A NEW TRANSONIC PROBE

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1. INTRODUCTION

The need to improve knowledge of steam flow in turbines and condenser had already led ELECTRICITE DE FRANCE (E.D.F.) to develop five holes velocity probes.

However, these probes were not suitable for measuring the supersonic and transonic Mach numbers found in the last stage of Low Pressure 600 MW turbines notably because of sonic blockage problems (Fig. 1).

E.D.F. therefore decided to design a transonic probe so that rates could be measured in the transonic and supersonic Mach number ranges (Fig. 2). The readings made with such probes could be used to make comparisons with the turbine flow calculations.

2 - THE SONIC BLOCKAGE

By placing a probe in a supersonic nozzle, the cross sectional area of the nozzle is reduced thereby creating a sonic throttle around the probe at a relatively low supersonic Mach number [1] (fig.3).

This phenomenon also occurs with probes placed near a cascade thereby disrupting the flow around the probe and distording the readings.

A similar phenomenon occurs for subsonic Mach numbers close to 1.

It can be seen from the sonic blockage curve (fig. 4) that the only way to reduce the Mach number range where the blockage occurs is to reduce the size of the probe.

It should also be pointed out that for Supersonic Mach numbers a bow shock wave forms in front of the probe as well as in front of its cylindrical stem (fig.2). It is quite clear that in order not to distort the measurement, the shock wave in front of the cylindrical stem must not affect the probe head [2].

3 - THE PROBE DIMENSIONS (fig. 5)

The probe is divided into several parts : the probe head where the pressure holes are located, the stem, and the dia. 25 cylindrical stem to guide it in the turbine.

In order to reduce the transonic domain to a minimum, the thickness of the probe and its stem must be as thin as possible. A 3 mm thick probe is used for a 300 mm high calibration nozzle (dimensions found in a turbine); these figures correspond to a Mach number M for which correct measurements cannot be made for M = 0,85 to M = 1,15.

A 200 mm long stem is used to prevent the detached bow shock wave in front of the dia. 25 mm cylindrical stem from affecting flow around the probe. This lenght is also calculated from the curve in fig 3.

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An elongated and very pointed wedge shape is used to adapt the form of the probe to the high flow rate figures. With this elongated shape, it is also possible to select calibration coefficients highly suited to subsonic meaurements.

These dimensions also correspond to the maximum mechanical strenght of the probe.

The probe head has the same shape as the probe stem (a wedge). It has 5 pressure holes : one on each side of the wedge and three others in the front notch [3] (fig. 6 and 7). The pressure holes have a diameter of 0.4 mm which is the minimum for proper response times.

4 - THE PROBE CALIBRATION

The aim of the probe is to measure velocities and pressures in the last Low Pressure stage of a 600 MW turbine : reading are therefore wet steam measurements.

The sound speed in wet steam is taken to be frozen sound speed (fig 8).

$$C_f = \sqrt{\gamma_f \cdot \frac{P_s}{\rho}}$$

where γ_f = isentropic exponent = 1,32

P_s = static flow pressure

ρ = density of steam (dry)

This means that the sound speed in wet steam is equal to the sound speed in vapor phase alone.

The frozen Mach number is used to calibrate the probe :

$$M = \frac{V}{C_f}$$

Where V = Steam velocity

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It can be concluded from above that the probe can be calibrated in slightly superheated steam without modifying compressibility phenomena.

In practice, calibration is made under the following conditions :

Total pressure	: 0,1 bar
Total temperature	: 130° c
Frozen Mach number	: 0,1 to 1,2

The following calibration coefficients have been defined for the calibration (fig. 9) :

$$K_\beta = \frac{P_3 - P_1}{P_5 - P_x} \qquad \left(P_x = \frac{P_2 + P_4}{2} \right)$$

$$K_M = \frac{P_5}{P_x}$$

$$K_{P_s} = \frac{P_S - P_x}{P_5 - P_x}$$

The definition of the realistic $K_M = \dfrac{P_5}{P_x}$ coefficient is made possible by the efficient form of the probe for which P_5 reflects the total pressure of a Pitot tube and P_x reflects the static pressure of a pitot tube (for subsonic Mach numbers).

K_β and K_M are both function of β and M but K_β is very sensitive to β and insensitive to M, and K_M is very sensitive to M and insensitive to β.

K_{p_s} is used to calculate P_S from M and β when making a measurement with the probe.

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For supersonic Mach numbers K_M is rather different of the theoretical curve but fortunately still increase with M. (fig. 10). The theoretical curve show that for a measured value of K_M it exists two values for the Mach number : a subsonic value and a supersonic value.

We must point out the problem to design a subsonic and supersonic probe. We don't know if K_M still increase with M for Mach numbers upper than 1,3.

5 - CONCLUSION

The transonic probe has already been manufactured and calibrated. Only actual testing in a turbine will provide definitive proof of its efficacy.

The main observation that has been maid with regard to this probe is that it tends to vibrate during tests. One possible solution to this problem may be a probe with a larger stem at the base.

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R E F E R E N C E S

[1] - P. REBUFFET

"Aérodynamique expérimentale - Tomes 1 et 2"
DUNOD - 1966 - 1969

[2] - 6th, 7th, and 8th Symposium on Measuring Techniques for Transonic and Supersonic Flows in Cascades and Turbomachinery
LYON 1981, AACHEN 1983, GENOVA 1985

[3] - H.G HOSENFELD, O.A SCHWERDTNER

"Strömungsmessungen an den beiden letzten Stufen einer Niederdruck - Teilturbine bei vershiedenen Lastpunkten"
(Forshung in der Kraftwerkstechnik 1980)

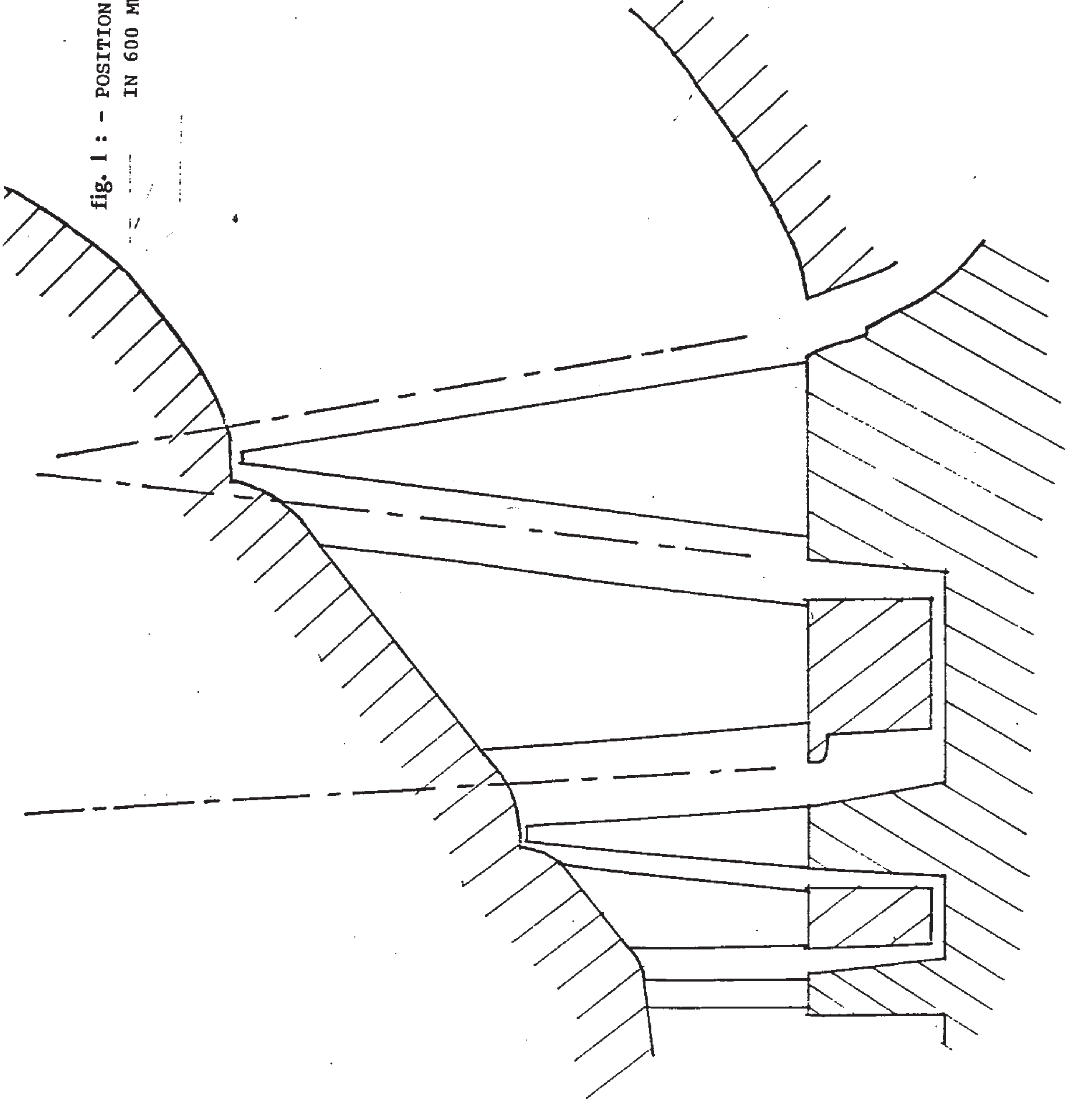


fig. 1 : - POSITION of ACCESS HOLES IN 600 MW TURBINE

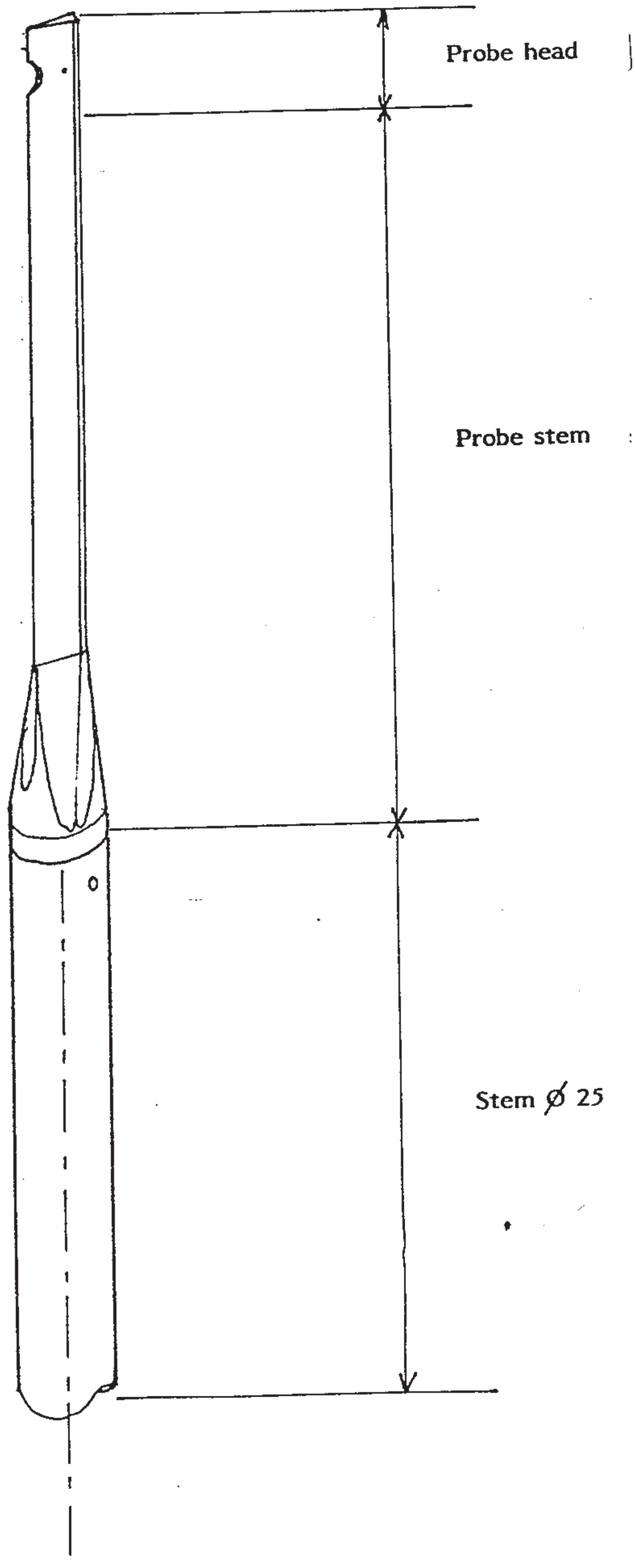


fig. 2 : The Probe and the stem for measurement in turbine

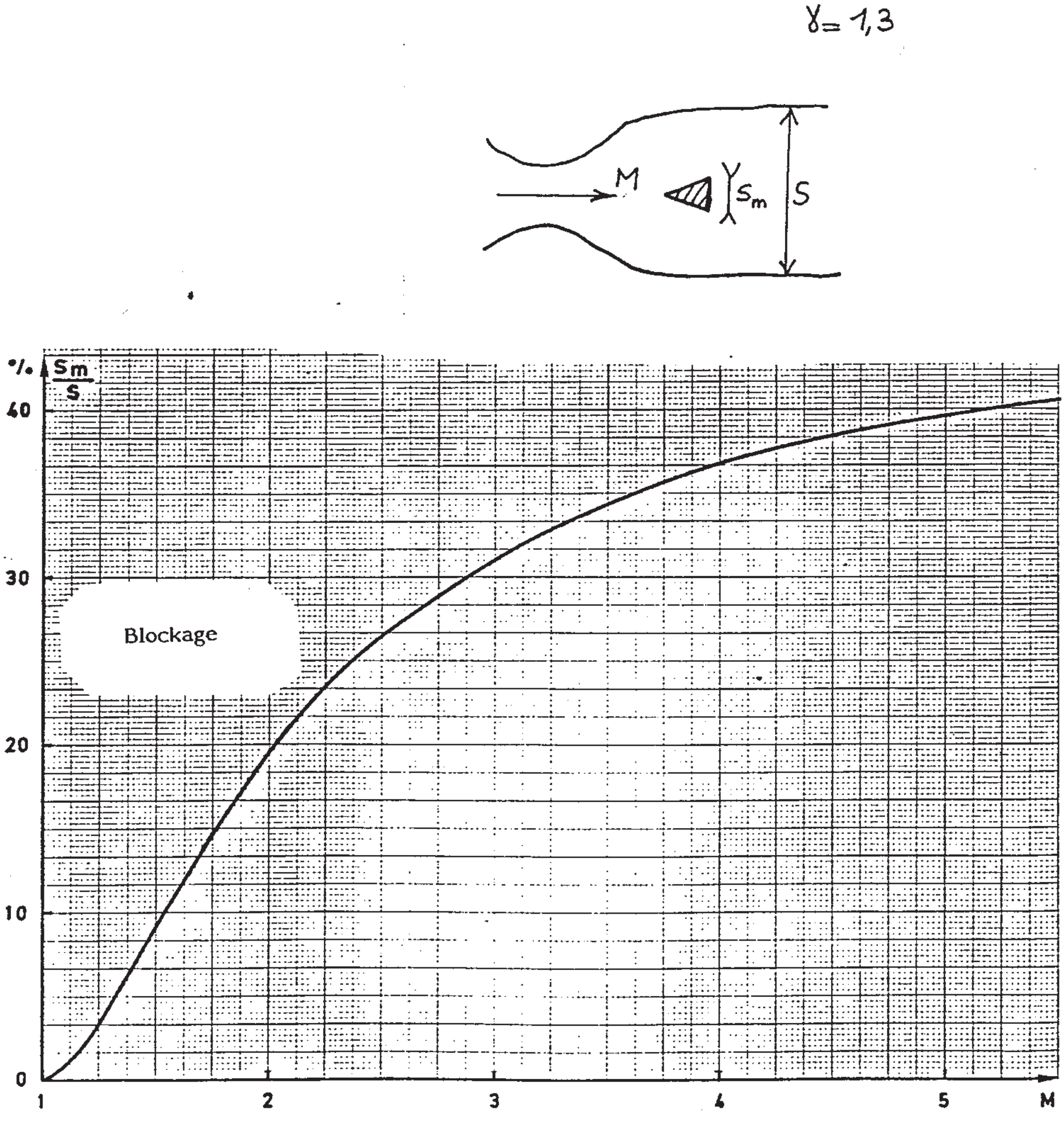


fig.3 : Blockage curve (M⩾1)

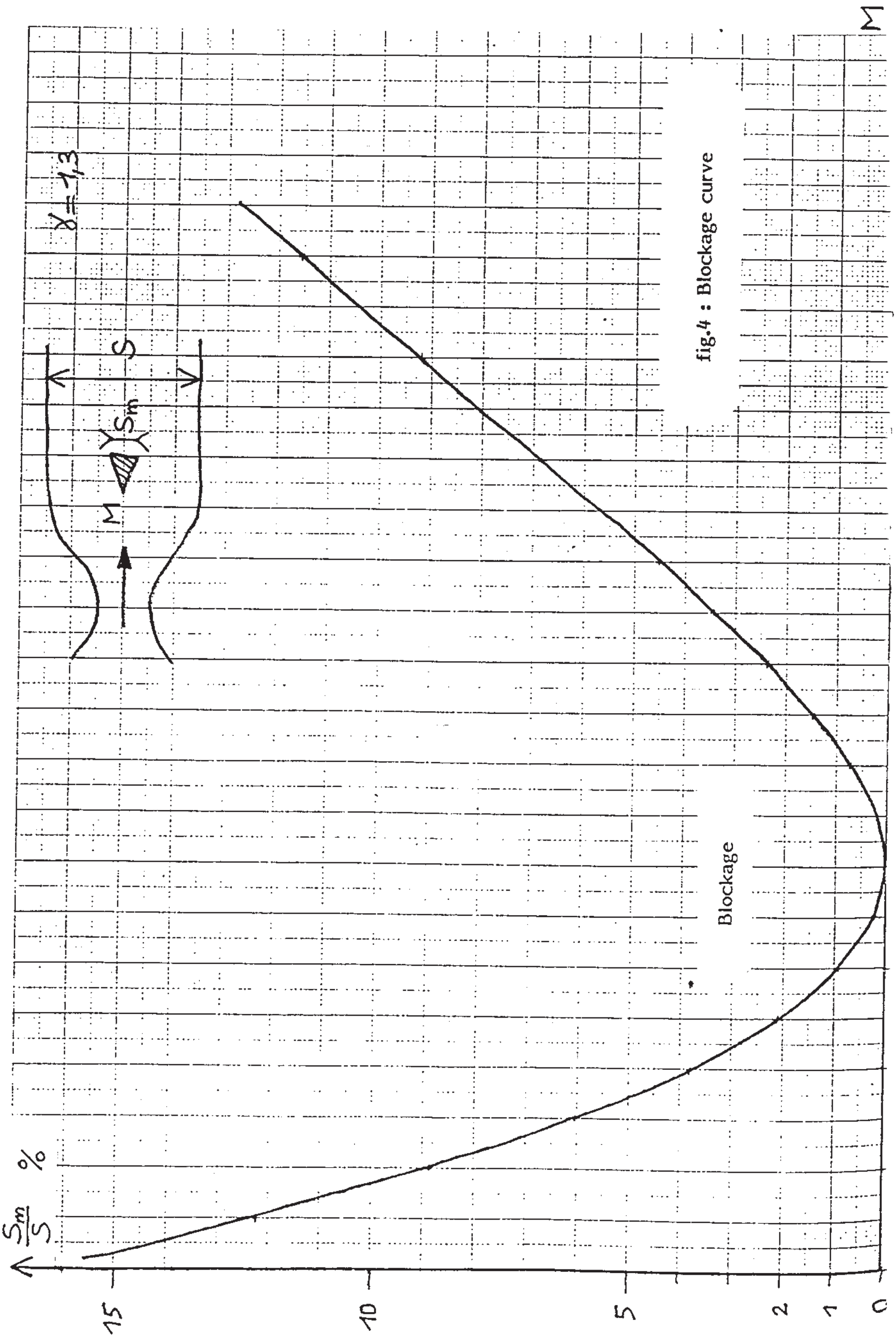


fig.4 : Blockage curve

$$\boxed{M \leqslant 1}$$

$$\boxed{\frac{S_m}{S} = 1 - \frac{1}{S/S_1} \simeq (1 - M)^2}$$

$$\frac{S}{S_1} = \frac{1}{M}\left[\frac{1 + \frac{\gamma-1}{2}M^2}{\frac{\gamma+1}{2}}\right]^{\frac{\gamma+1}{2(\gamma-1)}}$$

$$\boxed{M \geqslant 1}$$

$$\boxed{\frac{S_m}{S} = 1 - \frac{1}{\frac{S_1}{S_2} \cdot \frac{S}{S_1}}}$$

$$\left\{\begin{aligned} \frac{S}{S_1} &= \frac{1}{M}\left[\frac{1 + \frac{\gamma-1}{2}M^2}{\frac{\gamma+1}{2}}\right]^{\frac{\gamma+1}{2(\gamma-1)}} \\ \frac{S_1}{S_2} &= \left[\frac{\frac{\gamma+1}{2}\left(\frac{M^2}{1 + \frac{\gamma-1}{2}M^2}\right)^{\gamma}}{\frac{2\gamma}{\gamma+1} \cdot M^2 - \frac{\gamma-1}{\gamma+1}}\right]^{\frac{1}{\gamma-1}} \end{aligned}\right.$$

fig.4 bis: Undimensionnal blockage theory

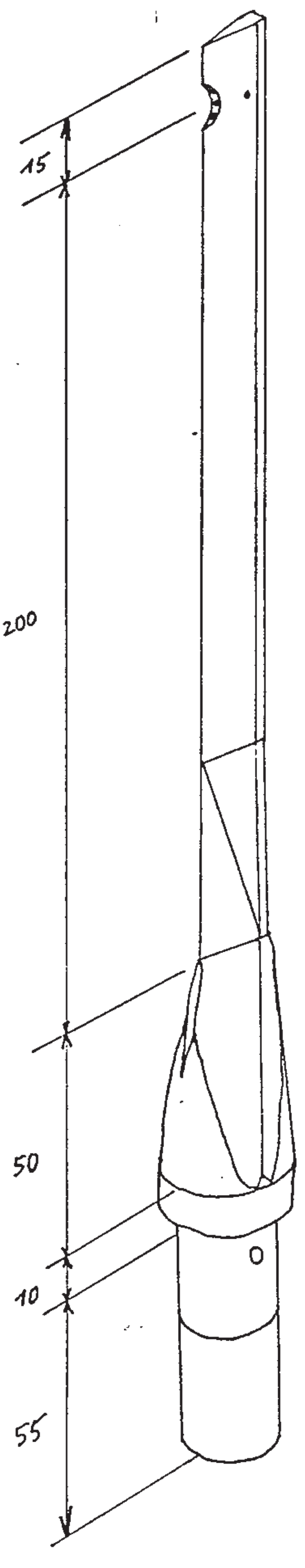


fig.5 : The probe

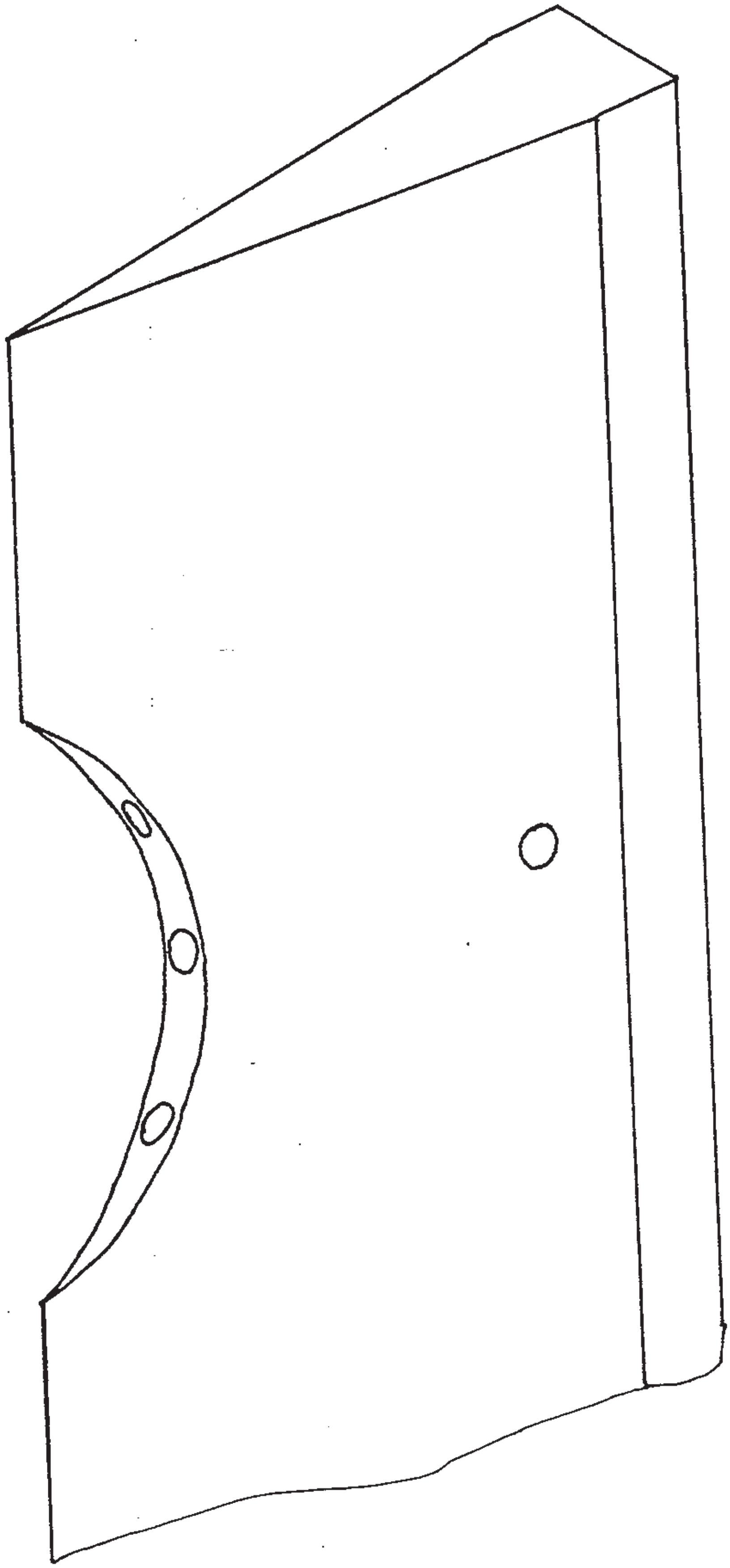


fig.6 : The probe head

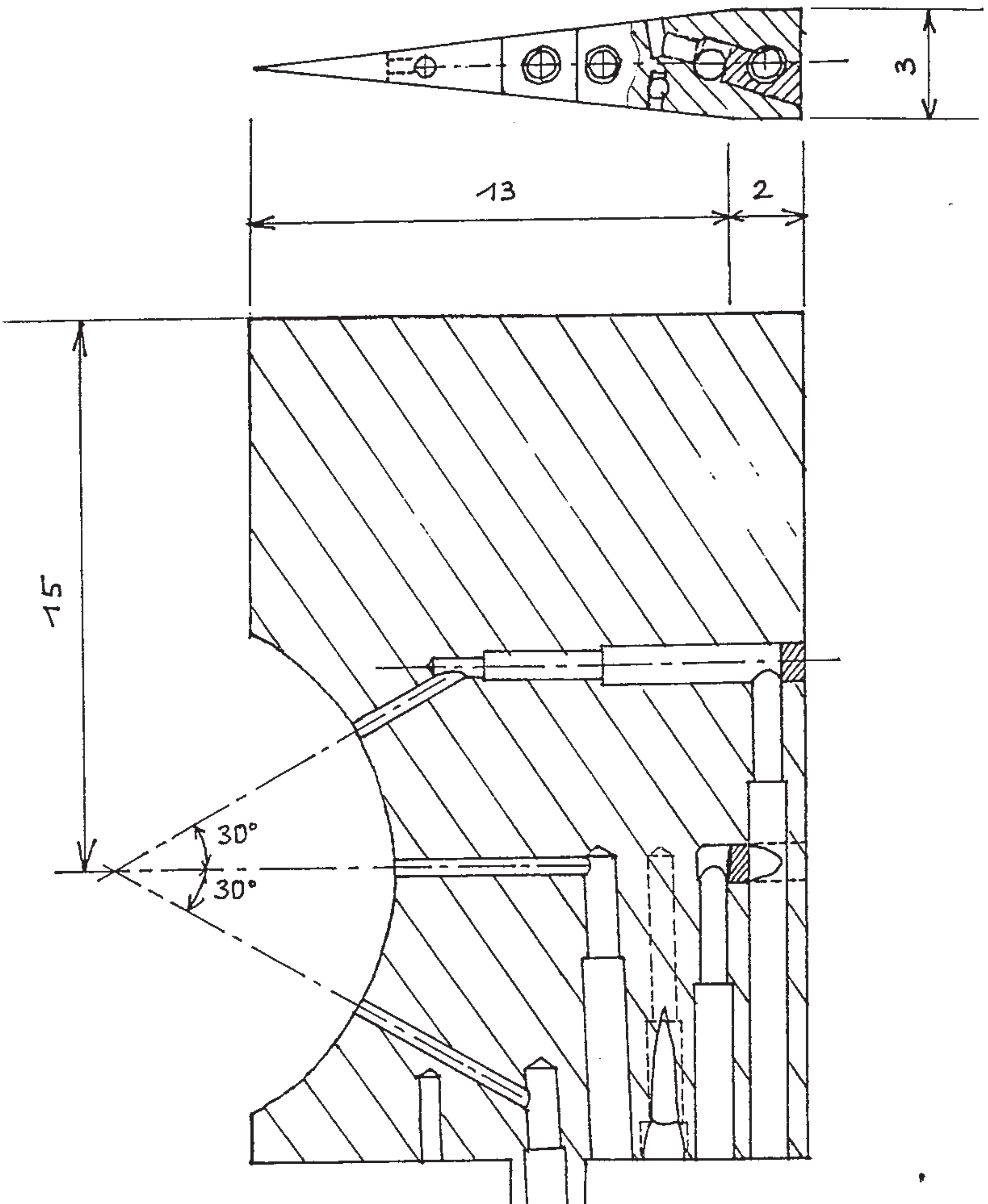


fig.7 : The section of the probe head

. **FROZEN SOUND VELOCITY**

$$C_f = \sqrt{\gamma_F \cdot \frac{P_S}{\rho}}$$

γ_F = isentropic exponent = 1,32 (Low Pressure)

P_S = static pressure

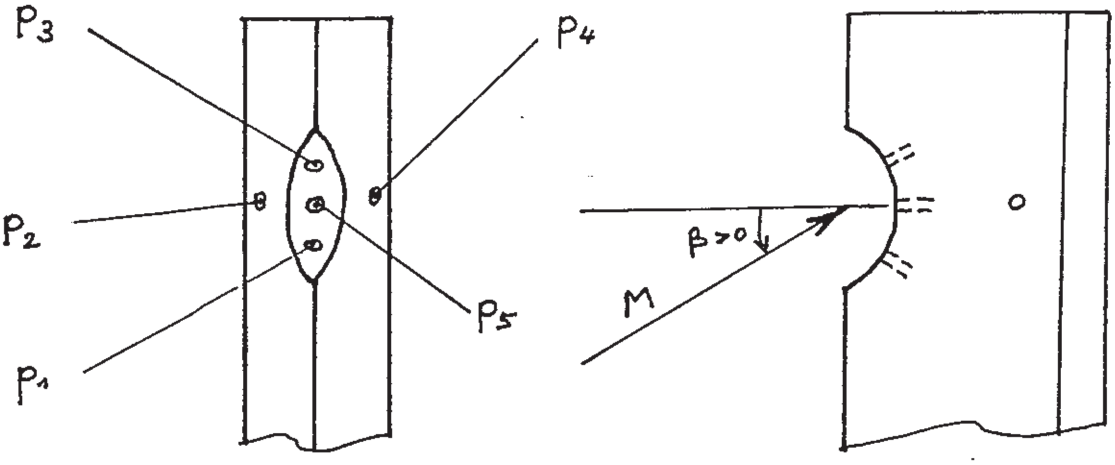
ρ = Density of the steam

- **FROZEN MACH NUMBER**

$$M_F = \frac{V}{C_f}$$

. V = The velocity of the steam

fig. 8 : Sound velocity and Mach number



$$K_\beta = \frac{P_3 - P_1}{P_5 - P_x} \qquad \left(P_x = \frac{P_2 + P_4}{2} \right)$$

$$K_M = \frac{P_5}{P_x}$$

$$K_{P_s} = \frac{P_5 - P_x}{P_5 - P_x} \qquad (P_s = \text{Static pressure})$$

fig.9 : The calibration coefficients

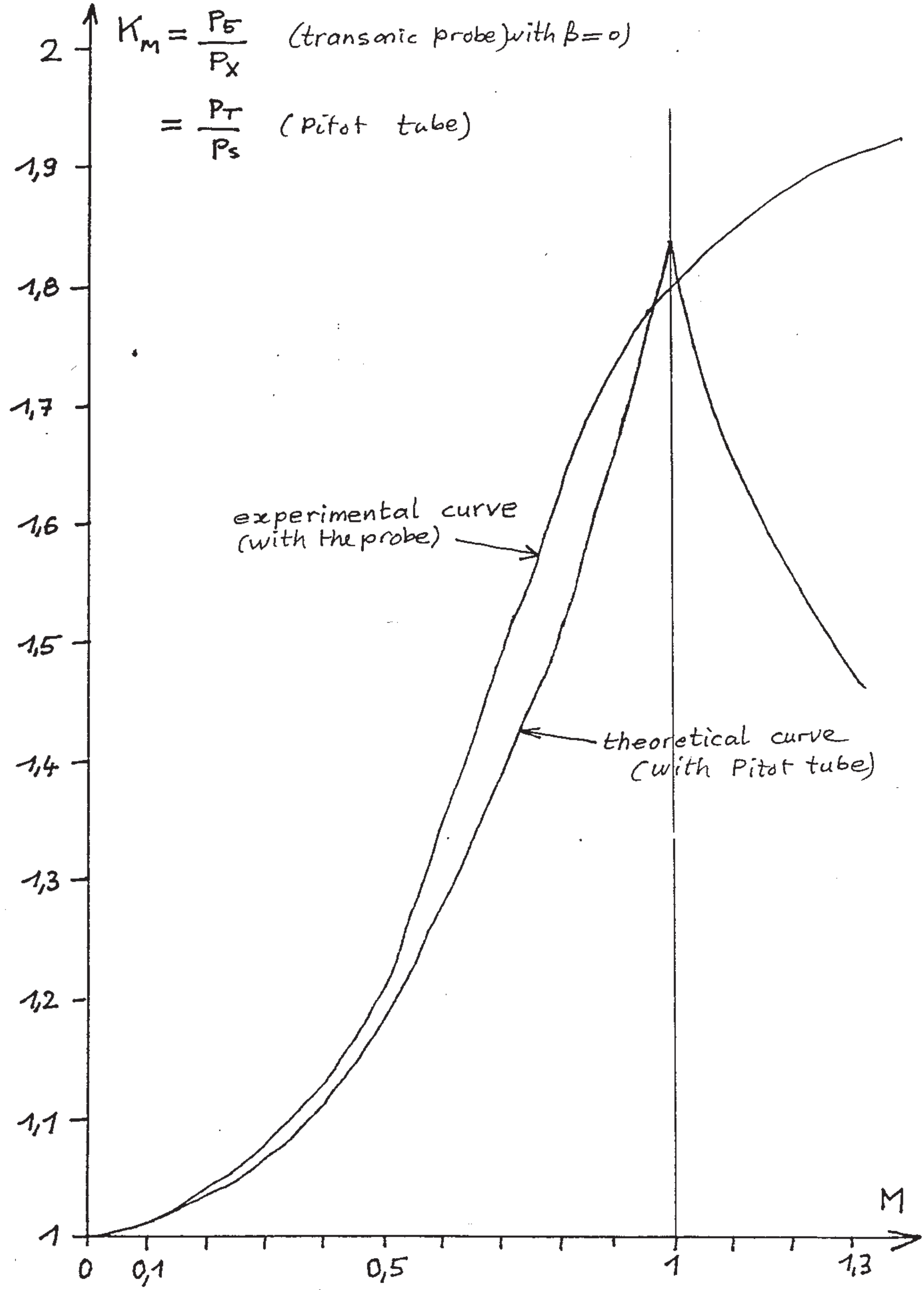


fig. 10 : Calibration curve $K_M(\beta = 0)$