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NUMERICAL ANALYSIS OF THE INFLUENCE OF THE VORTEX SHEDDER SHAPE ON THE CREATION OF VON KARMAN VORTEX STREET

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The paper presents the numerical analysis of the impact of chosen surfaces of a vortex shedder on selected parameters of the vortex flowmeter. In order to determine the effect of the shape of vortex shedder on the type of generated vortices, simulations for different flow velocities were carried out.
Keywords: vortex flowmeter, flow around vortex shedder

Стаття представляє чисельний аналіз впливу вибраних поверхонь вихорового розташування на параметри вихорового витратоміра. Для визначення ефекту впливу форми вихорової поверхні на вид генерованої вихорової доріжки було проведено моделювання для різних швидкостей течії.
Ключові слова: вихоровий витратомір, течія навколо вихорової зони.

Статья представляет численный анализ влияния избранных поверхностей расположения вихрей на параметры вихревого расходомера. Для определения эффекта влияния формы вихревой поверхности на вид генерируемой вихревой дорожки было проведено моделирование для разных скоростей течения.
Ключевые слова: вихревой расходомер, течение вокруг вихревой зоны.

Introduction. Vortex flowmeters are measuring devices which can be used to measure different densities and viscosities of liquids. Vortex flowmeters are resistant to the contamination of the liquid. The advantage of these devices is very small pressure drop across the meter. However, they have a relatively narrow measuring range [7].

The principle of operation of a vortex flowmeter is based on the formation of regular vortices, whose frequency is a function of the flow. Vortices are produced by a vortex shedder, the shape of which has a direct effect on the sensitivity and range of the flowmeter. Normalized frequency of vortices is a measure of the flow velocity stream and is expressed by the Strouhal number [10].

$$St = \frac{f \cdot d}{v}, \tag{1}$$

where: S_t – Strouhal number; d – characteristic length; f – frequency of vortex shedding; v – flow velocity.

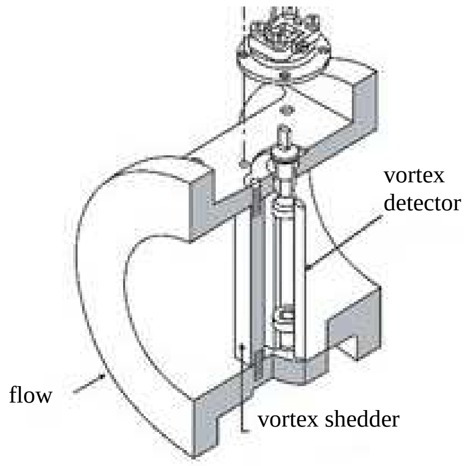

Figure 1 – Vortex flowmeter construction [10]

Figure 1 shows a typical construction of a flowmeter [10]. It consists of a vortex shedder that disrupts the flow. The vortex shedder creates von Karman vortex street. At a certain distance behind the vortex shedder, a detector is placed. Most often it is a pressure sensor with high dynamic measurement. The signal from the pressure sensor is converted into an electronic system to determine the frequency of changes in pressure.

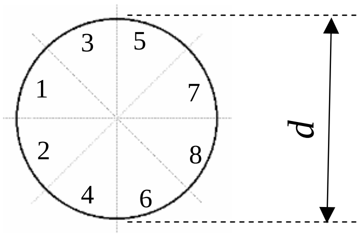

Figure 2 – The basic shape of a vortex shedder

The vortex shedder has a significant impact on the characteristic features and metrological properties of the flow meter [3]. It is very important that vortex shedder provide the formation of regular vortices. A lot of research works describe vortex shedders in the shape of a cylinder [2, 6], this shape will also be a benchmark in this work. A cylindrical shape may be used only in a narrow range of measurements, due to the inability to provide stable vortices [9]. The size and shape of a vortex shedder plays an important role in the correct operation of the vortex flowmeter [10], hence it is advisable to search for new shapes [5]. Currently a lot of profiles of vortex shedders are commercially available However, no universal form of a vortex shedder has been developed so far, hence the study of the influence of the shape of the vortex shedder on the parameters of the flow meter is a still a topic of crucial importance

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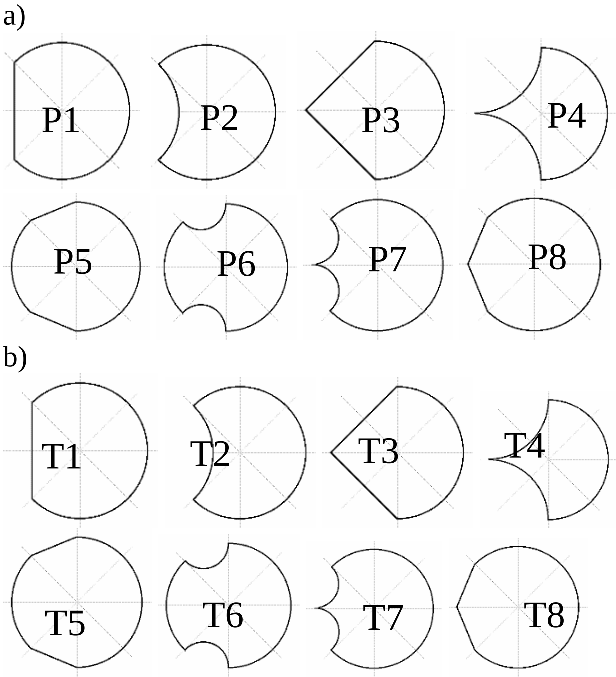

Figure 3 – Shapes resulting from a) rake surface modification b) runoff surface modification

The present work is devoted to the numerical analysis of the impact of selected surfaces of the vortex shedder on selected parameters of the vortex flowmeter.

As a primary shape a cylinder of the diameter d=20 mm (Fig. 2) was assumed. This cylinder was divided into eight symmetrical parts, four of which form a rake surface and the other four form a runoff surface.

In order to determine the impact of individual surfaces of the vortex shedder on the von Karman vortex street parameters, some modifications were made to a single symmetric surface. As a result, two groups of shapes were obtained. The first group consists of shapes in which changes to the rake surface were made (Fig. 3a). The second group subsumes the shapes resulting from changes in the runoff surface (Fig. 3b).

The Numerical Method. To model complex flow problems, predominantly numerical methods - CFD (Computational Fluid Dynamics) are used.

The modelling is based on Reynolds theory, which assumes that the movement of the fluid can be identified as a superposition of the mean and fluctuation motion.

This assumption entails the transformation of the Navier – Stokes equations into the form which additionally comprises the tensor of turbulent stresses. This results in the appearance of additional unknowns in the system of equations.

Accordingly, the Reynolds equations are supplemented with two-dimensional models, such as turbulence k-ε or k-ω [12]. The variety of existing numerical models causes that it is advisable to select a numerical method which to a satisfactory degree will simulate the process of creating von Karman vortex street.

The k-ε model is one of the most popular models, which is currently used for the modelling of an incompressible fluid, with low speeds. In the k-ε model there are additional differential equations of the transport of the kinetic energy of turbulence k and the dissipation of the kinetic energy of turbulence ε [12].

The k-ω model takes into account the relationship between vorticity and the kinetic energy of turbulence [12]. The k-ω mode, besides the solution of the kinetic energy of turbulence, also solves the element of the velocity of energy dissipation. In the k-ω model, just as in the k-ε, one k is the kinetic energy of turbulence, and ω is defined as the ratio of the velocity of energy dissipation ε to kinetic energy k.

A slightly different approach to solve flow equations was used in the DNS method (Direct Numerical Simulation). It is based on solving the

Navier - Stokes equations directly, without introducing additional turbulence models [12]. The DNS method allows for direct solution of vortex flow throughout its entire turbulence range. However, it also requires a very dense computing grid, which significantly increases the computation time. The advantage of the DNS method is proper rendition of the dynamics of turbulence.

To obtain correct results of a numerical simulation, it is necessary to use a suitable model and to determine the right boundary conditions. Existing scholarship on the topic shows many rules defining the scope of applicability of individual calculation models, as well as the requirements that the discretized area must meet [1, 11]. Therefore, it was decided to carry out research on selected computational models in order to select the optimal model for the calculations in this study.

In order to choose the optimal computational model we a computational grid for a rectangular channel with a length of L1 = 900 mm and a width of L2 = 600mm, was prepared inside which a cylinder (perpendicular to the flow)with a diameter of 20 mm was placed (Fig. 4). The width of the channel was chosen to eliminate the influence of the channel walls on the generation of vortices formed behind the cylinder.

For the studied area, a structural mesh consisting of rectangular elements of different shapes and sizes was generated. The highest density of the grid is present in the area immediately adjacent to the vortex shedder.

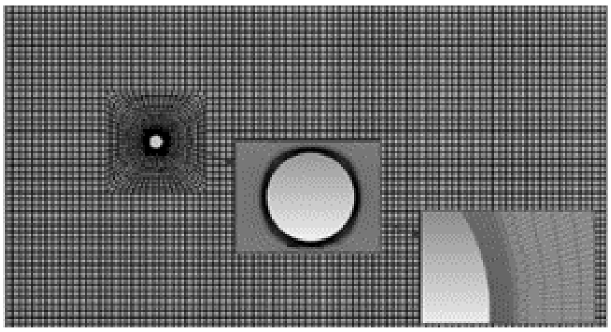

Figure 4 – Computational mesh

For generated in such a manner mesh, a series of calculations for selected models of turbulence were conducted. Computations were performed for the assumption that at the inlet channel there was a uniform distribution of the velocity v = 1m/s.

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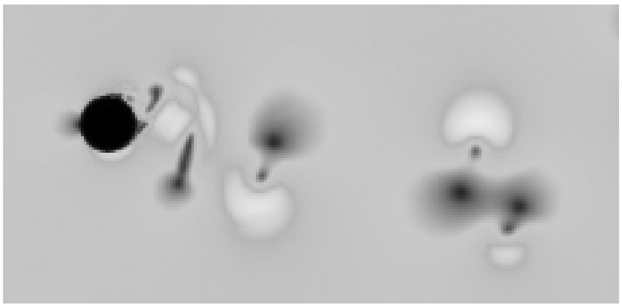

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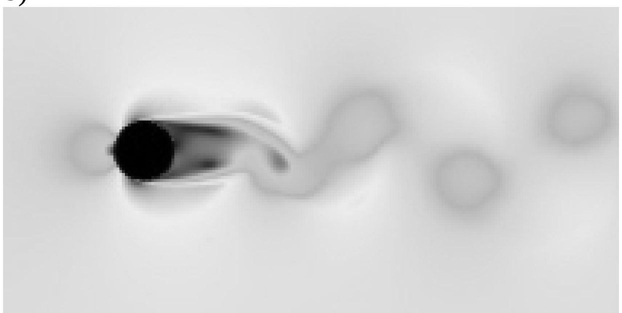

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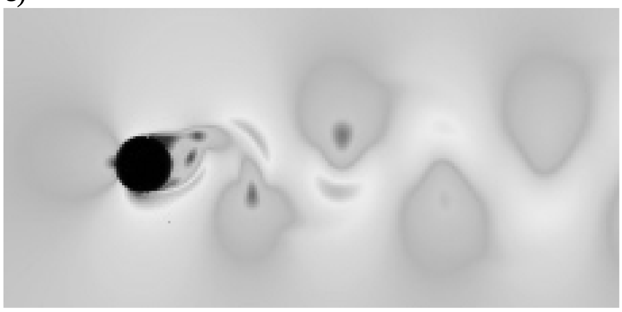


Figure 5 – Computational results for models: a) DNS b) k- ε c) k-ω

Figure 5a illustrates the simulation of results for the DNS method. It follows that the computation results are not stable. This is caused by an insufficient number of elements in the mesh. Increasing the number of mesh elements will significantly increase the computing time or will require the computing machine with a lot more processing power. Stable simulation results were obtained for models k-ε and k-ω (Fig. 5b and 5c). However, for the k-ε model irregularities were observed in the area of runoff streams, behind the vortex shedder. This method does not fully reflect the dynamic nature of the phenomenon of flow around. On the basis of this analysis, the optimum model suitable for the simulation of the von Karman vortex street is the method applying the k-ω model

In the vortex flowmeter a stable frequency of vortices is very important, as it will directly affect the measurement accuracy. Another important parameter is the amplitude of the pressure changes caused by the vortices, because the sensitivity of the flowmeter depends on it. Therefore, these two parameters were taken as a criterion for assessing the optimal computational mesh density. Ten different mesh densities were generated, starting from the grid consisting of 7 395 elements and 7 666 nodes and ending with a grid composed of 738 815 elements and 740 682 nodes.

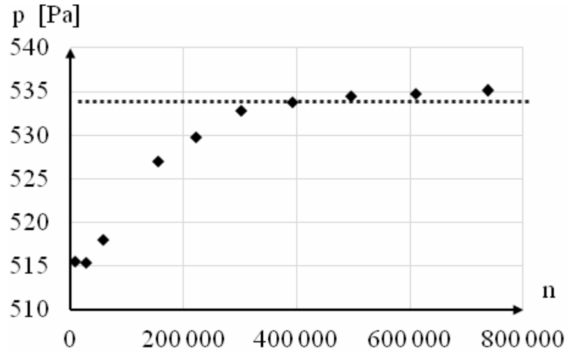


Figure 6 – Average values of the amplitude of pressure changes on the elements number of the computational mesh

Figure 6 shows calculation results of the average amplitude changes depending on the number of mesh elements. In turn, figure 7 shows calculation results of the average frequency values of wake vortices. On this basis, the optimum value of elements number of the grid is in the range of 350 000 - 500 000 elements. This range guarantees a stable value of the pressure amplitude and frequency. Increasing the number of mesh elements beyond this range will not improve significantly the results but it will only increase the computation time. Having analysed the unchangeable results for frequency and amplitude of pressure, it was assumed that the number of elements for the cylindrical shape would be 396 031 and 400 848 nodes.

Computional Results. In order to determine the effect of the shape of vortex shedder on the type of generated vortices, simulations for different flow velocities (0.5m/s, 1m/s, 2m/s) were carried out. The equations of the mathematical model were solved by the finite volume method using ANSYS Fluent. The Turbulence k-ω SST model was used [12] for two-dimensional velocity field and unsteady flow at a time step of the order of 10^{-4} to 10^{-5}. Computations were performed for two assumptions: the assumption that at the inlet channel there was a uniform distribution of speed and assuming rheological parameters of the liquid as corresponding to water.

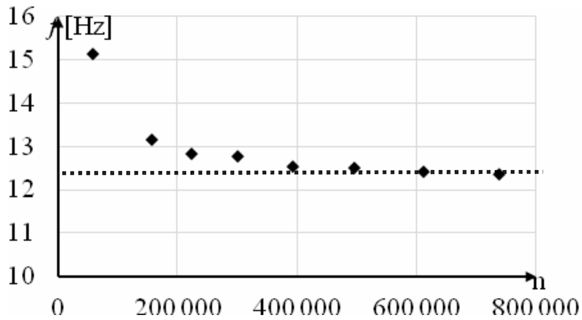


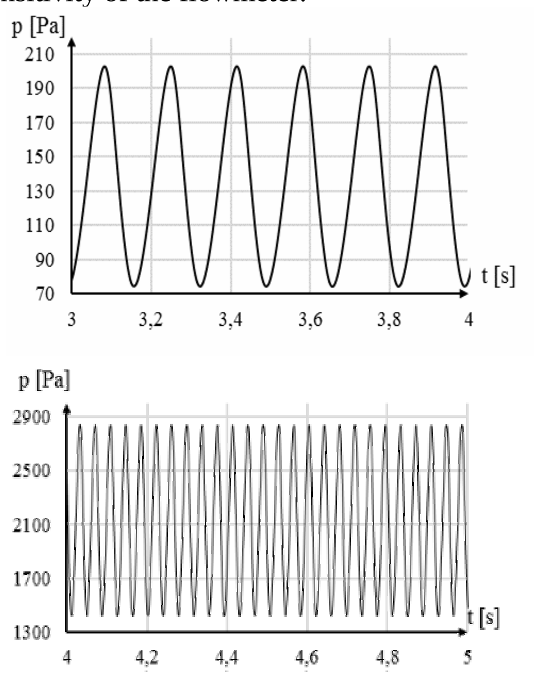
Figure 7 – Average values of the frequency of generated vortices on the elements number of computational mesh

The results of the calculations referred to the values of the basic shape (Fig. 2). For this shape, regular and stable results for the liquid flow rate of 0.5m/s, 1m/s and 2m/s were obtained.

Figure 8 presents an example of the changes, respectively for the flow rates of 0.5 m/s and 2m/s

The aim of the research is to determine the effect of individual surface of vortex shedder on frequency, pressure and stability of the formation of vortices.

Frequency has a very significant impact on the parameters of the vortex flowmeter. Changes in the value of frequencies in response to changes of the measured fluid flow have a direct impact on the sensitivity of the flowmeter.



a)
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Figure 8 – Average values of the frequency of generated vortices on the elements number of computational mesh

Figure 9 shows the results of the comparison of value of frequency changes of formed vortices with various surface modifications relative to the cylindrical shape. The results are presented as the ratio of the test vortex shedder to the reference value with the subscript "o". The reference value is the value that is generated by the vortex shedder in the shape of a cylinder (cf. Table 1).

Modifications which positively affect the sensitivity of the flow meter have the slope of characteristics.

A significant increase of the ratio of f/f0 proves that greater measurement sensitivity is obtained in the case of the use of the modification. Figure 9a shows that any modification of the rake surface reduces the sensitivity of the flowmeter. For the modification of the runoff surface, the improvement of the sensitivity of the flowmeter is obtained for the shapes T2 and T7. These shapes have a sharp edge, which facilitates the detachment of vortices.

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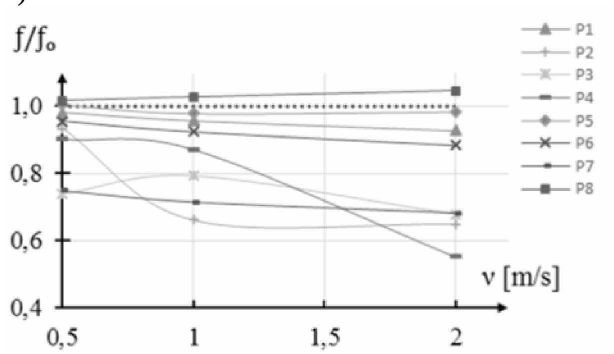

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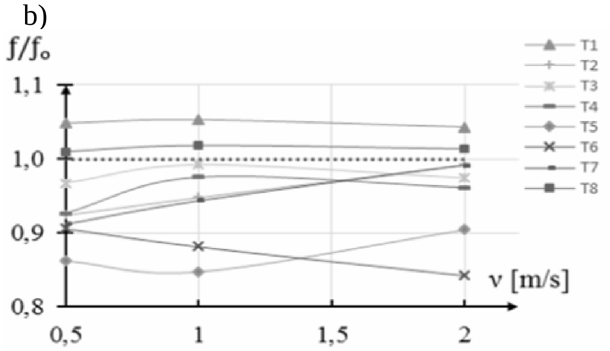

Figure 9 – The impact of shape modification of the vortex shedder to the frequency of vortices generated by a) the modification of the rake surface (shape from P1 to P7) b) the modification of the runoff surface (shape from T1 to T7)

Another parameter improving the properties of the flowmeter is the value of the pressure changes of generated vortices. This parameter causes that the higher pressure changes improve the signal to noise ratio. Figure 10 shows the results of the effect of rake and runoff surface modification on the amplitude of pressure changes for a vortex shedder.

Rake surface modification implying augmenting the drag coefficient, causes an increase in pressure differential behind the vortex shedder, which improves the properties of the flowmeter (Fig. 10a). However, this makes the characteristics become more non-linear. Improving the signal to noise ratio will be particularly noticeable for high velocities (Fig.10b).

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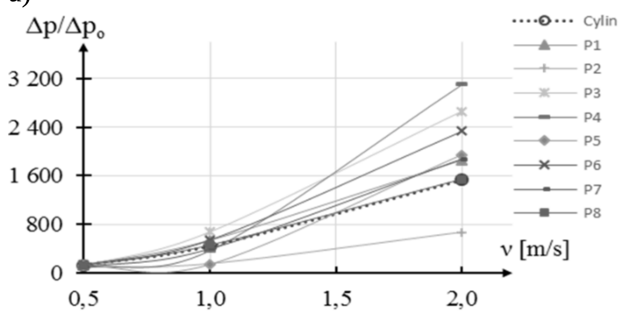

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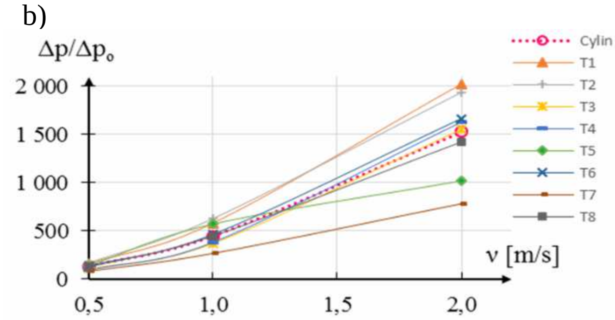

Figure 10 – The impact of modifying the vortex shedder shape on the pressure changes behind the vortex shedder a) the modification of the rake surface (shapes from P1 to P7) b) the modification of the runoff surface (shapes form T1 to T7)

Further research was carried out to determine the impact of changes in the shape of rake surface on the stability of vortex street. The introduction of modification for surface 1 and 2 (cf. Fig. 2) results in a destabilization of vortex street for higher values of the fluid flow (Fig. 11c and 11d). The flattening of this surface does not cause significant destabilization, but neither is a substantial reinforcement of the amplitude of the arising vortices achieved (Fig. 11 and 11b). In practice, the modification of the vortex shedder of this area will have a very restricted application. Surface modification marked with numbers 3 and 4 (Fig. 3) affects very negatively the regularity of detachment of vortices. Even for the low-velocity of fluid flow a loss of stability is observed (Fig. 12). Only the P5 shape does not cause meaningful instability, but it does not cause a significant increase in pressure behind vortex shedder, either. Due to high destabilization of vortices generation it is not recommended to modify these surfaces. Desirable are shapes that lead to the reduction of the drag coefficient induced by these surfaces.

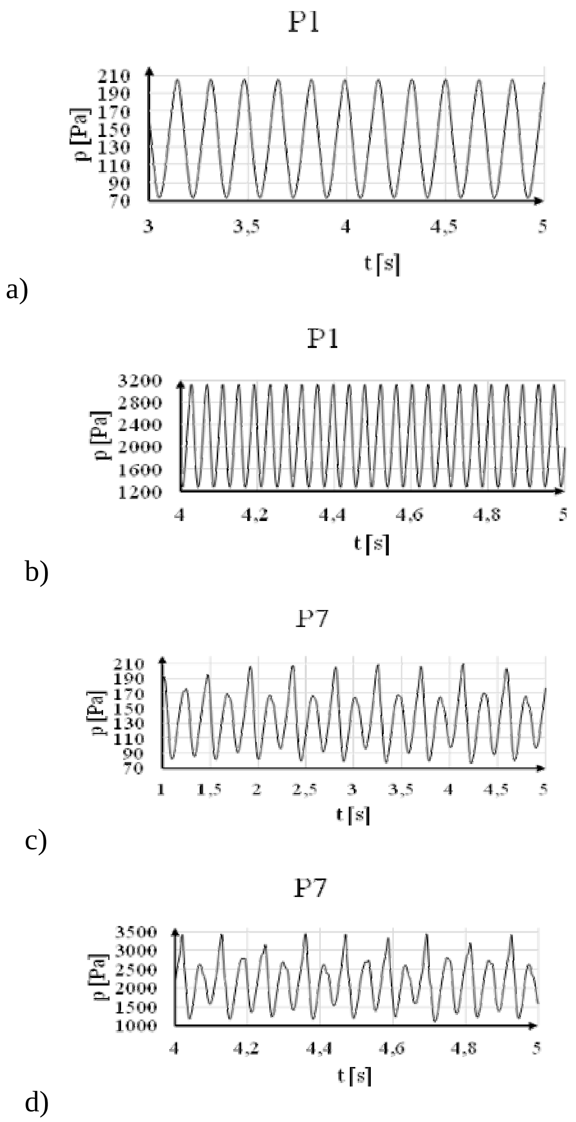

Figure 11 – The influence of 1 and 2 surfaces modification on the regularity of generated vortices. a) for P2 with v = 0.5m/s b) for P2 with v= 2 m/s c) for P7 with v = 0.5m/s d) for P7 with v= 2 m/s

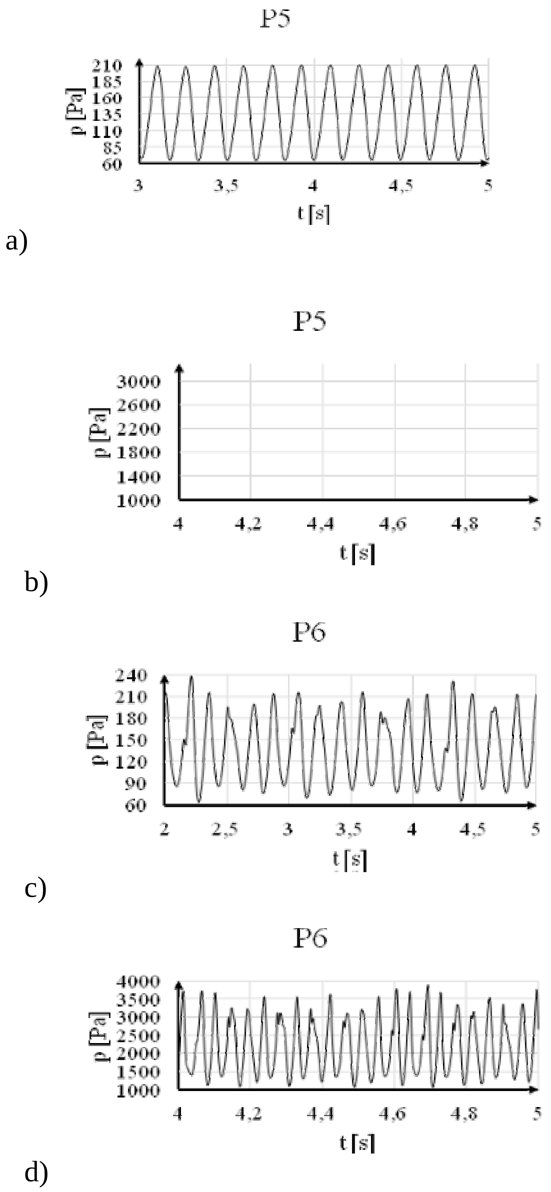

Figure 12 – The influence of 3 and 4 surfaces modification on regularity of generated vortices. a) for P5 with v = 0.5m/s b) for P5 with v= 2 m/s c) for P6 with v = 0.5m/s d) for P6 with v= 2 m/s

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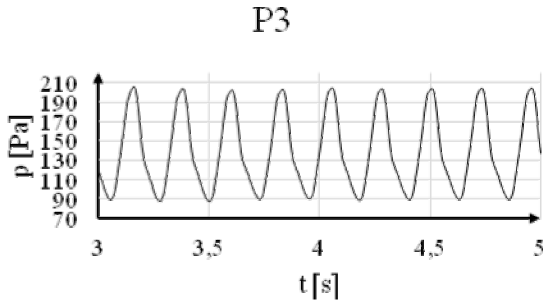

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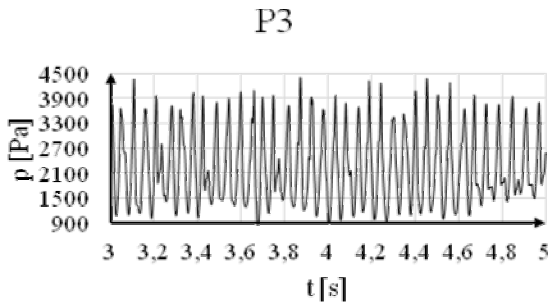

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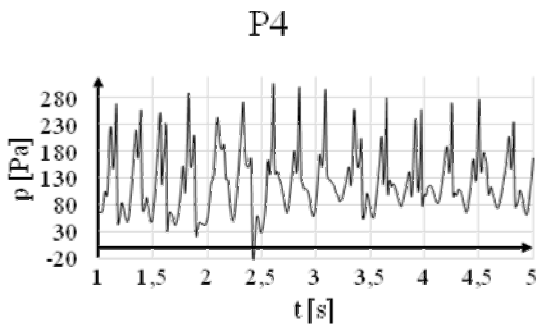

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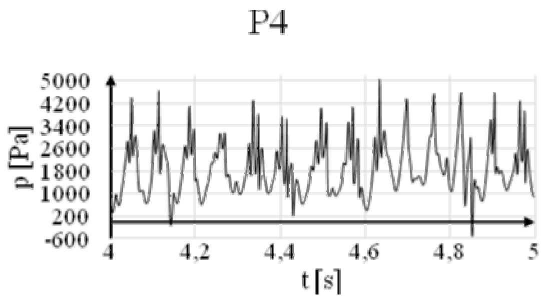

Figure 13 – The influence of 1,2,3 and 4 surfaces modification on the regularity of generated vortices. a) for P3 with v = 0.5m/s b) for P3 with v= 2 m/s c) for P4 with v = 0.5m/s d) for P4 with v= 2 m/s

Furthermore, the effect of modifications of the total rake surface (shape P3 and P4) was verified. The results of the analysis are shown in figure 13. Modification of this surface destabilizes the vortex street in the whole range of tested fluid velocity

Disturbances of vortex street are already noticeable for a very small velocity v = 0.5 m / s (Fig. 13). Even mild flattening results in a significant disruption. Although the P4 shape has the largest strengthening of the pressure amplitude behind the vortex shedder, such shapes can be suitable only for very small flow rates of the fluid. In addition, they narrow the measurement range.

Summarizing the carried out analysis, it can be concluded that for the production of stable and regular vortices, the most preferred situation obtains when the rake surface is the most perfectly streamlined possible, in which case it leads to the lowest drag coefficient.

Very similar numerical studies were carried out on shapes in which the runoff surface was modified (Fig. 3b). The simulation results for the 7 and 8 runoff surface modification are shown in Figure 14. A modification of this surface doesn't cause a significant change relative to cylindrical vortex shedder. It does not cause destabilization of stream. This is due to the fact that the detachment of vortices takes place on the 6 and 7 surfaces. However, they affect the pressure amplitude value of the vortices.

Secondly, a study was carried out to determine the impact of changes in the surface which are indicated in Figure 2 as 5 and 6. The results are shown in figure 15. The sharp edge of the runoff area causes changes in the way vortices detach. This results in a destabilization of the regularity of the vortices formation for higher fluid flow rate. On the other hand, slight flattening of the surface decreases the amplitude of pressure changes. Therefore, modifications of this surface will not affect favorably the metrological properties. It is preferable to leave the most streamlined shape.

The influence of the modification of the total runoff surface is shown in figure 16. Modification of this surface does not cause destabilization of the vortex street. Tightening the tear-off edge of vortices has a beneficial effect on lowering the static pressure behind the vortex shedder.

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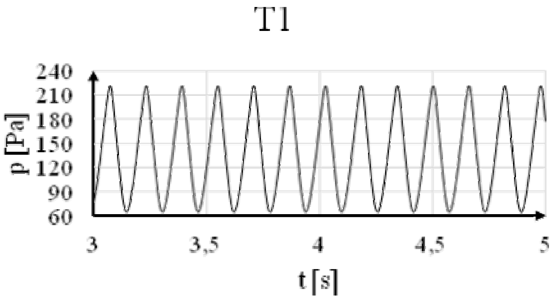

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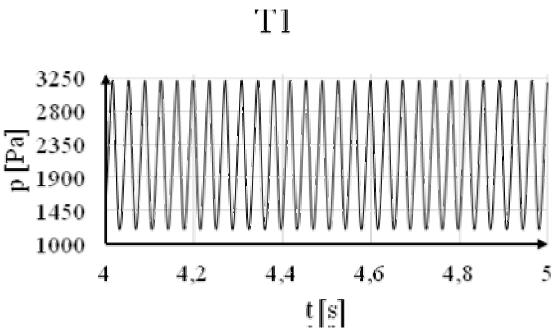

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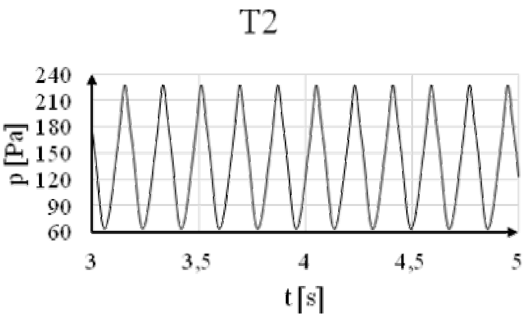

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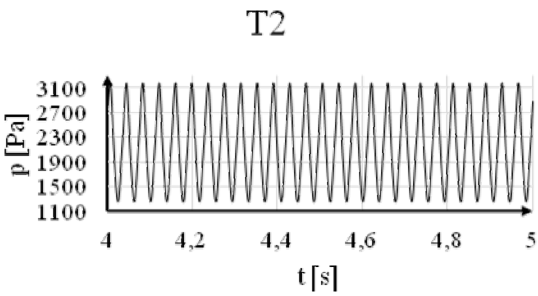
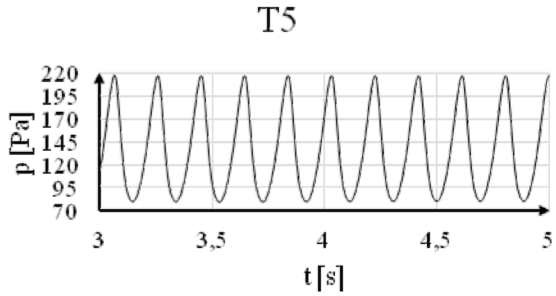


Figure 14 – The influence of 7 and 8 surfaces modification on regularity of generated vortices. a) for T1 with v = 0.5m/s b) for T1 ith v= 2 m/s c) for T2 with v = 0.5m/s d) for T2 with v= 2 m/s.

a)



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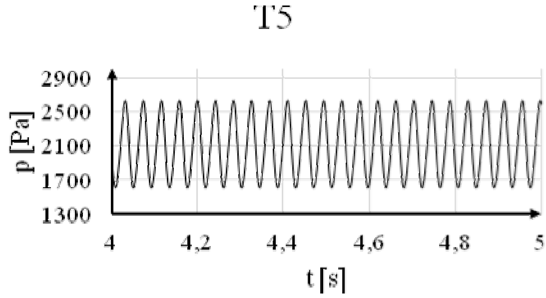

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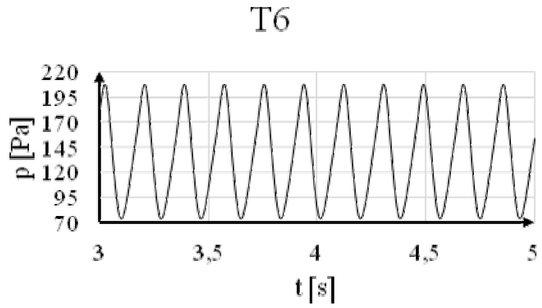

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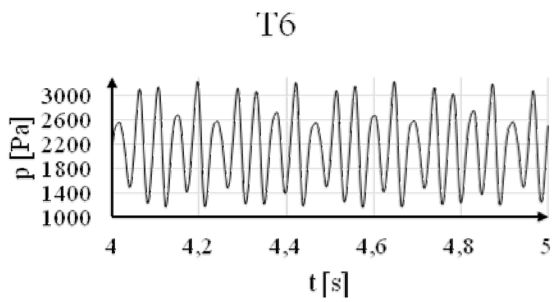

Figure 15 – The influence of 5 and 6 surfaces modification on the regularity of generated vortices. a) for T5 with v = 0.5m/s b) for T5 with v= 2 m/s c) for T6 with v = 0.5m/s d) for T6 with v= 2 m/s.

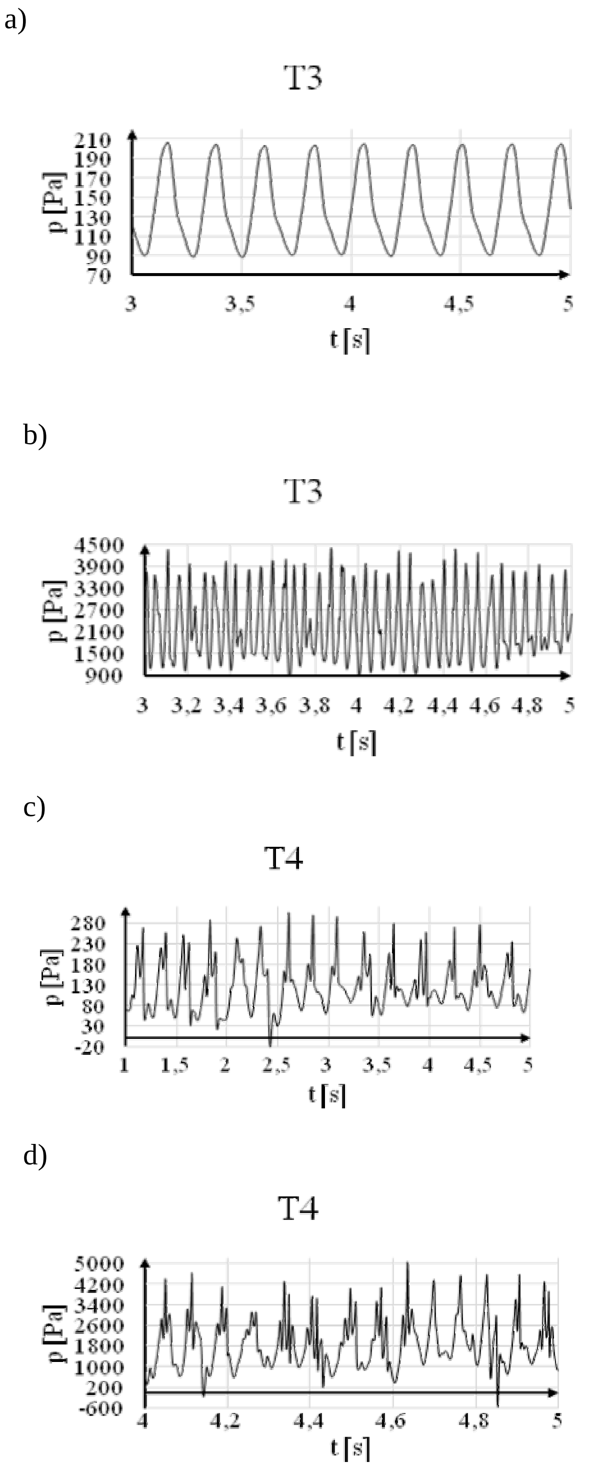

Figure 16 – The influence of 5,6,7 and 8 surfaces modification on regularity of generated vortices. a) for T3 with v = 0.5m/s b) for T3 ith v= 2 m/s c) for T4 with v = 0.5m/s d) for T4 with v= 2 m/s.

Conclusion. Based on the conducted research it was found that modifications of the rake surface lead to the strengthening of pressure amplitude, but they also cause destabilization of the process of creating vortices for higher velocities of the fluid flow. Increasing the drag coefficient improves the properties of the flow meter in the lower measuring range, but it will narrow its range.

Modification of runoff surface improves the sensitivity of the flowmeter. Particularly desirable in this range will be the shapes marked as T2 and T7. The results of the study can be used as guidelines in the design of vortex shedders for use in vortex flowmeters.

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