THE P.L.A. OF THE RUTHERFORD LABORATORY

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The P.L.A. of the Rutherford Laboratory consists of three separate cavities similar in arrangement to the 50 Mev linac injector for the CERN synchrotron. The nominal output energies of the three tanks are 10 Mev, 30 Mev and 50 Mev, respectively.

The linac is preceded by a 500 kev preinjector, using a Philips Cockcroft-Walton set as a dc generator. It is possible to use a normal proton source or a polarized proton source in the preinjector. The arrangement between preinjector and linac is given in Fig. 1, showing two sets of deflector plates for time-of-flight measurements. These are driven at a subdivision of the 202.5 Mc/s frequency used for the linac. This frequency is normally 11.25 Mc/s. It is possible now by rf deflection across the square aperture to produce one in 18 of the fine structure rf pulses, thus giving a time separation of 89 nanoseconds at the end of the machine which will permit time-of-flight measurements over a reasonable distance. The two plates are in the x and y orientations and can be used either separately or together to produce, for example, figures of eight, and therefore different burst spacings.

Following the time-of-flight deflectors is the buncher, also shown in Fig. 1. The rf excitation is obtained via a coupling loop from the first linac cavity. The backing plate on the buncher is insulated with PTFE (Teflon) and biased at 3 kv to stop multipactoring. The unloaded Q of the buncher cavity is only about 6000, owing to poor connections and closures.

This has been loaded down to ~ 400 by an external load. The phase of the buncher may be adjusted, but there is no automatic tuner.

Some parameters for the three cavities of the linac are given in Table 1.

Table 1

Output Energy	Length (ft)	Current	Peak Power	Avg. Power	Cavity Q
Injector 500 kev	---	5-7 ma	---	---	---
1st section 10 Mev	20	2-3 μa	0.6 Mw	12 kw	~80,000
2nd section 30 Mev	40	2-3 μa	1.25 Mw	25 kw	~60,000
3rd section 50 Mev	40	2-3 μa	1.4 Mw	28 kw	~45,000

The first cavity uses grid focusing with consequent large current losses. The current values shown were taken with a Faraday cup and are not particularly accurate. The rf power values shown should be considered accurate to about ± 20% only. The rf pulse length is 400 μsec with a duty cycle of 2%. The beam pulse length is 200 μsec.

To couple rf power into the cavities use is made of 3-inch, stub supported, lines tapering into 6-inch lines at the rf window. Reflectometers are used, calibrated by a 2 Mw load, to measure forward power to, and reverse power from, the cavities. The rf feed system to the first cavity is identical to that of the second and third cavity except that two grounded grid triodes are used for each of the latter two cavities. This necessitated four-armed combining bridges to add the power from two tubes.

The low level rf system makes use of a single grounded grid triode driven by a low power oscillator. The output of this triode is separated and fed to each of the three power amplifying systems.

Adjoining the linac area is the first experimental area separated by about three feet of concrete shielding. The linac output beam is passed through a bending magnet on a gun mount, thus permitting beam transport through any of seven beam channels.

The first experiments were carried out at an energy of about 30 Mev in mid-1960. A two-shift system of 8 hours per shift was introduced in February, 1961. This gave a potential running time of 16 hours (minus running-up and running-down time) per day from Monday to Friday with the weekends reserved for maintenance and new equipment. Under this system the whole machine was closed down for 8 hours each night. As a result there was always a high incidence of faults during running-up the next morning. An additional disadvantage was the limited availability of staff for maintenance during the weekends. Since the beginning of this year (1962) the per shift time has been increased from 8 to 12 hours, so providing 24-hour operation and allowing each experiment to be completed without interruption. In addition the maintenance periods have been arranged to fall mainly within the Monday to Friday period, thus insuring maximum staff and back-up effort to be available when actually required.

In the following, the more important faults causing lost operating time, are indicated for the period of March to September of 1961.

<u>Modulator Faults</u>

a) Failure of the ignitrons to hold off voltage under pulse conditions. Life times of these ignitrons varied from a few hours to perhaps 50 or 100 hours. When a new one was installed it was often necessary to try one or two before finding a good one.

Recently a deuterium thyratron, developed by G.E.C., has been acquired and the improvement has been substantial. Its characteristics are set forth in the following note:

VX3336 Deuterium Thyratron. This tube has been under development at the G.E.C. Research Laboratories, Wembley, for the last 5 years. Development has been sponsored by the Royal Radar Establishment, Malvern. The tube has been described, in its early form, by H.G. Cook at the Symposium on Hydrogen Thyratrons and Modulators held at Fort Monmouth, New Jersey, in 1960, and in its present form at this year's Symposium. Deuterium has a more advantageous Paschen breakdown characteristic than hydrogen, thereby permitting a higher working voltage while retaining the rapid ionization and deionization characteristics of hydrogen. The tube has an impregnated cathode for high emission and long life. Experience with smaller tubes suggests that lifetimes of upwards of 5000 hours may be expected. The tube has a metal envelope with ceramic and glass insulators. It is water-cooled. Design ratings of the tube are:

Maximum forward voltage:	40 kv
Maximum peak cathode current:	10,000 amps at 10 microsecond pulse length 1,000 amps at 100 microsecond pulse length
Maximum mean current:	15 amps
Heater rating:	10 watts, 160 amps
Trigger:	normally 1 kv but much less will do (100v negative bias)

The present application calls for:

Forward voltage	above 25 kv
Peak cathode current	300 amps at 400 micro-seconds pulse length, 50 pulses per second
Mean current	6 amperes

To date one tube has operated very satisfactorily for about 550 hours, another for about 250 hours. The modulator circuitry incorporates also deuterium filled triggered diodes, type VX3533 as inverse diodes connected to the non-discharge end of a pulse forming network. These tubes have also been developed by G.E.C. They are glass envelope tubes with oxide cathodes and can withstand an inverse voltage of 40 kv. Although the characteristic impedance of the pulse forming network is about 40 ohms, the load in series with a VX3533 is made larger than this, actually above 100 ohms, so that some inverse voltage is applied to help extinguish the VX3336 in the presence of a magnetizing current from the pulse transformer.

b) Voltage breakdown in the 100 kw modulators on the pulse forming network condensers and coils. Trouble on the latter has been aggravated by a tendency for the outer edges of adjacent coils to be pulled together by the magnetic forces. The manufacturers of the original condensers indicated that these condensers were not designed for pulse work. New condensers obtained from the same manufacturers have given no difficulties. The coils have been made much more rigid and no further trouble has been encountered with these.

c) Failure of components, particularly condensers, in the grid control circuit of the high voltage rectifiers (excitons) due to arc-back and unexplained voltage transients. Some of this type of difficulty seems to be the normal and unavoidable troubles one has with condensers in this sort of hookup.

Grounded-grid Triode Faults

A description of the grounded-grid triode would be pertinent here, for troubles with these and the associated circuits constituted the second largest cause of lost time. A diagram of this triode is shown in Fig. 2. General specifications of the Mark II triode are tabulated in Table 2. Performance characteristics are given in Figs. 3, 4, and 5. The construction of the cathode and filament structure is given in Fig. 6. This is essentially a cylindrical set of 65 strip beam electron guns. In each of the concave channels a carbonized thoriated tungsten cathode heater was placed. As shown, the ends of each cathode heater bar were tapered to distribute the heating more uniformly. These filaments take of the order of 20 kw (3800 amps at 4v). Extremely good lifetimes have been achieved with these filaments. The first one installed has been in operation for well over 20,000 hours, 15,000 hours at full duty.

Triode faults arising from the cathode structure have been zero, after the triode has been put into service. A few new triodes have had filament failure during the first 10 to 20 hours of tune up operation. This was mainly due to bent cathode bars. Very long life times have been experienced if one gets past this initial period.

The triode is an inside-out valve, designed in this way in order to maximize the cathode current; the anode is inserted into the cylindrical cavity from the top and is part of the resonant tuning of the output circuit. Power is coupled out through a loop, as shown in Fig. 2,

Table 2

Harwell Mark II Grounded-grid Triode Amplifier Valve

Internal tuned circuits
Frequency: - 202.5 Mc/s (anode circuit)
Grid circuit Pre-tuned by machining, following cold tests.

Original design specification

Output power	2 Mw peak
Duty cycle	2% (400 μsec pulses, 50 pulses/second)
Input power	100 kw peak
Anode voltage	40 kv peak
Anode current	125 amp peak

As used on P.L.A.

Max output power	750 kw peak into very high Q load (about 50,000)
Duty cycle	2%
Power gain	10
Anode voltage	30 kv peak
Anode current	70 amp peak (approx.)

Filaments designed to give absolute peak emission of 300 amps (64 carburized thoriated tungsten rods 0.060 in dia., emitting length 4 in).

Filament power: -	3800 amps at 4 volts, 50 c/s
Operating temperature	1650°C brightness.

Cooling

Demineralized water, conductivity better than 20 μ-m hos/cm

1. Cathode cooling circuit. Total flow = 10 gal/min max.
   8 gal/min min.
2. Top plate and anode circuit: Total flow = 10 gal/min max.
   8 gal/min min.
3. Water-cooled grid = Total flow = 5 gal/min max.
   3.5 gal/min min.
4. Air cooling of glass output window: About 4 cu.ft/min., directed on to window from 18 holes in outer conductor of output line.

Valve is continously evacuated using a Varian Vac-Ion pump of 140 liters/sec capacity. Filament outgassing is carried out initially using an auxiliary oil diffusion pump with liquid nitrogen trap.

through a slab line (for reasons of space) and then through a transforming section and finally into a coaxial line. A glass-to-metal seal is used on the coaxial line.

The anode assembly is, in effect, a half-wavelength line, shorted at both ends, and coupled in the current maximum region. There is a small tuning capacity in the system.

The cathode and the grid of the tube are water cooled. The grid cooling consists of a number of U-shaped stainless steel tubes, spot welded into the jacket. This quite literally grounds the grid of the triode; since one end of the cathode bars are not grounded some capacity between these and the grid is obtained. The input circuit is an open circuited half-wavelength line with the input power coupled in at the current maximum, again a glass-to-metal seal is used on the input.

The faults that have occurred are:

a) Rf breakdown at the input loop. This is a transformer section containing a low impedance line in order to match the 50 ohm impedance of the input line to that of the loop. The ceramic posts in this area used to arc down. Since replacing these with mica insulators very little trouble has been encountered.

b) Some filaments have jumped out of their spring loading and caused grid to cathode shorts. It was possible to salvage the main assemblies in every case.

c) Some of the tin seals have failed.

d) The output line has a spring which, if incorrectly assembled, will cause heating and start a leak in the glass-to-metal seal. This has caused most of the trouble in the last two months.

e) While using an oil diffusion pump on the triode frequent arcing occurred across the lower end of the anode at the point where the rf voltage is added to the plate voltage. Using a Vac-Ion pump reduced this considerably. The Vac-Ion pump has a capacity of 140 liters/sec, which is more than adequate because the valve has a volume of only 30 liters. The new pumping arrangement has reduced the incidence of this fault considerably.

RF Line Faults

a) Rf line breakdown has occurred mostly at the 3-inch input lines to the tank near the input window. The 3-inch line seems inadequate to handle the 1.4 to 1.5 Mw used in the third section. Presently the 3-inch line is being replaced with a 4.5 inch coaxial line in the high power sections.

b) Some trouble has been encountered with the connector passing through the rf window, which is shown in Fig. 7.

Apart from the foregoing, some minor trouble has been encountered in the past with the slow stablizer on the preinjector, the cooling water chilling plant and a few other items.

A record of operating time for the periods of March to September 1961, and for the period of January to June 1962, is shown in Fig. 8 in the form of a histogram.

During the first period, the ratio of operating to scheduled time was 54%. This increased to 78% since starting to run 24 hours a day. Also because of this the number of running hours increased from 1169 to 2129 hours, almost by a factor of two, for comparable periods in time. Maintenance time, as indicated, was taken up mainly (say up to 90%) by modification of equipment and installation of new equipment.

Discussion

I.J. Polk (BNL): Is it relatively simple to disassemble the 200 Mc/s grounded grid triode?

K. Batchelor (Rutherford): Yes, a tin ring seal is used in the anode assembly and another for the removal of the grid assembly.

I.J. Polk (BNL): Do you bake out this triode?

K. Batchelor (Rutherford): No, the whole system is worked up gradually to higher power levels.

R.P. Featherstone (Minnesota): You mentioned breakdown in the 3½ inch coaxial line, causing you to change to a 4½ inch line. Have these troubles been more of a voltage breakdown nature or was this caused by heating from average duty?

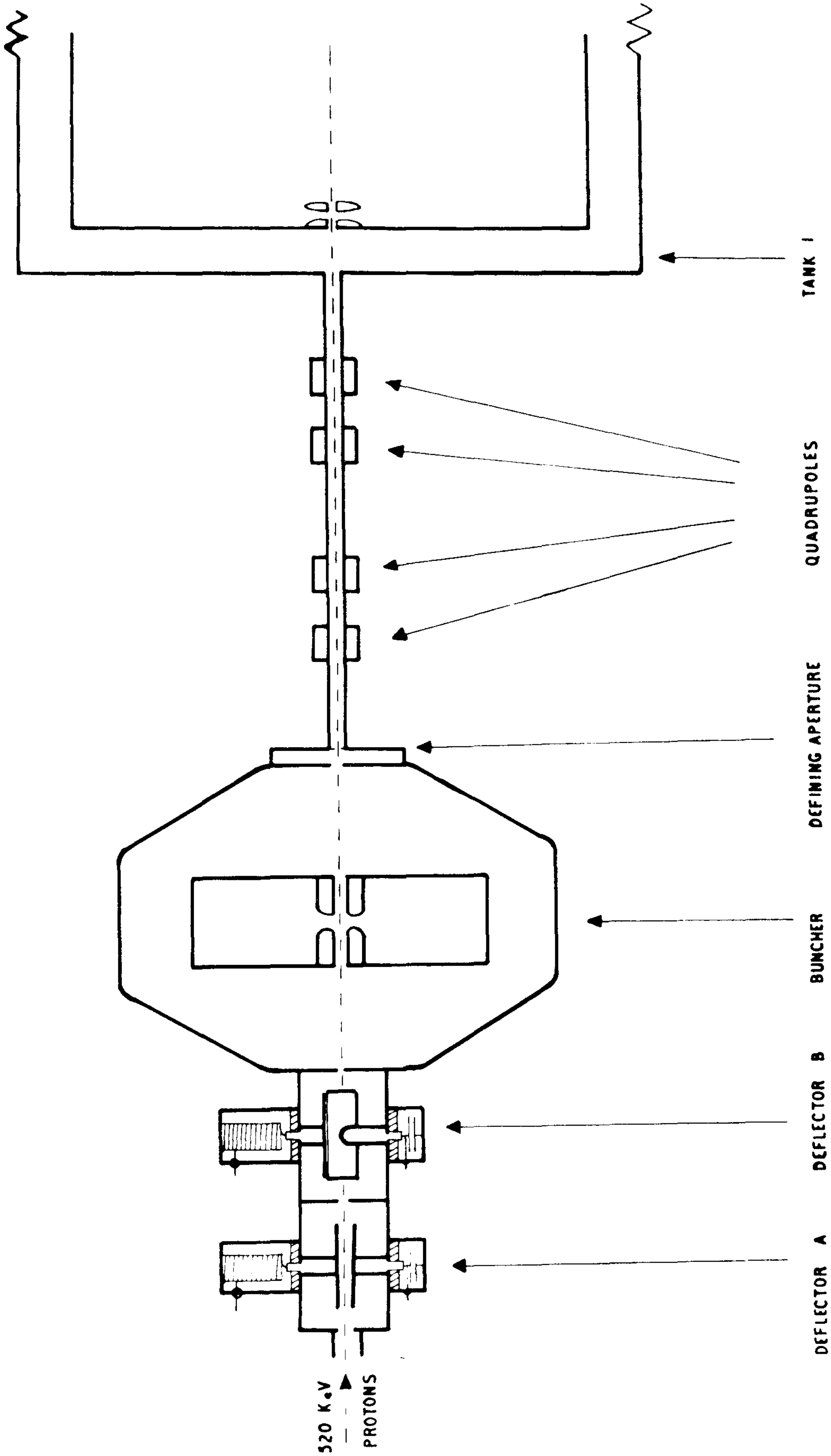
K. Batchelor (Rutherford): The effect is heating from average duty, which precipitates voltage breakdown. These rf lines run fairly hot; there is no cooling in that part of the system.

J.P. Blewett (BNL): Is there a tangential electric field at the rf window coupling the power triode to the linac tank?

K. Batchelor (Rutherford): The electric field is almost, not quite, normal to the window.

J.P. Blewett (BNL): Has there been solder joint trouble in the power dividing network?

K. Batchelor (Rutherford): There has been some trouble with solder joints. We had some very small finger strips in the movable joint of the line lengthener which deteriorated after a year or so; the solder softened under the high currents. We have gone over to spinning out and splitting the brass tube to complete the connection, and this has proved to be quite satisfactory.



ARRANGEMENT IN THE 520 KeV DRIFT SPACE

Fig. 1

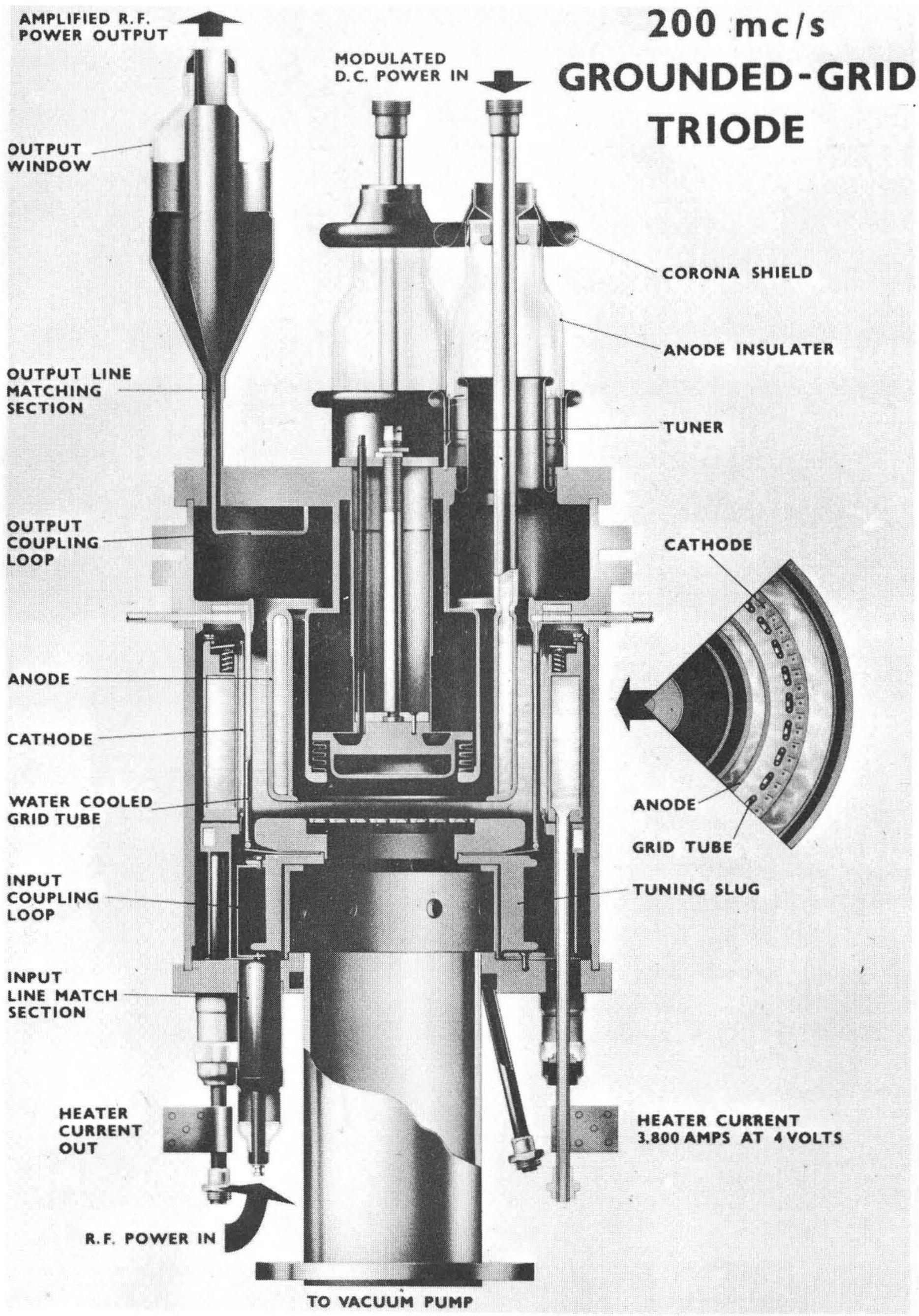

200 mc/s
GROUNDED-GRID
TRIODE
AMPLIFIED R.F. POWER OUTPUT
MODULATED D.C. POWER IN
OUTPUT WINDOW
CORONA SHIELD
ANODE INSULATER
OUTPUT LINE MATCHING SECTION
TUNER
OUTPUT COUPLING LOOP
CATHODE
ANODE
CATHODE
WATER COOLED GRID TUBE
ANODE
GRID TUBE
TUNING SLUG
INPUT COUPLING LOOP
INPUT LINE MATCH SECTION
HEATER CURRENT OUT
HEATER CURRENT 3.800 AMPS AT 4 VOLTS
R.F. POWER IN
TO VACUUM PUMP

Fig. 2

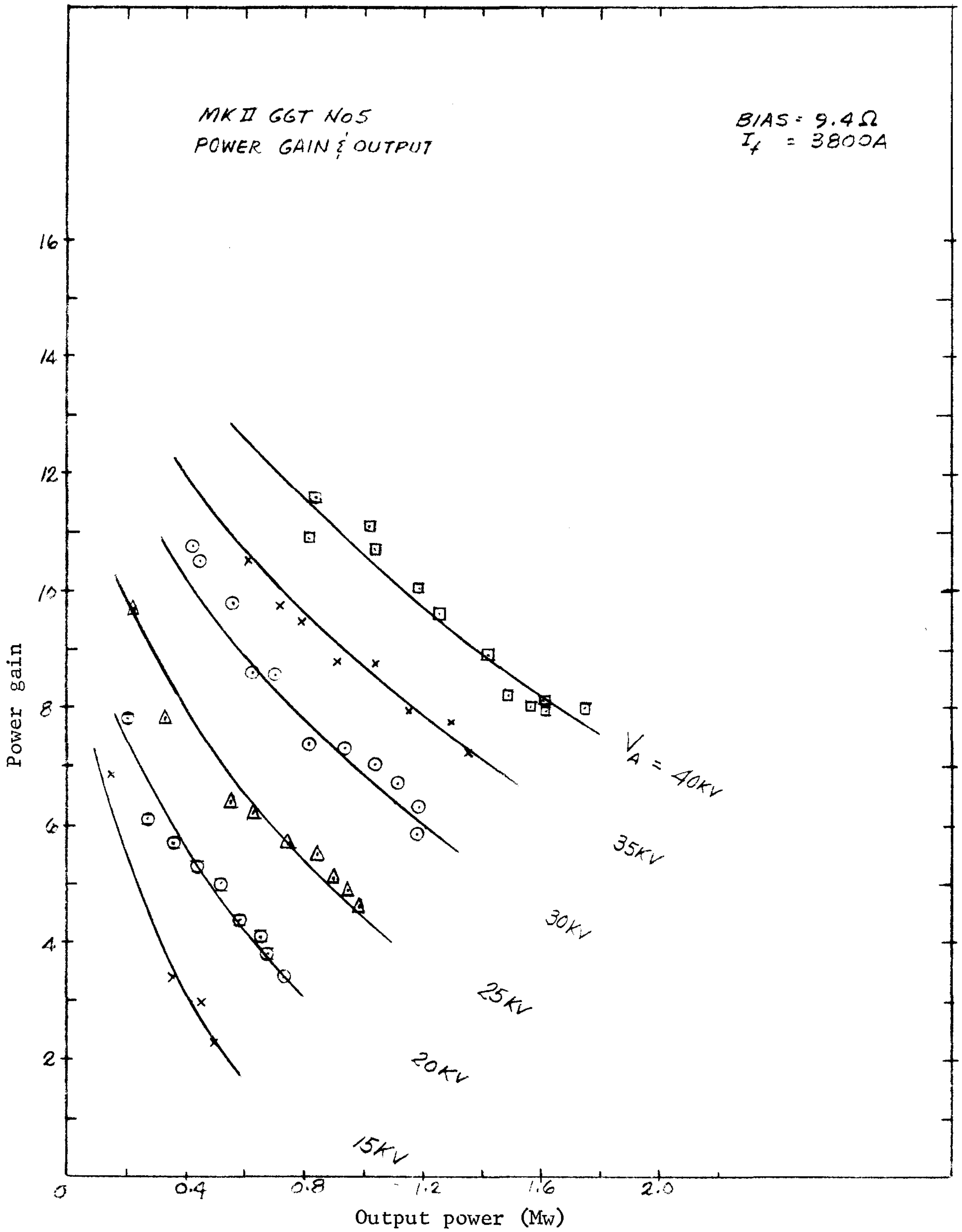

MK II GGT No5
POWER GAIN & OUTPUT
BIAS = 9.4 Ω
I_f = 3800A
Power gain
16
14
12
10
8
6
4
2
0
0.4
0.8
1.2
1.6
2.0
Output power (Mw)
V_A = 40kv
35kv
30kv
25kv
20kv
15kv

Fig. 3

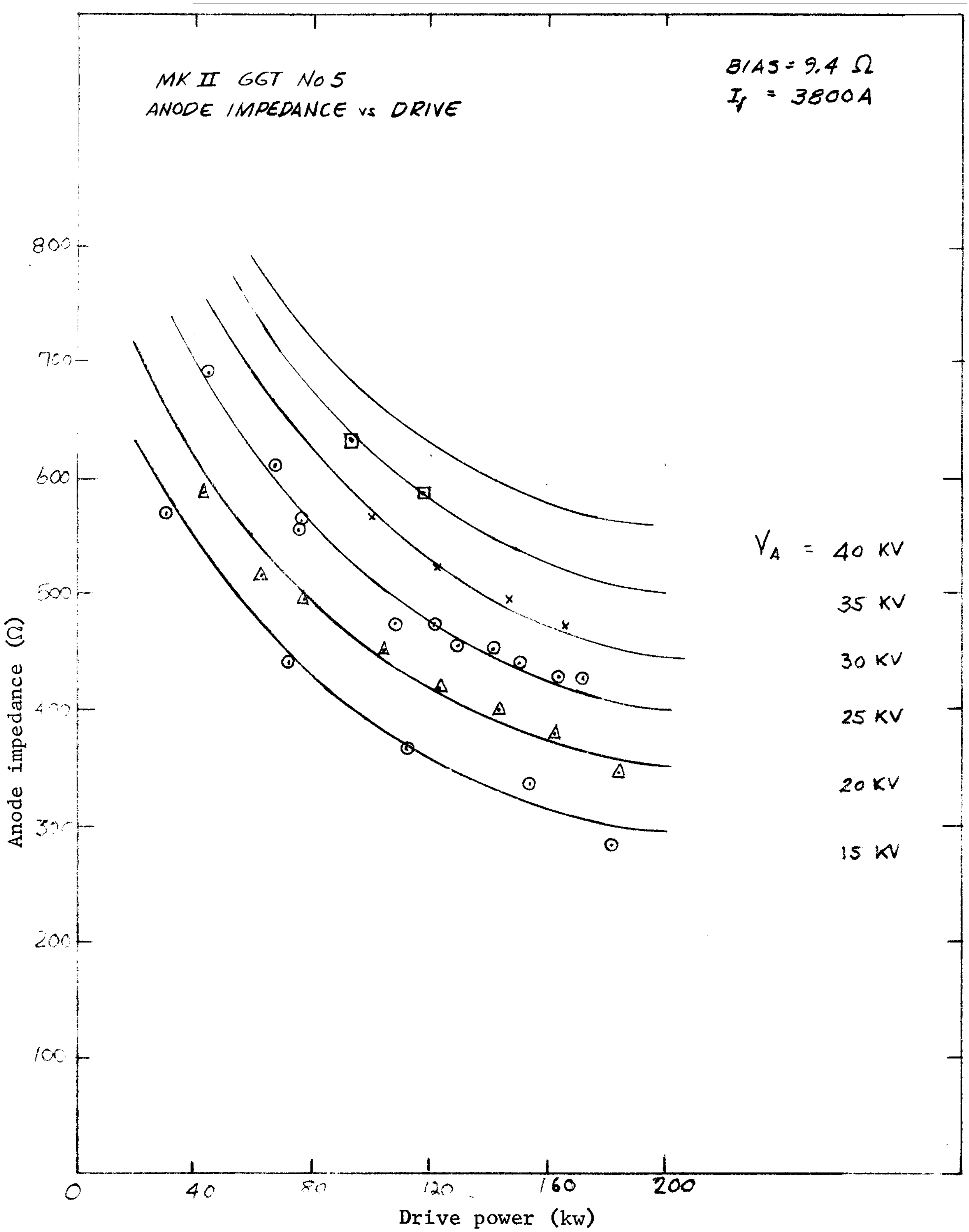

MK II GGT No 5
ANODE IMPEDANCE vs DRIVE
BIAS = 9.4 Ω
I_f = 3800A
V_A = 40 KV
35 KV
30 KV
25 KV
20 KV
15 KV
800
700
600
500
400
300
200
100
0
40
80
120
160
200
Anode impedance (Ω)
Drive power (kw)

Fig. 4

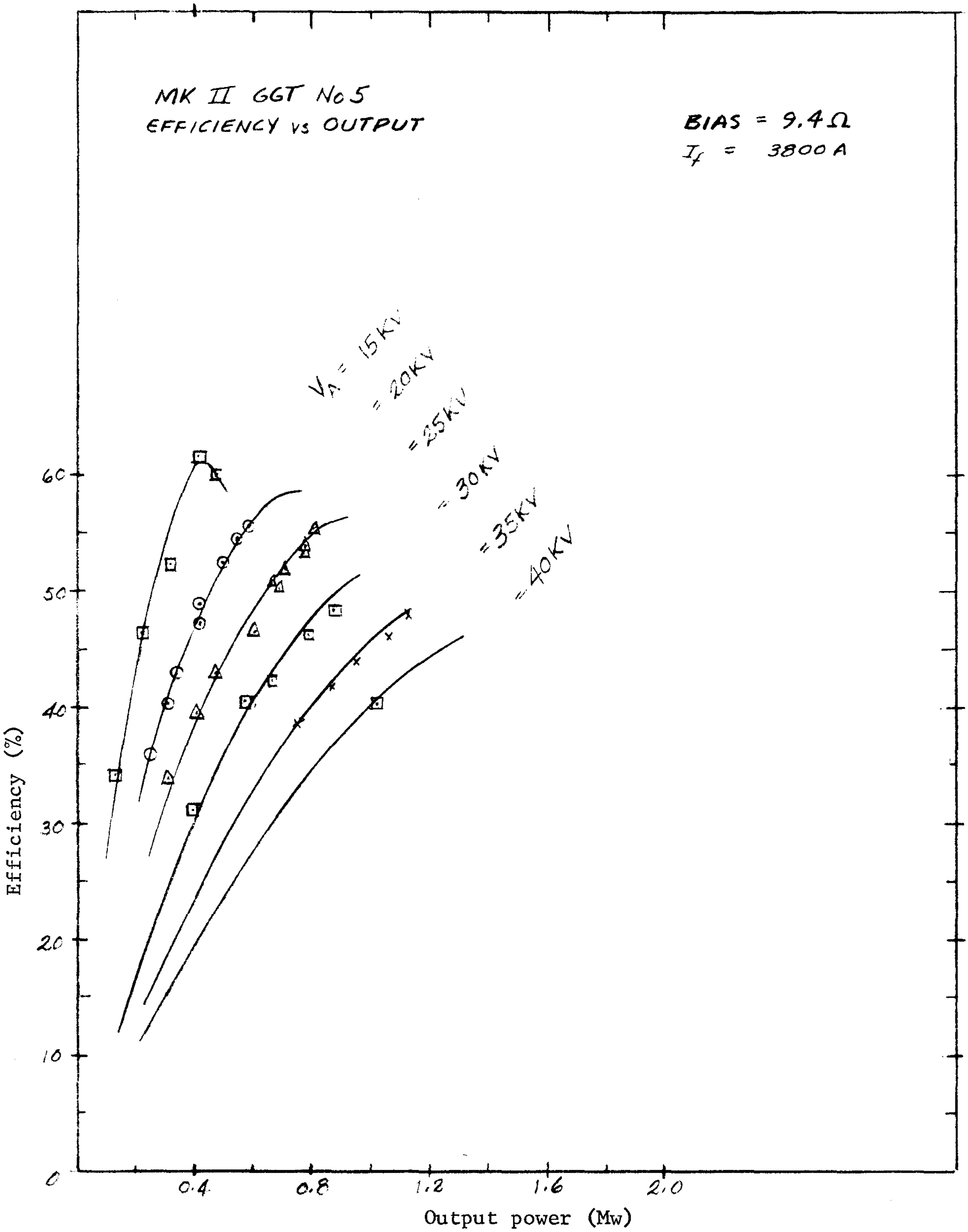

MK II GGT No 5
EFFICIENCY vs OUTPUT
BIAS = 9.4 Ω
I_f = 3800 A
V_A = 15 KV
= 20 KV
= 25 KV
= 30 KV
= 35 KV
= 40 KV
Efficiency (%)
Output power (Mw)
0
10
20
30
40
50
60
0.4
0.8
1.2
1.6
2.0

Fig. 5

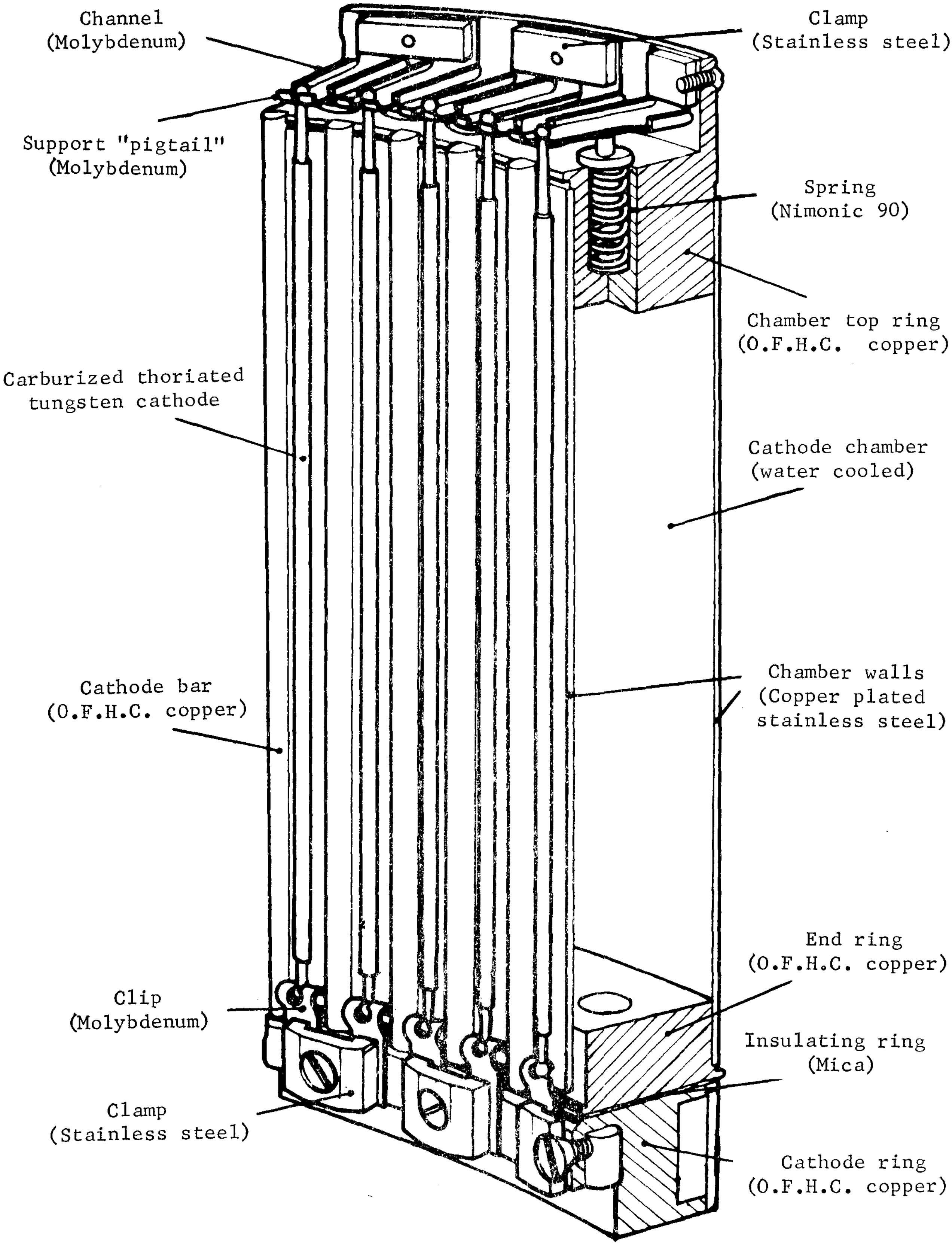
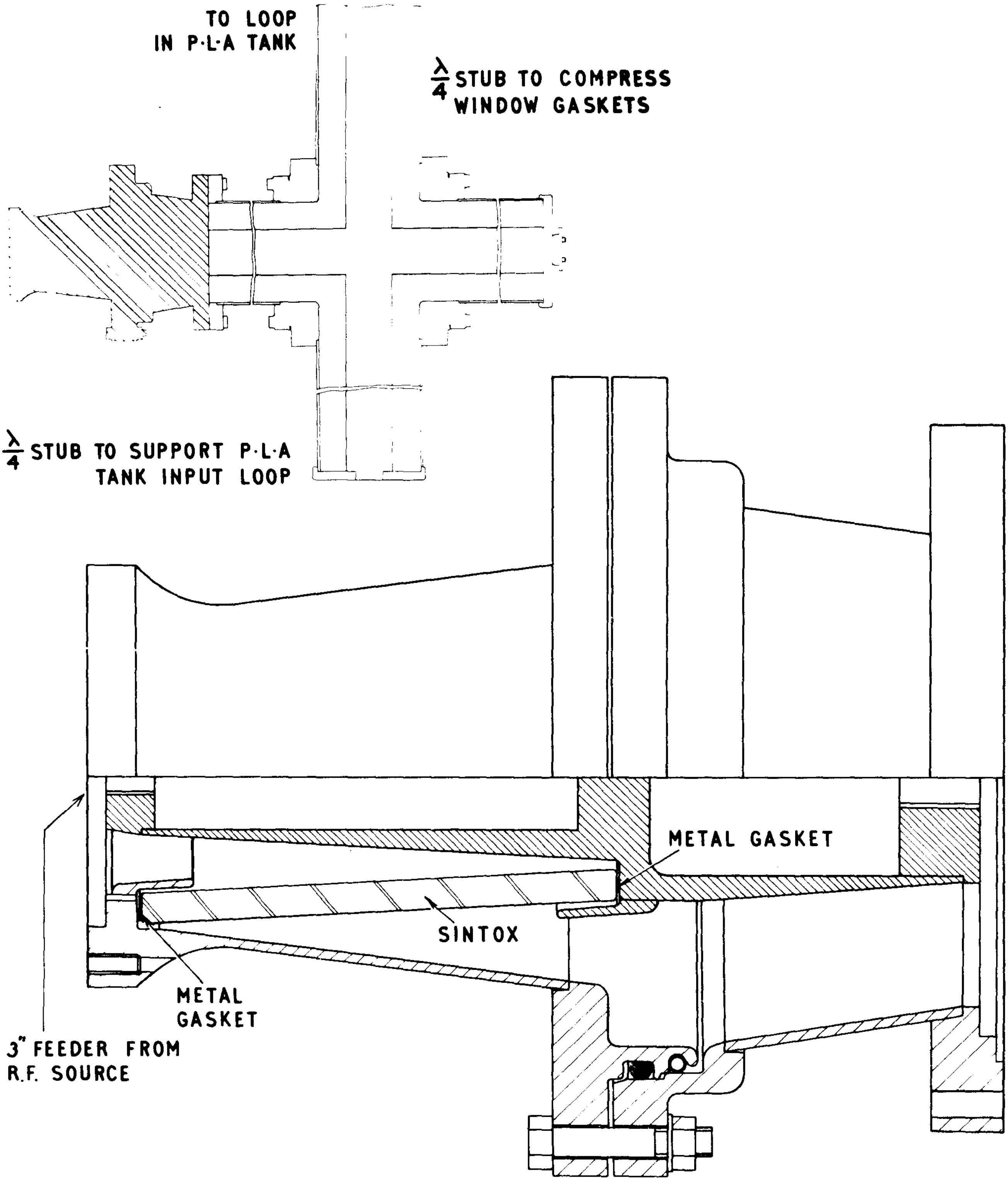

Channel
(Molybdenum)
Clamp
(Stainless steel)
Support "pigtail"
(Molybdenum)
Spring
(Nimonic 90)
Chamber top ring
(O.F.H.C. copper)
Carburized thoriated
tungsten cathode
Cathode chamber
(water cooled)
Cathode bar
(O.F.H.C. copper)
Chamber walls
(Copper plated
stainless steel)
End ring
(O.F.H.C. copper)
Clip
(Molybdenum)
Insulating ring
(Mica)
Clamp
(Stainless steel)
Cathode ring
(O.F.H.C. copper)

Fig. 6



COAXIAL SINTOX WINDOW FOR R.F. INPUT
TO PROTON LINEAR ACCELERATOR

Fig. 7

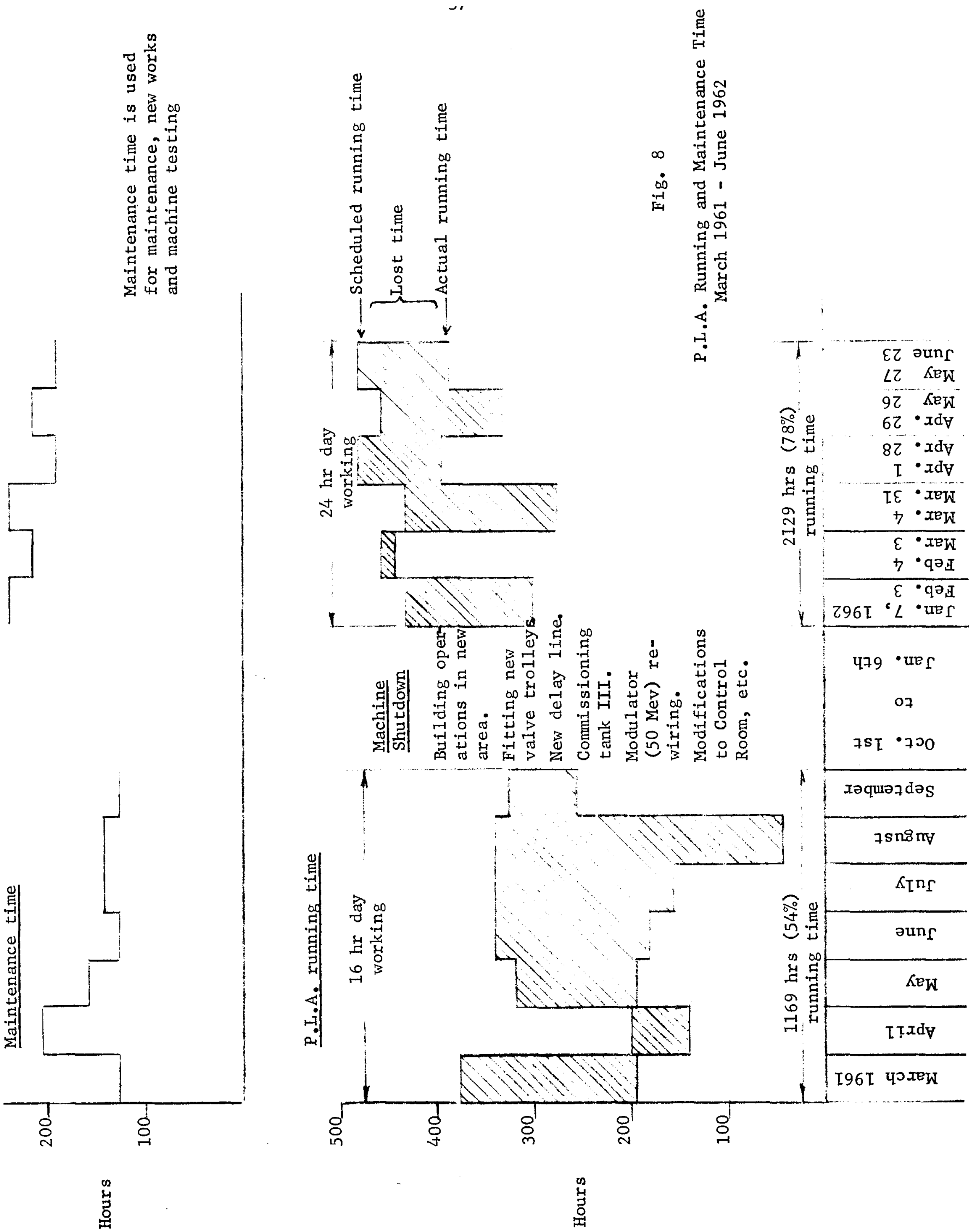


Fig. 8

P.L.A. Running and Maintenance Time
March 1961 - June 1962