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Technical Note

Reduction of motor fan noise using CFD and CAA simulations

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ABSTRACT

Motor fans used for cooling electric motors have long been recognized as one of the major noise sources. Current paper focuses on design of motor fan for electric motors that are used in submarines for pumping sea water. Noise reduction at source is very important and the critical task, for under water applications. An attempt has been made for reduction of motor fan noise by modification of noise sources. For this purpose computational fluid dynamics and computational aeroacoustics code FLUENT package is used to identify the noise sources and to know the overall sound pressure level of motor fan. From these results it is observed that aerodynamic noise is the dominate fan noise source. Aerodynamic noise of motor fan can be reduced by modifying fan geometry. The aerodynamic noise level of motor fan has been reduced by replacing the straight blades with various digits of NACA (National Advisory Committee for Aeronautics) 65 series airfoil sections. From the numerical results it is observed that the minimum sound pressure level for NACA 65-010 is 65.4 dB(A). These numerical results are compared with measurements in a semi-anechoic chamber. It is found that there is good agreement between numerical and experimental results.

1. Introduction

An electric motor converts electrical energy to magnetic energy and then to mechanical energy as an output in the form of a useful torque at the motor shaft. Part of the energy transformation is converted to heat, causing a rise in rotor, stator and casing temperature. Operating the motor at higher temperatures degrades its life. Therefore an electric motor must be supplied with a cooling fan (motor fan) system to have longer motor life. Motor fans used for cooling electric motors have long been recognized as one of the major noise sources. The need to reduce fan noise has become more and more essential, to make the motors quieter. It is imperative to incorporate the component of noise reduction in the early design stage itself to reduce the fan noise in a cost-effective manner.

There are four basic sources of noise in motor fan system: tonal, aerodynamic, mechanical and motor. Aerodynamic noise is comprised of three basic components: blade noise, turbulence, vortex shedding noise. Of these four, the blade-passing tone generally dominates the noise. The blade-passing tone results from the air impulses which occur every time a blade passes a given point. Each time when the blade passes a point in space, an impulsive force fluctuation is experienced. If a fan has '*n*' blades and the rotational speed is N rpm, then the number of impulses experienced per second is known as blade passing frequency (BPF = $nN/60$).

Aeroacoustic analysis is used to identify the noise sources and in redesigning the equipment identified as source of sound. The aeroacoustic modeling is based on the FW–H equation and it considers the mean velocities obtained from the CFD analysis to estimate overall SPL values. FW–H equation considers only the surface monopole and dipole noise sources and it is an exact rearrangement of the continuity and the momentum in the form of an inhomogeneous wave equation. Although Unsteady-Reynolds-Averaged-Navier–Stokes equation is a model that can be used for aeroacoustical analysis of an axial flow fans, LES is used in this work, because it gives time averaged values.

The aim of the present work is to design a motor fan for electric motors that are used in submarines for pumping sea water. Noise reduction at source is very important and the critical task, for under water applications. Motor fan consists of 10 straight blades and it is driven by 14.71 kW (20 HP) the induction electric motor. As the fan in this application rotates at single constant speed, the investigation is done at only one operating point, which corresponds to the flow resistance caused by electric motor surface having cooling ribs. The operating point corresponds approximately to the best efficiency point. The objective of the work is

Abbreviations: CFD, computational fluid dynamics; CAA, computational aeroacoustics; SPL, sound pressure level; NACA, National Advisory Committee for Aeronautics; NR, noise reduction; FW–H, Ffowcs Williams and Hawkings equation; BPF, blade passing frequency; RF, rotational frequency; MRF, multiple reference frames; LES, Large Eddy Simulation.

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to establish design criteria for the geometry of the fan in order to reduce the noise generated without changing the fan operating point and compare the numerical and experimental results of baseline fan (original configuration motor fan) fan and redesigned fan.

2. Literature review

The noise generated in motor fans is mainly due to aerodynamic noise. The subject of aerodynamically generated noise became of considerable interest around 1950 as result of the appearance of the aircraft jet engine. It is soon recognized as a remarkably powerful sound source which is likely to cause environmental problems. The basic sound sources are monopole, dipole, and quadruple. In motor fans, a monopole source is considered due to a fluctuation of mass and a dipole due to fluctuating force, i.e. changes in momentum, quadrupoles due to fluctuation in momentum flux. This physical significance of the basic sound sources—the monopole, dipole, and quadrupoles are described in relation to their occurrence in compressors and fans, and to their consequent radiation characteristics by Powell [1]. This makes clear the principles by which the various types of source are identified. The study of axial flow machines from an acoustical viewpoint can be said to have begun with Gutin [2], whose 1936 paper on propeller noise was the basis of most of the advances made during the next 20 years. Since then, Lighthill's development of aerodynamic sound theory [3], and in particular Curle's extension of the theory in 1955 to include solid boundaries [4], have been recognized as general foundation for further work in this area. The essential step taken by Lighthill was to incorporate the non-linear features of aerodynamic sound generation into a linear acoustic model.

The acoustic analogy developed by Lighthill, Ffowcs Williams and Hawkings [5] extended this procedure by taking into account the displacement of a rigid surface placed in the flow. The acoustic analogy generalized by FW–H equation is often applied in the prediction of the noise emission generated by rotating machines like rotors of helicopters, and axial fans. The study of noise generation mechanisms in axial fans started with Sharland [6]. He presented the various possible mechanisms of noise generation in axial flow fans. Neise [7] gave an excellent review of axial flow fan noise generation mechanisms and control methods. The review so far deals with noise sources and generation mechanisms in axial flow fans. With the advent of high-speed digital computers, the method of predicting noise using numerical simulations has been great advantage to identify the noise sources and generation mechanisms in turbomachines, and in particular in axial fans.

Now review of various computational methods follows. Noise prediction correlations are numerous. They consist of methods providing an estimate of the noise level as a simple algebraic function taking into account a certain number of aerodynamic performances and geometrical parameters defining the fan but also more powerful methods requiring a complete knowledge of the flow morphology such as the hybrid method. Maaloum et al. [8] use hybrid method to find noise sources. Their work deals with theoretical study of axial fan consists of two parts: (1) an aerodynamic approach based on the vortex surface method and (2) an aeroacoustic approach which mainly concerns the prediction of the tonal noise using the FW–H equation.

The dominant noise source in axial fans is aeroacoustic noise. It is due to the distribution of the fluctuating, unsteady, aerodynamic forces on the blades. Park [9] has presented the methodology for simulations of aeroacoustic noise of car radiator cooling fan using FLUENT. Three-dimensional laser equipment was used to obtain a digital model of the radiator fan. For steady-state simulations, the MRF model was used, for unsteady simulations, the sliding mesh model is adopted. A commercial CFD software code CFX was used for the computational analysis of complex internal flow in a cross flow fan by Govardhan and Lakshmana Sampat [10]. K-epsilon turbulence model was used to simulate the model with unstructured mesh. Sliding mesh interface was used at the interface between the rotating and stationary domains to capture the unsteady interactions.

A design of experiments has been done by Behzadmehr et al. [11] to study the effect of the entrance conditions of a backward-inclined centrifugal fan on its efficiency. This has shown that the motor's cap radius, as well as its interactions with other parameters, is not significant. Filios et al. [12] demonstrated a computational methodology for the noise prediction of a horizontal axis wind turbine rotor in time domain. Adama et al. [13] studied an aeroacoustics of automotive ventilation outlets. Simulations are performed with the CFD software POWERFLOW based on Lattice Boltzmann method. Low dissipative Lattice Boltzmann method scheme enables to compute aeroacoustic sources generated by turbulence fluctuations and to propagate them in the same simulation.

Gerard et al. [14] presented a novel approach for the passive adaptive control of tonal noise radiated from subsonic fans. The approach presented in this work uses obstructions in the flow to destructively interfere with the primary tonal noise arising from various flow conditions. The sound field is simulated by Yi Hsia et al. [15] using the boundary element method, which is a numerical technique to reduce the boundary integral equations using the fundamental solution and Green's transfer functions, for sound field analysis.

Reviews of the various noise reduction techniques follow. Noise problems can be described using the simple source-path-receiver model. The sources are of two main types: (1) Airborne sound sources caused by air fluctuation. (2) Structure-born machinery vibration sources. The paths may also be airborne or structure-borne in nature. Source modifications are the best practice and low cost options. The study of literature reveals many successful well documented methods that are used to reduce the noise of machines. It is advisable to consider noise control methods at the design stage itself. This is illustrated by Tandan [16], which describes some of the control measures that can be incorporated into the design of machines and structures. Noise reduction is obtained by modifying the noise producing equipment or redesigning the equipment identified as source of sound. This technique is applied by Duncan et al. [17] to axial flow machines and they obtained a large reduction in discrete tone radiation anticipated through a suitable choice of blade and vane numbers shown to be critically dependent on exact cascade geometry.

Tonal noise produced at a multiple of the rotational frequency of the fan, the so-called BPF and its higher harmonics generally dominate fan noise. BPF noise prediction technique, which consists of a CFD and sound wave propagation, was successfully developed by Kudo [18]. Tonal noise of axial fans can be reduced by irregular spacing of blades. This technique is applied by Cattanei et al. [19] for the reduction of tonal noise annoyance from axial flow rotors. WKim and Chung [20] presented the reduction of acoustic noise generated by electromagnetic forces in an induction motor. After summarizing the electromagnetic excitation forces due to the interaction between the stator–rotor slot permeance and the stator winding magnetomotive force, the effects of electromagnetic force on the noise and vibration of an induction motor are analyzed.

Several studies have stressed the growing importance of numerical methods in the description of the complex 3D unsteady flows for turbomachinery applications. However, the achievement of such 3D models becomes a difficult task if the balance between flow definition and Personal computer requirements is considered. Nevertheless, and as a generally accepted trend, both techniques (numerical and experimental) must work together to find a