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Characteristics of a dynamic pressure generator based on loudspeakers

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ABSTRACT

The dynamic pressure generator under discussion consists of two, face-to-face-orientated electrodynamic loudspeakers and the air chamber between. The aim of this paper is to investigate the static and dynamic characteristics of this pressure generator. Physical modelling and an experimental analysis were employed to demonstrate its capabilities and limitations. The generator's static sensitivity, which was defined by the ratio between the generated pressure and the excitation electric current, mainly depends on the ratio between the force factor and the effective area of the loudspeakers. The presented system has relatively good precision and stability, and a small sensitivity to changes in the internal volume. Its dynamic characteristics are defined by the properties of the loudspeaker diaphragm, the air chamber between the loudspeakers and the connection of the device under test to the pressure generator.

1. Introduction

Pressure is an important process variable in a wide variety of industrial and scientific applications. Whenever measurements and/or control of the changing pressure conditions are required, the installed sensors and other equipment should have suitable dynamic characteristics. As a result, the research and development of dynamic pressure generators are closely linked to the growing needs for dynamic testing and calibration of such equipment.

It is possible to choose from a variety of operating principles and configurations when it comes to dynamic pressure generators [1,2]. One of these operating principles relates to pressure generators based on loudspeakers, which are generally used for low-pressure amplitudes and acoustic frequencies. The accessible literature describes some of their potential areas of application: the dynamic calibration of low-range pressure sensors [3,4], the testing of the dynamic response of pneumatic transmission line systems [5–7], and the testing of hydrostatic pressure switches [8].

This paper deals with the loudspeaker-based pressure generator shown in Fig. 1. A similar configuration was introduced at the conference in 2000 [9], since when it has been successfully employed as a dynamic pressure generator in a variety of applications [6,8]. This pressure generator consists of two, face-to-face-orientated electrodynamic loudspeakers. On the circumference of the chamber between, there are evenly distributed points for connecting pressure sensors or other equipment under test. The employed loudspeakers were chosen on the basis of the large ratio between the force factor and the effective area, which determines the attainable magnitude of the generated pressure.

The aim of this paper is to investigate the static and dynamic characteristics of the loudspeaker-based pressure generator (see Sections 2 and 3, respectively). Physical modelling and an experimental analysis were employed to demonstrate its capabilities and limitations. The physical model of the pressure generator, presented in Sections 2.1 and 3.1, is based on the linear lumped models of mechanical and acoustical elements [10,11]. The employed acoustical model assumes that the wavelength of the generated pressure oscillations is large compared to the longest linear dimension of the air chamber, which assures that the generated pressure inside is essentially uniform. Similar assumptions are often used in basic modelling of a loudspeaker mounted in a (medium sized) closed box [12,13]. In Section 2.1, the acoustical load of the loudspeaker diaphragm due to the gas stiffness is briefly rederived to properly consider a simultaneous motion of both loudspeakers. The experimental work, presented in Sections 2.2 and 3.2, was designed to discuss the main characteristics of the pressure generator, such as the static sensitivity, the precision and stability, and the frequency range. A particular attention is focused on the influence of changes in the pressure-generator internal volume, which can occur in some applications. The findings of this paper will be useful for the proper application and the further development of such devices.

2. Static characteristics of the pressure generator

2.1. Static physical model

Both the loudspeakers of the pressure generator are modelled as being identical. The effective area S_d of their diaphragms is assumed

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Fig. 1. Pressure generator with two loudspeakers.

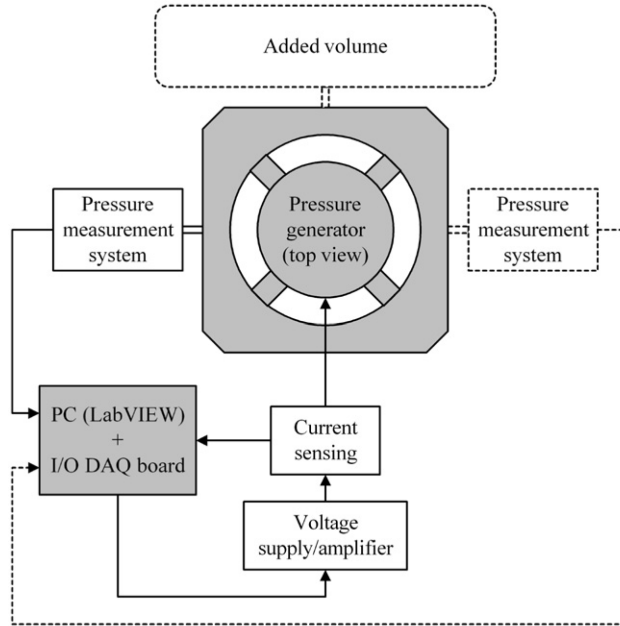

Fig. 2. Block diagram of the measurement system.

to be constant within the range of the displacements $x \in [-x_{max}, x_{max}]$. The x displacement of both diaphragms with respect to one another results in a change of the internal volume $V = V_0 - 2S_d x$, where V_0 is the initial internal volume. In the closed system, such a change in the volume of a gas leads to an increase in the absolute pressure, from an initial value P_0 to $P = P_0 + p$. The gas volume is considered as an adiabatically closed system in which PV^κ is constant, with κ being the adiabatic index [11]. For relatively small changes the following relation between the pressure change and the diaphragm displacement can be derived:

$$p = 2\frac{\kappa S_d P_0}{V_0}x \tag{1}$$

(If the gas volume were to change relatively slowly over time with respect to heat transfer to the surroundings, it might be more reasonable to consider the system as isothermal, in which PV is constant; substitute the derived expressions with $\kappa \to 1$).

When the diaphragm is moved, due to the pressure change the internal gas acts on the diaphragm as an added stiffness force, which can be expressed as follows using Eq. (1):

$$pS_d = k_{f,d}x, \quad k_{f,d} = 2\frac{\kappa S_d^2 P_0}{V_0} \tag{2}$$

where $k_{f,d}$ is the gas stiffness. The movement of the loudspeaker diaphragm results from the magnetic force BLi acting on the voice coil, where L is the effective length of the voice coil wire in the magnetic field B and i is the excitation voice coil current [10]. Within the framework of the static model there should be a balance between the excitation force and the combined influence of the gas stiffness force (2) and the suspension stiffness force $k_{susp}x$. This results in:

$$x = \frac{BLi}{k_{f,d} + k_{susp}} \tag{3}$$

Substituting Eq. (3) into Eq. (2) leads to the linear static characteristic of the pressure generator. This can be expressed in terms of the static sensitivity K_{PG}, which is defined by the ratio between the generated pressure change and the excitation electric current:

$$K_{PG} = \frac{p}{i} = \frac{BL}{S_d}\frac{1}{1 + k_{susp}/k_{f,d}} \tag{4}$$

The generator's static sensitivity depends linearly on the ratio between the force factor BL and the effective area S_d, but the last fraction represents some decreasing effect of the ratio between the suspension and the gas-related stiffness.

2.2. Static measurements

Fig. 2 presents a scheme of the measurement system where the experiments on the pressure generator were carried out. In the case of static measurements, the loudspeakers (Beyma, 5"MP-60/N) were electrically excited from a voltage amplifier connected to the analog output of a DAQ board (National Instruments, DAQPad-6020E, max. input range ± 10 V, resolution 12 bit, max. sampling frequency 100 kHz). The excitation current was determined by measuring the voltage drop across a known resistor. The generated pressure was measured by a single variable-reluctance pressure transmitter (Validyne, P855, measuring range ± 1400 Pa, output voltage ± 5 V, accuracy 0.15% of upper range limit, frequency range 0–250 Hz (−3 dB)). The signal acquisition and processing were realized in the Lab VIEW programming environment. In some experiments an additional volume V_{ADD} of 0.5 dm^3 or 1 dm^3 was connected to the pressure generator with the volume $V_0' \approx 0.26$ dm^3, so the total internal volume was increased to $V_0 = V_0' + V_{ADD}$.

The generator's static characteristic was measured at nine points, equally divided over the chosen testing range, including both increasing and decreasing pressure. Fig. 3 shows one example of the time variations of the excitation current and the generated pressure. For each testing point, the excitation voltage was set to some constant value for a stabilization time of about 10 s. The variation of the excitation current (and proportionally of the generated pressure) during the stabilization time, which is more evident at higher excitation voltages, results from the changing temperature of the loudspeaker coils. An increasing coil temperature leads to an increasing coil resistance and, consequently, to a decreasing current at a constant voltage supply.

The resulting static characteristic that relates to the last measured values at each testing point (after the stabilization time) is presented in Fig. 4. The measurements are approximated by a linear regression line through the origin, the slope of which rep-