Summary

It has been found experimentally that an isolated turbulent vortex ring radiates sound and this radiation level is sufficient for its reliable registration. The ring noise was determined from the ensemble averaged spectrum, manifesting itself by strong peaking of the spectrum in a narrow frequency band. Measurements of mean flow parameters of a vortex ring and data on their slow variation as the vortex moves permits comparing all the main characteristics of the radiation spectrum peak with the theoretical model for a considerable part of trajectory. It appears that within the limits of the theory derived one can readily explain all the experimental facts: peak existence, uniqueness of peak, peak width and narrow band stochastic feature of the signal, peak drift to the low frequency region of spectrum as the vortex moves.

On the other hand the theory predicts that three infinite families of modes are responsible for the unique peak in the noise spectrum. These modes have an identical frequency but differ in noise directivity. A new method of noise processing is proposed which is based on analyzing linear combinations of 6 signals and using a hexagon symmetry. It is shown that the noise of a free turbulent vortex ring really consists of three different types of quadrupoles predicted by the theory.

The agreement between the principal theoretical conclusions and the experimental results relating to a real turbulent vortex ring permits considering the theory mentioned above as a really dynamic model of sound radiation by a large turbulent vortex.

1. Introduction

Vortex ring is a vortex torus, which moves together with an ellipsoidal volume of fluid called the ring atmosphere. A detailed description of the steady model of vortex rings can be found, for example in [1-2]. At the same time in the early 1970's it become quite clear that the ideal model, even with account for viscosity, does not take the principal moments of vortex ring evolution into consideration. Numerous experimental investigations [3-6] have shown that there exist two qualitatively different flow regimes - laminar and turbulent ones. The critical Reynolds number Re_0 built according to the initial radius and velocity of the vortex ring is equal to about 10^3. At small Re -numbers there is formed a vortex with a characteristic and quite evident spiral structure [7-8]. At Re -numbers exceeding Re_0 the flow character fundamentally changes - the flow becomes turbulent. The main peculiarities of such a flow are that the flow structure appears to be close to the universal one and is independent of the vortex formation process peculiarities. In this case the flow is separated into two regions: the laminar core where the vorticity is concentrated and the "atmosphere" region where the fluid particles are in chaotic movement. (Fig.1). The most important and interesting moment is that the boundary between the turbulent and laminar regions remain sharp, despite the fact that the ring exist for a long time [9-10]. The turbulent flow regime peculiarities found in the experiment permitted formulating the semi-empirical self-similar theory [11, 3, 5-6] describing the evolution of mean parameters (radius, velocity, vorticity etc.), on assumption that the vorticity distribution in the core is close to uniform (solid-body rotation in the core). The measurements of forward translation velocity and of geometrical parameters of the ring confirmed the self-similar character of vortex development. However, the direct reliable measurements of vorticity in the vortex core have been practically not made. We mention the works [12-13] where the new measurements based on the PIV and HPV techniques are presented, related to not very high-velocity rings.

It appeared that a rigorous description of disturbance dynamics in the vortex ring [14] permitted the association of such problems as oscillation stability and mechanisms of energy exchange between the mean flow and separate modes, turbulence initiation in the vicinity of the vortex ring core and turbulent motion absence in the core [15], sound generation by turbulence and contribution into sound radiation of vortex core eigen-oscillations [14]. It is of great interest to confirm the main theoretical predictions in experiment and to establish what are the governing mechanisms of sound generation processes in turbulent vortex ring. Thus, the acoustic measurements of flow noise appears to be unique non-contact diagnostics method for investigations of very delicate and complex processes in turbulent flows.

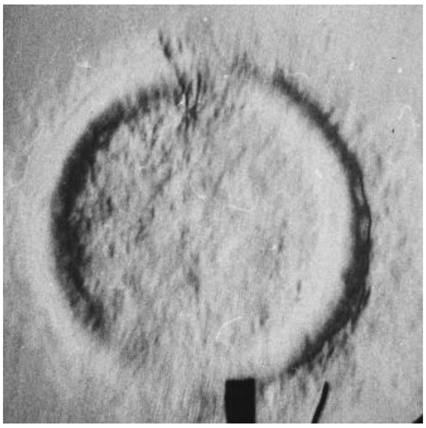

Fig.1. Turbulent vortex ring (front view)

Vortex ring as an object of experimental aeroacoustics has a number of merits. They are the simplicity of vortex ring generation under laboratory conditions and the possibility of investigating the vortex ring nature in the "pure" state, i.e. in the absence of external boundary influence. Despite the fact that the vortex ring is a rather popular model object in aerodynamics its application in aeroacoustics has begun comparatively recently. As it was already noted [16], the