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Abstract

Pressure distributions in the gap of a model of a rectangular reed valve are given for various gap height. The reed is modeled by a rigid plate fastened in various position in respect to the valve port. Aerodynamic force distributions and aerodynamic force coefficients are then calculated. The measured pressure distributions are compared with theoretical ones obtained by means of finite elements methods for a simplified mathematical model of the flow in the gap.

Introduction

The reed valves are mostly used in the small reciprocating compressors due to their simplicity and reliability. However, the flow in such valves is very complicated, especially if the reed has a complex shape. The flow is three dimensional and shows separation regions. Because the ratio of the reed area to the port area is relatively large the flow velocity varies strongly. Therefore the compressibility of the fluid should be taken into consideration. The gas friction is important too [1]. Moreover, strong interaction between the flow and reed deformations appears. From the above mentioned properties difficulties arise about the prediction of the flow and therefore in designing of the valve.
There are many mathematical models of valves [2,3,4] considering even very complicated shapes of reeds, but very often fine model of reed is accompanied by a very simple model of the flow. There are also experimental works [5,6,7] concerning valves of axial symmetry.

In this paper an experimental study concerning pressure distribution and resulting aerodynamic force is presented. These experiments have been made using a rectangular rigid plate fastened parallel or oblique to the seat. The pressure distributions have been compared with theoretical ones obtained for two extremal cases:

1. taking into account friction and neglecting flow inertia,
2. taking into account flow inertia and neglecting friction as well gas compressibility.

These cases correspond to narrow and wide gap respectively. The oil and shadowgraph technique has been applied to visualize the gas flow.

Small model

The small simplified model of the valve consists of a plate with a hole (of 10 mm diameter), modeling the valve port and a rigid plate (17*30 mm) located above the hole, modeling the reed. In first experiments the aerodynamic forces acting on the plate as a function of the pressure difference and the height of the gap were measured. In the range of pressure differences from 0 to 0.3 bar it was possible to estimate a curve showing the changes of the force coefficients (defined as a real force to the reference force - product of port area and pressure difference) with respect to the non-dimensional height of the valve gap. Such a curve is presented in Fig. 1. The wall pressure was measured too. The great positive value of the force coefficient for small gaps and negative value for large gaps is typical in this case. Fig. 2 gives a typical pressure distribution in the configuration with a small gaps. The pressure values in the whole area are higher then the ambient pressure. In Fig. 3 a typical pressure distribution in the case of a large gap is shown. Regions of negative pressures are clearly visible.

Theoretical models

Two theoretical models for the flow in valve gaps, a very small and large gap, were considered. In the analysis of the flow in small gaps the viscosity is dominant so the model of viscous compressible flow was used. The method of finite elements [8] was used to solve this problem numericaly. Fig. 4 shows the flow field in one quarter of the gap area whereas Fig. 5 presents corresponding pressure distribution. As mentioned above this model is valid only for very small gaps.

For the flow in large gaps when the inertia is dominant the model of potential flow was used. In this case the

method of finite elements required iteration. Fig. 6 presents the velocity vectors and Fig. 7 pressure distribution predicted by computation.
The calculated results using the first model coincide with the experimental ones quite well but only for very small gaps. The second model omits such important phenomena like boundary layer and flow separation and therefore the theoretical results are slightly different from the experimental ones. The theoretical models considered here describe only the extreme flow conditions.
It seems that the mathematical model taking into account both the flow inertia and the friction for compressible fluid has not been elaborated hitherto.

Enlarged model

Fine pressure measurements have been carried out using the enlarged model which was five times larger than the small one. It enabled us to use more pressure probes. Two basic plate geometries - a rectangular and a circular-axisymmetric have been used. Aerodynamic force distributions along the valve axis for the rectangular plate are presented in Fig. 8-10.
Fig. 8 shows the force distributions in the case of a valve gap of constant height with the plate clamped at one side and with the port located asymmetrically near to the free side of the plate. The strong variation of the aerodynamic force acting on the plate can be noticed.
Fig. 9 presents the force distribution in a similar gap geometry, but the port is located near to the clamped end of the plate. The large region of negative forces is visible (look for the force coefficient data).
In Fig. 10 the aerodynamic force distributions in the gap with linearly variable height of the gap is shown. In this case relatively large region of positive force can be noticed on the side of decreasing high of gap. It corresponds to large positive values of the force coefficient.
Fig. 11 presents an example of the pressure distribution in part of the gap with variable height.
Because of large ratio of outlet area to the minimum cross section area relatively high velocities in the vicinity of valve ports are generated. This phenomena was investigated in the axisymmetric valve model. Using this model pressure measurements and the oil and shadowgraph visualization were performed.
The next four figures (Fig. 12,13,14,15) show the pressure distribution on the upper (plate) and lower (seat) part of axisymmetric valve, for low pressure differences, and for small as well very small gaps respectively. One can notice the change of the pressure

distribution with the increasing height of the valve gap. A positive pressure (in respect to ambient pressure) which is observed in the vicinity of the valve port for small gap became negative for high gap withs.
Fig. 16 shows the pressure distribution on the lower part (seat) of the valve for relatively high pressure differences and large gap. In this case the flow becomes supersonic and is accompanied by complicated structures including shock waves (Fig. 18).
Three rings, corresponding to lines of flow separation caused by the rapid change of flow direction and the presence of shock waves, are clearly visible in Fig. 17 which is an example of the oil visualization.
The shock wave patterns has been visualized by means of the shadowgraph method.
A set of photographs showing the flow patterns with varying pressure ratio is presented in Fig. 18. Two different flow structures can be seen for Po/Pamb=1.4 . A histeresis is thus observed.

Conclusions

The pressure distribution in the gap of a given reed valve depends strongly on the reed valve position in respect to the seat (in the present experiments on the plate position). For a small height of the gap the overpressure is observed in the whole seat area. In the opposite case with relatively large height of the gap underpressure appears in the vicinity of the port. The mathematical model neglecting inertia forces gives results, which coincides well with experimental ones in the case of small height. The another extremal model taking into account flow inertia and neglecting friction effects gives insufficient accuracy. It is caused not only by friction effects such as a boundary layer but also by separation and flow discontinuities (shock waves).

Notation

A	- port cross section
D	- port diameter
Dp	- pressure difference
F	- aerodynamic force
Fref	- refference force (Dp*A)
H,h	- height of the gap
L	- length of the gap (plate)
P	- static pressure
Po	- stagnation pressure
Pamb	- ambient pressure
w	- width of the gap (plate)

Reference

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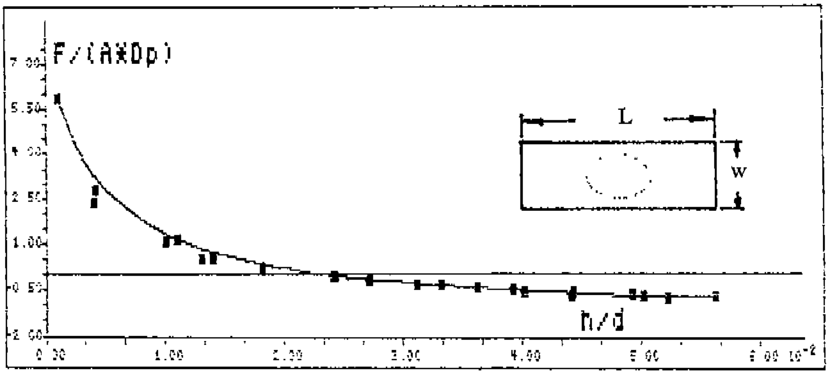

Fig. 1 Variation of the force coefficient (valve with single port)

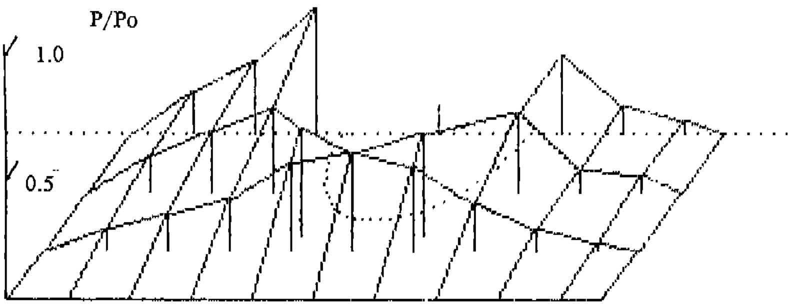

Fig. 2 Example of experimental pressure distribution in valve gap (h/D < 0.01)

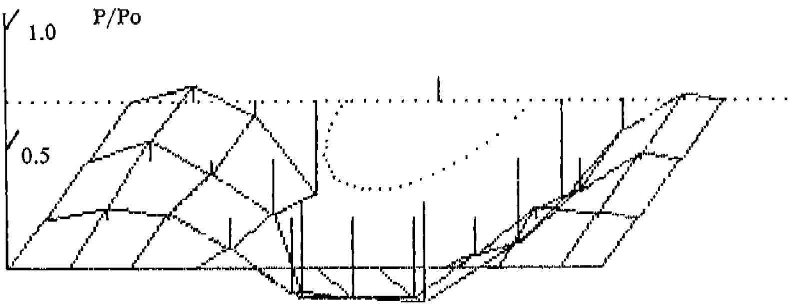

Fig. 3 Example of experimental pressure distribution in valve gap (h/d > 0.05)

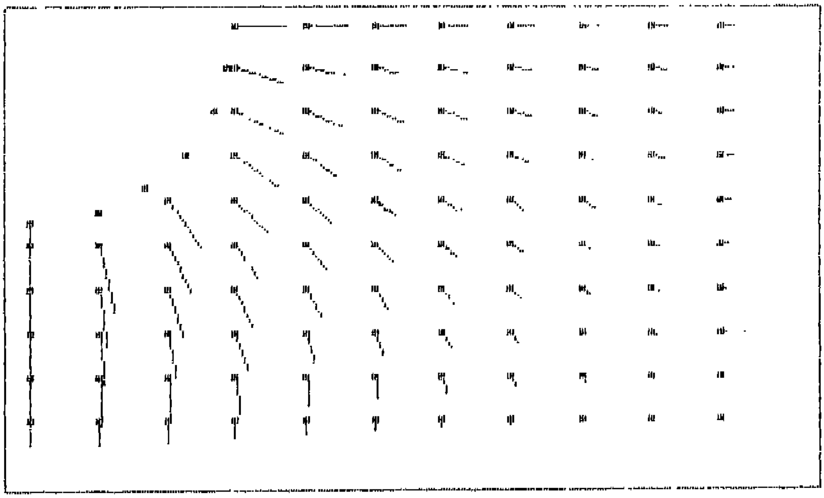

Fig. 4 Theoretical results: velocity vectors
(viscous flow)

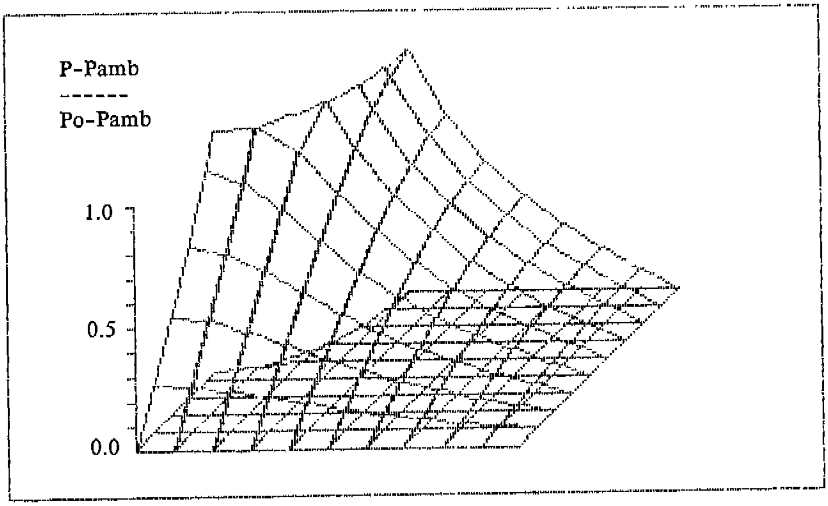

Fig. 5 Theoretical results: pressure distribution
(viscous flow)

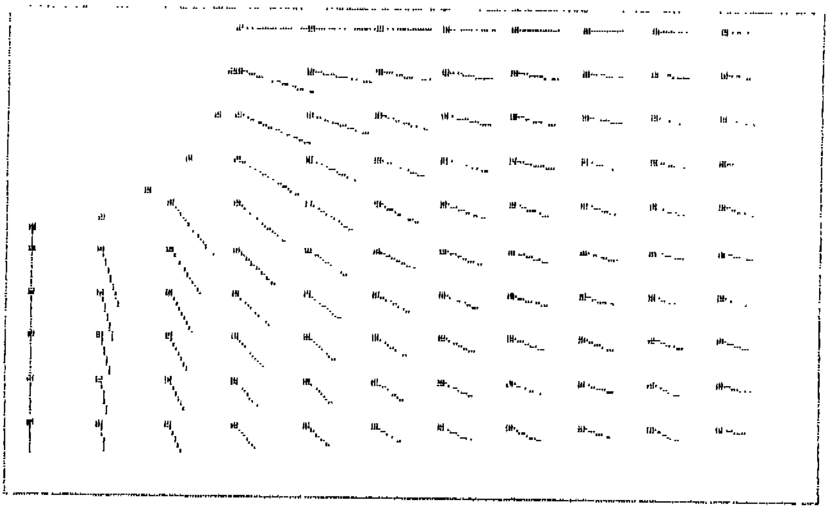

Fig. 6 Theoretical results: velocity vectors
(potential flow)

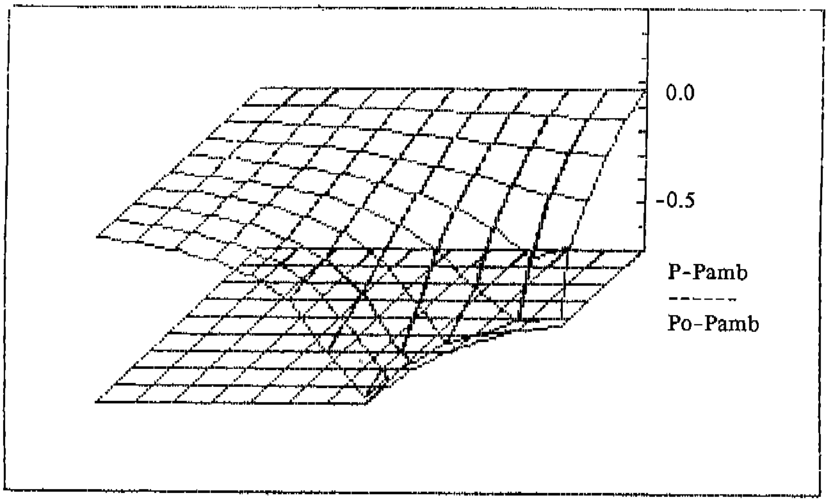

Fig. 7 Theoretical results: pressure distribution
(potential flow)

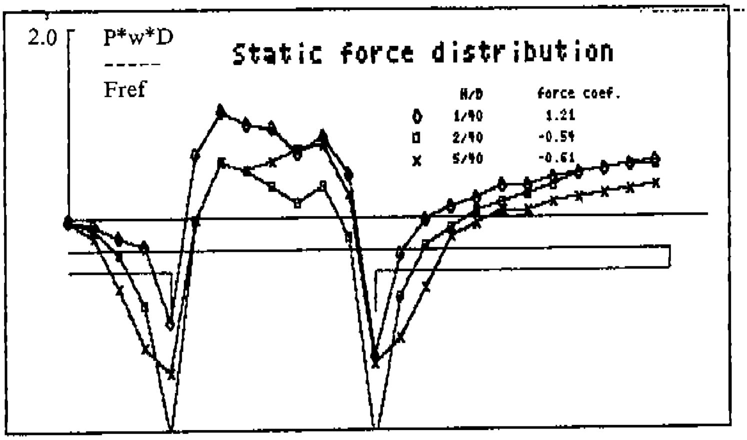

Fig. 8 Aerodynamic force distribution along valve axis
(configuration A)

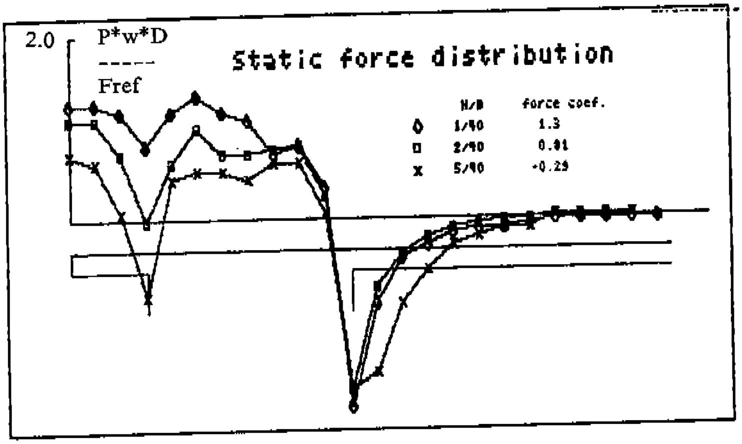

Fig. 9 Aerodynamic force distribution along valve axis
(configuration B)

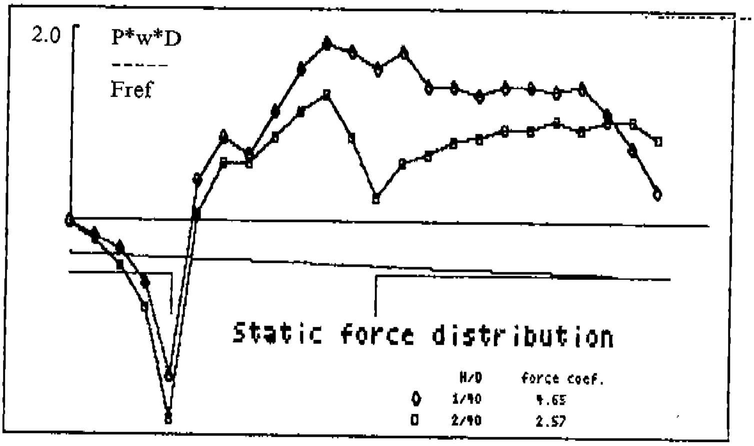

Fig. 10 Aerodynamic force distribution along valve axis
(configuration C)

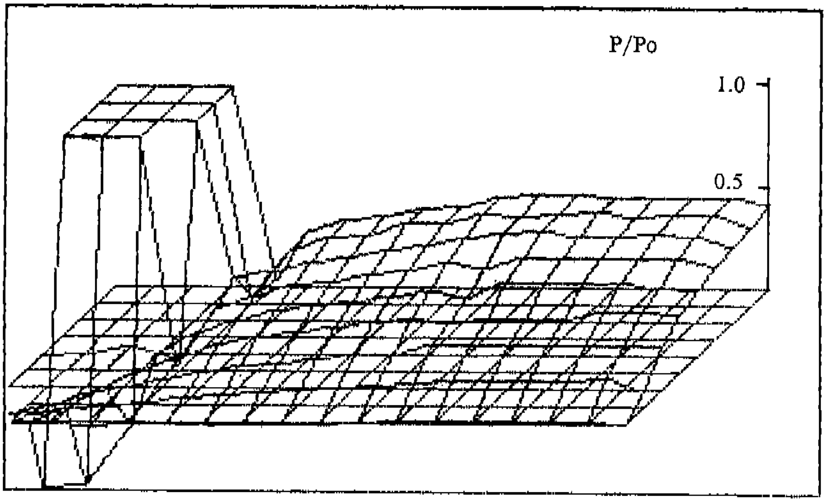

Fig. 11 Example of experimental pressure distribution
in part of valve gap (configuration C)

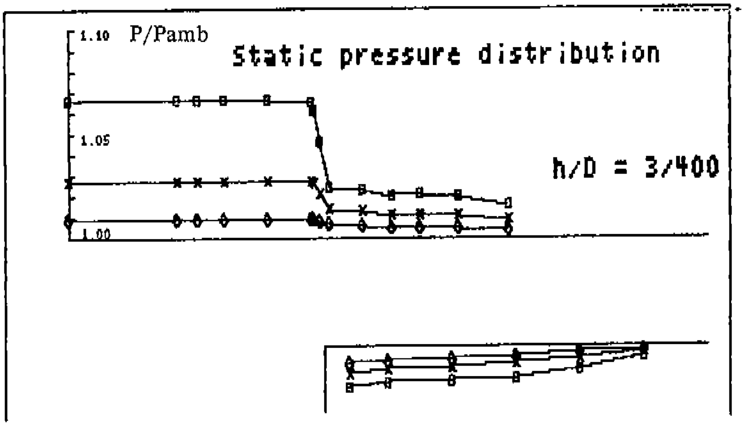

Fig. 12 Pressure distribution in valve gap
(axisymmetric flow)

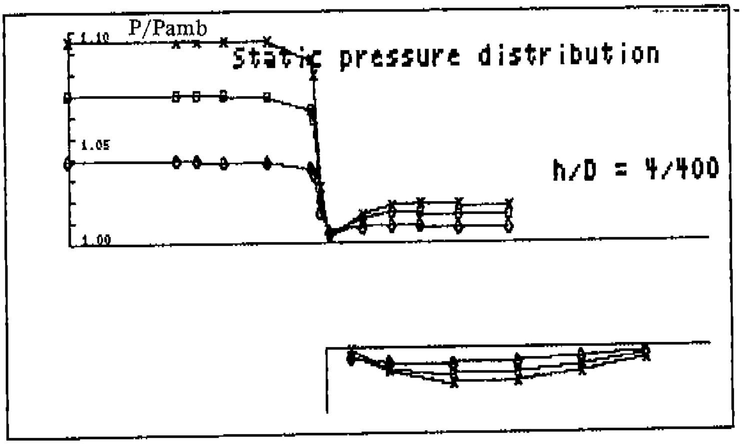

Fig. 13 Pressure distribution in valve gap

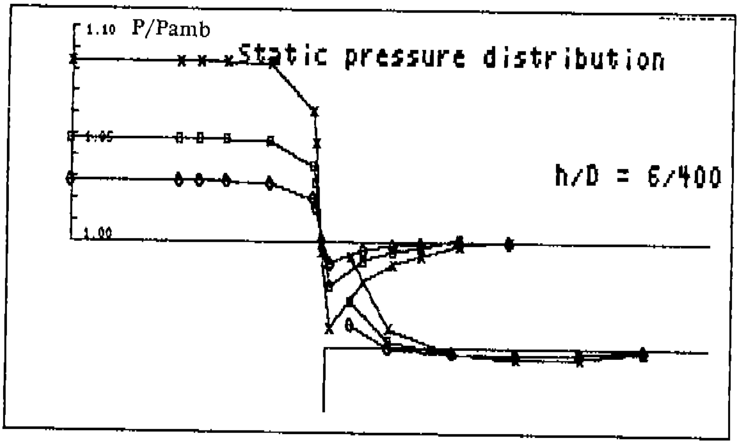

Fig. 14 Pressure distribution in valve gap

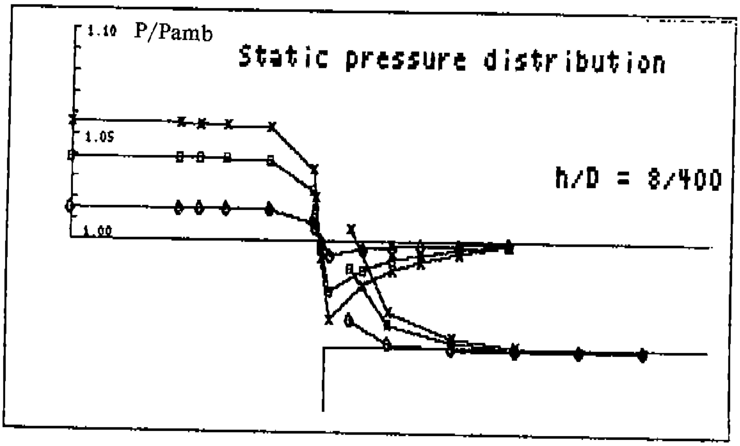

Fig. 15 Pressure distribution in valve gap

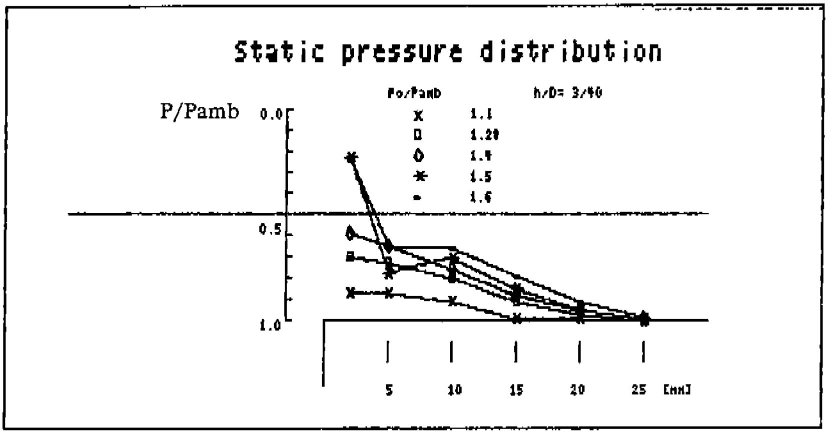

Fig. 16 Pressure distribution in valve gap

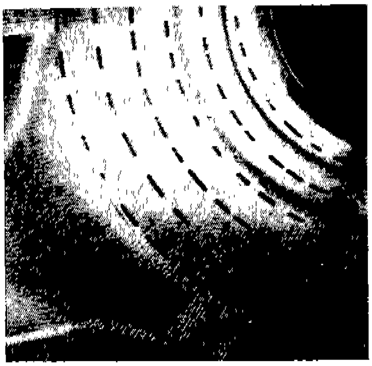

Fig. 17 Example of oil visualization of flow in valve gap

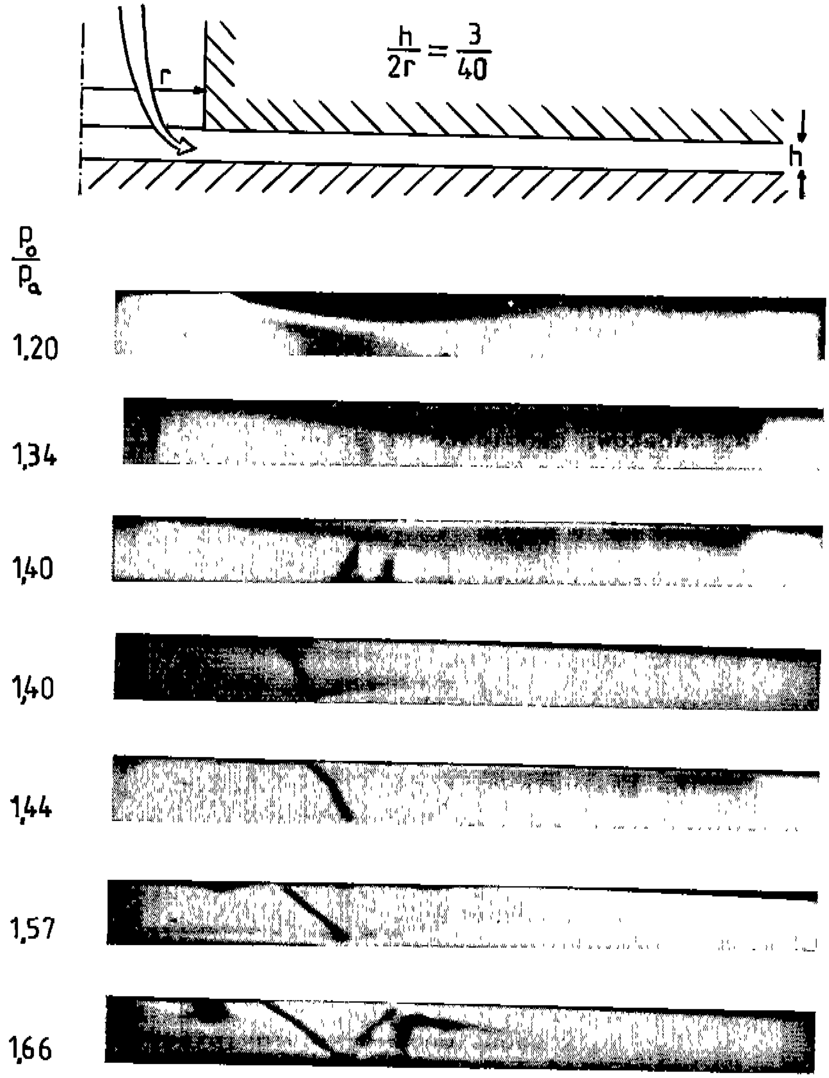

Fig. 18 Shadowgraph visualization of flow in valve gap