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LETTERS TO THE EDITOR

AN ERROR INHERENT IN THE USE OF THE TWO-MICROPHONE METHOD FOR GAS PULSATION MEASUREMENT IN A REFLECTIVE ENVIRONMENT

M. L. MUNJAL

Facility for Research in Technical Acoustics, Department of Mechanical Engineering,
Indian Institute of Science, Bangalore 560 012, *India.*
E-mail: *munjal@mecheng.iisc.ernet.in*

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1. INTRODUCTION

It is standard practice to provide anechoic termination in order to obtain consistent gas pulsation measurement data for the positive displacement machinery in the compressor industry [1]. The same holds for the measurement of acoustic power generated by fans or compressors. The underlying idea is to eliminate reflected wave. This prompted several researchers to make use of the so-called two-microphone method or the transfer function method to decompose the standing wave into the two constituent progressive waves [2] in order to meet the exigencies of the industrial applications where an anechoic termination may not be available. This is particularly true of the refrigeration compressor industry where it is difficult to control the terminal impedance in the suction or discharge lines of the regular testing facility in the factory environment [3]. However, it is generally not known or appreciated that the forward wave pressure or the associated power in a reflective environment is not equal to that in an anechoic environment. Therefore, extraction of the forward wave pressure from the standing wave pressure field by means of the two-microphone method is inherently falacious. This has been demonstrated by Lai through several tests on a simplified model [3]. The same is sought to be established here in a general way.

In this letter, making use of one-dimensional electro-acoustic analogy [4], the forward wave is broken into two components, one that would be generated against an anechoic termination and another that is the result of a reflective source as well as a reflective load impedance [5]. Thence, it is established that the two-microphone method would work satisfactorily only in the hypothetical case of an anechoic source; in general it would lead to erroneous measurements.

2. ANALYSIS

In general, a time-invariant linear source can be represented by a source of acoustic pressure p_s and impedance Z_s, analogous to the open-circuit electromotive force and internal impedance, respectively, in an electrical analogous circuit, according to Thevenin theorem [4]. When connected to an acoustic load impedance, Z_L, as shown in Figure 1, it will result in a forward moving progressive wave p_f and reflected wave p_r. As the source characteristics p_s and Z_s may be transferred readily across a passive one-dimensional filter

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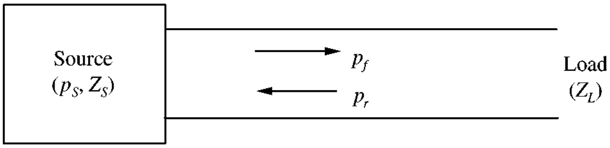

Figure 1. Schematic of the acoustic system.

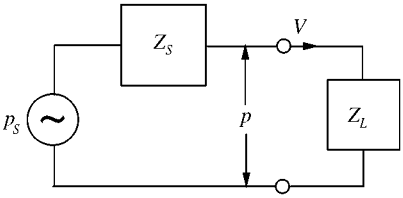

Figure 2. Electrical analagous circuit of the system.

including a tube as in reference [6], we can assume length of the connecting pipe tending to zero without loss of generality.

Referring to Figure 2, acoustic pressure p and volume velocity v are given by

$$p = p_f + p_r = \frac{p_s Z_L}{Z_s + Z_L} \tag{1}$$

and

$$v = \frac{p_f - p_r}{Y} = \frac{p_s}{Z_s + Z_L}, \tag{2}$$

where Y is the characteristic impedance

$$Y = \frac{\rho c}{S}. \tag{3}$$

ρ, c and S have the usual notation of density of the medium, sound speed, and area of cross-section of the tube.

Simultaneous solution of Equations (1) and (2) yields

$$p_f = \frac{p_s}{2} \frac{Z_L + Y}{Z_s + Z_L} \tag{4}$$

and

$$p_r = \frac{p_s}{2} \frac{Z_L - Y}{Z_s + Z_L}. \tag{5}$$

Equation (5) is, however, misleading inasmuch as p_r is not generated by the source. Alternatively, equation (5) may be utilized to eliminate Z_L and rewrite equation (4) as follows:

$$p_f = p_s \frac{Y}{Z_s + Y} + p_r \frac{Z_s - Y}{Z_s + Y}. \tag{6}$$

3. OBSERVATIONS AND CONCLUSION

The first component on the right-hand side of equation (6) indicates the pressure generated by the source against the characteristic impedance Y (see equation (1)), i.e., against an anechoic termination, and the second is the pressure that would be reflected from the passive source impedance Z_s if p_r were incident on it [4, 5].

Thus, the concept implied in equation (6) has a wider application than would be expected from a simple algebraic rearrangement of an equation. It separates the real driving effect of the source from the reflective effect of its internal impedance on the incoming or incident wave p_r. This latter effect can be appreciated better from the fact that the second part of equation (6) would vanish if p_r were zero.

It may be noted from equation (6) that the value of the forward wave gets altered by p_r and hence Z_L. Therefore, the two-microphone method which is used for decomposing the standing wave pressure into p_f and p_r, would be erroneous inasmuch as the value of p_f thus obtained is not equal to what would result against anechoic termination; it includes contribution from the reflected wave p_r as per equation (6).

This additional contribution would be zero if the source is anechoic ($Z_s = Y$) or the load is anechoic ($Z_L = Y$ leading to $p_r = o$). Therefore, the two-microphone method would work only for the hypothetical case of anechoic source (for any arbitrary load). Of course, the single microphone method would work for anechoic load/termination as envisaged in the standard [1] for any source.

ACKNOWLEDGMENTS

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