IDENTIFICATION OF MATRIX PARAMETERS OF ACOUSTIC SYSTEMS VIA TRANSIENT TESTING

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ABSTRACT

A transient testing technique has been developed for rapid testing of components of acoustic systems. Transient pressure data are digitized, recorded and utilized in frequency-domain to provide the dynamic characteristics of the system. The idea behind the method is to make use of the sampled time data of a sound source and two microphones measuring the pressure at two locations in a steel pipe attached to the component of the acoustic system. The analysis procedure is based on the construction of a mathematical model for the system from the experimental response data.

Experiments were conducted for many acoustic components of various geometrical configurations such as partition pipes and expansion chambers and excellent agreement between experimental and theoretical results is illustrated. The proposed approach is applicable to field testing situations where short duration testing with a minimum of portable equipments is desirable and no special requirements such as anechoic terminations are available.

INTRODUCTION

Often happens in practice that the exact geometrical configurations of some acoustic components are unknown. Consequently, an experimental approach to the determination of acoustic properties may be necessary. White[1] and Kandianis [2] developed transient testing technique for structural vibration via a deterministic model in the frequency domain. Holmes [3] extended their work to wave propagation systems. Howes [4] increased in scope the method originated by Davis [5] and Gatley and Cohen [6] to the measurement of reflection and transmission factors, using transient signals. Transient methods overcome the two major shortcomings of steady state approach: (1) it is time consuming;

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pressure p at station x along the pipe is

$$p = \rho\mu_t = j\rho\omega\,(B_1 e^{\gamma x} + B_2 e^{-\gamma x}) \qquad (4)$$

and the volume velocity v at that same station is

$$v = -s\,\mu_x = -s\gamma\,(B_1 e^{\gamma x} - B_2 e^{-\gamma x}) \qquad (5)$$

Considering the values at stations 1 and 2, and algebraic manipulations, yields the four-pole equations for the pipe in matrix form as:

$$\begin{bmatrix} p_1 \\ v_1 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} p_2 \\ v_2 \end{bmatrix} \qquad (6)$$

where $a_{11}=a_{22}=\mathrm{ch}\gamma l$, $a_{12} = z_i\,\mathrm{sh}\gamma l$, $a_{21} = (1/z_i)\,\mathrm{sh}\gamma l$, l = length between stations and $z_i = (\rho c'/s_i)$, the characteristic acoustic impedance of the medium in the system at cross-section s_i. It may be noted that a_{11} and a_{22} are dimensionless whereas a_{12} has the dimensions of an acoustic impedance and a_{21} has the dimensions of an acoustic admittance. Any acoustic system with a linearly-swept sinusoidal wave source will provide transient acoustic pressures and volume velocities. The corresponding Fourier-transformed values are complex. These will, in turn, give complex four-pole parameters of the acoustic system in question as

$$\begin{bmatrix} P_1 \\ V_1 \end{bmatrix} = \begin{bmatrix} a \end{bmatrix} \begin{bmatrix} P_2 \\ V_2 \end{bmatrix} \qquad (7)$$

in which the upper case letters represent the transforms of the corresponding lower case letters.

The parameter matrix of a compound acoustic system; that is, consists of more than one component; can be deduced by applying the law of mass conservation and may be written as

$$[a] = \prod_{i=1}^{n} [a]_i \qquad (8)$$

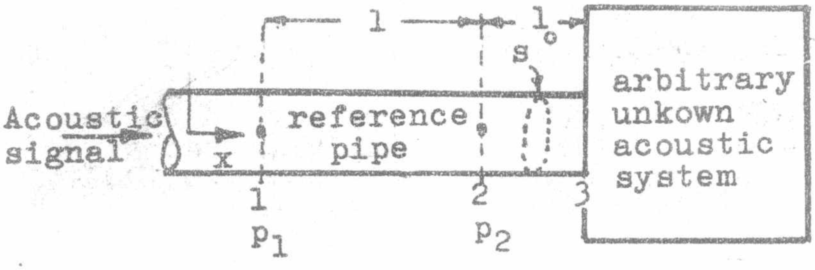

Fig.1. Acoustic system under test.

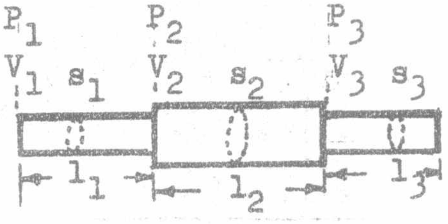

Fig.2. Tested expansion chamberi

nels are used per test. Notice that it is better to use formulas with denominators containing known matrix parameters for the experimental determination of matrix parameters of the unknown acoustic components. With known denominators, any pole created by the zero in the denominator can be prevented.

After the four-pole parameter of the tested system were determined, the following acoustic properties can be evaluated:

Reflection Factor R_{ik} :

A reflection factor at a station i of an acoustic system with end condition k is the complex ratio of the reflected pressure wave to the incident pressure wave at that station. It is related to the acoustic impedance at station i, Z_{ik}, looking toward the acoustic system by the following equation:

$$R_{ik} = (Z_{ik} - z_i)/(Z_{ik} + z_i) = (Z_{ik}/z_i - 1)/(Z_{ik}/z_i + 1) \qquad (15)$$

For example: $R_{2k} = (P_{1k}/P_{2k} - e^{\gamma l_o})/(e^{-\gamma l_o} - P_{1k}/P_{2k})$,

$R_{1k} = e^{-2\gamma l_o} R_{2k}$, and $R_{3k} = e^{2\gamma l} R_{2k}$.

Standing Wave Ratio N_{ik} :

The magnitude of the reflected acoustic pressure amplitude relative to the incident acoustic pressure amplitude is determined by measuring the so-called standing wave ratio. It is the ratio of the acoustic pressure amplitude at an antinode to the acoustic pressure amplitude at the node and is given by [5]:

$$N_{ik} = (1 + |R_{ik}|) / (1 - |R_{ik}|) \qquad (16)$$

where $|R_{ik}|$ is the magnitude of R_{ik}

Modified Transimission Factor T_{ik}:

A transimission factor T'_{ik} at station i of an acoustic system is the ratio of the transmitted acoustic pressure to the incident acoustic pressure. It is related to the reflection factor by the following equation

$$T'_{ik} = 1 - |R_{ik}| \qquad (17)$$

Equation (17) assumes that the acoustic system dissipates no energy. In practice this assumption is not satisfied. If the loss factor associated with the system is L_{ik}, (17) can be modified to amalgamate this term. Thus

$$T_{ik} = 1 - |R_{ik}| = T'_{ik} + L_{ik}$$

which is referred to as modified transmission factor. It should error introduced by these components can be automatically corrected for in this convenient and accurate manner. B is then used in all subsequent tests under similar ambient conditions and same gain settings of the measuring equipment. The sound pressure levels can be adjusted by using either the amplitude control of the sine-sweep oscillator or the volume control of the power amplifier or both to achieve, as much as possible, the best signal-to-noise ratios in both channels.

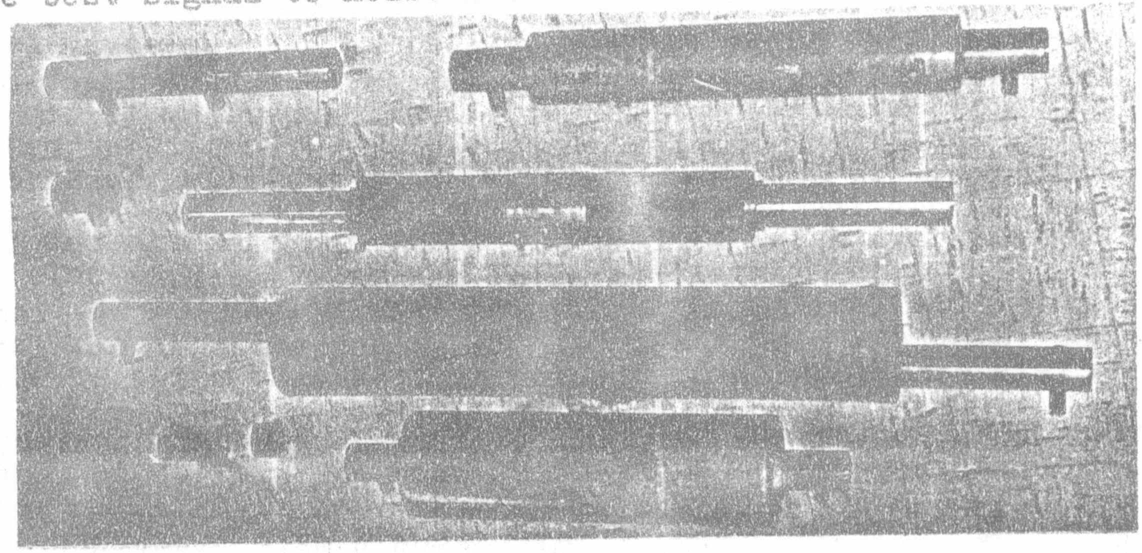

Fig. 3. piping components used in present investigation

EXPERIMENTAL WORK AND RESULTS

The stationary medium in the system was air. For all the tests performed the measured acoustic pressure levels were kept below 120 dB to ensure linear wave propagation. Following the calibration run, the microphones were relocated in their test stations 1 and 2 along the system. Many simple acoustic components; shown in Figure 3; were selected for the experimental

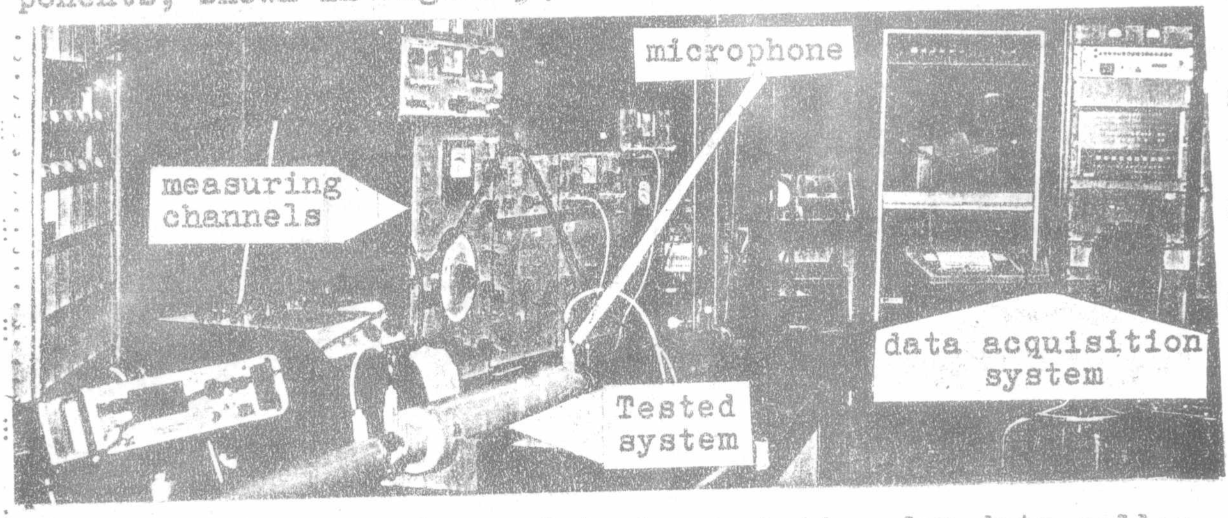

Fig. 4. Apparatus and instrumentation for data collection and analysis.

theoretical values confirms that the assumptions made in developing the theoretical base of the proposed technique are valid.

"On-line" experiments could have been conducted in all cases. However an FM tape recorder was used in some tests in order to prove the applicability of the method for field testing.

CONCLUSIONS

The transient testing technique developed in this paper is fast and accurate for the determination of acoustic properties, such as matrix parameters, for unknown systems in the range of frequencies of interest from measured experimental pressure data. The properties determined from this method include complex wave phenomena in acoustic systems. For example, three dimentional influence will be incorporated in the evaluated matrix parameters. Therefore, testing of complex components using this technique can be expected to be more accurate than theoretical predictions based on plane wave propagation. The results of the proposed technique have been tested against analytical results for simple components and the validity of the method has thus been established.

This technique is potentially more useful and applicable to field testing because the recording instrumentation is not as extensive, anechoic end is not a necessary condition in the test, and the analysis does not demand knowledge of the actual sound source. Moreover, this method of testing provides a great deal of information in one set of data and the results can be stored on magnetic tape for a future analysis or algebraic manipulations.

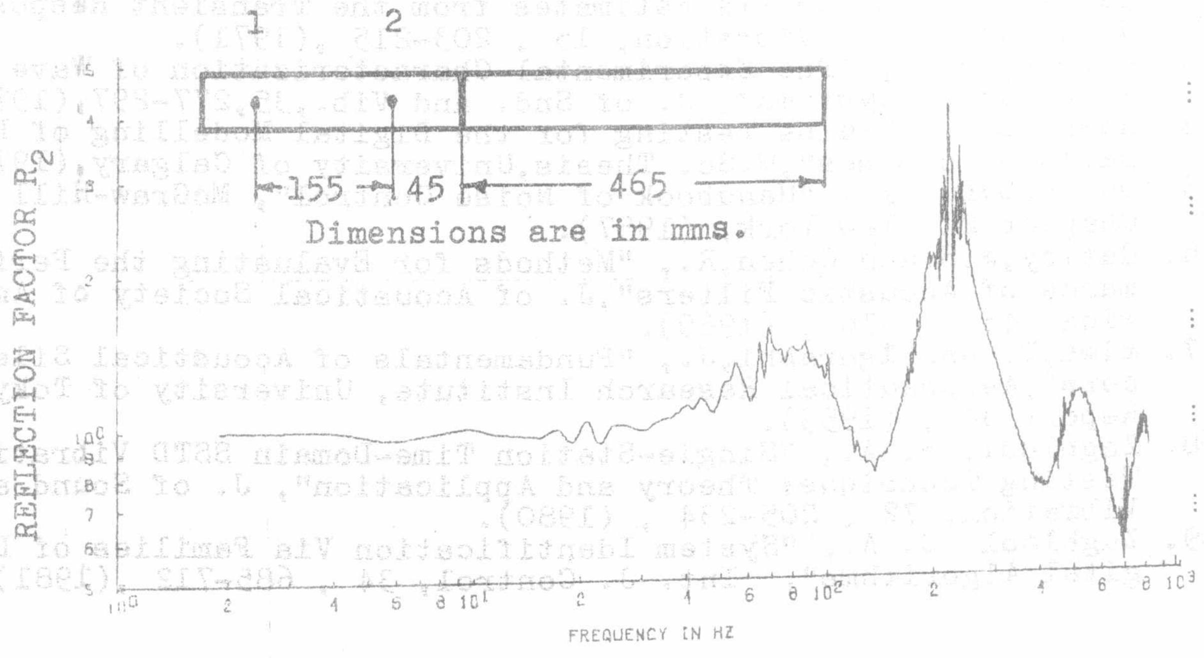

Fig. 6. Reflection factor R_2 of the pipe.