Test Report

Force applied by the Transducer of the Frequencer^{TM}, model 1001

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Abstract

This experiment examined the force applied by the transducer on the chest by the Frequencer^{TM}, model 1001. Knowing this value, it is possible to compare to any other method used to clear the mucus from the airways such as the clapping.

Introduction

The transducer is an electrical to acoustic converter fixed inside a custom enclosure. As its exact mathematical model contains many unknowns and requires complex software, we decided to measure the effect of the transducer on a passive system which mathematical model is known and available by the datasheet of the manufacturer. The passive system chosen here is a loudspeaker.

For a loudspeaker[1], the ratio of the velocity of the cone on the voltage at both ends of the coil is given by equation [1]:

$$\frac{u}{V} = \frac{Bl}{\left(j\omega m + (R + S\rho_0 c) + \frac{1}{j\omega Cms} \right) Z_{eb} + (Bl)^2} \qquad [1]$$

Where:

u is the velocity (m/s);
V is the voltage (V);
m is the moving mass (kg);
ω is the angular frequency (rad•Hz);
R is the mechanical resistance (kg/s);
S is the effective piston area (m^2);
ρ_0 is the air density (1.18 kg/m^3);
c is the speed of sound (340 m/s);
Cms is the suspension compliance (m/N);
Z_{eb} is the electrical impedance (Ω) and
Bl is the force factor (N/A).

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[1] Electroacoustic Transducer Design, Dr Ian Drumm, University of Salford, 2006.

R, S, Cms, m and Bl are value given by the manufacturer. Z_{eb} is given by:

$$Z_{eb} = R_e + j\omega L_e \qquad [2]$$

Where :

Z_{eb} is the electrical impedance (Ω);
R_e is the DC resistance of the coil (Ω) and
L_e is the coil inductance (H).

And R_e and L_e are also given by the manufacturer.

If an acoustic wave is applied on the cone of the loudspeaker, the movement will be transmitted to the cone of the loudspeaker and the equation of this movement can be expressed by:

$$x(t) = X\sin(\omega t) \qquad [3]$$

Where :

X is the displacement (m) and
t is the time (s).

Thus, the velocity is:

$$u(t) = (X \cdot \omega)\cos(\omega t) \qquad [4]$$

Where u(t) is the velocity (m/s).

Finally, the acceleration is:

$$a(t) = -(X \cdot \omega^2)\sin(\omega t) \qquad [5]$$

Where a(t) is the acceleration of the cone (m/s^2).

If we are interested only by the amplitude, the relation between u(t) and a(t) is:

$$|a| = \omega \cdot |u| \qquad [6]$$

Now, we can use the second law of Newton, which is:

$$F = m \cdot a \qquad [7]$$

Where :

F is the force (N);
m is the moving mass (kg) and
a is the acceleration (m/s^2).

We can combine equations [1], [6] and [7]. This will give us:

$$F = |V| \cdot \omega \cdot m \cdot \left| \frac{Bl}{\left(j\omega m + (R + S\rho_0 c) + \frac{1}{j\omega Cms} \right) Z_{eb} + (Bl)^2} \right| \qquad [8]$$

Considering the specifications given by the manufacturer, the last equation shows us that if we apply a sinusoidal acoustic wave to a loudspeaker, it is possible to know the force F applied at the cone if we measure the voltage V at the coil.

Equipment

For this experiment, we used:

1 Frequencer™, model 1001
1 Oscilloscope Tektronix TDS 2012
1 loudspeaker Aura NS4-255-4B

Experimental Procedure

First, we install the equipments as indicated by figure 1.

Figure 1: Test Setup

The critical step is to correctly install the transducer and the loudspeaker. As we can see in figure 2, the loudspeaker is directly applied on the transducer. This is similar to the normal use of the Frequencer™ where the transducer is directly applied on the chest.

Figure 2: Transducer and loudspeaker setup

Once installed, we can start taking measurements. We turn on the Frequencer™ and put the output volume to 100%, as we want to measure the maximum force applied to the chest. The measurements are taken by selecting a frequency in the 20 to 100 Hz range and writing the peak value with the oscilloscope of the voltage at the loudspeaker coil (see figure 3).

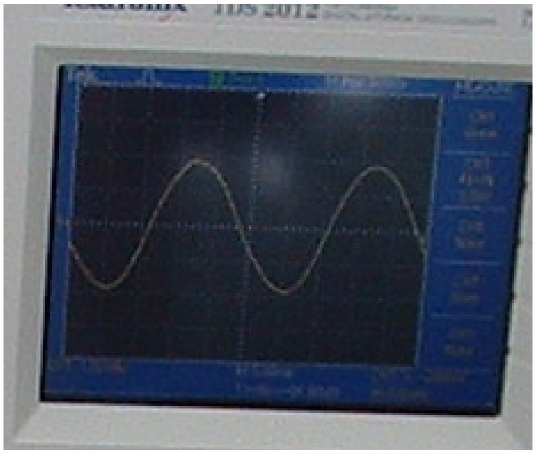

Figure 3: Reading on the oscilloscope

Results

Table 1 is giving the results for a frequency sweep of 20 to 100 Hz.

Table 1: Test Results

f (Hz)	w (rad/s)	|Ze| (Ohms)	|Zm| (Ohms)	u/V	V (Vp)	u (m/s)	a (m^2/s)	Fmax (N)
20	125,7	3,50	9,42	0,0791	1,60	0,127	15,91	0,07
30	188,5	3,50	6,07	0,1058	2,32	0,245	46,27	0,22
40	251,3	3,50	4,37	0,1276	2,64	0,337	84,66	0,40
50	314,2	3,50	3,38	0,1451	3,00	0,435	136,72	0,64
60	377,0	3,50	2,79	0,1579	3,28	0,518	195,31	0,92
70	439,8	3,50	2,47	0,1657	3,36	0,557	244,90	1,15
80	502,7	3,50	2,37	0,1684	3,56	0,600	301,37	1,42
90	565,5	3,50	2,42	0,1670	3,68	0,615	347,58	1,63
100	628,3	3,50	2,58	0,1630	3,92	0,639	401,50	1,89

where:

Re = 3,5 Ohms
Le = 2,15E-04 H
Bl = 3,68 N/A
m = 4,70E-03 kg
R = 0,355 kg/s
S = 5,03E-03 m^2
po = 1,18 kg/m^3
Cms = 8,20E-04 m/N
c = 340 m/s

The peak voltage measured at the coil varies from 1.60 to 3.92 V. It gives a peak applied force varying from 0.07 to 1.89 N.

Discussion

Marc Bacon in is white paper[2] wrote an applied force from 0.4 to 3 N. He based these values on the maximum displacement that the cone inside the Frequencer™ transducer can move, the maximum power at the input of the transducer and the efficiency we can expect from such devices. However, he had to work with a prototype that had slightly been modified since that time.

Based on the present test, the maximum force applied on the loudspeaker by the transducer of the Frequencer™ varies from 0.07 to 1.89 N.

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[2] Mechanical clearance of human airways using the Frequencer electro-acoustical transducer, André Cantin, M.D. & Marc Bacon, P.Eng.

Conclusion

Based on the parameters of the loudspeaker given by the manufacturer and on the values measured, we can conclude that the maximum force applied by the transducer of the Frequencer™ varies from 0.07 to 1.89 N. This value is lower than the values given by the clapping which is 58.10 ± 15.32 N[3].

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[3] Rate and force of application of manual chest percussion by physiotherapists, Blazey SM, Jenkins and Smith RA. Australian Journal of Physiotherapy 44: 257-264