REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE

~~February 1995~~

3. REPORT TYPE AND DATES COVERED

Final Report

4. TITLE AND SUBTITLE

High Cathode Temperature Experiments on an MPD Thruster Report #1

5. FUNDING NUMBERS

F6170893W0738

6. AUTHOR(S)

Ing. Fabrizio Paganucci

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Via A. Gherardesca, 5
56014 Ospedaletto Pisa

8. PERFORMING ORGANIZATION REPORT NUMBER

SPC-93-4051

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

EOARD
PSC 802 BOX 14
FPO 09499-0200

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

SPC-93-4051

11. SUPPLEMENTARY NOTES

2 documents: Final report and Review Report 1.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT (Maximum 200 words)

The first phase of the program was dedicated to improving the cathode heater to be mounted on the thruster, and to integrating the thruster with test equipment already available at CS. A more exhaustive description of this phase of the program was given in the review report number 1. The experimental activity of the second phase was performed in two steps: firstly the calibration of the gas feeding system was conducted, then the measurements of the electrical characteristics with cold cathode and with the cathode heated at about 2100K at the tip were taken. Argon, nitrogen, hydrogen and gas mixtures simulating hydrazine and ammonia were used as propellants.

14. SUBJECT TERMS

15. NUMBER OF PAGES

34,23

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19, SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

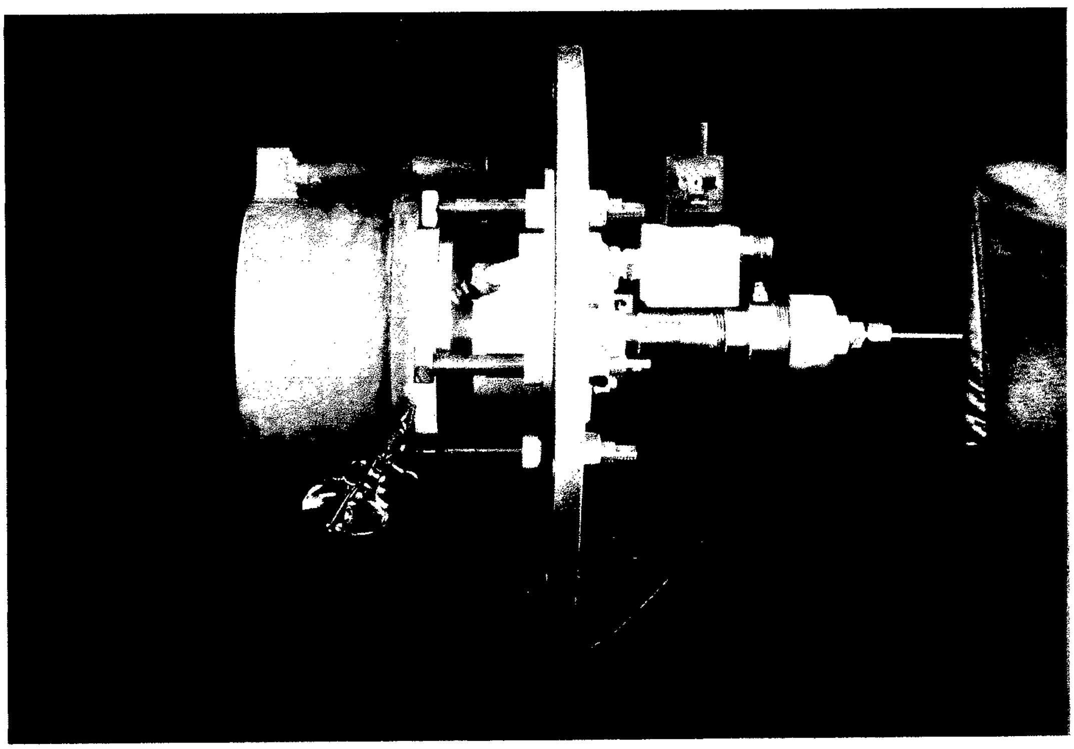
CENTROSPAZIO

Via A. Gherardesca, 5
56014 Ospedaletto Pisa
Tel. +39 (0)50 985097 / 985072
Telefax +39 (0)50 985069
Sede Legale:
Consorzio Pisa Ricerche
Via Risorgimento 9
56100 Pisa

Programme:

AFOSR Special Contract SPC-93-4051

High Cathode Temperature Experiments on an MPD Thruster



Review Report No 1

May 1994

Prepared by: **Ing. Fabrizio Paganucci**

Fabrizio Paganucci

Approved by: **Prof. Ing. Mariano Andrenucci**

Mariano Andrenucci

List of Contents

Foreword

This report describes the first phase of activities carried out at CENTROSPAZIO (CS) in the framework of the AFOSR special contract no. SPC-93-4051, "High Cathode Temperature Experiments on an MPD Thruster".

Following the agreement reached with AFOSR (M. Hallada) and NASA Lewis (R. Myers), the thruster and raw materials (thoriated tungsten, boron nitride) used for these activities were supplied by the NASA Lewis Laboratory.

As illustrated in the relevant technical and administrative proposal, the first phase of the programme was dedicated to improving the cathode heater to be mounted on the thruster, and to integrating the thruster with test equipment already available at CS. This work spans over a period of approximately two and a half months from delivery of the equipment by NASA Lewis in February 1994. The subsequent phase will be dedicated to thruster testing and characterization.

The appendix briefly illustrates the experimental equipment available at CS for MPD testing.

Requirements

Activities are aimed at carrying out a series of tests on a gas-fed MPD thruster operating in a pulsed mode, with the cathode artificially heated to temperatures above 2000 K. The test programme foresees the measurement of electrical characteristics with and without cathode heating, using different propellants (argon, helium).

Considering the limited budget available for this activity, it was decided to create a new thruster from one previously used at NASA Lewis on AFOSR programmes and to adapt a cathode heater and the test equipment already available at CS to this device. NASA Lewis thus provided CS with the components of two thrusters, as well as two pieces of boron nitride and a thoriated tungsten bar (see Figs. 1 and 2). The devices supplied are normally tested at NASA Lewis as gas-fed, continuous MPD thrusters with an external magnetic field, operating in a power range of 100 - 200 kW. The electrodes are water cooled during operation.

The new thruster was designed in accordance with the following requirements:

- the thruster must originate from the one supplied by NASA Lewis; the components delivered can be included in the new thruster without limitations, in line with the requirements of the activity;

- the cathode heater must allow the cathode tip to reach temperatures ranging from 300 K to 2500 K during testing

- the gas feeding system must supply gas pulses with a short transient (few ms) followed by a steady state phase of the mass flow (from 5 to 50 ms), during which the current discharge may occur. Steady state mass flow rates from 0.5 to 4 g/s of argon must be supplied.

- the thruster must be easily interfaced with the existing equipment for electrical characteristic measurements and plume diagnostics.

- in view of further activities, the thruster must be interfaced with the existing thrust stand without significant modifications.

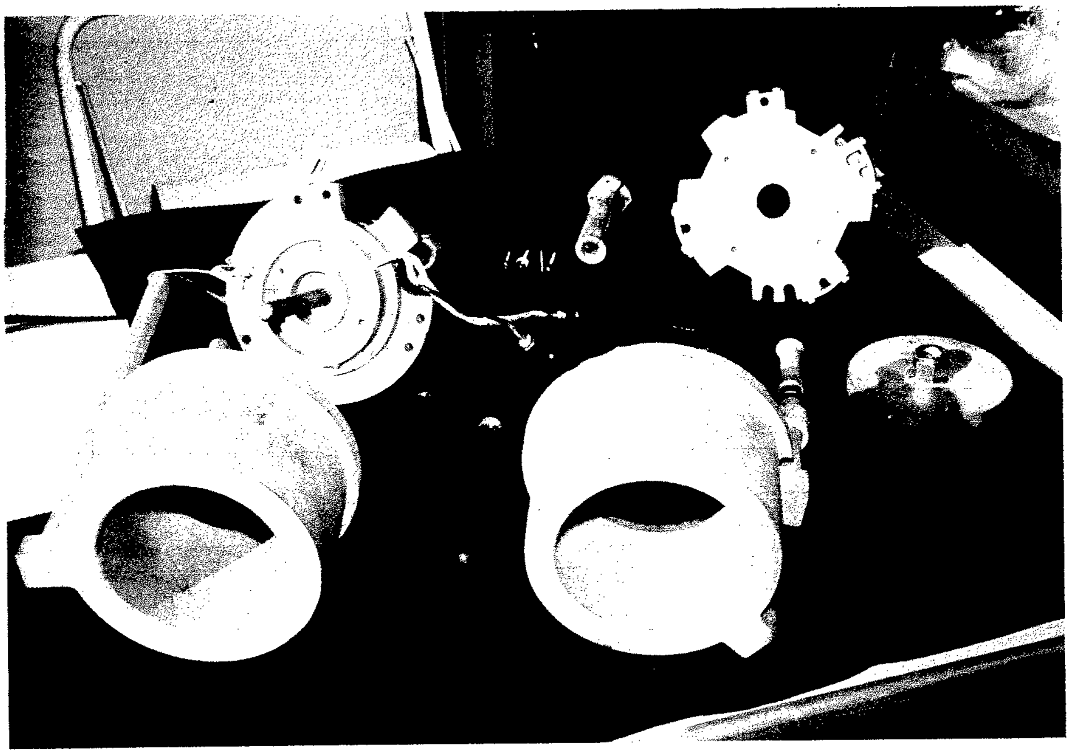


Fig. 1 - The thruster details from NASA Lewis

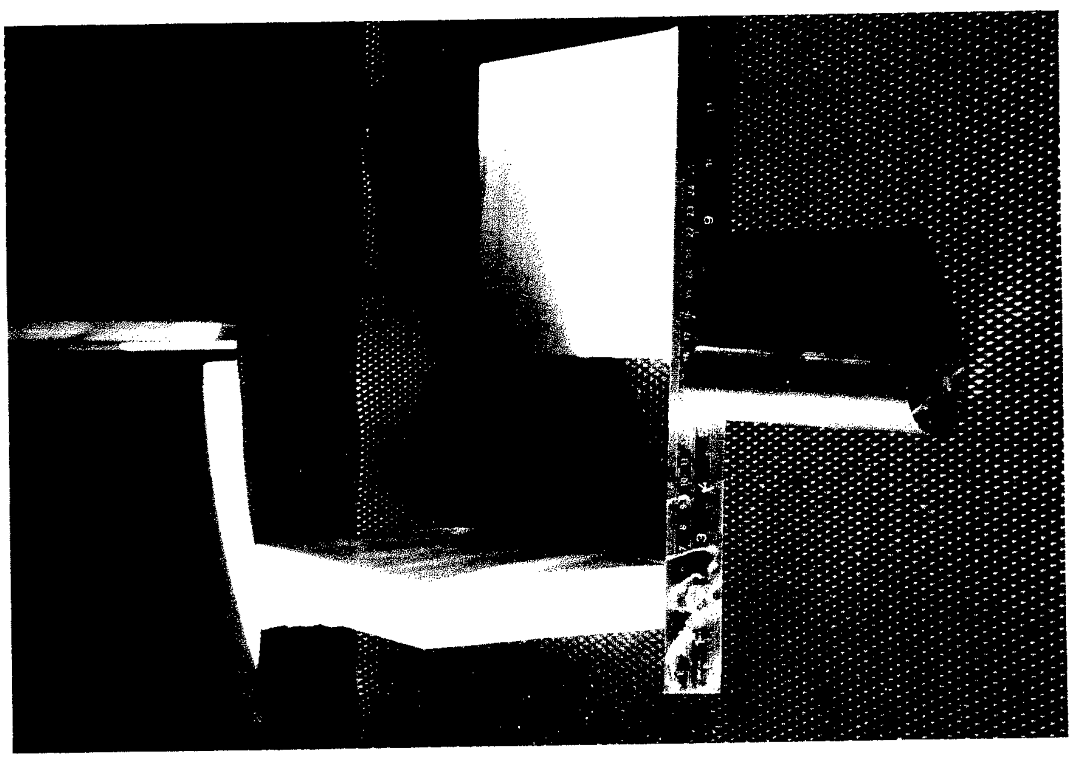


Fig. 2 - Raw materials from NASA Lewis

Thruster Design

In Figs 3 -8 the new thruster is illustrated. It is mounted on a standard, dedicated aluminum flange (12) which acts as an interface with the vacuum chamber IV2 (see appendix).

The copper anode (1) was taken from the AFOSR thruster making only slight modifications. Considering the discontinuous operation of the thruster and the thermal analyisis described in the next paragraph, no cooling system was adopted for the anode. However, the existing one could be restored easily, if necessary.

The gas is injected by a boron nitride plate located behind the anode (4). The gas flows through eight nozzles manufactured on the plate, while the choking orifices (0.5 mm in diameter) are located on an brass injector (6), behind the plate. The gas is distributed equally to the orifices by an annular volume, manufactured on a brass dispenser (7). The gas is fed to the dispenser by a lateral swagelock (16), to which a teflon tube (from the solenoid valve) is attached (17). All of the contact surfaces between the dispenser, the injector and the plate are sealed with graphite gaskets (5).

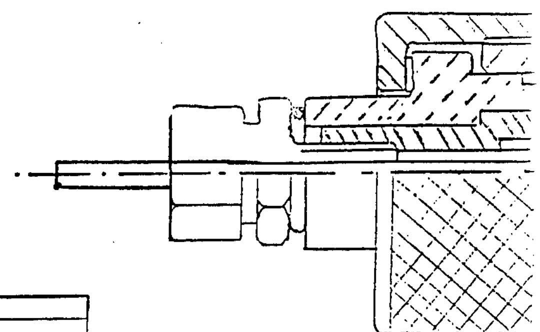
A boron nitride insulator (9) fixes the cathode position with respect to the anode. This detail is held in a central position to the plate with a boron nitride spacer (8).

The gas injection group (4, 6, 7) and the details 8 and 9 are held between the aluminum flange (12) and the anode by four copper bars (2). The bars are used to connect the anode to the PFN electrically and are isolated from the flange with teflon bushings (13).

The cathode with the heating system was developed during previous experimental activity on ESA contracts. This configuration was chosen due to its simplicity and the good operating mode shown in previous testing.

The cathode heating system developed at CS uses the heat supplied by an electric arc established between an inner electrode and the cathode. This electrode plays the dual role of anode to the internal arc during the heat-up phase and cathode to the thruster during discharge. It is a thoriated tungsten cylindrical element (20 mm in diameter), supported by a rear tungsten bar; the edge of the external surface is hemispherical. A cavity was drilled into the core of this electrode to hold the inner one. The bottom of the cavity is specially shaped to start up the internal electric arc. A thermal dam was machined onto the inner electrode to reduce its thermal conduction. The inner electrode is a thoriated tungsten stick, 3 mm in diameter, with a sharp conical edge. It is fixed to the boron nitride insulator with a swagelock. Alumina sticks are used to insulate the second electrode in order to avoid arc ignition in undesired sites along the electrode.

The cathode with the heater is placed in detail 9 and is held by the boron nitride spacer 22 and an aluminum spacer holder (23).

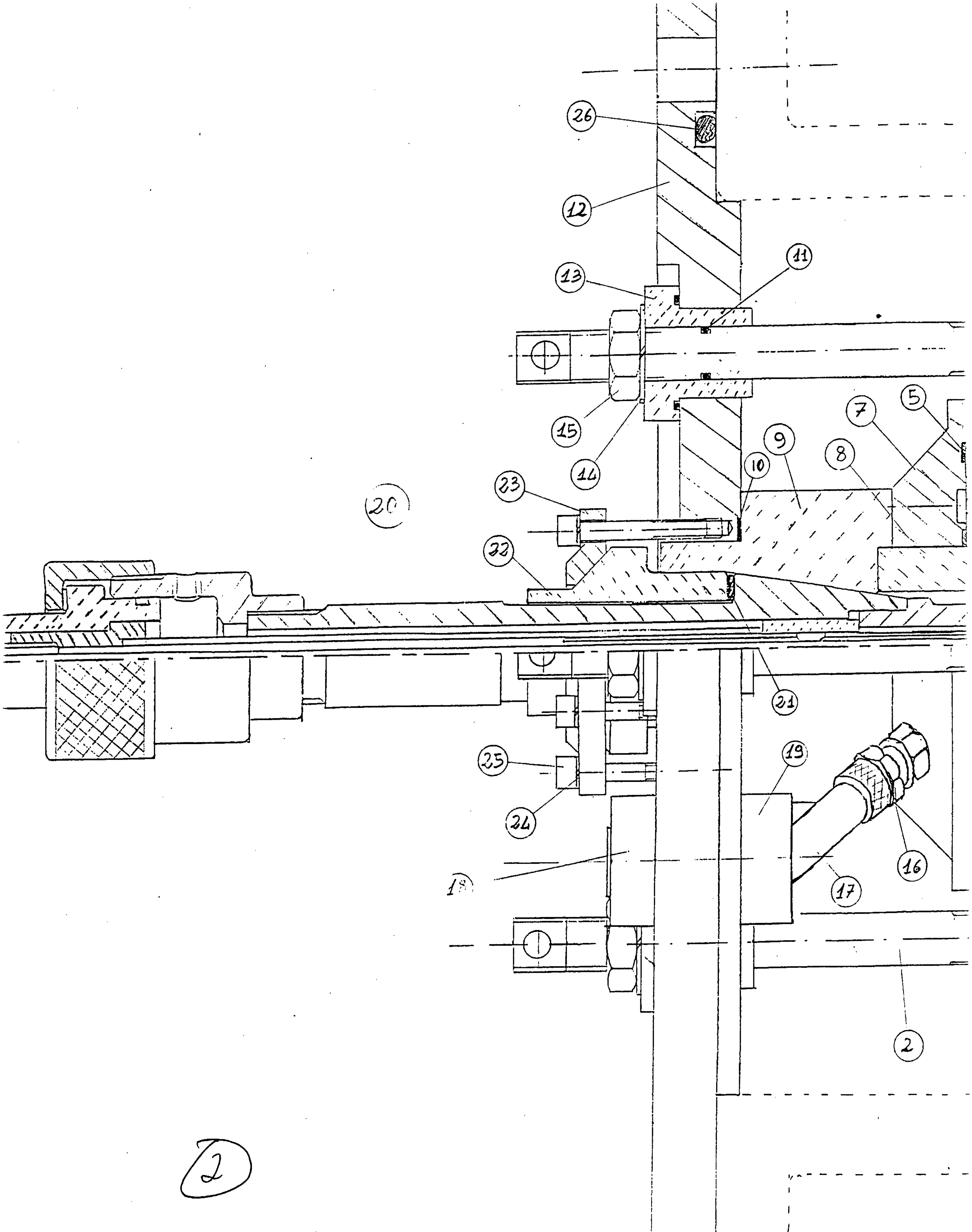


N° part.	NAME	N° pieces	MATERIAL	NOTES
26	O - RING	1	NEOPRENE	
25	SCREW M 4X40 UNI 5739-65	6	STAINLESS STEEL	
24	ELASTIC WASHER N° 2	6	C 98 UNI 3545	
23	SPACER HOLDER	1	ALLUMINUM ALLOY	
22	SPACER N° 2	1	H P BORON NITRIDE	
21	GASKET N° 3	1	GRAPHOIL	
20	CATHODE HEATING GROUP	1	Tungten/Allumina/HP Boron Nitride	From previous design
19	NUT N° 3	1	TEFLON	
18	VALVE ADAPTER	1	TEFLON /BRASS	Compound detail
17	TUBE	1	TEFLON	
16	SWAGELOCK	1	STAINLESS STEEL	
15	NUT N° 2	4	STAINLESS STEEL	
14	ELASTIC WASHER N° 1	4	C 98 UNI 3545	
13	BUSH	4	TEFLON	
12	FLANGE	1	ALLUMINUM ALLOY	
11	O-RING	9	NEOPRENE	
10	GASKET N° 2	1	GRAPHOIL	
9	CATHODE INSULATOR	1	HP BORON NITRIDE	
8	SPACER N° 1	1	HP BORON NITRIDE	
7	DISPENSER	1	BRASS	
6	INJECTOR	1	BRASS	
5	GASKET N° 1	4	GRAPHOIL	
4	INJECTION PLATE	1	HP BORON NITRIDE	
3	NUT N° 1	4	STAINLESS STEEL	
2	STAY BAR	4	COPPER	
1	ANODE	1	COPPER	

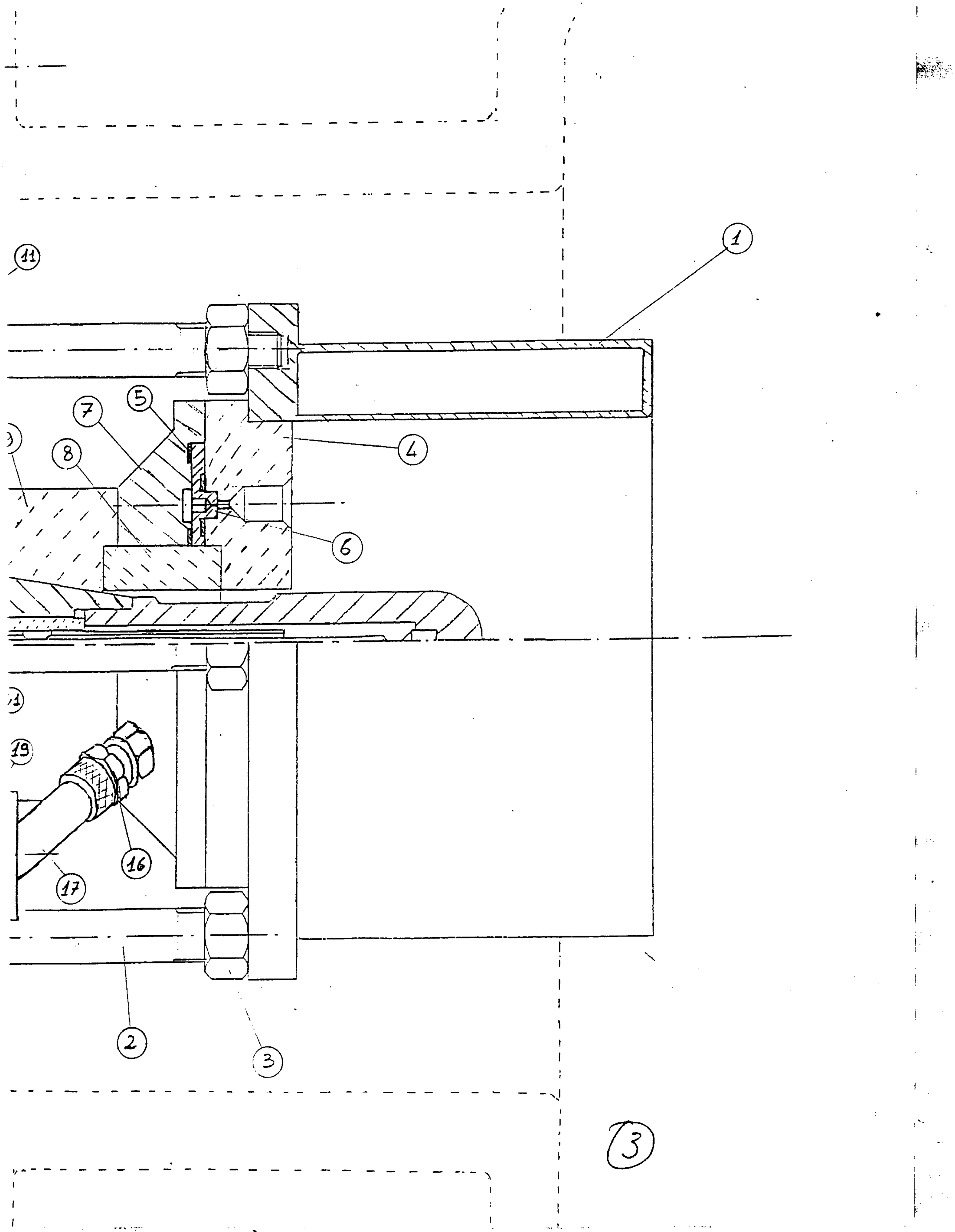
CENTRO SPAZIO	Major Assembly MPD THRUSTER WITH CATHODE HEATING	Project F6170893W0738
		Sheet 1 of 2

Date	Modifications	Sign.	Group	Designed	Scale 1:1
			Subgroup	Cecked	Date 3/15/1994
			Substitutes / Substituted	Approved	Code

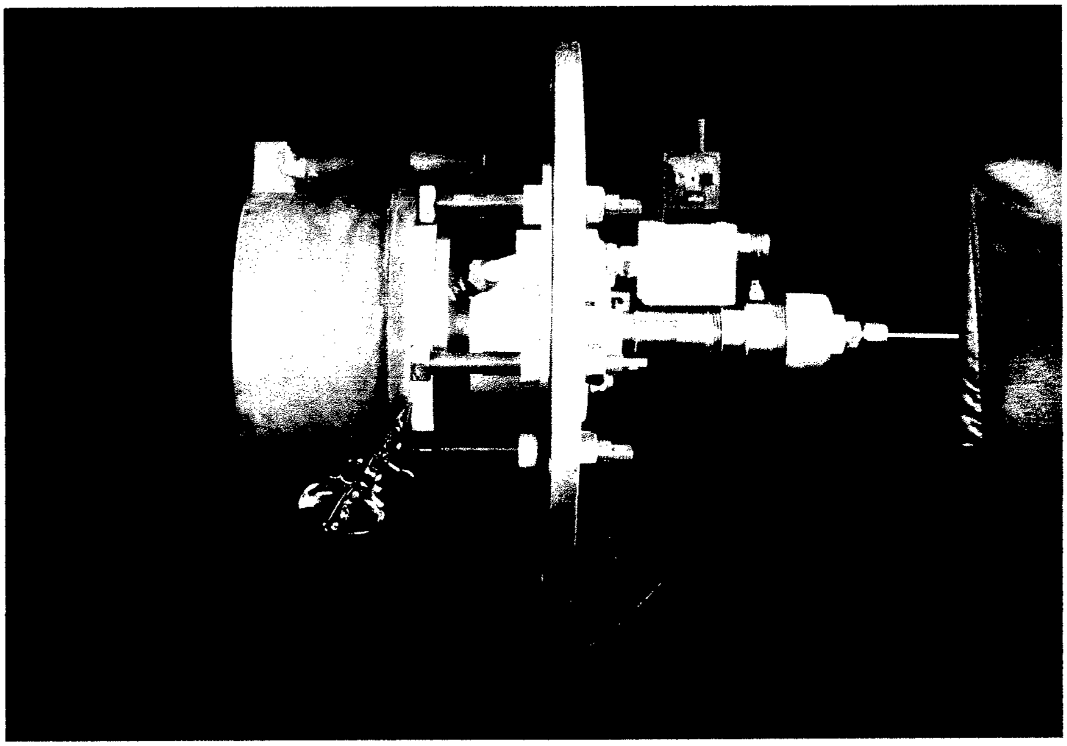
(1)



2



3



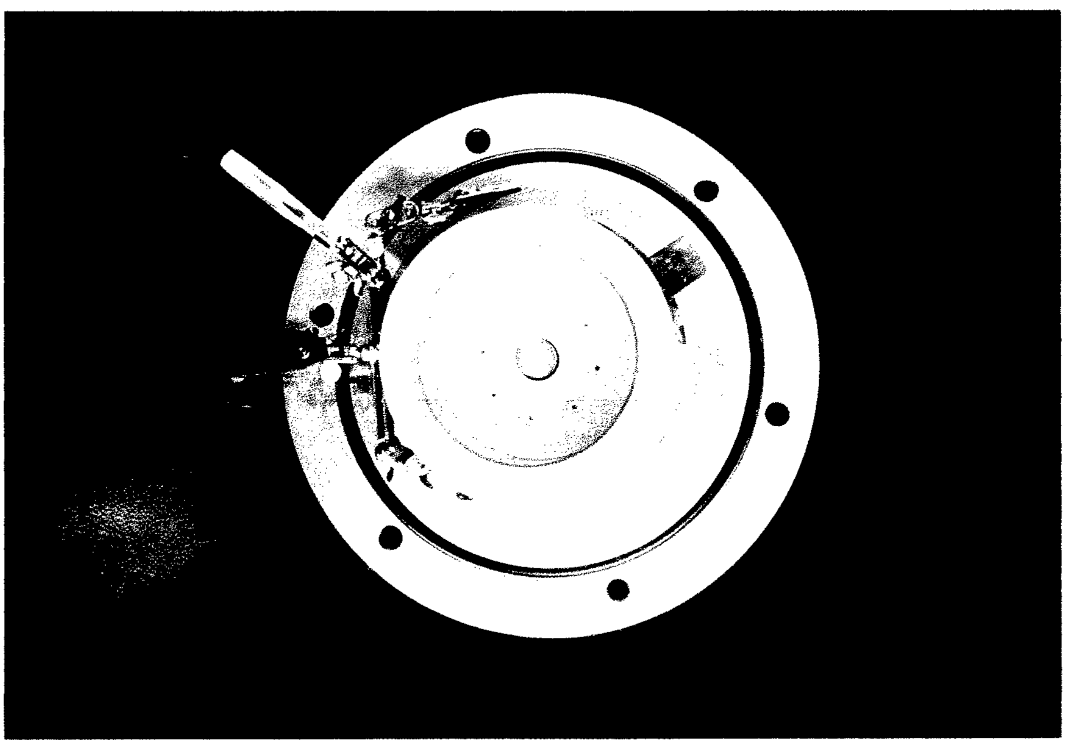


Fig. 4 and 5 - Thruster views

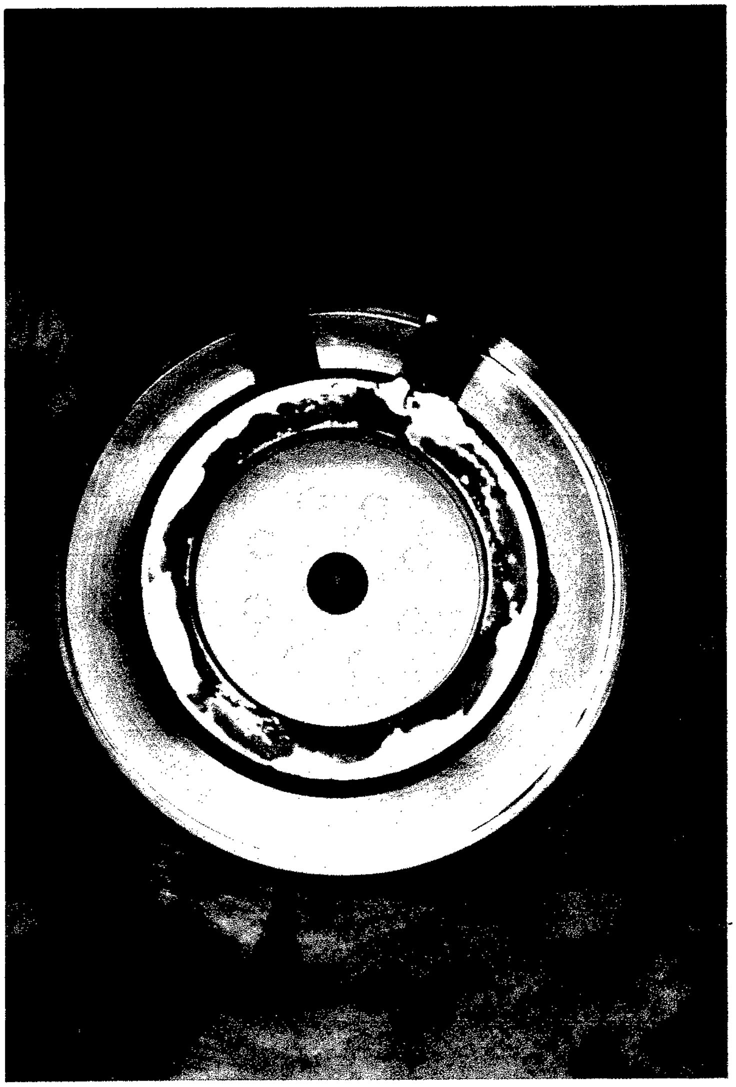


Fig. 6 - The thruster mounted on the vacuum chamber IV2

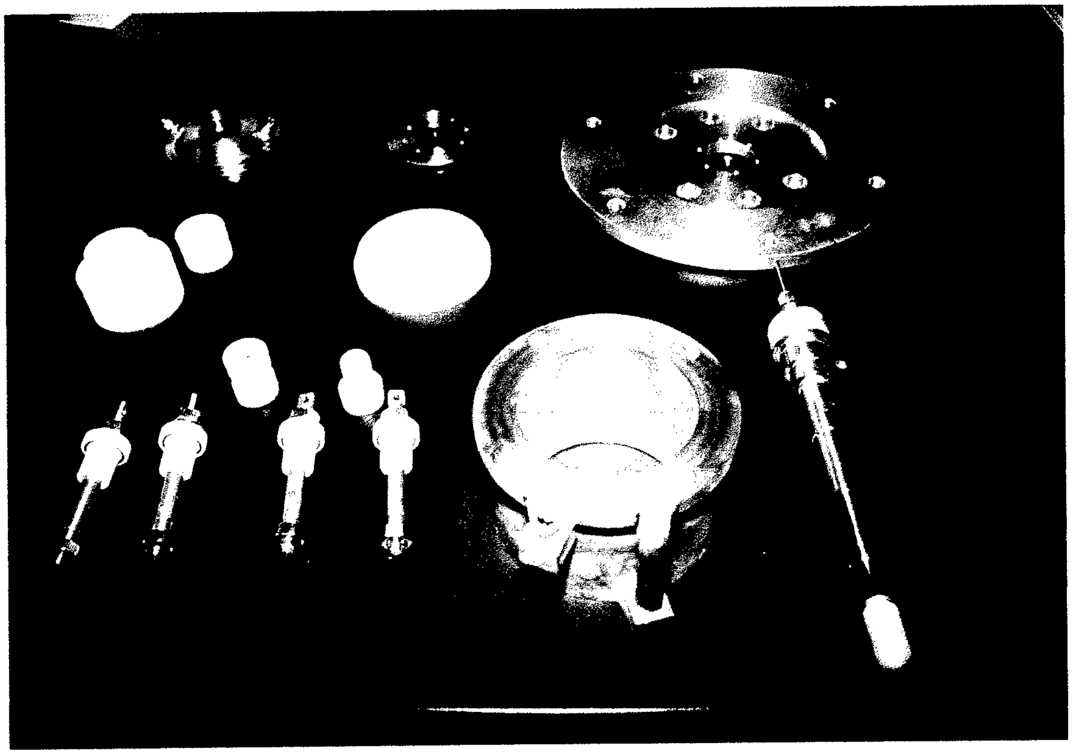


Fig. 7 - Thruster details

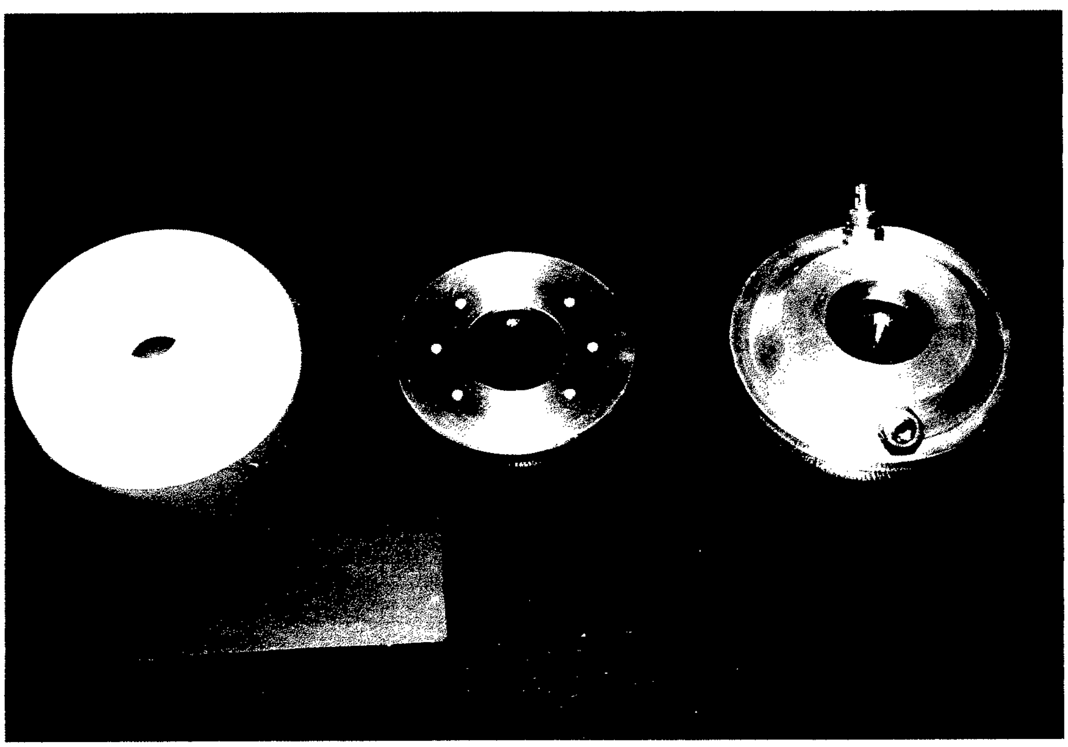


Fig. 8 - The gas injection group (plate, injector and dispenser)

Thermal Analysis

A typical testing cycle with cathode heating mainly consists of five phases:
- heater arc ignition (about 1 ms);
- cathode heating and, simultaneously, PFN charging (about 60 s);
- heater arc extinction (about 1 s);
- thruster discharge (about 1 ms);
- vacuum chamber evacuation until working pressure is reached and, simultaneously, cathode cooling by conduction and radiation (about 90 s).

Considering the duty cycle (about 180 s), the thermal stress is derived from the heat supplied by the cathode heater. The heat supplied by the discharge is infact negligible.

Previous experience has shown that the discharge chamber of the thruster must be cleaned after about ten heating cycles, as the cathode heater increases the deposit of char on the thruster (most probably due to the oil from the diffusive pump), which can alter the experimental results. As a consequence, a thermal analysis must demonstrate a safe operation of the thruster for about ten heating cycles.

Anode. The main source of heating for the anode is the radiation from the cathode. To calculate the anode heating the following assumptions have been made:

- the cathode temperature is considered as uniform on the entire external surface and equal to the temperature on the tip (conservative assumption);
- the anode is considered as a black body which absorbs all of the heat radiated by the cathode (conservative assumption);
- no thermal gradient is considered on the anode and its temperature is homogeneous at each time (simplifying assumption);
- the anode is considered as thermally insulated from the other components (conservative assumption).
- the maximum increase of anode temperature for safe operation is considered as ΔT = 300 ºC

As a consequence, the expression adopted to calculate the maximum number of heating cycles (n) compatible with a safe anode operation is:

$$c_a M_a \Delta T = n\, E_{rad} \qquad [1]$$

where:

c_a = 0.4 kJ/kg K, thermal capacity of the copper

M_a = 3.3 kg, anode weight

and

$$E_{rad} = \sigma A_c \int_0^t \varepsilon_c(T_c)\, T_c(t)^4\, dt \qquad [2]$$

is the energy radiated by the cathode surface (A_c = 2000 mm²), in accordance with the previous assumptions. E_{rad} was calculated numerically using the temperature law shown in Fig. 9, that is the cathode tip temperature measured by the pyrometer during a typical heating cycle on the ESA thruster (heater power: 1.4 kW). The cathode emissivity (ε_c) law (tungsten), shown in Fig.10, was obtained from data sheets (Metallwerk Plansee GmbH "Tungten").

Here, E_{rad} is about 25 kJ, representing about 35% of the entire energy supplied by the heater during each heating cycle (70 kJ).

From [1], the maximum compatible number of cycles is about 16, that is, sufficiently greater than 10. As a consequence, the anode is able to operate correctly without a cooling system.

Insulators and gas injection group. From the thermal point of view, the most critical component is the teflon tube, fixed at the dispenser by means of a swagelock. It means that its temperature must be below 200 ºC after ten heating cycles.

The boron nitride insulators and the gas injection group are heated by:

- the anode by conduction (detail 4)
- the cathode by radiation (details 4 and 8) and by conduction (details 9, 21-22).

Essentially, they transfer all of the heat to the alluminum flange (12), where it is dissipated by the cables and the atmosphere. We assume that the heat transfer towards the alluminum flange is negligible during the ten heating cycles and that those components are homogeneously heated (conservative).

The heat from the anode is negligible. In fact it is almost all transferred throughout the four copper stay - bars, each having about 1000 times the thermal conductivity of the backplate.

The heat from the cathode by radiation is calculated assuming a temperature on the cathode root similar to the cathode tip, but with a maximum of 1500 K (found assuming a linear gradient of temperature from the cathode tip and the back of the heater at ambient temperature). The calculation yields to about 9 kJ of energy for each heating cycle, that is about 12% of the total energy supplied by the heater (70 kJ).

The percentage of heat transferred to the detail 9 from the cathode by conduction can be estimated by comparing the thermal conductivity of the back of the heater with the conductivity of the boron nitride piece. The conductivity of the first is estimated about 10 times that the second. As a consequence, 1/10 of the heat that flows back (about 55% of the total) is transferred to the component 9 from the cathode, while the heat transferred to the component 22 is about 1/50. These two contributions represent about 6 - 7% of the total energy. As a result, it is reasonable to assume that 20 - 25 % of the heat supplied by the heater is dissipated on the BN insulators and on the gas injection group. It corresponds to about 175 kJ of thermal energy supplied in ten heating cycles. The entire thermal capacity of those components being about 1.3 kJ/K, the final temperature is about 150 ºC, which is less than 200 ºC, that is the maximum allowable.

The cathode and the cathode heater. It was designed to support very high temperature (up to 3000 K). In fact the critical components are made of refractory materials (tungesten, boron nitride, allumina), while the components on the back are of stainless steel, where the thermal requirements are less demanding.Moreover, the heat can easily flow throughout the electrical connection and dissipate through the cables and the atmophere.

Thermal expansion and stress. The effect of thermal expansion is limited, considering the relatively low heating of the thruster components and the low linear thermal expansion of the most stressed components (tungsten). Nevertheless, the cathode and the anode are fixed with screws with elastic washers, in order to prevent the thruster from thermal stress or from gaps due to the differential expansion of the components. This function is also partially carried out by the graphite gaskets and the teflon bushings that have a certain elasticity.

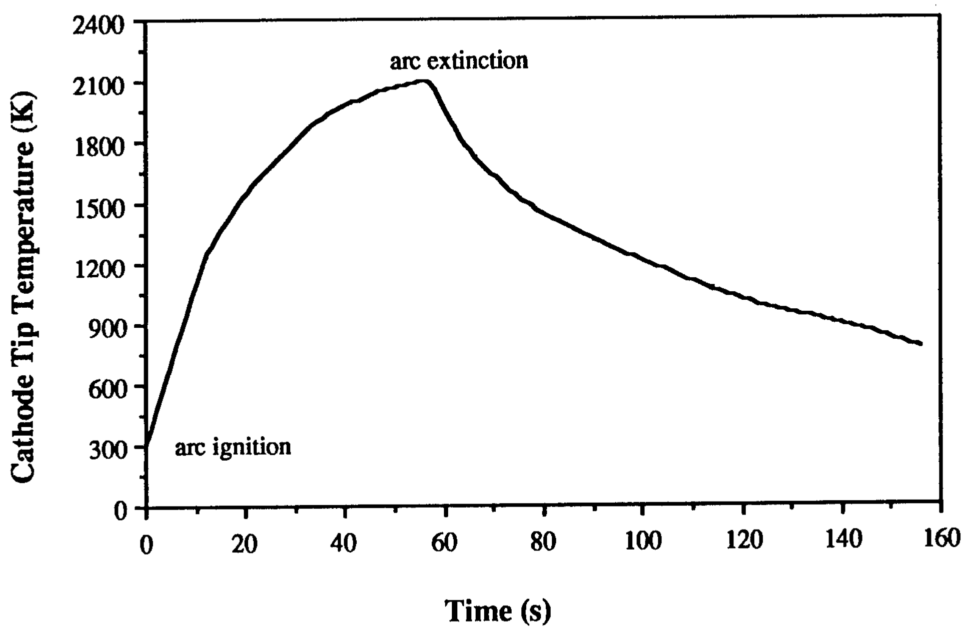


Fig. 9 - Thecathode tip temperature measured by the pyrometer during a typical heating cycle

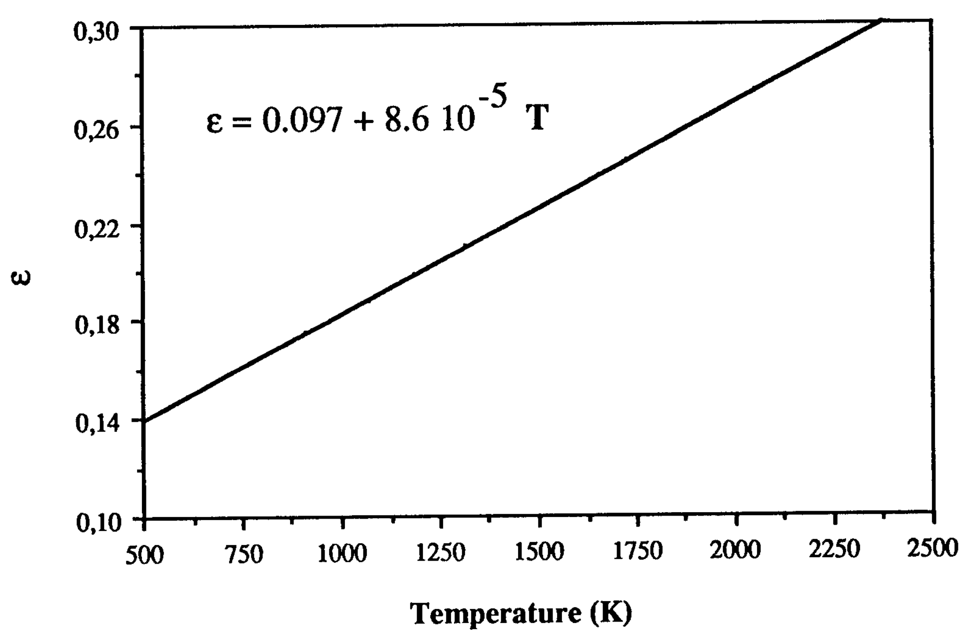


Fig. 10 - Thoriated tungsten emissivity vs temperature (from Plansee data sheet)

Gas Feeding System Design

The gas feeding system was designed using a mathematical model developed at CS, implemented on a computer code. The model gives the gasdynamic characteristic of the gas in the feeding system by means of the solution of the gasdynamic equations for an adiabatic, one-dimensional flow. The equations are solved for a lumped geometry, for which each section is characterized by the volume and the smallest area.

In Fig. 11 the pressure in the dispenser, measured by means of a piezoresistive gauge(blue), is compared with the relevant numerical result obtained with the code (red). A resevoir of about 500 cc is placed behind the valve. The reservoir is necessary to maintain a fairly constant pressure behind the valve and thus to have a sufficiently long steady state phase during the gas pulse. A good reproduction of the experimental data is obtained with the model in the initial transient and in the steady state phase, while the reproduction is not accurate in the final transient (valve closed).

The initial transient is about 9 ms in length, while the steady state phase is about 20 ms. These characteristics satisfy the requirements shown above.

The reference values of mass flow rates (0.5 - 4 g/s of argon) during the steady state phase of the gas pulse is obtained setting the pressure in the reservoir. It must be greater than the minimum admitted by the pressure reducers (1 bar absolute) and smaller than the maximum admitted by the solenoid valves (10 bar absolute).

The steady state mass flow rate (m) as a function of the dispenser pressure (p_r) is given by the following expression:

$$\dot{m} = \frac{C_w \Gamma A_t}{\sqrt{R\,T}} p_r \qquad [3]$$

where C_w is an empirical coefficient that depends on the orifice geometry (0.85 in this case), A_t is the total section of the orifices (1.57 mm^2), Γ and R are constants of the gas, 0.72 and 208.4 J/(kg K) respectively for the argon, T is the temperature in the dispenser (300 K).

From [3] is obtained:

for 0.5 g/s of argon	1.3 bar
for 4 g/s of argon	10 bar

The desired range can thus be covered with the current injector. The investigation of smaller or larger mass flow rates needs new injectors with different chocking orifices.

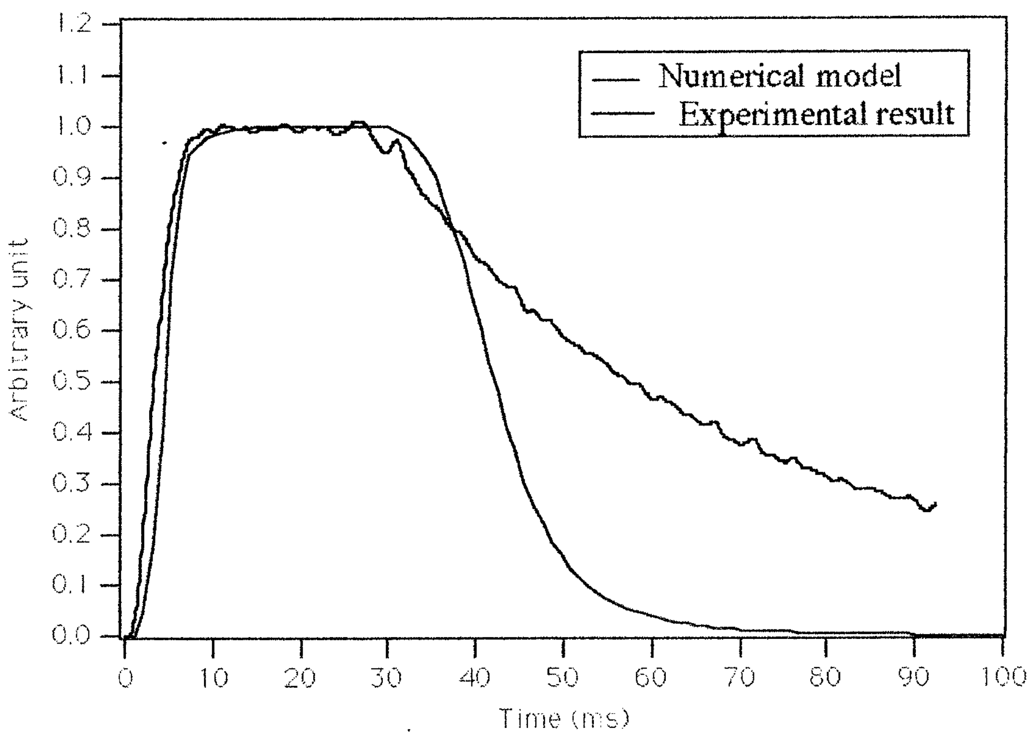


Fig. 11 - Gas pulse: comparison between experimental and numerical results

Appendix

Equipment available at CENTROSPAZIO for Testing on MPD Thrusters

(A1) The Vacuum Plant

The Vacuum Facility (IV2) consists of a fibre-glass chamber 800 mm in diameter and 1000 mm in length; the dielectric chamber permits testing on MPD thrusters without significant electromagnetic interference. The pumping system consists of a rotary pump for the rough vacuum (Balzers mod. DUO 170) and an oil diffusive pump for the high vacuum (Balzers mod. DIF 500). The ultimate vacuum allowed is 2 10^{-5} Torr with a pumping speed of 6500 l/s. The pumping system is connected to the fibre-glass chamber by a Balzers PVA 500 P gate valve. The pressure is controlled by two Pirani probes (mod. TRP 010), one placed in the vacuum chamber for the rough vacuum measurement, and the other in the diffusive pump to check the pressure before the oil-heating phase. High vacuum is measured by an ionization probe placed on the vacuum chamber (mod. HV 5).

The vacuum facility is manually controlled. A vacuum cycle consists of three phases. During the preliminary phase, lasting approximately 1 hour, the diffusion pump is evacuated and the oil is heated. When the diffusion pump is ready, the plant is set manually for the pumping phase (phase 2) during which the rotary pump evacuates the chamber until a pressure of about 0.1 Torr is reached; upon reaching this pressure, the rotary pump is automatically bypassed again on the diffusion pump, the gate valve is opened and the diffusion pump evacuates the chamber until an ultimate pressure of about 4-3 10^{-5} torr is reached (phase 3).

(A2) The Electrical Feeding System

The electrical feeding system consists of a Power Supply, a Pulse Forming Network (PFN), a 40 mΩ ballast resistor, an Ignitron and relative control unit and ten RG8 cables from the PFN to the thruster.

The Power Supply (HVL series 311-6203) has a charging rate of 600 J/s, a peak voltage of 2500 V and is used to charge the PFN before each thruster operation.

The PFN has an internal impedance of 40 mΩ, a total pulse length of 1 ms and stores 3.6 kJ at 2400 V. The total capacitance is 12500 μF, the total inductance 20 μH. The PFN is made up from ten sections, each containing 180 capacitors of 75 μF each and 180 coils of 1 μH each.

The PFN supplies a quasi-rectangular 1 ms current pulse up to 30 kA under normal operating conditions.

The PFN is equipped with a Dump Switch which allows the discharge of the PFN on an appropriate resistor.

The ballast resistor is used in order to match the internal impedance of the PFN with the external impedance, in order to obtain a rectangular current pulse from the PFN. The ballast was designed and manufactured by CS. It can be set from 0 to 40 mΩ and can stand currents of up to 50 kA for 1ms every 30 s without failure.

The ignitron is an electronically-controlled spark gap which permits discharge at a proper adjustable delay from the beginning of the gas pulse, when a steady state condition is reached.

The ignitron used is a National electronics inc mod. NL1037. An electronic ignition system was developed in order to control the spark gap ignition with a programmable delay.

(A3) The Gas Feeding System.

The gas pulse is supplied by solenoid valve(s) (SMC mod. EVT 317), placed as closest as possible to the injection plate(s). A reservoir is placed back to each valve in order to keep a steady pressure during the gas pulse. This is necessary to obtain a sufficiently long steady phase of the mass flow during the pulse. The gas is supplied to the reservoirs from a panel (Fig. A3) where two gases can be handled. The gases arrive from the high pressure bottles after a first pressure reduction, at a pressure of up to 20 bar. Four tanks are placed on the panel, three are used as pressure tanks (two for the thruster and one for the cathode heater) and one is used to compose the gas mixtures. A pressure gauge is placed on each tank . The tank for the cathode heater is filled with Argon, the pressure of which is maintained at about 1 bar. The pressure on the thruster injection lines can be set by means of two reducers for each line, mounted in parallel, to be used alternatively, depending on the setting pressure. In fact, the reducers have two different ranges (0 5 - 8.5 bar and 0.05 - 2 bar) to set the gas pressure (and, as a consequence, mass flow rates) at low and high values with the desired precision. The gas mixture can be composed in the dedicated tank, supplying alternatively the gases from the high pressure line. The composition of the mixtures is controlled by a pressure probe placed on the tank. The mixture can thus be supplied to the anode and/or the cathode injection line through the reducers described above, bypassing the line from the high pressure bottles. In order to purge the lines before testing, they are provided with venting lines linked to the vacuum chamber. The gas feeding system operation is currently manual, but could easily be automated in further activities.

(A4) The Cathode Heating Apparatus

The cathode heating apparatus consists of a TIG power supply (CETASS CM 520) equipped with a high voltage ignition system (developed in CENTROSPAZIO) and a series of contactors, necessary to properly perform the test sequence (cathode heating, PFN charging and firing). The electrical set-up, illustrated in Fig. A4.1, consists in two electrical networks with a common electrode (the thruster cathode). When the thruster is ready for discharge, three properly-delayed contactors are activated: the first one disconnects the heating power supply, extinguishing the inner arc. The second contactor disconnects the power supply electrodes from the thruster, the third one disconnects the PFN charging power supply from the discharge network and then the thruster is fired. The entire sequence is carried out in a few fractions of a second, during which the cathode thermal condition remains practically unchanged.

Pyrometer Moving System. The cathode temperature during the heating phase is controlled by a pyrometer, placed on the thruster axis, in front of the cathode tip (Fig. A4.2). Before each shot, the pyrometer is moved into a safe position by a moving system, in oder to prevent the pyrometer from being contaminated by the plasma exhaust. The moving system is a pendulum, attached to the PVC framework by a PVC chase. The arm is moved from measuring position (vertical arm) to the safe position (with an inclination of about 60°) by a synchronous motor. The positions are defined by two limit switches. The pendulum can be adjusted both vertically and horizontally in order to position the pyrometer correctly with respect to the thruster. The pendulum moving sequence is the following:

- The arm is brought to vertical position, the pyrometer is ready for temperature measuring;
- The heater arc is ignited, the cathode is heated to the desired temperature (read by the pyrometer);
- The arm is moved until the safe position is reached;
- The discharge sequence is performed;
- After firing, the arm is moved to the measuring position and the entire sequence can be repeated.

(A5) The Diagnostic Equipment

The following diagnostic facilities are normally used for calibrations, electrical characteristic and thrust measurements, following the procedures developed in the framework of previous programmes. Considering the reliability demonstrated in the previous activities and staff experience on these devices, they were adopted entirely for this programme too.

The diagnostic equipment consists of :

- a mass flow meter (Micro Motion mod. D6) used for the mass flow rate calibration;
- two piezoresistive pressure gauges (Kulite mod. HKM-375-250-G) used for the mass flow rate calibration;
- two high voltage probes (Tektronics P6015 1000X) for electrode voltage measurement;
- an operational amplifier (Tektronix AM 501) used for voltage measurement;
- a Rogoswski coil passively integrated for the current measurement;
- a proximity transducer (Bently Nevada mod 7200) for the measurement of the mobile mass displacement of the thrust stand;
- a pyrometer (Accufiber mod. 900-PY-HF1) to measure the cathode tip temperature.

The Thrust Stand. The thrust stand used was designed and manufactured at CS within a previous ESA ASTP3 programme. It consists of a mobile mass (on which the thruster is mounted) supported by four bars, each one with two phosphor bronze virtual hinges at the extremity. The thrust stand has a four bar linkage configuration, with one degree of freedom in the direction of the thrust, that is measured by detecting the horizontal displacement of the mobile mass immediately after a discharge by the proximity transducer. This permits to measure the impulse of the thrust and thus the instantaneous value of the thrust, if its time law is known. Fig. A5.1 shows the thrust stand assembly with a thruster mounted.

The Probe Positioning System. In the framework of plume diagnostics activities with electrostatic (Langmuir) and magnetic probes, a positioning system, made of PVC, was designed and manufactured. This device allows the probes inside the vacuum chamber to be placed and moved for the measurement of the physical quantities of the plume (temperature, density, magnetic field). Moreover, the device developed was also used successfully for Laser diagnostics with only minor modifications. The positioning system provides three degrees of freedom in accordance with a cylindrical reference system. The design allows further degrees of freedom to be added for future experimental requirements. The system is illustrated in Fig. A5.2. It permits the probes placed in the centre of the wheel to cover a cylinder of 300 mm in diameter and 480 mm in length. The system is moved by three step motors, one for each degree of freedom. Even if the structure is quite heavy, positioning and repeatibility errors are mainly caused by the PVC buckling rather than the step motor accuracy and the manufacturing precision. Moreover, a repeatability of less than +/- 1mm is normally obtained.

(A6) The Data Acquisition System

The data acquisition and analysis system consists of (Fig. A6):
- A transient recorder HP 5185 where the diagnostic signals are monitored and digitalized.
- The Macintosh IIvx computer, where data are transferred from the transient recorder via a IEEE 488 paralel gate.

Data are managed by means of LabView® programme for visualization, digital filtering and other analysis operations. The data are then normally stored in the computer hardisk or on floppy disks. It is possible to transfer selected data directly onto dedicated files for graphics, tables etc, that can be used for data reporting.

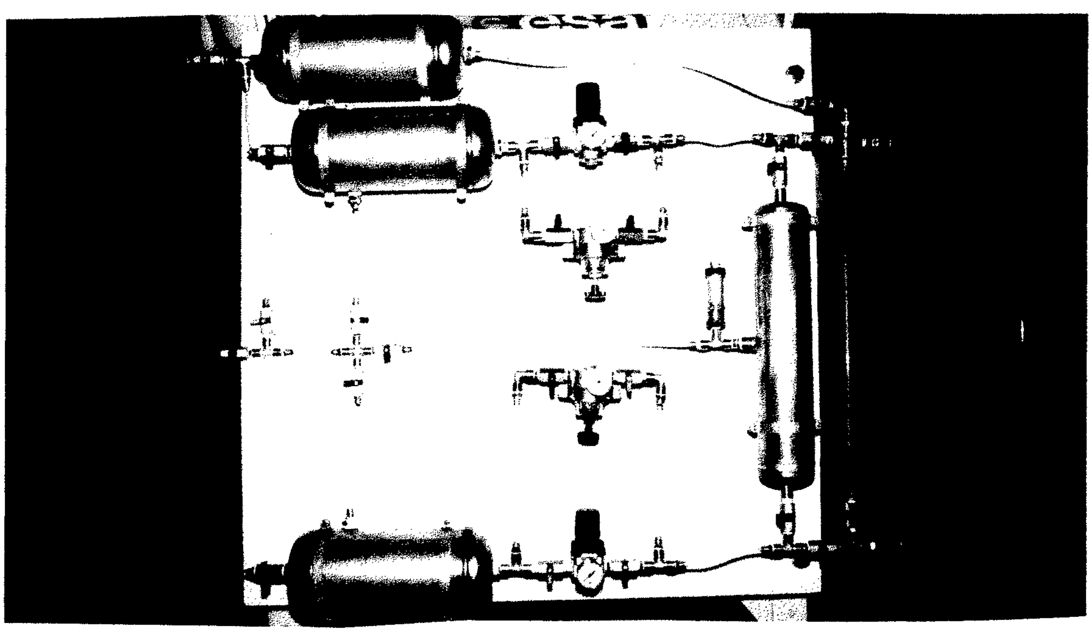


Fig. A3 - The gas panel

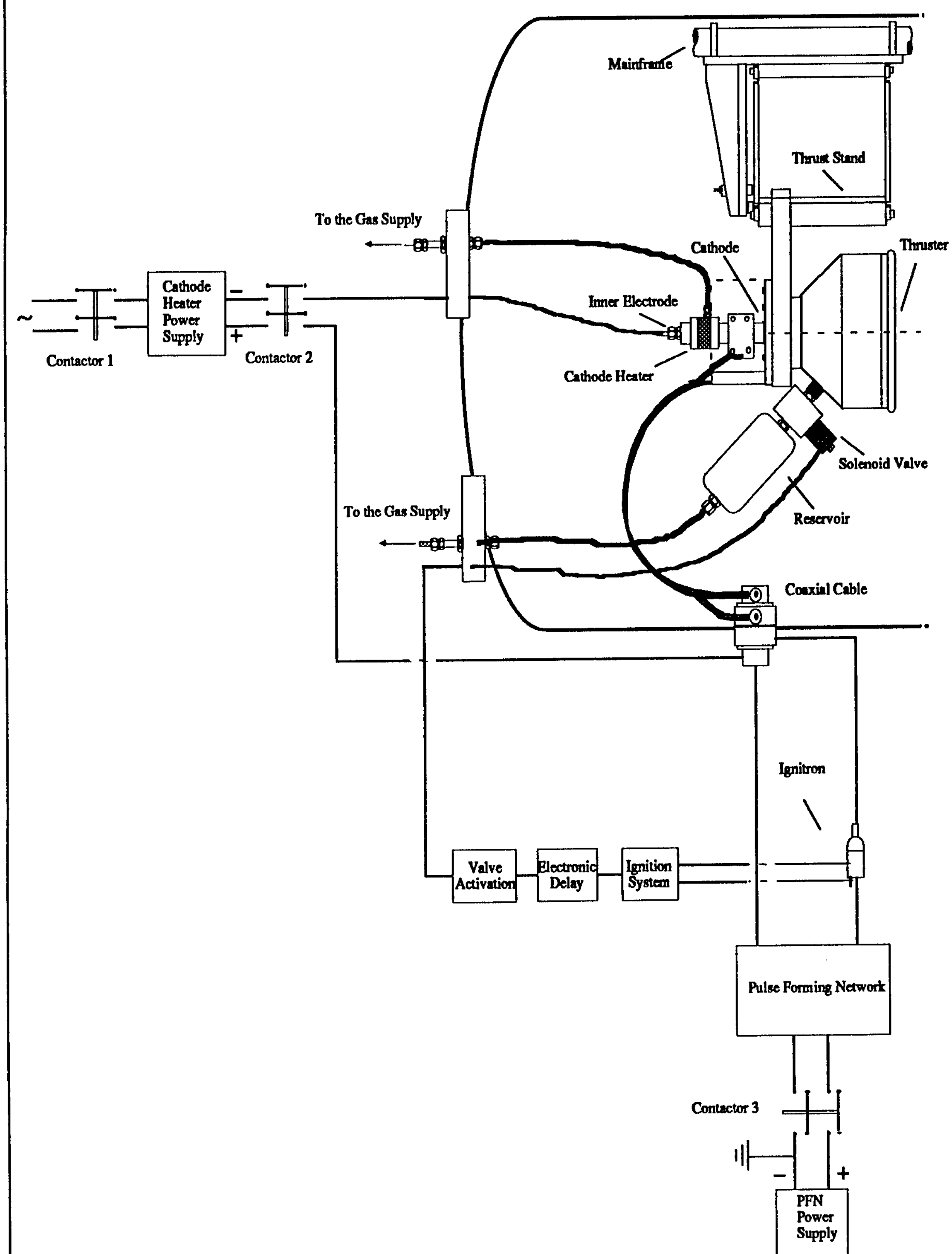


Fig. A4.1 - Test Equipment

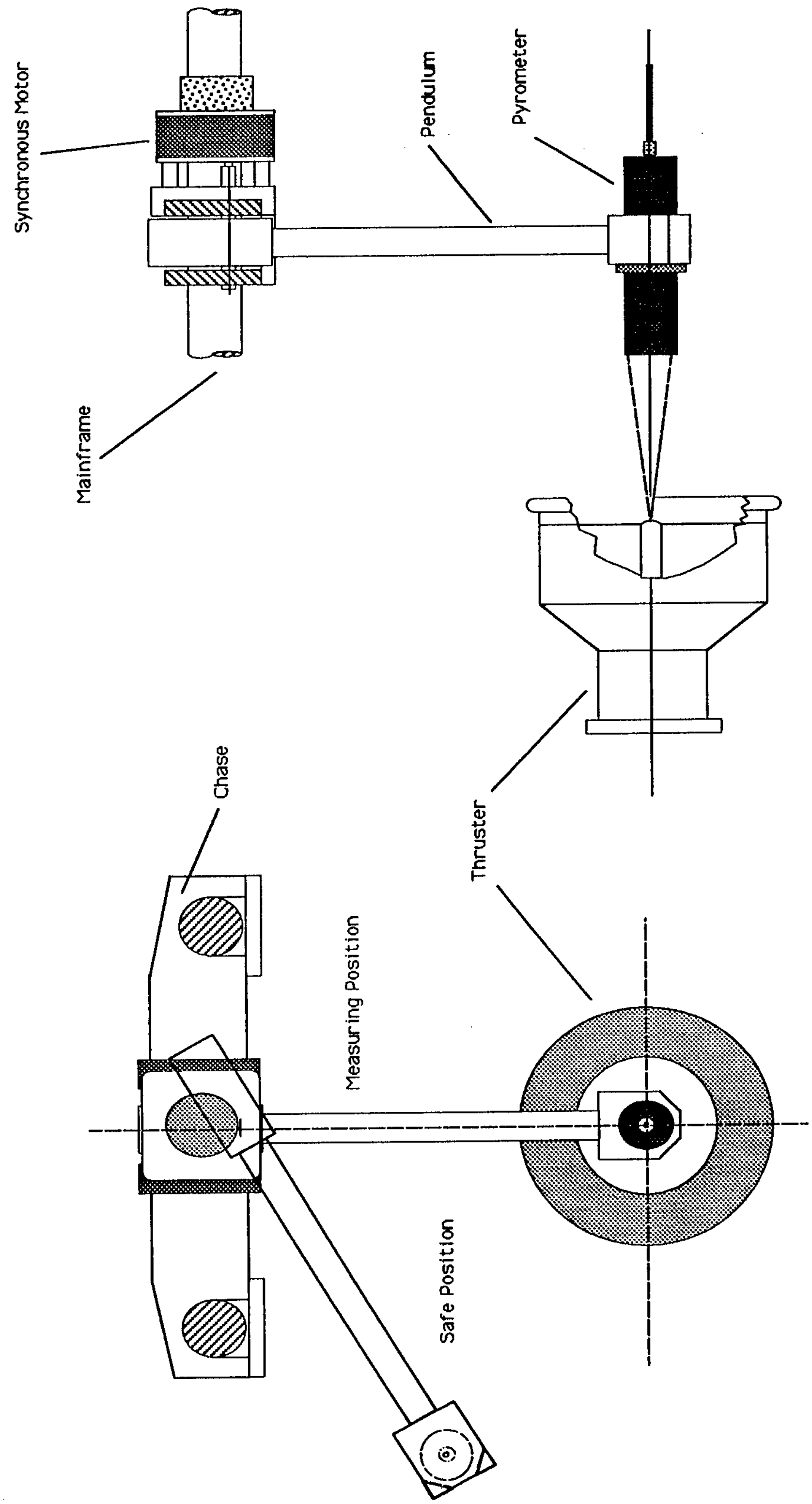


Fig. A4.2 - The Pyrometer Moving System Arrangement

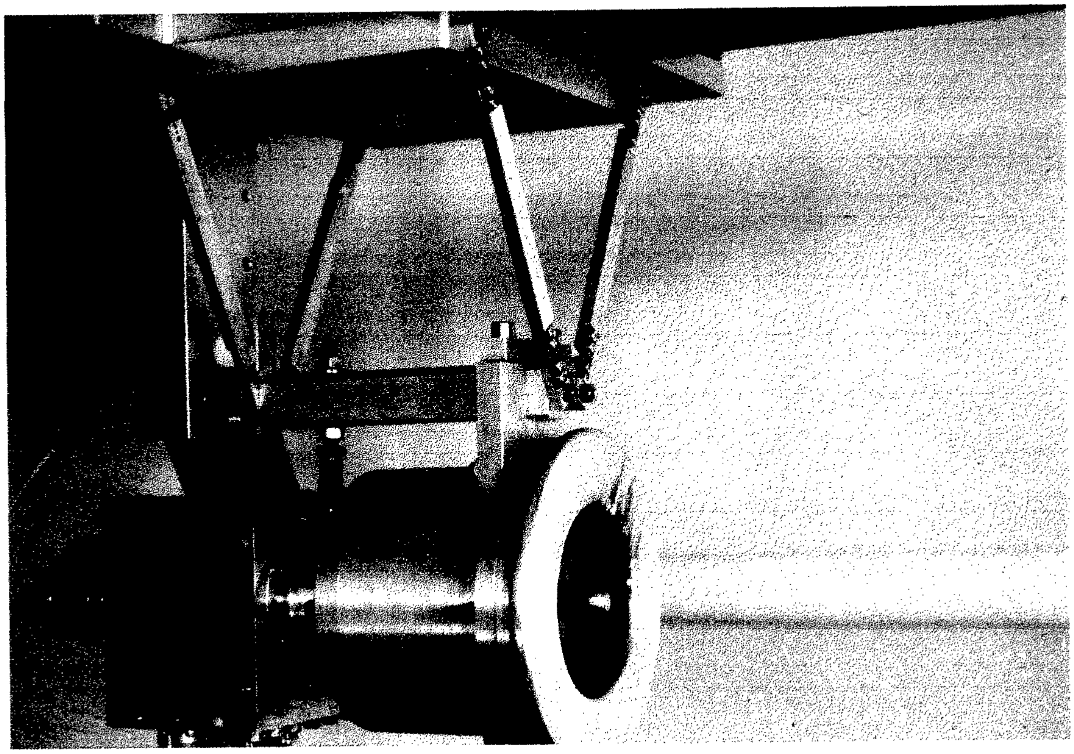


Fig. A5.1 - The thrust stand with a thruster

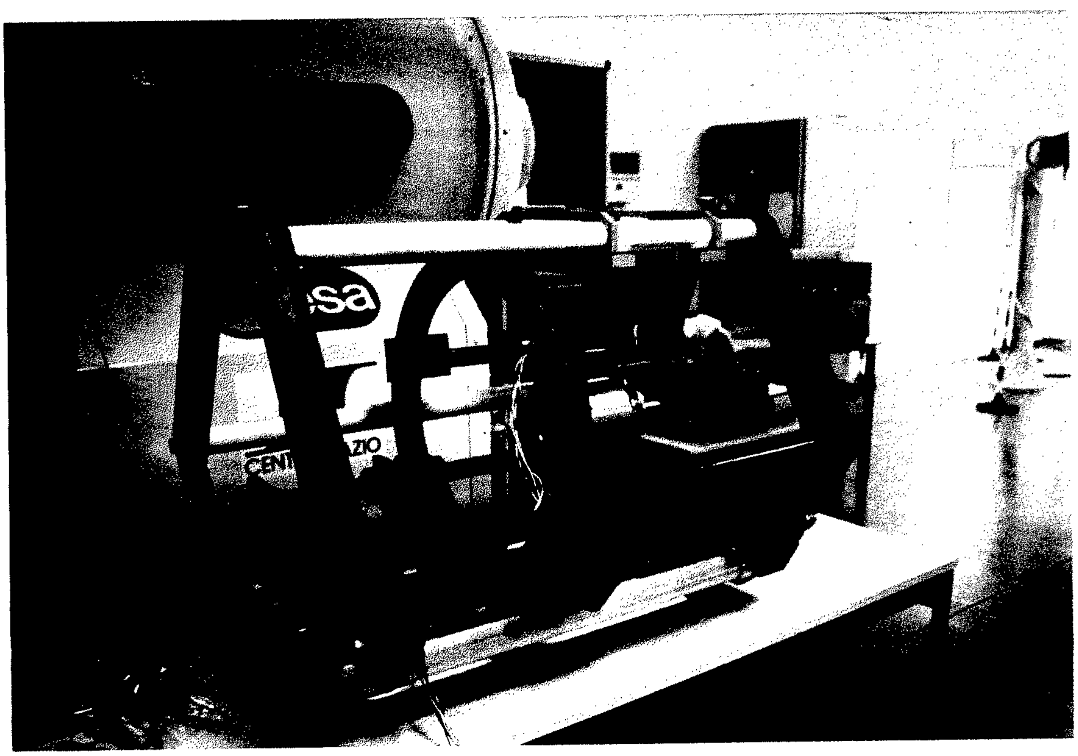


Fig. A5.2 - The probe positioning system

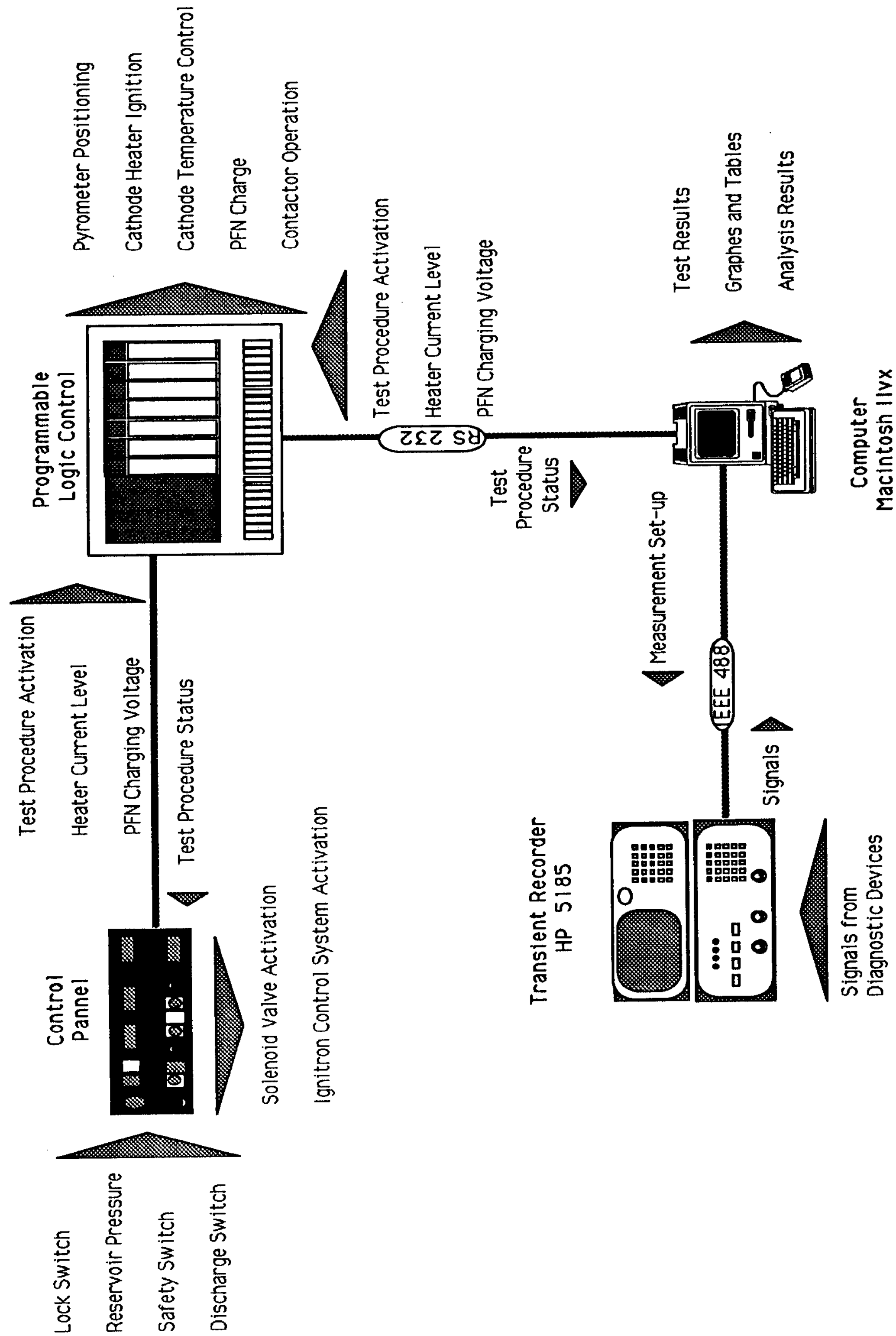


Fig. A6 - Test Automation and Data Acquisition System Arrangement