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Measurement of Nonlinear Time-variant Source Characteristics of Intake and Exhaust Systems in Fluid Machines

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Abstract

The acoustical sources of intake and exhaust systems in fluid machines are often characterized by the source impedance and strength using linear frequency-domain modeling. In the case of the sources which are nonlinear and time-variant, however, the source parameters were sometimes incorrectly obtained. In this paper, the source model and direct measurement technique are modified in order to evaluate the effect due to nonlinear and periodically time-varying source character as well as the linear property of the reflectivity of in-duct fluid machine source. With a priori known kinematical information of the source, the types of nonlinear time-variant terms can be presumed by a simple physical model, in which there is practically no restriction on the form of the model. The concept of source impedance can be extendable by introducing the linear frequency response function for each nonlinear or time-variant input. Extending the conventional method and adapting the reverse MISO technique, it is possible to develop a direct method that can deal with the nonlinear time-variant source parameters. The proposed direct method has a novel feature that there is no restriction on the probability or spectral natures of the excited sound pressure data. The present method is verified by the simulated measurements for simplified fluid machines. It is thought that the proposed method would be useful in predicting the insertion loss or the radiated sound level from intake or exhaust systems.

Keywords: *Source characteristics, Nonlinear time-variant source, Intake/exhaust*

I. Introduction

The acoustic performance of a silencing system depends upon the acoustic characteristics of the source as well as that of the silencer itself. For the prediction of radiated sound pressure levels, the information on the source parameters is essentially required. The acoustic analysis of the source is usually performed by assuming a linear and time-invariant source condition[1-4]. In the case of the sources which are nonlinear and time-variant, however, it is reported that unphysical source parameters were sometimes obtained[2-4]. In this paper, the source model and direct measurement technique are modified in order to evaluate the effect of nonlinear and periodically time-varying source character as well as the linear property of reflectivity of an in-duct fluid machine source. Here, the load is assumed as linear and time-invariant.

II. Nonlinear Time-Variant Source Model

Introducing a coefficient with memory for each nonlinear or time-variant input and extending the conventional linear source

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model one can obtain the nonlinear time-variant source model as

$$\int z_{s,0}(\tau)u(t-\tau)d\tau+\sum_{i=1}^{N}\int z_{s,i}(\tau)b_i(t-\tau)d\tau=p_s(t)-p(t)\,, \quad (1)$$

or, in the frequency domain,

$$Z_{s,0}(f)U(f)+\sum_{i=1}^{N}Z_{s,i}(f)B_i(f)=P_s(f)-P(f)\,, \quad (2)$$

where $p(t)$ and $u(t)$ denote the pressure and volume velocity, respectively, at the interface of source and load, $p_s(t)$ is the source strength, and $b_i(t)$ is the nonlinear or time-variant input. The internal structure and kinematical information of the fluid machine are known in most cases. With a priori known information on the source, the type of nonlinear time-variant term can be presumed by a simple physical model. For example, for a source having an orifice, the nonlinear input can be given as the quadratic damping term, i.e., $b_i(t)=u(t)|u(t)|$. If the source has a piston with a reciprocating motion, one can include the time-varying capacitance term, i.e., $b_i(t)=[1/v(t)]\int u(t)dt$, where $v(t)$ is the periodically time-varying volume which is already known. If an operating valve exists inside the source, the time-varying conductance and susceptance terms can be used for $b_i(t)$. There is practically no restriction on the form of the model or $b_i[u(t)]$. Negligible error may be introduced if the extra possible nonlinear or time-variant terms[5] are involved with. In order to obtain an accurate result, modelling of the nonlinear or time-variant input terms should be as precise as possible and the frequency range of interest should contain all frequencies of the major components.

III. Measurement Method

The measurement method for the parameters of nonlinear time-variant source can be developed by modifying the conventional direct method for linear source. Impedance terms are determined by exciting the source by an external acoustical source with random signal. In principle, the external source should be much stronger than the tested source so that $p_s(t)$ can be negligible. Fig. 1(a) shows the single-input/single-output (SISO) system of pressure and velocity at the source-load interface. 'NT' denotes the nonlinear or time-varying element and n is the extraneous noise term. The pressure is measured directly and the velocity can be obtained by using the wave decomposition technique[6].

The input u and b_i are correlated in general and $Z_{s,i}$ may be obtained by using the reverse mutiple-input/single-output (MISO) technique[5]. In this study, the model is revised as having the optimum linear system and the revised nonlinear or time-variant system, so that u and g_i are uncorrelated. Using the spectra among u, g_i, and p, $Z_{s,opti}$ can be easily calculated and all impedance terms are obtained. Then, by applying a load the source strength can be calculated from Eq. (1) or (2).

IV. Numerical Simulation

For a validating purpose, a simplified exhaust system having an orifice and a reciprocating piston is employed as the tested source, being represented as

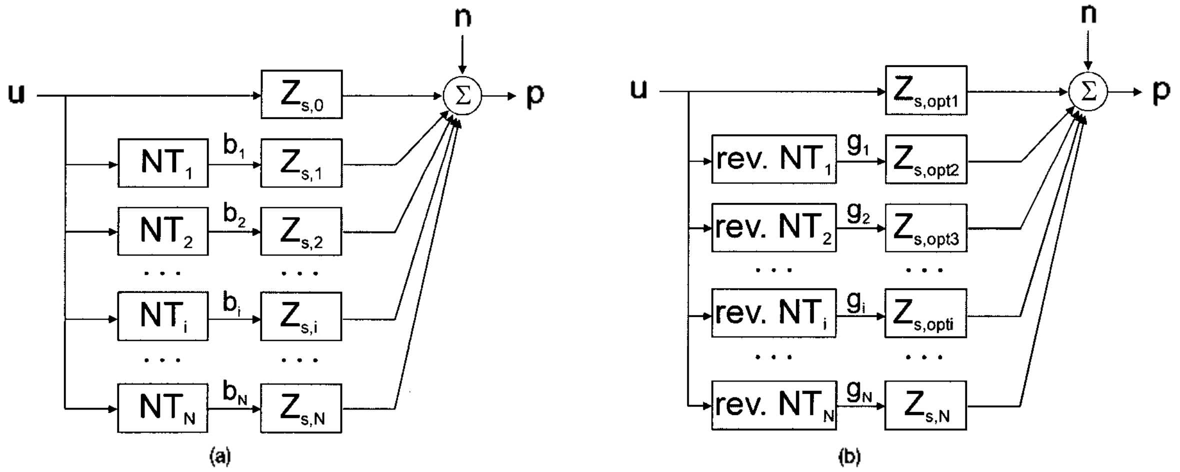

Fig. 1. Direct measurements of the impedance terms for nonlinear time-varying sources. (a) Original model in which inputs are correlated, (b) revised model in which inputs are uncorrelated.

$$m_{eq}\dot{u}(t)+c_{eq}u(t)+k_{eq}\int u(t)dt+d_1u(t)|u(t)|+d_2\frac{1}{v_c(t)}\int u(t)dt=p_s(t)-p(t), \tag{3}$$

where m_{eq}, c_{eq} and k_{eq} are the equivalent air mass, damping, and cavity compliance, respectively. Their values are chosen from the possible range in actual machines as

$$m_{eq}=1.0,\ c_{eq}=200.0,\ k_{eq}=4\times10^5,\ d_1=1\times10^5,\ d_2=3\times10^6, \tag{4a}$$

$$v_c(t)=1.2+\sin(120\pi t). \tag{4b}$$

The direct measurement with an external source is simulated by substituting broadband random signal for *p(t)* and neglecting $p_s(t)$. *u(t)* is obtained by solving Eq. (3) with the 5th order Runge-Kutta method. Then *p(t)* and *u(t)* are utilized as the input data to perform the simulations. Calculated results are compared with a priori known source parameters. In Fig. 2, it can be seen that the results of the present method agree well with the actual values. The results from the conventional direct method presuming the linear source condition are also shown in Figs. 2(a) and (b). They can be an approximation with insufficient parameters; however, the conventional method cannot yield the parameters which describe the physical character of the source.

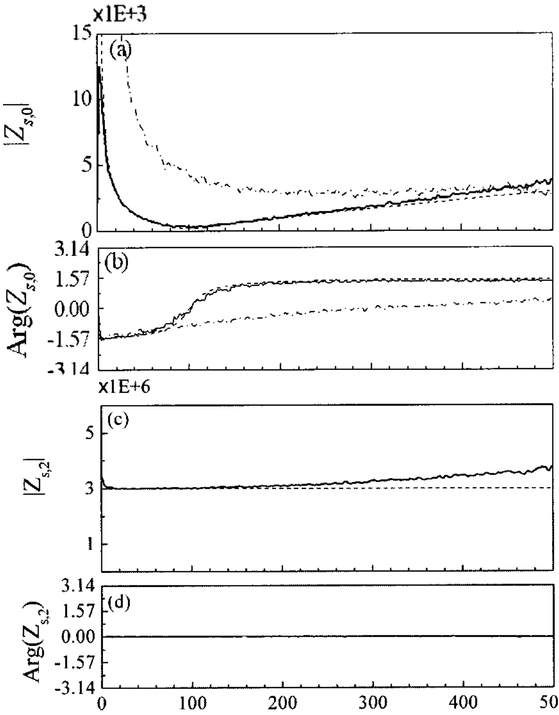

Fig. 2. A comparison of calculated source impedances. ——, Present method; — — —, conventional linear method; ………, actual value. (a) Magnitude of Zs,0, (b) phase of Zs,0, (c) magnitude of Zs,2, (d) phase of Zs,2.

V. Concluding Remarks

The concept of source impedance was extended by introducing the linear frequency response function for each nonlinear or time-variant input. Extending the conventional method and adopting the reverse MISO technique, it is possible to develop a direct method that can deal with the nonlinear time-varying source parameters. The present method is verified by the simulated measurements for a simplified fluid machine. It is thought that the proposed method would be useful in predicting the insertion loss or the radiated sound level from intake or exhaust systems of various fluid machines.

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[Profile]

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