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A NEW METHOD AND DEVICE FOR GAS FLOW-METER CALIBRATION ON AIR AT HIGH VELOCITIES

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Abstract: *The work presents the theoretical and experimental research on a new method, more precise and more advantageous than the ones already known, for the gas flow-meter calibration on air for however high flow-rates or flow velocities and without pressure loss. The research also deals with a patented device, which can be attained under the best technical and economical conditions even for the largest sizes. This is why we have made both the method and the device available for all interested companies and metrological laboratories.*

The theoretical research refers to the permanent, with axial symmetry flow of a compressible ideal or viscous fluid, in its isothermic or adiabatic evolution towards the entrance of a circular pipe.

The movement is obtained by the numerical integration of Euler or Navier-Stokes system of partial differential equations, completed with the equations of thermodynamic evolution for compressible fluids. We introduce the stream function and eliminate the pressure and density functions with unknown values along the boundary of the domain occupied by the fluid.

From experimental point of view, the used method consists in the gas exhaustion out of a large enough chamber with the following known characteristics: absolute pressure, temperature and humidity of the air and its recycling through a pipe.

These characteristics have been stabilised after a certain time interval and measured with good accuracy. We have also measured the relative pressure inside the pipe whose diameter is constant and known, and on which the calibration flow-meter is mounted under admitted metrological conditions.

What follows is the measuring in the pipe-entrance region of the relative static pressure of exhausted gas, the velocity distribution being uniform in the first section.

The device for the gas flow-meters calibration on air for large diameters and high velocities is made in entrance section, followed by an intermediary pipe section on which the calibration flow-meters are mounted, and at the end of this pipe there is an exhaustion blower with a valve at its outlet, for the adjustment of the exhausted flow-rate.

The greatest advantage of this method is that it can be applied under any atmospherical conditions and that it is not necessary to ensure the rigorous temperature conditions ($20 \pm 0{,}5^0$ C), which are required in the metrological laboratories and which are standardly imposed but exemplary. The only requirement is the ensuring of a certain permanence of the working gas parameters, but only during each measurement session.

Keywords: *Flow-meter, Gas Flow-meter, Flow-meter Calibration, Metrological Calibration.*

1 INTRODUCTION

The precise calibration of liquid flow-meters is ensured in temperature large limits by weighting method [1] of a liquid volume, delivered in also precisely measured time by the permanent motion of the fluid through the flow-meter mounted on the hydraulic circuit.

Since the great majority of flow-meters measures the volumetric flow-rate, it is very important to know the variation with the temperature of liquid density and flowing sections of the calibrated flow-meter, because the weighting balances offer a good accuracy about 1‰ in the large temperature limits of –10 to +40 ^{0}C and the stop-watches may be maintained at a convenient temperature.

However, the construction vices of the calibration stands on water (for example the other of RETROM-Pascani built in Romania after the model of the firm Foxboro), consisting in flow-rate oscillations due to the air cushions and cavitation phenomenon in hydraulic circuit [2][3][4], requires not only the lengthen of the measuring time, but makes almost impossible the flow-rate reading on the scale of flow-meter for calibration.

1.1 Calibration of gas flow- meters

For the calibration of gas flow-meters at low flow-rates and consequently small velocities or pipe diameters, one utilises the gas-tanks their cylindrical bells require a more precise geometry and also a constant temperature in laboratory rooms (20 ± 0.5 ^{0}C) and to obtain the greater velocities it is necessary to make their heavier.

However, constructive and operating undefeated difficulties have made that the bigger carried gas-tanks have the bell diameter of 3.6 m and pipe diameter of 100 mm and for the bigster with 5.5 and 8 m gas-tank diameter and with 200 and 400 mm pipe diameter respectively, it happened to have serious metrological difficulties.

For the greater velocities one extended the results obtained by means of gas-tanks of the easy carried diaphragms with sharp edge, but whose discharge coefficients run about 0.6, due to the flowing section contraction phenomenon, tending to an asymptotic value by increasing of the velocity and also of Reynolds number, that limits the usefulness of diaphragms to smaller pipe diameters (D > 50 mm) or to lower velocities [5].

In this way after 1930 on the basis of a impressive number and difficult laboratory measurements, the Germans have elaborated the VDE-Standard (1932) for measuring of flow-rate with diaphragm, which afterwards have been always improved, because the simple adopted for calculus formula was suitable for the liquids, to which one brought complicate empirically determined corrections, concerning the compressibility of the fluid, upstream velocity effect and the different flowing section contraction [5]. These values depends evidently more of the position of upstream and downstream pressure intakes, which have taken arbitrary and not scientifically in any technological variants, besides to reminds on uncertainty introduced by the place and the manner in which one measures the static temperature for the gases, what makes that the measuring accuracy of the diaphragm device to be recognised by the metrological laboratories in the limits of 2 to 3 %. As well we shall not discuss on the exaggerated energy consumption of this proceeding, prohibitive today.

After any years the attention of the researchers in the field of the flow-meter gauge for high velocities was drawn by other devices based of the same principle of flowing section contraction as:

- the **standardised nozzle** as geometry [5] with the discharge coefficient about 1, yet variable with the Reynolds number, offering a more complicated construction, but with smaller energy losses. This stayed on the basis of so called *sonic nozzle* [7] proposed for measuring of the gas high flow-rates, but with many meteorological uncertainties near the energy exaggerated consumption,
- the **Ventura tube** [6] more favourable concerning the energy consumption, but much more complicated to carry out, and in the last period,
- the **VORTEX flow-meter** with a reduced energy consumption, but according to our laboratory experiences [8][9][10] it deceived the researcher expectations concerning the fact, that the frequency of the alternative vortex separation was not depending of the fluid viscosity.

1.2 The method of the *constant velocity section* (CVS)

As a result of a varied laboratory activity carried on a long period concerning the testing on water and air of different liquid and gas flow-meters and the construction of their stands for calibration and scale conversion for other liquids or gases [3][11][12][13], an idea has occurred to us to built an *flow-meter gauge* [14], more precise than the one's existent by its constructive simplicity and the reduced number of physical parameters, measured in static and any environmental conditions, which in the same time not introduces neither energy loss and requires a very simple formula for the calculation of the flow-rate.

Using this device we could verify with an accuracy under 1% the indications of the standardised diaphragm device, installed in the correct metrological conditions.

Encouraged by these results we had the idea to utilise this device with the modern sensors and electronic interface for calculation and contorization of flow-rate available in the current manufacture of Trade Company AEROFINA in Bucharest – Romania, to offer on the market a very precise flow-meter gauge, easy to carry out and cheap, for the use in any environmental conditions.

Since the **constant velocity section**, which is situated at the entrance of the fluid in any pipe-line and on which one bases the patented method is just empirically unanimously known by all specialists in fluid mechanics under so called phenomenon of the stabilisation length of the fluid flow at the entrance in a pipe-line, in this paper we will present at first a theoretical solving of the steady movement with axial symmetry, which due to the complexity of the partial derivative equation system will be numerically solved.

2 PERMANENT SUCTION OF THE COMPRESSIBLE AND IDEAL FLUID INTO A CIRCULAR PIPE-LINE

The axial symmetry character of the suction flow of a compressible and ideal fluid in a circular pipe permits even the one-dimensional solving of the gas adiabatic evolution (fig. 1)

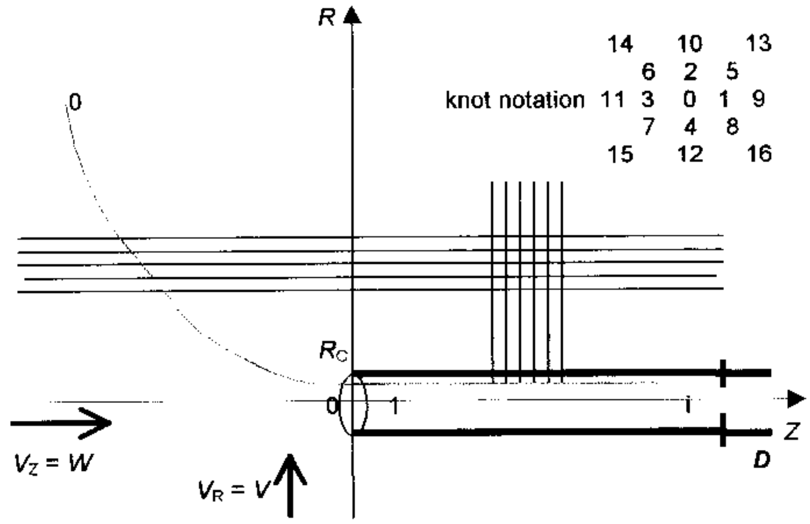

Fig. 1

2.1 Equation system

In this case the equation system consists of:

- **energy equation** to the entrance of the conduit and more far to the flow-meter **D** for calibration,

$$\frac{P_0}{\rho_0}+C_V T_0=\frac{P_1}{\rho_1}+C_V T_1+\frac{W_1^2}{2}=\cdots=\frac{P_i}{\rho_i}+C_V T_i+\frac{W_i^2}{2}\quad\left[\frac{\mathrm{Nm}}{\mathrm{kg}}=\frac{\mathrm{m}^2}{\mathrm{s}^2}\right],\qquad(2.1)$$

- **mass conservation equation** of the fluid in flow through flow-meter mounted on the tight pipe,

$$\dot{M}\left[\frac{kg}{s}\right]=\rho_1 S_1 W_1=\cdots=\rho_i S_i W_i, \tag{2.2}$$

- **gas state equation** of thermodynamic equilibrium in any place on the flowing route,

$$\Re\left[\frac{Nm}{kg\,K}\right]=\frac{P_0}{\rho_0 T_0}=\frac{P_1}{\rho_1 T_1}=\cdots=\frac{P_i}{\rho_i T_i}, \tag{2.3}$$

- **equation of thermodynamic evolution** as adiabatic-isentropic, due to the great flowing velocities

$$K_P=\frac{P_0}{\rho_0^{\kappa}}=\frac{P_1}{\rho_1^{\kappa}}=\cdots=\frac{P_i}{\rho_i^{\kappa}};K_T=\frac{T_0}{\rho_0^{\kappa-1}}=\frac{T_1}{\rho_1^{\kappa-1}}=\cdots=\frac{T_i}{\rho_i^{\kappa-1}};\frac{T_0}{P_0^{\frac{\kappa-1}{\kappa}}}=\frac{T_1}{P_1^{\frac{\kappa-1}{\kappa}}}=\cdots=\frac{T_i}{P_i^{\frac{\kappa-1}{\kappa}}}, \tag{2.4}$$

in which by index i we marked the physical quantities of the specific flowing section from flow-meters, mounted in series and submitted to the calibration operation.

2.2 The measured physical quantities

The small number of the physical parameters which must be measured and their static character assure a good accuracy of the original method, proposed by us for the flow-rate measuring. These quantities are:

- P_0 the absolute pressure of the gas in the suction room,
- T_0 the absolute temperature of the gas in the room from where it is inhaled,
- U_0 the gas humidity in the suction room, influencing substantial its density,
- $P_1 = p_1+P_0$ absolute and relative respectively pressure at the input in the suction pipe.

The good accuracy measuring of these physical quantities in the same time with the flow stability will permit this method to offer for the stand a gauging meteorological quality.

2.3 Calculation of gas flow- rate transported through the flow- meters

From the first equality (2.2) and using the relations (2.1) (2.3) and (2.4) we may deduce the massic gas flow-rate which pass through all the flow-meters tightly inseriated on the conduit.

$$\dot{M}\left[\frac{kg}{s}\right]=\rho_1 S_1 W_1=\frac{P_0}{\Re T_0}\left(\frac{P_1}{P_0}\right)^{1/\kappa}\frac{\pi D_1^2}{4}\sqrt{2C_p T_0\left[1-\left(\frac{P_1}{P_0}\right)^{\frac{\kappa-1}{\kappa}}\right]} \tag{2.6}$$

From the same relations (2.2) one remarks that the volumetric flow-rates, measured by many flow-meters mounted in series, are different. Thus, for our flow-meter placed at the entrance of the pipe we have

$$\dot{V}_1\left[\frac{m^3}{s}\right]=S_1 W_1=\frac{\pi D_1^2}{4}\sqrt{2C_p T_0\left[1-\left(\frac{P_1}{P_0}\right)^{\frac{\kappa-1}{\kappa}}\right]}, \tag{2.7}$$

and for the i^{th} flow-meter in absence of pressure drop

$$\dot{V}_i\left[\frac{m^3}{s}\right]=S_i W_i=S_i\sqrt{2C_p T_0\left[1-\left(\frac{P_i}{P_0}\right)^{\frac{\kappa-1}{\kappa}}\right]}, \tag{2.7'}$$

where S_i represents the flowing characteristic section, in which the fluid have the mean velocity W_i and the absolute pressure P_i.

2.4 Maximal relative errors to determine the massic or volumetric flow-rate

Applying the natural logarithm and differentiating the formulas above, we obtain the maximum relative errors for calculation of massic flow-rate

$$\frac{\delta\dot{M}}{\dot{M}} = 2\frac{\delta D_1}{D_1} + \left(1+\frac{1}{2}\right)\frac{\delta T_0}{T_0} + \left(1+\frac{1}{\kappa}+\frac{\kappa-1}{2\kappa}\right)\frac{\delta P_0}{P_0} + \left(\frac{1}{\kappa}+\frac{\kappa-1}{2\kappa}\right)\frac{\delta P_1}{P_1} \qquad (2.8)$$

and that a little more precise of volumetric flow-rate, at our flow-meter level

$$\frac{\delta\dot{V}_1}{\dot{V}_1} = 2\frac{\delta D_1}{D_1} + \frac{1}{2}\frac{\delta T_0}{T_0} + \frac{\kappa-1}{2\kappa}\left(\frac{\delta P_0}{P_0}+\frac{\delta P_1}{P_1}\right). \qquad (2.9)$$

3 STEADY AND AXIAL SYMMETRICAL SUCTION FLOW OF THE COMPRESSIBLE AND IDEAL FLUID IN A CIRCULAR PIPE-LINE

For the cylindrical co-ordinates, proper to the studied problem of compressible and ideal fluid suction in a circular pipe-line $\left(\partial/\partial t = \partial/\partial\theta = V_0 = 0\right)$ and denoting simply by *V* – the radial and *W* – the axial fluid velocity components, the Euler system of equations with partial derivatives [15] consists of non-linear equations of motion

$$\rho\left(V\cdot V'_R + W\cdot V'_Z\right) + P'_R = 0, \qquad (3.1) \qquad \rho\left(V\cdot W'_R + W\cdot W'_Z\right) + P'_Z = 0, \qquad (3.2)$$

equation of compressible fluid mass conservation

$$\rho\left(\frac{V}{R} + V'_R + W'_Z\right) + V\cdot\rho'_R + W\cdot\rho'_Z = 0, \qquad (3.3)$$

and state equation of the gas, in its supposed isothermic evolution in the case of small variations of pressure and density

$P = K_i\cdot\rho$, in which the constante K_i have the expresion $K_i = \dfrac{P_0}{\rho_0} = \Re T_0$. (3.4)

3.1 Undimensionalization of the partial differential equation system

For a more generalisation of the numerical solution, we shall introduce the dimensionless quantities in the equation system, choosing as characteristic parameters:

- R_C the radius of suction pipe-line,
- W_m the mean velocity, which transportes the volumetric flow-rate $\pi R_C^2 W_m$,
- P_0 the pressure in the suction chamber, (3.5)
- ρ_0 the gas density in the suction room at T_0 temperature and *U* humidity.

With the new dimensionless variables and functions:

$$r = R/R_C, \quad z = Z/R_C, \qquad (3.6)$$
$$v = V/W_m, \quad w = W/W_m, \quad p = P/P_0, \quad \delta = \rho/\rho_0,$$

the equation system in dimensionless quantities becomes:

$$\delta\left(v\cdot v'_r + w\cdot v'_z\right) + \mathrm{Eu}\cdot p'_r = 0, \quad (3.1') \qquad \delta\left(v\cdot w'_r + w\cdot w'_z\right) + \mathrm{Eu}\cdot p'_z = 0, \quad (3.2')$$

$$\delta\left(\frac{v}{r} + v'_r + w'_z\right) + v\cdot\delta'_r + w\cdot\delta'_z = 0, \quad (3.3') \qquad p = \delta, \quad (3.4')$$

in which we denoted by **Eu** the Euler number which characterises the flow.

3.2 Elimination of the functions, whose values on the boundary are not known

By introducing of the partial derivatives of the relation (3.4') in the motion equations (3.1') (3.2') and the partial derivatives δ'_r and δ'_z from these in the equation of mass conservation (3.3'), we obtain a single equation for the both two components of fluid velocity

$$\mathrm{Eu}\left(\frac{v}{r} + v'_r + w'_z\right) = v^2 v'_r + vw\left(v'_z + w'_r\right) + w^2 w'_z. \qquad (3.7)$$

With the aim to eliminate from the calculation programme the difficulties concerning the different values of the ideal fluid velocity on the exterior and interior respectively of the pipe wall, we shall introduce the stream function by the relations:

$$w = \psi'_r \quad \text{and} \quad v = -\psi'_z, \tag{3.8}$$

in which case, the partial derivative equation (3.8) becomes

$$\frac{Eu}{r}\psi'_z + \psi''_{rz}\left(\psi'^2_r - \psi'^2_z\right) + \psi'_r\psi'_z\left(\psi''_{z^2} - \psi''_{r^2}\right) = 0. \tag{3.8'}$$

Introducing in this non-linear equation (3.8') the partial derivatives expressions, deduced by simple algebric calculus from the finite Taylor developpements to the 2 [nd] order of the stream function ψ [16] in the knots of the quadratic network from figure 1, we obtain for instant the associated algebric relation

$$\psi_0 = \psi_3 + \frac{r}{4Eu\chi^3}\begin{Bmatrix} \frac{1}{4}(\psi_5 + \psi_7 - \psi_6 - \psi_8)\left[(\psi_1 - \psi_3)^2 - (\psi_2 - \psi_4)^2\right] - \\ -(\psi_1 - \psi_3)(\psi_2 - \psi_4)(\psi_1 + \psi_3 - \psi_2 - \psi_4) \end{Bmatrix}. \tag{3.9}$$

With this occasion we shall observe that, for the numerical solution stability ration, we explicitated the value of stream function in the knot 0 from the only liniar terminus of the (3.8') equation, but not only in this form.

3.1 Specific boundary conditions of the studyed problem

For the numerical integration we consider (fig. 2) the following boundary conditions:

- in the axis of the conduit $r = 0$ we take for the stream function the value ψ (z,0) = 0,
- on the pipe-line wall $r_C = 1$ and $z \geq 0$ we considere for the stream function the value ψ (z,1) = 1, in the same time with $v = \psi'_z = 0$ and also, for the ideal fluid, the shearing stress $\tau_{zr} = w'_r + v'_z = w'_r = \psi''_{r^2}/r - \psi'_r/r^2 = 0$, from which we have in the pipe $\psi(r) = (r^2+r)/2$ (3.10)

at the end of the conduit we consider the parallelism of the stream lines i.e. $\psi_1=\psi_0$, $\psi_5=\psi_2$, $\psi_8=\psi_4$

- among the specific boundary conditions of the stated problem there is the condition of *deformed reflection* applied to the pipe wall, thus taking into account the pressure loss.
- on quadratic boundary we consider the uniform velocity on the sphere $(4R_S^2 - r_C^2)v = r_C^2\,V$

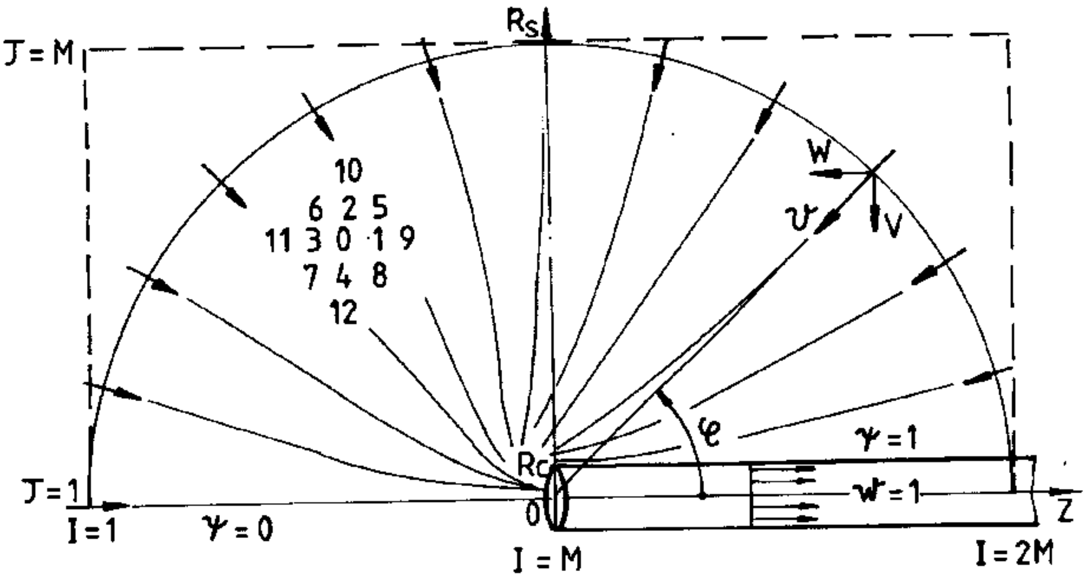

Fig. 2

4 STEADY AND AXIAL SYMMETRICAL MOTION OF A COMPRESSIBLE AND VISCOUS FLUID BY ITS SUCTION IN A CIRCULAR CONDUIT

In this case the motion equations [15] of Navier and Stokes, written in dimensionless variables and functions, are:

$$\delta\left(v \cdot v'_r + w \cdot v'_z\right) + \mathrm{Eu} \cdot p'_r = \frac{4}{3\mathrm{Re}}\delta\left(v''_{r^2} + \frac{1}{r}v'_r - \frac{v}{r^2}\right) + \frac{1}{\mathrm{Re}}\delta\left(v''_{z^2} + \frac{1}{3}w''_{rz}\right), \tag{4.1}$$

$$\delta\left(v \cdot w'_r + w \cdot w'_z\right) + \mathrm{Eu} \cdot p'_z = \frac{4}{3\mathrm{Re}}\delta w''_{z^2} + \frac{1}{\mathrm{Re}}\delta\left[w''_{r^2} + \frac{1}{r}w'_r + \frac{1}{3}\left(\frac{1}{r}v'_z + v''_{rz}\right)\right], \tag{4.2}$$

the both equations of mass conservation (3.3') and gas isothermic evolution (3.4') being unchanged.

4.1 Elimination of functions, whose values on the boundary are unknown

Proceeding as above (§ 3.2) we obtain the new partial differential equation between the two fluid velocity components

$$\mathrm{Eu}\left(\frac{v}{r} + v'_r + w'_z\right) - v^2 v'_r + v w\left(v'_z + w'_r\right) + w^2 w'_z + \frac{4}{3\mathrm{Re}}\left(v v''_{r^2} + \frac{v}{r}v'_r - \frac{1}{r^2}v^2 + w w''_{z^2}\right) + \frac{1}{\mathrm{Re}}\left[v v''_{z^2} + w w''_{r^2} + \frac{w}{r}w'_r + \frac{1}{3}\left(v w''_{rz} + \frac{w}{r}v'_z + w v''_{rz}\right) = 0\right], \tag{4.3}$$

in which, introducing the stream function by the same expressions (3.8), we shall have

$$\mathrm{Re}\left[\frac{\mathrm{Eu}}{r}\psi'_z + \psi''_{rz}\left(\psi'^2_r - \psi'^2_z\right) + \psi'_r\psi'_z\left(\psi''_{z^2} - \psi''_{r^2}\right)\right] = \frac{4}{3}\left[\psi'_z\left(\psi'''_{r^2z} + \frac{1}{r}\psi''_{rz} - \frac{1}{r^2}\psi'_z\right) + \psi'_r\psi'''_{rz^2}\right] + $$
$$+ \psi'_z\psi'''_{z^3} + \psi'_r\left(\psi'''_{r^3} + \frac{1}{r}\psi''_{r^2}\right) - \frac{1}{3}\left[\psi'_z\psi'''_{r^2z} + \psi'_r\left(\psi'''_{rz^2} + \frac{1}{r}\psi''_{z^2}\right)\right] \tag{4.4}$$

and by introducing the partial derivative expressions of the stream function ψ [16] from the finite Taylor developpments to the 3[rd] order, using the centred difference Ψ_1–Ψ_3 and uncentred differences Ψ_9–Ψ_0 or Ψ_{11}-Ψ_0 depending of the direction **+z** or **–z** respectively, for the expressions of the partial derivative

$$\psi'_z = \frac{1}{\chi}\left(\psi_1 - \frac{1}{3}\psi_3 - \frac{1}{2}\psi_0 - \frac{1}{6}\psi_9\right) \quad \text{or} \quad \psi'_z = \frac{1}{\chi}\left(\frac{1}{3}\psi_1 - \psi_3 + \frac{1}{2}\psi_0 + \frac{1}{6}\psi_{11}\right), \tag{4.5}$$

for the forward or back going respectively, we accomplish the calculus. With these we obtain a stable the associated algebraic relation, as for example

$$\psi_0^{\mp z} = 2\psi_{1,3} - \frac{2}{3}\psi_{3,1} - \frac{1}{3}\psi_{9,11} \pm \tag{4.6}$$

$$\pm\frac{r}{\mathrm{Eu}\chi^3}\left\langle \begin{array}{l} \frac{1}{2}\left\{\left[\frac{2}{3}(\psi_2 - \psi_4) + \frac{1}{12}(\psi_{12} - \psi_{10})\right]^2 - \left[\frac{2}{3}(\psi_1 - \psi_3) + \frac{1}{12}(\psi_{11} - \psi_9)\right]^2\right\}(\psi_5 + \psi_7 - \psi_6 - \psi_8) + \\ + 2\left[\frac{2}{3}(\psi_1 - \psi_3) + \frac{1}{12}(\psi_{11} - \psi_9)\right]\left[\frac{2}{3}(\psi_2 - \psi_4) + \frac{1}{12}(\psi_{12} - \psi_{10})\right](\psi_1 + \psi_3 - \psi_2 - \psi_4) \end{array}\right\rangle \mp$$

$$\mp\frac{2r}{\mathrm{ReEu}\chi^3}\left\langle \frac{4}{3}\left\{\begin{array}{l} \left[\frac{2}{3}(\psi_1 - \psi_3) + \frac{1}{12}(\psi_{11} - \psi_9)\right]\left[\psi_3 - \psi_1 + \frac{1}{2}(\psi_5 + \psi_8 - \psi_6 - \psi_7)\right] + \\ + \frac{\chi}{4r}\left[\frac{2}{3}(\psi_1 - \psi_3) + \frac{1}{12}(\psi_{11} - \psi_9)\right](\psi_5 + \psi_7 - \psi_6 - \psi_8) - \frac{\chi^2}{r^2}\left[\frac{2}{3}(\psi_1 - \psi_3) + \frac{1}{12}(\psi_{11} - \psi_9)\right]^2 + \\ + \left[\frac{2}{3}(\psi_2 - \psi_4) + \frac{1}{12}(\psi_{12} - \psi_{10})\right]\left[\psi_4 - \psi_2 + \frac{1}{2}(\psi_5 + \psi_6 - \psi_7 - \psi_8)\right] \end{array}\right\} + \right\rangle$$

$$\left\langle \begin{array}{l} +\left\{ \begin{array}{l} \left[\frac{2}{3}(\psi_1-\psi_3)+\frac{1}{12}(\psi_{11}-\psi_9)\right]\left[\psi_3-\psi_1+\frac{1}{2}(\psi_9-\psi_{11})\right]+ \\ \left[\frac{2}{3}(\psi_2-\psi_4)+\frac{1}{12}(\psi_{12}-\psi_{10})\right]\left[\psi_4-\psi_2+\frac{1}{2}(\psi_{10}-\psi_{12})+\frac{\chi}{r}(\psi_2-2\psi_0+\psi_4)\right] \end{array} \right\}- \\ -\frac{1}{3}\left\{ \begin{array}{l} \left[\frac{2}{3}(\psi_1-\psi_3)+\frac{1}{12}(\psi_{11}-\psi_9)\right]\left[\psi_3-\psi_1+\frac{1}{2}(\psi_5+\psi_8-\psi_6-\psi_7)\right]+ \\ +\left[\frac{2}{3}(\psi_2-\psi_4)+\frac{1}{12}(\psi_{12}-\psi_{10})\right]\left[\frac{\chi}{r}(\psi_1-2\psi_0+\psi_3)+\psi_4-\psi_2+\frac{1}{2}(\psi_5+\psi_6-\psi_7-\psi_8)\right] \end{array} \right\} \end{array} \right\rangle .$$

5 EXPERIMENTAL RESEARCH

The experimental research are focused on the determination of static pressure distributions along the entrance zone in a circular conduit, for different flow-rates (fig. 3), with the aim to establish the very suitable place of the pressure intake for our measuring device.

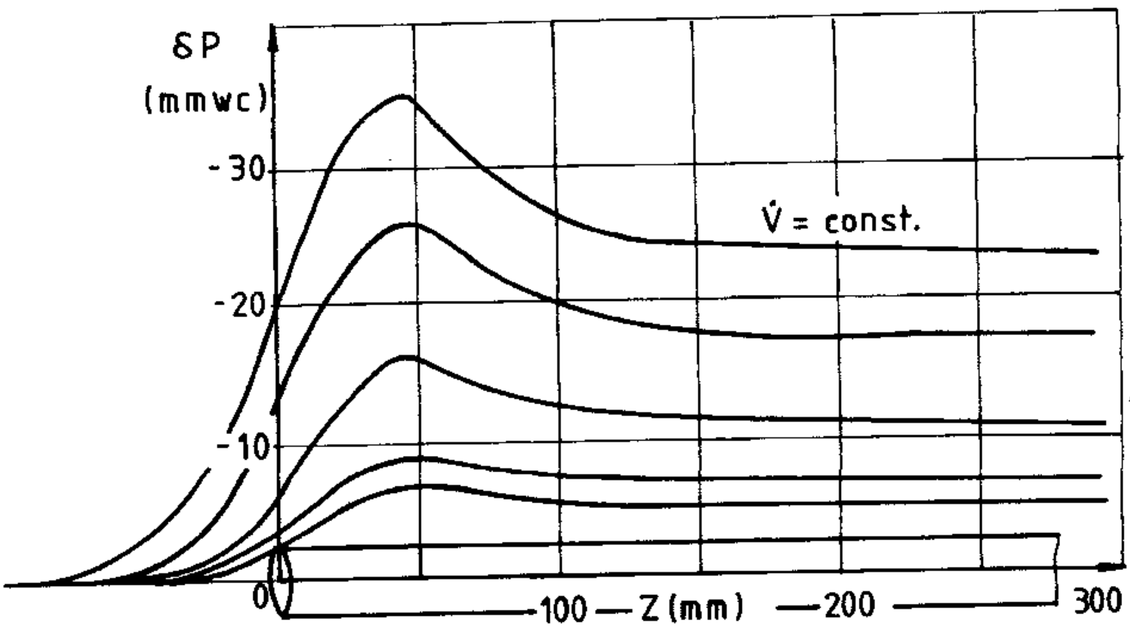

Fig. 3

5.1 Experimental installation

The experimental stand (photo. 1) consists in two pipe-line section, between which one mounted in the standardised metrological conditions the flow-meter for calibration or a diaphragm respectively, for flow-rate measuring to verify our device.

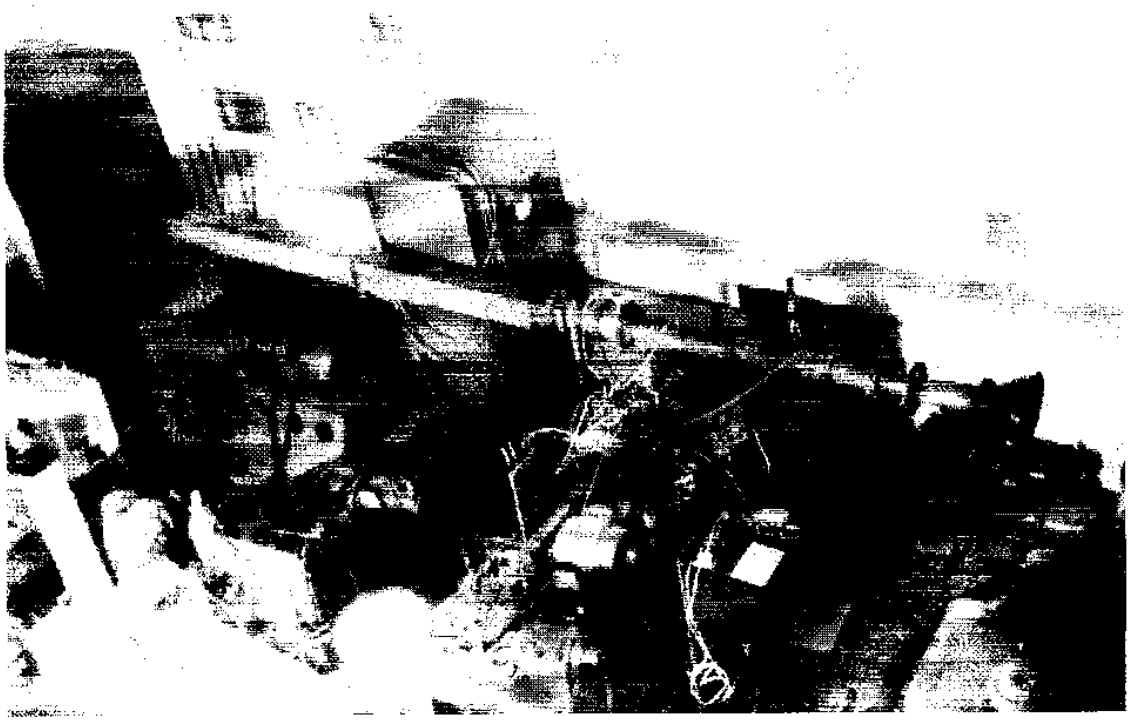

Photo. 1

At the pipe extremity of the fluid entrance in the first conduit, equipped with a row of static pressure intakes, we mounted our patented device and at the out of the second pipe is mounted a flow regulator and a high pressure exhauster, foreseen at its outlet with a valve for the fine adjustment of the flow-rate.

The pressure measuring continues along the pipe, moving away from the entrance cross-section, following, for the sake of the result accuracy, a helicoidal line of place distribution in which the pressure intakes are mounted and putting down for every point the values of the measured pressures for different flow-rates, in order to establish the best place of the pressure intake.

5.2 Measuring apparatus

The used measuring apparatus consists in:

- a **barometer** for the absolute pressure measuring of the air from suction chamber (accuracy 0,5 mb),
- a **thermometer** for air temperature measuring in laboratory chamber (accuracy 0,02 ^{o}C),
- a **hygrometer** for measuring of air relative humidity in the laboratory room (accuracy 1 %),
- **manometers** with liquid for the relative pressure measuring (accuracy 0,5 mmwc).

The high number of rotations of the blower and the flow without vortex separations into the chamber and the conduit assure the permanence of the gas flow without flow-rate and pressure pulsations.

The great volume of the laboratory chamber, possibly in free communication with the outside room, ensure the invariability of the physical quantities and their measuring accuracy.

In conclusion, we can say that the described method is extremely precise, requiring only four static measurements: the barometric pressure, the temperature and humidity of the chamber gas, and also the relative static pressure inside the pipe. The device is simple, it can be achieved without any special technological efforts, which is why we are willing to offer it to the interested firms and laboratories.

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