ACOUSTICAL MODELING OF SIGNAL HORNS - TAKING INTO ACOUNT NON-LINEAR EFFECTS

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1. INTRODUCTION

One method to model electroacoustical transducers is to describe its basic system components using lumped elements which are analogous to those in electrical networks [1]. In the past the method has been widely used. However, the validity of the underlying simplifications has to be proofed in particular cases.
In this paper the study of the acoustical behavior of a signal horn considering non-linear effects shall demonstrate the efficiency of the method.

2. FUNCTIONALITY OF A SIGNAL HORN

The function profile of the signal horn is drawn in figure 1. At the time (t=0) the DC-circuit is closed by the breaker S1 the attracting force of the electromagnet leads to a displacement of the steel diaphragm towards the electromagnet. The interrupter switch S2 is coupled mechanically to the diaphragm. Therefore, as the diaphragm reaches the position $x=x_{S2}$ the switch S2 interrupts the DC-circuit. The electromagnetic force acts no longer, so, drawn by elastic forces, the diaphragm reverses its motion back toward its neutral position. On the

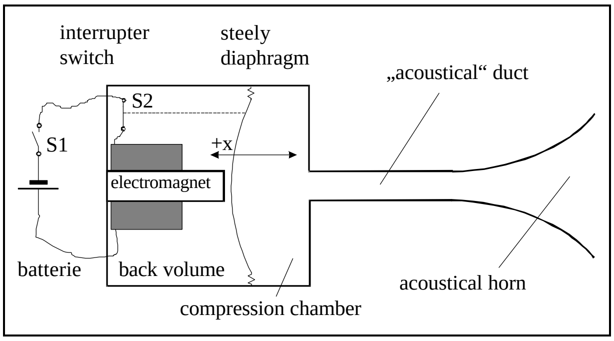

Figure 1. Function profile of a signal horn

diaphragm position x_{S2} the interrupter switch S2 closes the DC-circuit again, consequently starting a cycle of oscillation. In our example the basic frequency of this oscillation lies in the range of 400-500Hz.

3. THE LINEAR MODEL

The modeling was executed in two steps. To validate the simplifications of the model (e.g. assuming the mass of diaphragm as a point mass) in a first step a linear model in the frequency domain was established [2]. This model omits non-linear effects (e.g. the effect of the interrupter switch S2). Hence it follows that the model cannot be used for the complete description of the acoustic behavior.

However the linear model enables the examination of the small-signal behavior. This allows the validation of the parameter data won by measurement or calculation. Furthermore, in the result of an executed sensitivity analysis the model was simplified.

The chassis of the signal horn has to be small as possible, therefore the acoustical horn is wound up. The response function of a straight acoustical horn can be approximated by use of Webster’s horn equation [1]. The applicability of this equation to wound up horns was proofed by a survey that covered BEM-models of differently shaped horns. The response functions of straight and „wound up“ acoustical horns are in a satisfactory agreement within the required frequency range (100-6400Hz).

4. CONSIDERING NON-LINEAR EFFECTS

By use of the won knowledge the non-linear effects which are seeming to be most essential were included: the effect of the interrupter switch, the connection between electrical input current and mechanical force, the relation between stiffness of diaphragm and its elongation, the nonlinear behavior of the air inside the compression chamber and the wave steepening of the sound waves inside the acoustical horn due to the high sound pressure level.

While the linear model may be treated in frequency domain, the calculation of the non-linear model has to be carried out in time domain. This can be easily done by use of one of the commercially available network analysis software tools common in electrical engineering.

Figure 2 shows the model of a signal horn. The elements with the considered non-linear effects are marked by bold faced frames.

As aforementioned the state of the interrupter switch S2 depends on the position of diaphragm. By integration of the velocity time function $v_{Diaphragm}(t)$ the position of the diaphragm at a certain time x(t) can be reached. The constant x_0 is the neutral position of the diaphragm.

The relation between the flux quantities electrical input current and mechanical force of the electromagnetic transducer is $F \sim I^2$ (the direction of diaphragm displacement is independent of the polarity of the electrical input current). The relation of the according field quantities electrical voltage U(t) and velocity of diaphragm $v_{Diaphragm}(t)$ were found from the balance of energy.

The most important non-linear effects of the acoustic part are occurring inside of the compression chamber and inside of the acoustical horn and duct.

The acoustical compliance N_c describes the behavior of air inside of the compression chamber. The parameter N_c can be assumed as linear if the sound pressure inside of the chamber is small compared to the static pressure p_0 and if the change of volume is small compared to the volume of the chamber.

In that case the change of volume is a function of displacement of diaphragm and diaphragm cross-section. Because of the very small volume of the compression chamber and the high SPL inside of it (more than 160dB) non-linear effects are occurring. The parameter N_c has to be considered as a function of the diaphragm displacement and of the sound pressure - $N_c = f(x,p)$ [3].

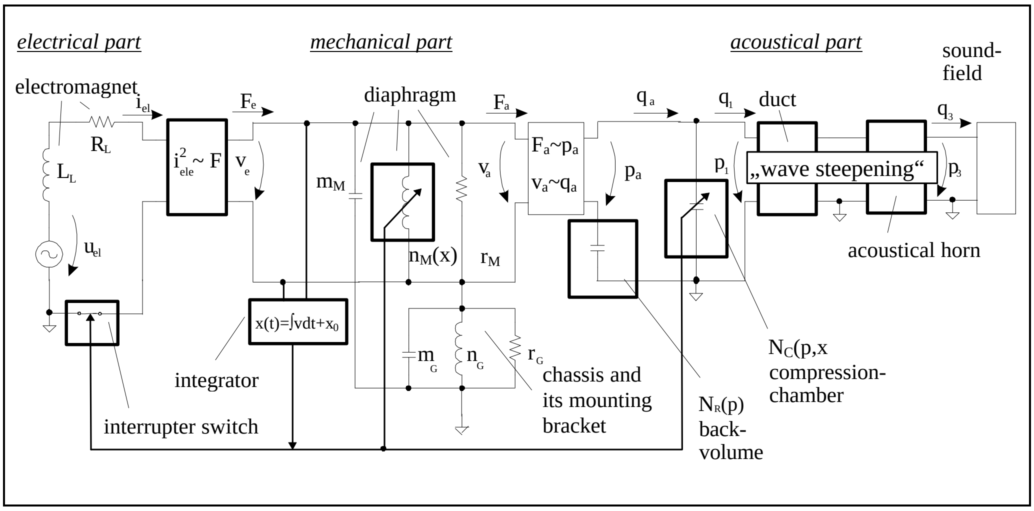

Figure 2. The acoustical model of a signal horn - considering non-linear effects

If the amplitudes of sound pressure are small compared to the static pressure p_0 the propagation of sound waves can be described by assuming the relation between sound pressure p and volume velocity q (flux) as linear - the traveling speed of sound is taken to be constant.

For the propagating sound waves very high amplitudes of sound pressure (SPL>160dB) were recognized inside of the acoustical horn and duct. In that case a strong difference of pressure and density at wave maximum and minimum occurs. This implies a significant difference of sound wave traveling speed at wave maximum and minimum. Because at higher pressure and density the sound traveling speed will be higher, the wave maximum will travel with higher speed. This leads to the steepening of the wave.

In the model the acoustical horn is split in very small segments to account for this effect. The additional higher and lower propagating speed of wave phases is modeled by volume velocity sources [4] on the input of the segments. The quantity of this sources depends on the sound pressure.

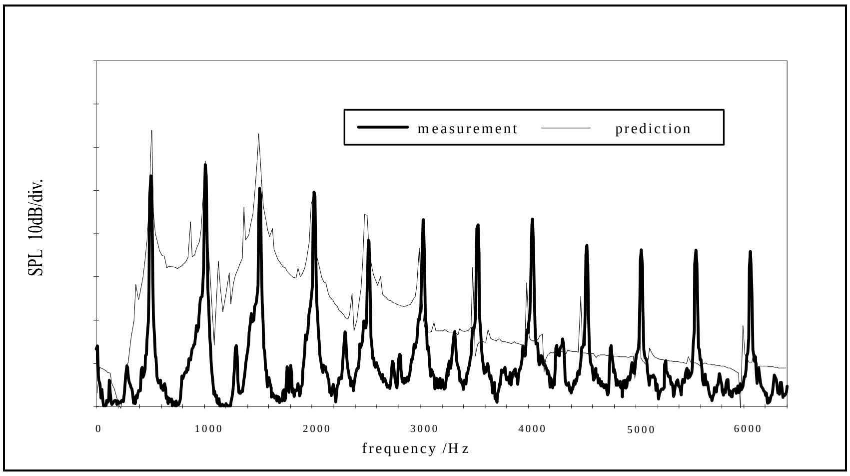

Figure 3. SPL on the output of the acoustical horn

5. CONCLUDING REMARKS

Using this model the time transient of all field and flux qualities of the signal horn can be examined. The frequency spectrum can be reached by applying the FFT on the results of the steady state (see Figure 3).
The predicted behavior of the model within the frequency range 100 to 3500Hz were compared with measured data. It was found that the model is able to predict the effect of parameter changes in the most cases. Deviations are mainly caused by inaccuracies in the determination of certain parameters (e. g. distance of breaker to diaphragm, factor of transducer coil).
A parameter analysis helped to find out the parameters with the strongest influence on the acoustical behavior.
The model provides the possibility to include the results of the FEM-analysis or the BEM-analysis, for those system parts which cannot be reduced to lumped elements. Moreover, the model enables a relatively fast and inexpensive examination of the system characteristics compared to the FEM or the BEM-Analysis. It can be easily adapted to similar horn types.

6. REFERENCES

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