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FREQUENCY RESPONSE EXAMINATION OF CONE CIRCULAR ACOUSTIC TRANSDUCER

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Abstract
In this paper the problem about frequency response of a circular piston transducer with a cone form of the membrane is considered. Theoretical approach and expression are proposed for calculating sound pressure level (SPL) dependency on frequency. Graphical representation of frequency response of a circular piston transducer is given. Conclusions with practical value have been made. Experimental measurements of frequency response have been made to prove the practicability of the proposed approach to determine frequency response.

Keywords: frequency response, sound pressure level (SPL), cone circular piston transducer

INTRODUCTION

The acoustic transducer's frequency response is of great interest recently due to the increased demand of quality radiators for echography, geology and architectural acoustics [1]. Furthermore requirements for the design and modeling of loudspeakers for audio systems are increased [2]. Therefore, a theoretical analysis of the expressions for calculating the frequency response of a circular piston acoustic transducer with conical form is made. Analytical expression for calculating frequency response of circular piston with conical shape radiator is proposed. A unified approach for explaining the cone circular acoustic transducers' frequency response is proposed. An experiment has been conducted to measure a cone shape loudspeaker frequency response to demonstrate the practicability of the proposed expression.

EXPOSITION

A. Analytical solution

The purpose of this study is a circular piston transducer with a conical shape of the membrane. To calculate the frequency response is suffusion to calculate SPL on the axis of radiation of the cone dependent to the frequency [3]. Because of cone symmetry with respect to the z axis (fig. 1) it can be assumed that conical piston frequency response will be one with rotation symmetry with respect to the elementary emitter E. In order to determine this symmetry, it is sufficient to determine the sound pressure level at a distance d=OA from the center of the cone to the point of the observer.

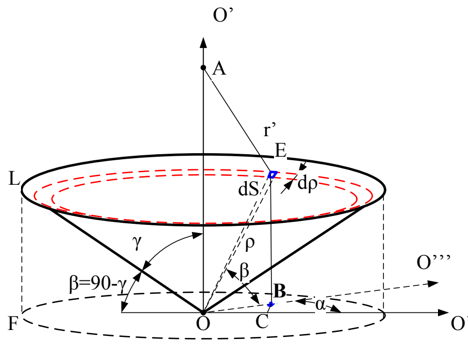

Fig. 1. *Geometry of conical piston acoustic transducer*

In order to understand the sound field created by a transducer it is necessary to examine its spatial characteristics. The latter depends on constant and variables parameters. Parameters independent of the source of acoustic waves (i.e. the transducer), but dependent on the environment are:

- speed of sound - c_0;
- atmospheric pressure - p_s;
- particles velocity - v_m;
- density of the environment - ρ_s;
- temperature - t^o.

Parameters related to the source of acoustic waves are:

- transducer's radius - r;
- transducer's height – h.

The acoustic pressure generated by an emitter in the environment can be calculated by assuming that its surface consists of a plurality of elementary sections dS that can be obtained by the solution of a differential equation (1).

$$dS = \sqrt{EG - F^2}\, d\alpha\, d\rho \qquad (1)$$

where:

$$E = \left(\frac{\partial x}{\partial \alpha}\right)^2 + \left(\frac{\partial y}{\partial \alpha}\right)^2 + \left(\frac{\partial z}{\partial \alpha}\right)^2$$

$$G = \left(\frac{\partial x}{\partial \rho}\right)^2 + \left(\frac{\partial y}{\partial \rho}\right)^2 + \left(\frac{\partial z}{\partial \rho}\right)^2$$

$$F = \frac{\partial^2 x}{\partial \alpha \partial \rho} + \frac{\partial^2 y}{\partial \alpha \partial \rho} + \frac{\partial^2 z}{\partial \alpha \partial \rho}$$

where:

$$x = \frac{r\rho}{\sqrt{r^2 + h^2}} \cos(\alpha)$$

$$y = \frac{r\rho}{\sqrt{r^2 + h^2}} \sin(\alpha) \quad 0 \le \rho \le \sqrt{r^2 + h^2} \text{ and } 0 \le \alpha \le 2\pi$$

$$z = \frac{\rho \cdot h}{\sqrt{r^2 + h^2}}$$

where

- ρ and α are current radius vector and angle;
- *h* – height of the cone transducer;
- *r* – radius of the piston.

x, y, z are the coordinates of the point of the elementary emitter E.

As a result of the solution of the equations, the following result was obtained:

$$dS = |r\rho| \sqrt{r^2 + h^2}\, d\alpha\, d\rho \qquad (2)$$

The elementary section *dS* creates, a sound pressure at point A which is at a distance r' from the point of the emitter to point of the observer. This elementary sound pressure is [4]:

$$dp_\theta = \frac{r_0 \cdot p_m}{r'} e^{j(\omega t - kr')} \qquad (3)$$

where

r' - distance from the elementary emitter to the point of observer M;

p_m - the amplitude of the sound pressure;

r_0 - distance OE which is distance from the center of the cone to emitting section dS.

$$p_m = \rho_s c_0 k r_0 v_m \qquad (4)$$

where

- $k = \frac{2\pi}{\lambda}$ - a wave number;
- λ - wavelength.

After multiplying both sides of equation (4) with and also multiplying the right side with $\frac{2\pi}{2\pi}$, taking into account that the elementary area of the emitter is $dS = 2\pi r_0^2$ therefore:

$$r_0 \cdot p_m = \frac{\rho_s \cdot c_0 \cdot k \cdot v_m}{2\pi} dS \qquad (5)$$

If the expressions (2) and (4) are replaced in (5) the elemental sound pressure will be:

$$p = \int_0^{\sqrt{r^2+h^2}} 2\pi\rho r \sqrt{r^2 + h^2} \frac{e^{-jk\sqrt{\left(\frac{\rho r}{\sqrt{r^2+h^2}}\right)^2 + \left(d - \frac{\rho h}{\sqrt{r^2+h^2}}\right)^2}}}{\sqrt{\left(\frac{\rho r}{\sqrt{r^2+h^2}}\right)^2 + \left(d - \frac{\rho h}{\sqrt{r^2+h^2}}\right)^2}} d\rho \qquad (6)$$

Expression (6) is proposed by the author for calculating SPL on the axis of radiation of cone transducer. The later can be used to calculate dependency between SPL and frequencies of cone circular transducer by vary of the frequency from 0 to 100 kHz with constant distance and geometrical parameters of the cone.

B. Graphical solution

By using expression (6) in Mathcad software are calculated and presented on **Fig. 2** results for circular cone transducer with following membrane geometrical parameters: with flat dense line for cone membrane with h=0.071 (relevant to height Selenium 10MB3P loudspeaker), with dot line flat piston (h=0), and with dashed line h=0.1145m (90° central angle of the cone) on distance 0.045 m.

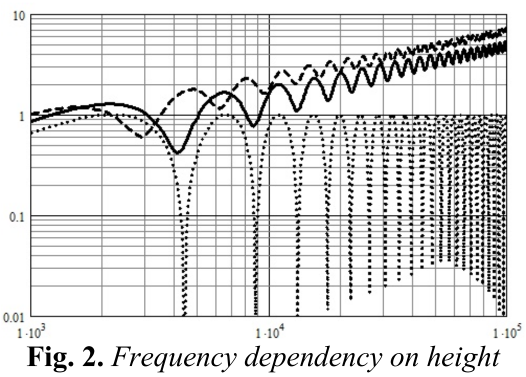

Fig. 2. *Frequency dependency on height of the cone*

Expressions (6) if it is calculate in Mathcad with vary of the height from 0 to 0.1145 is also capable to represent 3D frequency response (**Fig. 3.**) of the conical transducer dependency by height of the cone which allows designers of cone acoustic transducers to choose proper height for the demand frequency response for the given geometrical radius of the cone on distance 0.045m.

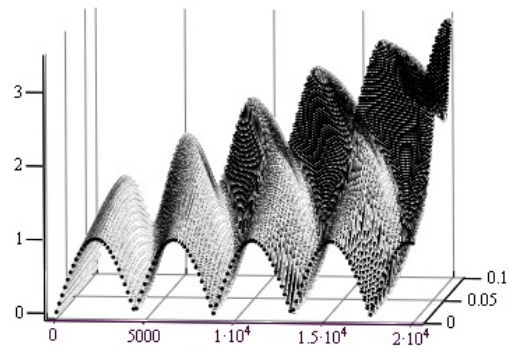

Fig. 3. *Frequency 3-dimensional dependency on height of the cone*

Distance is very important because minimums occur when the point of observer is in near field of the transducer which is very important for specialized applications of cone transducers because when the distance passes the boundary of the near field, the minimum pressure is blurred within the range of the noise and cannot be counted [3,5].

C. Experimental solution

On **Fig. 4.** is presented analytical calculation of the SPL of cone piston transducer [6, 7] with equal geometrical parameters to Selenium 10MB3P loudspeaker h=0.071m and r=0.1145m. by using equation (6) on distance 0.045 m. result shows minimums of the SPL on 3900Hz and 8200Hz in the frequency range of the loudspeaker from 150Hz to 12 kHz.

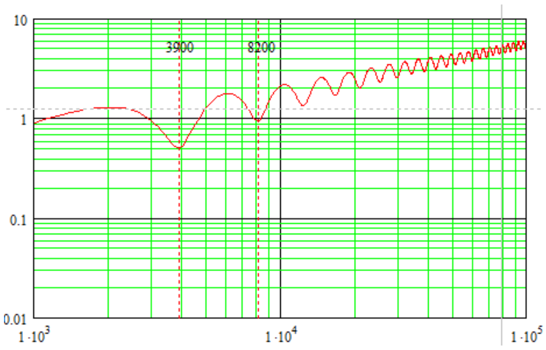

Fig. 4. *SPL vs Frequency calculate by equation (6)*

Frequency response of Selenium 10MB3P loudspeaker was measured with Loudspeaker LAB 3 Std. Version 3.01 software by using pink noise test signal (**Fig. 5**). Measurement was repeated with Realtime Analyzer Version 5.1.0.10 software by using frequency sweep test signal from 20 to 20 kHz (**Fig. 6)** and pink noise test signal (**Fig. 7**.)

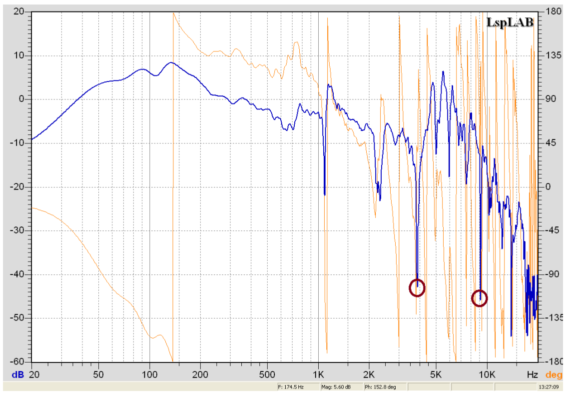

Fig. 5. *Frequency response of Selenium 10MB3P loudspeaker (pink noise) LspLAB*

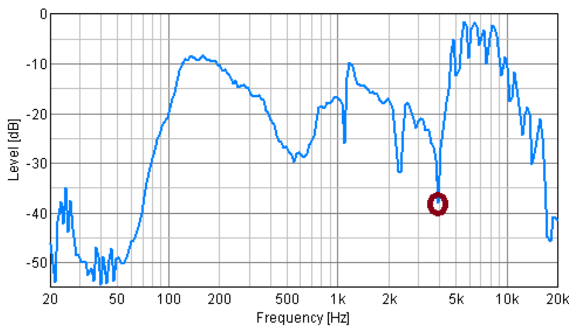

Fig. 6. *Frequency response of Selenium 10MB3P loudspeaker (frequency sweep) Realtime Analizer*

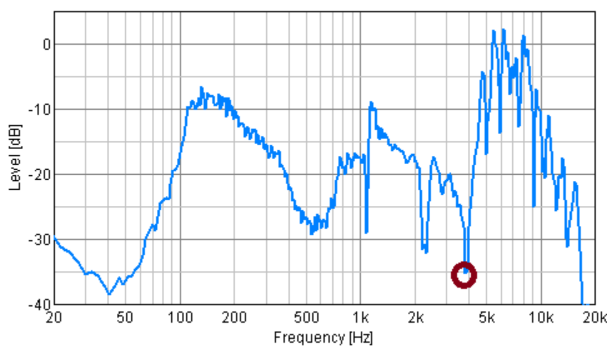

Fig. 7. *Frequency response of Selenium 10MB3P loudspeaker (pink noise) Realtime Analizer*

Measurements were performed in the Technical University of Varna anechoic chamber, using the Robotron Präzisions with microphone MK221, sound card Realtek High Definition Audio for generator. During the experiments level of noise and temperature were measured by professional multimeter MS 6300 and noise level measured was 26 dB. The temperature in the chamber was 21°C.

CONCLUSION

As a result of the theoretical analysis and performed experiments about frequency response of cone circular piston acoustic transducer the following results and conclusions were obtained:

- Proposed expression (6) can be used to determine sound pressure minimums of frequency response in the near field area of circular cone piston acoustic transducers.
- Proposed equation (6) allows designers of precision cone transducer to calculate height of the cone circular piston transducer depending on desired frequency response.
- Analytical analysis on **Fig. 2.** and **Fig. 3.** leads to a practical conclusion about dependency minimum of the frequency response from the height of the cone: Increasing the height of the cone reduces the frequency of which appears the minimum but reduces its level.
- Conducted experiments demonstrate the applicability of the known approach for circular piston [3] upgraded to analyzing the dependency of the frequency response in the near field on height of the circular cone acoustic transducer.
- The occurrence of minimums in experiments at accurate analytically calculated frequencies of 3900Hz (**Fig. 5, 6, 7**) and 8200Hz (**Fig. 5**) with expression (6) demonstrates the precision of the approach and its practical applicability.

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