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TRANSONIC PROBE CALIBRATION WITH DRY STEAM AND WET STEAM

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1 - INTRODUCTION

The need to improve knowledge of the flow in large steam turbines of Power Plants has led Electricité de France (EDF) to develop both measuring technics and numerical codes.

In the last stage of Low Pressure steam turbines (such as 600 MW turbine or the new 1450 MW nuclear turbine in Chooz), steam flow is supersonic between the fixed blades and rotating blades; Mach number is expected to reach 1.5

In addition to classical five hole probes used for subsonic measurements, a transonic probe was designed at EDF. This probe has been presented in the 9th Symposium on Measuring technics in 1988 by Mr Brunot. (reference 1)

The aim of these probes, transonic or subsonic ones, is to measure velocities and pressures in stages of turbines where the steam flow can be dry or wet. Global moisture rate can reach 12% at the outlet of turbines, local rate is less : 7 or 8%

In a first time, the probes were calibrated with dry steam in a wind tunnel, the hypothesis being made that the sound speed in wet steam is taken equal to the frozen sound speed. Consequently, the probe can be calibrated in slightly superheated steam without modifying the physic of compressibility phenomena.

In a second time, we studied the influence of moisture rate up to 8% over the calibration coefficients for both transonic and subsonic probe. The main difficulty comes from the variation of sound speed with frequency of the sound wave, with moisture rate and with water droplet size.

This paper presents the results of this study .

2 - TEST RIG AND PROBES.

The wind tunnel (figure 1) is fed with steam coming from 2 boilers at 10 bars, 180°C (saturation) and 10 ton/hour.
Pressure can be adjusted to the right value for calibration down to 80 mbars absolute at the inlet of the nozzle.

For tests in wet steam, water is injected in an injection chamber, then a 6 m chamber allows thermodynamic equilibrium between liquid and gaz phases.
Different Laval nozzles are available (just converging or converging- diverging).

The test section dimensions (200x300 mm) are representative of inter-blade channel found in turbines.

Transonic probe is shown on figure 2. Its shape has been specially adapted to minimize sonic blockage while keeping a good resistance to the flow stress when the probe is introduced on a great length in turbine (up to 1.4 meter inside the flow section).

For measurements in turbines, the probe is first balanced around its axis to equalize pressures P_2 and P_4 on each side of the wedge : so is physically found the first angle we need to define the velocity vector.
The two other parameters are the results of calibration.

3 - CALIBRATION IN WET STEAM

3.1 - Moisture rate

Moisture rate in the test section is determined in two steps .

a)- moisture rate at the inlet of the nozzle is calculated by an enthalpic balance built on the thermodynamic characteristics of steam, injected water and purges.
Test rig capacity allowed to realize initial wetness up to : 6% for Mach =1.4
12% for Mach =0.3

b)- moisture in the test section at the outlet of the nozzle is calculated by a numerical code of condensation in the steam expansion through a nozzle. When steam at the inlet is wet, in addition to wetness ratio, we need to know the droplet size.
Droplet size at the inlet of the nozzle have been measured with a micro-video probe, developped and qualified at EDF (reference 2) : injected droplet rays are 20 microns.

Some results of expansion calculations are shown on figure 3 : with an initial moisture of 3.4%, steam expands with a 'condensation shock' to reach a final moisture rate of 4.3% mainly composed of the "big" initial droplets (not really grown) and small condensation droplets of 0.3 µ. (We can see the influence of initial droplet size on the expansion line).
This kind of granulometry is not too far from what is found in turbines.

3.2 - Calibration coefficients

Three coefficients are necessary to find velocity , pitch angle and static pressure.

If P_x is the average of P_2 and P_4 , P_s static pressure and P_T total pressure, these coefficients are :

$$K_M = \frac{P_5}{P_x} \qquad K_\beta = \frac{P_3 - P_1}{P_5 - P_x} \qquad K_{ps} = \frac{P_3 + P_1}{2P_s}$$

Calibration has been made with 2 parameters : β angle and the ratio $\frac{P_T}{P_S}$ which is linked to Mach number in a simple way in dry steam. P_T is measured upstream the nozzle.

Each coefficient is both function of β and $\frac{P_T}{P_S}$ but K_M is very sensitive to $\frac{P_T}{P_S}$ and relatively insensitive to β, and K_β very sensitive to β and relatively insensitive to $\frac{P_T}{P_S}$.

Calibration has been made for different moisture rates, according the steam flowrate.

3.3 - Results.

Results are presented on figure 4 and 5, respectively for transonic and subsonic probe. As the curves are finally not so different in dry steam and in wet steam (for the moisture rates tested), we opted to write, for each curve, the Mach number M calculated as in dry steam with $\frac{P_T}{P_S}$: while keeping this signification in mind, curves are more expressive.

K_β does not vary between dry and wet steam.
For subsonic probe, there is no significative differences for K_{PS} and K_M.

For transonic probe, K_M is less in wet steam than in dry steam; difference appears for Mach number greater than 0.8. This difference comes from moisture losses in the nozzle (and additional losses through the shock for M>1) ; for a same ratio $\frac{P_T}{P_S}$ as in dry steam, these moisture losses reduce total pressure in the test chamber, and so P_5 which is used to calculate K_M.

When we correct the value of K_M to take into account the loss of total pressure according to moisture rate (see some measurement results on figure 6), difference between dry and wet coefficient tends to disappear.

4 - CONCLUSION

No sensitive difference is noted between dry or wet steam calibration, as far as moisture rate of the flow is less than 8% and for Mach number less than 1.5
Results available now in this field indicate that the proportion of losses due to the shock increases with Mach number, to the detriment of moisture losses .

Those limits are in fact due to the present test rig : in a next future, modifications will allow to obtain greater moisture rate.

Measurements have already been made in the last stage of a 600 MW turbine at Cordemais : a good agreement with calculations is found for pressures and velocity angles; measurements show a radial variation of velocity greater than calculation results. A great part of these radial variations are due to the tri-dimensional complexity of the flow, that our meridian computer code cannot simulate.

Moreover, complete measurements will be soon realised in the new 1450 MW turbine which is running on this year : flow velocities are expected to higher values, that will avoid the difficult field close to Mach 1.

References

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3- Variation of sound velocity in wet steam. V.Petr *Wet steam 4 Conf. University of Warwick,1973.*

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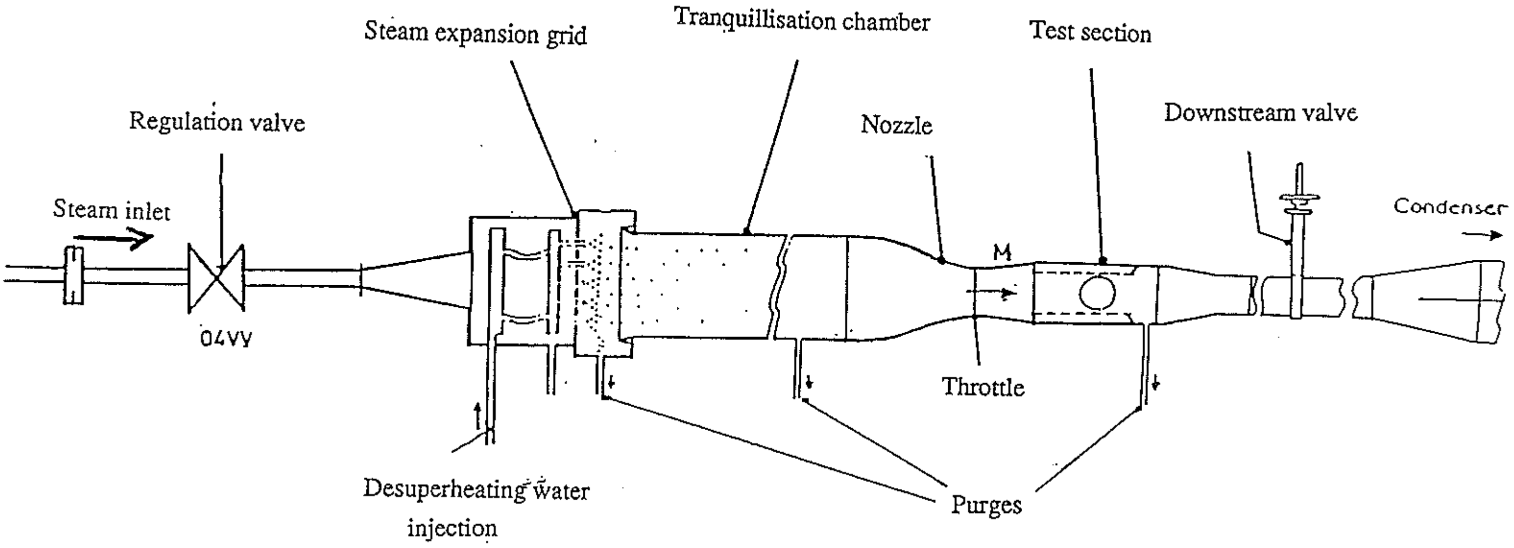


FIGURE 1 .TEST RIG

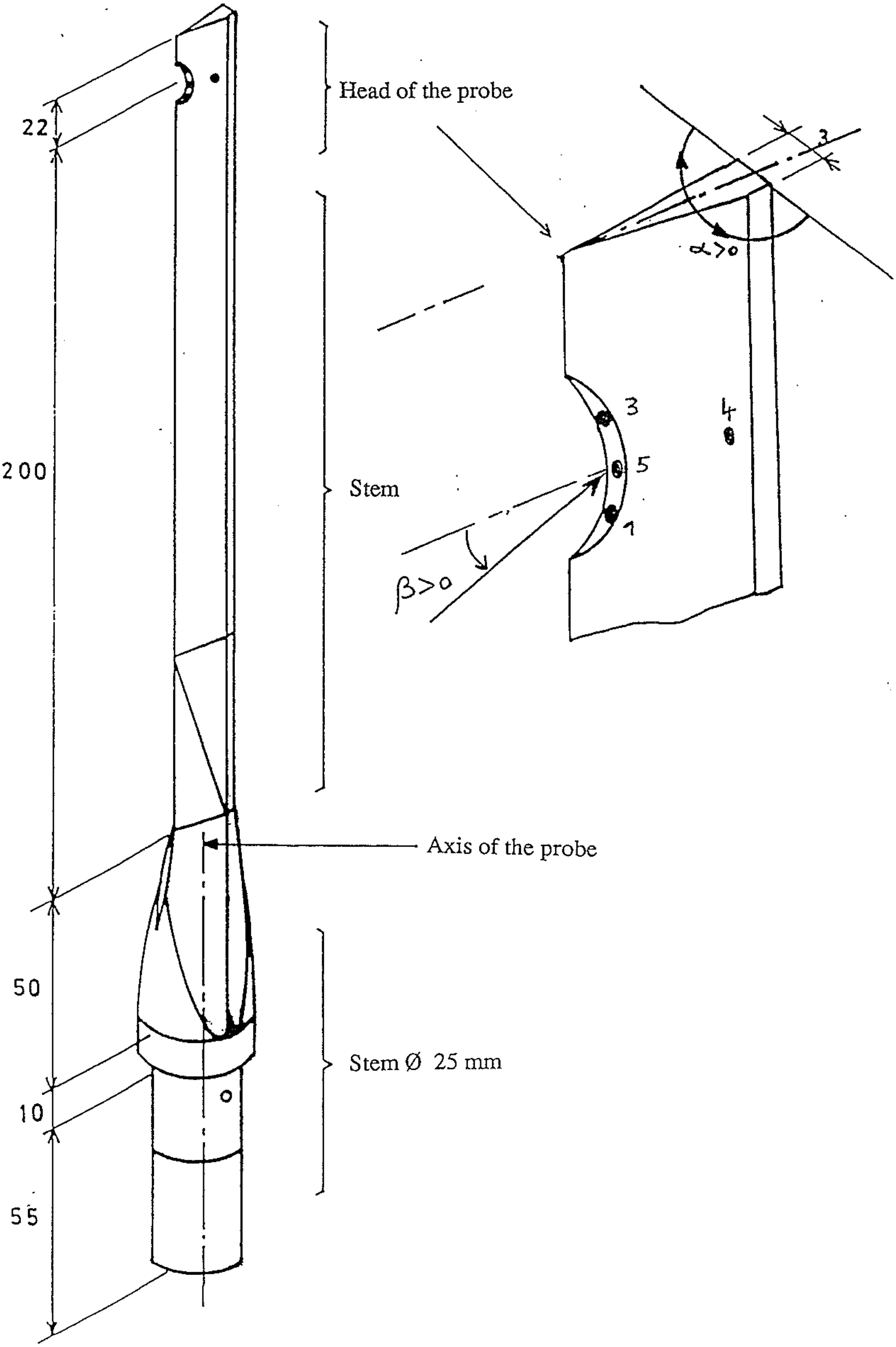


FIGURE 2 TRANSONIC PROBE

FIGURE 3

Expansion calculation along the axis

initial conditions :

pressure 0.130 bar
temperature 50°C
wetness 3.4%
droplet ray 20µ

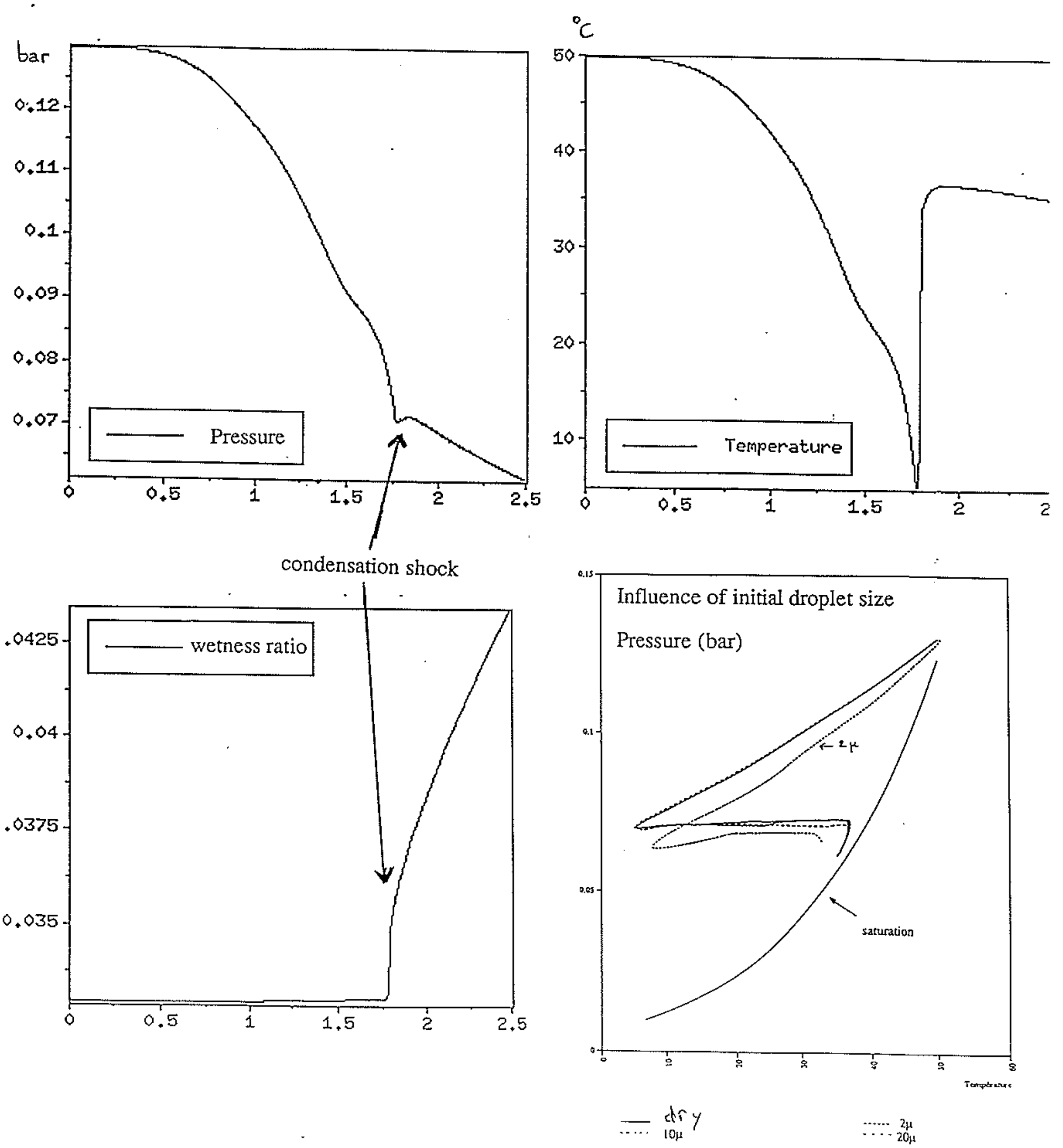
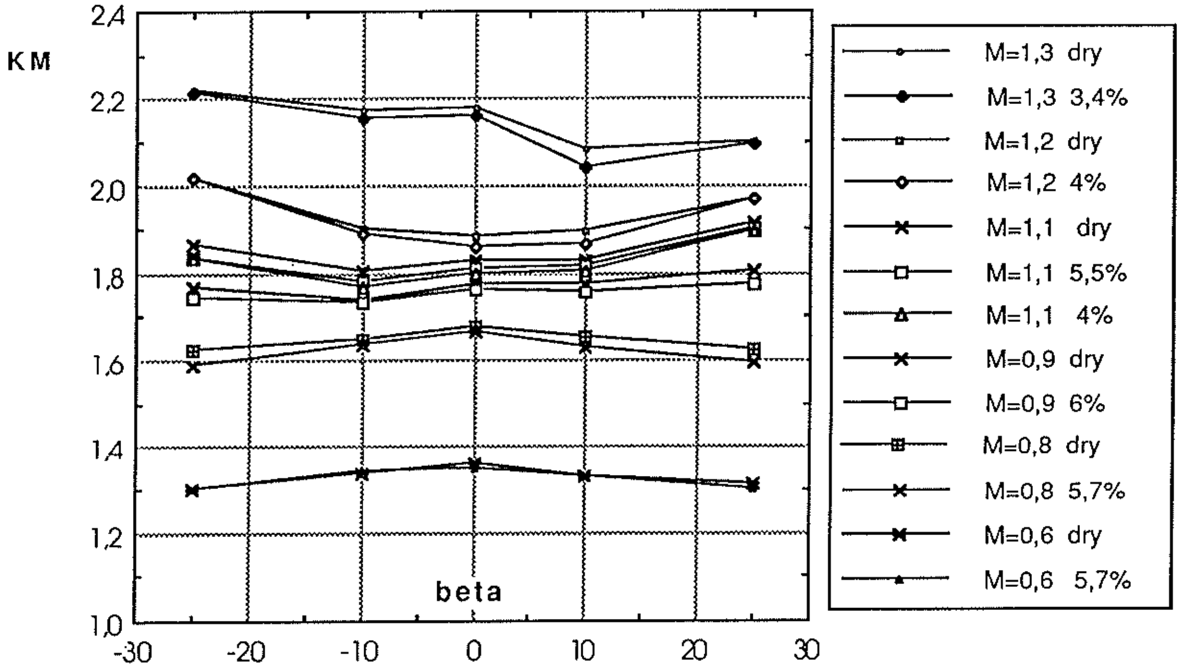


FIGURE 4

TRANSONIC PROBE
KM function of Mach and moisture ratio



Kps function of Mach and moisture ratio

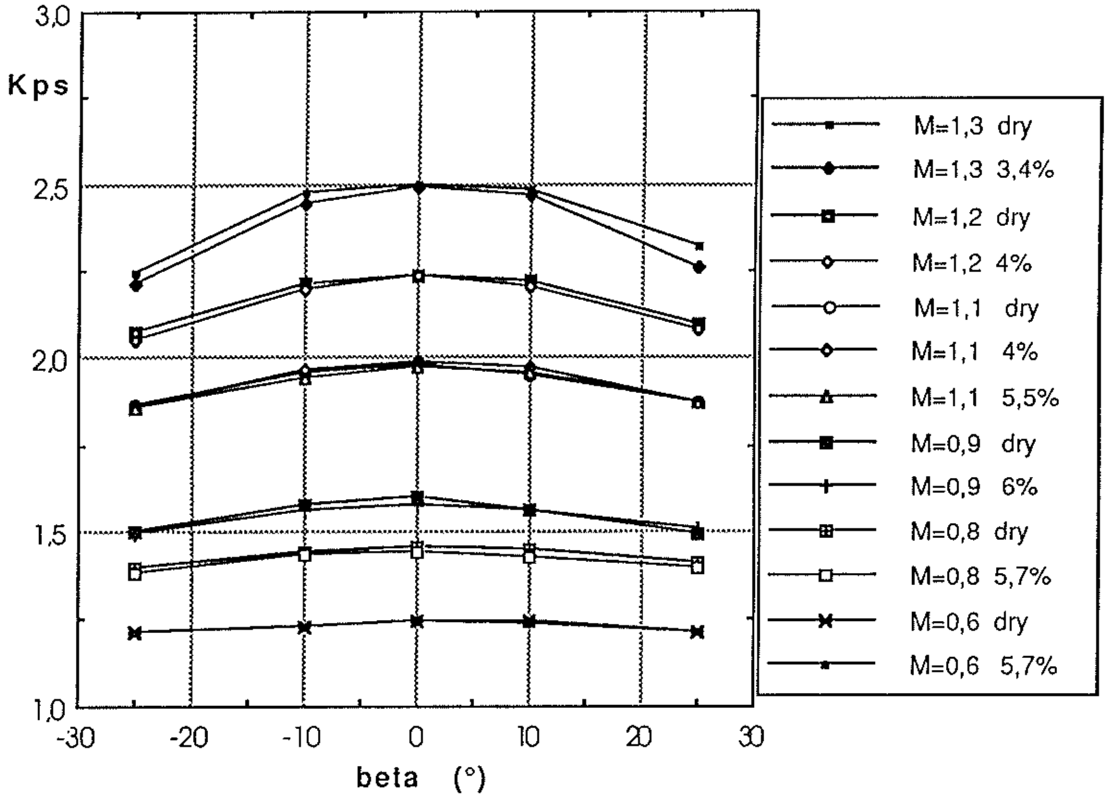
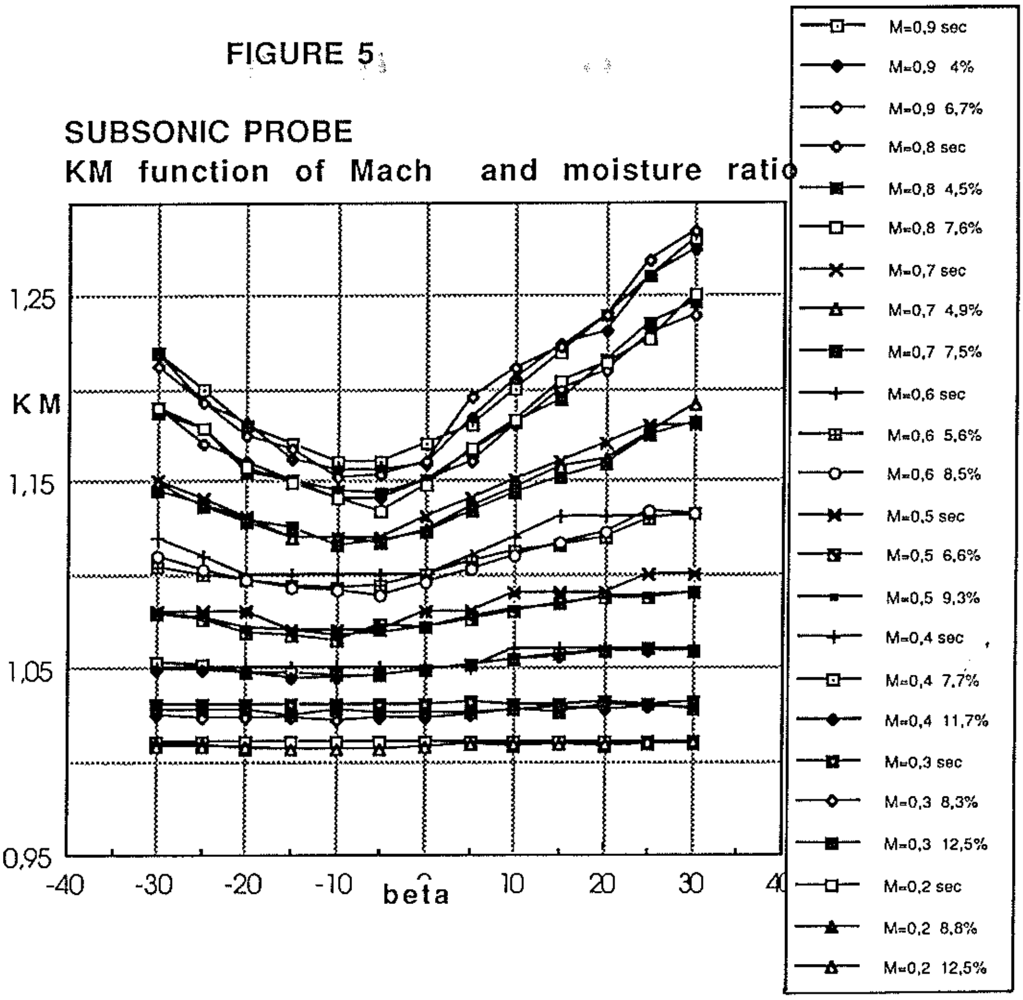


FIGURE 5

SUBSONIC PROBE

KM function of Mach and moisture ratio



Kps function of Mach moisture ratio

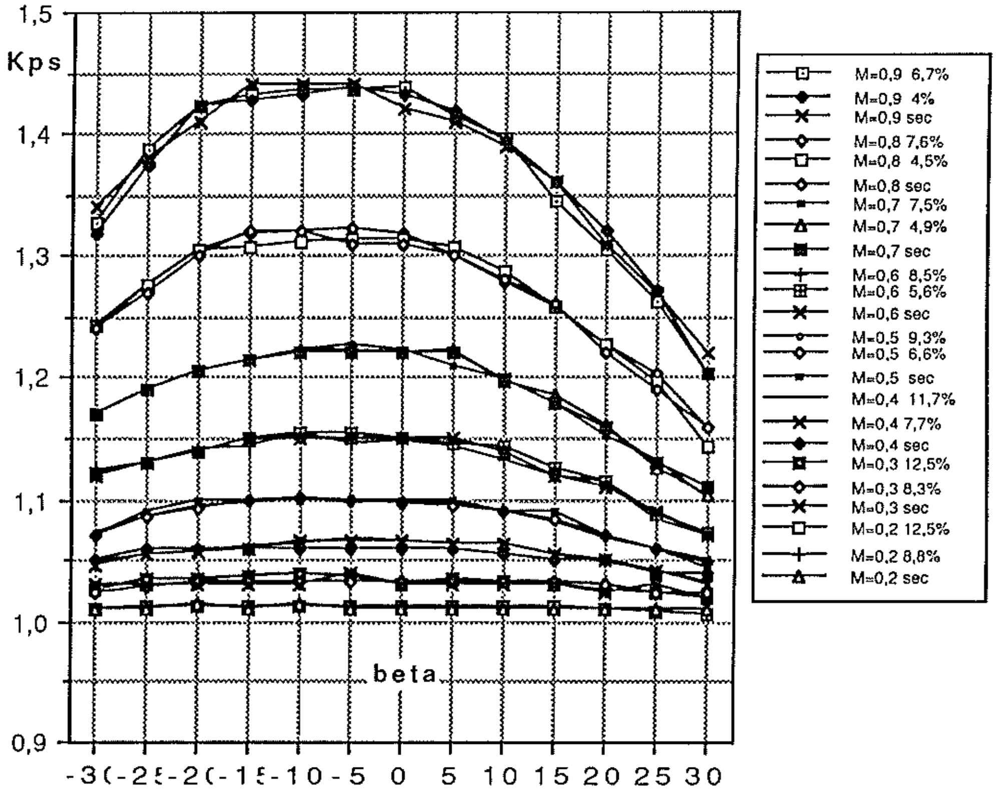


FIGURE 6

Total pressure ratio
downstream/upstream nozzle