THE WET STEAM FACILITY OF IS.MA.GE.

by

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1. Introduction

The theoretic and experimental wet steam research activities, directed to improve the efficiency of steam turbines for large power output, have been developed since 1970 at the "Istituto di Macchine" of "Università di Genova". Studies have been carried out on some calculation methods for the prediction of condensation shocks in supersonic nozzles, analysis of droplets trajectories about probe heads or within blade channels, the measurements of wet steam properties (i. e., vapour total pressure and velocity, wetness, droplet velocity and diameters), calibration of probes and sonic flow analysis through blade cascades with wetness control.

2. Description of test facility

We have used the wet steam tunnel in fig. 1 for both the experimental evaluations of steam flows in nozzles or through turbine blade cascade and the calibration of optical systems and of our aerodynamic probes. The operation of the test facility is as follow:

A mass flow of saturated steam is produced by a water tube boiler; the maximum steam flow is 700 kg/h at 19 bars. After leaving the test section, the steam is decelerated through a diffuser and goes to a condenser (pressure 0.07÷0.06 bar absolute), from which the condensate is returned to the boiler by way of a feed tank open to the atmosphere.

The steam, produced by the boiler, moves through a throttling valve and is desuperheated by injecting water as a spray of drops. The mass flow in the test section depends on the pressure of the boiler. The pressure upstream the working section depends on:

1 - The condenser pressure and the loss of head between the station after the throttling valve and the condenser, if the flow is everywhere subsonic;

2 - The loss of head between the station downstream the throttling valve and the test section when the flow is supersonic.

The pressure in the condenser is regulated by introducing air in it. The mass rate of cooling water is constant and, in his turn, is cooled by evaporation in a cooling tower. The steam throttled and desuperheated can be made wet before the settling chamber or upstream of the contraction by a very fine spray of steam assisted injectors (drops of 10 μm in diameter).

The wet steam produced artificially does not correspond to the working fluid in steam turbine, which contains fog of submicron drops and coarse water (in the L. P. steam conditions the minimum size of coarse water drops is believed to be of the order of 10 μm whilst the largest ones are governed by Weber number). The coarse water lies between 5 and

8% of the total wetness). However the vapour phase and the small size drops, without both velocity slip and heat and mass transfer between them, can be considered as a continuous omogeneus medium, while the large drops, forced by inertia forces, have their velocity and paths different from the steam ones.

The artificial wet steam produced in the tunnel is thought acceptable in reproducing those phenomena where the coarse water plays the leading role such as:

1 - to study the process of water films formations on the blade surface and process of drop stripping from the frailing edge;

2 - to analyse the behaviour of hollow slotted blades for the control of the water film deposited on the blades and to observe the droplet life in the blade wakes.

The steam tunnel was built so that the settling chamber, the working section and the diffuser can be easily changed, according to the several kinds of experiments carried out. The instrumentation with wich the steam tunnel is provided allows to measure static pressure and temperature in each section and to execute an enthalpy and mass balance. In order to perform the pressure measurements it is important to keep the lines connecting the sensing point free from water. The intermittent purge arrangement (with a suitable electric valves system) is used. The suction of a sufficient amount of air from the atmosphere will blow out the pockets of water.

The steam tunnel has also the possibility of being utilized as probe-calibration tunnel. In past times, several static, total and combined probes have been calibrated in wet and superheated steam. The combined probes in particular were calibrated also in a wind tunnel in the low and high subsonic regimes for aim of comparison. These probes are:

- two-directional probes with five-holes sensor heads of the conical, hemispherical and prismatic types;
- two-directional disc probes with four and five holes.

For the calibration of directional probes the test section was employed which is presented in fig.2 . The cross sectional area of the test section is 70x90 mm^2. A probe positioning mechanism is located on the side wall: it allows the orientation of "L" shaped probes to be performed with the selected pitch and yaw angles. The operating principle is shown in the scheme of fig.3 . The main characteristics of the rig are the following:

- the supporting ring,
- the two wheels R_1 and R_2, with axes I and II crossing each other in the test point at an angle of inclination γ .

The smaller wheel R_2 holds the probe letting it rotate around its axis III. The probe axis crosses the test point and is inclined of γ too, with respect to R_2 axis.

The yaw angle excursion is effected simply by imparting an α_s rotation to the stem.

The pitch angle excursion is effected, on the contrary by imparting combined α_1 and α_2 rotations to axes I and II. Actually, starting from the configuration in fig.4 and effecting a rotation of R_2, the probe moves along a portion of a conic surface and will leave the test plane. By imparting a suitable rotation of R_1 the probe may be brought again on to the test plane. In this way the pitch angle will assume a different value with respect to the initial configuration: this angle can be measured by means of the rod and the protractor reported in picture.

3.Wetness control test section

The test section used to study the wetness control in cascade with hollow slotted blades, was designed for receiving a particular kind of profiles at one only angle of incidence. The positions of the walls wich define the upper and lower sides of the duct past the cascade, have been determined with test in air to obtain a good periodicity of the flow downstream of the cascade. It is made in plexiglass to observe the formation of water film on the blades and the formation of droplet at the trailing edges.(Fig.5,6)

The dimensions of test section are 274x70 mm^2. The pitch of the cascade is 48.6 mm and the pitch/chord ratio is 0.64 (relative gap).In the 6 airfoils cascade only two hollow slotted blades are placed and three different kinds of slot have been tested. The inner of the slotted blade has been connected with a little auxiliary condenser with vacuum pump, obtaining a circuit which allows to measure at the same time the water mass flow from the slot.

The water film has been produced also bY injecting a known water mass flow on the leading edge by a hypodermic injector.

The three kinds of slot were arranged

1 - at the trailing edge
2 - at the pressure side near the trailing edge
3 - at the suction side near the leading edge

The Mach downstream of the cascade was included between 0.5 and 0.85, Reynolds number between $(1,5 \div 4)\times 10^5$.

The test section is moreover provided with instrumentation to fluid-dynamic analysis of wet steam in cascade: static pressure volues can be measured upstream and downstream of the cascade by pressure tapping in the side walls.

Transverses of total pressure, total temperature and flow angle can be made in the some stations with two-dimensional probes (axial distance of 10 mm upstream and downstream of the cascade). Each measuremant is executed after purging air flow aut of all lines.

The coarse water distribution after the profile rig was determined by a isokinetic probe, able to analyse a sample of wet steam, drawn from the main flow.

The isokinetic probe was elementary. It had the form of a hollow tube with its sampling head to the average flow direction, which was provided with a suitable slot. An accettable orifice capture efficiency was evalueted for the more significant drop sizes, which were present in the flow. By the knowledge of the static pressure values and the velocity of the flow downstream of the cascade and by assuming all the drops at the same velocity as the stream, the correct mass flow rate accepted by the probe was evalueted.

Accordingly the vacuum pump, connected to the condenser of the probe, was regulated.

The balance of the mass flow rates (injected, collected by the hollow blades, and intaked by the isokinetic probe) has been analysed at the different test conditions.

4.Test section modified

The necessity of doing more accurate analyses on the behaviour of the water film on the blade surfaces and of the droplets downstream of the trailing edge has suggested to develop a new test section design. This section (fig.7-8)contains only two consecutive blade channels and on the central blade measurements are executed employing also a radioactive source. This blade can be easily replated with other blades with the same profile but different inner structure according to the test program (measurement of the water film thickness, film control by suction blowing or heating, comparison of different slot types). The outer blades present, past their trailing edges, adjustable walls whose shapes have been optimized to obtain flow periodicity in two consecutive channels.

At present, the section is utilized to measure water film thickness on the blades through the absorption of the γ rays produced by a radioactive source disposed inside the central blade. It is possible to put the source in three positions to verify the effects of the water control devices. A signal detector through the upper blade counts the impulse number. The water film present on the upper blade surface in the region connected with the detector is eliminated by local air blowing. The beam of γ-rays is obtained with an americium-241 source of 100 mCi of activity (peak energy equal to 60 keV) and, without previous calibration, it is possible to measure the film tickness with an approximation of less than 0.05 mm. A greater precision, but with an accurate calibration, is obtained utilizing β-rays produced by a strontium-90 source of 50 mCi. Preliminary tests have been performed measuring with a β-absorption the water film thickness in a wet steam flow. For a Mach number equal to 0.5, changing the dryness fraction, water film thickness have been measured between 0.1 and 0.5 mm.

5. The new working section for blade cascade

On the previous experience on the wind tunnel for blade cascade and the two wet steam test sections above described, a new stainless steel, test section was designed fig.9-10. It is suitable to receive several kinds of blade cascade, corresponding to the different sections of L. P. turbine blade at various radial heights. Its settling chamber is located downstream the wetting section of the tunnel, where the mechanical and steam assisted injectors are set-up. After the cascade, a large exhaust room without diffuser is attached to the condenser. The contraction upstream of the casca de can adapt to both the value of the stagger angle of the cascade and the incidence flow angle.

The blades are fixed by means of lugs on the bottom of two rotating cylinders, so that the cascade turns around its centre. One of the cascade side walls is transparent to consent optical analysis of the flow. Over it, tappings are made for measuring static pressure values upstream and downstream of the aerfoils rig. In the same stations, the transverses of both the total and static pressure and the flow angles can be carried out by means of two two-diretional probes, moving along two slots in the side walls.

The leakage problems through the probe slots are eliminated by closing the probe stems with their carriages in two vacuum tight boxes. They are placed in one of the rotating cylinders, so that only the signal pressure tubes and the carriages devices leave the tunnel.

Since the boiler mass flow rate is hardly sufficient for feeding the steam tunnel at its maximum load, little internal steam leakage between the stagnation chamber and the exhaust room brought up a static pressure reduction ahead of the cascade and a decrease of the Mach number after the blades. The careful investigation for such a leakage location eliminated their serious effects.

The position of the walls wich defines the upper and lower side of the duct past the cascade, can be varied to obtain a good periodicity of the flow past the cascade.

The exhaust room downstream the test section is large, and it is connected directly with the condenser.

The walls of the tunnel are very strong to with stand safely the greatest excess pressure wich occurs when the tunnel is running at top speed (pressure at the condenser about 0.05 bars), and they are stiff enough to avoid any deflection appreciably.

The maximum test section is (70x230) mm^2.

Actually 8 blades,which correspond to the hub section of L. P. fixed blade, have been placed in the working section, and the central blade channel of the cascade has been instrumented: the pressure side by means of 23 static pressure tappings, and the suction side by 32 ones. The blades cascade is tested at an inlet angle $\alpha_1 = 90^0$ (in tangential direction) over the outlet Mach number range $M_{2is}=0.8-1.8$; $\alpha_2=-20^0$.

The tunnel characteristics don't allow one to vary separately the Reynolds number and the Mach number.

The cascade stagger angle is 90°, the spacing of the blades is 45 mm. The pitch-chord ratio is $t/l = 0.45$.

The nominal pressure ahead of the blades is $p_1 = 0.2$ bar and the temperature $T_1 = 60$ C.

By static pressure measurements over the blade we analysed the pressure steps of the spontaneous condensation at different test conditions (varying p_2, T_1).

The width of the blade channels is large enough to make the phenomenon two-dimensional.(Fig. 11).

The experiments are now in course of execution.

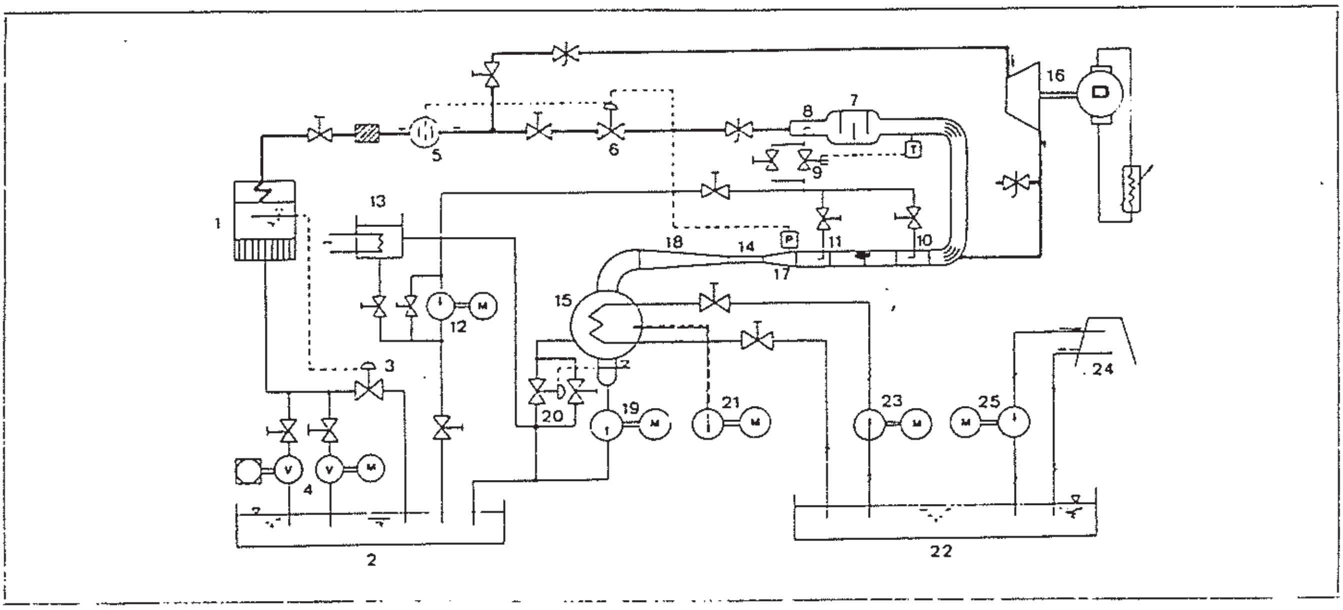


Fig. 1

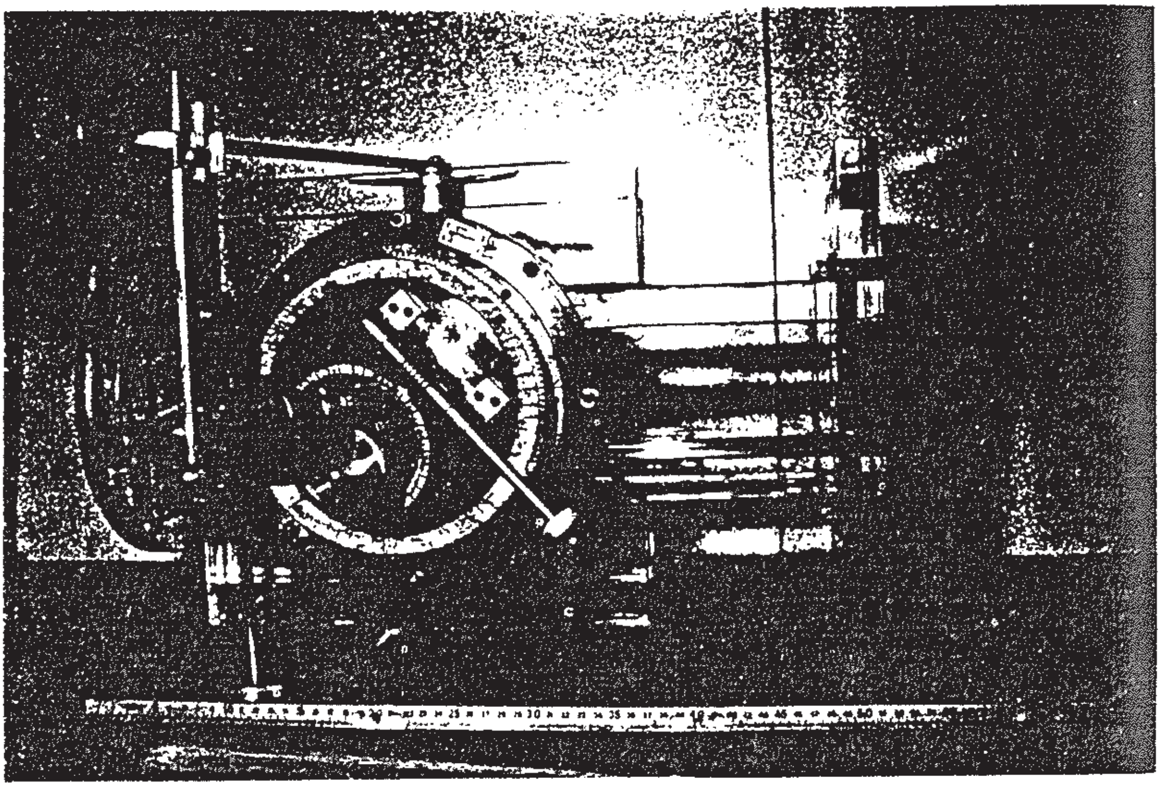
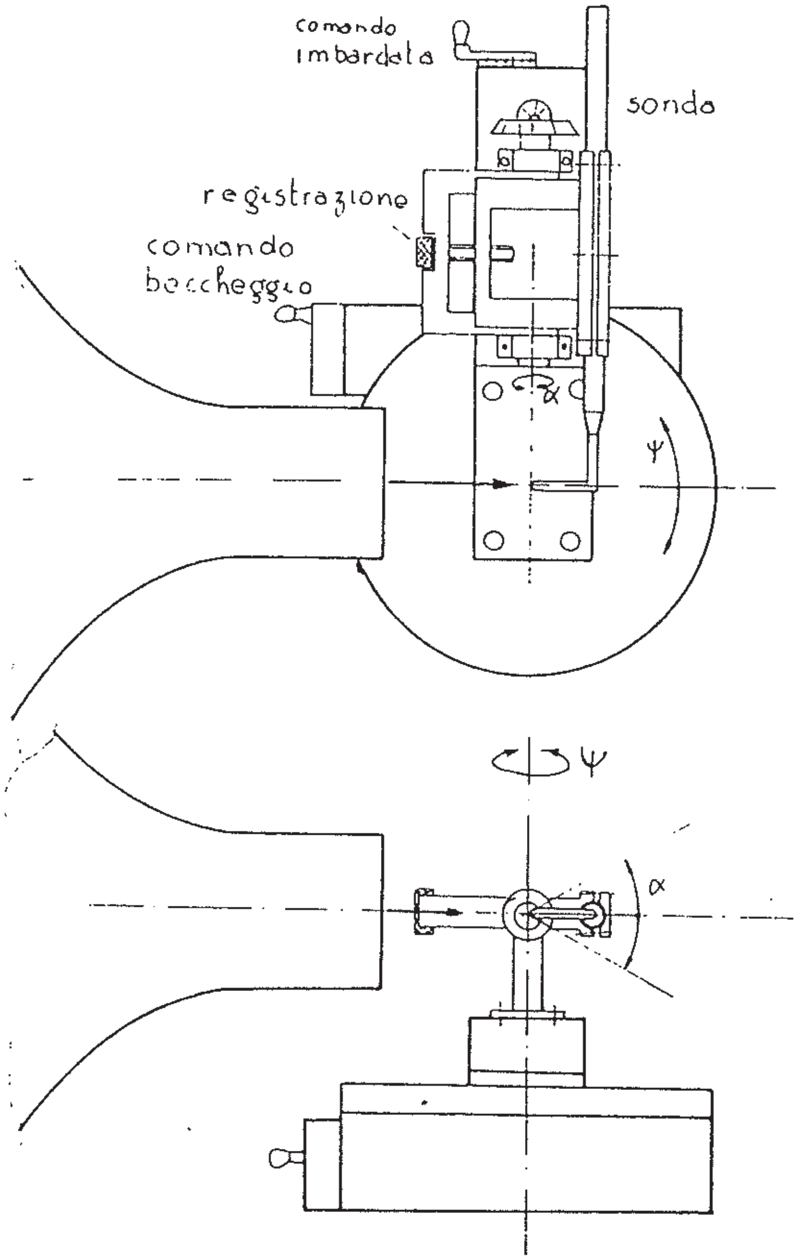


Fig. 2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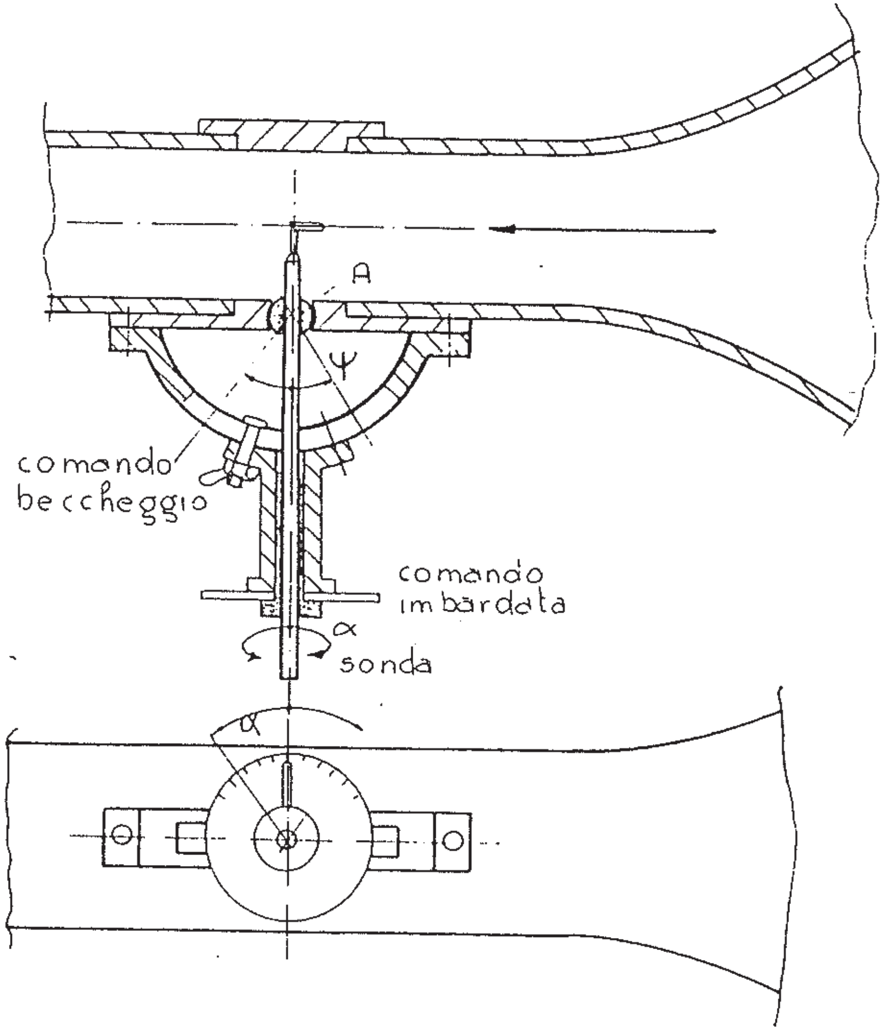
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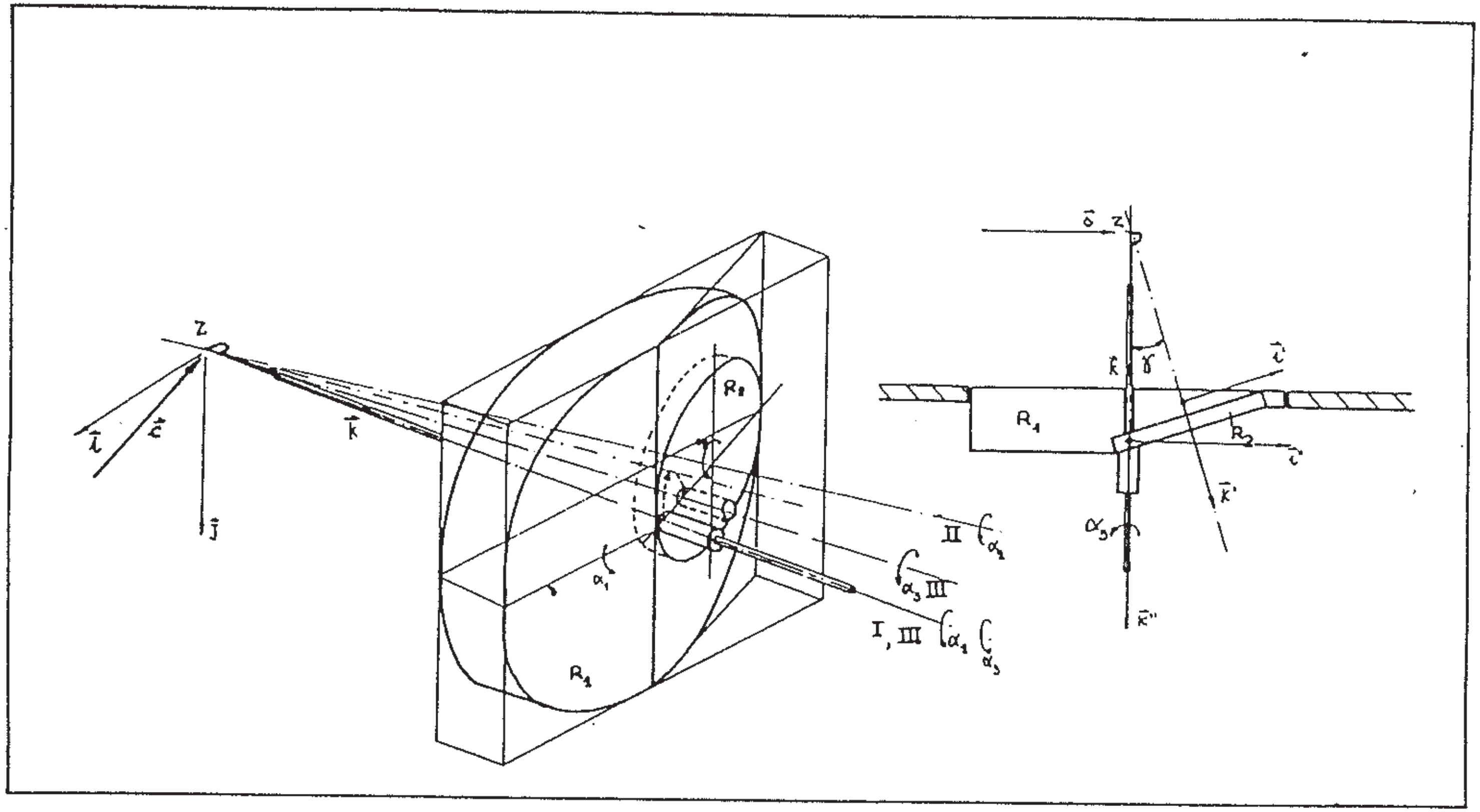
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fig. 4

Fig. 5

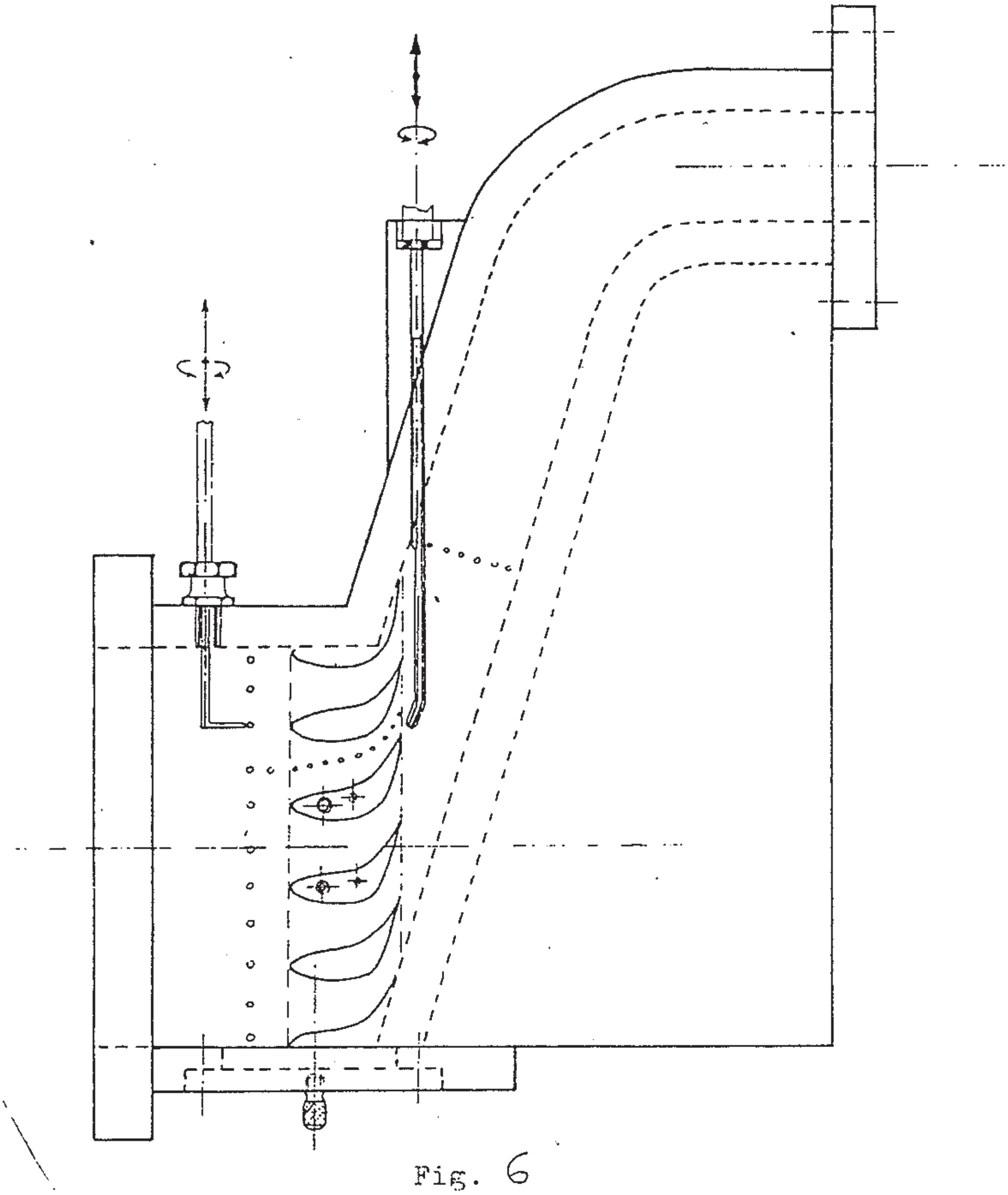

Fig. 6

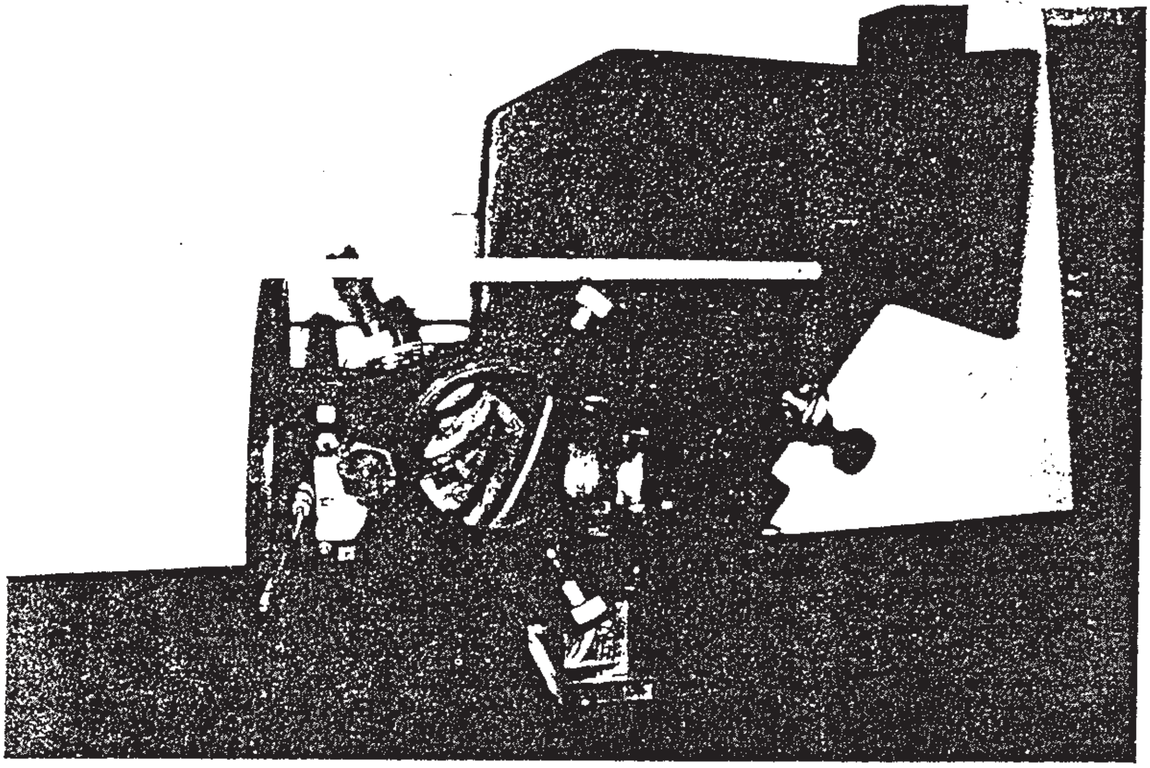

Fig. 7

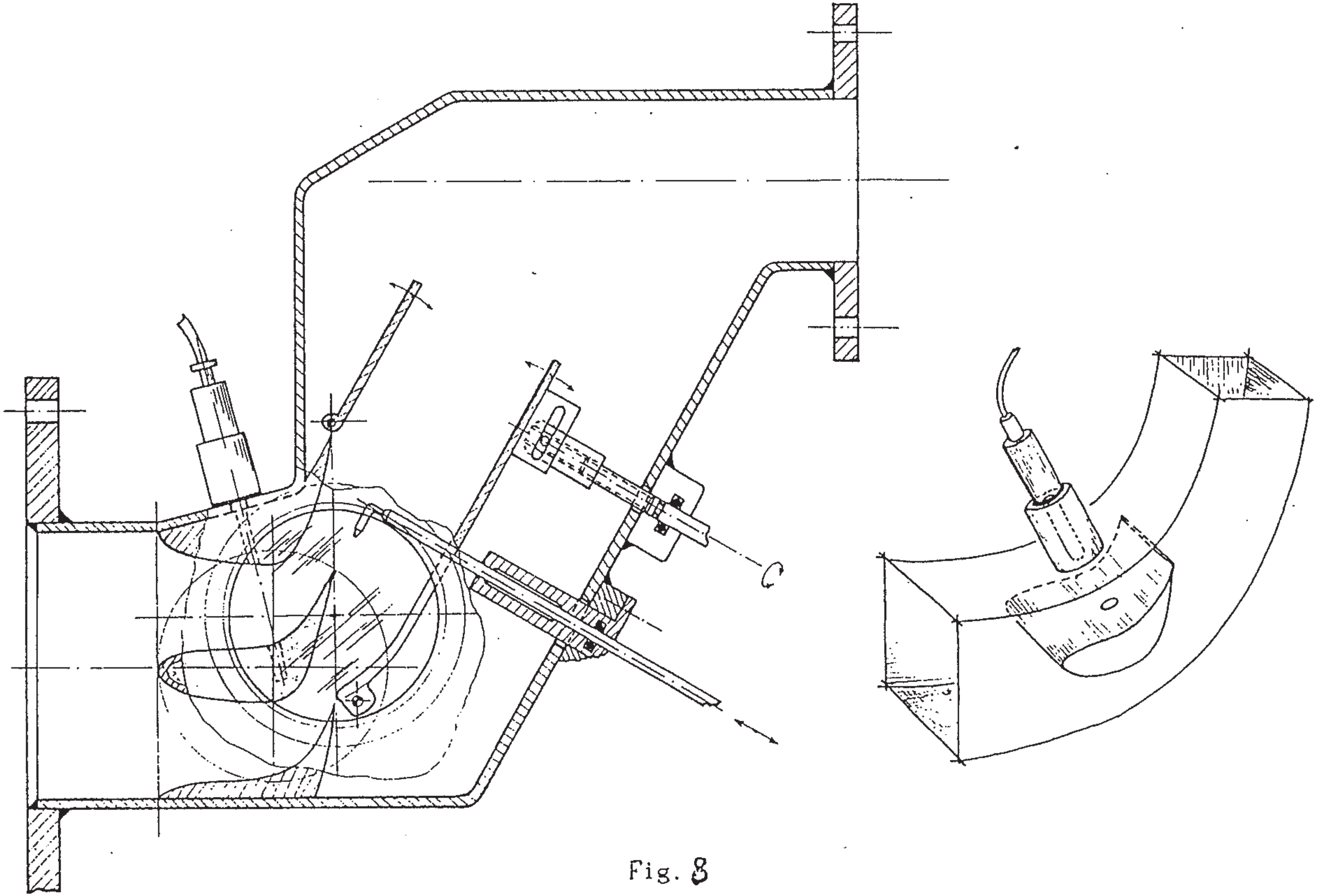

Fig. 8

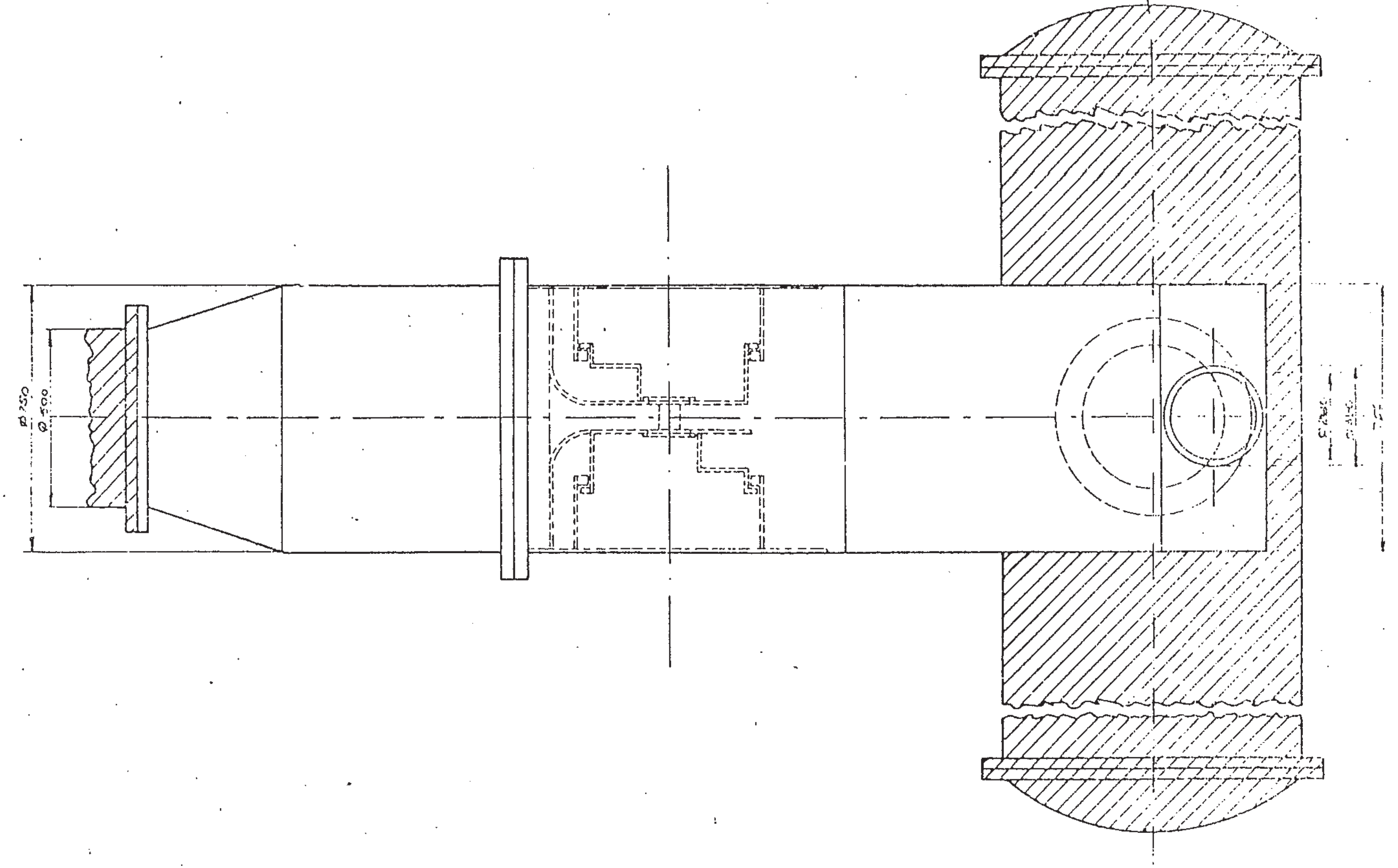

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Fig 9

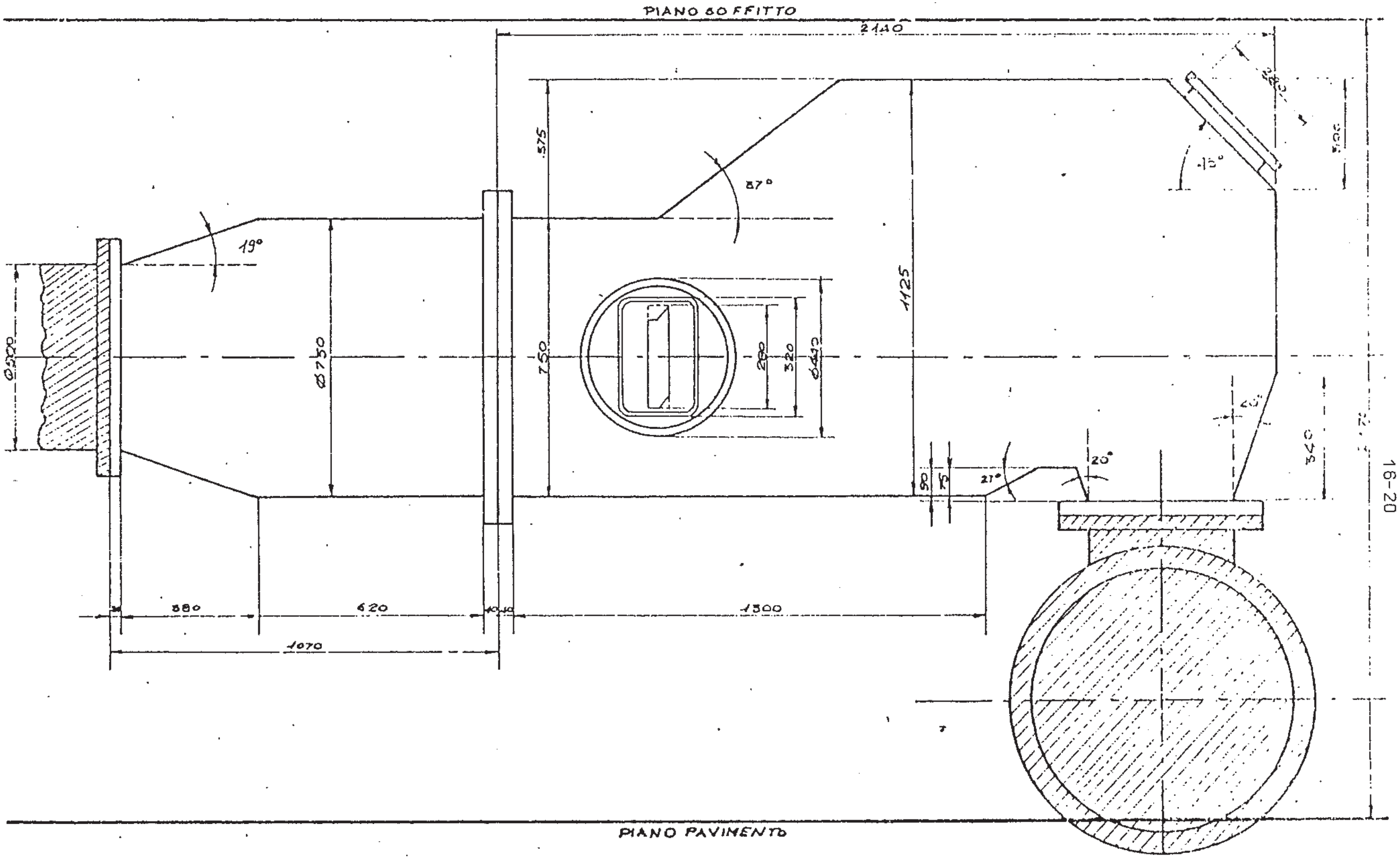
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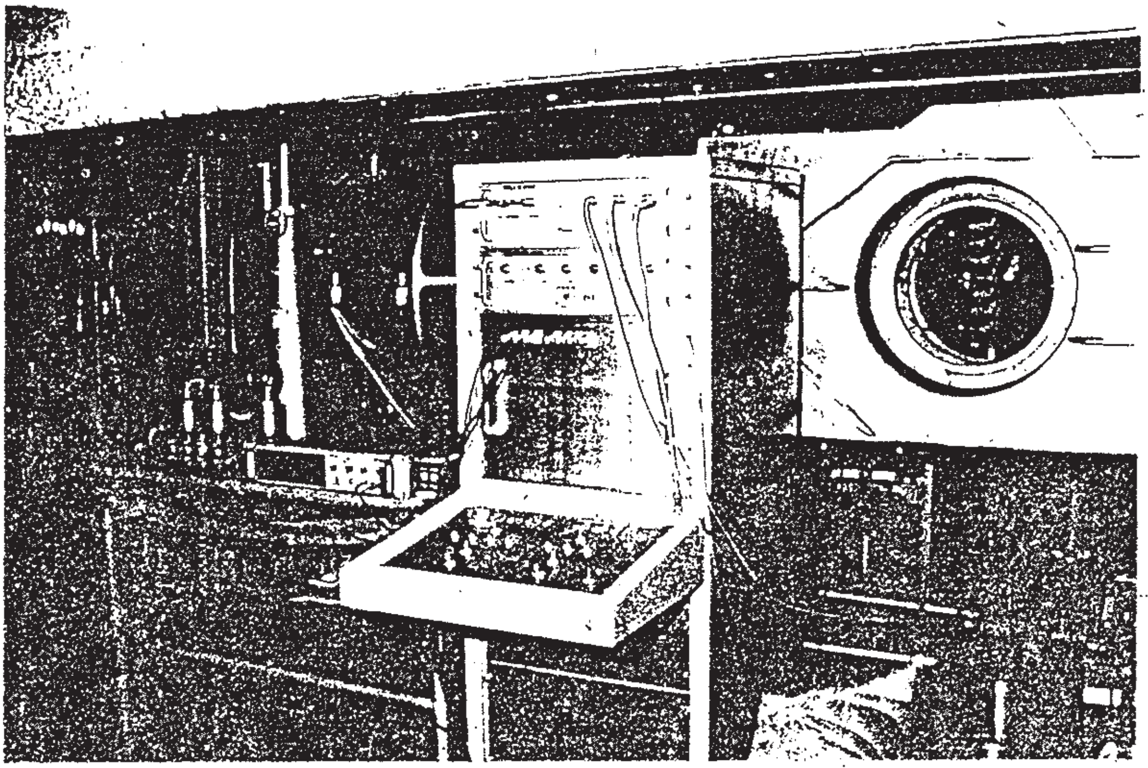
Fig. 10



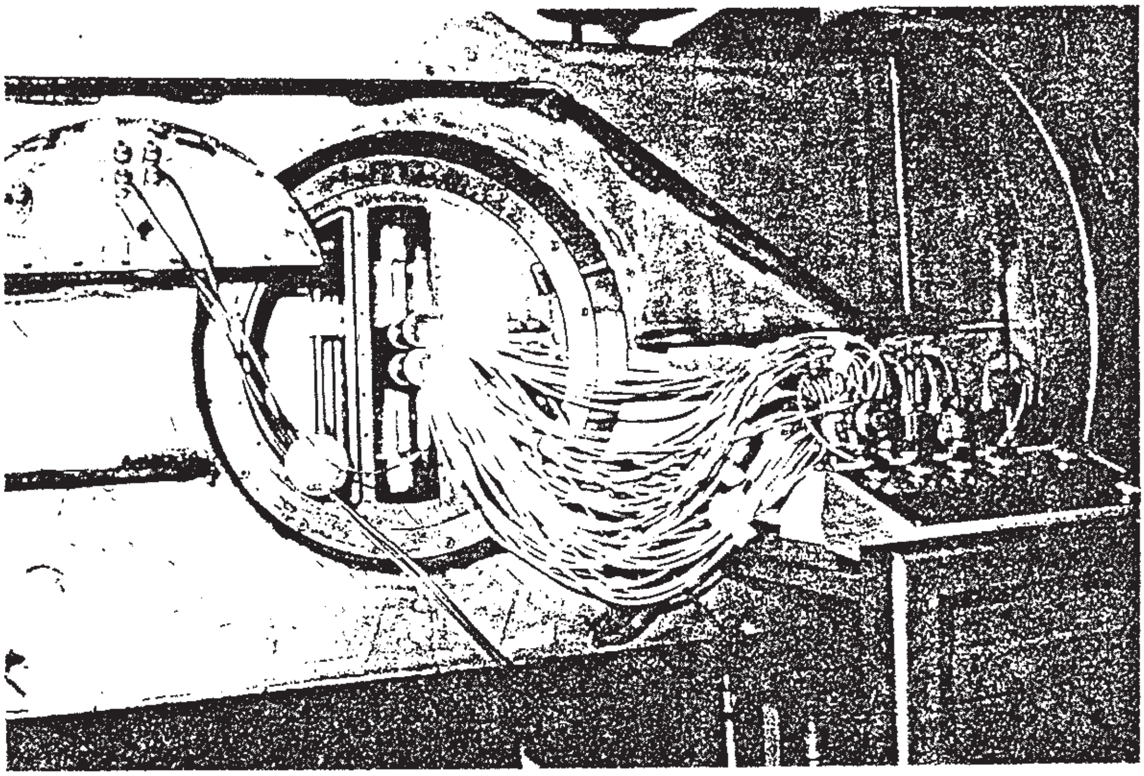


Fig. 11