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poświęcone są publikacjom naukowym z zakresu teorii i badań doświadczalnych w dziedzinie mechaniki i termodynamiki przepływów, ze szczególnym uwzględnieniem problematyki maszyn przepływowych

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exist for the publication of theoretical and experimental investigations of all aspects of the mechanics and thermodynamics of fluid-flow with special reference to fluid-flow machinery

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PRACE INSTYTUTU MASZYN PRZEPŁYWOWYCH

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Gdańsk

The Influence of the Rotating Disc Edge Shape on the Flow Through the Circumferential Gap

The influence of the disc edge shape on the mass flow rate coefficient and the structure of the flow at the circumferential gap has been investigated. The circumferential gap was created between rotating disc placed in the tube and the tube walls.

1. Introduction

Circumferential gaps can be commonly found in turbomachinery and rotor devices. The shape of the gap affects essentially the flow field and thus the mass flow rate through the gap.

The geometrical situation investigated by the authors of this report is shown in Fig. 1.

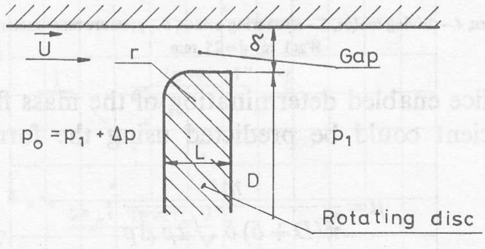

Fig. 1. Geometrical parameters of the circumferential gap ($D=2R=150$ mm, $L=1$ mm, $\delta=1$ mm)

It can be easily noticed that the shape of an individual gap can be described by four geometrical parameters: δ, L, r and D. The influence of the nondimensional parameter r/L on the mass flow rate was the subject of investigation discused in this report while the influence of the parameter L/δ has been reported in the previous paper [1]. It has been found that the increase of L/δ and rotation speed of the disc decreases the mass flow rate.

The geometry of the experimental arrangement shown in Fig. 2 resembles the geometry of the stand used by Vogel [2] and Escudier [3], where a rotating disc was immersed in a closed cylindrical container. These experiments [2, 3] concerned the vortex breakdown phenomena in laminar region. In the present paper – like in the previous one [1] – the main attention is paid to the leakage through the gap. The behaviour of the bulk of the flow in front of the disc has been visualized. The rotation Reynolds number $\frac{\Omega R^2}{\nu}$ has reached the value up to 10^6, which is much higher than that reported in [3]. This value is characteristic rather for the discs applied in turbomachinery and operating in the turbulent flow regime.

2. The Experimental Stand and the Method of Measurement

The scheme of the stand is shown in Fig. 2*).

Following quantities have been measured at this facility:

1) pressure and temperature ahead of the measuring orifice p_0, t_0,
2) pressure drop across the measuring orifice Δp,
3) rotation speed of the rotating disc,
4) flow visualisation has been carried out additionally ahead of the disc.

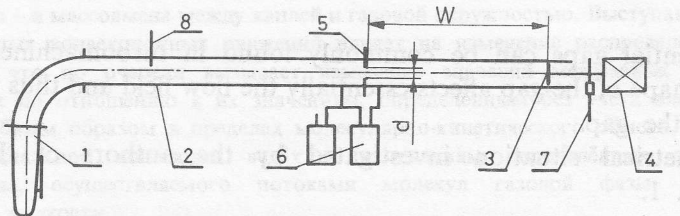

Fig. 2. Schematic diagram of the experimental stand

1 – ventilator, *2* – pipe, *3* – rotating disc, *4* – driving motor, *5* – measuring orifice, *6* – pressure manometer, *7* – photocounter, *8* – thermometer; $W \cong 1$ m, $d = 25$ mm

The measuring orifice enabled determination of the mass flow rate m. Hence the mass flow rate coefficient could be predicted using the formula:

$$\mu = \frac{m}{\pi (D+\delta)\,\delta \sqrt{2\rho\, \Delta p}}, \tag{1}$$

where ρ – density, Δp – pressure drop across the gap Fig. 1.

The denominator in (1) represents the mass flow rate through the circumferentional gap with the isentropic velocity

$$w = \sqrt{2 \frac{\Delta p}{\rho}}. \tag{2}$$

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*) This stand was partly equipped by the Lehrstuhl für Strömungslehre Universität Karlsruhe within the framework cooperation with the Institute of Fluid-Flow Machinery of the Polish Academy of Sciences.

The investigations carried out previously [1] have shown very significant influence of the parameter u/w (where $u=\pi Dn/60$ – circumferential velocity of disc) upon the mass flow rate coefficient.

As the result of measurements reported here the function

$$\mu=\mu\left(\frac{r}{L}, \frac{u}{w}\right) \tag{3}$$

has been established.

The rest of geometrical parameters shown in Fig. 1 was kept constant. Maximum pressure ahead of disc was 850 Pa and rotation speed of the disc was varied within the range of $n=0\div 20{,}000$ r.p.m.

3. Results of the Measurements

The mass flow rate coefficient μ as a function u/w is shown in Fig. 3 for various values of the parameter r/L.

It is worth while to notice the essential difference between curve *1* obtained for the "sharp edge" disc – $r/L\approx 0$ $(r/L<0.1)$ – and curves *2* corresponding to the rounded edge disc.

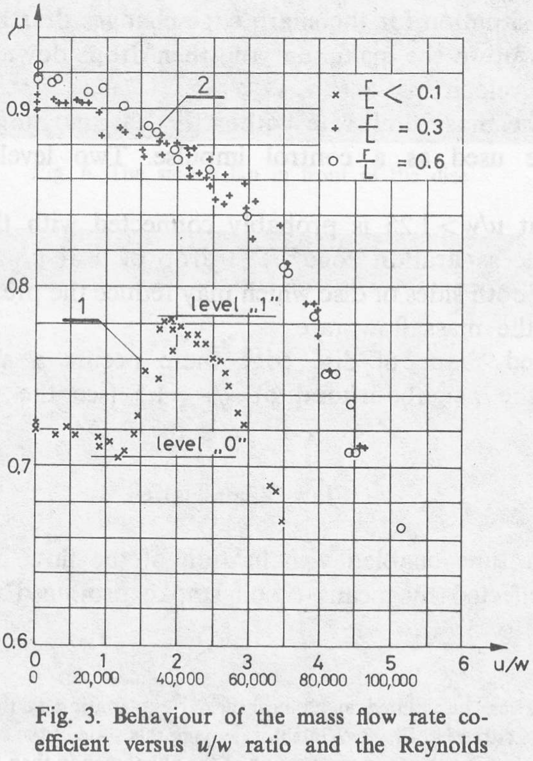

Fig. 3. Behaviour of the mass flow rate coefficient versus u/w ratio and the Reynolds number $Re=\Omega R^2/\nu=(\pi/120)\cdot D^2 n/\nu$ for two kinds of disc edge

The "sharp edge" means here a technologically sharp one. It has been estimated by means of the microscopic observation that the aproximate radius of curvature of the "sharp edge" is less than 0.1 mm.

The presumable reason for this difference comes out from the flow separation occurring in the sharp edge gap. The scheme of the flow is shown in Fig. 4.

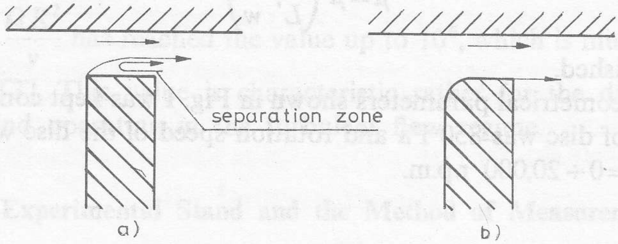

Fig. 4. Two possible situations in the gap

The flow separation inside the gap could be observed only by means of visualisation techniques applied in this narrow region. No technical possibility for such a visualisation was at hand during the experiments reported.

The rounded edge does not cause the contraction which can explain the difference in the magnitude of μ for small value of $u/w<1.25$. In the region of $1.25<u/w<2.0$ the situation for the sharp edge changes drastically. The mass flow rate coefficient rises up to the maximum and then drops down with the increase of the circumferential velocity.

This jump in the mass flow rate within the narrow range of circumferential velocities could be used as a control impulse. Two levels "0" and "1" are marked in Fig. 3.

The rise of μ at $u/w>1.25$ is probably connected with the decrease or even disappearence of the separation zone*). The drop of μ at $u/w>2.0$ is the effect of pressure rise on the both sides of disc which may reduce the pressure drop across the gap and decrease the mass flow rate.

For the rounded shape of disc edge there occurs a slight disturbance in μ distribution in the neighbourhood of $u/w\simeq1.5$ (see the points + for $r/L=0.3$ in the Fig. 3).

4. Flow Visualisation

The transparent tube enabled visualisation of the flow in front of disc. The visualisation was effected by means of oil smoke produced and supplied by the system shown in Fig. 5.

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*) One of the reviewers has hinted at an unsufficient explanation of the jump in the mass flow coefficient following from curve *i* in Fig. 3. While not denying this state of the art the authors point to the lack of sufficient justification of any other explanation of the phenomenon than that of the separation zone disappearence within the gap.

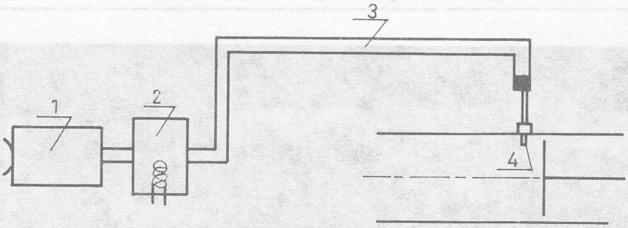

Fig. 5. Schematic diagram of the smoke supply system
1 – ventilator, *2* – smoke generator, *3* – transparent pipe, *4* – probe

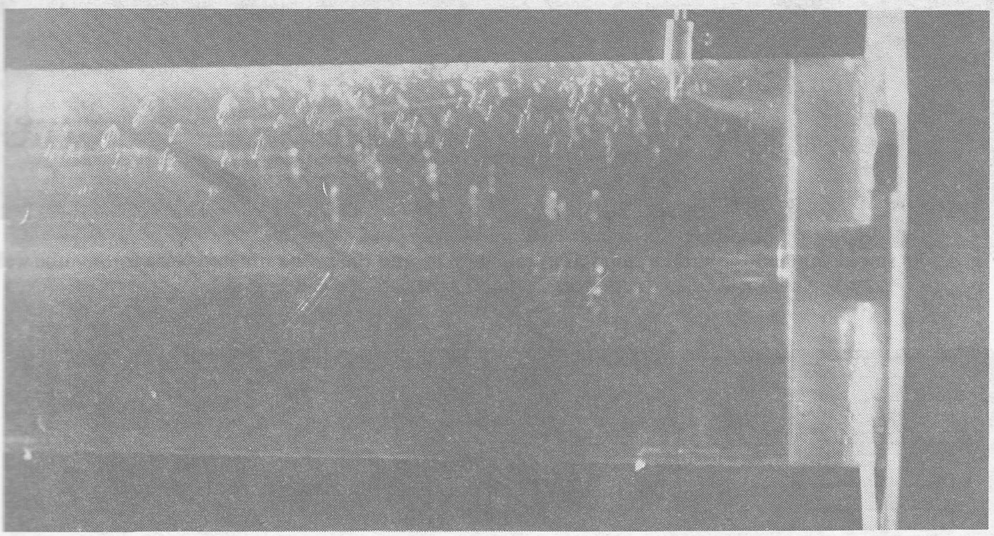

Fig. 6. The smoke fan in front of the disc

Fig. 7. The smoke fan and the smoke cloud in front of the disc at $n=5000$ r.p.m.

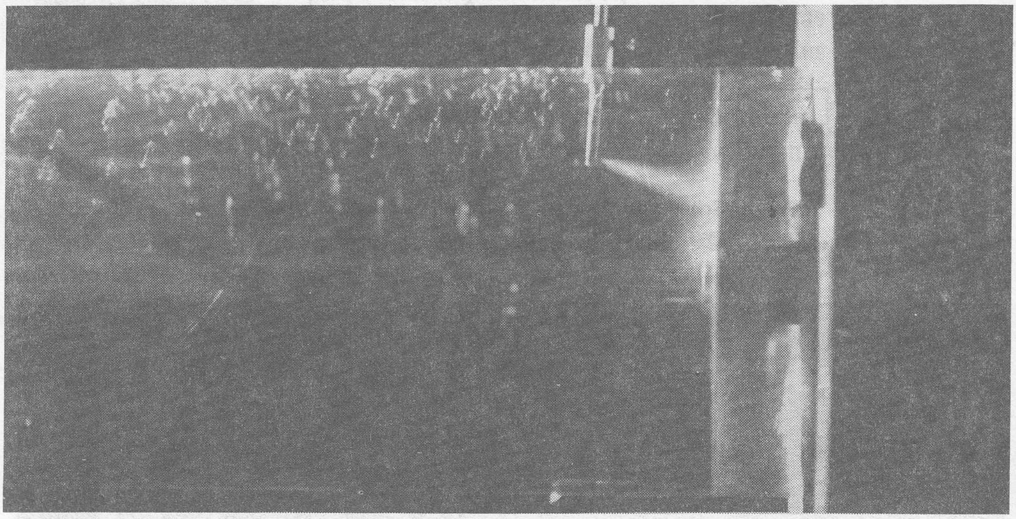

Fig. 8. The smoke fan and the smoke cloud at $n=5000$ r.p.m. and the probe situated close to the tube wall

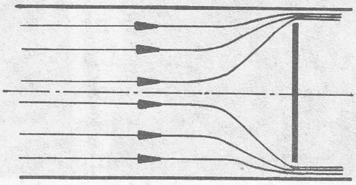

Fig. 9. A sketch of the flow pattern in front of the sharp-edged disc at low circumferential speed

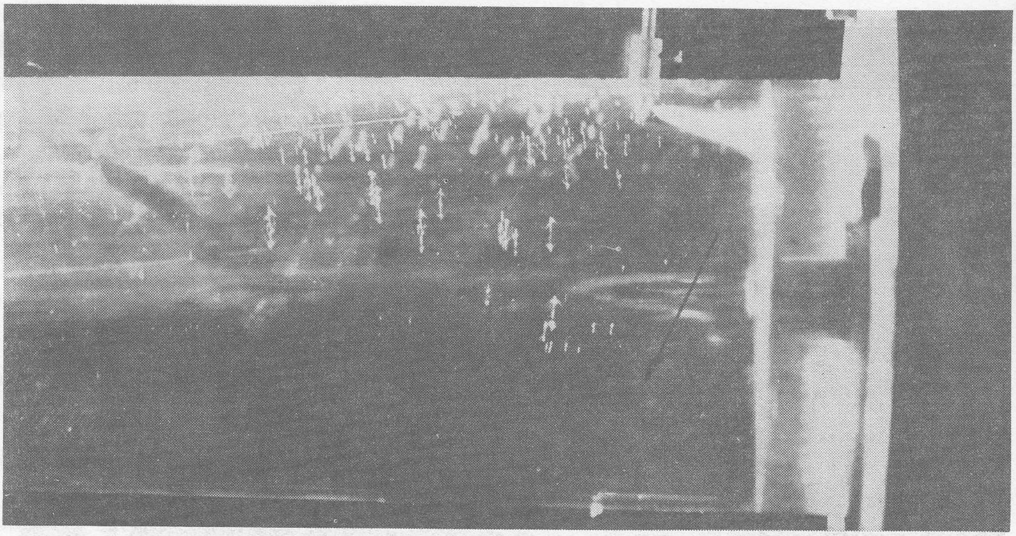

Fig. 10. The sign of the "backward spiral" flow at $n=7500$ r.p.m.

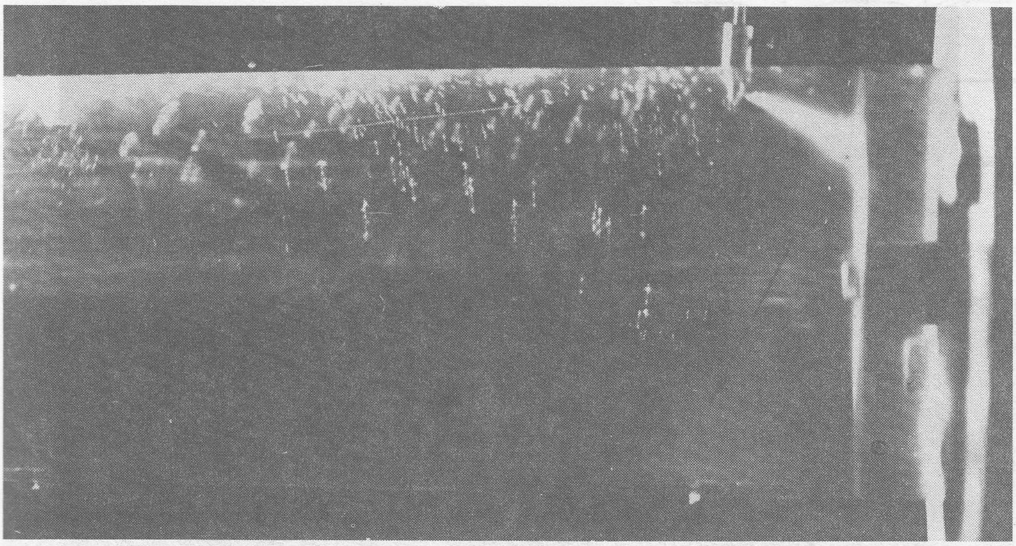

Fig. 11. The "backward spiral" flow at $n=10,000$ r.p.m.

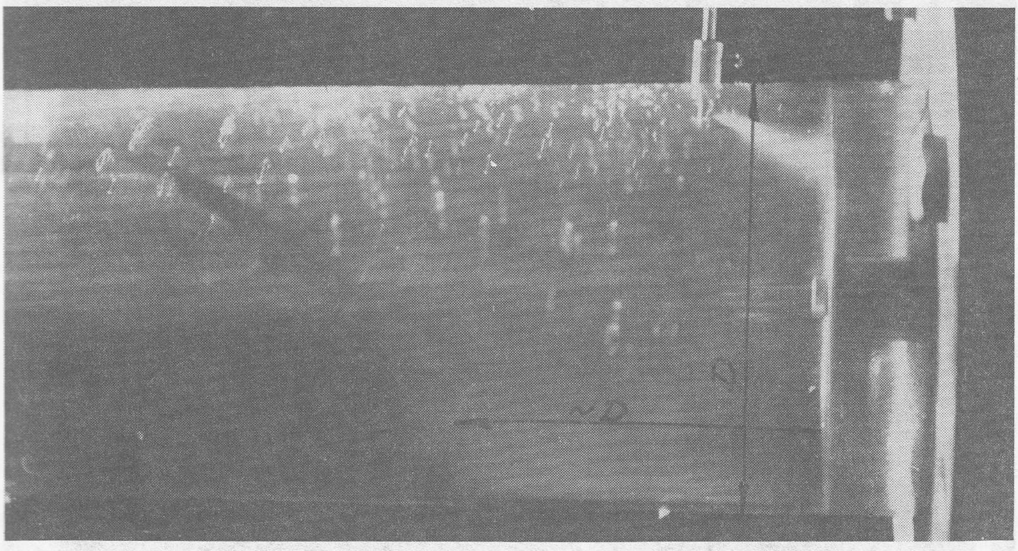

Fig. 12. The smoked region in front of the disc at $n=12,000$ r.p.m.

The pressure level for the smoke supply was controled by a small ventilator. The transparent pipe between smoke generator and probe in front of the disc, made it possible to control the intensity of smoke injection. In this way too high pressure of smoke injection was avoided. The main obstacle in getting a clear image of smoke flow was turbulent diffusion. The Reynolds number was $Re=wD/\nu\approx 7000$ in front of the disc. This is shown in Fig. 6.

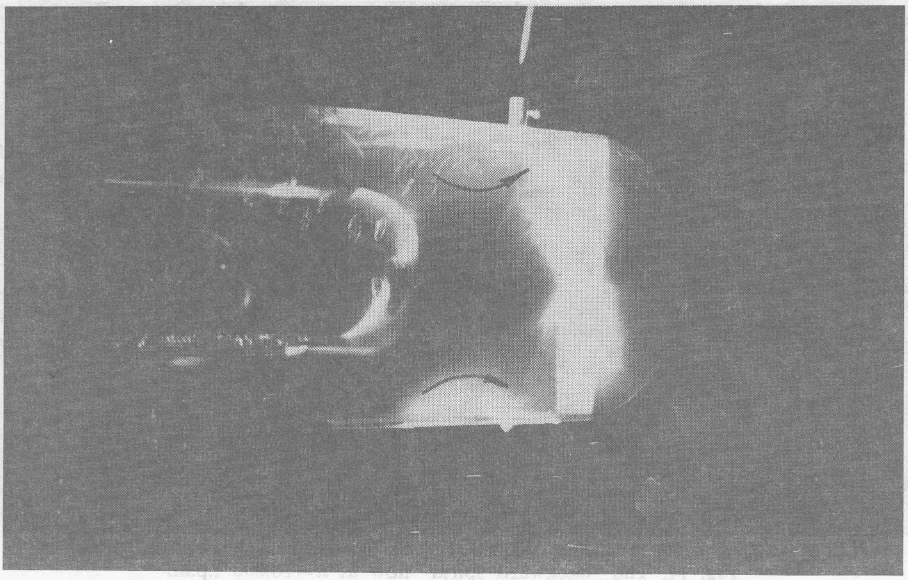

Fig. 13. The smoked region cut by a parallel beam of light

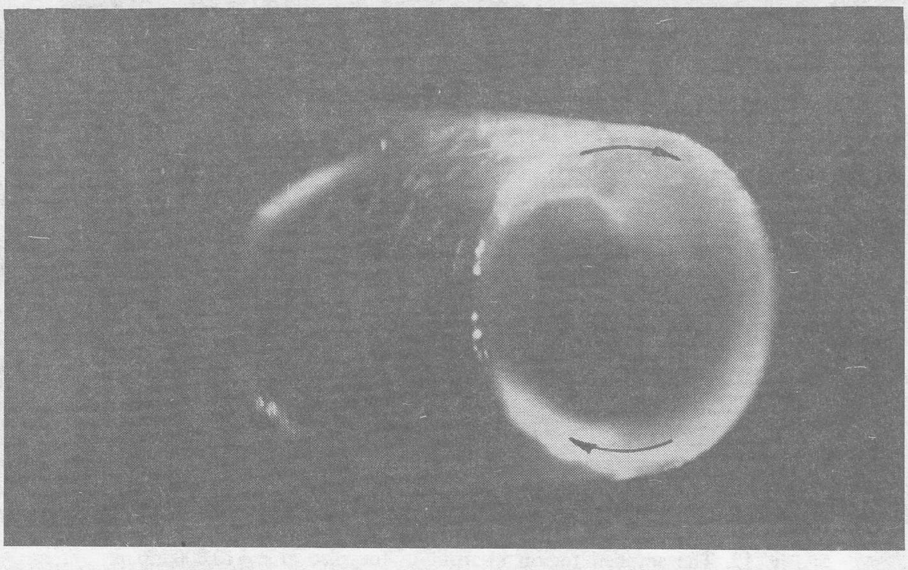

Fig. 14. The smoked region cut by a perpendicular beam of light

For rotation speed of the disc $n=5000$ r.p.m. which corresponds to $u/w \approx 1$ diffusion of smoke is visible in Fig. 7 and 8.

In Fig. 7 and Fig. 8 a cloud of smoke formed at the disc is visible. The smoke flows to the gap. A sketch of the flow pattern is shown in Fig. 9.

These pictures were taken for the disc with a sharp edge. Stream lines converge at the gap as it shown in Fig. 9.

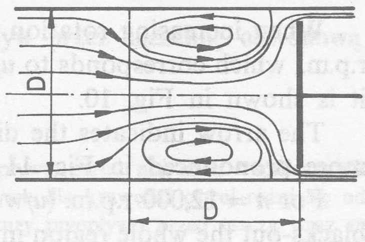

Fig. 15. A sketch of the flow pattern in front of the sharp-edged disc at high circumferential speed

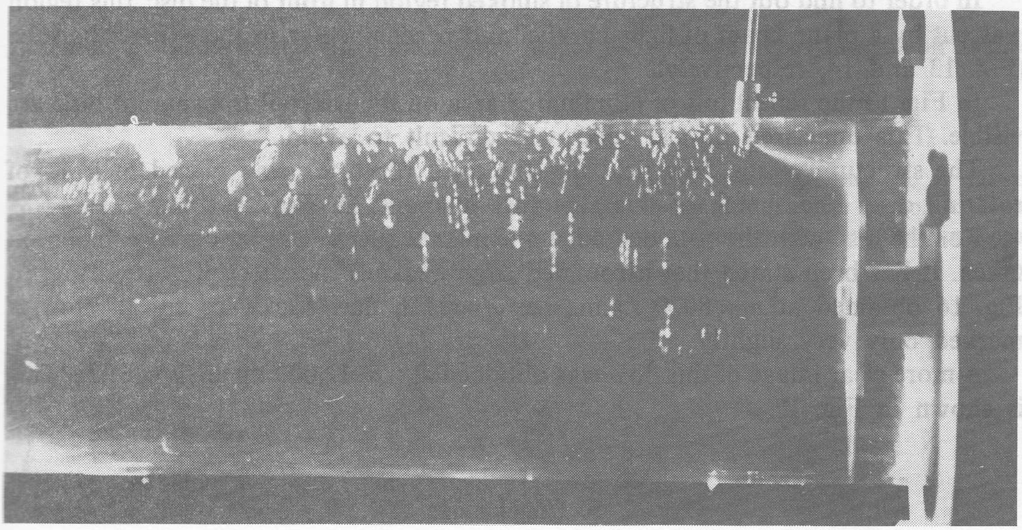

Fig. 16. The smoke fan for the rounded edge of the disc at $n = 8000$ r.p.m.

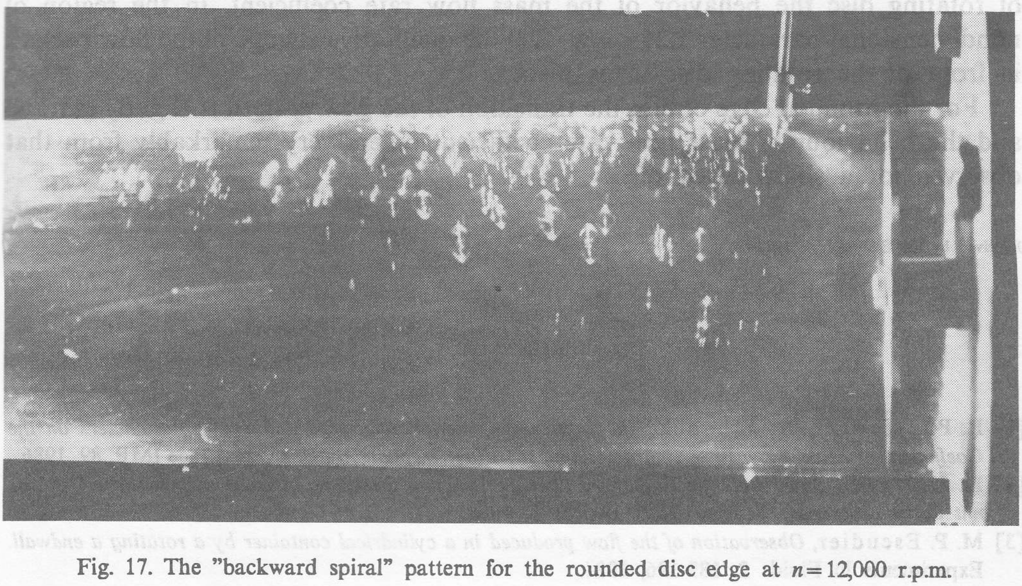

Fig. 17. The "backward spiral" pattern for the rounded disc edge at $n = 12{,}000$ r.p.m.

When increasing rotation speed of the disc the situation changes. At $n = 7500$ r.p.m., which corresponds to $u/w \approx 1.6$, a "backward spiral" of smoke can be seen, as it is shown in Fig. 10.

The arrow indicates the direction of the smoke flow. This "backward spiral" is more pronounced in Fig. 11 which has been obtained at $n = 10{,}000$ r.p.m.

For $n = 12{,}000$ r.p.m. ($u/w \approx 2.6$) the backward flow is so intense that the smoke blacks-out the whole region in front of the disc. The region spreads over the distance close to D (Fig. 12).

In order to find out the structure of smoked region in front of the disc, this region was cut by a plane beam of light parallel and perpendicular to the axis of the tube (Fig. 13 and 14, respectively).

In Fig. 13 the reflections of illuminated area on the walls of transparent pipe are visible. This undesired optical effect was difficult to avoid.

The structure of the flow field has the form of vortex ring placed in front of rotating disc. The sketch of this structure is shown in Fig. 15.

For the disc with the rounded edge a similar sequence of photographs has been taken. It has been stated that a rounded edge weakens the effect of vortex ring. In Fig. 16 obtained at $n = 8000$ r.p.m., i.e. $u/w \approx 1.8$, the "backward spiral" flow is marked only very slightly.

A more clear image of this flow was obtained at $n = 12{,}000$ r.p.m. ($u/w \approx 2.6$). This is shown in Fig. 17.

5. Conclusions

The investigation carried out shows a very significiant influence of the sharp edge of rotating disc the behavior of the mass flow rate coefficient. In the region of nondimensional parameter $1.25 < u/w < 2.0$ the qualitative change of the flow pattern in front of the rotating disc takes place.

For the rounded edge of disc the transition of the flow pattern is slightly marked and the behaviour of mass flow rate coefficient differs very remarkably from that observed for a sharp-edged disc.

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Wpływ kształtu krawędzi tarczy wirującej na przepływ przez szczelinę obwodową

Streszczenie

Przebadano wpływ kształtu krawędzi tarczy na pole przepływu przed nią oraz współczynnik przepływu masowego. Przebieg masowego współczynnika przepływu dla krawędzi ostrej różni się od przebiegu dla krawędzi zaokrąglonej. Stwierdzono zmianę struktury przepływu przed tarczą wraz ze wzrostem prędkości obrotowej.

Влияние формы кромки вращающегося диска на течение через окружной зазор

Резюме

Происследовано влияние формы кромки диска на поле течения перед ней, а также коэффициент массового расхода. Ход массового коэффициента расхода для острой кромки отличается от хода для закругленной кромки. Констатируется изменение стуктуры течения перед диском связанное с возрастанием скорости вращения.