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# Investigation of Reynolds Stress in Fluid Flow

# Výzkum Reynoldsova napětí v proudu tekutiny

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*In the case of pulsatile flow we are dealing with a complicated task taking in account a non-stationary character of the process. The change of flow characteristics is of fundamental importance for the solution of many technical problems. The investigation of pulsatile Newtonian fluid flow in circular rigid pipes is presented in the paper. The aim of the research was to deepen the knowledge of effect of model geometry and flow characteristics on Reynolds stress. Interesting results which were obtained will be used in practise. Velocity profiles were measured with a laser-Doppler anemometer. The assemble-average velocity profiles, fluctuating components of velocity and the Reynolds normal stress have been experimentally evaluated. One of the important features that accompany this type of fluid motion is the transition from laminar to turbulent flow. In our research we have focused on this factor and we tried to solve the dependence of the flow characteristics on dimensionless products such as Reynolds number and frequency parameter. The evaluation of the Reynolds normal turbulent stress help us to determine the values of Reynolds tangential stress, which causes hydraulic loss in the tubes.*

**Keywords: Turbulence, Reynolds stress, pulsatile flow**

## Experimental apparatus

The flow channel is shown in Fig.1.

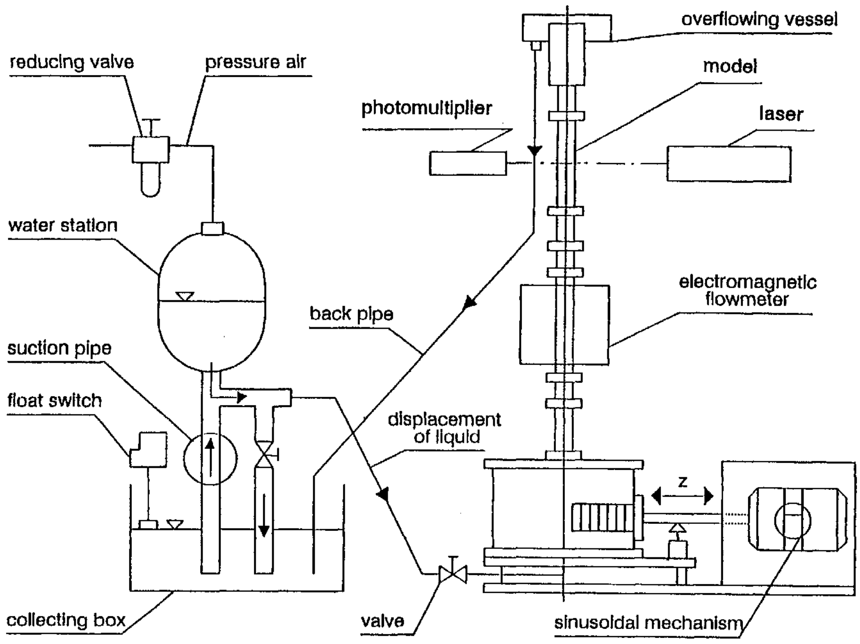


Fig.1

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For these experiments the model is a circular tube with rigid walls and a diameter d = 2R = 20 mm located in a vertical position. The measured pulsatile flow is a result of superposition of stationary flow and periodic oscillations. A water station supplies stationary flow $Q_s$. A piston with sinusoidal mechanism is the source of oscillations $Q_p$.

The flow is characterised by a flow ratio $\lambda$ and a frequency parameter $\alpha$. $\lambda = Q_{pm}/Q_s$ is a ratio between the maximum amplitude of the oscillatory component of the volume flow rate $Q_{pm}$ and the corresponding stationary component. Frequency parameter $\alpha = d/2\sqrt{\omega/\nu}$, where $\omega$ is angular frequency and $\nu$ is kinematic viscosity. The measurement was performed for two values $\lambda$ ( 0,45 and 0,9 ), for a number of values $\alpha$ ( 8 - 30 ) and for five stationary components of the flow $Q_s$ ( 1-5 l min$^{-1}$ ). $\mathrm{Re}_m$ is Reynolds number for stationary velocity $\bar{v} = 4Q_s/\pi d^2$. The values of $\mathrm{Re}_m$ for particular values of $Q_s$ are as follows: $Q_s$ =1 l min$^{-1}$ - $\mathrm{Re}_m$ = 1050, $Q_s$ =2 l min$^{-1}$ - $\mathrm{Re}_m$ = 2090, $Q_s$ = 3 l min$^{-1}$ - $\mathrm{Re}_m$ = 3130, $Q_s$ =4 l min$^{-1}$ - $\mathrm{Re}_m$ = 4180, $Q_s$ = 5 l min$^{-1}$ - $\mathrm{Re}_m$ = 5220.

The velocity was measured at 30 points along the pipe diameter. Amplitude and frequency of pulsations are set by adjusting of a piston stroke and a number of asynchronous motor revolutions. The height of water level in overflowing vessel and its temperature is kept constant during the measurement.

## Velocity measurement

A single channel laser -Doppler anemometer operating in a forward scattering mode was used to obtain the local value of fluid velocity. The time-mean velocity is calculated from formula $\bar{v} = \frac{1}{T}\int_0^T v\,dt$, where $v = v(t)$ means instantaneous velocity and $T$ is period of cycle. The ensemble-average of velocity is given by formula

$\langle v_k \rangle = \frac{1}{n}\sum_{j=1}^{n} v_{jk}$, where index $j$ counts periods and index $k$ counts phases in period. Symbol $n$ represents a number of measured periods, $v_{jk}$ is velocity in the $j$-th period and $k$-th time of period. Number of periods is $n$=50 and number of phases is $n_p$=720 in each point ( it gives 36 000 data ). The fluctuating component of velocity can be expressed by formula

$v'_{jk} = v_{jk} - \langle v_k \rangle$.

Experiments on transition to turbulence in a pulsatile pipe flow were performed for various values of parameters $Q_s$, $\lambda$ and $\alpha$ in several points along the diameter.

## Reynolds normal stress evaluation

The Reynolds normal stress will be calculated from formula

$\sigma = \rho\left\langle v_k'^2 \right\rangle = \frac{\rho}{n}\sum_{j=1}^{n} v_{jk}'^2$, where $\rho$ is the fluid density.

The Reynolds normal stress distributions for $\mathrm{Re}_m$=2090, 3130 and 5220, $\alpha$ = 16 and $\lambda$ = 0,45 along the tube diameter is in Fig. 2. Figure 3 shows the dependence of the value of normal stress $\sigma_m$ on $\mathrm{Re}_m$ and $\lambda$ for $r$ = 7,2 mm ( $r$ is distance of measured point from axis of the tube ). Symbol $\sigma_m$ means time-mean value within the disturbance.

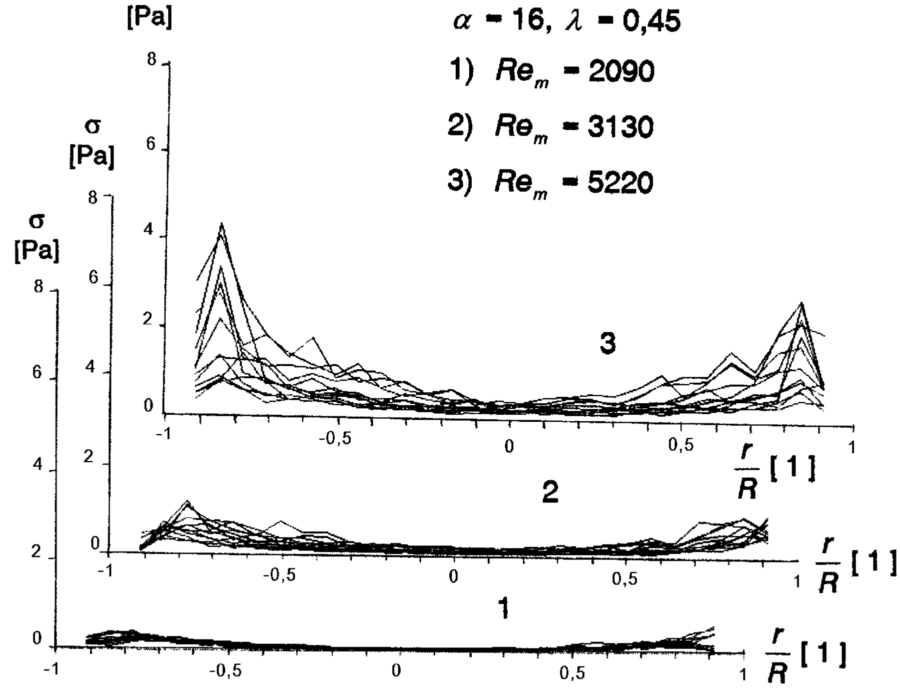


Fig. 2

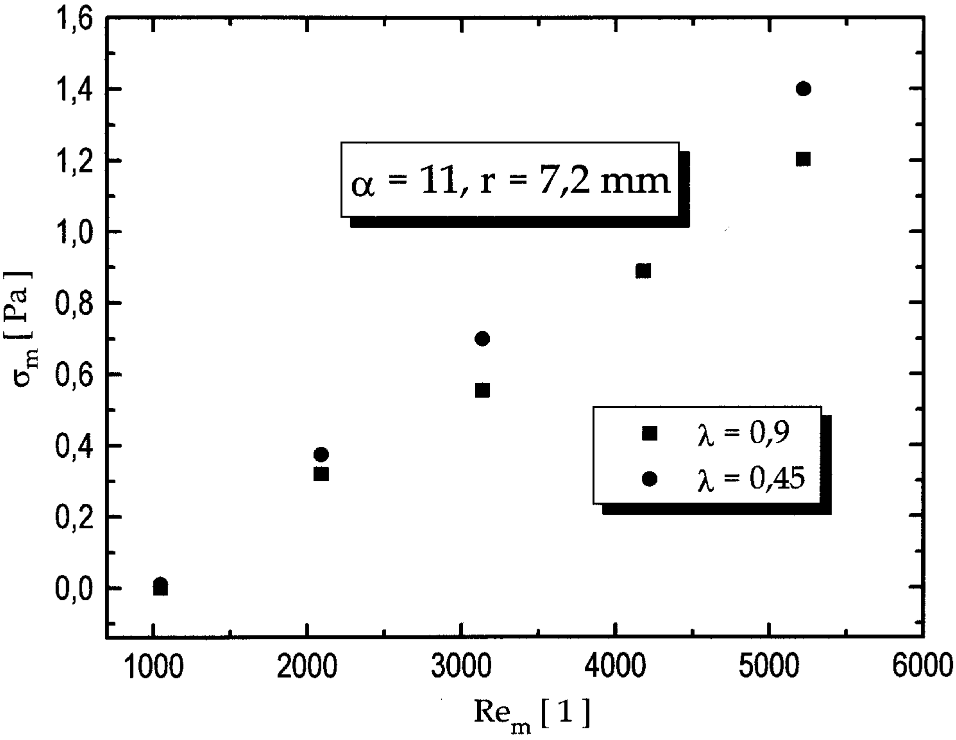


Fig. 3

The dependence of the mean value of stress $\sigma_m$ on $\alpha$ for $Re_m = 3130$ and $Re_m = 4180$ ($Q_s$ = 3, 4 l $min^{-1}$), $\lambda = 0{,}9$ and point r = 7,4 mm can be read from Fig. 4.

## Conclusions

From the results of the experiments carried out within the described range of $Re_m$ ,α, λ and *r* the following conclusions can be formulated:

A. For the first time the turbulent disturbances appear when $Re_m$ =2090. At certain measured point there is only one disturbance during a period and is phase locked.
B. The intensity of turbulent disturbance is growing in the direction to the tube wall.
C. The value of mean turbulent Reynolds stress of disturbance $\sigma_m$ depends on $Re_m$, $\alpha$, $\lambda$ and $r$. The value of $\lambda$ being constant, at certain measured point the value of $\sigma_m$ increases simultaneously with increasing value of $Re_m$ ($\alpha$ being constant) and decreases simultaneously with increasing value of $\alpha$ ($Re_m$ being constant). When the value of $\lambda$ increases ($Re_m$ and $\alpha$ being constant) it causes rising of the maximal value of stress in the area of turbulent disturbances but drop of the mean value of stress.

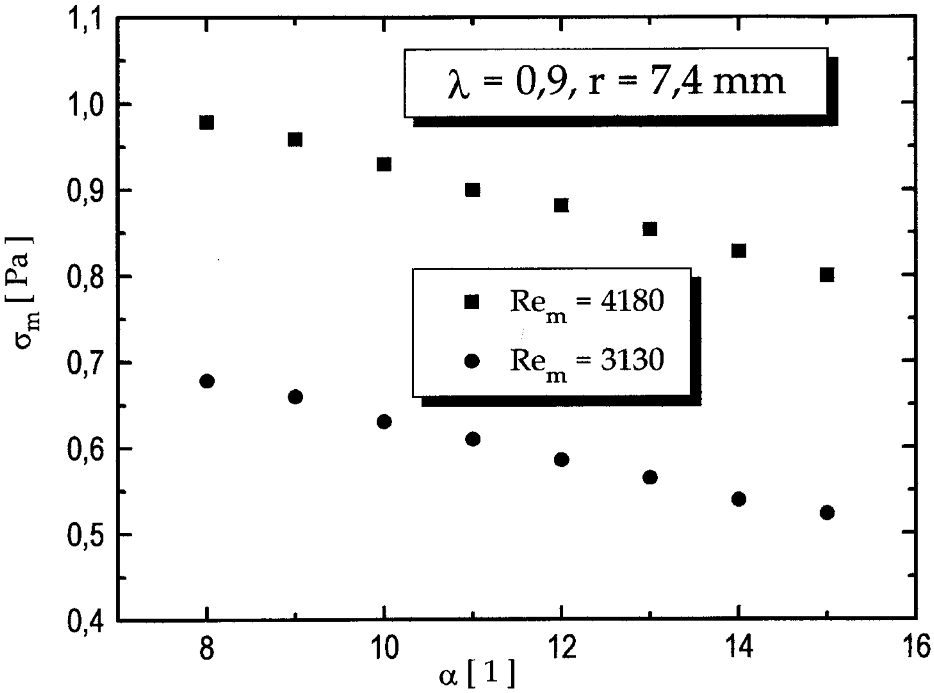


Fig. 4

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