Research on Dynamic Inductance Characteristics and Directivity of Cluster Wave Generator

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Abstract. The experimental research on the cluster wave generator is carried out, and the time-varying model of the diaphragm displacement of the cluster wave generator is established. The position-varying model and time-varying model of the dynamic inductance of the cluster wave generator are further established. The circuit of the cluster wave generator is studied. The influence of dynamic inductance on the current in the loop is analyzed. The sound field simulation of the cluster wave generator is carried out, and the directivity distribution of the cluster wave generator is analyzed. The results show that the current amplitude and decay time in the cluster wave generator circuit are reduced due to the existence of dynamic inductance. The cluster wave generator has not directivity at low frequencies, medium frequency directivity is good, and high frequency directivity is poor.

1. Introduction
The cluster wave generator is a transducer device [1]. Its sound source signal has good repeatability and be used widely. Previous studies on cluster wave generators have also make some progresses. Some scholars study on the equivalent circuit to illustrate the working principle of the cluster wave generator [2-4], and some calculation formulas of engineering design are given. Some scholars have determined the optimal value of the lift distance between the diaphragm and the coil through electromagnetic field simulation [5]. However, these studies have not considered the influence of diaphragm displacement. This paper will try to study the influence of diaphragm displacement on inductance and current, establish time-varying model and position-varying model of inductance, and analyze the influence of dynamic inductance on current, analyze the directional distribution of the cluster wave generator by comsol simulation.

2. Position -varying model of cluster wave generator inductance
Figure 3 shows a physical model and 3D model of the cluster wave generator. The working principle of the cluster wave generator is that there is an alternating current flowing in the coil, and so an alternating magnetic field is generated around the aluminum diaphragm. The aluminum diaphragm generates an alternating eddy current in the alternating magnetic field, and the diaphragm is forced to vibrate, and then the air medium generates vibration. The vibration of the air medium causes the sound waves to radiate outward.
Since the inductance of the cluster wave generator circuit will change when the diaphragm of the cluster wave generator is displaced, in order to establish the positional variation model of the cluster wave generator inductance, the micrometer is used to measure the displacement of the diaphragm, and the digital bridge measure the various inductance value of the cluster wave generator, the test platform is shown in Figure 2. The measured inductance value and diaphragm displacement value are shown in Table 1.

A total of five sets of data were measured, and the five sets of data were fitted as shown in Fig. 3. The fit map obtained by averaging the five sets of data is shown in Fig. 4. As can be seen from the figure, there is a linear relationship between inductance and displacement, and the mathematical expression is:

$$L(x) = 15.4x + 113.8$$ (1)
Where: $x$ represents the diaphragm displacement and $L$ represents the loop inductance.

Figure 3. Inductance and diaphragm displacement fit curve

Figure 4. Relationship between diaphragm displacement and inductance

3. **Inductive time-varying model**

In order to obtain the time-varying model of the inductance, it is necessary to obtain the variation model of the displacement with time. Here, the simulation study is carried out by using ABAQUS to establish the relationship between the displacement of the diaphragm and the time. The graph of the middle of the diaphragm with time is shown in the figure 5.

Figure 5. Central node displacement of diaphragm changes with time
It can be concluded from the figure that the diaphragm displacement with time is:

\[ x(t) = 2000t \]  

(2)

The \( x \) unit is mm, and combining equation (7) can get the inductive time-varying model as:

\[ L(t) = 5.4x(t) + 113.8 \]
\[ = 15.4 \times 2000t + 113.8 \]
\[ = 10800t + 113.8 \]  

(3)

4. Influence of Dynamic Inductance on Loop Current of Cluster Wave Generator

The coil inductance changes as the diaphragm displacement changes. The change in inductance affects the change in current, and the changing current produces a changing magnetic field. As shown in Figure 6, the discharge circuit of the entire cluster wave generator can be regarded as an equivalent RLC discharge circuit. The inductance in the circuit is a dynamic inductance, and the dynamic total inductance in the equivalent circuit is \( L \). The resistance of the coil \( R_1 \), the resistance of the wire is negligible, and the capacitance of the disk coil is small and negligible. Then the equivalent resistance in the whole circuit is:

\[ R = R_1 \]  

(4)

![Figure 6. The discharge circuit of the cluster wave generator](image)

Where \( C = 40 \mu f \), the static inductance value is 108.79\( \mu H \), and the resistance value in the circuit is 0.187\( \Omega \). The loop is a second-order system [6], when the dynamic inductance is not considered, the current waveform in the circuit is shown in Figure 7. When the dynamic inductance is considered, the current waveform is shown in Fig. 8.

![Figure 7. Current waveform when dynamic inductor is not considered](image)
Comparing Figures 7 and 8, it can be seen that due to the influence of dynamic inductance, the current decay speed in the circuit becomes faster, and the current peak is reduced. This is because the inductance increases as the displacement increases, and the attenuation factor $\psi = \frac{R}{2L}$ shows that as the inductance increases, the attenuation factor becomes smaller and the decay time becomes shorter.

5. Cluster wave generator directivity distribution analysis

Due to the limited computing power of the computer, the simulation of the 3D model is sometimes slow. Therefore, for some symmetrical models, the 3D simulation model can be simplified without affecting the result [7], as shown in Figure 9 established in COMSOL.

The directivity analysis of the cluster wave generator is carried out in COMSOL and the post-processing is performed to obtain the directivity distribution of the cluster wave generator as shown in Fig. 10, the abscissa represents the logarithm of the frequency. The angle between the point at which a
point in the space is connected to the cluster wave generator and the axis perpendicular to the diaphragm of the cluster wave generator is expressed as the ordinate in degrees.

It can be seen from the figure 10 that the cluster wave generator in the low frequency band does not have directivity. The mid-band increases with the frequency of the acoustic wave. The beam angle of the generator is smaller, and the directivity is better, there is slight fluctuation, but the overall fluctuation is not large, the sonic energy is concentrated, and the directivity of the cluster wave generator in the high frequency band is poor.

6. Conclusion

Through the research, it is found that there is a proportional relationship between the displacement of the diaphragm and the inductance. The existence of the dynamic inductance reduces the current amplitude and decay time in the loop of the generator. Through the directivity study, the results show that the cluster generator has not directivity in the low frequency band, the medium frequency band has good directivity and the high frequency band has poor directivity.

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