PC. CIRCLE
Circular Duct Silencer Performance Prediction Software

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1.0 Introduction

Design curves for lined circular silencers are available in the literature [1,2]. Extensive set of design curves for circular and annular duct silencers were made available recently [3,4]. The generation of a design curve to predict the silencer insertion loss spectrum for each application is a time consuming effort in a personal computer environment. A computer software for DOS machines was developed and released by Ramakrishnan and Ball for conventional rectangular duct silencers [5]. The software eliminated the tedious effort required for the generation of the theoretical prediction scheme for each individual silencer configuration. The development of a software for circular and annular duct silencers is presented in this paper.

2.0 Theoretical Background

Examples of silencer configuration are shown in Figure 1. Circular silencers with sound absorbing centre bullets are more commonly used in HVAC system ducts than simple lined circular ducts. Simple lined ducts are also shown in Figure 1. for completeness. The main aims for HVAC system duct designers are twofold, namely, to compute the silencer insertion loss spectrum for a given silencer configuration and to calculate the pressure drop across the silencer for a given face velocity.

2.1 Acoustical Evaluation

The insertion loss of a duct silencer is made of three components namely: entrance loss, exit loss and the loss due to the sound absorbing material [6]. The procedure presented in this paper is limited to the loss due only to the absorbing material. Proper adjustments would have to be added to account for the entrance and exit losses.

The acoustical evaluation follows conventional methods [7]. The methodology requires a complete description of the sound absorbing material. The material is considered to be homogeneous, isotropic and made up of either fibrous or foam type material. It is also considered to be bulk reacting unlike the locally reacting model assumed in references 1 and 2. The propagation in the material is thus included with proper accounting of the bulk properties of the acoustic material.

The sound field in the duct is evaluated by the following set of wave equations:

$$\frac{\partial^2 p}{\partial z^2} + \frac{\partial^2 p}{\partial r^2} + \frac{1}{r}\frac{\partial p}{\partial r} + \frac{1}{r^2}\frac{\partial^2 p}{\partial \phi^2} - \frac{1}{c_1^2}\frac{\partial^2 p}{\partial t^2} = 0 \quad (1)$$

$$\frac{\partial^2 p}{\partial z^2} + \frac{\partial^2 p}{\partial r^2} + \frac{1}{r}\frac{\partial p}{\partial r} + \frac{1}{r^2}\frac{\partial^2 p}{\partial \phi^2} - \frac{1}{c_2^2}\frac{\partial^2 p}{\partial t^2} = 0 \quad (2)$$

Equation (1) is valid in the open airway with c_1 being the sound speed and equation (2) is valid in the sound absorbing material with a complex sound speed of c_2. Pressure and velocity continuity are applied at various interfaces [one for Types (a) and (b) and two for type (c) shown in Figure 1.] between the absorbing material and the open airway. The two equations are solved for the common axial wave number k_z by applying a cubic finite element algorithm [8].

The characteristic impedance and propagation constant in the sound absorbing material are obtained from Beranek [9] and reference 2. The real part of the axial wave number k_z is directly proportional to the attenuation rate per unit length of the silencer.

All possible radial modes up to an azimuthal mode order of 5 are evaluated at each frequency of interest. Only those modes with slow rates of attenuation are summed to determine the final insertion loss by assuming that these modes carry equal amount of the incident sound energy.

2.2 Pressure Drop Evaluation

References 1,2 and 6 had outlined simple methods to estimate the expected pressure drop across the length of the silencer for a given face velocity. The interior details of the silencer are shown in Figure 2.

k_1 through k_5 are the loss coefficients that represent the losses associated with the shape of the silencer restricting the flow. Standard aerodynamic flow equations were used to estimate the loss coefficients. The coefficients depend on the length of the silencer, the open area to total silencer area ratio, radius of the nose cone and the tail diffuser angle of the silencer.

The total loss is represented by,

$$k = k_1 + k_2 + k_3 + k_4 + k_5 \quad (3)$$

The pressure drop across the silencer is then given by,

$$pd \text{ (inches of water)} = 1/2\, \rho_0\, (v_0)^2 k \quad (4)$$

where, ρ_0 is the density of the medium and v_0 is the face velocity at the silencer.

3.0 Development of PC. CIRCLE

The theoretical background for the evaluation of silencer insertion loss and pressure drop was presented in Section 2. It is seen that the pressure drop calculations are straight forward once the interior details of the silencer geometry are known. However, acoustic insertion loss calculation time for each individual silencer configuration is considerable (approximately 2.5 hrs in an AT personal computer with a math coprocessor). Enough curves to cover the silencer range of interest can be generated and insertion loss can be estimated by interpolation. The parameters to consider are: silencer overall diameter (from .31m to 1.53m), frequency (from 100 Hz to 10000 Hz), centre bullet size as a percentage of the silencer diameter (usually three sizes are used), liner thickness if used and the sound absorbing material to be used. The required number of design curves is therefore very large.

The required number of curves can be substantially reduced by grouping the design curves. The grouping of the design curves is aided by the fact that the sound propagation in the silencer can be completely described by the following four non-dimensional parameters: $N_1 = d / (2h)$; $N_2 = d / (2t)$; $R = (zd) / (2z_0)$ and $\mu = (fd) / (2c_1)$ where z is the specific flow resistance of the sound absorbing material per unit thickness, f is the frequency and z_0 is the characteristic impedance of the flow medium.

Approximately 600 design curves were generated to cover the range of parameters possible for the three types of conventionally manufactured silencers for low speed HVAC systems (Fig.1). Instead of solving the wave equations for each individual silencer configuration, i.e., generating a fresh design curve, a linear interpolation scheme is applied to calculate the insertion loss spectrum from the design curve set stored in a large data base.

The scheme is as follows: the four non dimensional parameters are evaluated from silencer details such as overall diameter, bullet size, liner thickness, silencer length, tail diffuser shape and length, and the sound absorbing material type. The closest design curve or curves form the data base are used to perform a linear interpolation and the insertion loss at 18 third octave bands from 100 Hz to 5000 Hz is calculated. Exact shape of the silencer is used in the interpolation scheme, i.e, different values of the non dimensional parameters are used for different sections of the silencer. One set is used for the straight section of the silencer and a minimum of three locations are used to represent the tail diffuser section. The insertion loss values at the 18 bands are calculated by averaging a band of values centred around the third octave frequency [2]. The final insertion loss at the 18 frequencies is calculated by summing the values at each section of the silencer with the appropriate lengths. The results at the 18 bands are then combined together to determine the values at six octave bands from band No. 2 through 7. The evaluation time for each silencer configuration is about 30 seconds.

4.0 PC. CIRCLE

PC. CIRCLE is a computer program for the IBM PC or compatible personal computer that calculates the insertion loss and the pressure drop of a circular/annular duct silencer. The objective of the program is to provide a quick and simple, but comprehensive evaluation tool.

The program is written in the computer languages 'C' and 'FORTRAN'. In addition, FORTRAN links with a copy-righted GRAPHICS package. FORTRAN is used as it can handle mathematical computations in a simple way and is widely available. C language is used for Input/Output and screen presentations as it is versatile and is widely applied. In order to achieve simplicity and clarity, the program is driven through simple in-put menus and pull-down windows.

4.1 Hardware Requirements

Any PC or PC compatible with at least **512K RAM** is sufficient for the execution of the program. A hard disc drive is a must for the smooth execution and for storing all the required Files. The only other necessary requirement is that the machine must be equipped with a Monochrome Graphics or a Colour Graphics Card. **NOTE: The Computer** must have sufficient **RAM memory** available if DOS SHELL is invoked while executing the program.

4.2 Sample Screen Presentation

The program is executed by typing CIRCLE and the return key. The front panel with the Serial No. and the User address will be shown first. The second screen will be as shown in Figure 3. The top line is the Menu-Bar level. The bottom line contains various prompts for the User. Five Menus are available. Display will present graphic details of the silencer and the definitions of the required input variables. Acoustics evaluates the insertion loss and Pressure Drop calculates the pressure drop. Utilities sets the program and hardware requirements. Quit enables to Dos Shell or stop the execution of PC.CIRCLE.

The results of choosing Type 1 Display option are shown in Figure 4. In addition to providing a sketch of the silencer, the details of the necessary parameters are also presented. By appropriate selections of the various menus and windows, the data can be input to the program and the results will then be shown on the screen. The Program can be executed in any sequence, as there are default dummy variables defined within the program.

References

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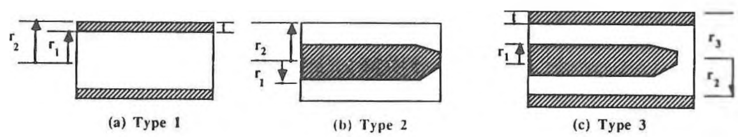

Figure 1. Conventional Circular Duct Silencers

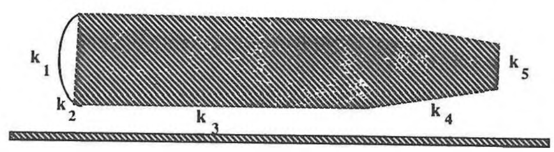

Figure 2. Loss Coefficients for Pressure Drop Calculations

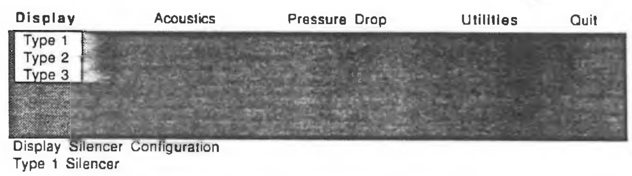

Figure 3. PC. CIRCLE Screen

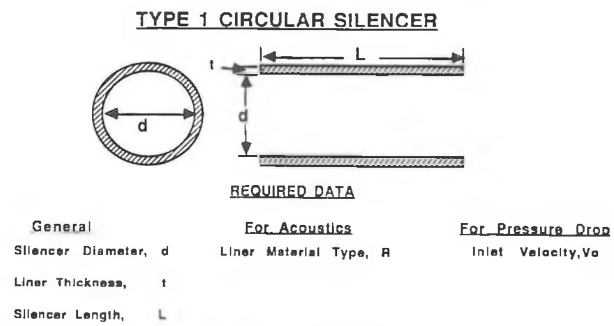

Figure 4. Type 1 - Display Option