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OPERATION, MAINTENANCE AND INSPECTION OF HENDEL FROM MARCH 1986 TO FEBRUARY 1987

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The technical features are summarized with important test results and disturbances through the operation of HENDEL in the period from March 1986 to Feburuary 1987. In the period, HENDEL M+A loop was operated comparatively stable with T_1 and newly adapted T_2. As to the adaptation of T_2, the hot gas duct was dismantled and examined for old one and new ducts were constructed between M+A loop and T_2. Besides the operation and adaptation, the adjustments and maintenance had been carried out for the regular inspection and safety operations.

The technical disturbances were encountered with the gas circulators and the electric power system through the operation. From the countermenasures and the tests for them, some technical informations have obtained and are expected to give valuable data for design and operation of the VHTR and general industrial system.

Keywords: HENDEL, Helium, Hot Gas Duct, Gas Circulator, Whirling, T_1, T_2, Flange, Hastelloy-X, Gas Bearing, High Voltage

1986年3月から1987年2月までのHENDELの運転，保守及び検査

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1986年3月より1987年2月に至る期間中のHENDEL運転を通して，その技術的主要内容とT_1及びT_2試験部を除く試験内容，障害等を含めて要約した。当期間において，T_1及び新たに設置したT_2試験部を含めてM＋Aループは比較的安定に運転された。T_2試験部については既設高温配管を解体，検査すると共にM＋AループとT_2試験部との間に新たに高温配管及び中温配管を建設した。運転及び改造の他に官庁検査及び安全対策のための調整あるいは整備を実施した。

当該期間内にはガス循環機及び電気系統に関する障害等も発生した。それらに関する対策及び試験を通してガス循環機及び圧力容器等に関して有用な技術情報が得られた。これらの技術的データは高温ガス試験研究炉あるいは一般産業機械技術にとって有益なものとなろう。

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CONTENTS

目　　次

1. INTRODUCTION

In last one year (March 1986 to February 1987) M+A loop including T_1 and T_2 test sections was operated in comparatively stable condition. During the period, main events on the HENDEL were installation and initiation of operation of T_2 test section which aims to test main high temperature parts of in-core structure of experimental VHTR. Installation of T_2 test section including newly adapted hot gas ducts was finished in March 1986. The acceptance test operation of it was also carried out from 16th April through 6th June 1986 without large trouble.

As to the T_2 installation, the flow diagram of HENDEL's high temperature portion was partially modified, i.e., the entering and returning to and from T_2 hot gas ducts in which nearly 1,000°C helium flows were newly connected. Relatively low temperature pipings(~400°C) were also connected between T_2 and M+A loop.

The hot gas duct formerly used as a part of high temperature helium circuit was removed from the loop and was examined its integrity, mechanical properties and oxidation etc.. The examinations of the old hot duct are being continued still now and will give the valuable information on VHTR's hot gas duct.

The test on T_1 using smaller loop of HENDEL(M_1) is also continued including natural convective cooling, simulated cooling channel closed condition, etc..

The disturbances had been experienced on gas circulator(B_1) and its back up machine used for M_1 loop which have a regenerative type impeller. Those disturbances are bearing and shaft damage caused by shaft whirling(low frequency vibration) and non-starting difficulty from wearing of journal bearing shaft and pads. The latter one on the gas circulator is in couse of repairing and examination.

The test section on high temperature helium heat exchanger(T_4) will be postponed more from budget reasons, however, the preparation of a partial model will be started in 1987 fiscal year and tests in high temperature atmosphere will be succeeded to it.

2. OPERATION HISTORY, MAINTENANCE AND INSPECTION

2.1 OPERATION

From April 1986 to February 1987, four cycles operation have been carried out with two loops of HENDEL, i.e., M_1 loop with T_1 test section and M_2+A loop connected with the newly installed T_2 test section.

Figures 2.1.1 to 2.1.4 show the operating histories from No.16 cycle operation in April 1986 to No.19 cycle operation in February 1987. Operating hours of them are as follows:

	M_1+T_1 loop	M_2+A+T_2 loop
No.16 cycle operation (16 April - 6 June 1986)	943 hours	808 hours
No.17 cycle operation (18 June - 9 July 1986)	451 hours	307 hours
No.18 cycle operation (22 October - 18 November 1986)	594 hours	552 hours
No.19 cycle operation (4 February - 24 February 1987)	306 hours	441 hours
Total	2,294 hours	2,108 hours

Test objectives of these operations are as follows:

(1) Heat transfer and fluid-dynamic tests on the experimental VHTR simulated assembly with T_1 test section.

a) Natural convection test of the VHTR fuel block using the multi-channel test rig(in No.16-17 cycle operation)

b) Forced convection test in the case of one channel among twelve channels is closed with the multi-channel test rig(in No.18 cycle operation).

c) Pressure drop and friction factor measurement of the VHTR control rod channel with the single-channel test rig(in 16-19 cycle operation).

(2) Performance tests of sealing and thermal insulation of the experimental VHTR core structure with T_2 test section(in No.17-19 cycle operation).

a) Sealing performance test of the fixed reflector blocks around the core bottom structure.

b) Mixing test of helium gas in the hot plenum.

c) Insulation performance test of the core bottom structure including carbon blocks.

(3) Vibration and bearing tests on the gas circulators.

Test items and conditions from No.16 to No.19 cycle operation are summarized in Table 2.1.1.

During the operations, the impurities concentration in the helium were measured continuously with gas chromatograph and were kept low enough. Figures 2.1.5 and 2.1.6 show typical results of the measurement.

2.2 MAINTENANCE AND INSPECTION

(1) REGULAR INSPECTION AND ADJUSTMENT

From July through September 1986, adjustments and regular inspections were carried out on high pressure helium gas system and high pressure cooling water system which cools down very high temperature helium in HENDEL's M+A loop and T_1 test section. In these adjustments and inspections, the pressure vessels were inspected using magnetic particle test, fluorescent color check, leakage check with bubble method and pressurizing test. The wall thicknesses were also measured for pressure vessels of large heaters, coolers and test sections employing an ultra-sonic device, however, any remarkable defect was not found.

(2) ADJUSTMENT AND REPAIRING

Adjustments and repairing were made for the instrumentations and control systems for M+A loop and test sections. Among them, measuring transmitters of temperatures, pressures, differential pressures were accurately re-calibrated using a special tool, and some circuits cards were exchanged. The digital control systems were tested and adjusted for the system of M+A loop("MICREX"), T_1("U-PACK") and the process controlling computer("U-400"). Among the those tests and adjustments, cleaning and testing were made for the main hardwares including processors, disks and input/output devices. The memory test and I/O interface tests were also done for the control systems. The softwares were checked on the operating system and the apllication softwares using a special software tool and dummy input signals. The key boads and the cathode ray tube(CRT) displays of operator's consoles were adjusted and exchanged with some new parts including CRT, contacts and electronic parts.

The electric power supplying system were also adjusted and inspected for high voltage and low voltage lines. In the high voltage 6kV commercial line, power cubicles which include vacuume circuit breaker(VCB), protecting relays and instrumental transformers etc. were adjusted and renewed with some contact parts. After the adjustments, insulation resistances were measured and the withstand voltage tests were carried out applying high voltage between the circuit line and ground. For the low voltage 400V, 200V and 100V commercial lines, the "POWER

CENTER"s and "CONTROL CENTER"s were adjusted and tested in likely way to the high voltage line. The former one means a cubicles in which a large capacity switch gear and some accessories are equiped, and in latter one, a large number of various capacity circuit breakers, magnetic contactors and auxiliary relays are installed. The battery inverter which feeds non-stoppage current to the control systems was also adjusted and tested for semi-conductor devices and alkali-batteries.

3. MODIFICATION

Some modifications associated with the adaptation of T_2 test section to M_2+A loop were made for the succeeding operation of HENDEL in last one year. The summaries of the modifications are described in the following subsections.

3.1 M_2+A LOOP

M_2+A loop was modified for the adaptation of T_2 test section. Figures 3.1.1 and 3.1.2 show the flow diagrams of M_2+A loop before and after the modification respectively. Besides these adptation, the electric power supplying system and the instrumentation/control system were newly adapted for the T_2 test section.

The items of modifications are as follows:

(1) A hot gas duct between the heater H_{32} and the cooler C_{31} was removed, and new hot gas ducts were mounted between M_2+A loop and T_2 test section.

(2) Comparatively lower temperature gas pipings were installed between M_2 loop and T_2 test section.

(3) Software and hardware for the process control computer were partially modified associated with the operation of T_2 test section.

(4) The digital control system ("CENTUM") was installed and software of it was settled for direct digital control of T_2 test section.

(5) The electric power supplying system was newly adapted for the internal heaters (region heaters) and the valves etc. to high and low voltage lines respectively.

(6) The data acquisition network ("Shared Resource Management", SRM) system was established with hardware and software.

3.2 CONTROL AND ELECTRIC POWER SYSTEM

Seven internal heaters (region heaters) are allocated in the T_2 test section above the simulated core bottom structure. These heaters are used for raising up the temperature of helium gas from 930 to 1,050°C in the flow rate of 4 kg/s.

The electric power supplying system consists of four pairs of 900kVA induction voltage regulators(IVR), transformers(TR) and high voltage switch gear cubicles for these internal heaters. Valves, vacuum pumps and other auxiliary components for the T_2 are fed by low voltage lines from "CONTROL CENTER" which was also adapted. The skeleton diagram of the electric power supplying system is shown in Fig.3.2.1 with former and newly adapted circuits. Electric power of internal heater in T_2 test section was distributed from 6kV commercial line via the vacuum circuit breaker(VCB(52F22)) and was divided into four circuits via four VCBs. Maximum electric capacities of the heaters are 730kW for the heater in central region, 365kW for each of six heaters in circumferential region.

As the control system for the T_2 test section, the digital control system ("CENTUM") was installed, and the application software of Process Control Computer("U-400") was partially modified. Figure 3.2.2 shows the schematic diagram of the control system of M_2+A with T_2 test section.

3.3 HOT GAS DUCT

New hot gas ducts were installed between M_2+A loop and T_2 test section. Figure 3.3.1 shows an appearance of the hot gas duct connected with the helium gas inlet of T_2 test section. Main specifications of these hot gas ducts are shown in Table 3.3.1 and cross sectional view of them are shown in Fig.3.3.2. Both of them are insulated by KAOWOOL and dividing metal plate inside of the pressure tube, however, they differ in the shape of spacer rings each other as described in subsection 4.1. The KAOWOOL used in them are recently modified one, and are improved against the deterioration of insulation for a long time exposure in high temperature atmosphere.

4. TECHNICAL TOPICS AND TEST RESULTS

The technical topics and disturbances in last one year are summarized in following subsections through the operation of M+A loop.

4.1 EXAMINATION OF USED HOT DUCT

As to the adaptation of T_2 test section, newly manufactured hot ducts and relatively low temperature pipings connected between M+A and T_2 test section. There are two types of new hot gas ducts, however, the specifications of them are same except for spacer rings as shown in Figs.4.1.1(a) and (b). The reason why two types of hot gas ducts are used is that the manufacturers of them are different and judgements for the stress in the spacer rings are not quite same, moreover, the experiences on manufacturing the hot duct are different between them.
On the other hand, the formerly used hot gas ducts which has the construction as same as the new type hot gas duct shown in Fig.4.1.1(a), was removed from the loop and was cut into some pieces. Thereafter total integrity, mechanical properties and micro-structures of Hastelloy-X liner tube were examined.

From the examination on the old hot duct, the total integrity of it indicated no remarkable problem through the service time of nearly 6,000 hours which contains more than 30 percent of over 500°C service. As expected naturally, the mechanical properties of liner tube are found to be significantly aggravated as shown through Figs.4.1.2 to 4.1.4. It is considered that the aggravation of mechanical properties are mainly associated with formation of rough grains and with formation of grain boundary precipitates. Results on the examination will be reported in detail in the another report.

4.2 TECHNICAL DISTURBANCES ON GAS CIRCULATOR(B_1)

Technical disturbances had experienced twice on gas bearing type helium gas circulators for the original and the backup machine which had been installed for M_1 loop in that time. The main specification of them are almost same except for lining material of journal shaft and pads, i.e., type, flow rate, pressure, gas temperature, speed and power are regenerative, 0.4kg/s, 4MPa, 400°C, 12,000 rpm and 119kW respectively. Those disturbances and countermeasures are described in following subsections.

(1) WHIRLING TROUBLE ON GAS BEARING

The gas circulator(original) had been damaged in the end of 1985, however, the technical reason and conditions had not been clarified for a long time. Because some troublesome discussions wasted the time to make materialized countermeasures. The discussion means the responsiblity on repairing of the preceding trouble(cf. KVK/HENDEL J-7).

After all of those discussions the circulator was overhauled and examined in detail. It was found from the examination that the upper journal shaft and pads had been damaged considerably as shown in Figs.4.2.1, 4.2.2 and the pad supporting pivot was also damaged as shown in Figs.4.2.3, 4.2.4. After the examination, the sleeve, pads and the pivot of upper journal bearing were renewed or partially repaired.

As the damage had occured in only a few seconds at the operating condition of nearly 9,000 rpm in 4MPa helium, it was presumed the damage might be caused from the whirling or "Oil-Whiping" of the shaft. Proving the realistic reason of the damage, a series of running test were carried out after repairing in both air and helium with various pressures.

In the series of tests, measurement items were the shaft displacement at both shaft ends in right angular directions, fluid dynamic forces on pads of upper and lower journal shaft and vibrational acceleration of the machine body. Figure 4.2.5 illustrates the schematic arrangement of pivots with and without load cell, inlet and outlet nozzles and the direction of forces shown in Fig.4.2.7. Spectral vibrational force to the pivot and displacement of the shaft showed the half-speed-whirling in the range of over 8,000 to 9,000 rpm as shown in Fig.4.2.6. It was found moreover, the difference of static forces shown in Fig.4.2.5 increases proportinally with the pressure rise in the circulator as shown in Fig.4.2.7.

From the facts mentioned above, it should be concluded that as the pressure rise around the impeller of the circulator causes a force perpendicular to its axis. Then it makes the shaft eccentricity in bearing so large that it makes impossible to keep balanced condition of tangential forces around the journal shaft. Finally the shaft will be forced in tangential direction and rotationwise, and then it grow into a whirling condition.

(2) STARTING DIFFICULTY OF GAS CIRCULATOR

At the begining of 19 cycle operation of HENDEL in Feburuary 5th, 1987, it became impossible to start the gas ciculator(back up) with over current in driving circuit. Therefore the electric circuit devices were ckecked, however, no defect could be found. So that the machine was overhauled and preliminary examinations were made visually and the wearing conditions of journal shaft and pads were measured. On the other hand, the suspended machine(original) was mounted instead of failed one immediately after of the failure to continue the operation.

Through the preliminary examination it was found that the journal shaft and pads are weared in unexpected degree and substance which must be from the weared parts are sticked on the surface of thrust collar. Moreover, the surface of motor rotor were considerably rusted inspite of use in helium atmosphere. Figures 4.2.8 through 4.2.13 show the weared shaft and pads and the results of wearing measurements are shown in Figs.4.2.14 and 4.2.15.

From the preliminary examination mentioned above, it might be thought that the humidity in the helium increased abnormally and then it caused rust on rotor surface at the first step. The rust powder separated from the rotor might drop in the clearance of the bearings, so it caused wearing unexpectedly. The powder or weared substances from the parts also might enter into the gap between thrust collar and pads which supports dead weight of the rotating part. The weared substances onto the thrust bearing assembly were sticked on it by the heat from the extremely high speed friction of the bearing.($\leqq$169m/s)

The assumption mentioned above will be probably trustful, however, the humidity in helium have been kept below the level for dew point of -20 to -60°C. So it is unknown the reason how the rotor had been rusted in such condition at the present time.

4.3 HIGH VOLTAGE POWER SUPPLY DISTURBANCE

The short-circuit disturbance had happened in high voltage power circuit for helium heater(H_{32}) of M_2+A loop. The disturbance was also encountered in the begining of 19 cycle operation(February 6th, 1987) when the vacuum circuit breaker(VCB) for the heater was turned on via control system. Figure 4.3.1 shows power circuits of the heater, VCB(074-04) was turned on from the control room and VCS(42) followed it automatically, just on the time a bursting sound had heard and the commercial line had stopped.

Checking the causes of the disturbance, it was found that the cause of it was simple but results from it were considerably serious. The short circuit was made by the temporarily connected wires in secondary side of the VCS(42) in Fig.4.3.1 which were used for the preceding insulation test and were left by carelessness. From this happening, the cubicle which made of steel plates and equiped the switch gear(VCS) and some accessories was considerably deformed. The VCS itself and some devices in the cubicle were considerably damaged as shown in Figs.4.3.2 to 4.3.4. Moreover, the VCB(074-04) also tripped and the Main-Frame computers and some important machines in Tokai site were tripped or halted by the current stoppage or a shock pulse from the very large current. All of damaged devices were exchanged into new one or repaired and tested immediately after of the happening and the operation have started.

4.4 MEASUREMENT OF HELIUM LEAK RATE FROM MAIN FLANGES OF PRESSURE VESSELS

The helium leak rate was measured to estimate it from the main flanges of large reactor vessels and some reactor components. For this purpose, the pressure veseel of T_2 test section was used for convinience of measurement. Sectional view of the flanges and the measuring set up are illustrated in Fig.4.4.1. As shown in the figure, sealing is made by double INCONEL O-rings which plated with silver and outer peripheral of the flanges were absolutely sealed by welded metal plate("U-seal"). The space between O-ring and O-ring and the space between O-ring and "U-seal" are led to the pressure guages in usual operation.

For the purpose of present measurement, the two spaces mentioned above were conducted to the manometers and the measuring glass cylinders as shown in Fig.4.1.1.

Figure 4.4.2 shows measured helium flow rates from inner and outer spaces in the condition of cold(room temperature) helium gas. The mesured flow rate from the inner space was found to be 1.6 to 3.4 x 10^{-3} (cc/sec) during the operation.

On the other hand, the measured value from outer space was detected only when the helium temperature and pressure were changed. It might be caused by the thermal expansion of the gas contained in the space before measurements.

These facts indicates that the sealing method with double O-rings is highly effective to reduce helium leakage from the flanges of vessels.

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TABLE 2.1.1 TEST ITEMS AND TEST CONDITIONS (OPERATIONS FROM APRIL 1986 TO FEBRUARY 1987)

	TEST ITEMS	TEST CONDITIONS		
No.16 CYCLE TEST OPERATION			SINGLE CHANNEL	MULTI CHANNEL
$M_1 + T_1$ LOOP	1) FUEL STACK TEST PRESSURE DROP MEASUREMENT IN CONTROL ROD CHANNEL WITH T_{1-S} NATURAL CONVECTION TEST WITH T_{1-M}	INLET HE GAS TEMPERATURE:	28 - 62 °C	-
		PRESSURE :	0.5 MPa	1.0 - 4.0 MPa
		FLOW RATE :	3.0 - 14.6 g/s	-
		INLET REYNOLDS NUMBER :	1900 - 8500	
		HEAT INPUT :	-	(0.2-1 kW)x 6
	2) VIBRATION AND BEARING TESTS ON HELIUM GAS CIRCULATOR B_1	HE GAS TEMPERATURE :	RT - 378 °C	
		HE GAS PRESSURE :	1.0 - 4.0 MPa	
		REVOLUTION SPEED :	3000 - 12000 rpm	
$M_2 + A + T_2$ LOOP	1) VERIFICATION OF CONTROL AND MEASUREMENT SYSTEM	INLET HE GAS TEMPERATURE :	RT	
		OUTLET HE GAS TEMPERATURE :	RT	
		HE GAS PRESSURE :	2.0 - 4.0 MPa	
		HE GAS FLOW RATE :	0 - 4.0 kg/s	
		PRESSURE DIFFERENCE BETWEEN HOT HELIUM GAS AND COLD HELIUM GAS:	300 - 3000 mmAq	

TABLE 2.1.1 TEST ITEMS AND TEST CONDITIONS (OPERATIONS FROM APRIL 1986 TO FEBRUARY 1987) (CONTINUED)

	TEST ITEMS	TEST CONDITIONS		
No.17 CYCLE TEST OPERATION				
$M_1 + T_1$ LOOP	1) FUEL STACK TEST		SINGLE CHANNEL	MULTI CHANNEL
	MEASUREMENT OF PRESSURE DROP AND PRESSURE FLUCTUATION IN CONTROL ROD CHANNEL WITH T_{1-S}	INLET HE GAS TEMPERATURE:	40 - 75 °C	-
		PRESSURE :	0.5 MPa	0.5 - 4.0 MPa
		FLOW RATE :	3.3 - 17.8 g/s	-
	NATURAL CONVECTION TEST WITH T_{1-M}	INLET REYNOLDS NUMBER :	2000 - 10100	
		HEAT INPUT :	-	(0.5 - 1.0 kW) x 12
	2) VIBRATION AND BEARING TESTS ON HELIUM GAS CIRCULATOR B_1	HE GAS TEMPERATURE :	RT - 313 °C	
		HE GAS PRESSURE :	1.0 - 4.0 MPa	
		REVOLUTION SPEED :	3000 - 12000 rpm	
$M_2 + A + T_2$ LOOP	1) IN-CORE STRUCTURE TEST	INLET HE GAS TEMPERATURE :	RT - 930 °C	
	SEALING PERFORMANCE OF PERMANENT REFLECTOR BLOCKS AROUND THE CORE BOTTOM STRUCTURE	OUTLET HE GAS TEMPERATURE :	RT - 1050 °C	
		HE GAS PRESSURE :	2.0 - 4.0 MPa	
		HE GAS FLOW RATE :	2.0 - 4.0 kg/s	
	MIXING CHARACTERISTICS OF HOT PLENUM	PRESSURE DIFFERENCE BETWEEN HOT HELIUM GAS AND COLD HELIUM GAS:	300 - 3000 mmAq	
	INSULATION PERFORMANCE OF THE CARBON BLOCK			

TABLE 2.1.1 TEST ITEMS AND TEST CONDITIONS (OPERATIONS FROM APRIL 1986 TO FEBRUARY 1987) (CONTINUED)

	TEST ITEMS	TEST CONDITIONS
No.18 CYCLE TEST OPERATION $M_1 + T_1$ LOOP	1) FUEL STACK TEST MEASUREMENT OF PRESSURE DROP AND FRICTION FACTOR FOR ISOTHERMAL FLOW WITH T_{1-S} HEAT TRANSFER AND FLUID-DYNAMICS TEST FOR HEATED FLOW WITH T_{1-S} HEAT TRANSFER AND FLUID-DYNAMICS TEST WITH T_{1-M} IN CASE THAT ONE AMONG 12 COOLANT CHANNELS IS CLOSED.	SINGLE CHANNEL / MULTI CHANNEL INLET HE GAS TEMPERATURE: 63.0 - 142 °C / 155 - 240 °C OUTLET HE GAS TEMPERATURE: 60.0 - 640 °C / 155 - 560 °C PRESSURE : 1.0 - 3.0 MPa / 1.0 - 3.0 MPa FLOW RATE : 3.0 - 21 g/s / 55 - 240 g/s INLET REYNOLDS NUMBER : 1800 - 11400 HEAT INPUT : 18 - 43 kW / (0 - 36.4 kW)x 12
$M_2 + A + T_2$ LOOP	1) IN-CORE STRUCTURE TEST SEALING PERFORMANCE OF PERMANENT REFLECTOR BLOCKS AROUND THE CORE BOTTOM STRUCTURE MIXING CHARACTERISTICS OF HOT PLENUM INSULATION PERFORMANCE OF THE CARBON BLOCK	INLET HE GAS TEMPERATURE : 400 - 930 °C OUTLET HE GAS TEMPERATURE : RT - 1000 °C HE GAS PRESSURE : 2.0 - 4.0 MPa HE GAS FLOW RATE : 2.0 - 4.0 kg/s PRESSURE DIFFERENCE BETWEEN HOT HELIUM GAS AND COLD HELIUM GAS: 300 - 3000 mmAq
	2) VIBRATION AND BEARING TESTS ON HELIUM GAS CIRCULATOR B_{21}	HE GAS TEMPERATURE : RT HE GAS PRESSURE : 0.6 - 1.4 MPa REVOLUTION SPEED : 3000 - 12000 rpm

TABLE 2.1.1 TEST ITEMS AND TEST CONDITIONS (OPERATIONS FROM APRIL 1986 TO FEBRUARY 1987) (CONTINUED)

	TEST ITEMS	TEST CONDITIONS
No.19 CYCLE TEST OPERATION		
$M_1 + T_1$ LOOP	1) FUEL STACK TEST MEASUREMENT OF PRESSURE DROP AND FRICTION FACTOR FOR ISOTHERMAL FLOW WITH T_{1-S} HEAT TRANSFER AND FLUID-DYNAMICS TEST WITH T_{1-S}	SINGLE CHANNEL / MULTI CHANNEL INLET HE GAS TEMPERATURE: 30 °C / – OUTLET HE GAS TEMPERATURE: 540 °C / – PRESSURE : 2.0 MPa / – FLOW RATE : 3.0 - 26.0 g/s / – INLET REYNOLDS NUMBER : 1900 - 16300 / – HEAT INPUT : 7.3 - 63.4 kW / –
$M_2 + A + T_2$ LOOP	1) IN-CORE STRUCTURE TEST SEALING PERFORMANCE OF PERMANENT REFLECTOR BLOCKS AROUND THE CORE BOTTOM STRUCTURE MIXING CHARACTERISTICS OF HOT PLENUM INSULATION PERFORMANCE OF THE CARBON BLOCK	INLET HE GAS TEMPERATURE : 400 - 930 °C OUTLET HE GAS TEMPERATURE : 80 - 1000 °C HE GAS PRESSURE : 2.0 - 4.0 MPa HE GAS FLOW RATE : 2.0 - 4.0 kg/s PRESSURE DIFFERENCE BETWEEN HOT HELIUM GAS AND COLD HELIUM GAS: 300 - 3000 mmAq

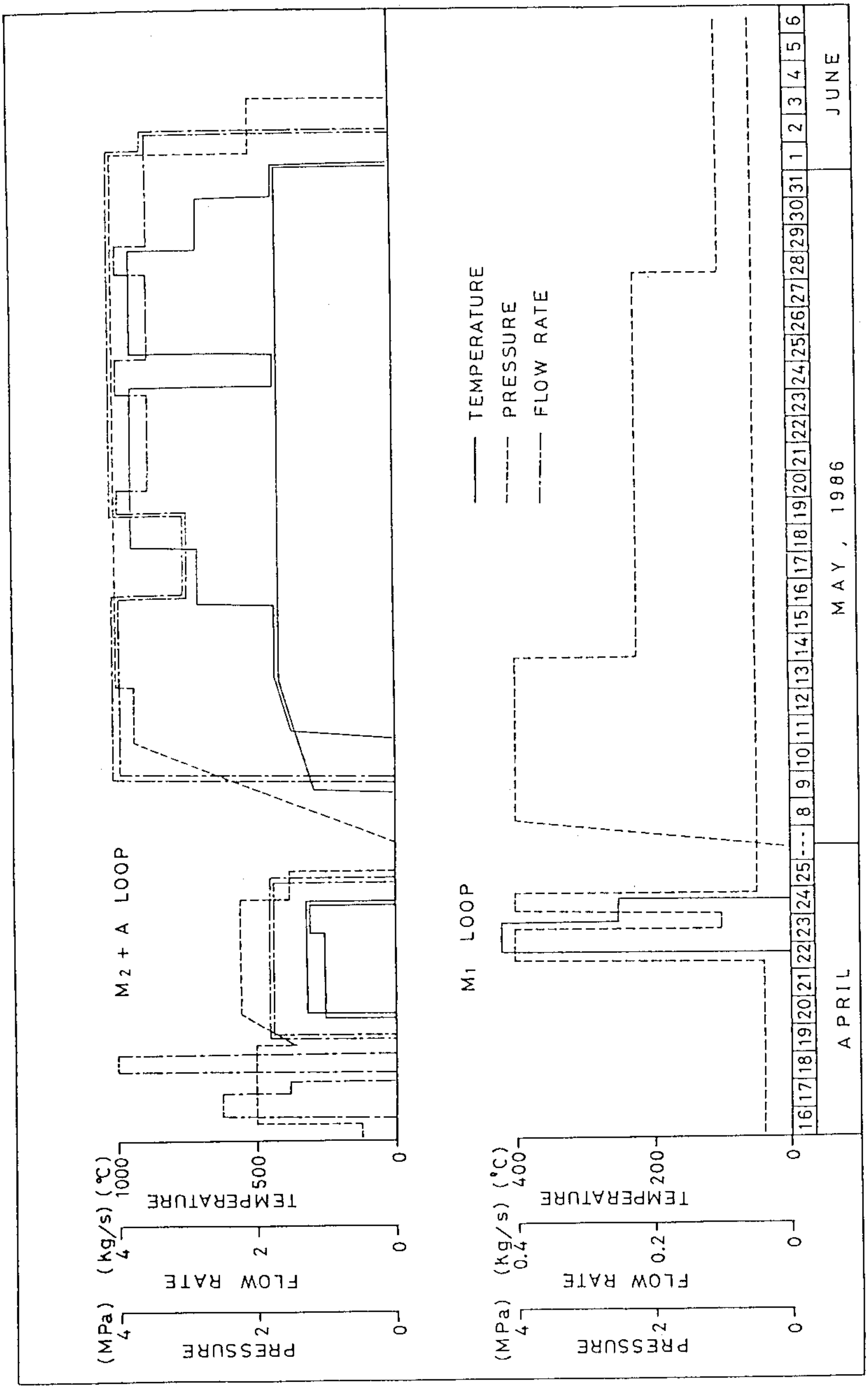


Fig.2.1.1 No.16 Cycle test operation (Apr.16,1986 - Jun.6,1986)

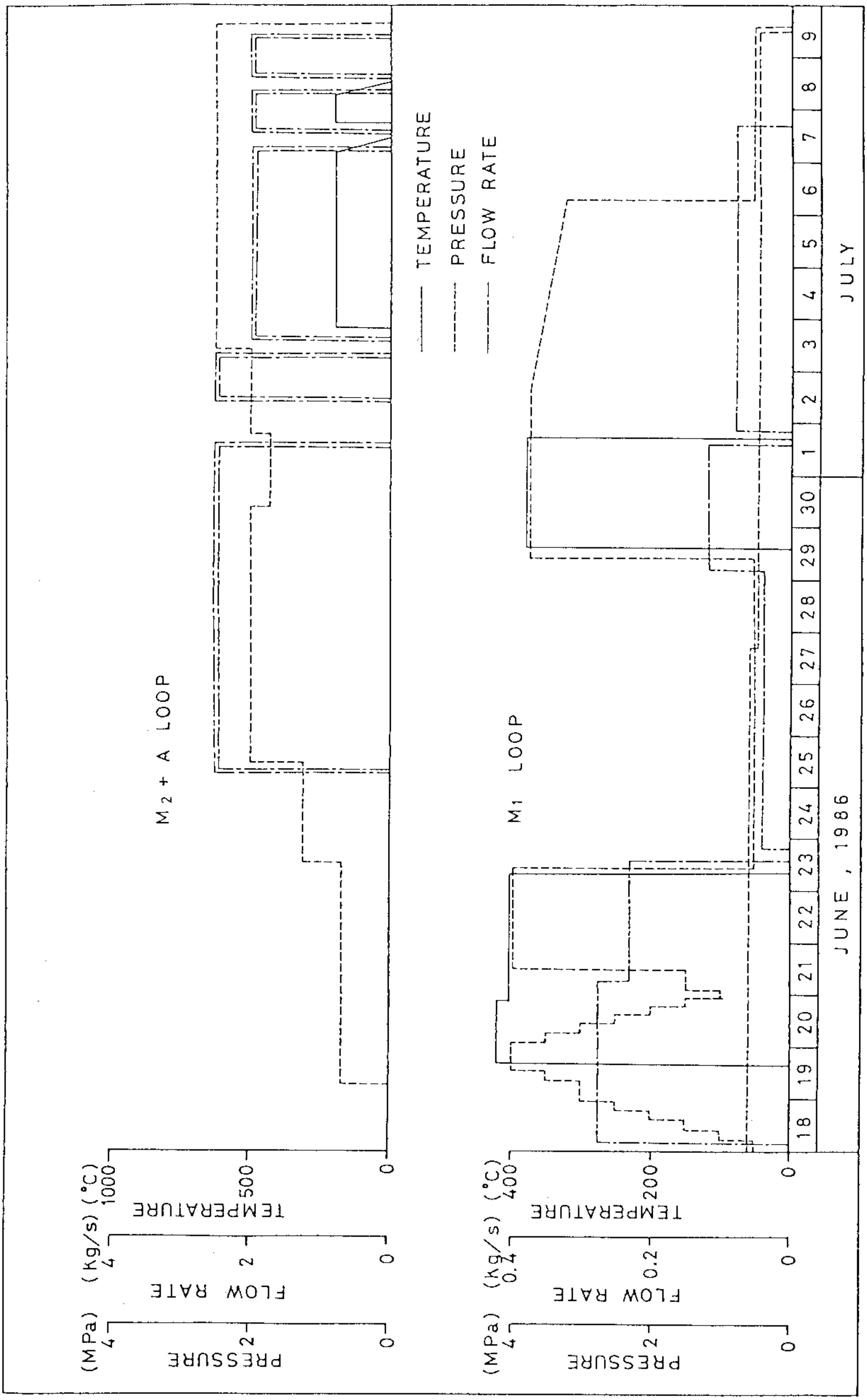


Fig.2.1.2 No.17 Cycle test operation (Jun.18,1986 - Jul.9,1986)

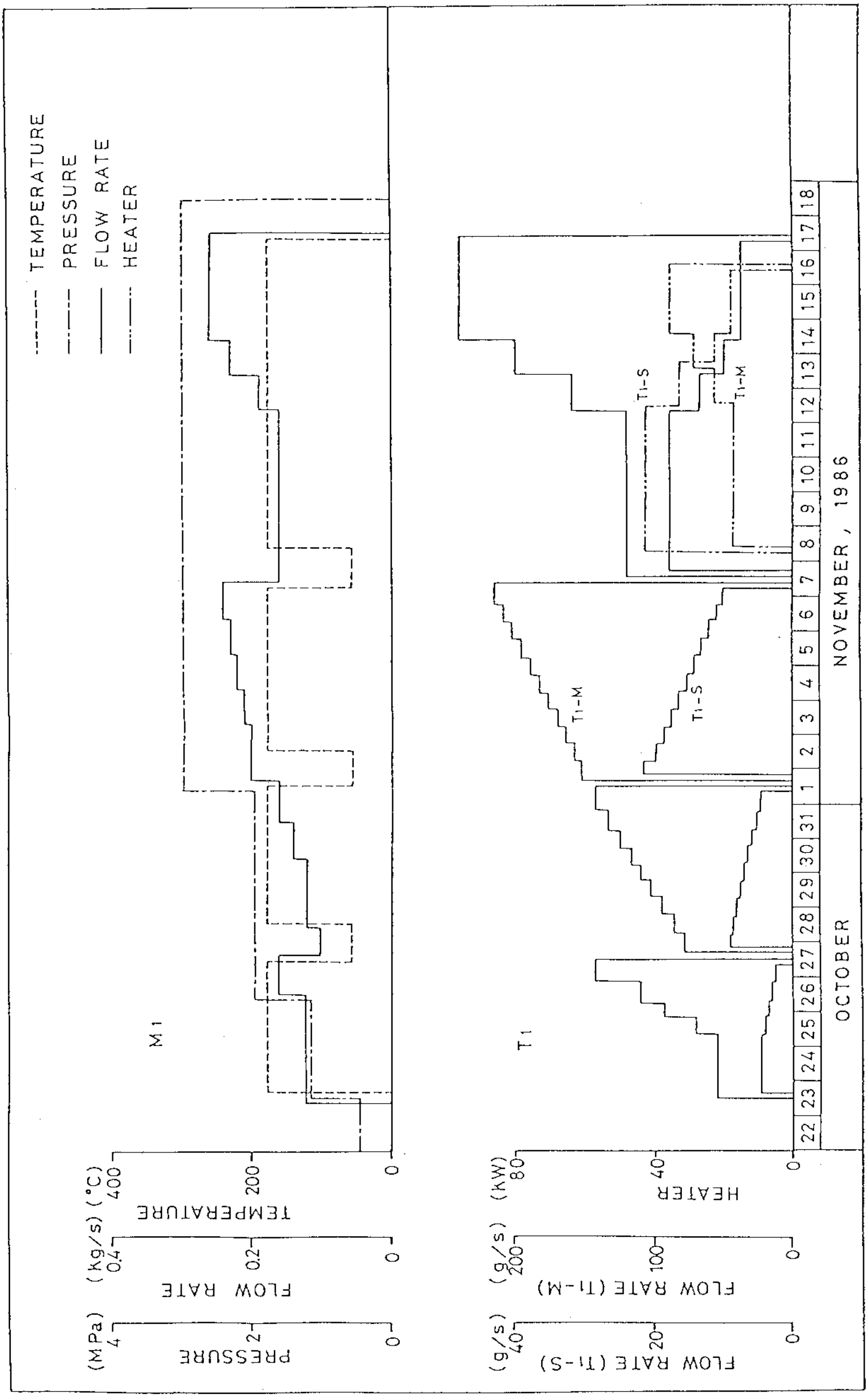


Fig.2.1.3(a) No.18 Cycle test operation (Oct.22,1986 - Nov.18,1986) $M_1 + T_1$

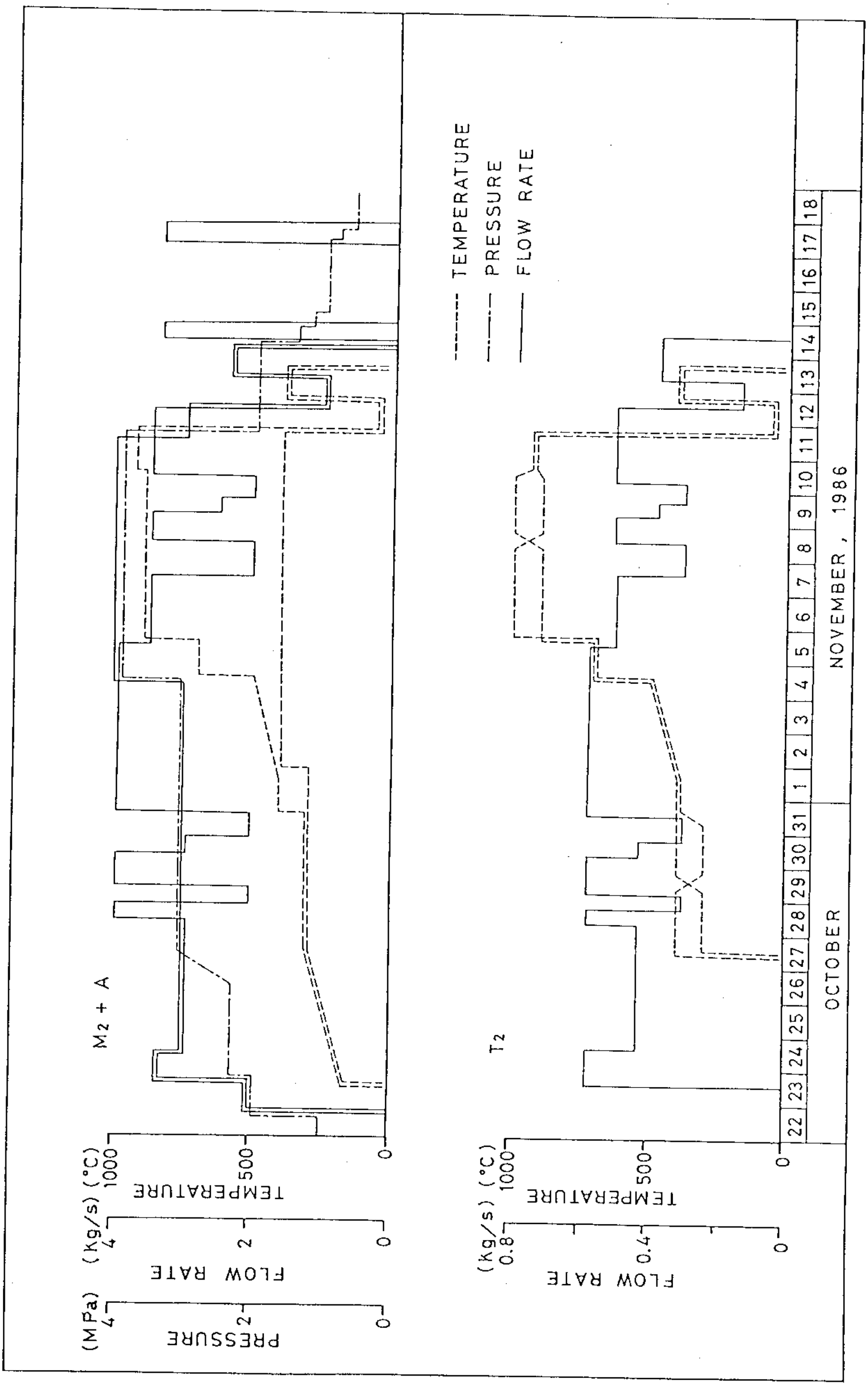


Fig.2.1.3(b) No.18 Cycle test operation (Oct.22,1986 - Nov.18,1986) $M_2 + A + T_2$

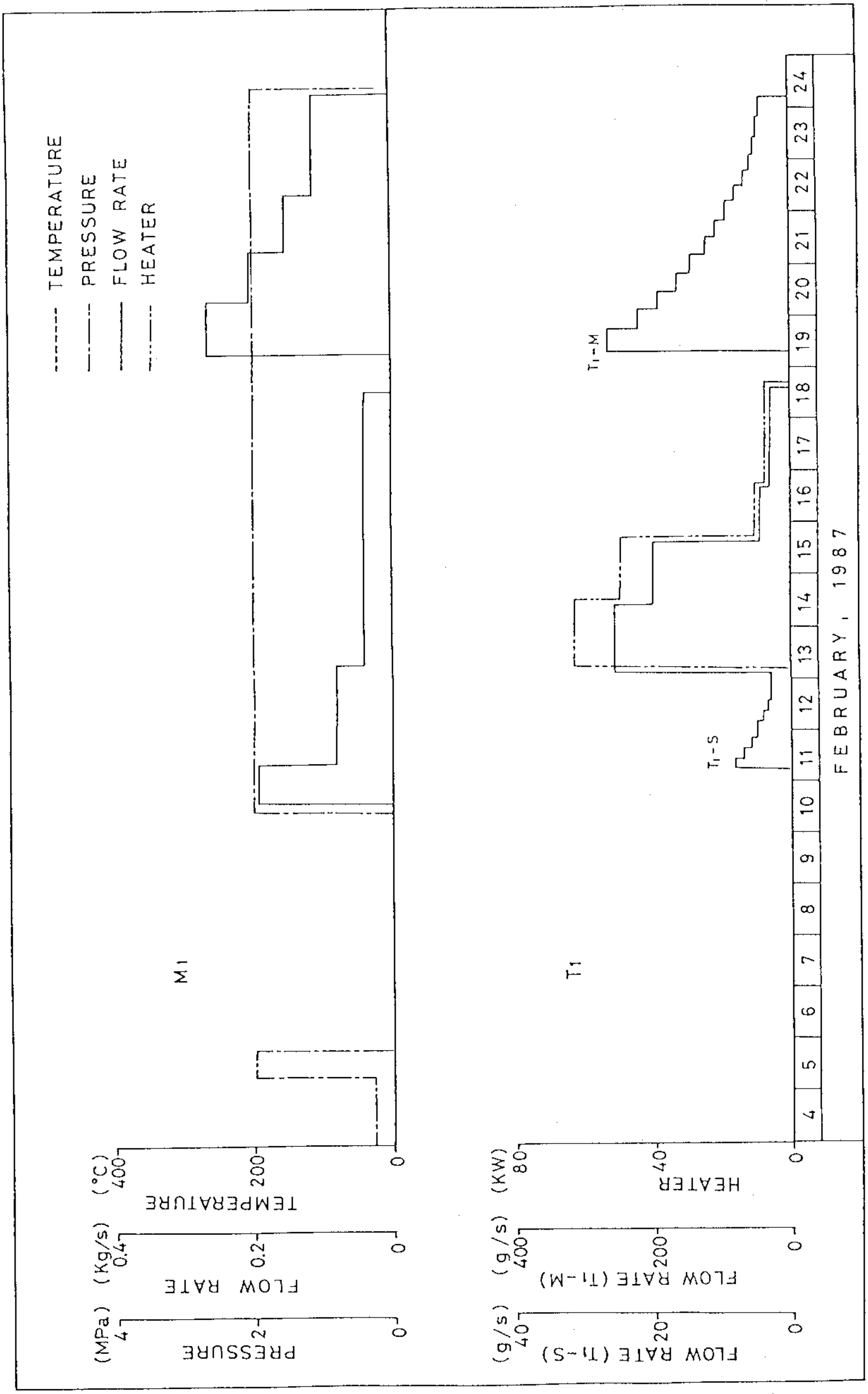


Fig.2.1.4(a) No.19 Cycle test operation (Feb.4,1987 - Feb.24,1987) $M_1 + T_1$

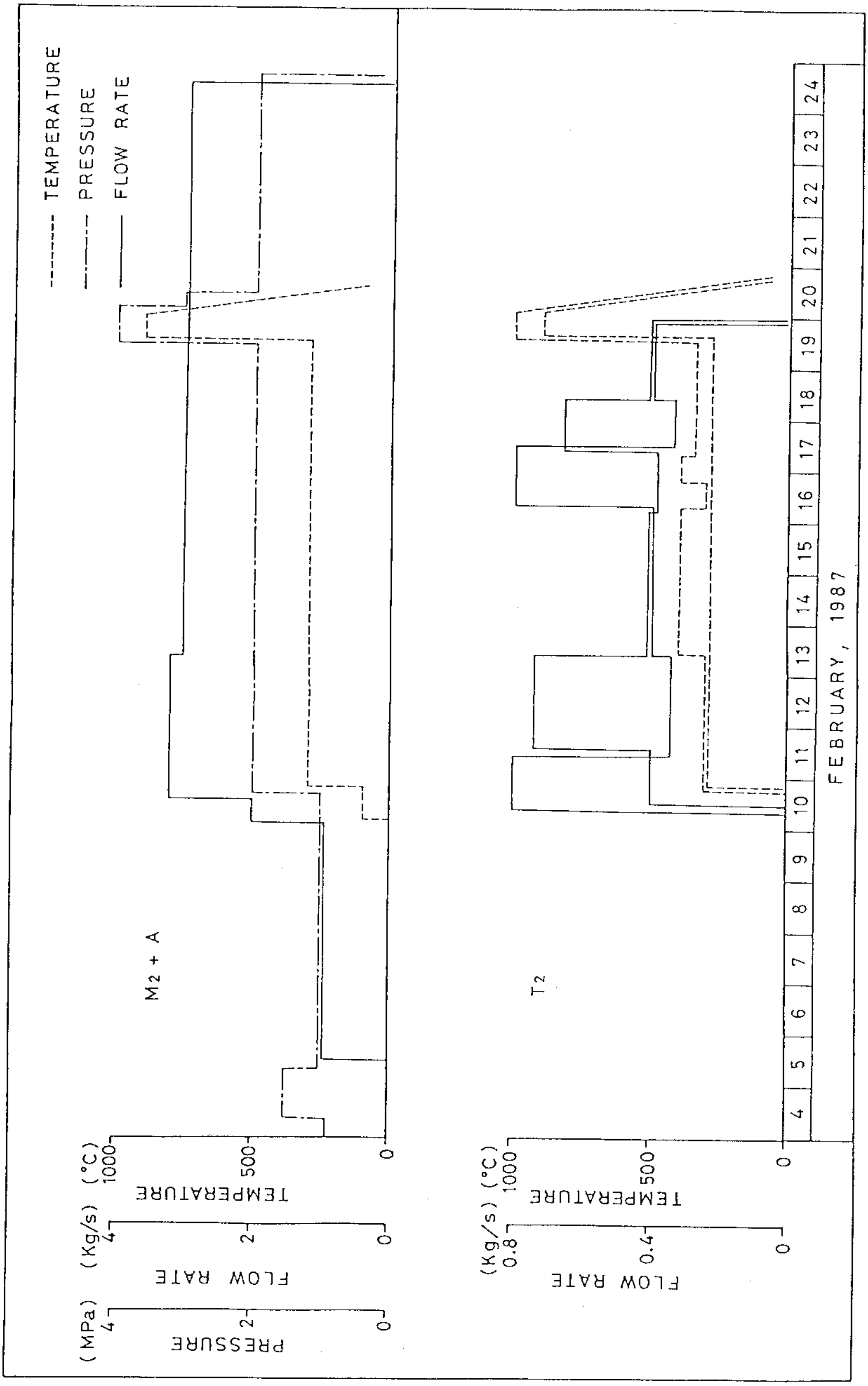


Fig.2.1.4(b) No.19 Cycle test operation (Feb.4,1987 - Feb.24,1987) $M_2 + A + T_2$

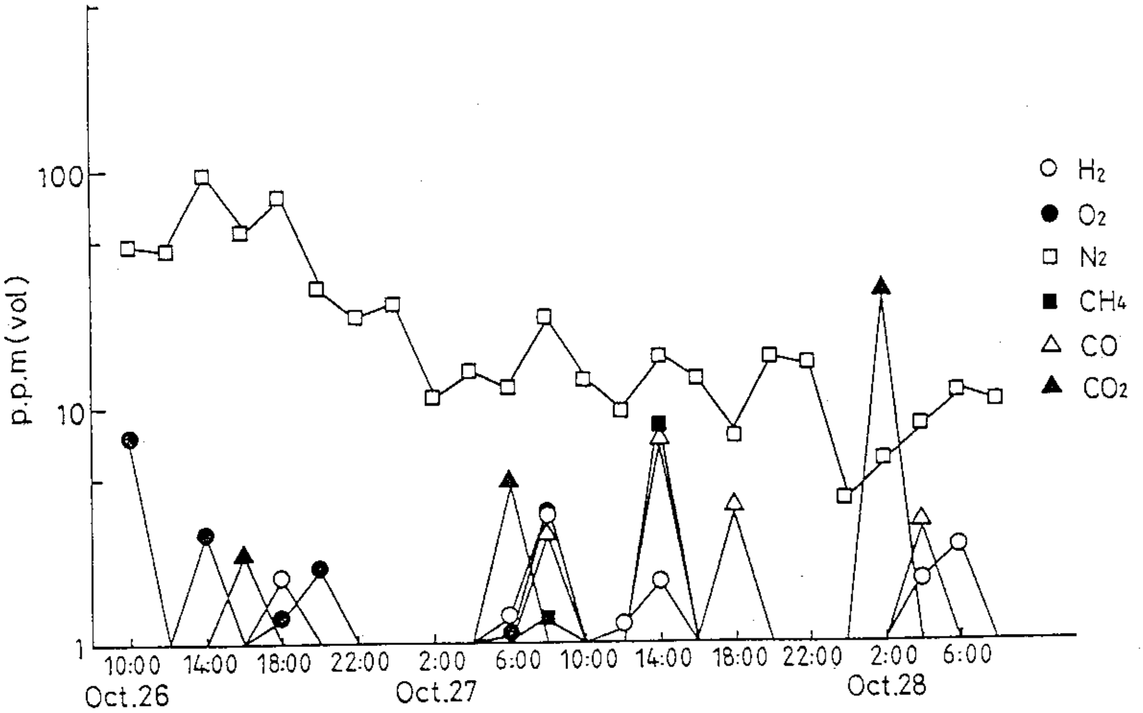


Fig.2.1.5 Impurity Concentration (Just after start-up of purification system)

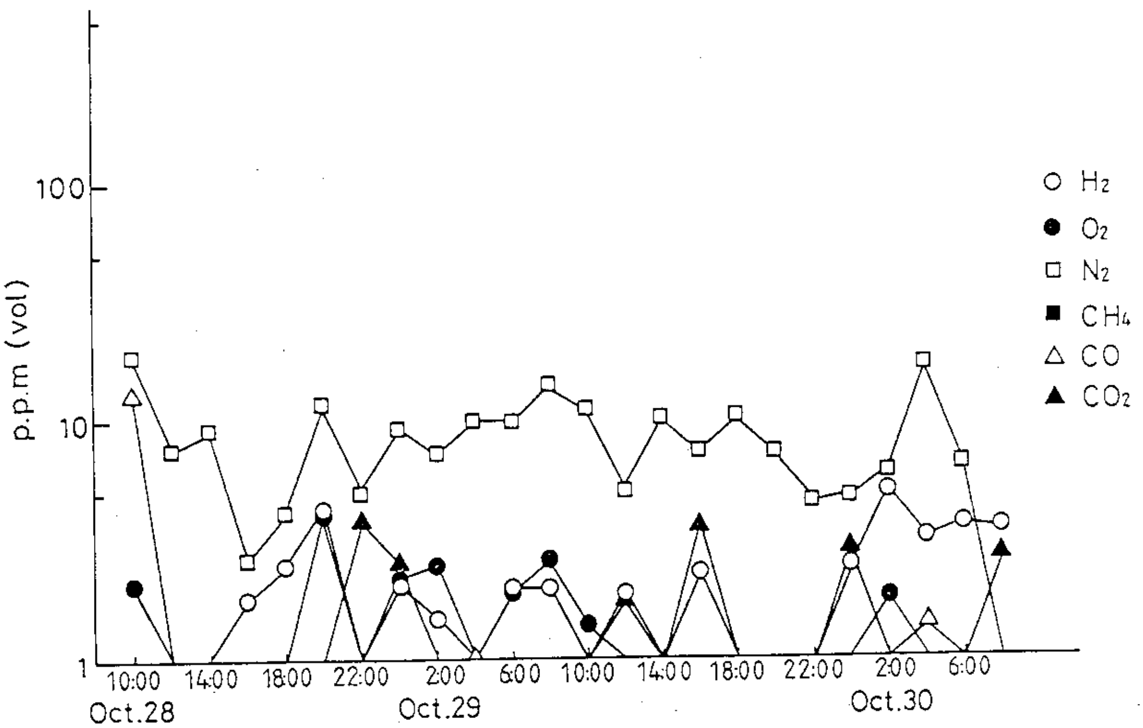


Fig.2.1.6 Impurity Concentration

(in stable condition)

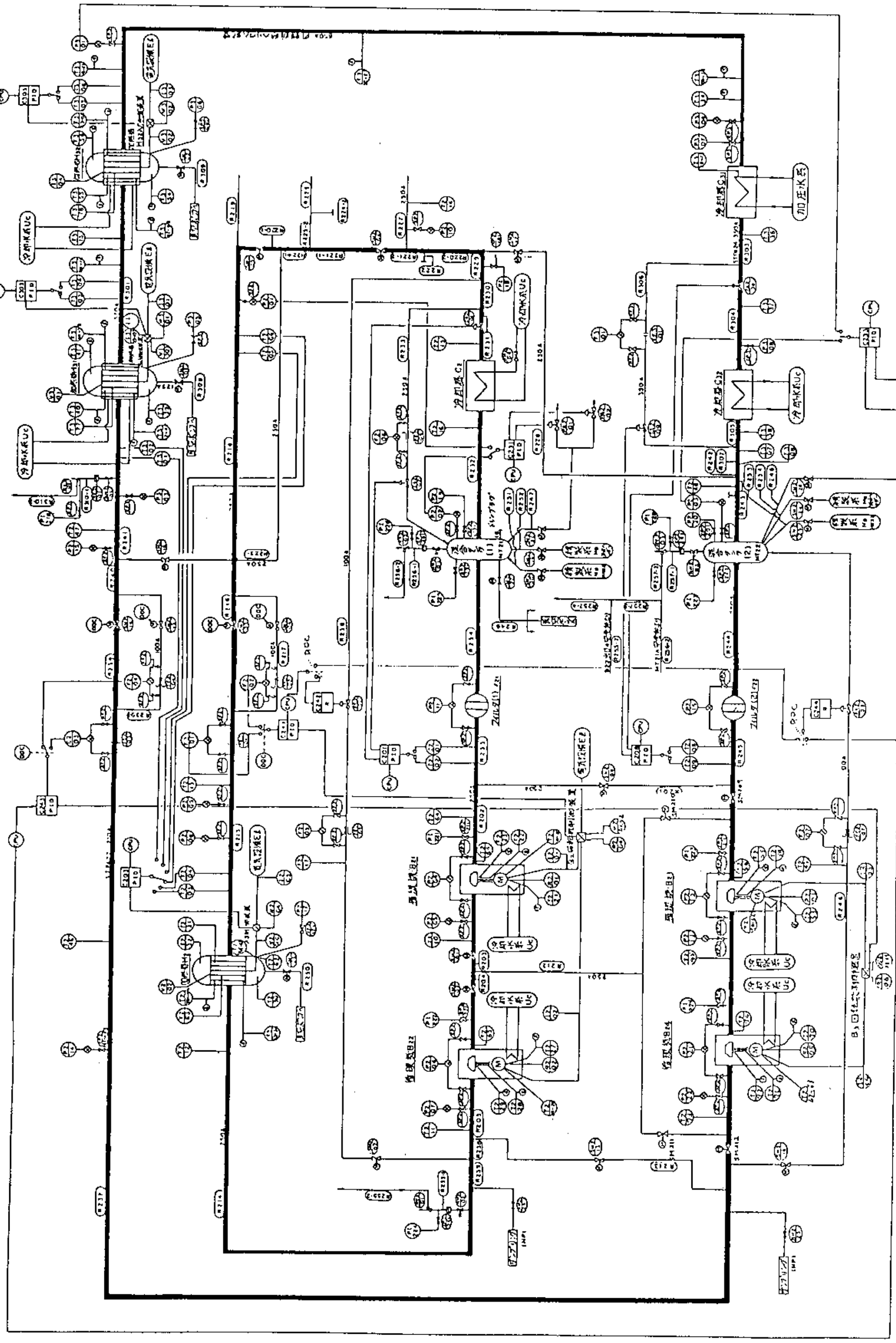


Fig.3.1.1 Flow Diagram of M_2+A loop (before Adaptation of T_2)

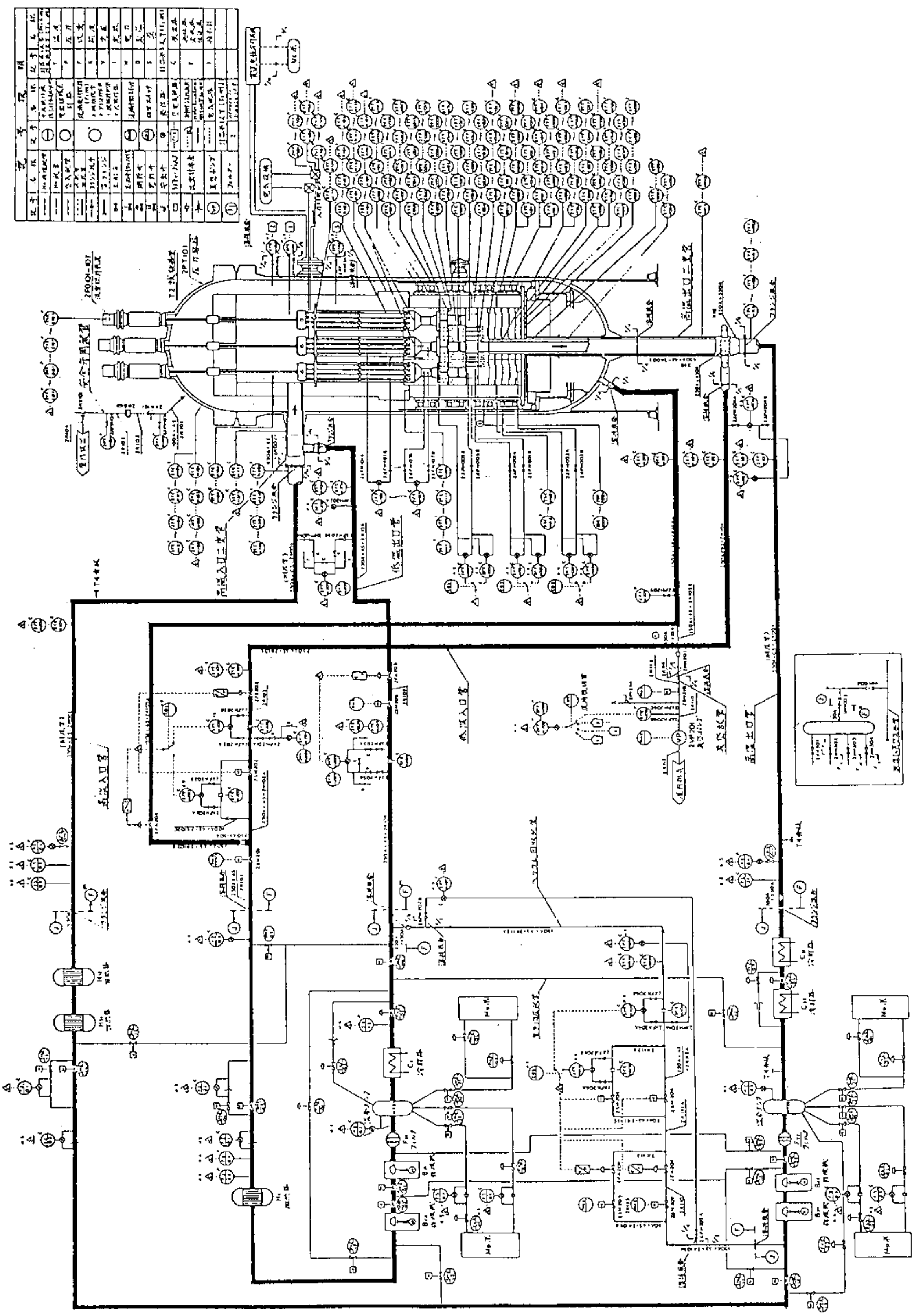


Fig.3.1.2 Flow Diagram of M_2+A loop (after Adaptation of T_2)

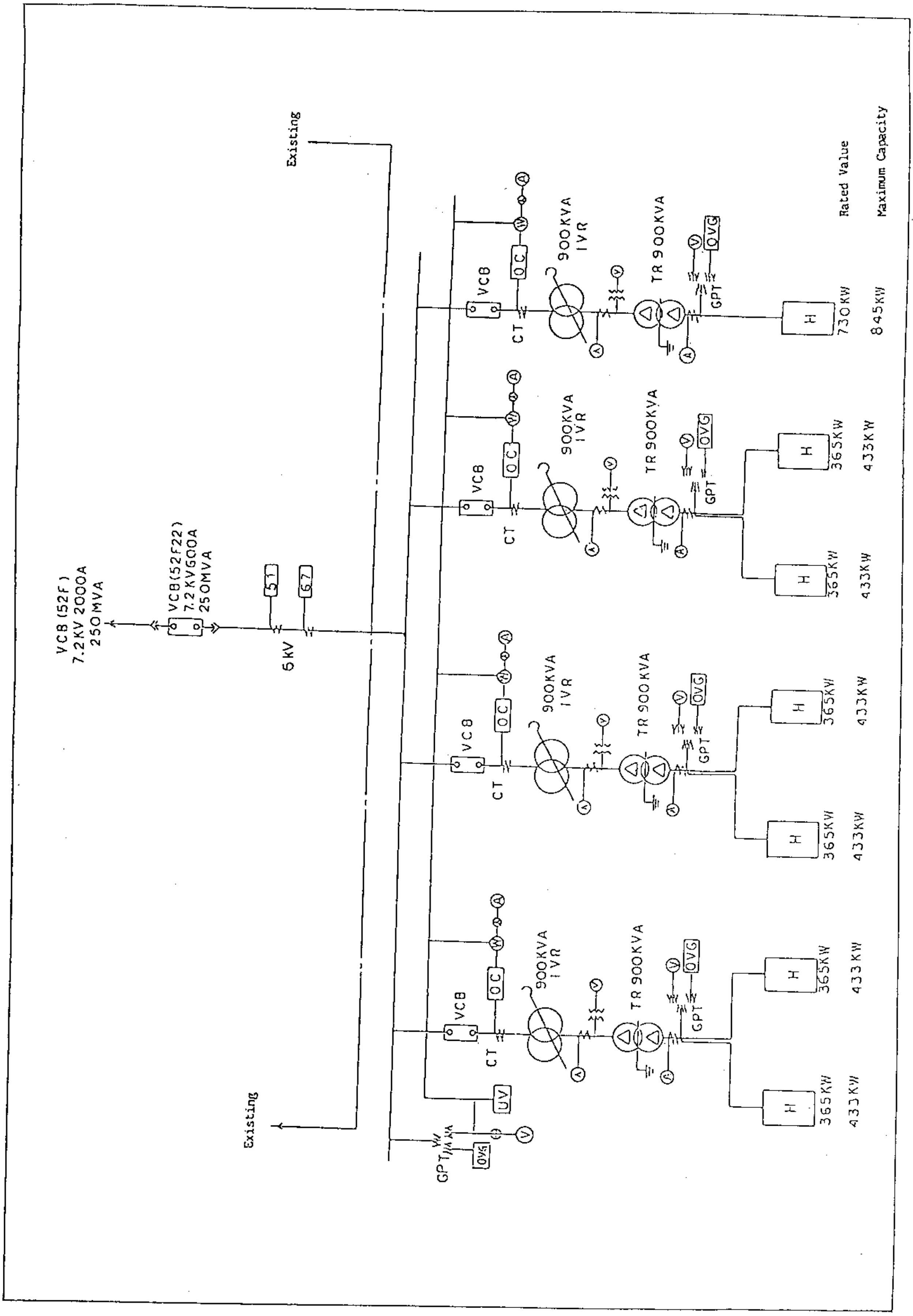


Fig.3.2.1 Schelton Diagram of Electric Power Supplying System

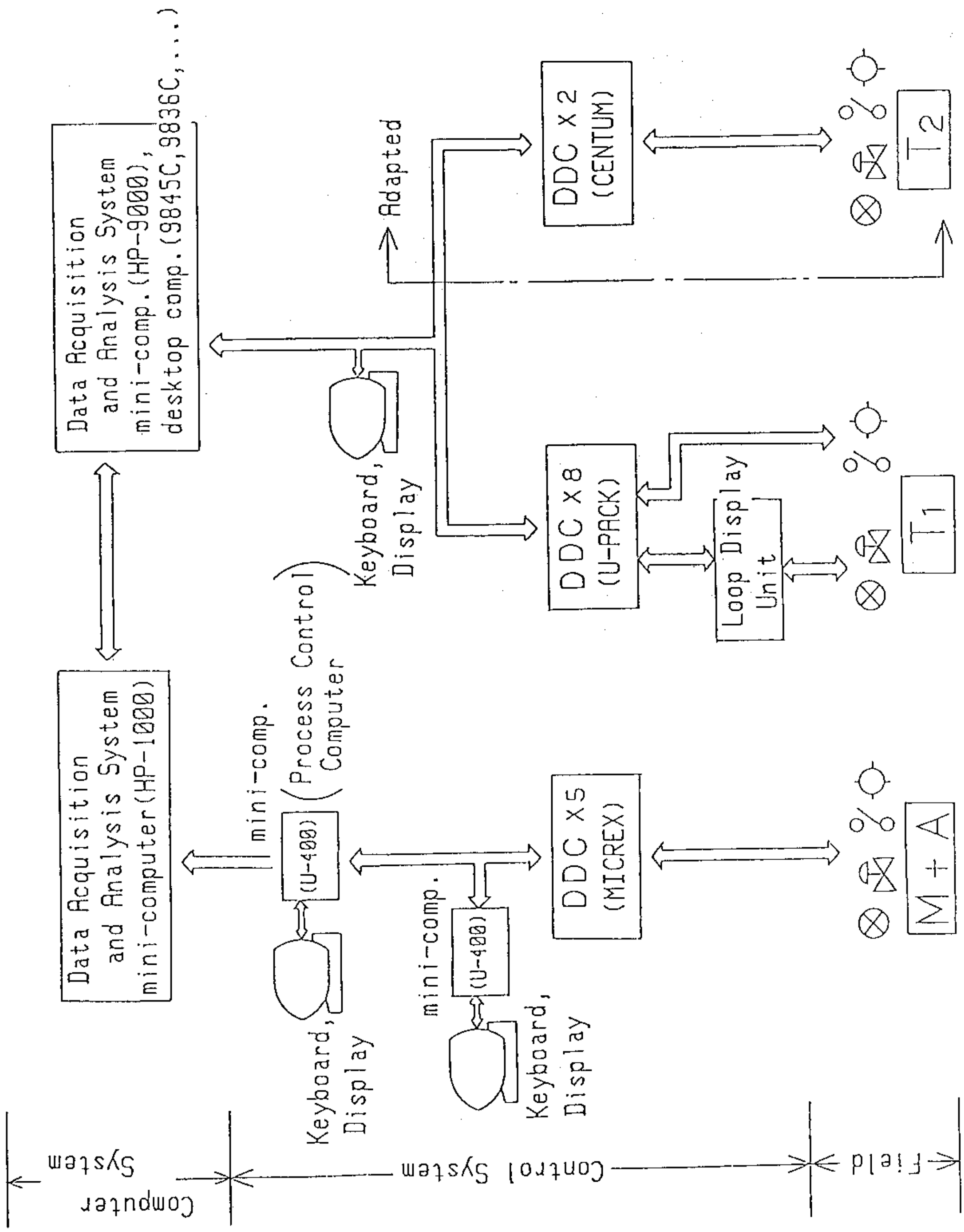


Fig.3.2.2 Schematic Diagram of Control System of M_2+A loop with T_2

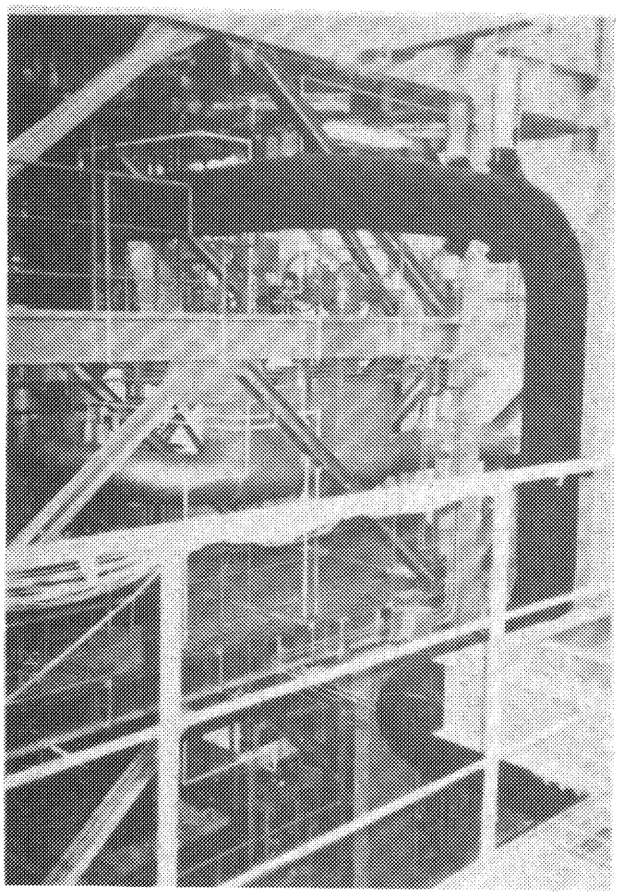
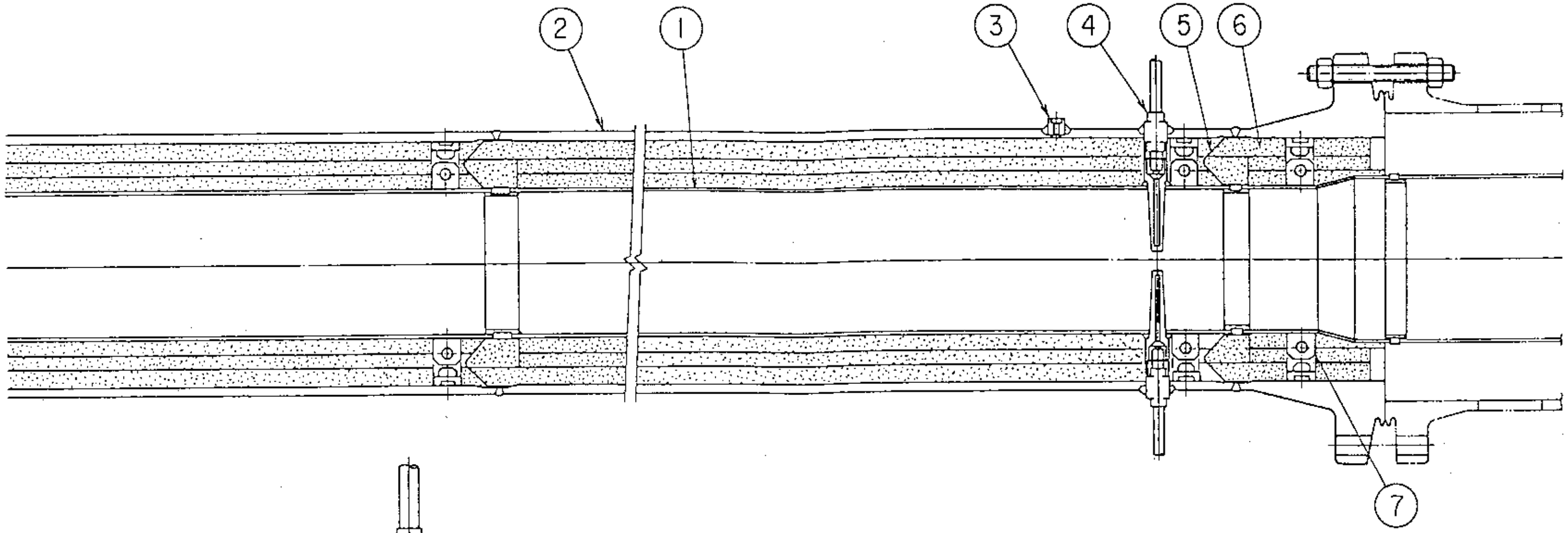
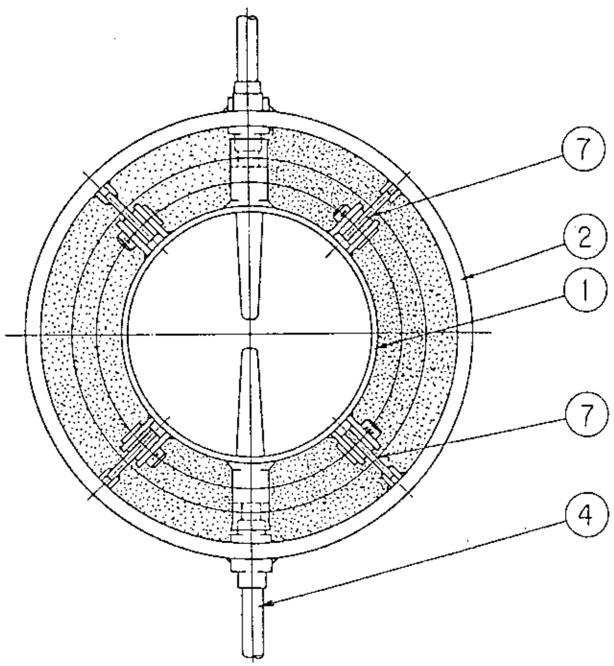


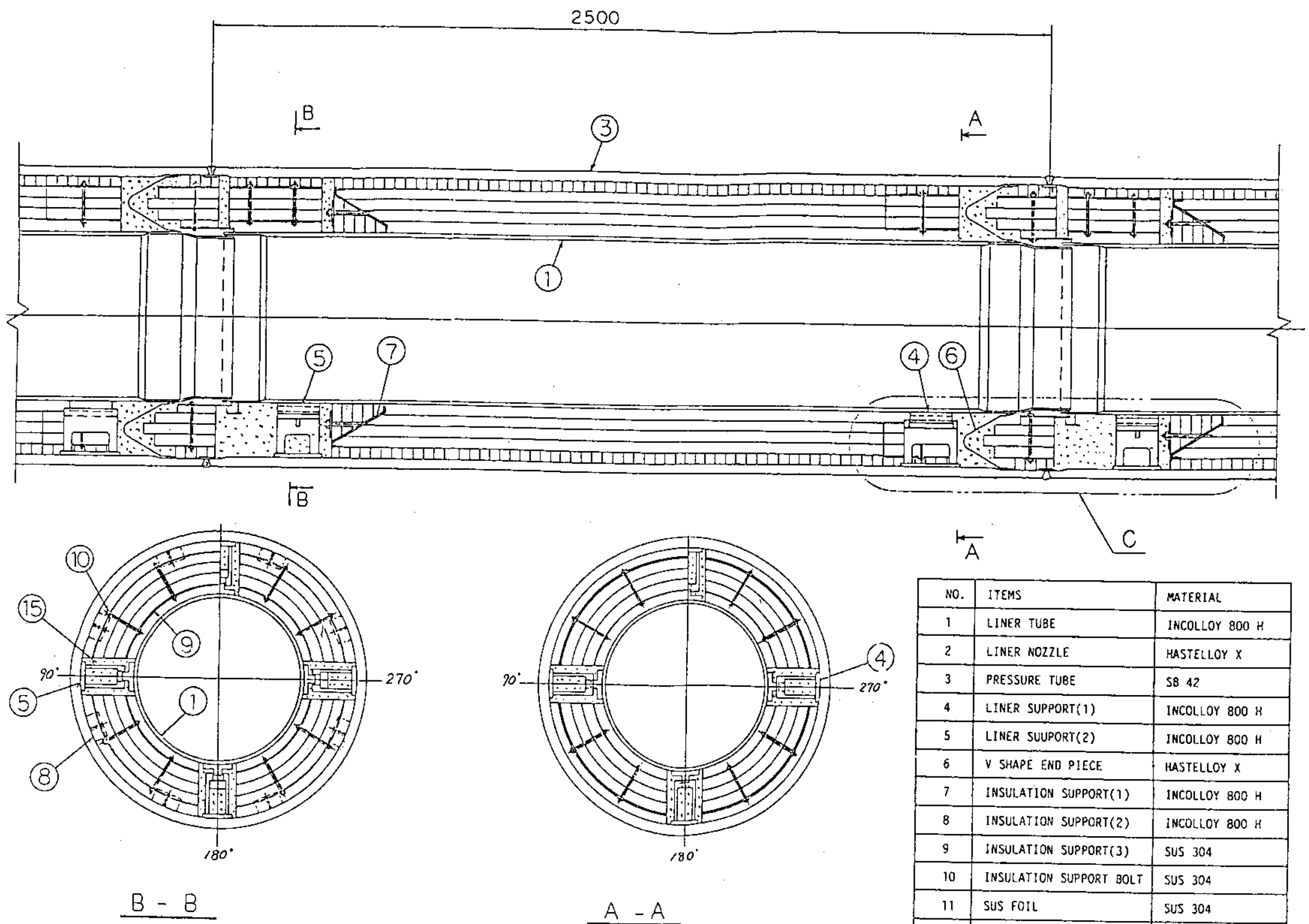
Fig.3.3.1 Appearance of Hot Gas Duct connected with Gas Inlet of T_2





NO.	ITEMS	MATERIAL
1	LINER TUBE	INCOLLOY 800 H
2	PRESSURE TUBE	SB42
3	PRESSURE GAUGE ADAPTER	S25C
4	THERMOCOUPLE ADAPTER	SUS 304, S25C
5	V SHAPE END PIECE	INCOLLOY 800 H
6	INSULATION	KAOWOOL 1400 S
7	LINER SUPPORT	INCOLLOY 800 H

Fig.3.3.2(a) Cross Sectional View of New Hot Gas Duct (Inlet Side of T_2)



NO.	ITEMS	MATERIAL
1	LINER TUBE	INCOLLOY 800 H
2	LINER NOZZLE	HASTELLOY X
3	PRESSURE TUBE	SB 42
4	LINER SUPPORT(1)	INCOLLOY 800 H
5	LINER SUUPORT(2)	INCOLLOY 800 H
6	V SHAPE END PIECE	HASTELLOY X
7	INSULATION SUPPORT(1)	INCOLLOY 800 H
8	INSULATION SUPPORT(2)	INCOLLOY 800 H
9	INSULATION SUPPORT(3)	SUS 304
10	INSULATION SUPPORT BOLT	SUS 304
11	SUS FOIL	SUS 304
12	INSULATION BLANKET(1)	KAOWOOL 1400 S
13	INSULATION BLANKET(2)	KAOWOOL 1260 S
14	INSULATION BLANKET(3)	KAOWOOL 1260
15	INSULATION BALK	KAOWOOL 1400 S

Fig.3.3.2(b) Cross Sectional View of New Hot Gas Duct (Outlet Side of T_2)

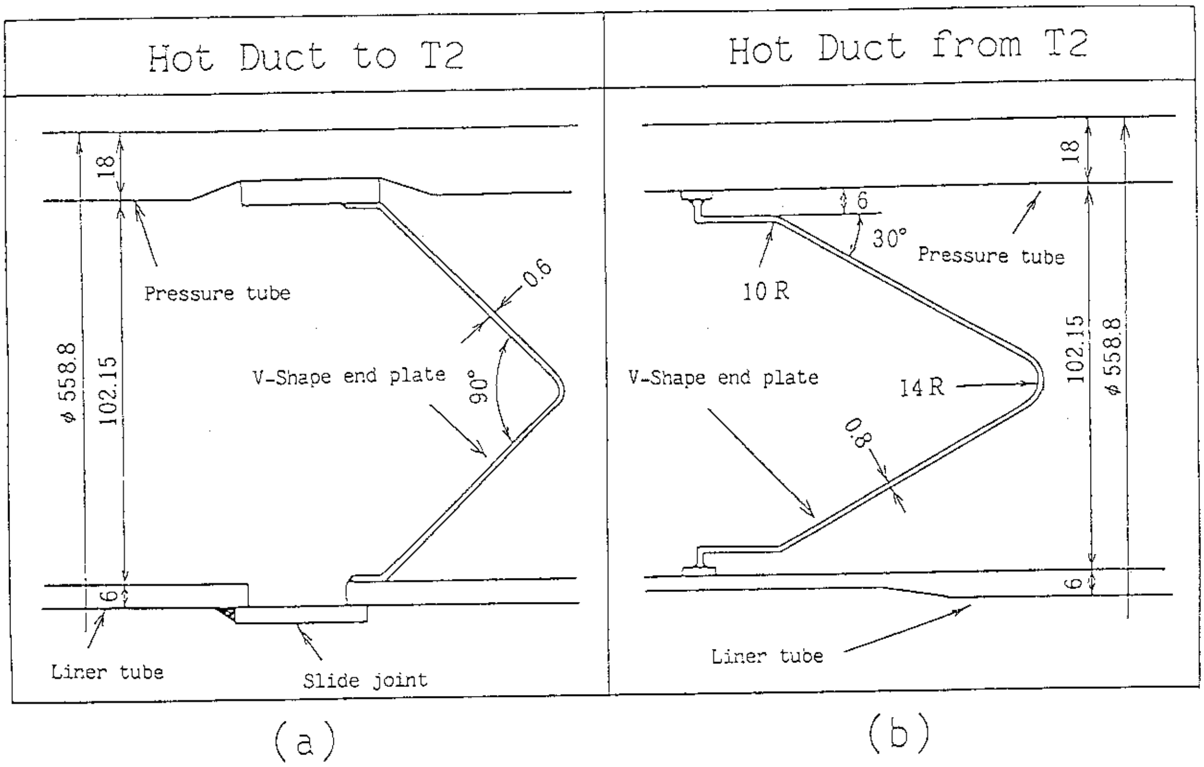


Fig.4.1.1 Sectional View of New Hot Gas Duct for T_2

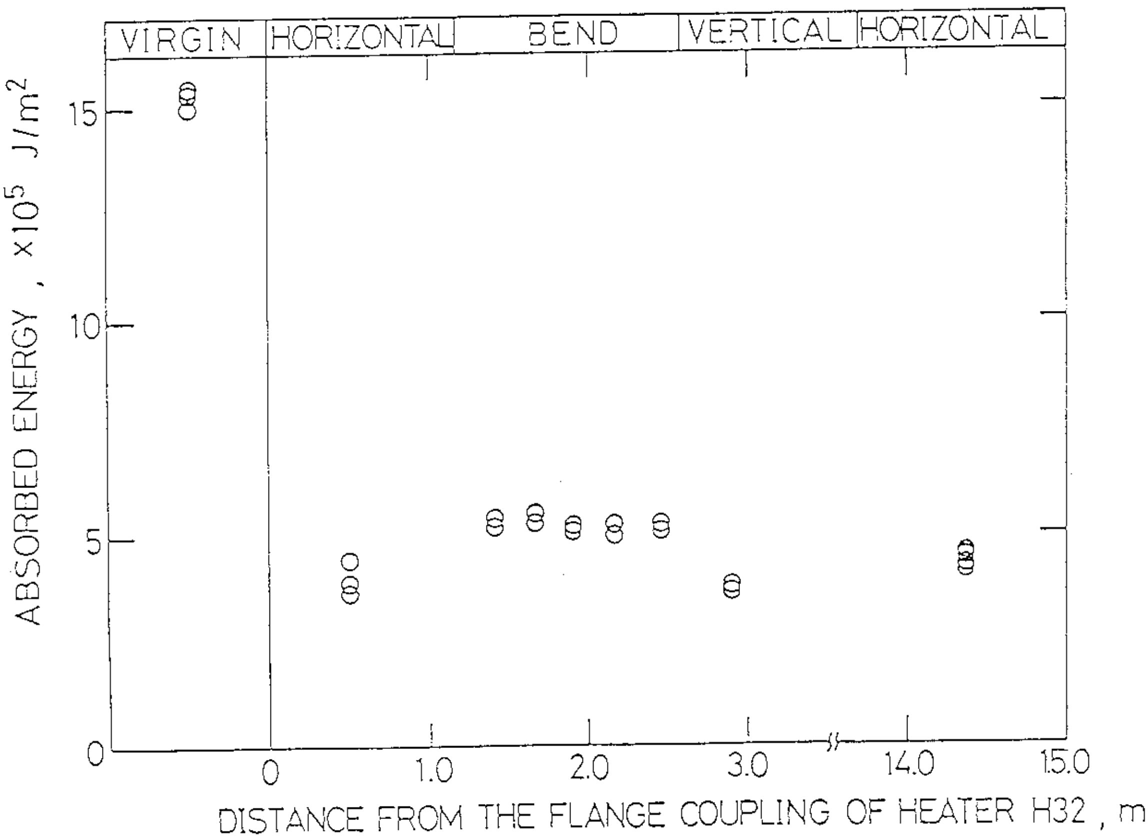


Fig.4.1.2 Absorbed Energy of Hastelloy X Obtained by Room-Temperature Impact Test

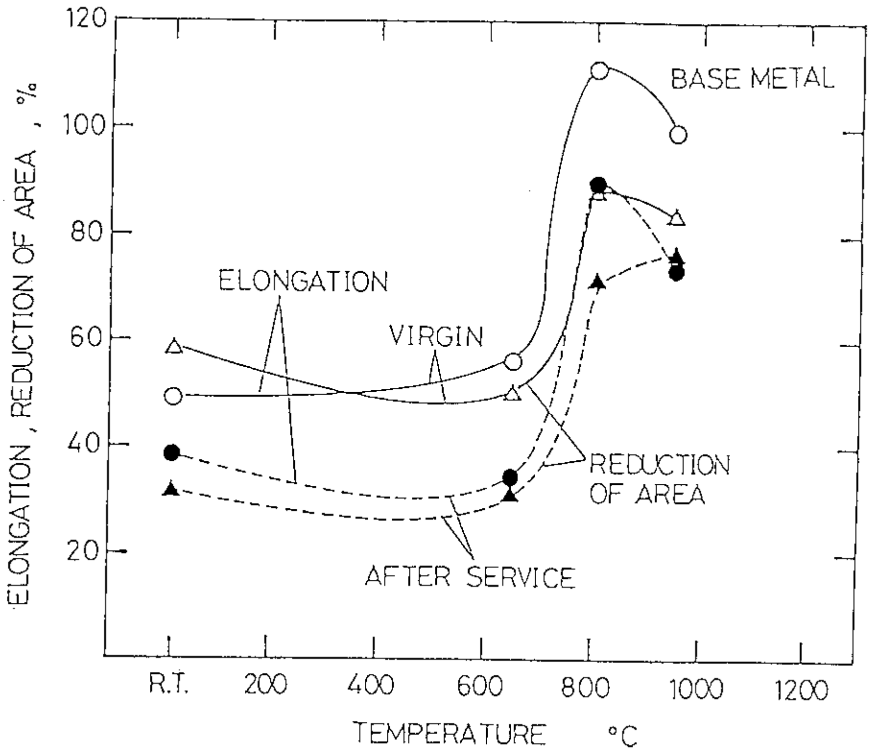


Fig.4.1.3 Relation between Mechanical Properties of Hastelloy X and Temperature (Elongation and Redaction of Area)

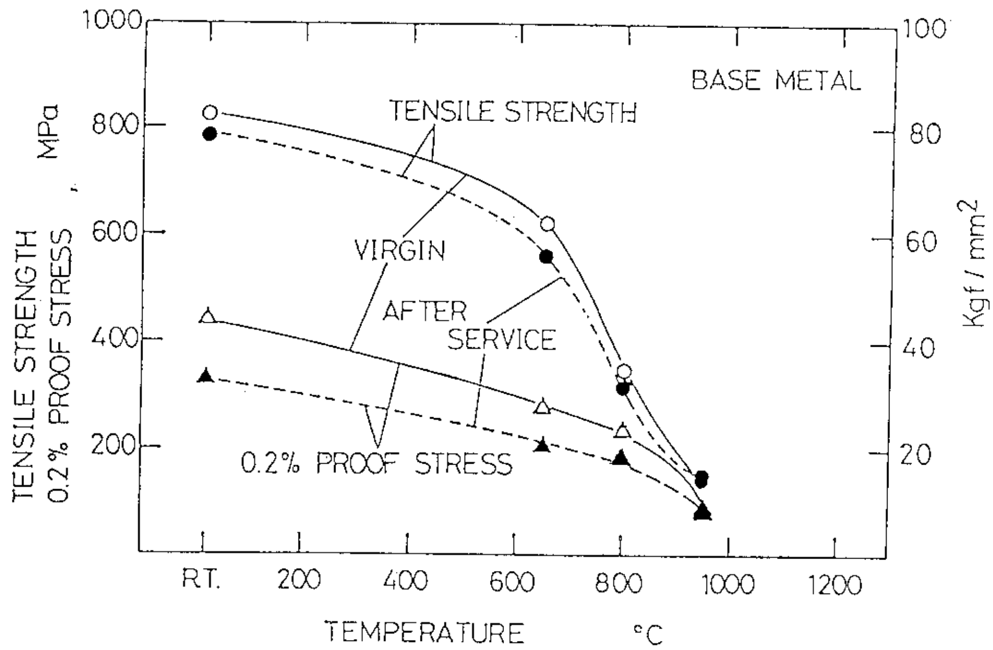


Fig.4.1.4 Relation between Mechanical Properties of Hastelloy X and Temperature (Tensile Strength and 0.2% Proof Stress)

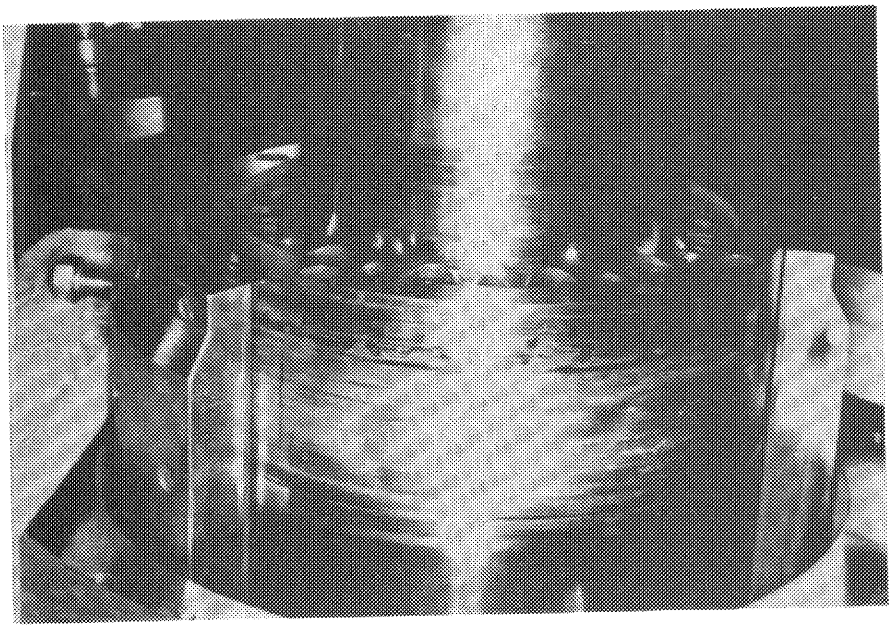


Fig.4.2.1 Damaged Journal

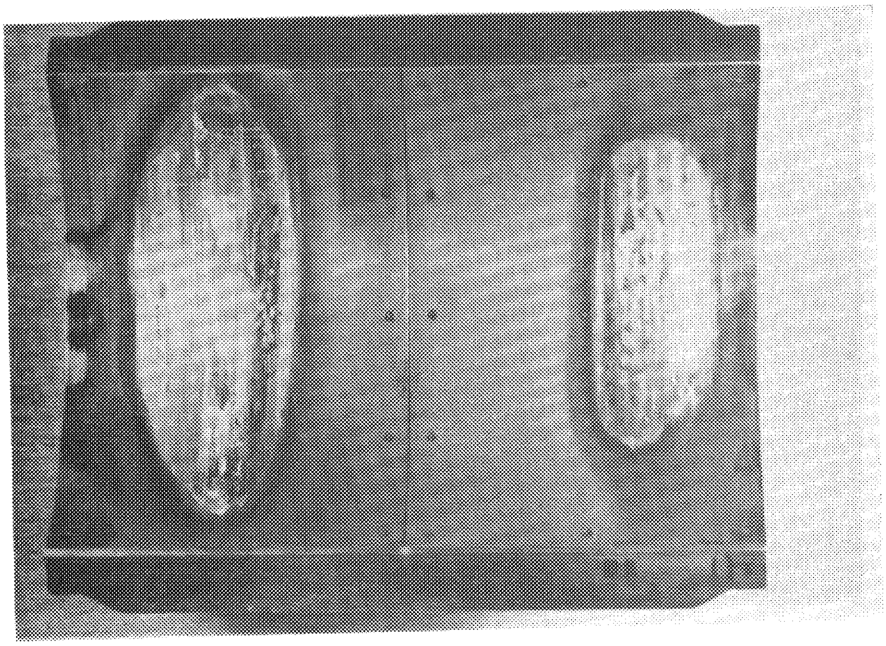


Fig.4.2.2 Damaged Upper Journal Bearing Pad

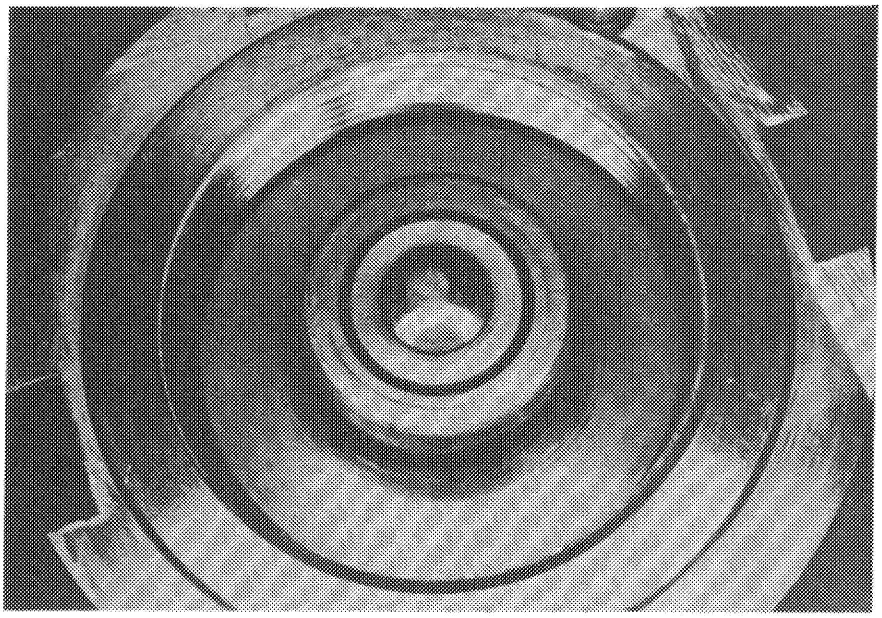


Fig.4.2.3 Damaged Pad Supporting Pivot

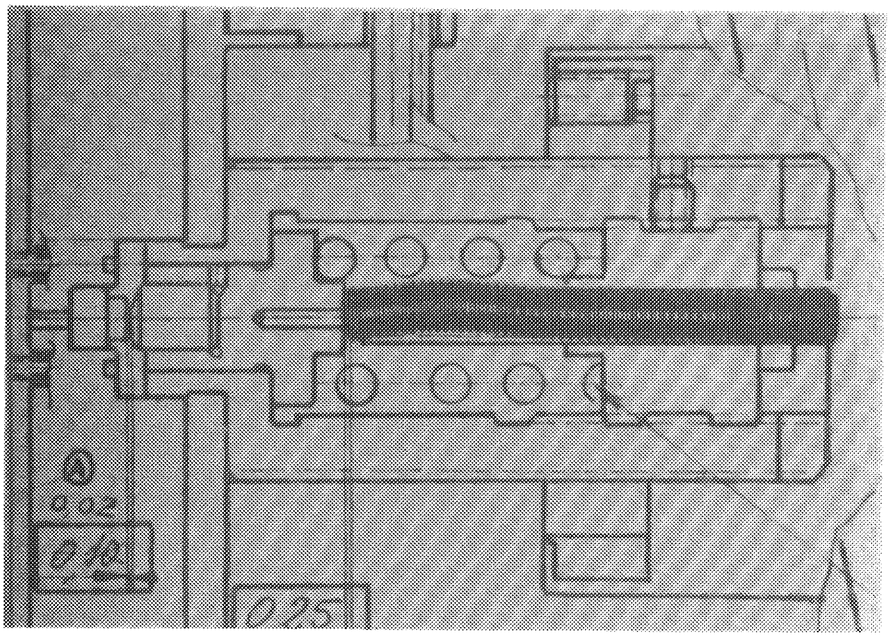


Fig.4.2.4 Damaged Pad Supporting Pivot (Sectional View)

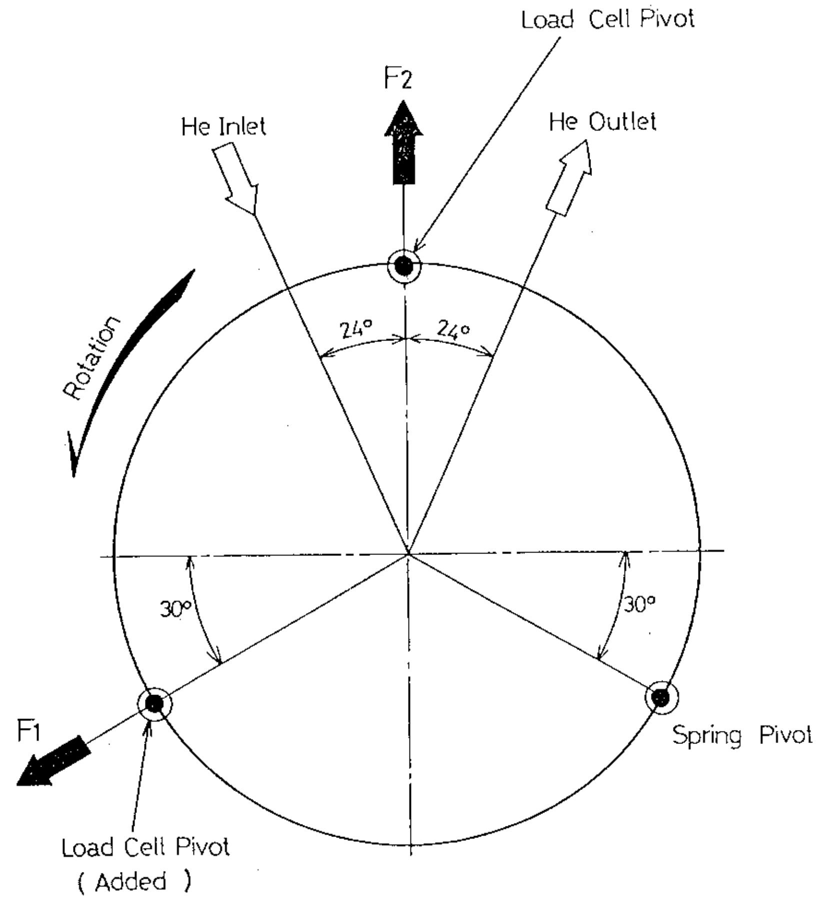


Fig. 4.2.5 Schematic Arrangement of Pivots and Direction of Measured Forces F_1,F_2

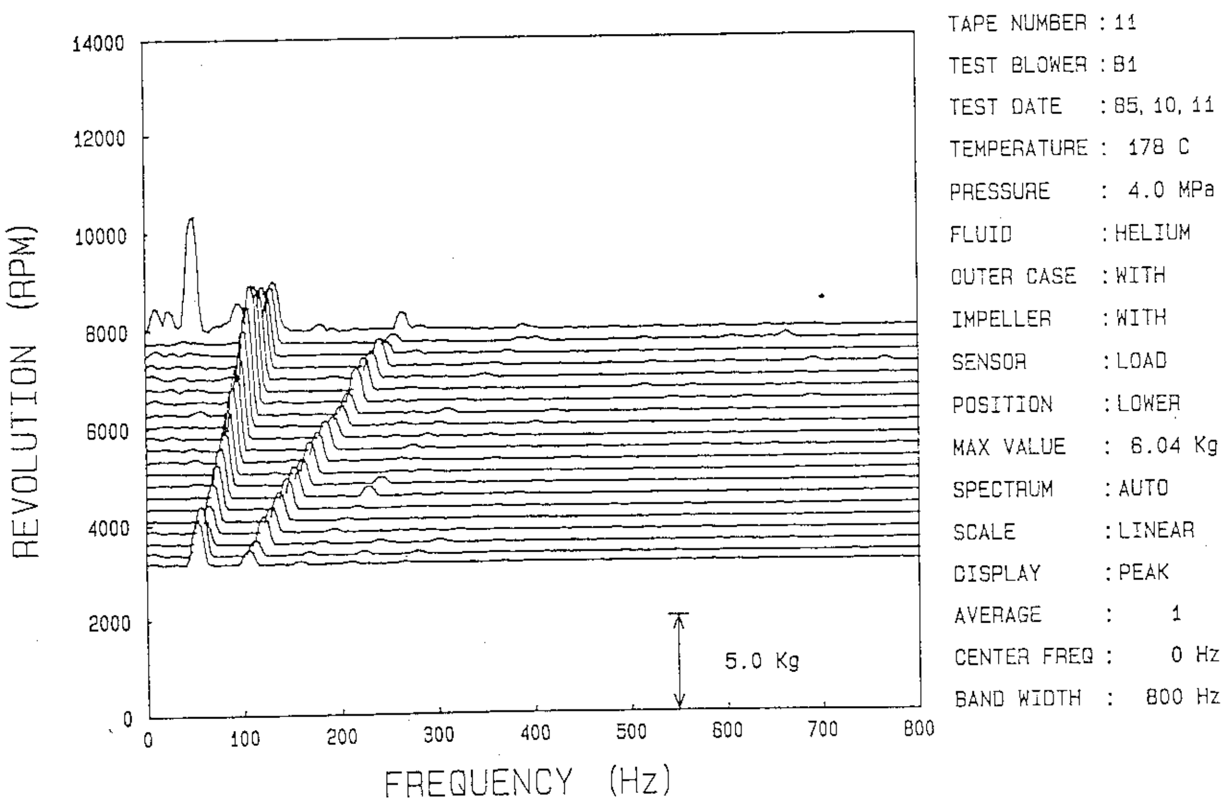


Fig. 4.2.6 Spectral Map of Vibrational Force to Pivot

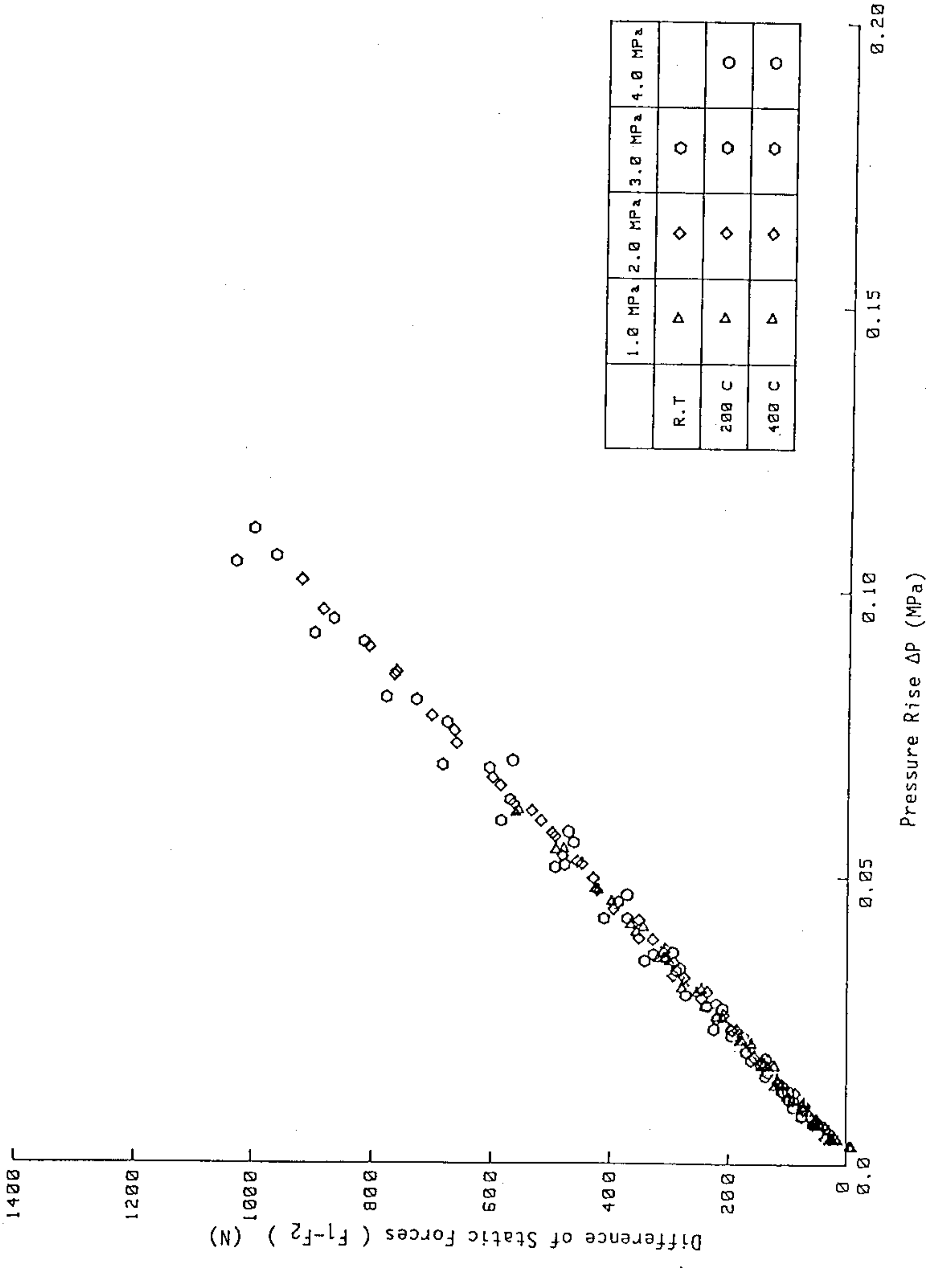


Fig.4.2.7 Relation between Pressure Rise and Static Force Difference

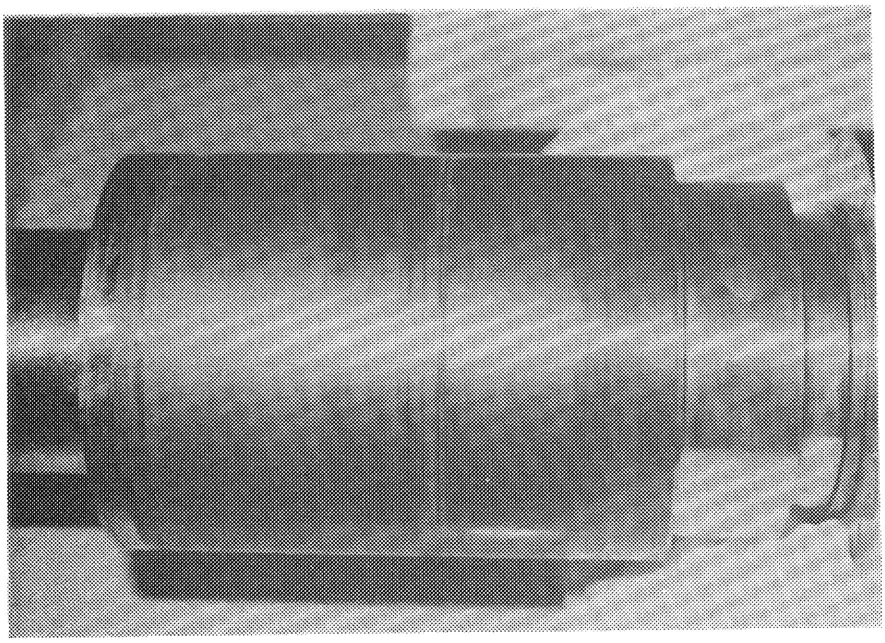


Fig.4.2.8 Upper Journal

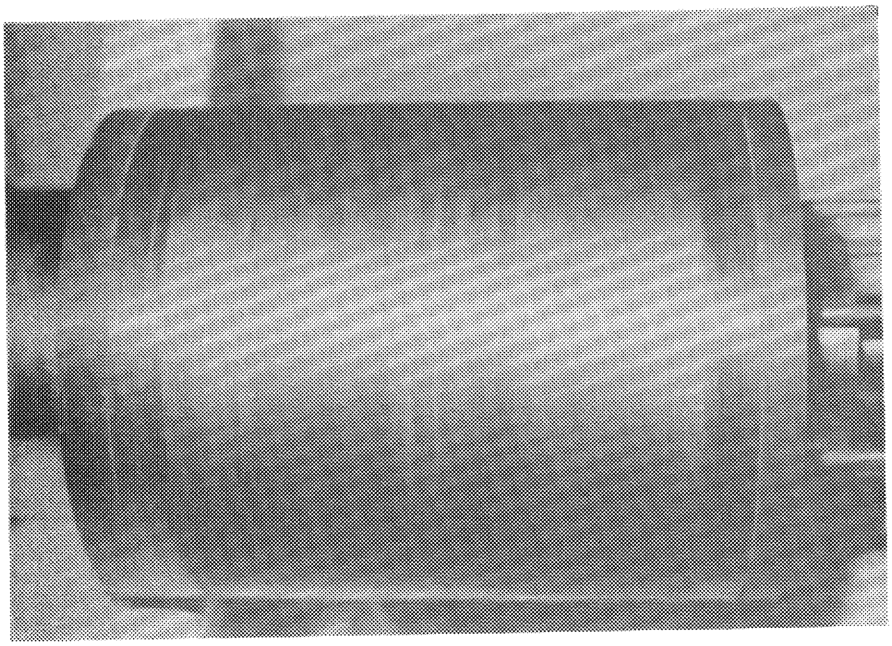


Fig.4.2.9 Lower Journal

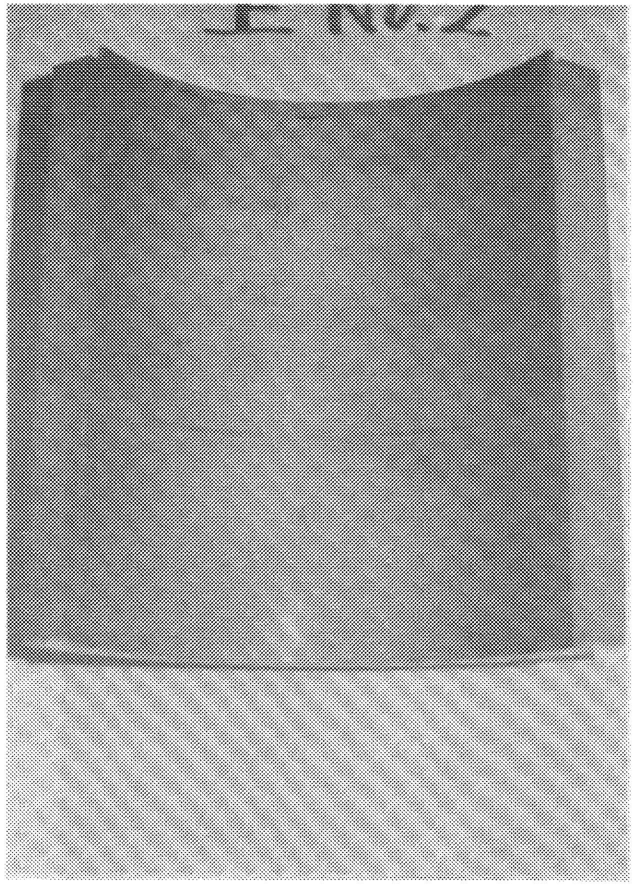


Fig.4.2.10 Upper Journal Bearing Pad

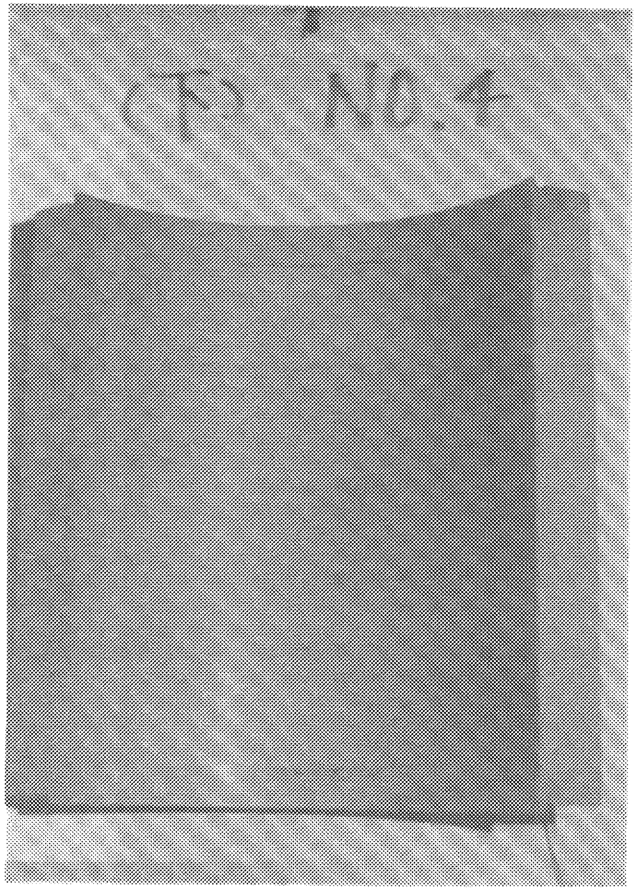


Fig.4.2.11 Lower Journal Bearing Pad

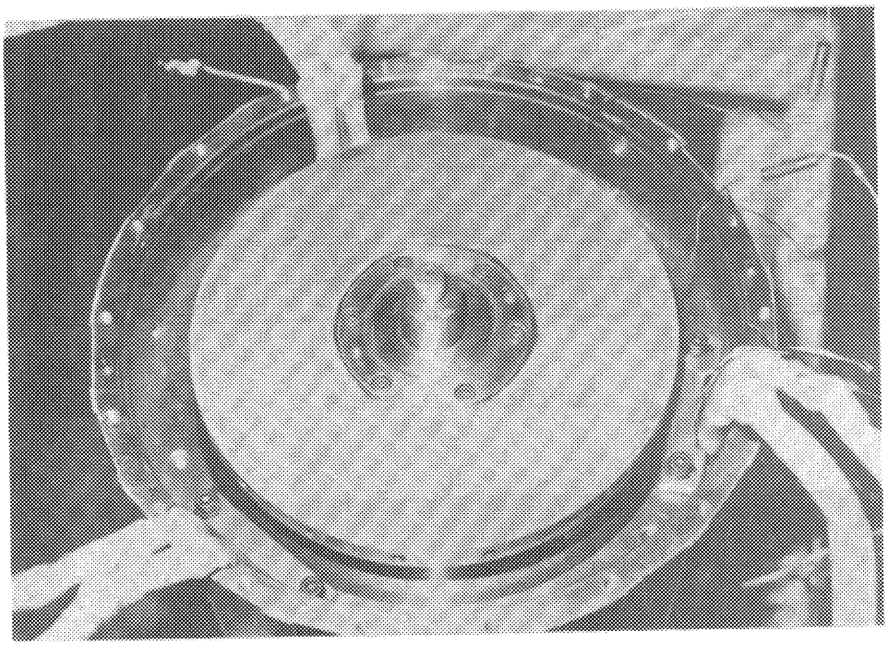


Fig.4.2.12 Thrust Collar

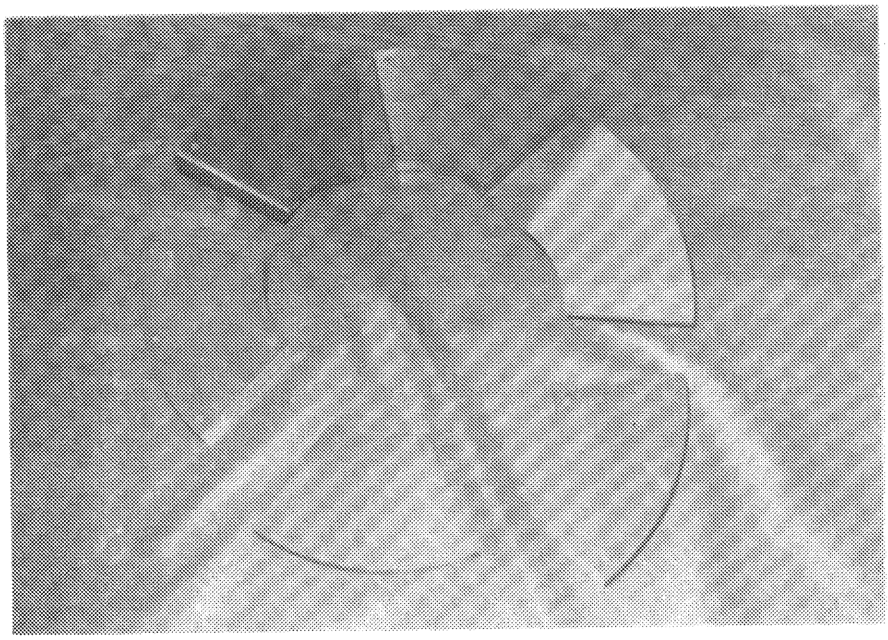
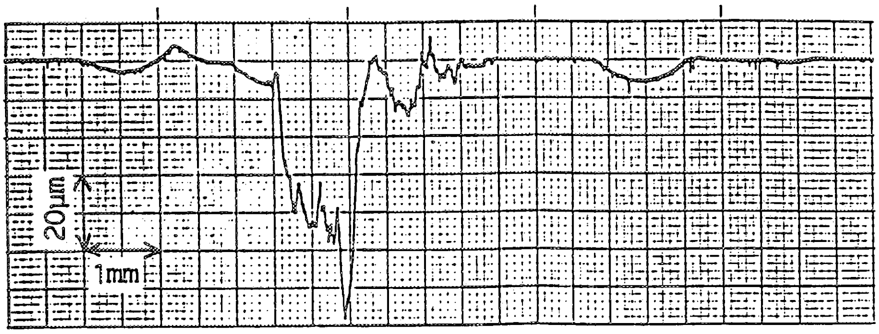


Fig.4.2.13 Thrust Bearing Pad



Surface Roughness

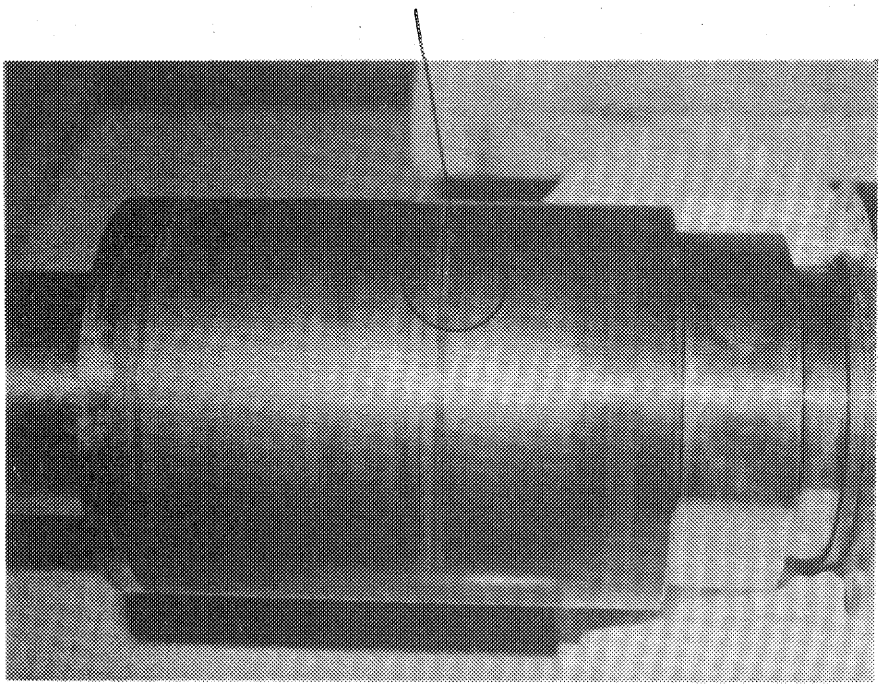
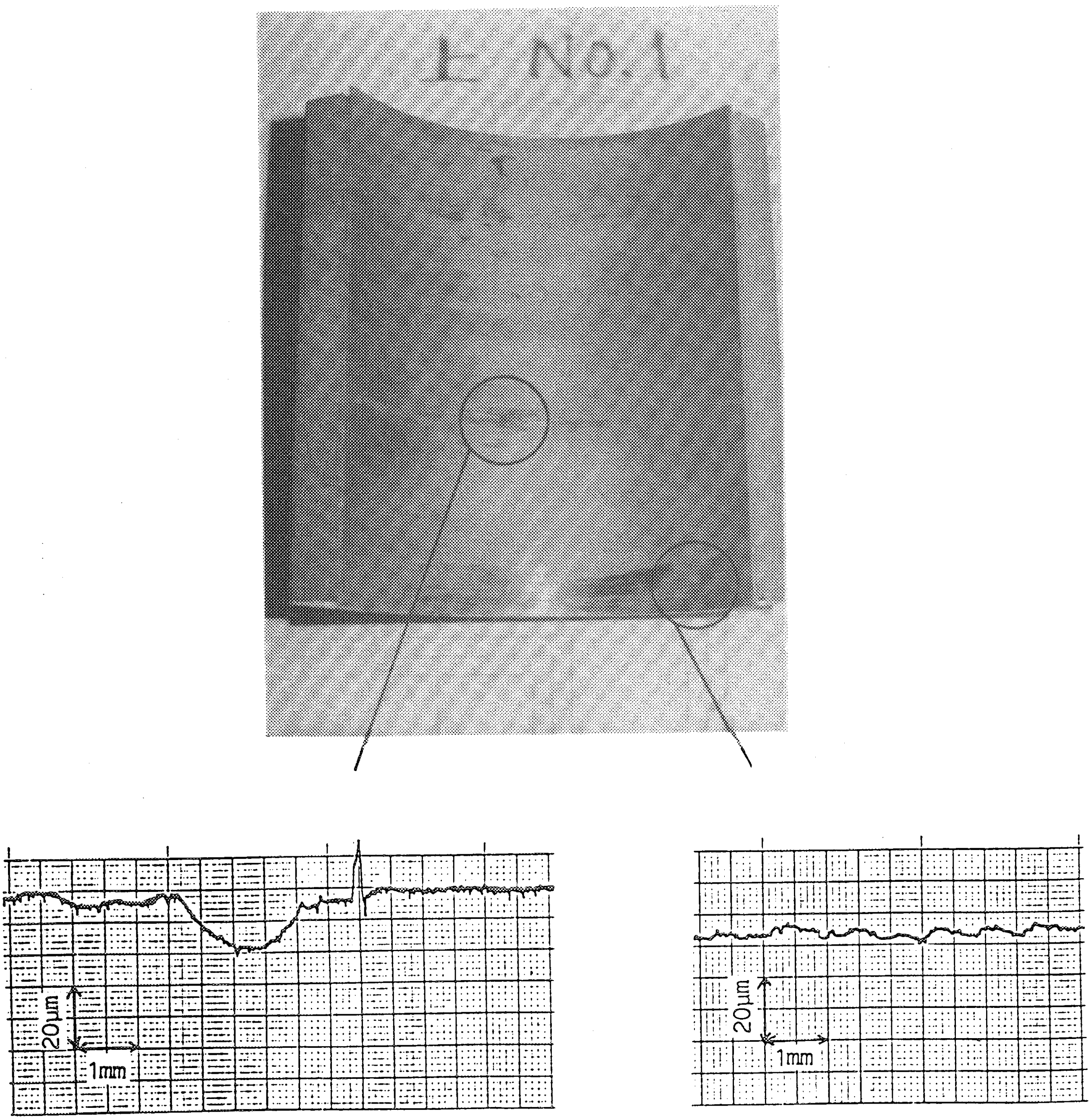


Fig.4.2.14 Damaged Condition of Upper Journal



Surface Roughness

Fig.4.2.15 Damaged Condition of Upper Journal Bearing Pad

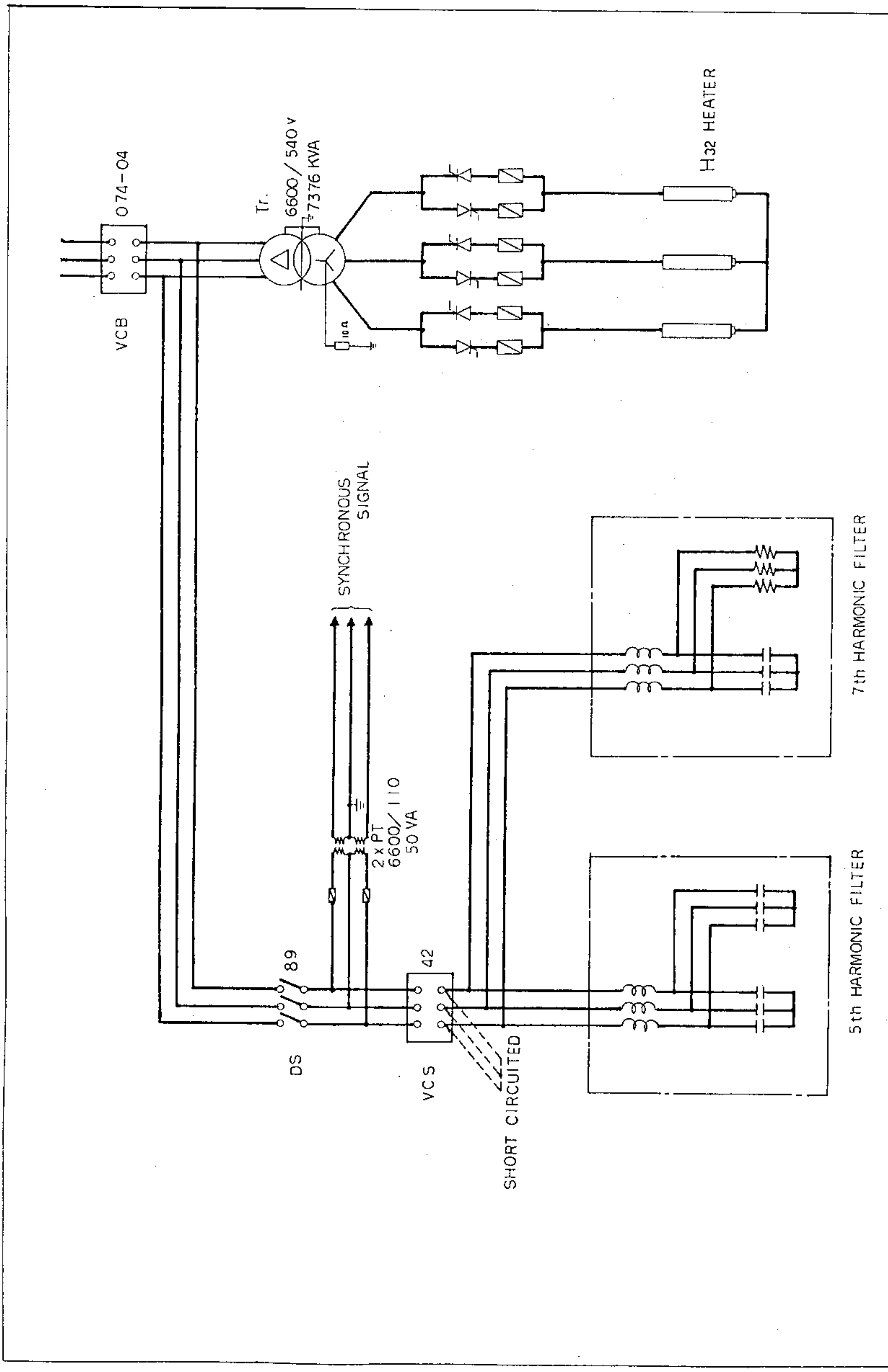


Fig.4.3.1 Heater H32 Wiring Diagram

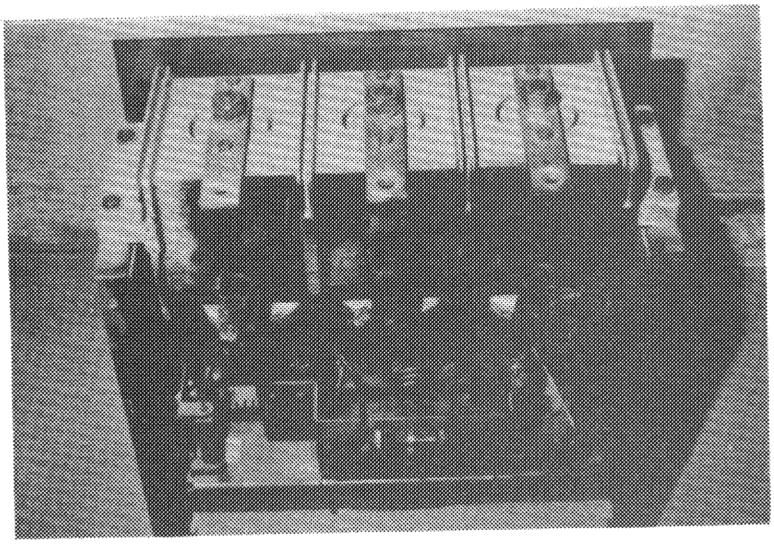


Fig.4.3.2 Vacuum Magnetic Contactor Switch (VCS)
(Connected Cables are partially melted.)

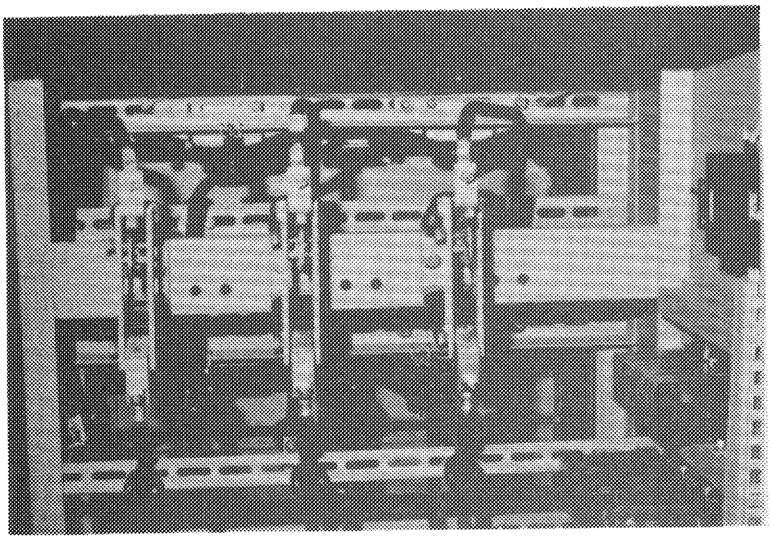


Fig.4.3.3 Disconnecting Switch in VCS Cubicle

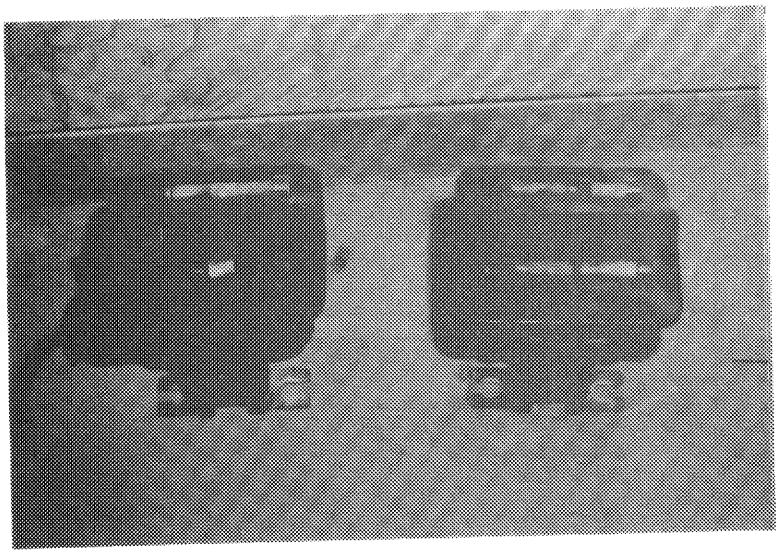


Fig.4.3.4 Damaged Potential Transformer in VCS Cubicle

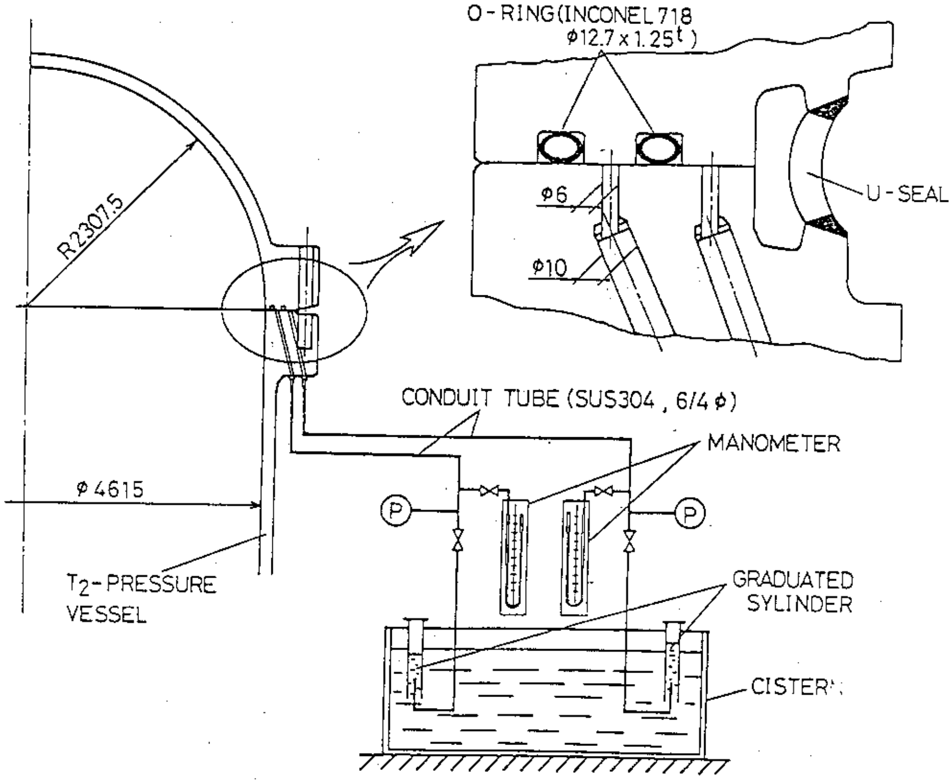


Fig.4.4.1 Sectional View of Flanges and Measuring Set Up

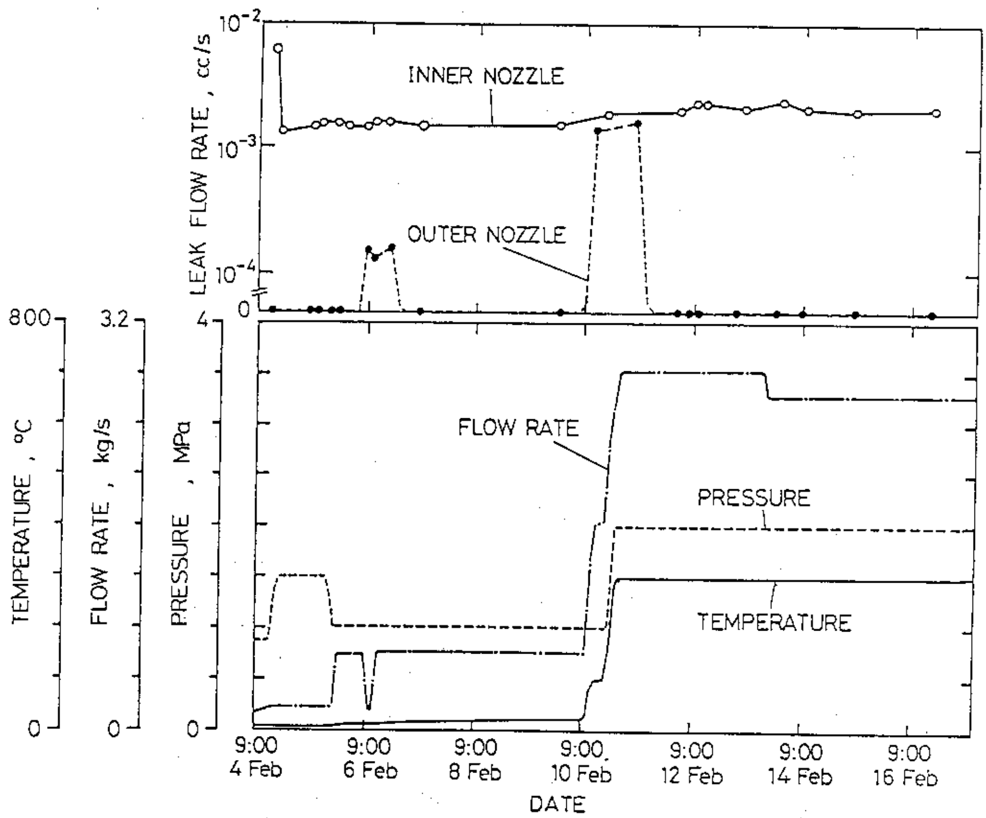


Fig.4.4.2 Measured Helium Flow Rates from Inner and Outer Spaces