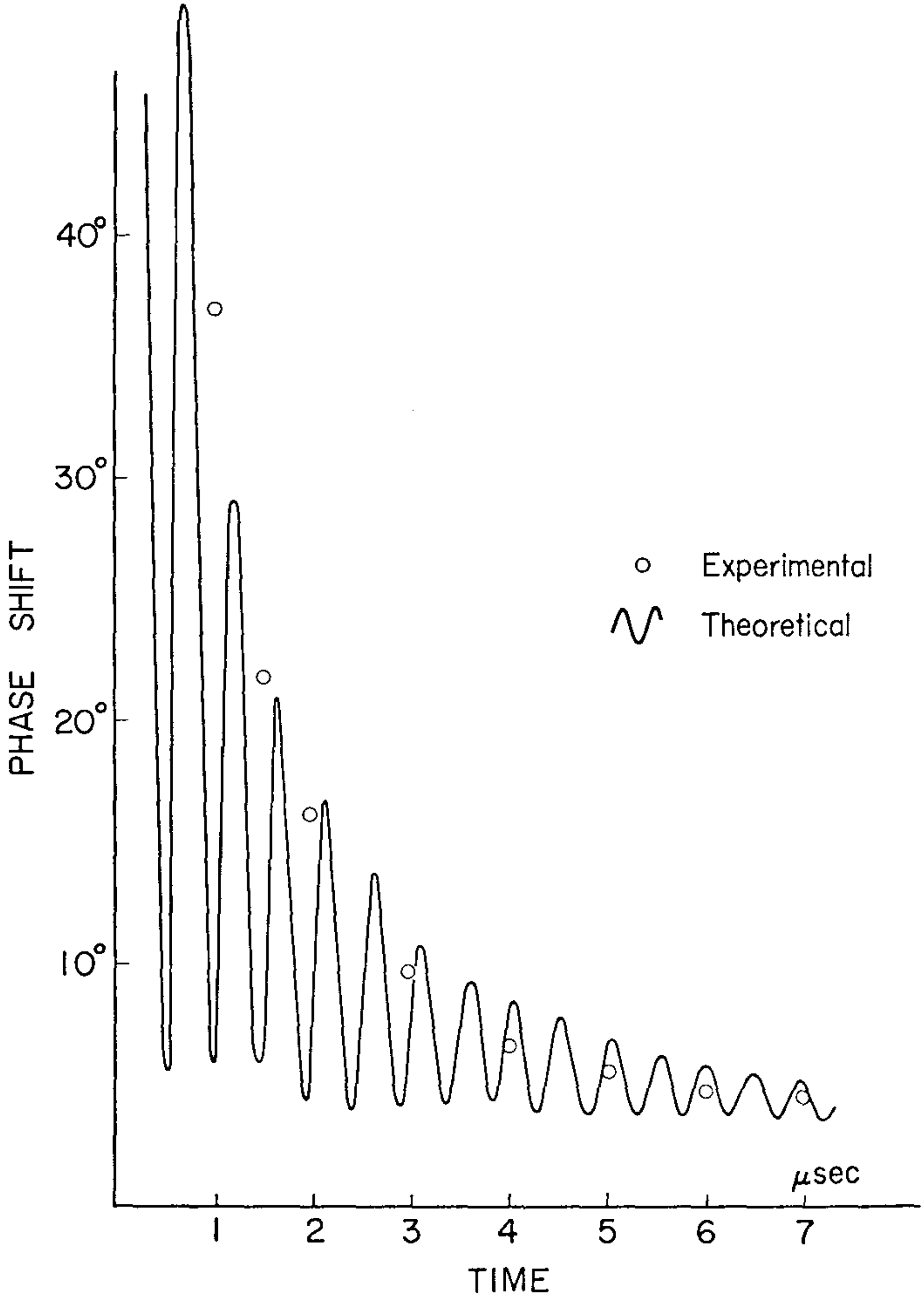


Fig. 2. Transient phase shift between the low-energy end and the high-energy end of the cavity. The cavity is fed at the low-energy end.

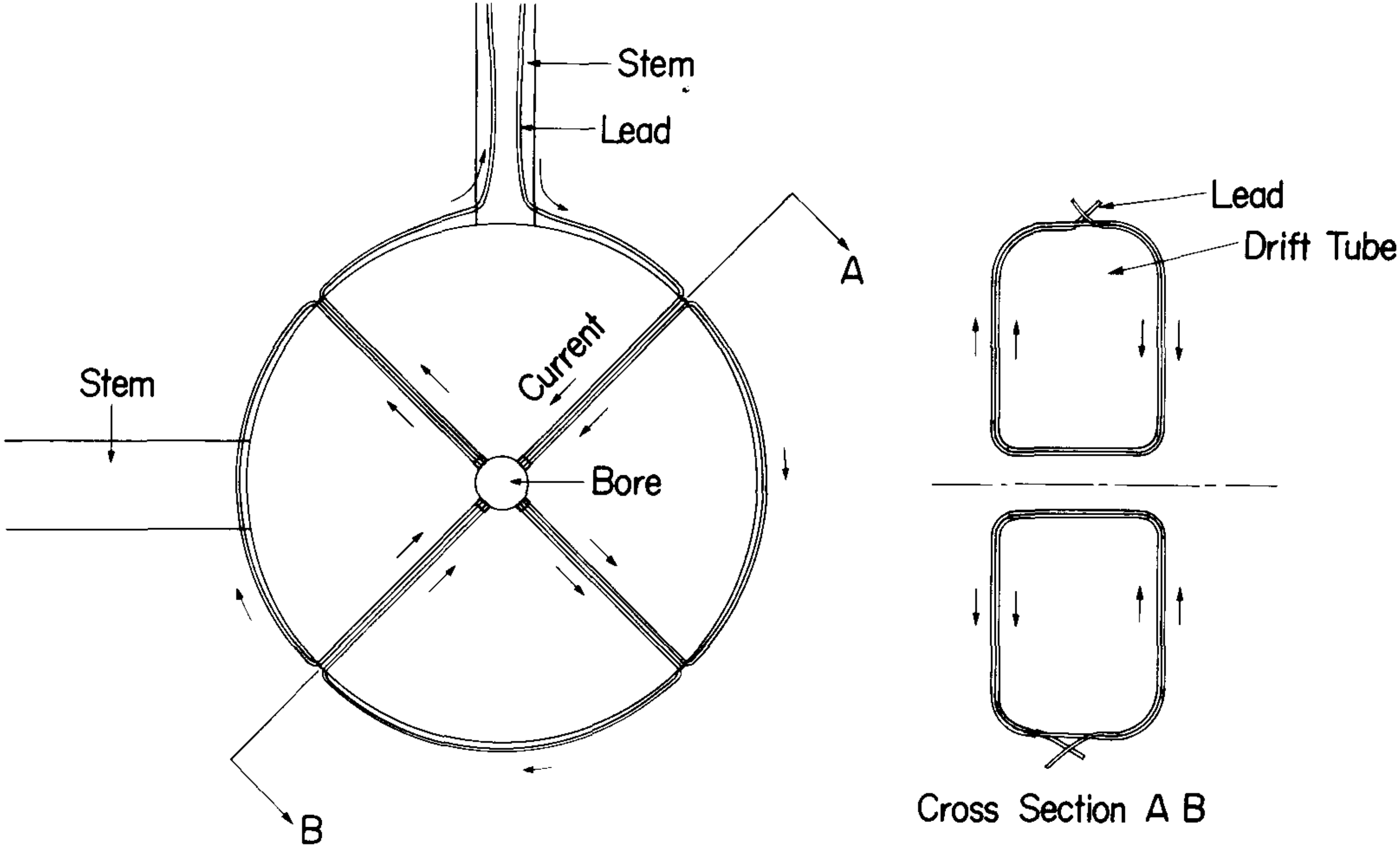


Fig. 3. Coil winding of Q-focusing field for the electron model.

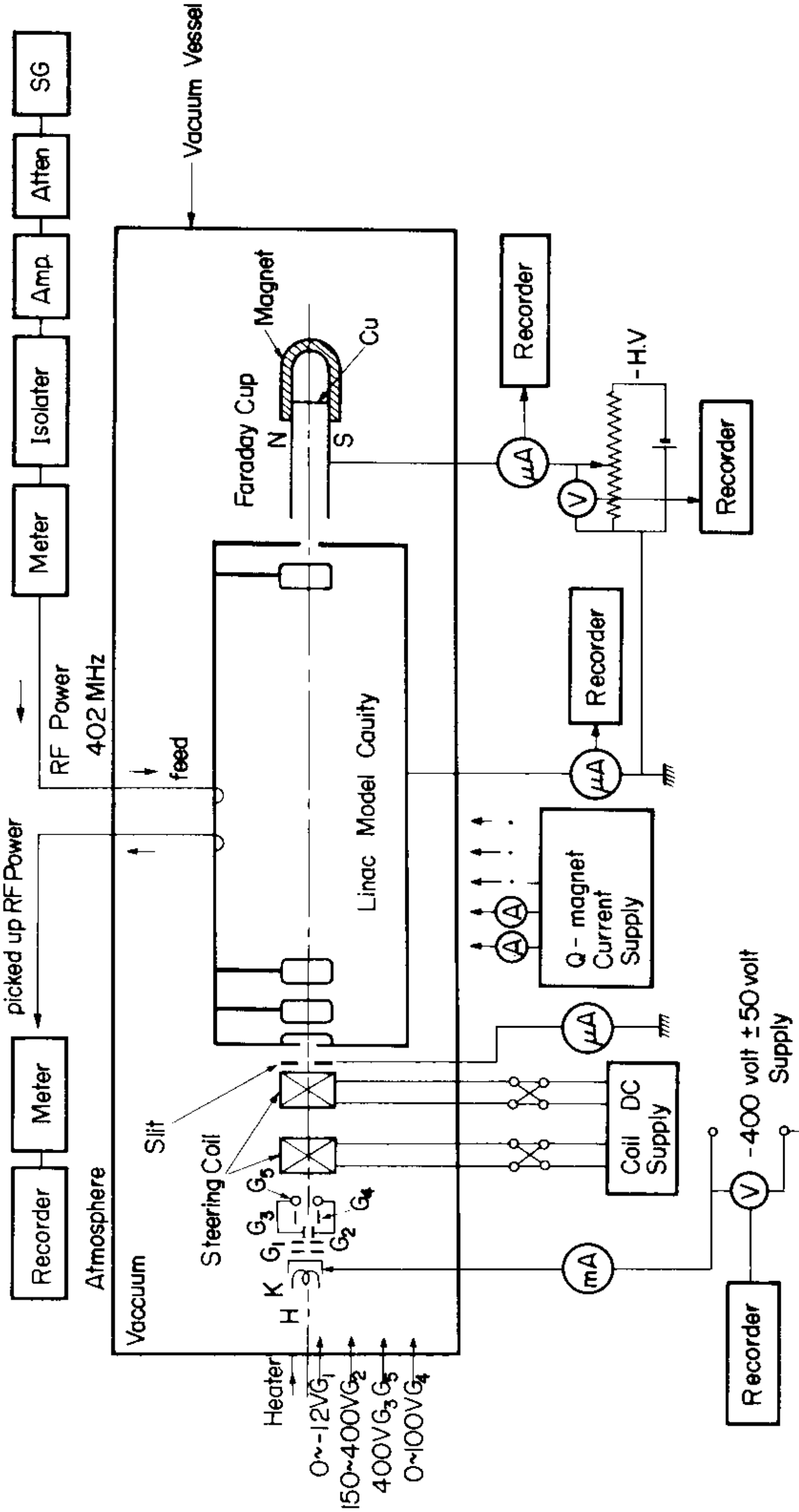


Fig. 4. Schematic diagram of the electron model experiment.

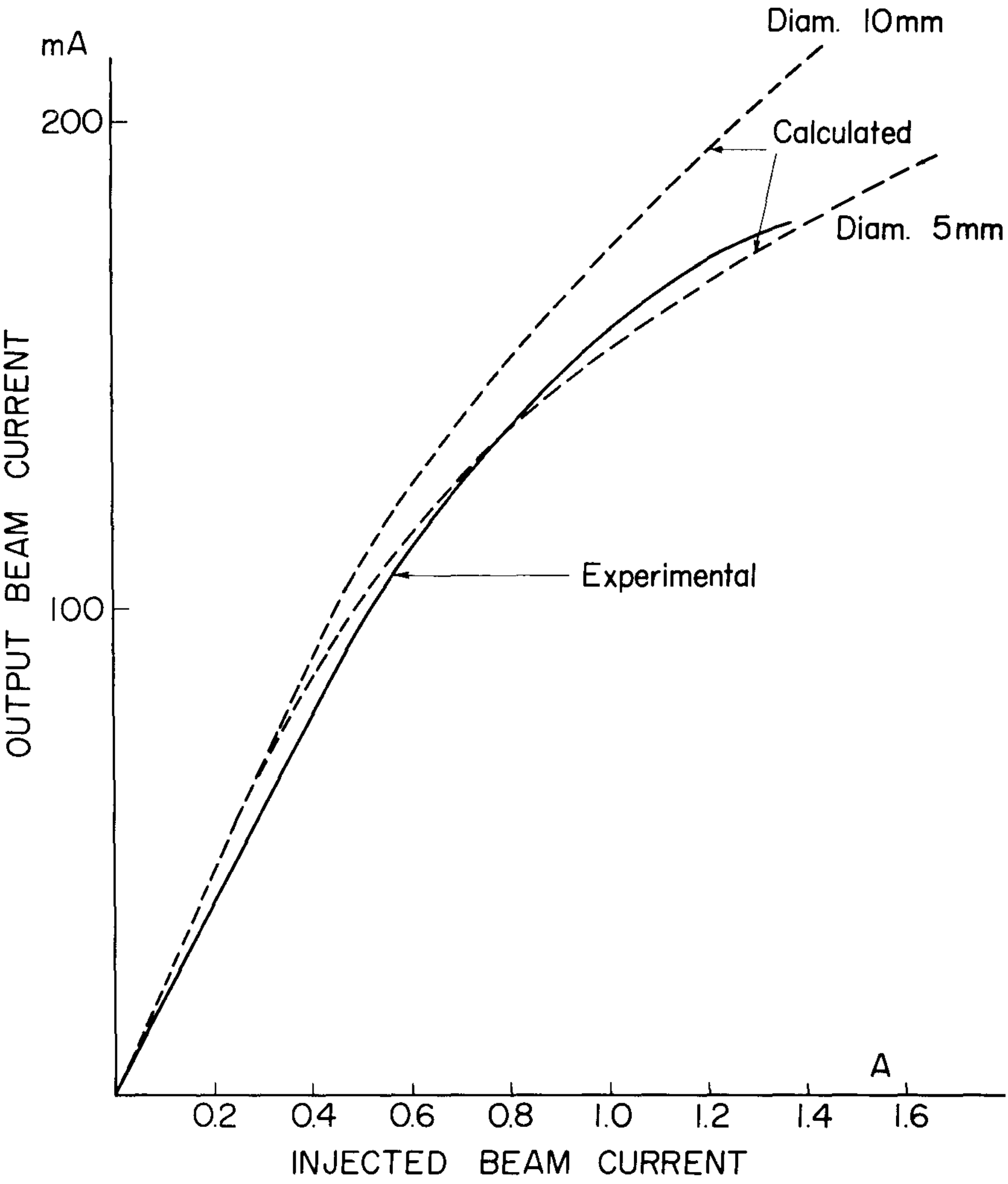


Fig. 5. Output beam current as a function of injection current. The electron currents are converted into proton currents by multiplying mass ratio. The dotted lines are calculated under an assumption that the beam diameter is constant along the linac. The total number of cells is 24.

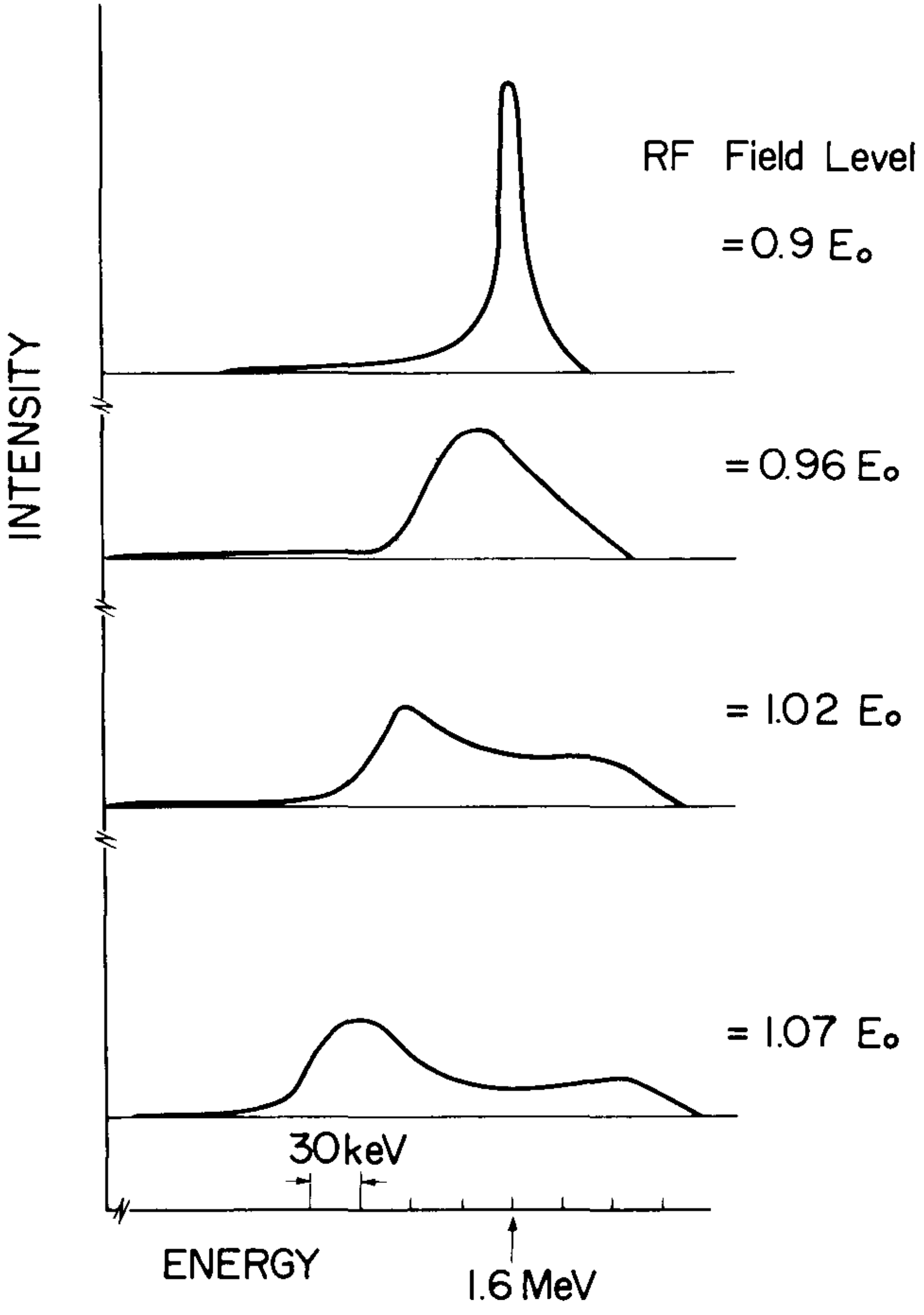


Fig. 6. Measured energy spectra for various rf field levels. E_0 is the design value of rf field. The total number of cells is 12.

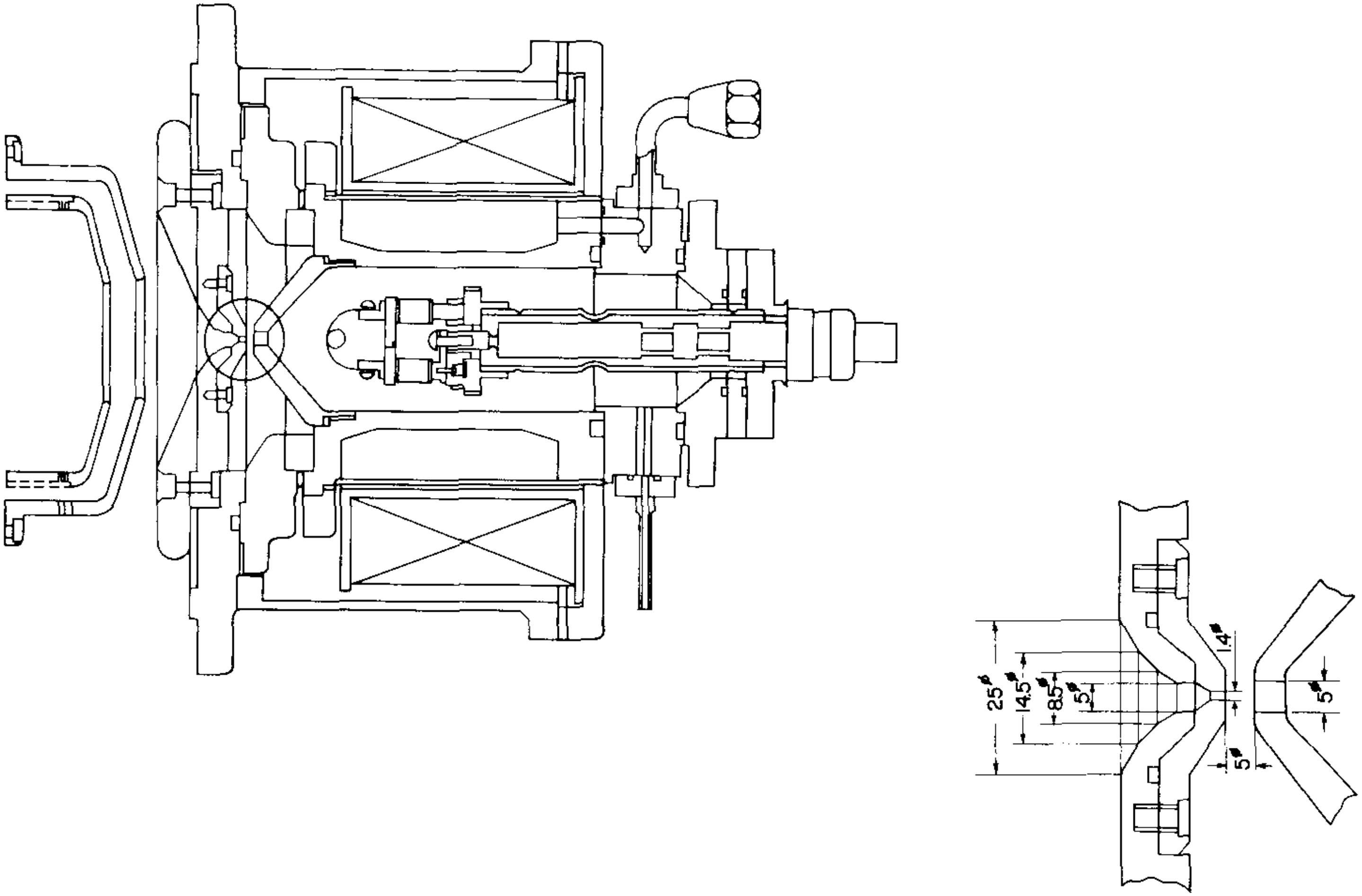


Fig. 7. Cross section of a duoplasmatron under study.

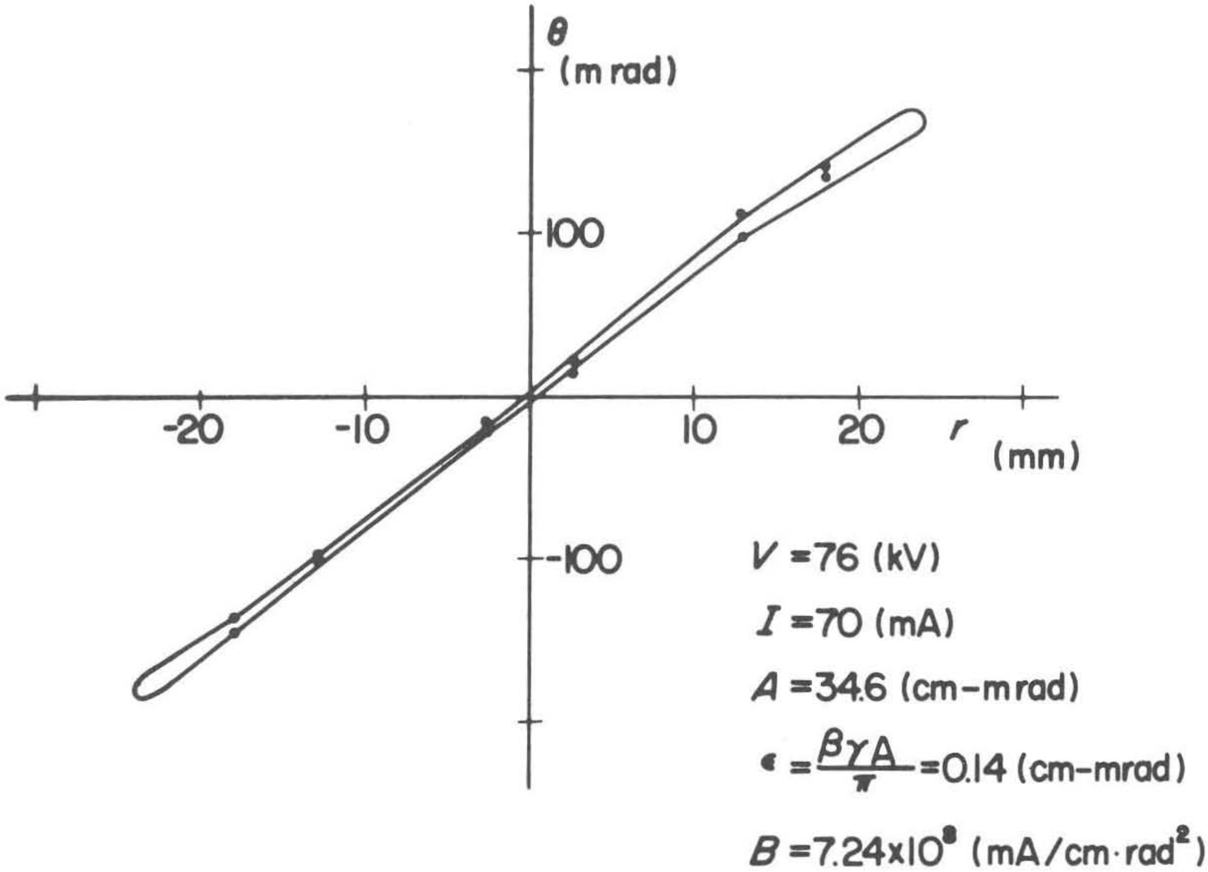


Fig. 8. Emittance diagram of the duoplasmatron shown in Fig. 7.

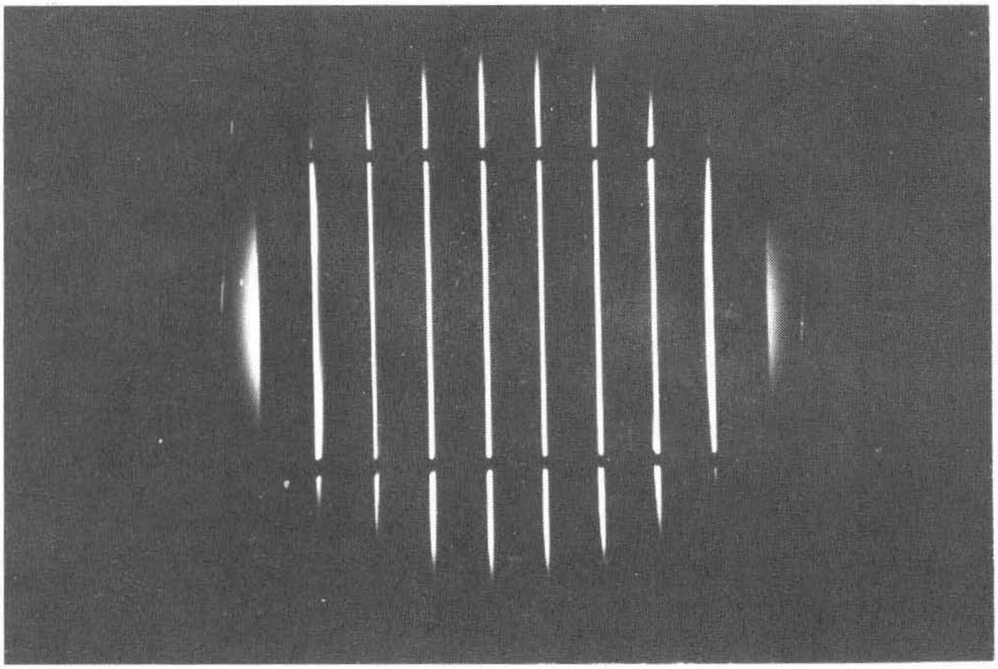


Fig. 9. Images of the emittance measurement of the duoplasmatron.

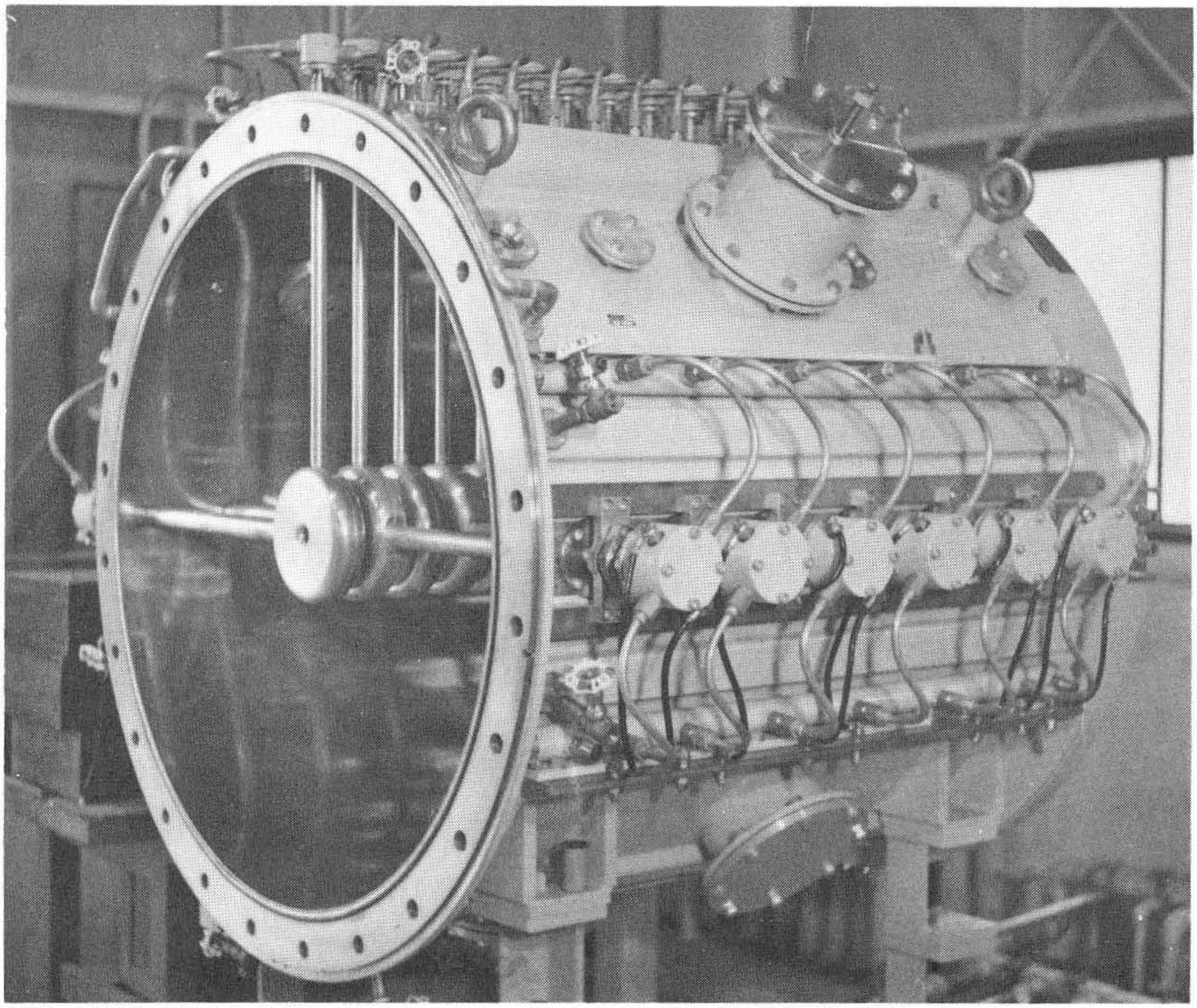


Fig. 10. Photograph of the prototype cavity fabricated by the electroplating method.

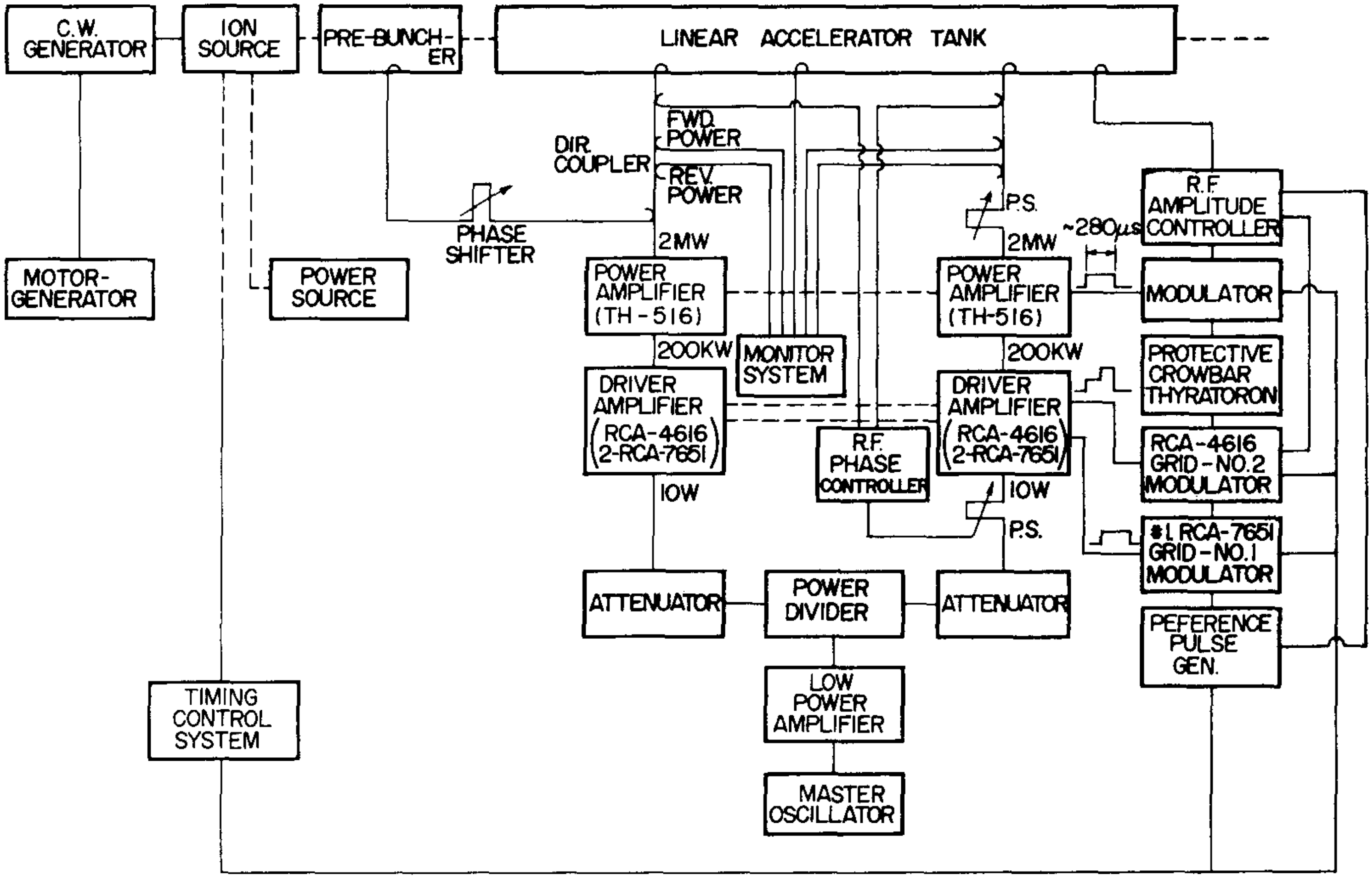


Fig. 11. Block diagram of the rf system.

DISCUSSION

J. P. Blewett (BNL): Is any polishing done either before or after electroplating?

T. Nishikawa (Univ. of Tokyo): No. We use only the usual chemical treatments before and after the plating process.