

# Dynamics of flow in a branch of a branching channel

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**Abstract.** Flow in a branched channel is studied experimentally using the PIV technique. The branches are issuing from the main channel perpendicularly, all channels are of rectangular cross-section. The flow dynamics in one particular branch is investigated using the OPD method.

## 1 Introduction

The branched channels are applied in many practical situations. In general, the main goal of the branching is distribution of the flowing fluid across the various locations. However, the flow-rate distribution across the branches is irregular even if their geometry is similar.

There are extensive knowledge resources in available literature, 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 many numerical studies on the problem with detailed analysis of the flow-field available.

The presented study was motivated by geometry of cooling channels in rotor of a power generator.

## 2 Experimental setup

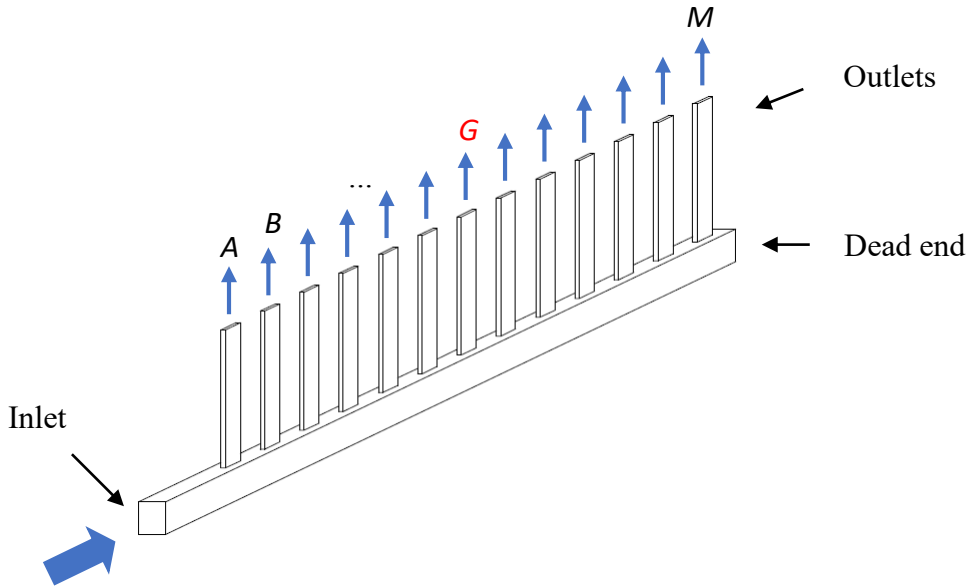
The experimental model was designed and fabricated from the Plexiglas to allow optical access to the flow. Experiments were performed using the time-resolved PIV technique.

### 2.1 Channel geometry

The main channel was of the cross-section 25 x 30 mm<sup>2</sup>, 1 450 mm long with the dead-end. The 13 branches (A, B, ..., M) of reduced cross-sections 38 x 4 mm<sup>2</sup> are distributed regularly along the main channel perpendicularly to the main channel axis, as shown in schematic picture in Figure 1.

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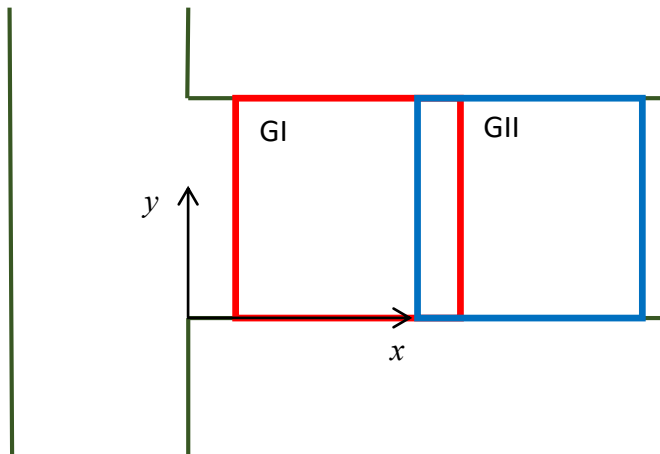


**Fig. 1.** Schematics of the channel.

In the inlet, fully turbulent and developed channel flow was present. The air flow in the main channel inlet is characterized by Reynolds number of 11 300, velocity of the air in the input is about 6.4 m/s. However, in the presented paper we are interested in the selected branch only, the branch G in the middle of the main channel. Flow rate in the selected branch G is about  $3 \cdot 10^{-4} \text{ m}^3/\text{s}$ , maximal velocities 5 m/s.

Detailed description of the channel model used for the experiments is given in [3].

Schematics of the branch G under study is in Figure 2, the Cartesian coordinate system is introduced. The measuring plane was located in the mid-span of the channel. The area of the branch was divided into 2 overlapping parts GI and GII for technical reasons.



**Fig. 2.** Schematics of the branch G.

## 2.2 Instrumentation

The time-resolved PIV method was used for the experiments in the channel model. The measuring system DANTEC consists of the double-pulse laser with cylindrical optics and CMOS camera. The software Dynamics Studio 3.4 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 with maximal resolution 1 280 x 800 pixels and corresponding maximal frequency 3 000 double-snaps per second. For the presented measurements, the frequency 1 kHz and 4 000 double-snaps in sequence corresponding to 4 s of record for mean evaluation was acquired. As particles the oil droplets generated by SAFEX fog generator was used.

Detailed description of the measuring system could be find in [2, 4].

## 2.3 Analysis methods

Instantaneous velocity fields in the measuring plane have been evaluated using “Adaptive PIV” method. The averaged velocity field has been evaluated first to obtain the flow statistics and remove the mean flow. Mean flow structure is evaluated as well as velocity components variances and correlation coefficient distributions.

For study of dynamical properties of the flow-field the Oscillation Pattern Decomposition method (OPD) was adopted resulting in series of OPD mode. Each OPD mode is characterized by topology in complex form (consisting of real and imaginary parts), frequency and attenuation of the pseudo-periodic (oscillating) behaviour. Attenuation or amplitude decay is described by e-folding time representing mean time period of the mode amplitude decay by “e”. The other decay characteristic is “periodicity” which express the e-folding time in multiples of periods.

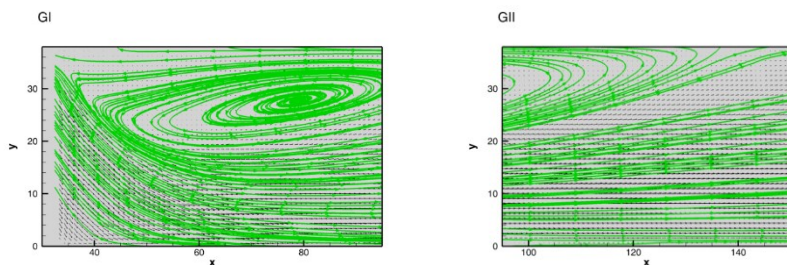
The details on OPD method could be find in [5].

## 3 Results

The results are divided into two parts. The first part is oriented on time-mean results, while the second part characterizes the flow dynamics using the OPD method.

### 3.1 Time-mean

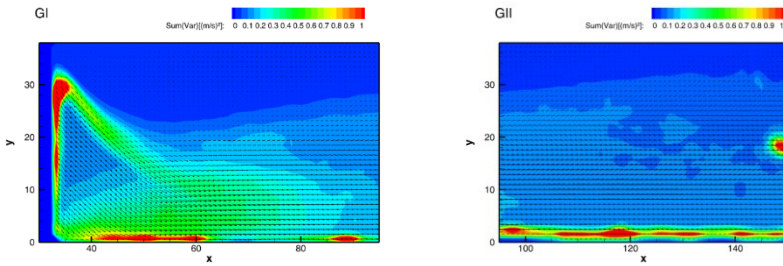
The averaged characteristics will be presented in each figure both for the part GI on the left- and the part GII on the right-hand side. The distributions of mean characteristics follow from one part to the other satisfactory.



**Fig. 3.** Mean velocity vector fields.

Mean velocity vectors distributions for GI and GII areas are shown in Figure 3. For clarity the vector lines are added arbitrarily. The back-flow region associated with the vortex, centre located in position [79;26], is visible clearly.

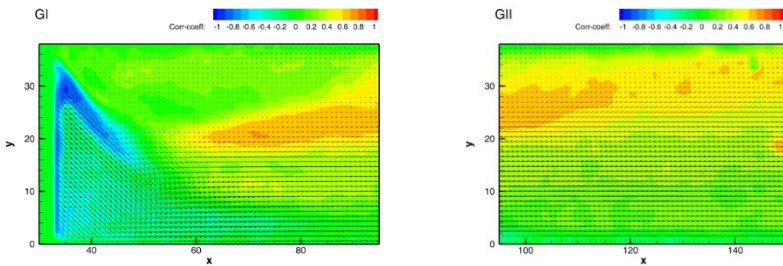
To indicate regions with high dynamical behaviour the sum of variances x and y velocity components is to be presented next in Figure 4.



**Fig. 4.** Velocity components variances sum distributions.

In Figure 4 dark-blue colour represents low dynamical activity regions, red colour corresponds to excessive dynamics due to frequent errors in velocity evaluation using the standard PIV evaluation procedure in near-wall regions. Finally light-blue and green parts are those with high dynamical activity in the flow itself.

To estimate turbulence generation the correlation coefficient is evaluated in Figure 5.



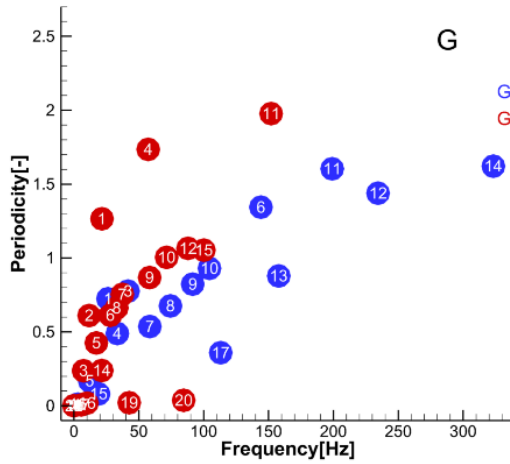
**Fig. 5.** Velocity components correlation coefficient distributions.

The correlation coefficient value close to 0 indicates low or even no turbulence generation, while negative (or positive) values approaching 1 indicate turbulence production regions.

### 3.2 Dynamics

The OPD method has been applied on the GI and GII zones respectively. The analysis of both parts is completely independent to each other and OPD modes from one part could not be linked directly to those of the other part.

In Figure 6 there are OPD modes frequency and periodicity combinations evaluated by the standard procedure. The results for the GI part correspond to blue points, while red points correspond to the part GII. Numbers of the modes ordered according to the e-folding time (descending order) are indicated within the points.



**Fig. 6.** OPD modes, frequency and periodicity.

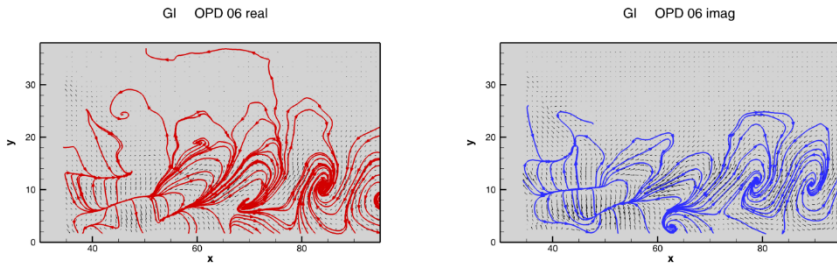
A few modes have been selected with the highest value of periodicity, in particular modes 6, 11, 12 and 14 for the GI and 1, 4 and 11 for the GII. Those modes could be considered as oscillating or pseudo-periodic, the others decay too quickly. All parameters, of the selected modes, frequency, e-folding time and periodicity, are given in Table 1.

**Table 1.** Selected OPD modes.

	OPD mode	frequency [Hz]	e-folding [ms]	periodicity [1]
GI	6	144.2	9.32	1.34
	11	199.1	8.05	1.60
	12	234.5	6.13	1.44
	14	323.2	5.02	1.62
GII	1	21.5	58.71	1.27
	4	57.2	30.31	1.73
	11	152.0	13.00	1.98

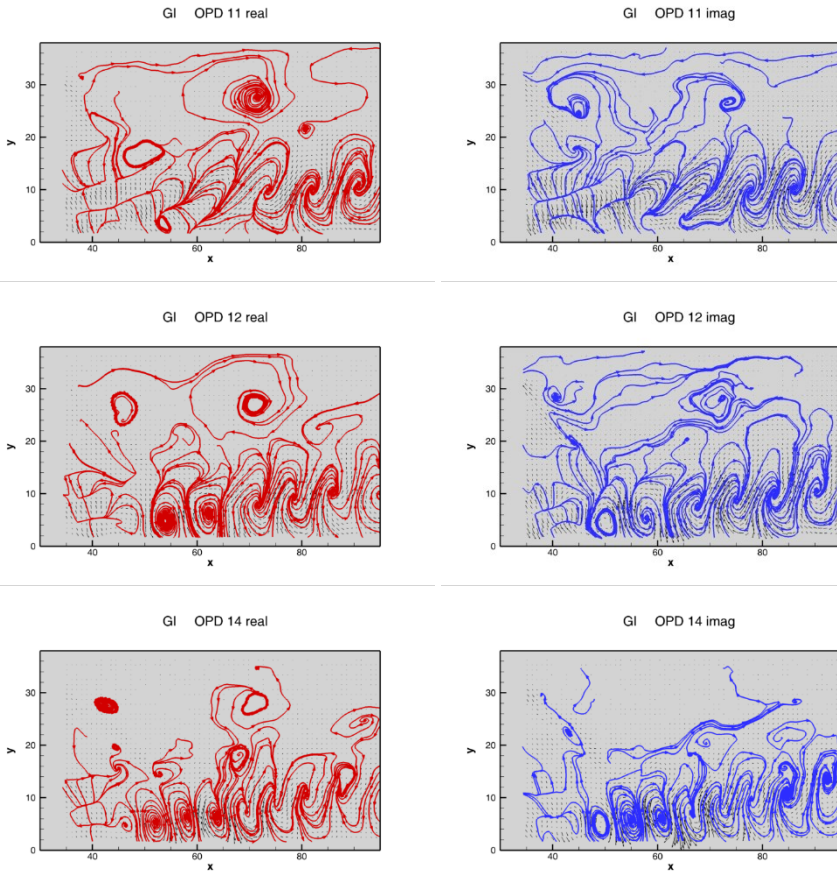
Topology of the selected modes is to be shown next. Each mode topology consists of real and imaginary parts respectively. The real part corresponds to the phase angle 0, phase angle  $\pi/2$  corresponds to the imaginary part, than phase  $\pi$  is characterized by negative real part and  $3\pi/2$  by negative imaginary part. The process is pseudo-periodical with decaying amplitude.

Topology is shown as vector fields. For better clearness the vector lines are added arbitrarily, for the real part in red and for the imaginary part in blue colours. The GI OPD modes are to be presented first. In Figure 7 the GI OPD mode number 6 is shown, real and imaginary parts.



**Fig. 7.** Topology of the OPD mode 6, GI, real and imaginary parts.

The OPD mode 6 for the GI region is characterized by vortex train of 5 vortices located in the lower part moving in the x direction, alternate orientation. Topology of the OPD modes 11, 12 and 14 is rather similar, so they are presented in one Figure 8.



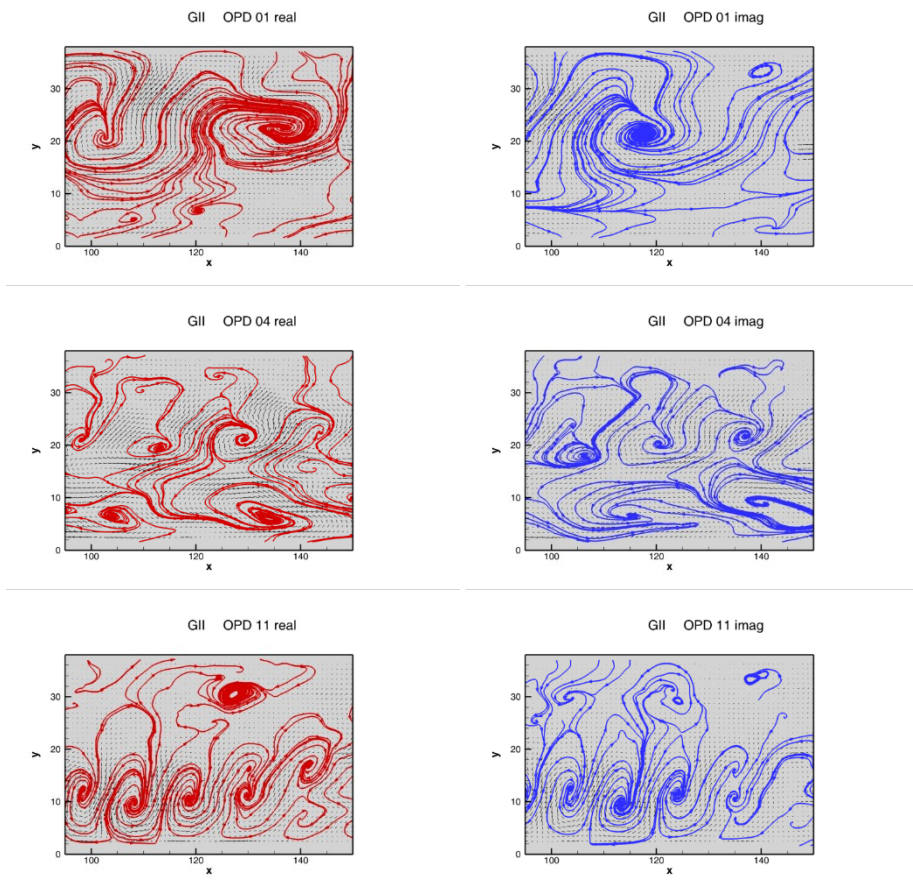
**Fig. 8.** Topology of the OPD modes 11, 12 and 14, GI.

The OPD modes 11, 12 and 14 are characterized by vortical structures in one row approximately in the x direction. They are of alternate orientation and they differ by number of vortical structures from 5 to 8. The frequencies are also different (see Table 1). Generally: higher number of structures, higher frequency of the mode indicating approximately constant structures propagation velocity, this velocity is close to the mean-flow velocity in the given



area. All vortical structures are located within the shear layer between the back-flow (upper part) and forward flow (bottom) regions – compare with the mean velocity vector field in Figure 3.

Next, the OPD modes topology in the GII region is to be presented. Unlike in the GI region, the selected modes with high periodicity are of the three completely different types. The OPD modes 1, 4 and 11 are presented in Figure 9.



**Fig. 9.** Topology of the OPD modes 1, 4 and 11, GII.

The OPD mode 1 is characterized by very low frequency 21.5 Hz and the advected vortices are of the size of the whole domain.

The OPD mode 4 consists of the two rows of vortices in chequered configuration. The vortices are relatively small.

The OPD mode 11 is similar to the modes in the GI region presented above, it is formed by vortical structures in a single row in the streamwise direction located in the channel bottom.

Vortical structures in all presented modes propagates in the streamwise direction, as visible from the phase shift between the imaginary and real parts.

## 4 Conclusions

In the paper the flow structure of a selected branch of the branched channel is shown as a result of PIV experiments.

Both statistical methods based on averaging and special methods for vector field frequency analysis are applied. Typical pseudo-periodic dynamical structures are detected. The typical dynamical structures are trains of vortices of alternative orientation aligned in the  $x$  direction and propagating in the streamwise direction.

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## References

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