inter•noise 96
25th Anniversary Congress – Liverpool

INCE: 11.5.3

THE INFLUENCE OF THE UNSYMMETRIC ALTERNATOR FAN BLADE-SPACING TO THE TOTAL SOUND PRESSURE LEVEL AND SPECTRA OF AERODYNAMIC NOISE

M Mesaric, M Boltezar & A Kuhelj

University of Ljubljana, Faculty of Mechanical Engineering, Slovenia

1. INTRODUCTION

Demand for smaller and more efficient alternators forced designers to place two radial cooling fans inside the casing which improved cooling. Due to this change the aerodynamic noise that is dominant at higher rotating speed of rotor increased.

In our work the sources of the aerodynamic noise of alternator were identified and the influence of irregular blade-spacing on total sound pressure level (SPL) and spectra was theoretically and experimentally analysed. According to the theoretical results various fans with irregular blade-spacing were manufactured and measurements of total SPL and spectra of radiated noise were performed.

2. THEORETICAL APPROACH

The forces excerted by the air flow on the fan blades and casing are the primary cause of the noise radiated from fans with low blade-tip mach number [5]. Forces with periodic time history lead to discrete sound components and random forces are responsible for the broadband noise.

Assuming blades are thin, expression (1) describes sound pressure radiated by a point blade force T_j acting at the aerodynamic center of blade (Fig. 1) [2,3].

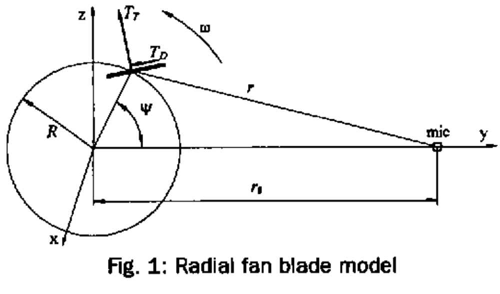

Fig. 1: Radial fan blade model

$$4\pi\left(p-p_0\right) = -\frac{\partial}{\partial x_j}\left[\frac{T_j}{r\left|1-M_r\right|}\right] \tag{1}$$

Defining the fluctuating force T_j by a Fourier series and adopting the theory describing the discrete frequency sound radiated by axial fans to the radial fans, expression (2) for calculating the complex magnitude of sound pressure of the *n*-th harmonic radiated by a single blade was obtained [4].

$$c_n = -\frac{in\omega}{4\pi r_0 a_0} e^{in\left(\frac{\omega r_0}{a_0} - \frac{\pi}{2}\right)} e^{-in\psi} \cdot \sum_{\lambda=-\infty}^{\infty} T_\lambda (-i)^{-\lambda} \left[i\cos\beta_s \left(J_{n-\lambda-1}(nM) - J_{n-\lambda+1}(nM) \right) + 2\sin\beta_s \frac{n-\lambda}{nM} J_{n-\lambda}(nM) \right] \tag{2}$$

If variations of fan blade spacing angles ϕ are small, blade size and shape changes can be neglected. Therefore all blades radiate much the same but phase shifted sound fields. Expression (3) describes the interference of sound fields radiated from blades [1] where B stands for the number of blades.

$$F\left(\phi_j\right) = 1 + e^{in\phi_2} + e^{in(\phi_2+\phi_3)} + \ldots + e^{in(\phi_2+\phi_3+\ldots+\phi_B)} \tag{3}$$

Discrete frequency sound pressure radiated from radial fan is given by the equation (4) from which the expression for sound pressure level can be derived.

$$p(\mathbf{x},t) = \sum_{n=-\infty}^{\infty} c_n(\mathbf{x},t) F\left(\phi_j\right) e^{-in\omega t} \tag{4}$$

3. EXPERIMENTS

The measurements of total SPL and spectra of noise radiated from various fans were performed in an anehoic chamber with following dimensions: W 1.70 m, L 2.60 m and H 2.65 m. Alternator was belt driven by the electromotor and the microphone was mounted in the plane of fan, 0.50 m away from the axis of rotation.

4. COMPARISON OF THEORETICAL AND EXPERIMENTAL RESULTS

Radial cooling fans are made of one millimeter steel-sheet. Fans that are currently being manufactured have 12 equally spaced blades and are named FAN-R (Fig 4*a*). In order to avoid unbalance first studies of the influence of irregular blade spacing on total SPL and noise spectra were performed on symmetrical fans - FAN-1 (Fig. 5*a*).

Definition of blade force with periodic time history

Since fan is mounted inside the casing the flow over the blades is unsteady causing fluctuating blade forces. Presumed periodic blade force time history is shown in figure 2.

According to the calculated results we found that sound pressure magnitude depends primary on the amplitude of the blade force fluctuation - $\frac{1}{2}(T_b - T_a)$ - and that the relative relations of calculated sound pressure for various fans are equal in wide area of changing the amplitude. Therefore the desired fan blade spacing can be obtained without knowing actual blade force magnitude [4].

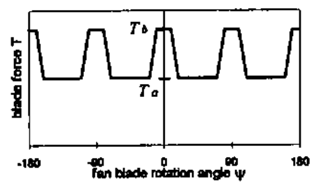

Fig. 2: Blade force with periodic time history

Total sound pressure level

Measured values (Fig. 3*a*) and relative comparison of calculated values (Fig 3*b*) for various fans shows that total sound pressure level doesn't depend on fan blade spacing what matches with results found in literature [5].

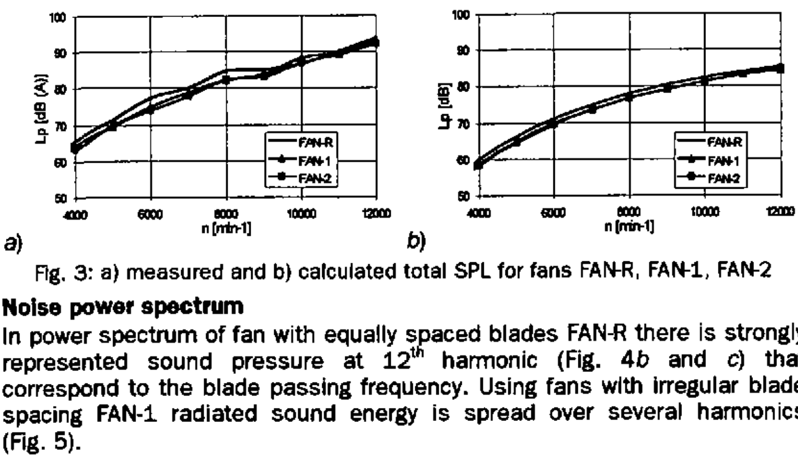

Fig. 3: a) measured and b) calculated total SPL for fans FAN-R, FAN-1, FAN-2

Noise power spectrum

In power spectrum of fan with equally spaced blades FAN-R there is strongly represented sound pressure at 12^{th} harmonic (Fig. 4*b* and *c*) that correspond to the blade passing frequency. Using fans with irregular blade spacing FAN-1 radiated sound energy is spread over several harmonics (Fig. 5).

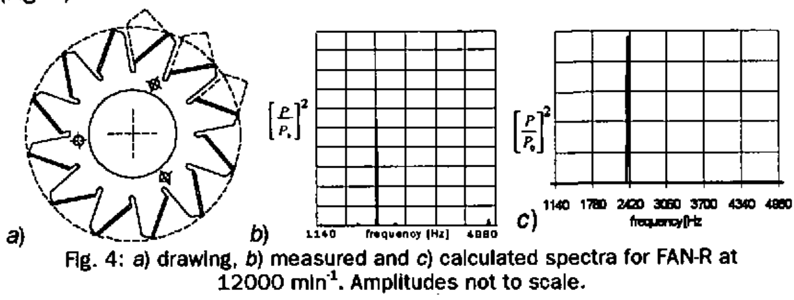

Fig. 4: *a*) drawing, *b*) measured and *c*) calculated spectra for FAN-R at 12000 min^{-1}. Amplitudes not to scale.

Due to the prospective results in reducing the siren effect the fan with unsymmetrical blade spacing FAN-O whose sound power is spread over many harmonics was designed (Fig. 6). Unbalance of fan was reduced with minor decrease of lengths of some blades.

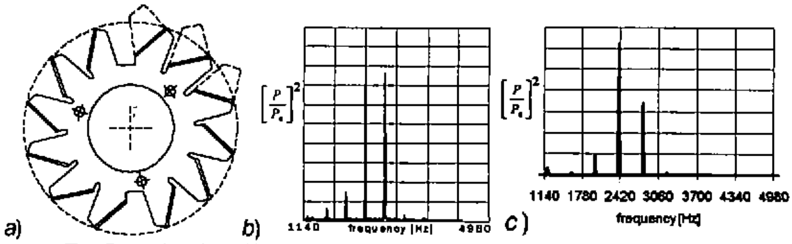

Fig. 5: *a*) drawing, *b*) measured and *c*) calculated spectra for FAN-1 at 12000 min^{-1}. Amplitudes not to scale.

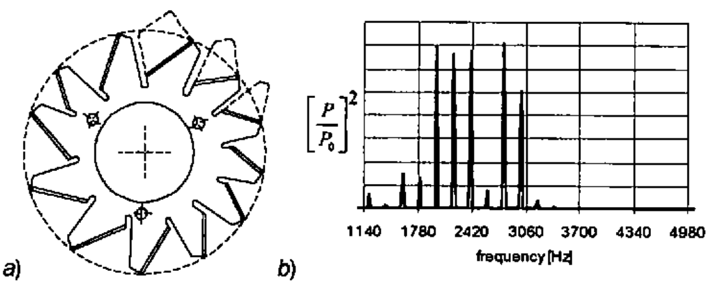

Fig. 6: *a*) drawing and *b*) calculated spectra for FAN-0 at 12000 min^{-1}

5. CONCLUSIONS

Linear acoustics formulas for calculation of radial rotating blade noise were derived on the basis of the acoustical analogy. Theoretical and experimental results confirm that fluctuating forces excerted by the unsteady flow on the fan blades and casing are the primary cause of the noise radiated from radial fan. By irregular fan blade-spacing the blade passage sound is spread over a wider frequency band. This is desirable from a subjective point of view but the total sound power level remains unchanged. Unbalance can be simply reduced by changing blade lengths.

References:

[1] W. DOBRZYNSKI: Propeller Noise Reduction by Means of Unsymmetrical Blade-Spacing, *Journal of Sound and Vibration*, **163**, p.123-136, 1993

[2] D.L. HAWKINGS AND M.V. LOWSON: Theory of Open Supersonic Rotor Noise, *Journal of Sound and Vibration*, **36**, p.1-20, 1974

[3] M.V. LOWSON: Theoretical Analysis of Compressor Noise, *Journal of the Acoustical Society of America*, **47**, p.371-385, 1970

[4] M. MESARIČ: The Reduction of the Aerodynamic Noise of Alternators, Final degree project, University of Ljubljana, Faculty of Mechanical Engineering 1995 (in Slovene)

[5] W. NEISE: Noise Reduction in Centrifugal Fans, *JSV*, **45**, p.375-403, 1976

[6] W. NEISE: Review of Fan Noise Generation Mechanisms and Control Methods, *Fan Noise - An International INCE Symposium*, CETIM, 1-3 Sep. 1992