The Steam Test Rig at KWU and its Cascade Steam Tunnel

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Summary

The cascade steam tunnel of the steam test rig at Siemens UB KWU is presented. Regarding the uniformity of cascade inlet flow, problems and their solutions are shown.

Introduction

Whenever possible, in our flow laboratory at KWU in Mülheim we investigate flow problems at models with air as working fluid. Nevertheless, in special cases it is unavoidable to test original turbine parts and/or to use other fluids, e.g. freon or nitrogen or steam. In case of the latter, the use is necessary when wetness effects are important or condensation takes place. Therefore, we have a steam test rig in our lab. Two steam tunnels belong to it: a probe calibration steam tunnel (EMS) and a cascade steam tunnel (GMS).

The EMS has two interchangeable test sections:
Firstly a transonic test section, secondly a supersonic test section with some laval nozzles for different Mach numbers. In the latter the calibrations for the European Workshop on Probe Calibrations [1] took place. Both test sections were already presented in former symposia [2, 3].

The GMS is an important tool for blade development between calculation and test in a model steam turbine.

Steam test rig, Fig. 1

The steam (max. 15 t/h) is delivered by the central heating station of our plant with a pressure of 10 bar and saturation temperature.
By means of water separator, electric superheater, throttle valve, and steam cooler we achieve steam pressure conditions from about 60 mbar to 10 bar and temperatures up to 250 °C. The wetness of the steam is produced by injection of water or by expansion in a steam turbine. The only task of this turbine is to generate wet steam with the same size and distribution of droplets as they occur in a low pressure turbine. The inlet pressure is 2.5 to 8 bar, the temperature slightly superheated. The curtis wheel has two blade rows. The wetness of the exhaust steam is 4.7

to 5.3%. The power (max. 500 kW) is taken up by an electric brake.

The steam can be led to the EMS or via a mixing chamber with a free connection for other investigations to the GMS. Each steam tunnel has its own condenser. The condensate is pumped back to the heating station by a common condensate pump. From main gate valve to condenser entrance all test rig parts which come into contact with steam are made of rustproof materials.

Cascade steam tunnel

Fig. 2 and Fig. 3 give principle drawings of the GMS in general and in more detail. The steam flows from the mixing chamber (1) through the settling chamber (2) and the inlet casing (3) to the cascade (4). The flow area is reduced twice, the contraction ratio at settling chamber entrance is 2.6:1, at inlet casing entrance 13:1 to 5:1 depending on the cascade height. The cascade height can be varied between 300 and 800 mm.

The left and right side walls of the inlet casing are fixed, the width of the inlet duct is 150 mm. Also in operation, the lower and upper are movable in flow direction and perpendicular to it. Additionally, they can have a maximum inclination angle of 3 degrees. By this it should be possible to match the exact cascade inlet area and to neutralize boundary layer effects.

The inlet duct has windows in both sides in order to measure wet steam inlet flow conditions by optical methods.

The cascade support is inserted in a circular casing. This is turnable in order to achieve a given inlet angle. The centre of the casing is the fixed point of the whole test rig, for compensating temperature effects, the parts before and behind can move into flow direction or against, respectively. Windows in the centre of the cascade support enable the application of optical methods, e.g. holographic interferometry or Schlieren method.

The cascade exhaust flow is guided only by the rigid side walls, at the lower and upper side it behaves like a free jet, i.e. no tailboards are used. From the exhaust casing (5) the steam flows through a so-called steam chamber (6) and a butterfly valve to the condenser. By means of this valve the exhaust pressure of the cascade is varied.

Instrumentation

In Fig. 4 one can see the turnable discs with the cascade support. In front of the cascade at both sides of the tunnel, slots are parallel to the cascade. By these slots condensate can be sucked from the side walls and be prevented from flowing into the cascade. Condensate on the lower and upper wall is sucked off through the gaps between wall and blade.

The total temperature is measured in the mixing chamber by thermocouples, the total pressure by a pitot tube in the inlet duct.

Between suction slots and cascade 65 wall tappings allow the measurement of the static pressure distribution. The total pressure distribution in front of the cascade is checked by pitot probes which can be traversed over the tunnel height at 8 positions. At the same positions wedge probes can be traversed for measuring the inlet angle distribution. The downstream flow field is measured by traversing a wedge probe in the middle of the tunnel parallel to the exit plane. The probe, Fig. 5, is like those used in the DFVLR, AVA, in Göttingen, but has larger bores. In the AVA it is manufactured and calibrated in air up to Mach no. = 2.0.
At measurements in wet steam condensate can penetrate into the pressure lines, and in superheated steam the steam can condense in the cooler lines. Therefore, they have to be purged. We do this by intermittend purging with air.

Inlet flow

From the double contraction (at settling chamber entrance and exit) one should expect a uniform flow distribution in front of the cascade. However, our measurements showed that this is not always the case. The following values are significant for a homogeneous flow distribution: the static pressure p, the total pressure p_{ges}, and the angle deviation $\Delta\beta_1$, i.e.the difference between the local angle and the angle given by the lower and upper inlet duct walls.

Static pressure: Fig. 6 gives the pressure distribution along the inlet duct. At the beginning the pressure sinks caused by the growing boundary layer. At the second half of the duct it remains more or less constant.
The pressure distribution over blade height is supposed to be constant.
In Fig. 7 the influence of the movable wall position referred to the blade leading edges is shown by the static pressure distribution over the height of the inlet area. The influence is very strong, but it is rather simple to achieve a uniform distribution by lowering or lifting the corresponding wall. The Mach number at the inlet of this cascade was $Ma_1 = 0.27$. With a smaller inlet duct and $Ma_1 = 0.4$ the distribution was good too, see Fig. 8. In both cases the pressure ratio of the cascade was supercritical.

Inlet angle difference $\Delta\beta_1$:

The definition of $\Delta\beta_1$ is given in Fig. 9. To get a uniform distribution over blade height was rather difficult. From orientating measurements with the cascade shown in Fig. 7 we knew that we had at least to put a perforated plate into the exit of the mixing chamber. This plate had an open area of 22.5%.

For a cascade of flat plates the resulting distribution of $\Delta\beta_1$ in probe position 3 is very bad, see Fig. 9, symbol Δ. Therefore, the plate was replaced by another one with an open area of only

10%. Now the distribution (symbol o) was different but still inadequate. That means, probably the reason is not the inflow from the mixing chamber into the settling chamber but from that into the inlet duct. At this point swirls may arise which disturb the inlet flow heavily.

In order to reduce the effect of these swirls by flow acceleration we gave a slight inclination (2 deg) to the walls. The angle distribution (symbol ▽) became better but not good enough. In a last step we did what we had tried to avoid: We put a flow straightener into the entrance of the inlet duct, see Fig. 6; the walls were horizontal again. Now $\Delta\beta_1$ is rather constant over the blade height (symbol ●), except near the side walls.

The small deviation from the wall direction can be influenced by the cascade itself and is then unavoidable.

Total pressure: The total pressure distribution over blade channel height, in Fig. 10 plotted as velocity distribution, depends strongly on the channel height or the boundary layer thickness, resp. The flat plate cascade with an inlet angle of 159 ^{o} and an inlet Mach number $Ma_1 = 0.39$ gives a quite good velocity distribution (symbol Δ and ●). Using plate B and a flow straightener (symbol ●) the boundary layer is somewhat smaller than using only plate B (symbol Δ). With increasing inlet angle the boundary layer thickness compared with the duct area increases rapidly and fills nearly the complete channel height (symbol +).

In order to avoid this we put a contoured insert under the upper wall for additional flow acceleration. This is shown for a cascade of typical tip section blades in the sketch of Fig. 11. Obviously by this measure not only the velocity distribution is improved but also the inlet angle distribution.

Conclusion remarks

Our experience is that in a steam tunnel with a long duct one needs special measures to achieve a satisfactory flow distribution in front of the cascade. This means a lot of work before each test series, and we would be glad to find easier methods.

References

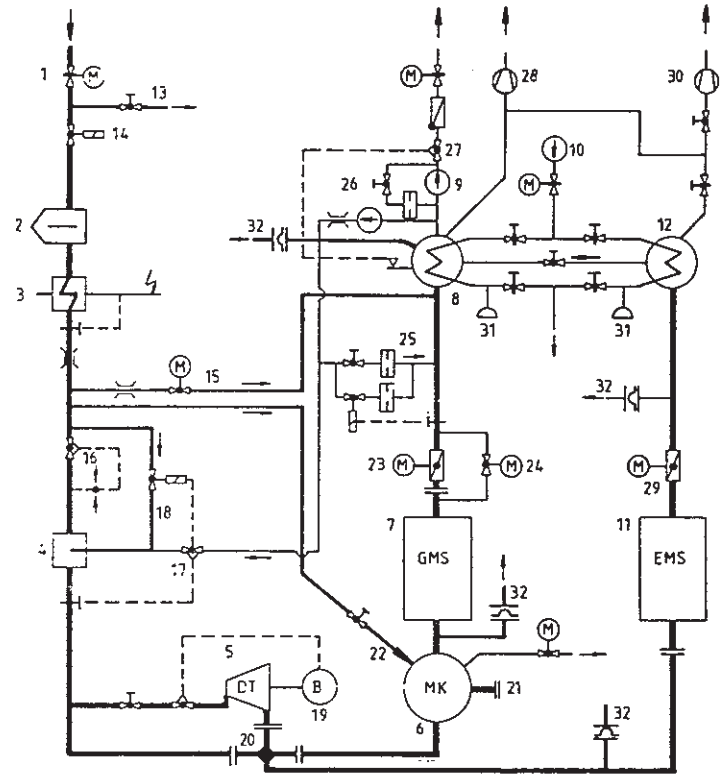
[1] European Workshop on Probe Calibrations. Proceedings. Aachen, December 1984

[2] D. Granser: Test measurements on a Steam Channel for Probe Calibrations. Measuring Techniques in Transonic and Supersonic Cascade Flow. Proceedings of the 5th Symposium in Leatherhead, March 22 - 23, 1979

[3] D. Granser: A Transonic Steam Channel for Probe Calibrations. Measuring Techniques in Transonic and Supersonic Cascade Flow. Proceedings of the 7th Symposium in Aachen, Sept. 21 - 23, 1983.

Dampfversuchsstand: Schaltplan
Steam Test Rig: Schematic Plan

1



- Hauptdampf/Main steam
- Dampf/Steam
- Wasser,Kondensat/Water,condensate
- Luft/Air

1 **Hauptabsperrschieber**
Main gate valve

2 **Abscheider**
Separator

3 **Überhitzer**
Superheater

4 **Dampfkühler**
Steam cooler

5 **Dampfturbine**
Steam turbine

6 **Mischkammer**
Mixing chamber

7 **Gittermeßstrecke**
Cascade test section

8 **Kondensator 1**
Condenser 1

9 **Kondensatpumpe**
Condensate pump

10 **Kühlwasserpumpe**
Cooling water pump

11 **Eichmeßstrecke**
Calibration test section

12 **Kondensator 2**
Condenser 2

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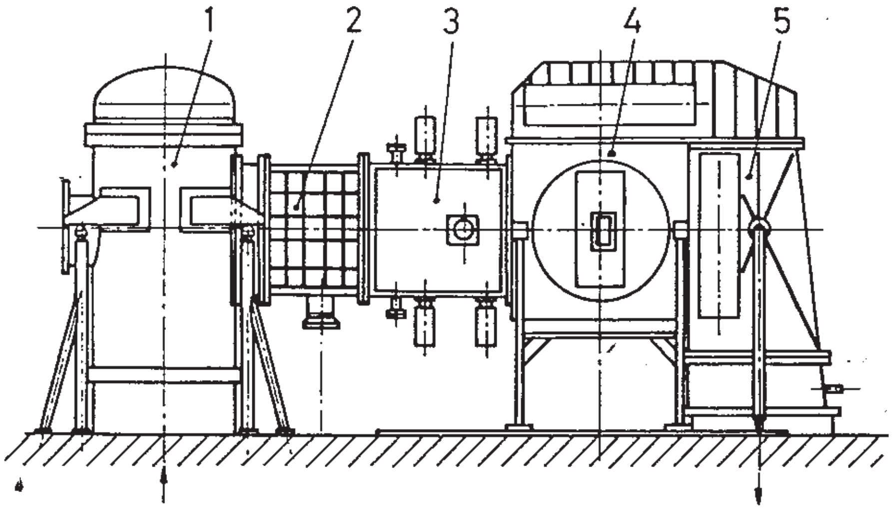
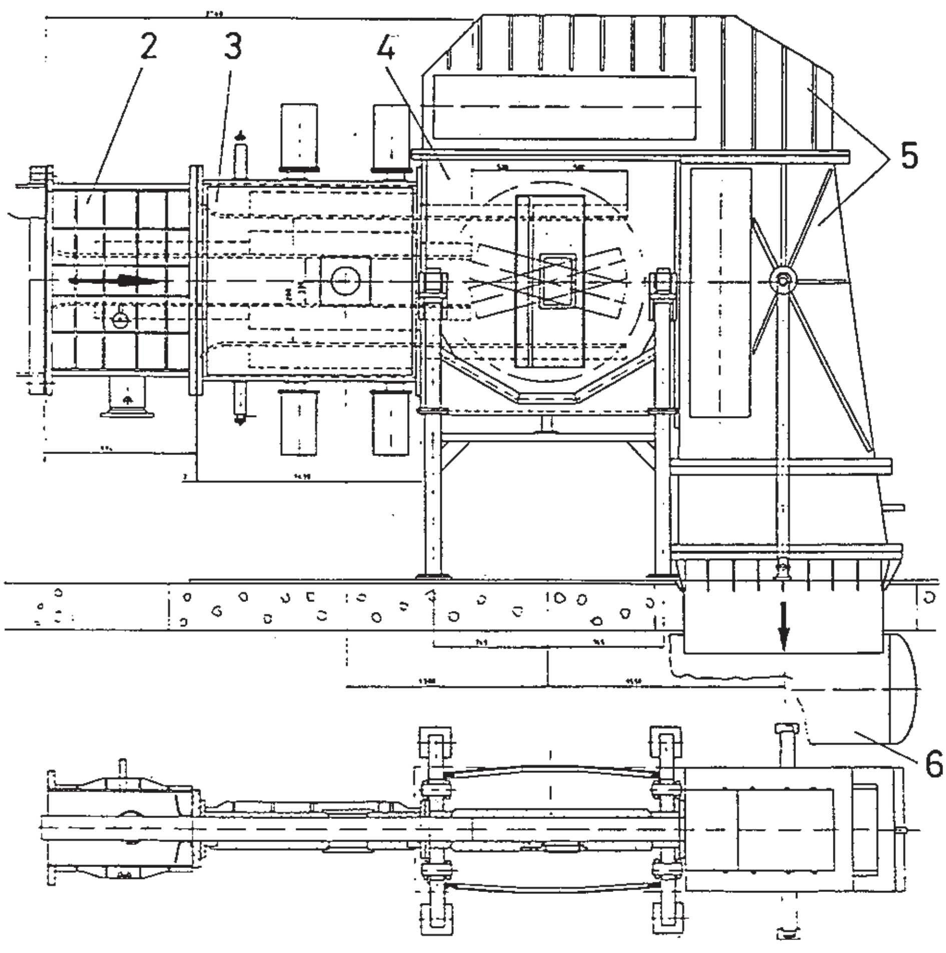
Cascade Steam Tunnel (general) | 2

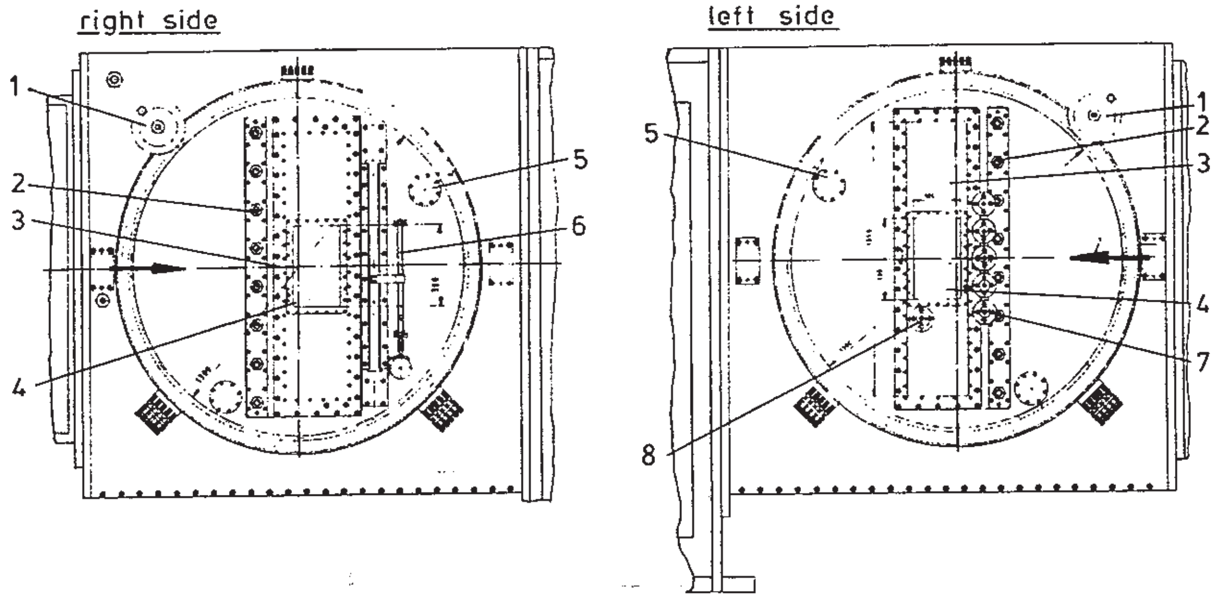


1 Mixing chamber
2 Settling chamber
3 Inlet casing
4 Cascade casing
5 Exhaust casing

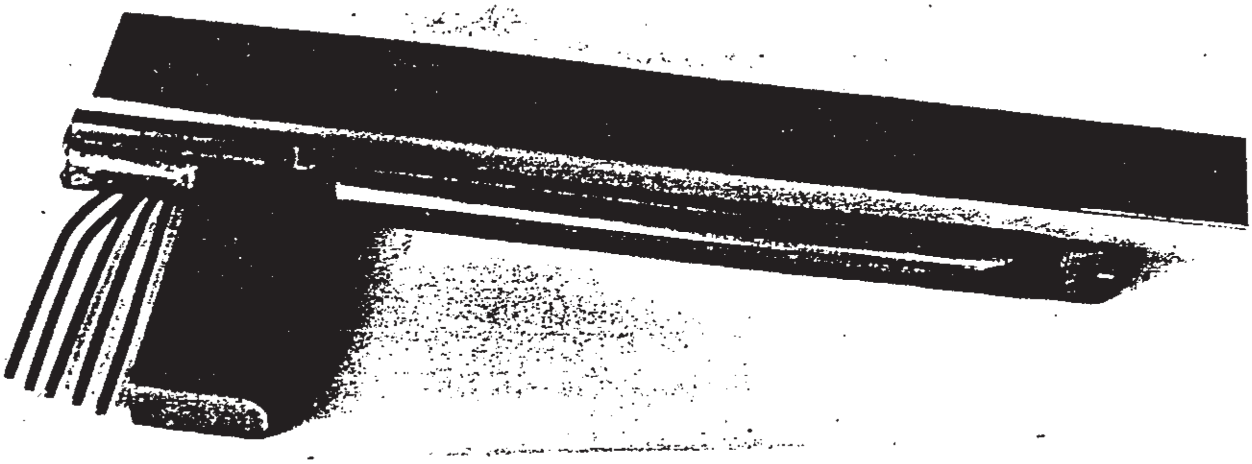
Cascade Steam Tunnel (detail) | 3

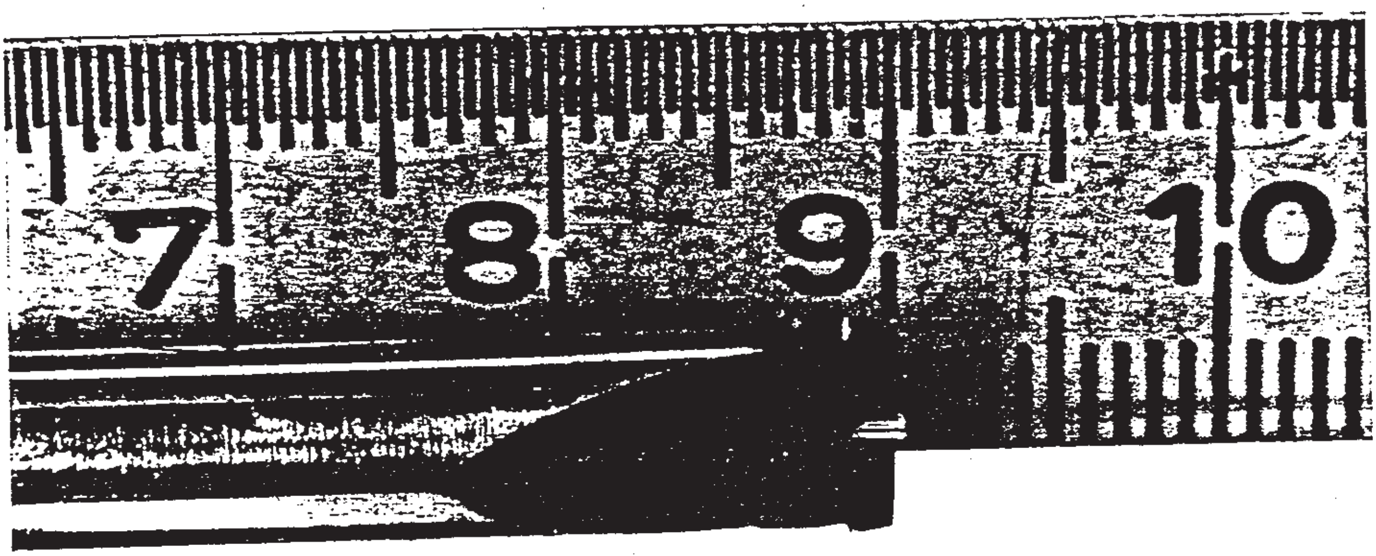


2 Settling chamber
3 Inlet casing
4 Cascade casing with cascade support
5 Exhaust casing
6 Steam chamber

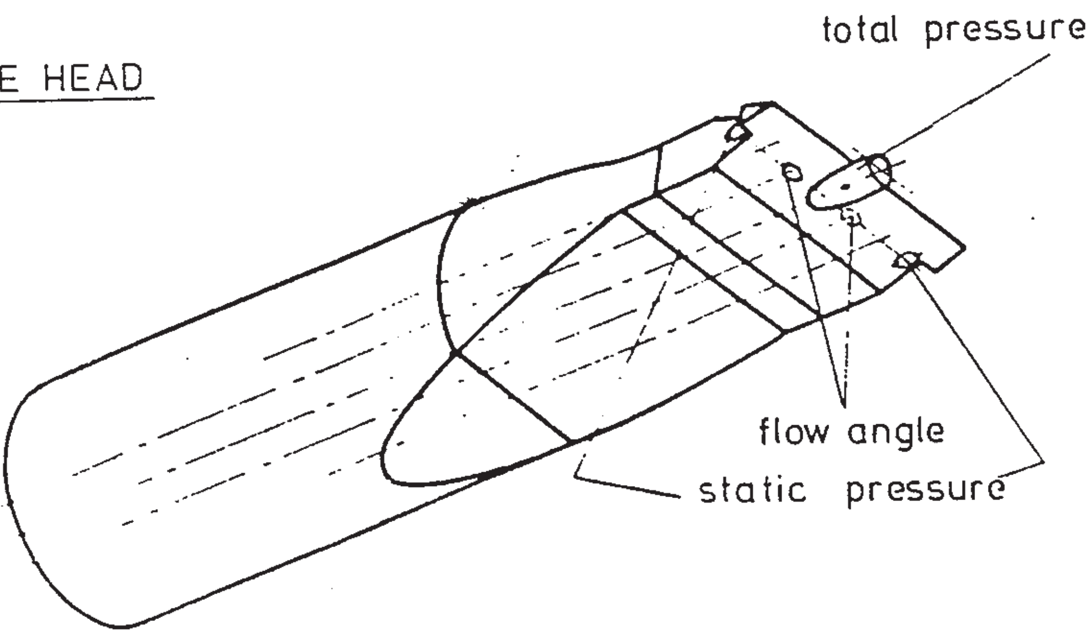


1 Turning device 2 Suction 3 Cascade support 4 Window
5 Spacer bolt 6 Probe traversing device 7,8 Probe connection

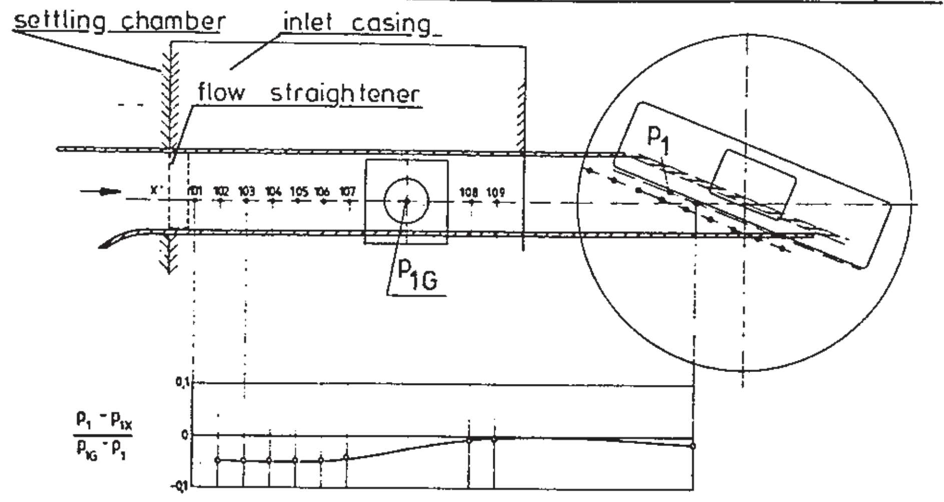




PROBE HEAD

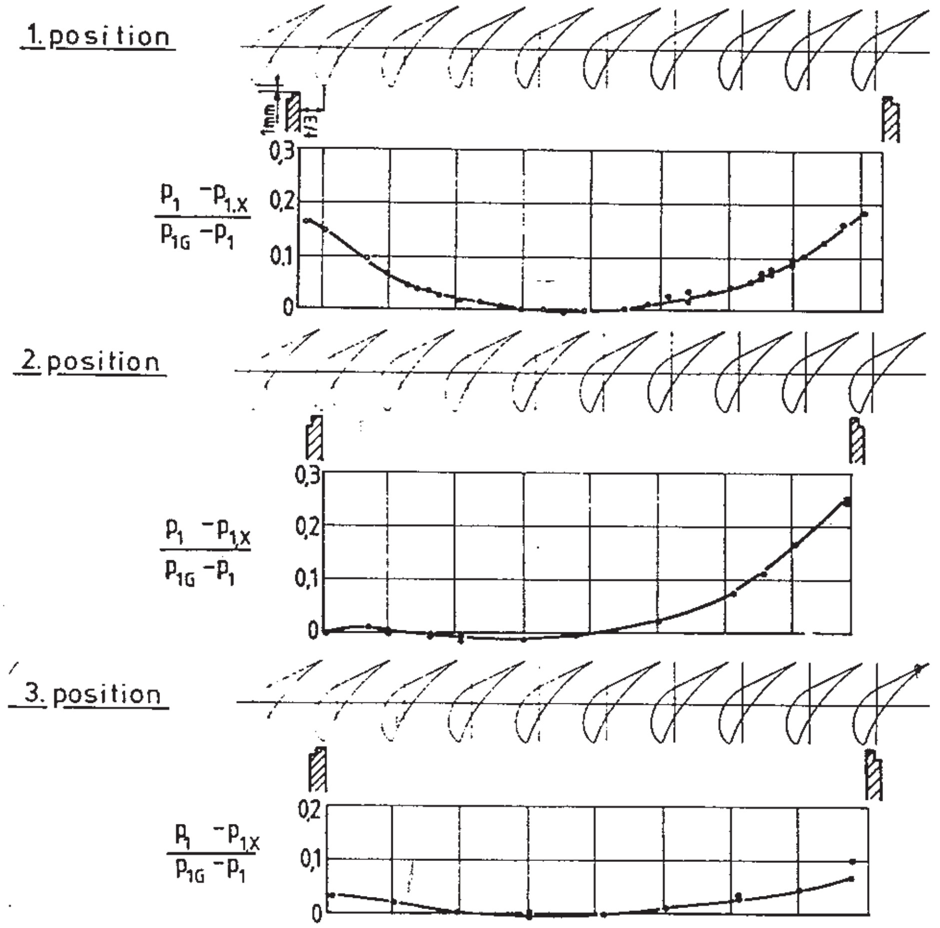


Distribution of Static Pressure in the Inlet Duct | 6



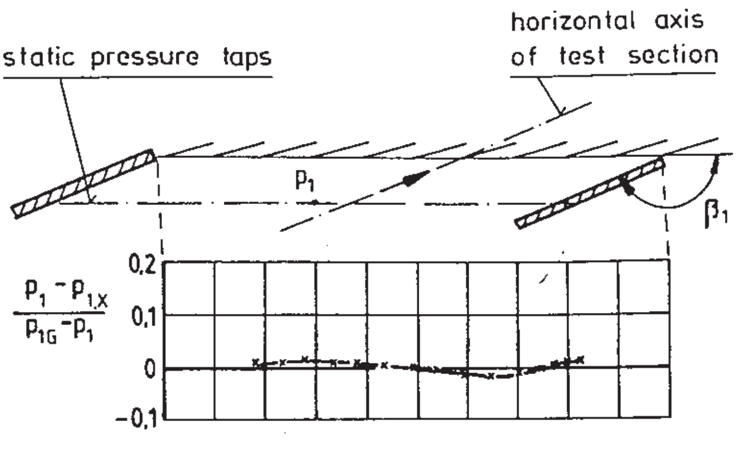
cascade of flat plates: $t/l = 1{,}0$; $\beta_{Bi} = 14{,}5°$; $\beta_1 = 159°$

Pressure Distribution in front of a Cascade Depending upon Wall Position | 7



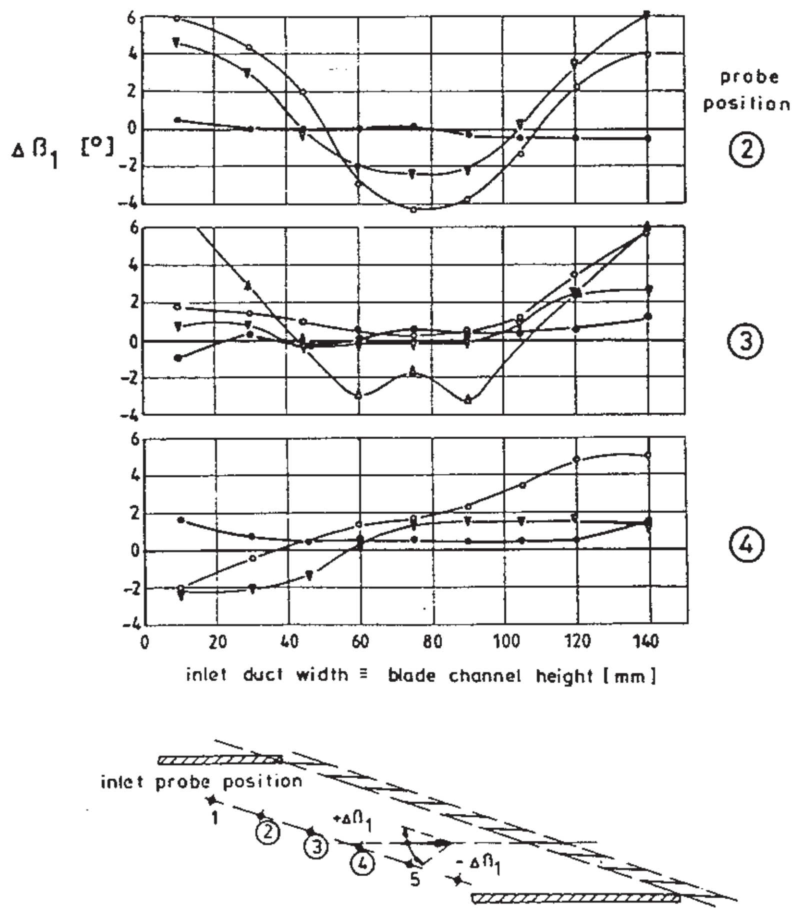
cascade: $t/l = 0{,}65$; $\beta_{Bi} = 50°$; $\beta_1 = 90°$

Pressure Distribution in front of a Cascade of Flat Plates — 8



cascade: $t/l = 1{,}0$; $\beta_{Bi} = 14{,}5°$; $\beta_1 = 159°$

Inlet Angle Deviation — 9



—Δ— perforated plate A in mixing chamber (22,5 % open)

—o— " " B " " " (10 % ")

—∇— plate B and convergent inlet duct

—•— plate B and flow straightener

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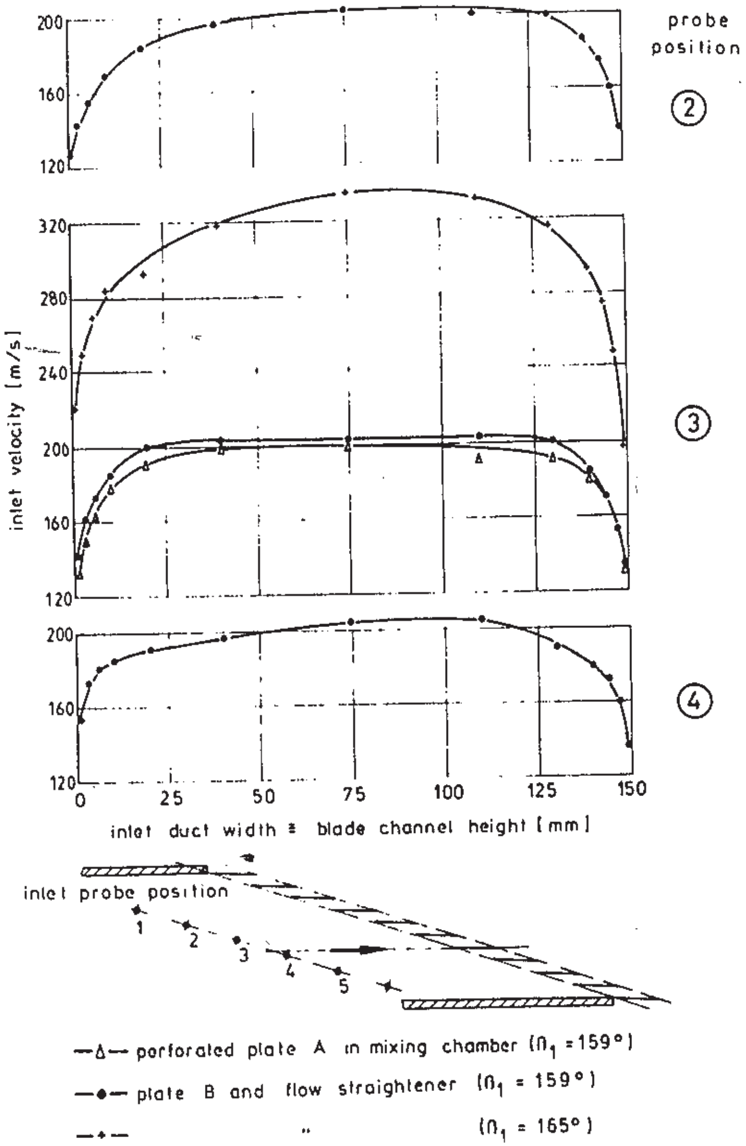
Inlet Velocity Distribution



Inlet Angle and Velocity Distribution with a Contoured Wall