EXPERIMENTAL STUDY OF PRESSURE LOSSES IN A WALL ATTACHMENT TYPE BISTABLE LARGE-SCALE FLUID ELEMENT

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Preface

In the examination of turbulent bistable fluid logic elements the most important viewpoints have so far been their application in automation. Even though the researchers studied these elements from the fluid dynamics aspects, they concentrated mostly on the analysis of those parameters which influence the characteristics connected to the control techniques (switching time, stability, recovery of pressure and flow) (e.g. [1], [2], [3], etc.). Others again studied the relation between the position of the individual structural elements (e.g. splitter), the dimensional ratios (aspect ratio, offset) and the velocity distribution, on the experimental and theoretical features of the switching mechanism (e.g. [4], [5], [6]). Since the size of the lateral bubble and the reattachment point are important factors in controlling these parameters, the pressure distribution was measured mainly along the side wall (e.g. [7]). Although SAWYER [8] performed pressure measurements also in the free jet, his experimental rig, having only one side-wall, was asymmetric and besides, he evaluated his findings from different aspects.

If a fluid element is built large not only for experimental purposes but because its utilisation calls for a large-scale element — for instance to function as a single switching element — then the examinations must meet another requirement, namely the determination and possible reduction of the losses and the loss sources.

Examination method, measurement results

For practical application a bistable switching element is one of the most important large-scale elements. Its simplest type is the wall attachment device on which, obviously, no vent must be provided because the discharge of the medium through it would necessarily cause losses in the mass flow.

When such a switching element is integrated in a system, it may naturally be substituted with some other, more conventional, structural part as, for instance, a valve. It is therefore justified to expect that the advantages it offers should not be offset by a much greater pressure loss than would occur in the classic layouts. To study this problem, the bistable element illustrated in Fig. 1 was integrated in an experimental rig which permitted to measure the pressure and velocity distribution within the element in question. As seen in the figure, the element is of an average geometry. Its individual dimensions have no significance for either the test method or its results.

Several preliminary tests were performed in the equipment with air before the final method has been developed. The flow structure was examined by a cylindrical probe with three bores, with its axis normal to the plane of Fig. 1. The cover plate of the element was so designed as to allow the probe to move not only in the direction of $x - y$ marked in the drawing but also in z direction, namely, perpendicularly to $x - y$. As shown, the aspect ratio of the nozzle was 2.64, viz. the height of the element $H = 76$ mm. Like in similar tests [8], the question emerged whether a flow between two parallel

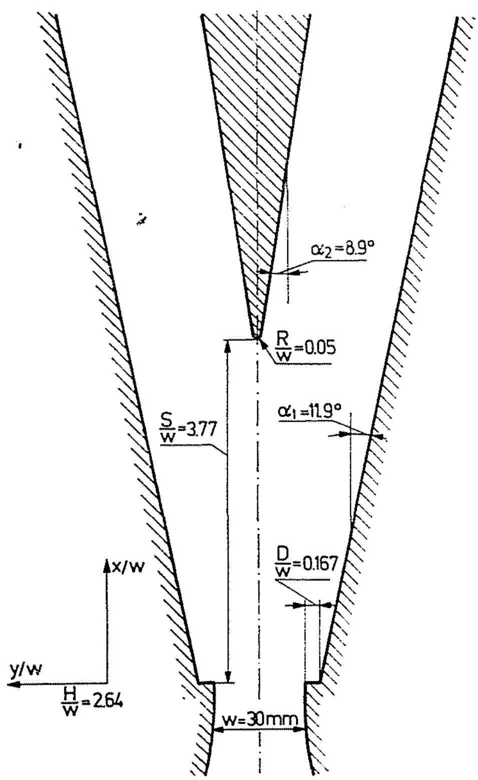

Fig. 1

plates at such distance apart might or might not be regarded to be planar. The answer to the question, like in the case of SAWYER, was reassuring: the deviation between the results obtained at different heights proved negligible. Thereafter, the experiments were performed at the height of $0.5 \times H$. The volumes of air passing through were measured by orifices on the feed side and in the two branches. The throttles were so adjusted as to prevent inflow from the outside space along the passive branch.

The cylindrical probe enabled the simultaneous measurement of direction, total head and velocity distribution. The probe diameter was 4 mm, therefore the values obtained near the walls were obviously inaccurate.

In the evaluation of the findings a method similar to Sawyer's was used, namely, assuming the values measured close to the walls to be approximative only, first the distribution curves were plotted then the values near the walls were corrected in consideration of the continuity. In the measurements the Reynolds number was 54 000, calculated with the average velocity determined in the nozzle and with a nozzle width W as the characteristic length.

The total head and velocity distributions were determined altogether in twenty $x =$ constant sections. Fig. 2 shows a number of characteristic velocity distribution curves and defined boundary streamlines. By boundary streamlines those two lines were meant which bounded that part of the jet issuing from the nozzle which actually passed through the element — which thus met the criterion of continuity. In this way, as known, the "mixing zone" ahead of the splitter is divided into three parts: one bubble, the main flow and the zone of contact with the medium in the passive branch. The main flow along the boundary streamlines entrains by friction and turbulent diffusion, also the medium in the two adjacent zones and causes vortices. Obviously, due to turbulent diffusion, the boundary streamlines are abstractions only, but rather illustrative. The media in the main stream and in the dead spaces move at identical velocity along the streamlines. This is evident from the figure. As a result, the velocity of the mean stream will be zero only at the boundaries where the stream contacts the solid wall. The point of reattachment shows fair agreement with the data found in literature (e.g. [9]).

To determine the changes in the total head the relationship

$$p_{ti} = \frac{1}{\bar{v}_i y_i} \int_{I_i} v_i p_i dy_i$$

was used which refers to an average total head p_t changing in the direction of x in the ith section where:

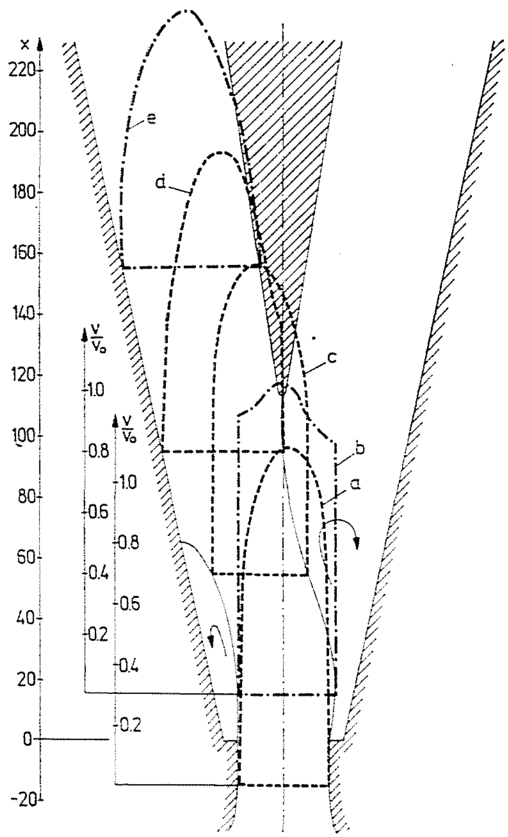

Fig. 2

v_i, p_i is the local velocity and the total head measured at various points.

$\bar{v}_i$ the average velocity of the main stream.

y_i the width of the mean stream at the point x_i under study.

Marking this average total head in the cross section of the nozzle outlet with p_{t0}, the change

$$\frac{p_i}{p_{t0}} = f\left(\frac{x}{W}\right)$$

has been plotted in Fig. 3.

A glimpse at Figs 2 and 3 will show that the bounding walls prevent the jet from spreading in the manner of free jets. Another limitation is caused by the lateral eddies. The variation of the total head along x, characteristic of the losses, gives clear indication of the location of the major loss sources. The total head drops by 54% compared to the value in the inlet cross section, but approximately 30% of this drop occurs along a stretch x which corre-

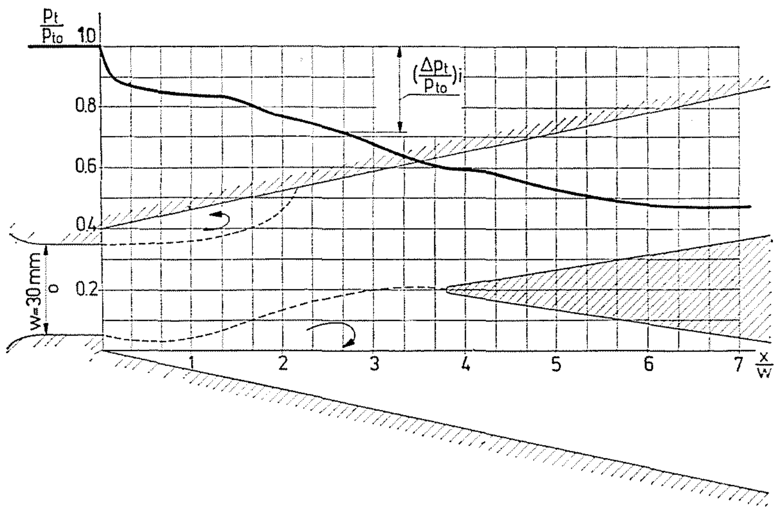

Fig. 3

sponds to 0.5 times the throat width (W). In the relatively flat and long lateral bubble and in the opposite dead space, obviously, high velocities evolve along the stretches nearly parallel to the boundary streamlines, while over the path nearly normal to the wall, the velocity is low. The initially high loss is probably caused by the fact that the parts of the lateral boundary zones contact the mean stream issuing from the nozzle at the point where the velocity differences are highest and acceleration seems to dissipate energy.

The coefficient of loss caused by a device inserted into a pipeline is generally interpreted by the term

$$\zeta = \frac{\Delta p}{\frac{\varrho}{2} v^2}$$

where

Δp denotes the loss in the total head,

ϱ the density of the flowing medium,

v the velocity of the flow at the inlet into the device.

Assuming unilateral outflow, in a branch-off controlled by gate valves the loss coefficient is approximately 1.5. If a valve is applied, this value becomes 4.5 on an average. In the experiments the inlet and outlet cross sections of the element were equal, the ratio of the total head to the dynamic pressure at the inlet 3.5. Since the flow up to the outlet cross section of the nozzle is accelerating, the total head loss up to that point is negligibly small. Denoting the pressure at the inlet into the element with the subscript e, the loss coefficient of the element in the classic interpretation will be:

$$\zeta = \frac{p_{te}}{p_{de}} \left(\frac{p_{t1}}{p_{t0}} - \frac{p_{t2}}{p_{t0}} \right) = \frac{p_{t0}}{p_{de}} \left(\frac{\Delta p_t}{p_{t0}} \right) = 1.89$$

(where subscripts 1 and 2 denote the outlet cross sections of the nozzle and of the element, resp.). This shows that the loss coefficient is higher than that estimated for a gate valve.

Further examinations are necessary to determine — in the knowledge of the major loss sources — what modification of the dimensions would enable a further reduction of this loss, or, what other advantages may compensate for the slightly higher loss coefficient.

Summary

When large-scale fluid elements are applied, the problem of losses assumes increasing importance. The paper deals with the experimental determination of the changes of the total head in flow in a wall-attachment bistable element and established that 30% of the loss occurs along the stretch immediately behind the nozzle outlet. The losses are probably caused by the local highest velocity differences between the lateral zones and the main stream.

References

1. Kirschner, J. M.: Jet Flows. Fluidics Quarterly 1, 3, 33 (1968).
2. Leván, J.—Manion, F. M.: Jet-Attachment Distance as a Function of Adjacent Wall Offset and Angle. H.D.L. (1), TR-1087.
3. Olson, R. E.—Chin, Y. T.: Studies of Reattachment Jet-Flows in Fluid-State Wall Attachment Devices. H.D.L. (3), AD-623911.
4. Wada, T.—Shimizu, A.: Experimental Study of Attaching Jet Flow on Inclined Flat Plate with Small Offset. 2nd IFAC Symposium on Fluidics, Paper A5.
5. Williams, C. J.—Calborne, W. G.: Splitter Switching in Bistable Amplifiers. Paper presented at ASME-CSME Conf., Montreal, CSME Paper 74-CSME 83.
6. Moses, H. L.—Camparian, R. A.: The Effect of Geometric and Fluid Parameters on the Static Performance of Wall-Attachment Type Fluid Amplifiers. Paper pres. at Fluid-State-of-Art Symp. (H.D.L. 1974). 1. pp. 403—431.
7. Bekaert, G.—Carbonaro, M.: Experimental Study of the Switching Characteristics of Bistable Amplifiers in the Turbulent Flow Regime. Report AD-782892, 75 pp. (1974).
8. Sawyer, R. A.: The Flow Due to a Two-Dimensional Jet Issuing Parallel to a Flat Plate. Journal of Fluid Mechanics, Vol. 9. Part 1. 1960.
9. Jones, N. S.—Foster, K.—Mitchell, A. E.: A Method of Calculating the Wall Reattachment Pressure Distribution in a Turbulent Reattachment Bubble. C.F.C. (2), Paper A3.

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