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A MATHEMATICAL MODEL OF THE FLUID FLOW IN THE TEE-JUNCTION. THE COMPARISON OF THE CFD COMPUTATION AND THE MEASUREMENTS.

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Abstract: *This paper deals with a mathematical model of fluid flow in Tee-junction with the 90° angle of adjacent branch and with the same diameter of all branches. There is only a brief theory for some term explanation at beginning of the paper. Some measurements were done for determining of the Tee-junction coefficients. These coefficients are function of a ratio of flow rates in given branches, see Fig 02. These results were compared with CFD calculations.*

Keywords: ***T-junction, fluid flow in pipeline net, steady flow, unsteady flow, mixing.***

1. Introduction

The mathematical model of the fluid flow in the Tee-junction with the 90° angle (MMFFTJ90) of the adjacent branch and with the same diameter of all branches is presented in this paper. This kind of Tee-junction is one of the adapting pieces and it is used very often. It is used for the division or the combination of flow in pipeline Fig. 2. Sometimes it is also used as a mixing device of two different liquids or phases. It is necessary to have a mathematical model of this Tee-junction because of solving of the flow parameters in the pipeline. The simplest and very often used model is based on an assumption that the pressure is constant at the ends of all branches connected to the T-junction. It is obvious that this model is not precise and that this assumption is not true (Štigler 2006, Part1). Therefore a new mathematical model of Tee-Junction was derived (Štigler 2006, Part1). This new MMFFTJ90 is also possible to use for both steady and unsteady flow (Štigler 2007), it takes into account position of the Tee-junction in respect of gravity acceleration and it is also possible to use it for a mixture flow. This model introduces coefficients of the Tee-Junction which have a correct physical meaning. This model has been also extended for an arbitrary angle of the adjacent branch (Štigler 2010). The Tee-junction coefficients are dependent on the ratio of flow rates in two branches. These coefficients were expressed by using of CFD computations (Štigler 2006, Part2). There is presented a comparison of these CFD computations with experiment in this paper, now. There were made some experiments for example by (Oka K & Ito H. 2005). New experiments have to be made because there was not enough information in papers where the previous measurements were presented.

2. Brief Theory

The details of the theoretical backgrounds of the MMFFTJ are outlined in (Štigler, 2010). The mathematical model of the Tee-junction consists of three equations. Power equation, which represents the energy conservation law, Momentum equation, which represents of the momentum conservation law and the last equation is the continuity equation which represents the mass conservation law. The tests presented in this paper were done under next assumptions: steady flow, plain of T-junction was horizontal, incompressible liquid (water), the angle of adjacent branch was 90° and diameters of all branches were the same (50 mm).

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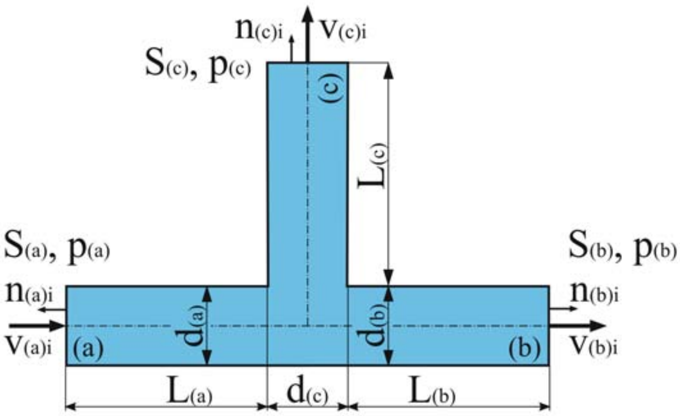
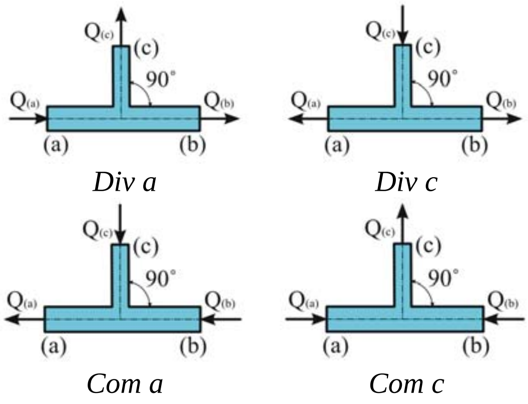


Fig. 1: T-Junction and variables.



$$q_{(ca)} = \frac{Q_{(c)}}{\left|Q_{(a)}\right|} \qquad q_{(ac)} = \frac{Q_{(a)}}{\left|Q_{(c)}\right|}$$

Fig. 2: Flow adjustments and variable ratio of flow rate.

MMFFTJ has this form under these assumptions

Power equation

$$\left(\frac{1}{2}\alpha_{(Ca)}\cdot\frac{Q^2_{(ma)}}{\rho^2.S^2}+\frac{p_{(a)}}{\rho}\right).Q_{(ma)}+\left(\frac{1}{2}\alpha_{(Cb)}\cdot\frac{Q^2_{(mb)}}{\rho^2.S^2}+\frac{p_{(b)}}{\rho}\right).Q_{(mb)}+ \\ +\left(\frac{1}{2}\alpha_{(Cc)}\cdot\frac{Q^2_{(mc)}}{\rho^2.S^2}+\frac{p_{(c)}}{\rho}\right).Q_{(mc)}+\frac{1}{2}\xi_{(P)}\cdot\frac{Q^2_{(mC)}}{\rho^2.S^2}\cdot\left|Q_{(mC)}\right|=0 \tag{1}$$

Momentum equation

$$\left(\frac{Q^2_{(ma)}}{\alpha_{(Ba)}.\rho.S}+p_{(a)}.S\right).n_{(a)i}+\left(\frac{Q^2_{(mb)}}{\alpha_{(Bb)}.\rho.S}+p_{(b)}.S\right).n_{(b)i}+\left(\frac{Q^2_{(mc)}}{\alpha_{(Bc)}.\rho.S}+p_{(c)}.S\right).n_{(c)i}+ \\ +\xi_{(M)i}\cdot\frac{Q^2_{(mC)}}{\rho.S}=F_{(g)i} \tag{2}$$

Continuity equation

$$Q_{(ma)}+Q_{(mb)}+Q_{(mc)}=0 \tag{3}$$

Where $Q_{(mx)}$ is the mass flow rate in the particular branch $\alpha_{(Cx)}$ is a kinetic energy correction factor on the particular cross-section, $\alpha_{(Bx)}$ is a Bousinesque number on the particular cross-section, $n_{(x)i}$ is an outward unit normal vector of the particular cross-section, $p_{(x)}$ is an average pressure on the particular cross-section. The letter x should be replaced with the letter a, b, c. This letters determine the branch to which the given quantity is related. Next quantities are ρ – density, S-area of the branch cross-section. $Q_{(mC)}$ is a total mass flow rate. The letter C should be replaced with the letter mark of the branch where the total flow rate is in it.

There are introduced the two coefficients of the T-junction in the above equations. First, the power coefficient $\xi_{(P)}$ which represents the energy losses in the T-Junction, second, the momentum coefficient $\xi_{(M)i}$ which represents a vector which is proportional to the force which the flow affects the T-Junction. The proportionality is given through a momentum magnitude in the branch with total flow rate. Each of these coefficients can be divided into two parts

$$\xi_{(P)}=\xi_{(PF)}+\xi_{(PG)} \tag{4}$$

$$\xi_{(M)i}=\xi_{(MF)i}+\xi_{(MG)i} \tag{5}$$

The first parts $\xi_{(PF)}$ and $\xi_{(MF)i}$ represent influence of friction in the Tee-junction. These coefficients can be determined from pressure drop in straight pipes. The second parts $\xi_{(PG)}$ and $\xi_{(MG)i}$ represent the influence of T-Junction shape or geometry. The goal of the experiments and CFD computations is to find these geometry coefficients.

3. Solution

3.1. The testing circuit description and measuring procedure

The testing circuit has been built in a heavy laboratory of V. Kaplan's Department of Fluid Engineering of Brno University of Technology, Faculty of Mechanical Engineering. The testing circuit was designed as an open loop. The scheme of testing circuit is in the Fig. 4. The model of the Tee-junction together with straight pipes was fixed to the special construction which allowed the horizontal adapting of the supports to ensure horizontal position of the plane of Tee-junction. The Tee-junction was made of the special optical glass, because the PIV measuring has been also planned. The pipes connected with the T-junction were made from transparent PVC. The measured quantities are as follows: average absolute pressure at branch marked *a* see Fig. 4, the pressure differences ($p_{(b)}–p_{(a)}$) and ($p_{(c)}$-$p_{(a)}$), flow rates in each branch $Q_{(a)}$, $Q_{(b)}$, $Q_{(c)}$ and the temperature of water. Absolute pressure has been measured with manometer, pressure differences were measured with two different methods, first using the membrane differential manometers, second using the U-tube manometers. Each branch was equipped with the magnetic flow-meter. The total fluid flow was driven by the pump equipped with the frequency variator.

Fig. 3: Photo of the testing circuit.

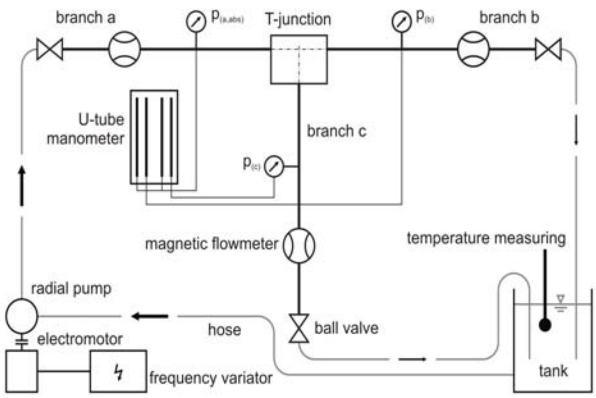


Fig. 4: Scheme of the testing circuit.

The goal of these measurements was to find the coefficients of Tee-junction which can be applied in a MMFFT90. These coefficients are the function of the ratio *q* of the given flow rates with respect to particular flow order. The ratio value of flow rates *q* varies from 0 to 1. The measurements were made for all flow adjustments Fig. 2. The eleven different ratios of flow rates were measured for each flow adjustment. The measurement was repeated.

3.2. CFD Computation

The coefficients of Tee-junction were also determined by using CFD calculations. The geometrical model of the Tee-junction was created in the preprocessor GAMBIT 2.2.30. The computational mesh contained approximately the 2.3 million hexahedral cells with the worst skewness equal to 0.51. The straight pipes were extended in the length of 25 diameters from the T-junction. The computational mesh set in this way was consequently used for the analysis of pressure field in software Fluent 12.1. The setting of solver was chosen according to the dominant flow i.e. unsteady calculation with k-ε realizable turbulence model and non-equilibrium wall functions. The velocity inlet or outflow boundary conditions were used on cross-sections $S_{(a)}$, $S_{(b)}$ and $S_{(c)}$. Twenty different values of ratios q of flow rates were calculated for each flow adjustment.

3.3. Comparison of results and discussion

The comparison of the geometrical coefficients $\xi_{(MG)1}$, $\xi_{(PG)}$ gained from the experiment and coefficients gained from the CFD computation are in the Figs. 5 - 8. These coefficients are evaluated for all kind of flow adjustments. There is a very god agreement in case of the flow combination. In case of flow division there are slight differences in case Div a for low ratios of flow rates $q_{(ca)}$. The worst agreement is in case of Div c. The flow was very unsteady in this case. This is probably the reason for the disagreement.

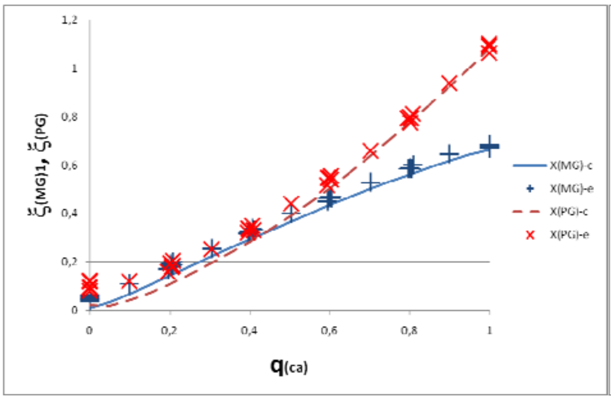


Fig. 5: Geometry coefficients for Div a.

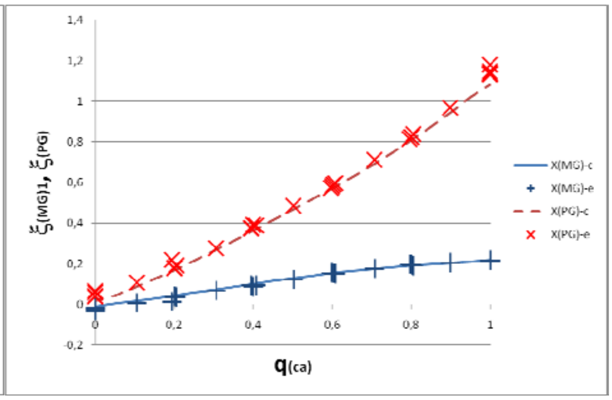


Fig. 6: Geometry coefficients for Com a.

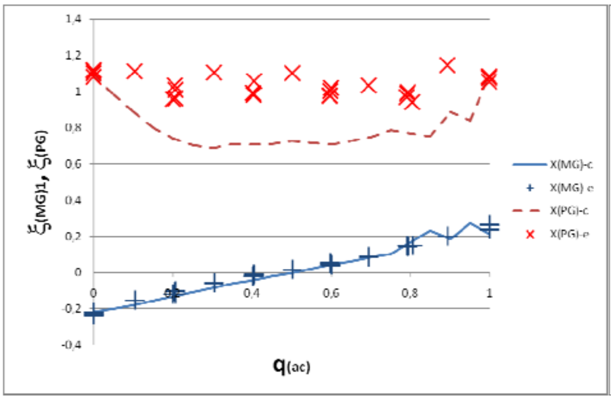


Fig. 7: Geometry coefficients for Div c.

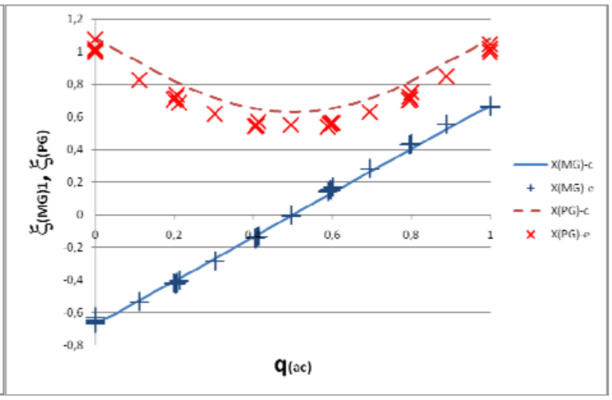


Fig. 8: Geometry coefficients for Com c.

4. Conclusions

The agreement between the measurements and CFD calculations is very good. The determining of friction coefficients in experiment plays very important role.

Acknowledgement

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