FLOW IN BRANCHED CHANNEL

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Abstract

Flow in a branched channel is investigated experimentally using the PIV method. The branches are issuing from the main channel perpendicularly, all channels are of rectangular cross-section. The time-mean flow-fields in the main channel and in the branches are studied in details.

Keywords: channel, branches, PIV

1 Introduction

The branched channels are used in many practical applications. In general, the purpose of branching is distribution of the flowing fluid across the different locations. However, the flow-rate distribution across the branches is irregular.

Many authors address this problem both from theoretical and practical point of view. In classical engineering book [1] there are a lot of variants of this configuration. Recently there are numerical studies on the problem with detailed analysis of the flow-field. As an example, see the study [2].

The flow by the channel towards the branches could be either out or in – blowing or suction. In our case we consider blowing through the channel from the inlet in the main channel, outlets are located in the ends of each branch.

This configuration is motivated by geometry of cooling channels in rotor of a power generator.

2 Experimental setup

The model of the channel was designed and fabricated from the Plexiglas to allow optical access to the flow. Experiments were performed using the PIV technique.

2.1 Channel geometry

The main channel was of the cross-section 25 x 30 mm², 1450 mm long with the dead-end. In the inlet, fully turbulent and developed channel flow was present.

![Figure 1: Schematics of the channel](https://example.com/figure1.png)
The 13 branches of reduced cross-sections 38 x 4 mm$^2$ are distributed regularly along the main channel perpendicularly to the main channel axis, as shown in schematic picture in Figure 1.

The channel dimensions are given in Figure 2. The inner space is depicted, the real model is made of the Plexiglas 15 mm thick.

![Figure 2: The channel dimensions](image)

In Figure 2 the global Cartesian coordinate system has been introduced with origin in the main channel inlet.

### 2.2 Measuring technique

The time-resolved PIV method was used for the experimental investigation of the flow in the channel plane of symmetry. The measuring system DANTEC consists of the double-pulse laser with cylindrical optics and the CCD camera. The software Dynamics Studio 5.1 was used for velocity-fields evaluation. Laser New Wave Pegasus Nd:YLF, double head, wavelength 527 nm, maximal frequency 10 kHz, a shot energy is 10 mJ for 1 kHz (corresponding power 10 W per head). Camera Phantom V711 has maximal resolution 1280 x 800 pixels and corresponding maximal frequency 3000 double-snaps per second. The presented experiments are intended to cover low-frequency dynamics offering good statistics. Thus, for the measurements, the frequency 100 Hz and 1000 double-snaps in sequence corresponding to 10 s of record for time-mean values evaluation was acquired. Details on the measuring technique are given in references [3,4].

The measuring plane was the plane of symmetry of the channels in a specific locations. The measuring zones were attached to each branch, depicted in Figure 3.

![Figure 3: Measuring zones for a branch](image)
There are 3 measuring zones for each branch, the zone I in blue represents flow in the main channel, and the other two zones II (red) and III (green) represent flow in the branch itself. Those two zones are considered together as the branch zone. The red dot indicates the sharp edge, where flow separates and it defines the relative coordinate system origin (see hereinafter).

Please note, that the space closer than 3 mm to the upper main channel wall, as well as to the branch exit, is not resolved for technical reasons.

Not all results are to be shown here because of a huge amount of evaluated data.

3 Results

The flow in the main channels and the branches is to be shown in following sections, respectively. The time-mean vector fields have been considered in the presented paper only. In the main channel inlet the well-developed turbulent channel flow was present, the velocity modulus and turbulent kinetic energy (TKE) profiles are shown in Figure 4, measured 100 mm downstream the inlet.

The balance of the volumetric flow-rate have been performed. The flow-rates in the channel and branches have been evaluated by integration of mean velocity profiles. The total volumetric flow-rate in the main channel has been evaluated in the channel inlet: 0.00480 m$^3$/s. Volumetric mean velocity in the main channel input was 6.4 m/s, corresponding Reynolds number 11 300.

The flow-rates in branches V are evaluated at location $y = 130$ mm, this means 27 mm upstream the branch outlet. Results are shown in Figure 5.

In the first 5 branches the flow-rate is nearly constant, while further downstream it grows. Maximum flow-rate is indicated in the last branch no. 13.
3.1 Main channel

The time-mean flow-fields in the measuring zone I for each branch have been evaluated. As the flow-character is changing gradually along the main channel, only 4 examples are to be presented here: the first branch no. 01, the branch no. 07 in the middle of the main channel and the two last branches nos. 12 and 13.

The evaluation of the mean velocity modulus, mean velocity vectors with corresponding vector lines and sum of velocity components variances distributions are to be shown. In Figures 6-9 the results are presented for the selected locations, from the left to the right.

The development of the velocity modulus along the main channel indicates decay of the mean velocity from 7 m/s in the channel inlet down to 1 m/s in the end. The velocity distribution becomes more unsymmetrical along the main channel, shifting maximum towards the upper wall, where branch channels are present. The vector lines of mean velocity field are oriented more and more toward the branch axis. Behind the last branch 13 there is recirculation, the vortex in filling the dead-end. The turbulence activity decays along the main channel.
3.2 Branches

The flow entering to the branch from the main channel turns 90 degrees upwards, the boundary layer separates on the corner creating the recirculation zone on the branch wall located upstream the main channel (left). The separation occurs on the sharp edge marked by the red point in Figure 3. The flow-field is changing along the main channel, part of fluid is removed from the main channel flow in each branch.

In Figures 10-13 the results are presented for the selected branches. Again, the mean velocity modulus, mean velocity vectors with corresponding vector lines and sum of velocity components variances distributions are shown from left to right.

![Figure 10: Flow-field within the branch 01](image1)

![Figure 11: Flow-field within the branch 07](image2)

The velocity modulus has its local maximum in branch no. 01 (in red), however the recirculation zone is detected close to the left-wall of a branch channel. The recirculation is characterized by existence of the vortex and the back-flow region. The vortex is visible in picture in the middle representing mean velocity vector field with vector-lines.

The back-flow region is limited by positions, where the vertical velocity component is zero – represented by the white line in the velocity modulus distribution map (left picture). This means, that the area on the left from this line exhibits negative vertical velocity component. This is the back-flow region. In the case of the last branch no. 13 the boundary layer separation has not been detected because of too
small velocity, however the separation bubble could be located within the unresolved region, closer than 3 mm from the corner.

The flow unsteadiness is characterized by sum of the velocity components variances shown in right-hand side picture. The maximum dynamical activity i.e. maximum of velocity variance is located close to the free shear layer forming by the separated boundary layer and close to the downstream wall (right).

The separation zone has been studied in details along the channel. Positions of the vortex centres have been evaluated for all branches, result is shown in Figure 14.

For this purpose, the relative coordinate system was defined, the same for each branch. Origin is located in the sharp edge, where flow separates – see the red dot in Figure 3, coordinates $x_r$ and $y_r$. The vortex centres are represented by green points with white numbers indicating number of the branch.

The vortex centre position for the first branch is located in 1/3 of the branch width and close to its half-length. For the branches 02-04 the $x_r$ positions are nearly the same as for the 01, but the centre travels towards the branch output. Then, the 05 vortex centre position moves back to the position of the 01 but closer to the left wall, this trend continues ending close to the left wall upstream.
Topologies of the back-flow regions are shown in Figure 15, where lines of zero vertical velocity component are depicted for all branches (B01-B13) distinguished by colour. The lines represent limit of the back-flow region.

The lines B01-B04 do not hit the left-hand wall, this means that the flow is not reattached at all. The boundary layer separation has been detected in all branches on the sharp corner. Only for the very last branch 13 the separation has not been captured. The reattachment point is detected for branches 05-12. In the branches 01-04 the flow is detached even in the outlet, so suction within part of outlet is detected.

Position of the reattachment point \( y_{ra} \) on the left-hand wall \( (x_e = 0) \) is shown in Figure 16 for all branches.

For branches nos. 1-4 the reattachment point does not exist, for the last branch no. 13 its position approaches 0. The separation bubble length is decreasing linearly from the full branch length for the branch no. 5 down to 40 mm for the branch no. 12.
4 Conclusion

In the paper the mean-time flow in branched channel is shown as a result of PIV experiments. Maximal flow-rate was evaluated in the last branch, where the local velocities are small, but no recirculation was detected. In first 4 branches the recirculation was so strong, that no reattachment was observed and the back-flow was present in the branch outlet. In the other branches flow-field the recirculation bubble was observed. This behaviour affects distribution of the volumetric flow-rate across the branches.

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References