KOLMOGOROV LAW IN ANALYSIS OF THE TURBULENT SWIRL FLOW IN PIPE

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ABSTRACT

A major problem in modeling turbulence is its anisotropy. Reflections on local-isotropic turbulence Kolmogorov formulated in his two hypotheses of similarity [1]. In addition, Kolomogorov refined his theory in [2].

The dynamic role of the interaction of strain-rate fluctuations and evolution of vortex deformation in dynamic mechanisms of transferring energy from large to small proportions and its dissipation in the smallest vortices is confirmed by the equations that describe the interaction of vorticity, Reynolds stresses and the strain-rate field. Namely, a small part of their energy is absorbed by large vortices by direct dissipation, since the distribution of energy between the vortex is subject to the principle of cascade energy transfer [3]. “Big whirls have little whirls that feed on their velocity, and little whirls have lesser whirls and so on to viscosity – in the molecular sense.” (Richardson, [3]).

By use of the non-linear dissipative mechanism of the spectral energy transfer, viscous dissipation occurs in the smallest velocities, i.e. in fine vortex structures which belong to the regions of large wavelengths in the spectrum of turbulent flow energy (Kolmogorov's hypothesis, [1]). The vorticity, or enstrophy, of small vortices is much higher than in the case of the large vortices, while vice versa for their energies. All of these phenomena classify turbulence into highly suppressed nonlinear stochastic systems.

Here is discussed Kolmogorov’s law in the study of the turbulent swirl flow in pipe on the axial fan pressure side. This fan generates Rankine vortex where four zones are distinguished (vortex core region, shear stress region, sound flow region and boundary layer). In Figure 1 is presented spectral density of circumferential velocity fluctuations till frequency f = 200 Hz in the function of the frequency, i.e. $\Phi_{ww}(f)$, obtained on the basis of the velocity field measured by use of the laser Doppler anemometry (LDA) [4]. Fan rotation speed is 1500 rpm which corresponds to the frequency f = 25 Hz. Achieved high Reynolds number, calculated on the basis of the average velocity $U_m = 4Q/(D^2\pi)$, where Q is volume flow rate and D is pipe inner diameter, is $Re = U_m D/\nu = 277018$, where ν is kinematic viscosity. Here is applied one-component LDA system for measurements of three velocity components (axial U, radial V and circumferential W), subsequently. On the basis of axial velocity distribution is

calculated volume flow rate (Q). The highest sampling rates are achieved for circumferential velocity, so it was used for the analysis presented here.

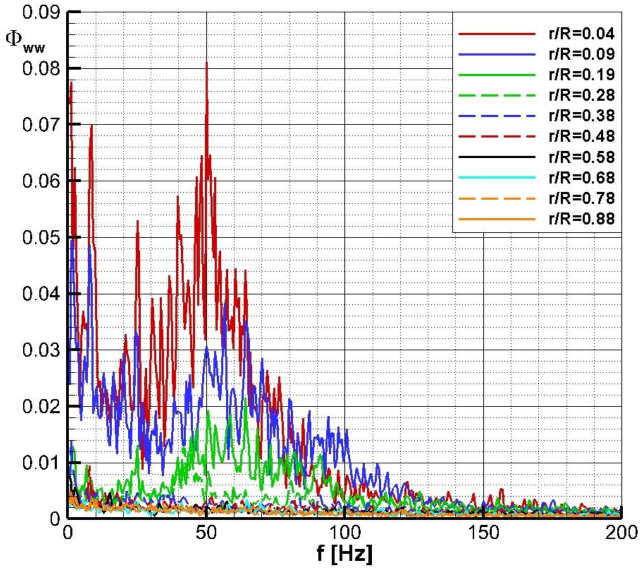

Figure 1. Spectral densities of the circumferential velocity fluctuations.

It is obvious that the most of the energy is distributed in the region of lower frequencies, which correspond to the fan rotation speed. This is completely clear for the first three points in the vortex core region. Spectral densities are presented, also, in log-log diagram in Figure 2. It is obvious that high spectral densities are obtained for low frequencies, which are almost hierarchically distributed in this region starting from the point in the vortex core (r/R=0.09, where R = D/2) till the lowest values in the sound flow region.

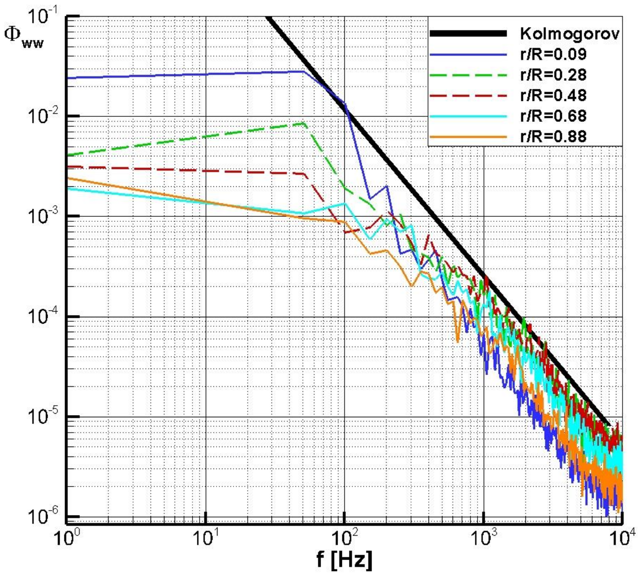

Figure 2. Log-log plots of spectral densities of the circumferential velocity fluctuations.

Frequency increase leads to the spectral density decrease and in the inertial spectrum part almost completely follows Kolmogorov law $\Phi_{ww}(f) \propto f^{-5/3}$. For the frequencies higher than 1 kHz spectral density curves have common tangent line with slope -5/3.

This research proved that Kolomogorov law could be well applied in the turbomachinery research. It reveals zones with coherent vortex structures with high energy, as well as zones with higher frequencies which are related to the energy dissipation mechanisms.

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