N.V. NEDERLANDSE GASUNIE
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TURBINE METERS FOR GAS.

by

H. Bellinga

1. Introduction

The history of the turbine meter for gases goes back to the beginning of this century. At that time the size of the wet drum type gasmeters had increased to impractical dimensions and the search for other flow measuring techniques started.

One of the techniques was to measure the velocity of the medium by means of a propellor.

In these early turbine meters the shaft was always vertical in order to decrease bearing load thus minimising friction and wear (fig 1)

Because of the lack of proper materials and bearings these meters were regarded as unreliable and were only used for industrial measurements. However, at that time it is already recognized that these meters were highly sensitive to changes in the flowrate had a good repeatability and a one to ten rangeability. That was in the mid thirties.

Not untill the technology permitted the manufacture of bearings, comparable with the modern bearings the development of the turbine meter as we know it today started.

2. Metrological position.

Prior to dealing with the properties of the turbine meter itself a comparision will be made between the two systems in use for large scale gas flow measurement.

The uncertainity of a well maintained system consisting of an orificeplate, a dp cell, a densitometer and a flow computer, operating with high pressure gas at 70% of its rated capacity is estimated to be 0,7%.

The uncertainity of a system consisting of a turbine meter, calibrated with high pressure gas a densitometer and a flow computer, operating under comparable conditions amounts to 0,45%. Application of the most accurate secondary instrumentation would bring down these figures. For the orifice plate system to 0,6% and for the turbine meter system to 0,35%.

The price for this improvement is the cost of an automatic differential pressure gauge (Dfl 180.000) in the case of the orificeplate.

In the turbine meter system a flow computer with linearisation for the error curve of the turbine meter has to be installed at an extra cost of approximatily Dfl 8000.

The rangeability of the orificeplate system is one to three with the penalty of increased uncertainty at low flowrates. For the turbine meter system the rangeability is one to ten with a constant figure for the uncertainity over the whole range. For the more sophisticated systems for the orifice plate the penalty of increased uncertainity is removed while the rangeability of the turbine meter system increases to one to twenty and in some cases even to one to fourty.

Although the orifice plate is more simple and more robust than a turbine meter it requires more secondary instrumentation. Especially when high accuracy is required the complexity of this secondary instrumentation is such that the simplicity of the primary element is compensated.

In general the upstream lenght for a turbine meter is shorter than for an orifice plate, thus offering the opportunity to build more compact installations.

3. Operating principle.

The axial flow turbine meter is a device that measures the velocity of the medium, flowing through a passage of known area. This passage is formed by the hub of the turbine wheel and the wall of the meter hou- sing. The blades on the turbine wheel are positioned under an angle with the direction of the flow.

The ideal turbine meter has infinitily thin helical blades and is not subject to any kind of friction.

Under the conditions mentioned above it would be possible to calculate the relationship between throughput and speed of the rotor from the dimensions of the meter. That relationship is linear can be represented as:

$$\frac{c.n}{\varnothing} = \frac{f}{\varnothing} = a$$

Where C is a constant determined by the gear train, n the rotor speed, Ø the actual flowrate, f the indicated flowrate and a the coefficient depending on meter geometry.

In the real meter however the blades have a certain thickness, friction occurs obstructions in the flowpath are present.

The result of this is that the relationship between rotorspeed and throughput is not any more lineair.
It can be represented as:

$$\frac{c.n}{\varnothing} = \frac{f}{\varnothing} = a_1 + \frac{a_2}{\varnothing} + \frac{a_3}{\varnothing^2} \quad (1)$$

The values of a_1, a_2, a_3 are determined by curve fitting of the calibration data. The value of a_1 in general differs from the value a.

4. Construction

In general axial flow gas turbine meters consist of a pressure resistant spoolpiece in which the measuring element is inserted, so the static pressure does not influence the dimensions of the measuring element. At the moment the products of most gas turbine meter manufacturers present a strong similarity in aerodynamic design.
(1) Upstream of the measuring element is the flow conditioning zone which consist of a nose cone provided with flow guide vanes at its upstream end. The annular passage between the nose cone and the wall of the spoolpiece in most cases has a constant cross sectional area over a length of about eight times its width.

As the majority of the gas turbine meters are used for custody transfer they have to fulfill a number of requirements. A good survey of these requirements is given in the EEC directives (2). One of these requirements is that the meter should have a mechanical index.

That mechanical index is driven by the turbine wheel by means of a gear train. Part of this gear train is a magnetic coupling that brings the rotation of the drive shaft outside the pressure resistant housing. In addition to the mechanical index most turbine meters have one or two electronic sensors as a second means of read out. In the case of application of a flow computer this is a must. This can be a sensor direct to the turbine wheel or to a disc on the mainshaft or a sensor to a disc on a shaft on the atmosferic side of the magnetic coupling somewhere in the gear train.

A combination of the two offers the possibility of a continuous check of the integrity of the electronic output of the meter.
As the robustness of meters is increasing there is a tendency to rely on a combination of sensor in the gear train solely.

On the gas turbine meters there is one or somethimes two pressure tappings in the same plane, marked Pr, where the relevant pressure must be measured.

The position of this tapping is the result of carefull investigation during the design and testphase of the meter. In the case that for the computation of the mass flowrate through the meter the pressure, measured at another tapping would be used an unknown error is introduced.

As the expansion over a turbine meter is low the point where gas temperature in measured is of little importance; some larger meters do have a thermometer pocket. For the smaller meters it is recommended to measure the temperature as close to the outlet flange as possible.

Another important feature of the construction of a turbine meter is the choice of the bearings of the turbine shaft. This a compromise between low friction and durability.

Initialy the turbine meters were used to measure gas at low pressure. That means driving torque is low, so the bearing friction has to be low to achieve good rangeability. However bearing load was also low. The calibration of the meters was performed with air under atmosferic conditions. Lateron with the increase of the pressure of the gas to be measured the bearing load increased. The calibration with atmosferic air however remained the criterion for acceptance and judgement of the quality, especially the rangeability, of the meters. At the moment the equilibrium between durability under high pressure and rangeability with atmosferic air has been achieved, provided the gas conditions are not too adverse. An additional benefit of this develop- ment is that the rangeability at high pressure is extremely large. Unfortunately only very few users do need that.

With the appearance of the calibration of gas meters under operating conditions the situation is changing. As soon as the high pressure calibration has the same official status as the low pressure air calibration the task for the meter designers will be to find the new equilibrium between durability and rangeability both at high pressure. It will enable the manufacturers to build meters that will be able to withstand even more adverse conditions than the pre- sent meters already do.

5. Characteristics

Deviating from the representation given in chapter 3 in practice the behaviour of the gasmeter is represented by the error in the reading at various flowrates. The reason therefore is that the same way of representation is used in the legal prescriptions and certificates.
The error is defined as:

$$Y = \frac{f - \emptyset}{\emptyset} \cdot 100\%$$

where f is the indicated flowrate and $\emptyset$ the actual flowrate.
The results of a calibration are presented as a table containing the measured data and the following polymonium which represents the best fit curve of the measured data. (fig. 3).

$$Y = A_o + A_1X^m + A_2X^n + A_3^o.$$

Y = error of the meter in %

$X = \frac{\emptyset}{\emptyset_{max}}$

$m = -0,2$

$n = -0,33$

$o = -2,0$

The exponents m, n and o always have the values mentioned above. The values A_o A_1 A_2 A_3 are characteristic for the individual meter.

Much can and has been said about the behaviour of turbine meters under various operating conditions, In the following those properties that are of importance for the practical application will be discussed.

1) Turbine flowmeters always repeat very well, in the order of 0,1 per cent ($2\sigma = 0,1\%$) or better as long as the properties of the medium do not change too much. The lowest flow rate for which this statement is valid depends on the static pressure and decreases with increasing pressure.

2) For the majority of the modern meters it is possible that the calibration curve with atmosferic air and with gas at elevated pressure are both within the legal tolerance limits (fig. 4). As the shift of the error curve under influence of the density is individual a calibration under conditions approaching the operating conditions is

necessary to get the full profit from the good repeatability. In this case it may be necessary to adjust the meter in such a way that the air curve lays outside the tolerance limits. (fig. 5).

3) With increasing density of the gas the linearity at low flowrates improves resulting in an increased rangeability (3). For larger meters a rangeability of one to fourty is no exception. (fig. 6). For the smaller meters this figure is one to thirty. (fig. 7)

4) When operated with gas at high pressure (40 bar and higher) bearing friction only influences the error curve at very low flowrates.

6) Installation and operating conditions.

The general statement can be made that disturbances in the gasflow upstream of a turbine meter should be avoided. Anything other than a straight pipe must regarded as a source for disturbances. Disturbing elements can be devided into two groupes. High level disturbances and low level disturbances. The first catagory is generated by throttling elements with over critical expansion. The second catagory is generated by piping configurations as bends, Tee's and headers in which the velocities are of the same order as the entrance velocity of the meter.

In the case that high level disturbances are present the application of a modified Sprenkle straightening (fig. 8) vane installed as indicated in fig 9 will make sure that the error of the meter will not deviate by more than 0,2% from the error in an undisturbed flow (4). The high pressure drop of this type of flow straightener can be accepted because of the presence of the throtting element with the overcritical expansion.

When low level disturbances occur the application of a flow straightener with a lower pressure drop will be sufficient. The tube bundle straightening vane is the most wellknown type (fig. 10). To give an impression of the influence of one of the most severe low level disturbances, two bends not in one plane, the following. This disturbance ten pipe diameters upstream of a turbine meter causes a shift in error between 0,1% and 0,8%. These figures have been measured in a test with 5 meters of different construction.

The more vanes the internal flowstraightener of the meters has, the lower is the influence of the disturbance.

More difficult to quantify is the influence of flow pulsations so only some qualitative remarks will be made.

Pulsating flow will not influence the indication of the meter as long as its frequency is low in respect to the time constant of the turbine wheel. When the frequency is such that there is an influence, that influence is smaller as the amplitude is smaller with respect to the avarage flow rate. More detailed and quantified information on this subject is given by Dijstelbergen. (5).

Recent developments

One of the most recent innovations in turbine meter construction is the auto adjust meter manufactured by Rockwell. In this meter downstream of the main turbine wheel a second free running turbine wheel with only a very small blade angle is installed. Because of the friction of the meter the flow downstream of the main rotor is slightly rotating, proportional to the friction of the mainrotor. This rotation will influence the rotation of the second turbine wheel (sensor rotor) proportional to the slip of the main rotor. So the slip of the main rotor is measured and is corrected for electronically.

In this meter errors caused by changes in the mechanical friction are corrected.

Changes of the error caused by an increased inlet velocity at the turbine wheel because of blockage of the flowpath will not or only partly detected. A more detailed description is presented by the manufacturer (6).
Another design which mechanically very much resembles the Auto Adjust meter is a prototype of a direct massflow meter.

NOT ACCURAT

It consists of a normal turbine wheel which is coupled to a (constant torque brake.) Downstream of the turbine wheel is a free running sensor wheel with straight vanes that measures the swirl of the gasflow downstream of the turbine wheel. Both rotors have an electronic readout. It can be derived that the mass flow through the meter is:

$$q_m = K.\frac{\Omega}{\omega}.$$

in which q_m = kg/sec.
K = a constant.
Ω = speed of the turbine wheel.
ω = speed of the sensor wheel.

INFERIOR METER TO STD. TYPE

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Ripple Road, Barking, Essex, England.

2 a Recommandation Internationale No 6: PRESCRIPTIONS GENERALES pour les COMPTEURS de VOLUME de GAZ.
Bureau International de Metrologie Légale, Paris.

2 b Recommandation Internationale No 32: COMPTEURS de VOLUME de GAZ a PISTONS ROTATIFS.
COMPTEURS de VOLUME de GAZ a TURBINE.
Bureau International de Metrologie Légale, Paris.

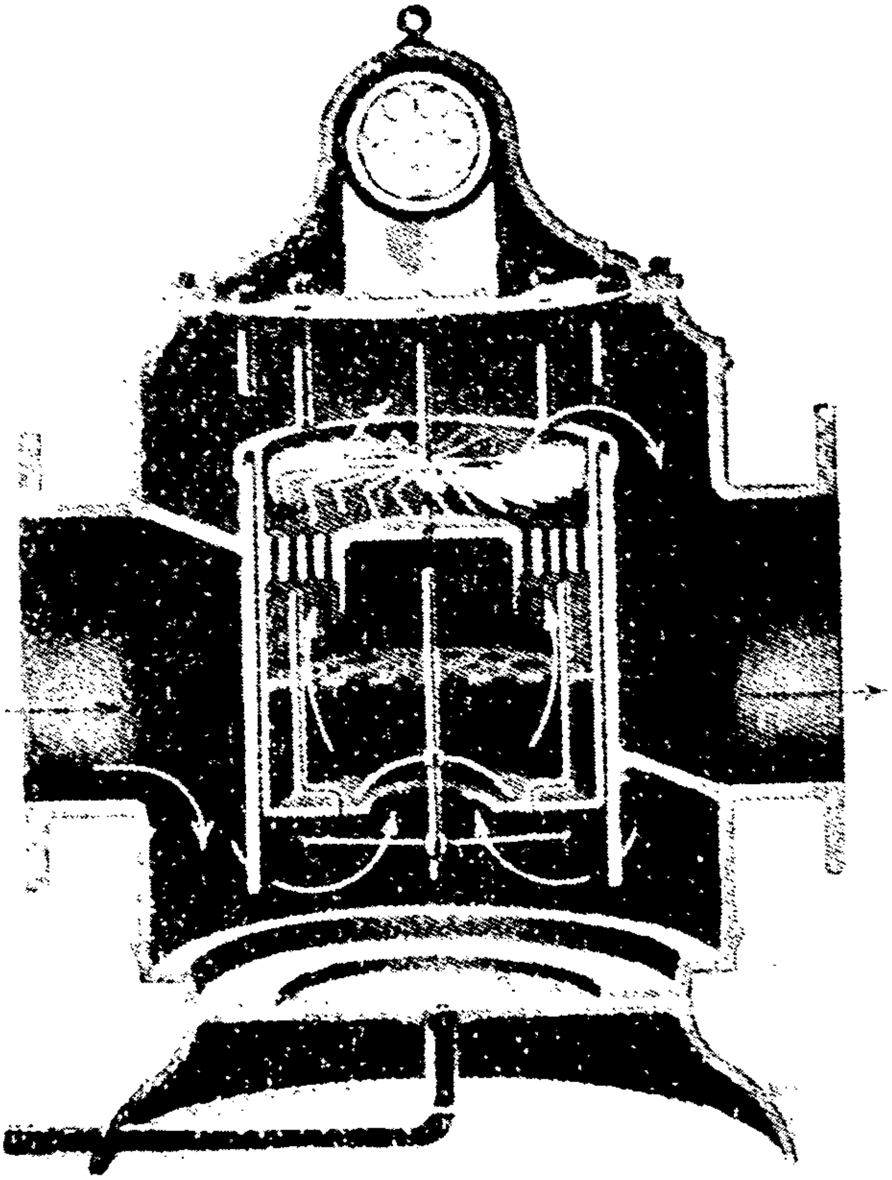
3) Enjen E., Untersuchungen über die Meszeigenschaften von Hochdruckgaszählern.
II Teilbericht: Messungen an Schraubenradgaszählern.
1964 Gas und Wasserfach. 105. Jahrg Heft 43.
seite 1192 - 1200 23 oktober 1964.

4) Bellinga H. and Stronk H.B., The practical application of flow straighteners with turbine flowmeters for gas. Paper BFL 242. Presented at the IMEKO VII Congress. London May 10 - 11, 1976.

5) Dijstelbergen H.H., Dynamic response of turbine flowmeters.
Instrument Review 241 - 4. June 1966.

6) The Auto Adjust Turbo-meter: Development and Theory.
Gas Line Vol 6 number 2 1980.
publ: Municipal and Utility Division
Rockwell International
Pittsburgh USA.

FIG. 1



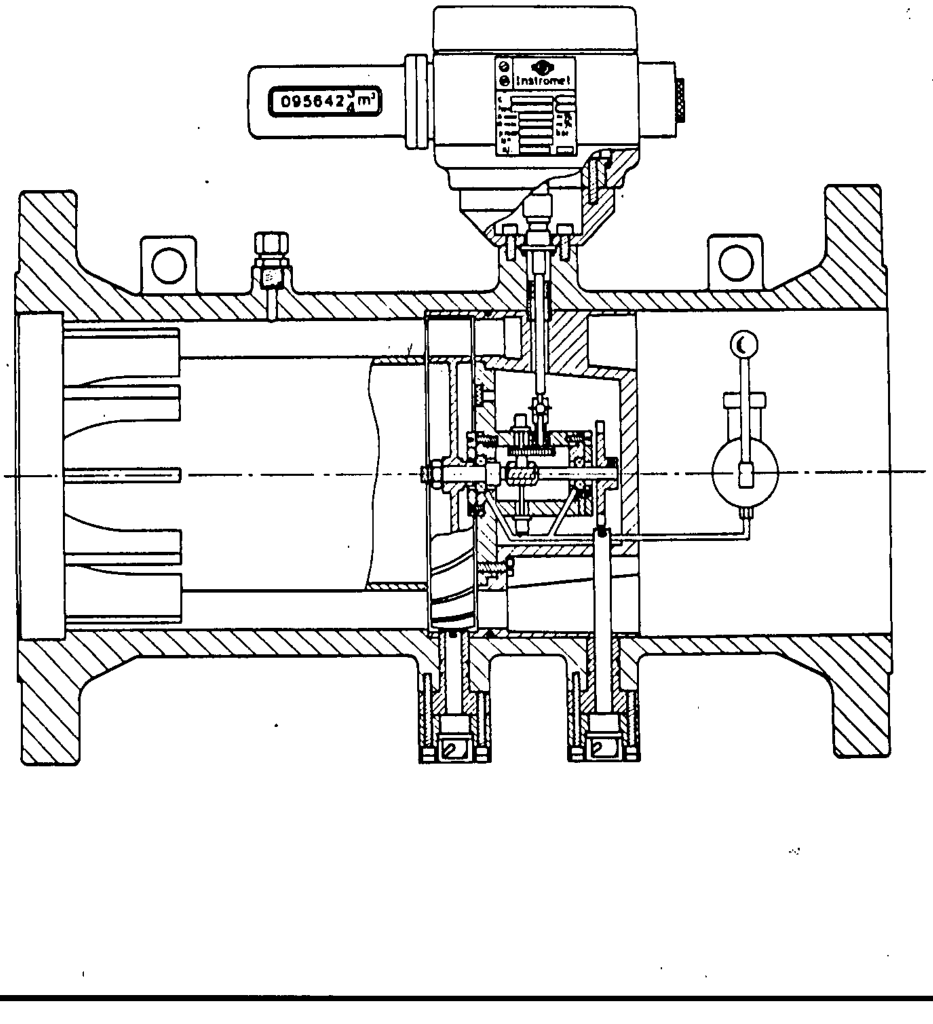


FIG. 2

DIENST VAN HET IJKWEZEN

60cm
METER

Certificaat

29110131

Soort meter : Turbinegasmeter

Fabrikaat : Instromet

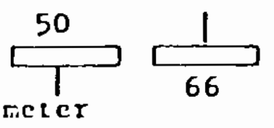
Nummer + jaartal : 27452 – 1975

G- waarde, type ∅: G 16000, SM-RI-D 600 ∅

Qmax/Qmin : 25000 / 1300 m^3/h

pmax : 80 bar

justeerwielen



debiet m^3/h	fout % 62 bar	fout % bar
20400	+0,1	
20160	+0,2	
15640	+0,3	
13200	+0,4	
9870	+0,4	
8120	+0,4	
6040	+0,4	
4040	+0,3	
2600	+0,2	
1270	+0,2	

polynoom

$Y = A_0 + A_1X^m + A_2X^n + A_3X^o$

waarin:

Y = fout van de meter in %

$X = \frac{Q}{Q_{max}}$ in m^3/h

$m = -0,2$
$n = -0,33$
$o = -2,0$
$A_0 = -9,3271$
$A_1 = 19,7645$
$A_2 = -10,3709$
$A_3 = 0,0034$

fout = $\frac{\text{aanwijzing meter – doorgestroomd volume}}{\text{doorgestroomd volume}} \times 100\ \%$ $\left(Y = \frac{\ell - \phi}{\phi} \cdot 100\%\right)$

druk bij P_r is bij de bepaling van de fout maatgevend gesteld

testmedium : gas 58 kg/m^3

bijzonderheden : plaats Westerbork , datum 30 maart 1981

datum onderzoek : 30 maart 1981

eindstand telwerk : 00019157 x 10 m^3

aantal ijkmerken : 11 stuks

opschrift :
vol.massa gas 0,5 – 65 kg/m^3

1 m^3 ≙ 90,0124 imp.

J.P.A. van Meulen
Afd. Hoeveelheidsmeting Gassen

Fig 3

FIG. 5

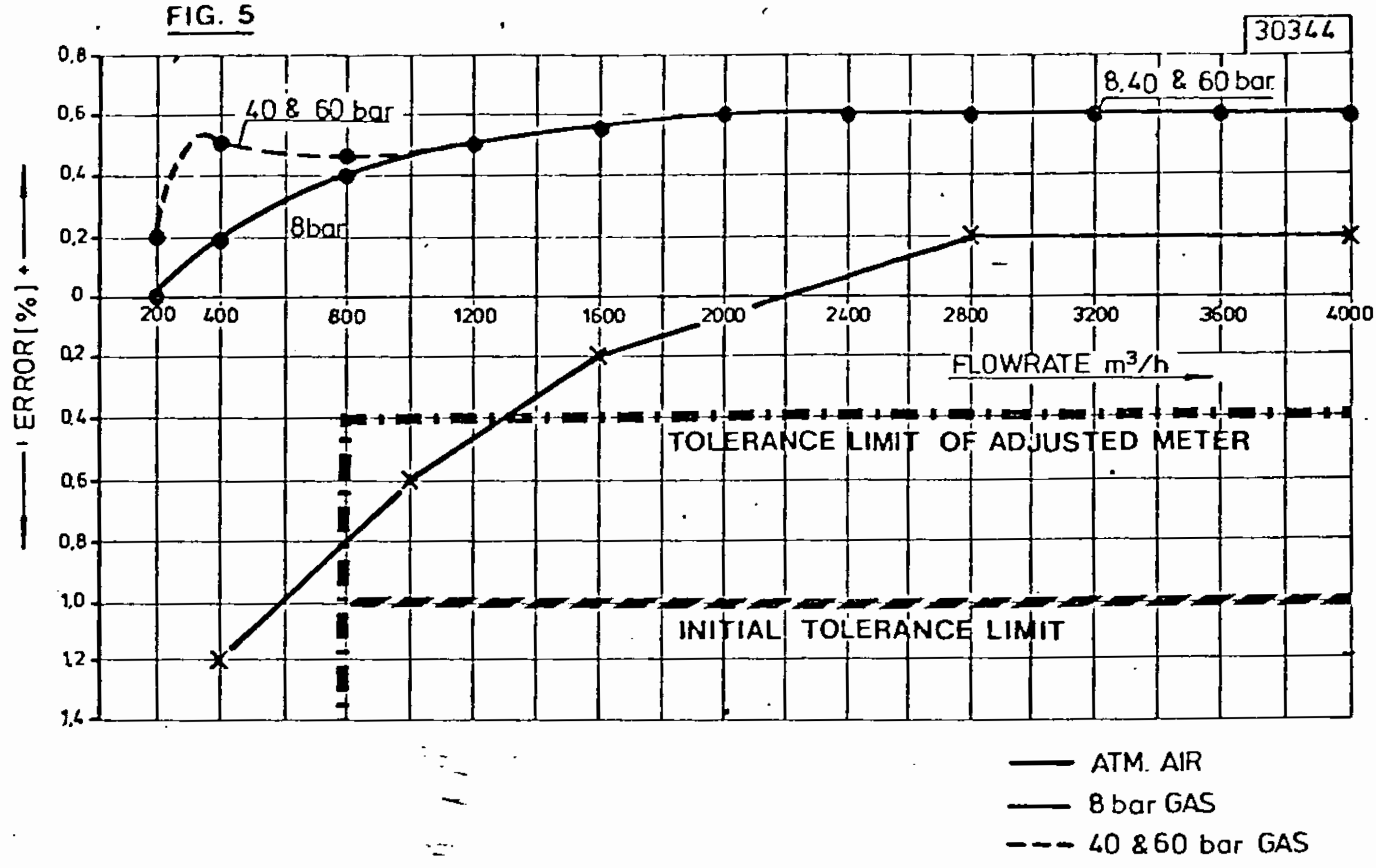
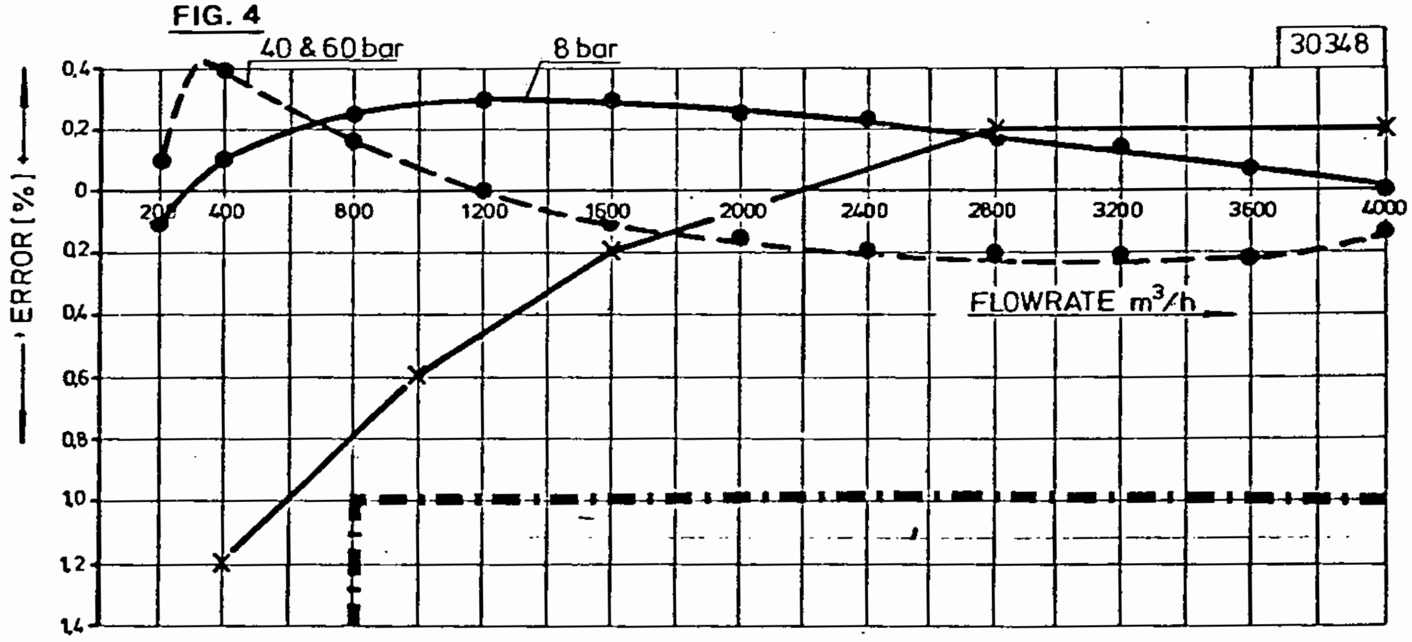


FIG. 4



CALIBRATION CURVE OF TWO TURBINE FLOWMETERS.

—— ATM. AIR
—— 8 bar GAS
– – – 40 & 60 bar GAS

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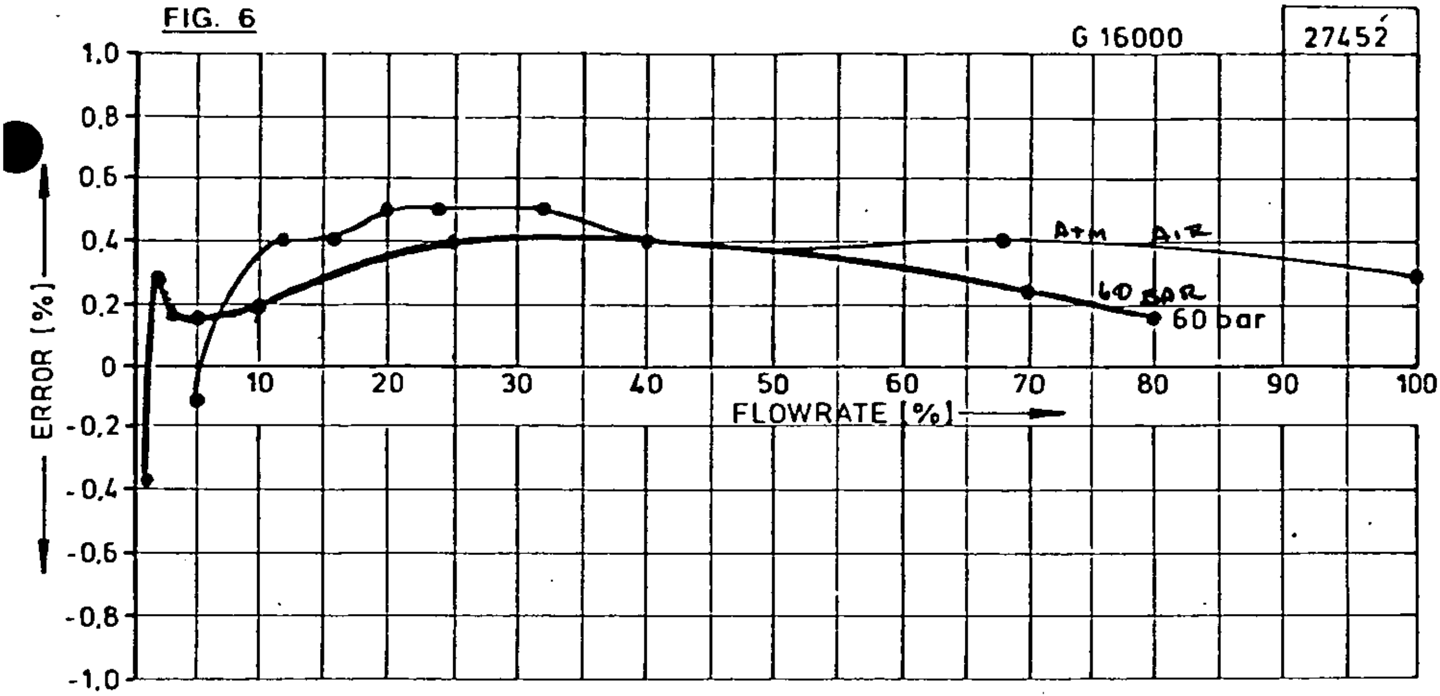
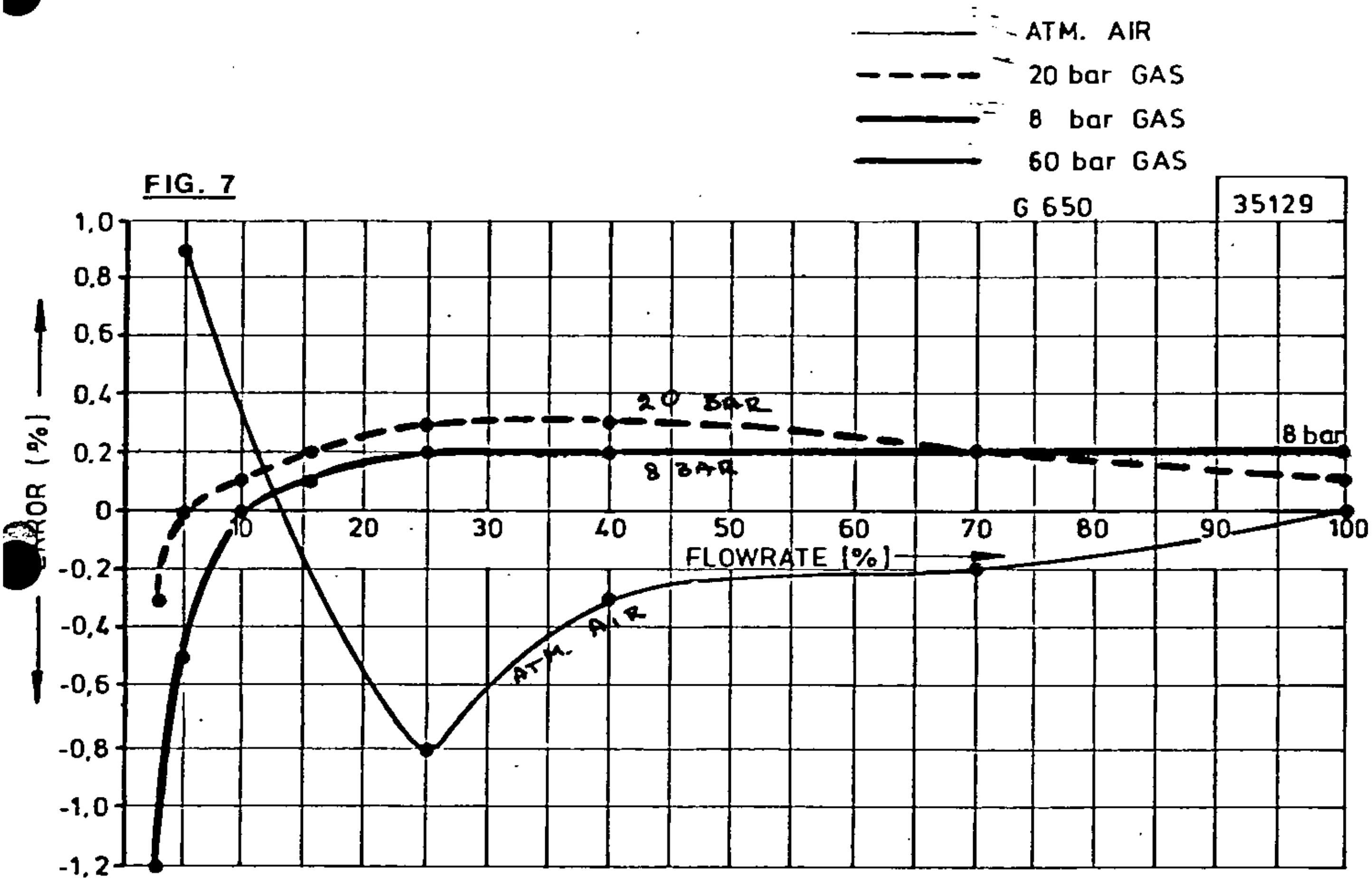
FIG. 6

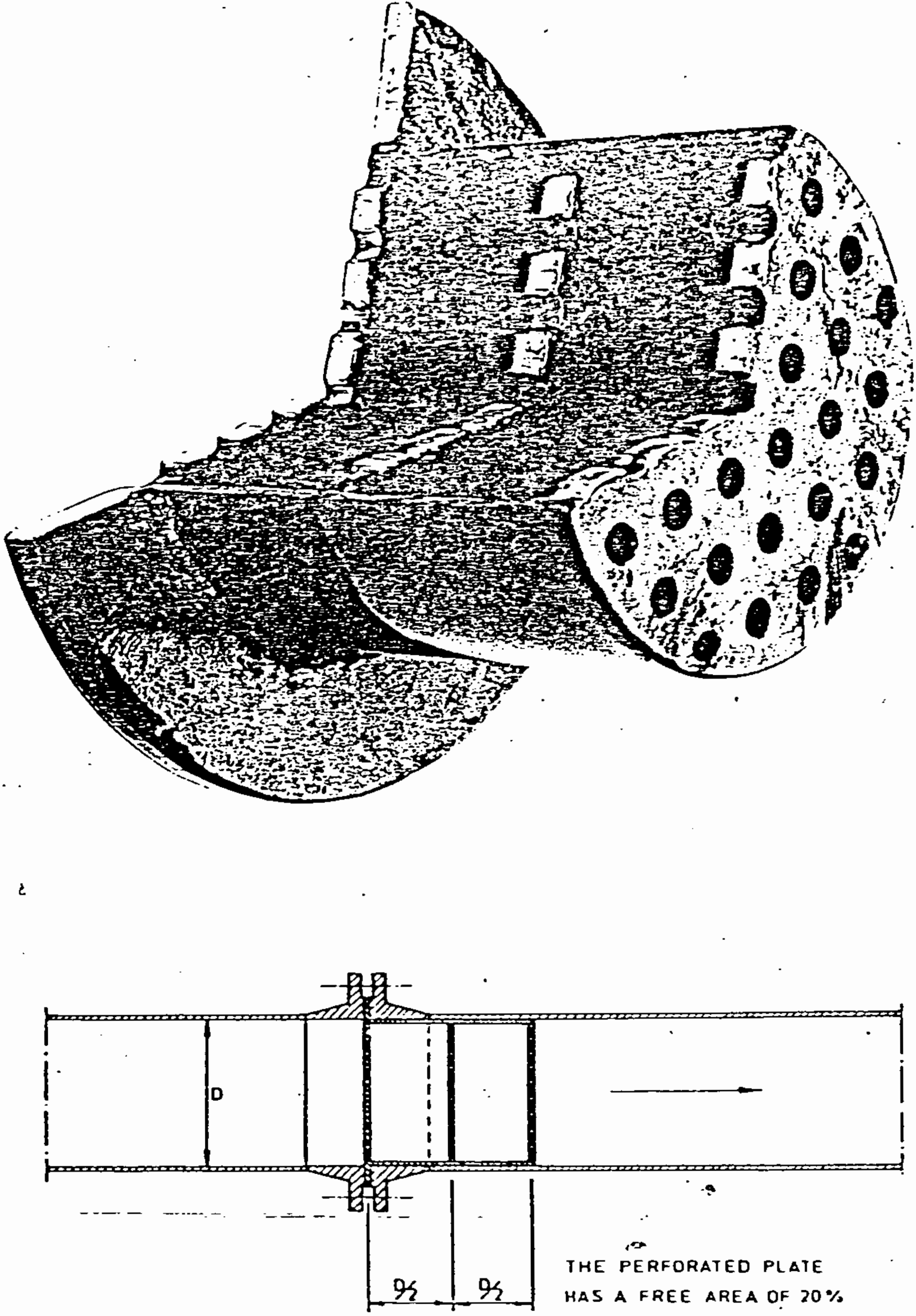


60cm

FIG. 7

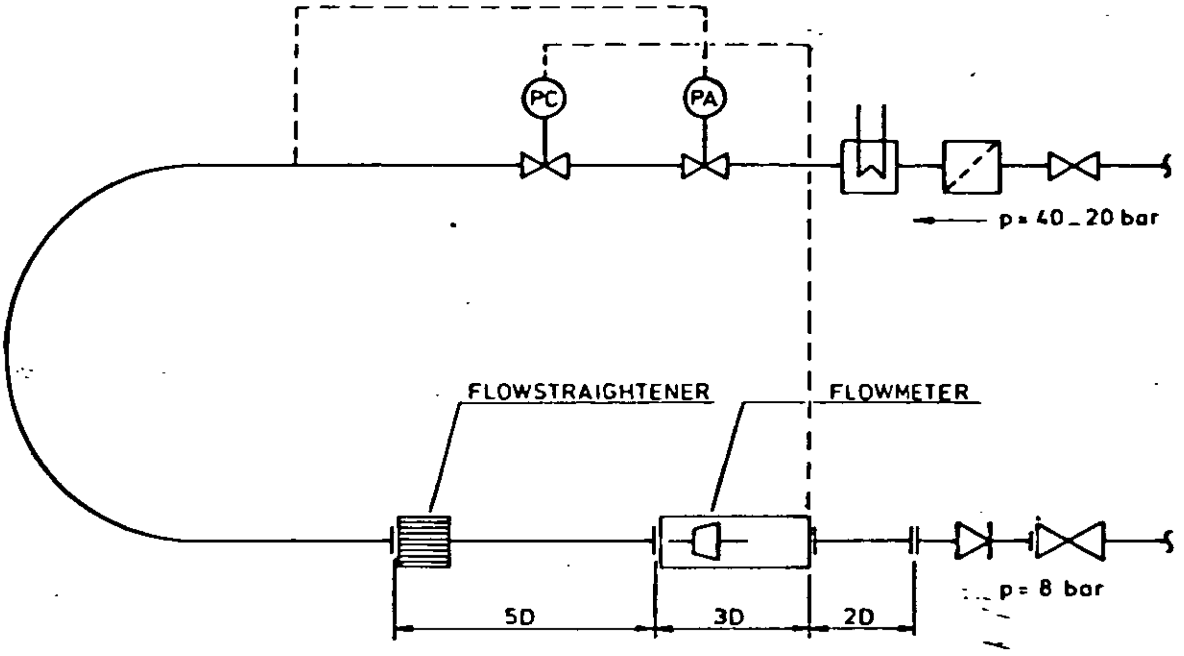


CALIBRATION CURVE OF TWO TURBINE FLOWMETERS



THE PERFORATED PLATE
HAS A FREE AREA OF 20%

FIG. 8



GAS PRESSURE REGULATING AND METERING UNIT

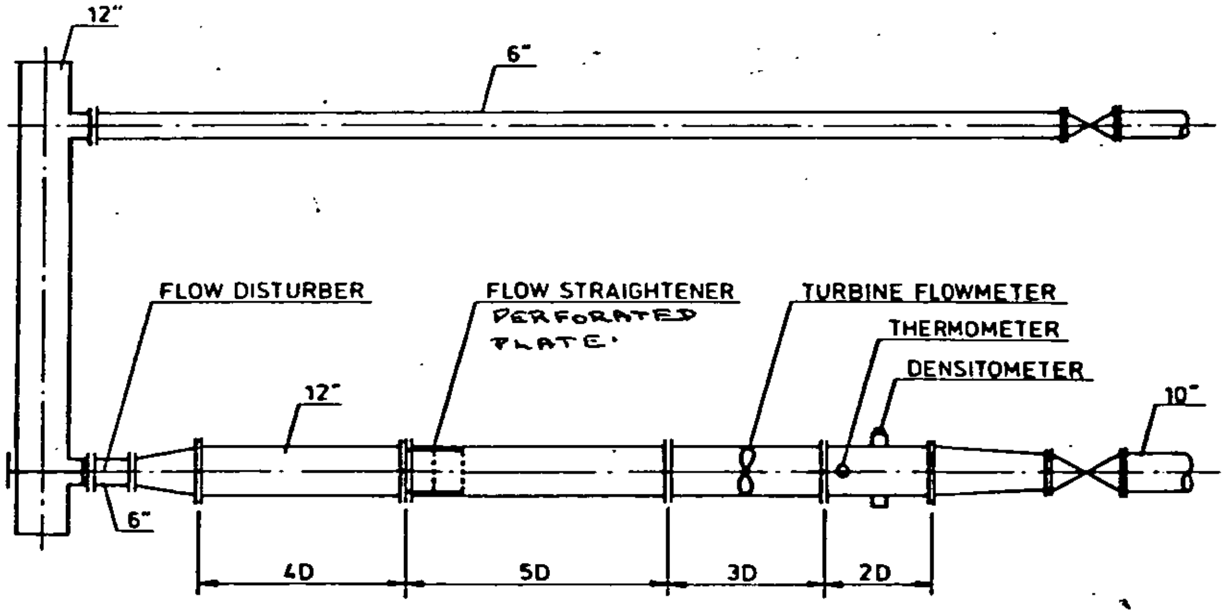


FIG. 9

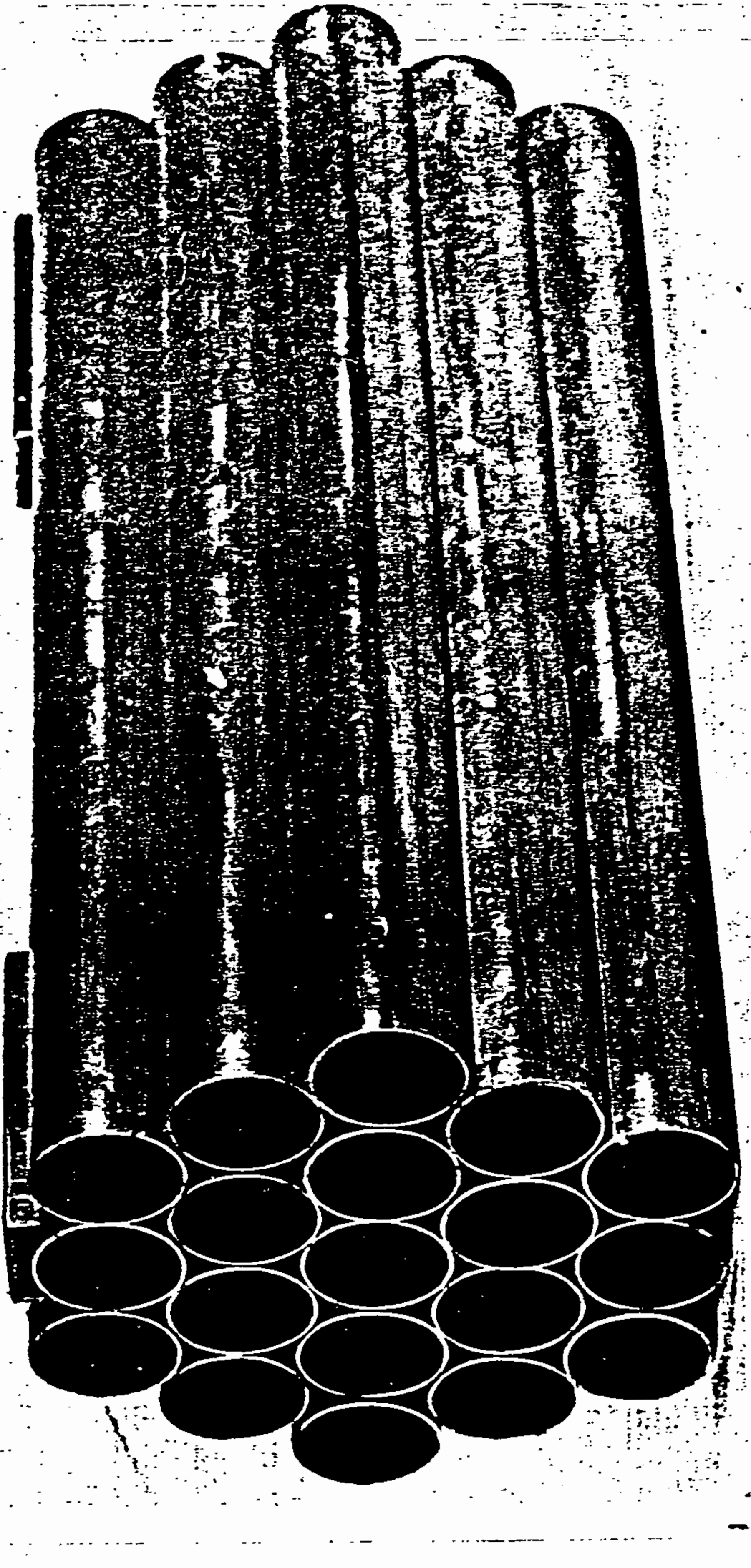
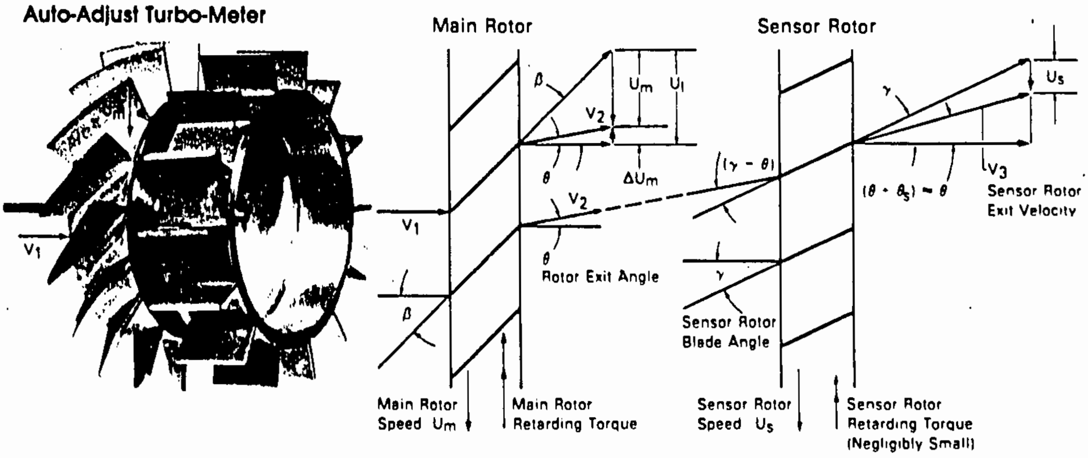


FIG. 10

FIG. 11



Defined Auto-Adjust Turbo-Meter Accuracy $\propto \dfrac{U_m - U_s}{U_l} = \left(\dfrac{U_m}{U_l}\right) - \left(\dfrac{U_s}{U_l}\right)$

$$= \left(1 - \frac{\text{Tan}\,\theta}{\text{Tan}\,\beta}\right) - \left(\frac{\text{Tan}\,\gamma}{\text{Tan}\,\beta} - \frac{\text{Tan}\,\theta}{\text{Tan}\,\beta}\right)$$

$$= \left(1 - \frac{\text{Tan}\,\gamma}{\text{Tan}\,\beta}\right) = \text{Constant}$$

FIG. 12

FIG. 12