ZÁPADOČESKÁ UNIVERZITA V PLZNI

FAKULTA STROJNÍ

KATEDRA ENERGETICKÝCH STROJŮ A ZAŘÍZENÍ

ZÁPADOČESKÁ UNIVERZITA V PLZNI

POWER SYSTEM ENGINEERING, THERMODYNAMICS & FLUID FLOW

2013

JEDNOTLIVÝ PŘÍSPĚVEK ZE SBORNÍKU

evropský sociální fond v ČR

EVROPSKÁ UNIE

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

OP Vzdělávání pro konkurenceschopnost

INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

BOUNDARY LAYER CONTROL IN PLANAR DIFFUSERS

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The aim of this study was to acquire knowledge of the effect of the boundary layer formed on the angled wall of planar diffusers. To begin, two devices were separately researched, i.e. a planar diffuser and a synthetic jet generator in various selected operating regimes. The task was to find a suitable setting for both devices to ensure successful control of the boundary layer.

Keywords: synthetic jet, planar diffuser, boundary layer

Annotation

As part of this study, results are published from experiments conducted separately on a planar diffuser, synthetic jet generator and a planar diffuser fitted with the mentioned synthetic jet generator.

In terms of the planar wide-angle diffuser, the aim was to determine the characteristics measured in several operating regimes in an aero-dynamic tunnel. Above all, this concerns the input and output speed profiles which can be used in the form of boundary conditions for any numeric simulation, and also characterize the operation of the device. In addition to the speed profiles, the key characteristic of the operation of the diffuser is the gradient of static pressure measured along its length. As this concerns a wide-angle diffuser, it is probable that boundary layer separation will form and develop and from this viewpoint, it was necessary to address the position of the separation point and any other important characteristics associated with this phenomenon.

The second key area of the work was to acquire knowledge of synthetic jet generation in a calm environment, respectively the properties of the synthetic jet generator. The proposed experiment was suitable for creating the basic concept of what occurs in the flow field during synthetic jet generation and primarily concerns the full frequency characteristics of a jet generator consisting of a harmonic signal, generator operating amplifier and an excited pressure chamber with a gap generating synthetic jet. Moreover, the focus of interest was the allocation of speed on the surface of the gap and the development of the jet at an increasing distance from the generator gap at various exciting frequencies. In this phase, various algorithms for signal processing were proposed and tested and consequently used in more complex cases.

The last phase of the work was to fit the generator into the diffuser neck which, when both devices are suitably set, enables to control the boundary layer so the secondary flow area is fully eliminated or restricted. Particular attention was given to the characteristics of the planar diffuser. The last metrics which express the effect of the synthetic jet on the flow in the planar diffuser is the energy short-circuit coefficient, see Zarjankin (2002).

It appears that it would be suitable to separate both devices and in the very first phase, to deal with both devices separately which could enable to gain the required experience with experimental equipment, as well as to collect and evaluate primary data. Results acquired from the study of synthetic heat generated in a calm environment enable to significantly narrow the scope of the researched area during the control of the marginal layer in the planar diffuser.

2. Planar diffuser

Measurement was taken on the diffuser displayed in the following diagram on the left. As previously mentioned, this concerns a planar diffuser where the input is adapted for suction from the surrounding calm environment. On the contrary, the prolonged output terminates into the axial ventilator suction with the delivery terminated outside the laboratory.

The diffuser is designed so that both sides can be independently opened in the interval $\langle 0;21{,}5°\rangle$, which means that the maximum angle for opening the diffuser corresponds to 43°. It was demonstrated for this work it is more favourable to use a single-sided open diffuser (see the following diagram where the lower wall is tilted at a horizontal angle with the respective value of 20.5°. Due to the preparation for assembly of the synthetic jet generator, the first measurement of static pressure was located at a distance of 67 mm from the beginning of the planar wall, see the following diagram on the right; further measurements were taken in spans of 20 mm, with a total of 19 measurements. Dynamic and static pressures in the mouth of the diffuser were measured using a Prandtl probe; see the diagram on the left.

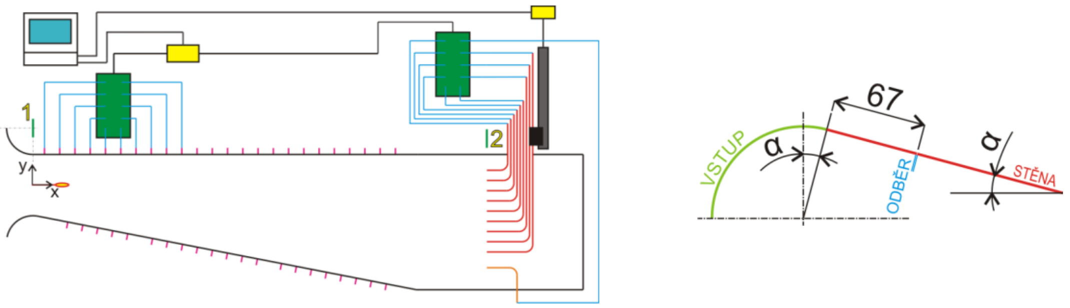

Fig. 1: Diagram of the diffuser, detail of input parts of the tunnel and the position for measuring static pressure.

Results from pneumatic measurements are shown in the following diagram on the left. The vertical axis of the graph is normalized so that for "regime 10" the output pressing is equal to one; nevertheless, in all displayed cases, it concerns the difference in the static pressure at the stated point and the pressure in the mouth of the diffuser normalized by the resulting pressing of "regime 10".

Measurements were taken for six operating regimes selected for the aero-dynamic tunnel; see the marking in the graph legend. For further use, the most important "regime 6" was used in the case of the control of the boundary layer; see the red curve in the left graph. It is evident that immediately behind the input into the diffuser there is an expansion which is accompanied by a decrease in the static pressure within an approximate distance of 70 mm from the input. Moreover, the working medium is compressed, which is reflected from the beginning by the relatively fast increase in pressure which reaches the maximum within a distance of 350 mm from the input. In the last area of the diffuser, there are only slight oscillations from the course and no significant pressing; nevertheless, it is time centered.

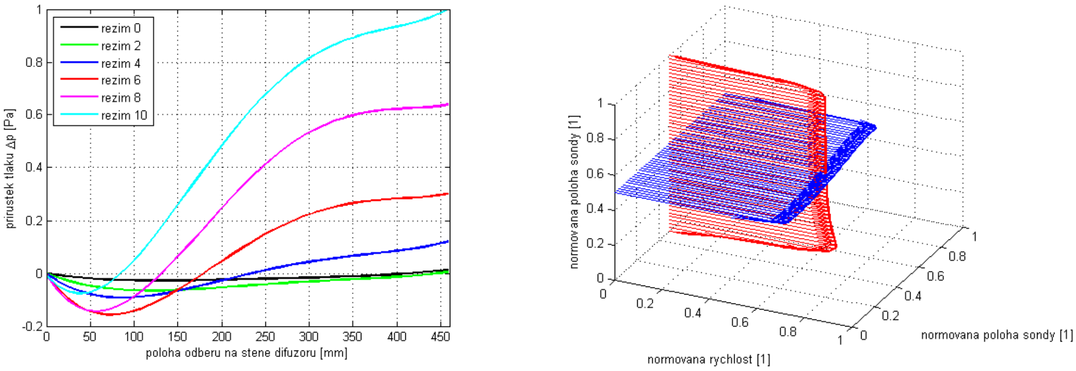

Fig. 2: The static pressure gradient along the length of the diffuser, input speed profiles

The previous diagram on the right shows the course of the speed along the height and width of the cross-section of the diffuser input. The speed profile drawn in blue corresponds to the allocation of the speed along the width of the input area; it is evident from the course that the profile of the speed is balanced and the thickness of the boundary layer is the minimum. On the contrary, the speed profile measured along the height of the diffuser shows an increase in speed in areas close to the walls, i.e. the maximum speed is on the side of the speed profile. The thickness of the boundary layer in this area varies by several millimetres. Nevertheless, such input speed profile is according to Dejče (1967) mainly suitable from the viewpoint of energy which is concentrated in the boundary layer area. Therefore, the resulting current field would be more resistant to the origination of separation. The measurement was taken in the input, i.e. the narrowest cross section of the diffuser using the CTA method.

In the following diagram on the left are the courses of the output speed profiles in all six operating regimes for the aero-dynamic tunnel. The red curve shows the course of the profile for regime 6. On the basis of the source of the curve, it can be stated that the flowing medium mainly flows in the upper part of the flow area, whereas in the lower part of the area the speeds are significantly lower. From the mentioned course it can be assumed that in the diffuser there is full separation, or the origination of a large separation bubble on the lower (angled) diffuser wall. It would not be possible to measure the output speed profiles in the output area of the diffuser, although it would be possible in the prolonged output which can be the reason for the partial levelling of the profile.

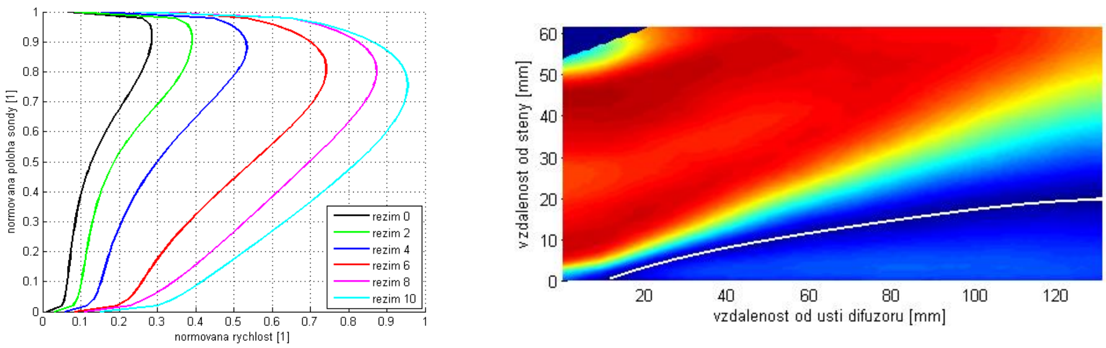

Fig. 3: The output speed profile in selected operating regimes, detail of scalar field of the longitudinal speed for regime 6

The presumption regarding the origination of the separation of the flow from the lower wall was confirmed by further results acquired by using the PIV method in the vertical area of the diffuser symmetry; see the previous diagram on the right. The horizontal axis represents the lower (angled) wall; its beginning corresponds to the input into the diffuser, the white curve is the connecting line of the point of zero speed in the current field. This means that there is separation of the boundary layer closely behind the entrance into the diffuser; under the white curve is the back flow area and above this curve is the free sliding area. Throughout the overall view it concerns a typical “delta” wind which affects the area from the input up to the output, where only part of the wall is displayed. This presence significantly causes an increase in losses and a decrease in pressing the working medium in the diffuser.

In terms of the control of the boundary layer to decrease losses, this area is interesting as with suitable modifications to the diffuser or by setting the synthetic jet generator, there is the possibility to suppress or reduce the polluted area.

It is evident that due to the scope of the paper, it is not possible to mention all results which were achieved within the measurement or evaluation of primary data. Some conclusions are based on results not published in this work.

3. Synthetic jet

The synthetic jet generator consists of a pressure chamber where the walls are represented by a pair of deep-tone loudspeakers, see the diagram in Fig. 5. The chamber terminates into a rectangular gap, where the synthetic jet is generated on the edge at a frequency corresponding to the future frequency of the loudspeakers. In the first phase it was necessary to address the electric part of the generator which is characterized by the following diagram on the left. Using the inserted bypass and the oscilloscope, the exciting output was measured, as well as the transfer of the electric signal by the system and the transfer of the whole system terminating through the gap generating the synthetic jet where the CTA method was used. The result of the measurement of the transfer is shown in the diagram on the right; the green curve indicates the amplitude and the blue curve indicates the phase transfer of the signal. On the first mentioned signal there are two peaks corresponding to the system frequency. On the curve of the phase-frequency characteristics, it is possible to see the start of a large delay which is gradually deceased with increased frequency; despite this fact, it is still necessary to be compensated when measuring.

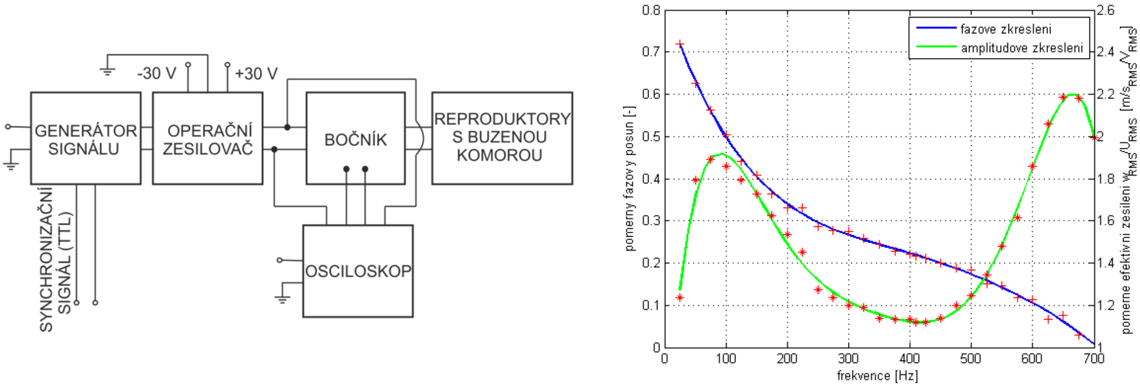

Fig. 4: Connection diagram of the synthetic jet generator, Bode characteristics

The following diagram shows the result of measuring the allocation of speed along the width of the jet which runs at a distance of 0.5 mm from the area of the gap. 17 points were measured for ten frequency excitations; due to the character of the jet, the results are displayed in the form of effective speeds, see the diagram on the right. It is evident from the graph that the synthetic generated jet is relatively narrow, i.e. outside the gap there is a relatively fast decrease of speed.

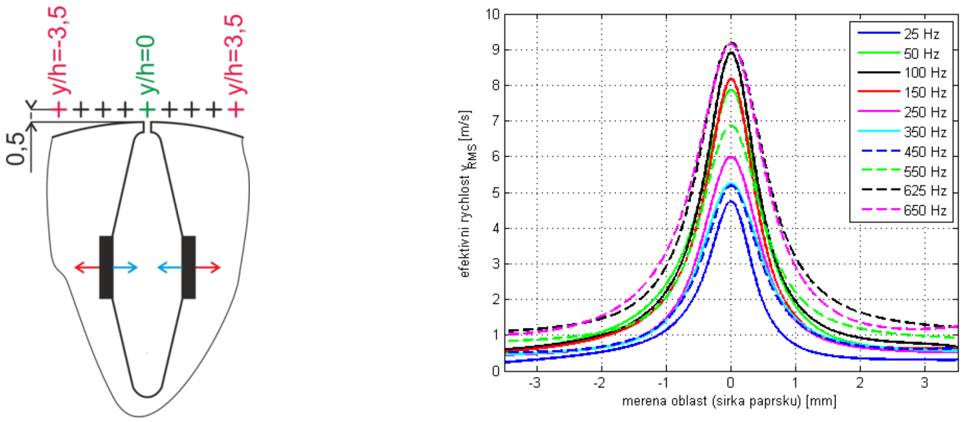

Fig. 5: Diagram of the generator for measuring the cross allocation of speed, speed profiles of elective speed

It resulted from processing the speed profile for the frequency 150 Hz that during jet generation there is a contraction. Therefore, the width of the generated jet does not correspond to the width of the gap: whereas the width of the gap is 1 mm, the width of the jet was evaluated at 0.98 mm.

4. Boundary control in the diffuser

The final chapter examines the results of the control of the boundary layer originated on the angled diffuser wall. For a better concept of the whole system, the following diagram on the left shows the jet generator fitted into the mouth of the diffuser. The generator output gap is situated on the border between the cylindrical and the plain side of the diffuser. Various excitation frequencies were used for the boundary layer, nevertheless, this only resulted in the case of excitation by the frequency 150 Hz, although this was for a set of several oscillations of the excitation voltage or outputs. The result in the form of a static pressure gradient along the length of the diffuser is shown in the following diagram on the right. The effect of the excitation output is shown, expressed in the form of the oscillation of the excitation voltage. The measurement was taken within the range from 0 V, which means that this concerns a simple diffuser up to the maximum oscillation value of 35 V; this is the limit of the operating amplifier at the frequency 150 Hz. It is evident from the graph that in the case of zero oscillation, the phenomena originate which were described in Chapter 2. By increasing the excitation output, the expansion is gradually suppressed and fully disappears at the value of 6 V. With a further increase in the excitation output, the working medium pressure increases. In the case of oscillation of 12.8 V then some saturation of the gradient towards the excitation output can be monitored. Further growth of the output flow from the operating amplifier into the generator is irrelevant from this viewpoint.

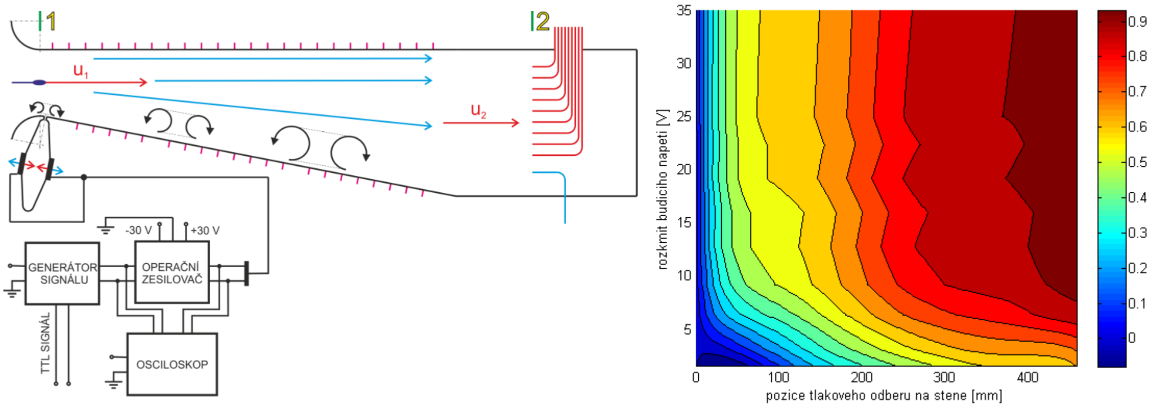

Fig. 5: Diagram showing the fitting of the synthetic jet generator into the planar diffuser and the static pressure gradient under various operating regimes for the synthetic jet generator

An interesting perspective view is that of the whole scalar field for the longitudinal speed near the lower (angled) wall, see the following diagram. The scanned area starts at the same point as in the previous case; nevertheless, the scalar field is drawn along the whole wall. Compared with the case without excitation, there is evident adhesion of the main stream to the beginning of the flow around wall. The white curve indicates the area of zero speed despite the fact that an area of separated stream originates when compared with a simple diffuser; in this case that area is relatively small and closed. The influence of the boundary layer excitation suppresses the development of the whirl; nevertheless, the separation bubble originates on the flow around the wall.

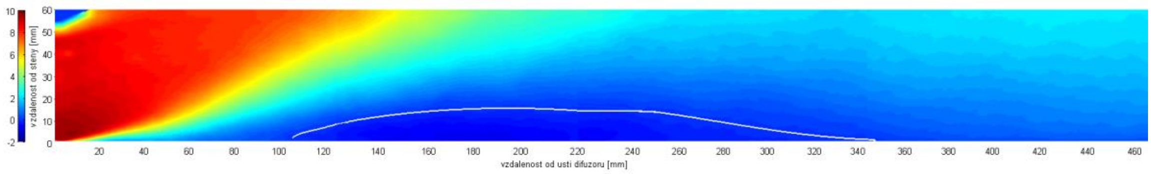

Fig. 6: The scalar field of the longitudinal speed in the planar diffuser during control of the boundary layer

In terms of the energy loss factor, a decrease of up to 16% can be achieved, provided that the synthetic jet generator is highly tuned to the diffuser operating regime. Otherwise, the status where the value of the loss coefficient is increased can be achieved.

Conclusion

The course of the pressure gradient on a simple (uncontrolled) planar diffuser was achieved where the tendency towards the origination of the separation of the boundary layer was uniquely reflected. The energy loss coefficient was also evaluated. For further work then input and output speed profiles for several operating regimes for the diffuser can be used.

In terms of the synthetic jet generator, the course of amplitude – frequency and phase – frequency characteristics was achieved. To do this, the dependence of the output flow from the operating amplifier into the synthetic jet generator was achieved within the relatively large scope of the oscillation of the excitation voltage. In accordance with this fact, the flow field was researched.

On the basis of the above-mentioned results, the operating regimes of the synthetic jet generator and the diffuser were selected, and combinations of these operating regimes were tested. The results showed that there is a diffuser speed field with the controlled boundary layer, output speed profiles and gradients of statistic pressure with several regimes. It appears that with a suitable setting, it is possible to achieve a reduction of losses originating due to the secondary flow in the diffuser and the suppression of the dynamism of the output speed and pressure field.

It is an interesting and demanding issue which requires further research and in particular, to acquire results that can assist in understanding the area of the boundary layer control by a synthetic jet.

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Acknowledgements

The authors of the paper wish to express their thanks for the financial support from student project SGS-2012-072.

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