Sound Quality Analysis and Optimization of Loudspeakers Based on Electromagnetic Principle

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Abstract.

The sensory feeling brought by the speaker's sound quality determines the speaker's quality, and whether a better speaker can be designed depends on whether the factors affecting the speaker's sound quality can be correctly analyzed. Through the analysis of the loudspeaker structure and the application of physics in the loudspeaker, the factors affecting the sound quality of the loudspeaker are analyzed from the two aspects of the magnetic circuit system and the vibration system, which is intended to help designers analyze and understand the physical characteristics of the loudspeaker, to make better audio equipment.

Keywords: Loudspeaker, sound quality, magnetic field, impedance.

1. Introduction

Sound quality is the overall evaluation of sound quality through people's sensory feelings and the embodiment of sound in sound technology. Sound quality includes three aspects: loudness, tone, and timbre. Loudness is the intensity and amplitude of a sound. Pitch is the frequency of sound vibration. Timbre is the vibration characteristic of different objects and different materials. Sound quality is mainly to measure whether the above three aspects of the sound have reached a certain level: whether the voice can be stable at a frequency to emit a relatively strong sound. A loudspeaker is an important sound equipment. The most widely used moving coil loudspeaker uses the principle of electromagnetism in physics to produce sound. The sound quality of the loudspeaker is a key factor in determining its quality, and it is also a common concern of loudspeaker designers and users. The objective and accurate analysis of the sound quality of loudspeakers is an important prerequisite for the design and optimization of loudspeakers. To improve people's hearing experience, this paper will be divided into two parts: the loudspeaker magnetic circuit system and vibration system, according to the physical principle of loudspeaker energy conversion, from the magnetic material, electromagnetic induction principle, loudspeaker voice coil structure, circuit impedance, and frequency response to analyzing the sound quality of the loudspeaker, to optimize the audio experience of the loudspeaker.

2. Analyze the Sound Quality Through the Magnetic Induction Intensity

2.1 General Statement

The magnetic circuit system composition of the moving coil speaker can be divided into T iron, magnet, washers, basin stand, voice coil, and terminal [1]. The principle of the moving-coil speaker is that the current-carrying conductor is stressed in the magnetic field, and the amperage force of the permanent magnet on the current-carrying coil is

$$F = BIL \tag{1}$$

B is the magnetic induction intensity in the magnetic field, I is the magnitude of the current passing through the coil, L is the effective length of the coil wire in the magnetic field, and F is the force of the magnetic field on the entire coil. For existing speakers, the length of the coil is fixed, so the magnetic induction intensity B of the magnet inside the speaker and the alternating current entering the coil directly affect the force of that magnetic field on the entire speaker, which affects the sound quality, especially in audio equipment and sound systems. Some factors related to the magnetic circuit system and magnetic induction B may affect sound quality[2].

2.2 The Choice of Magnetic Materials

Different magnetic materials have different magnetic induction intensities, and the performance of magnetic materials will directly affect the magnetic induction intensity and the speaker's sound quality. Since the energy conversion of the loudspeaker is converted from electrical energy to the final mechanical energy, relying on vibration to sound, the choice of magnetic materials is more inclined to materials with stable magnetic induction strength, such as permanent magnets with larger coercive force and wider hysteresis loops[3].

2.3 Uniformity of Magnetic Induction Intensity and Influence of External Magnetic Field

The uniformity of magnetic induction intensity B has the most direct influence on sound quality. The middle part of the loudspeaker magnetic gap has a uniform distribution of magnetic flux lines, but the upper and lower areas of the voice coil are different [4]. The uneven magnetic field leads to the different forces of the voice coil at different positions, affecting the frequency of the voice coil vibration, and the electrical signal is difficult to completely transmit to the diaphragm, which is the main cause of sound distortion. The uniformity of magnetic induction intensity is the magnetic characteristics of the magnetic components of different loudspeakers. Different from the influence of the magnetic characteristics of the speaker itself on the magnetic field and sound quality, external magnetic fields may also interfere with the magnetic induction intensity. Usually, in areas with strong magnetic fields, such as high-voltage lines and transformers, the external magnetic field will affect the magnetic field strength near the voice coil, resulting in changes in sound quality. In the sense of hearing, the greater the force coefficient BL, the speaker will lack power [1].

2.4 Inductance and Electromagnetic Induction

Inductors are often used in audio circuits, and there is a certain relationship between inductance and magnetic induction intensity B. A loudspeaker's voice coil is made of enameled wire, which has certain inductance characteristics. The inductor's current changes nonlinear nonlinearity, affectingmal transmission of the original electrical signal into the audio signal. At the same time, because the voice coil force vibration, it will cut the magnetic induction line in the magnetic gap; through the principle of electromagnetic induction, this process will induce an induced voltage and induced current in the direction of the audio signal opposite, this induced current will weaken the audio signal current in the original voice coil, thus increasing the impedance of the voice coil. Larger audio signal frequencies tend to result in higher impedance [5]. When transmitting low-frequency audio, the speaker's sound quality is often more realistic due to the relatively small circuit impedance. Moving-coil speakers tend to have a better bass effect, so the sound performance will be warmer.

2.5 Voice Coil and Energy Loss

Coil refers to the winding wire at the periphery of the voice coil, and the force generated by the magnetic field on the current drives the coil to make the reciprocating motion in the gap magnetic field [6]. The choice of wire also has a certain impact on the sound quality. Tweeters usually use copper wire or aluminum wire, and aluminum wire response speed will be faster than copper wire. Woofers, on the other hand, usually use copper wires with lower resistance and greater durability. Moreover, tweeters burn out more quickly than woofers for the same reason. A portion of the electric energy brought by the current is turned into joule heat during the loudspeaker's energy conversion process, which cannot be prevented. The coil usually chooses a material with small resistance to reduce energy loss. It must have a certain heat resistance to prevent the coil from burning after a long work, damaging the speaker. The shift in the voice coil's position will also affect the force it is subjected to, resulting in distortion of the sound quality. The voice coil exhibits nonlinear behavior when the input signal grows, that is, when the current increases. This is because the reverse current created by electromagnetic induction also exists simultaneously, increasing the voice coil's vibration amplitude. The voice coil exhibits nonlinear behavior when the input signal grows when the current increases. This is because the reverse current created by electromagnetic induction also exists simultaneously, increasing the voice coil's vibration amplitude [7]. The voice coil is potentially unstable. By positioning the voice coil in the initial position, the asymmetry of the nonlinear factors can be suppressed to a certain extent [7].

3. Analyze the Sound Quality Through the Impedance of the Circuit

3.1 General Statement

Impedance is the obstruction of alternating current in a circuit with resistance, inductance, and capacitance. The speaker's voice coil has a resistance but also a certain inductance characteristic, which will hinder the incoming current. The smaller the speaker's impedance, the easier the entire speaker system is to drive. There is a certain relationship between the speaker's sound quality and the circuit's impedance; different impedances will also have different effects on the sound quality. Here are some factors related to circuit impedance that may affect sound quality.

3.2 Impedance Matching

The ratio of the speaker voltage to the current flowing through the speaker determines the speaker's rated impedance. Different voltages at both ends of the speaker and different current flows will not change the speaker's rated impedance. The rated impedance is the speaker's property at the production time, and different speakers have different rated impedance. It can be seen from the equivalent circuit of the loudspeaker that the total electrical impedance of the loop is equal to the voice coil impedance plus the insertion impedance, and the total force impedance of the loop is equal to the force impedance of the vibration system plus the insertion impedance [7]. The rated impedance of the loudspeaker does not determine its quality. The sound quality of the loudspeaker is the best only when the input resistance is equal to the output resistance. In real life, the closer the input and output resistance are, the better the impedance matching can be achieved [8]. To save costs and improve efficiency, the method of modifying the circuit is often used in reality to achieve the best impedance match [8]. By increasing the series resistance, the pass-frequency width can be increased to improve the sound quality of the loudspeaker. According to

$$P = U2 / R \tag{2}$$

when the voltage is certain, the power is only related to the resistance, and the power and sound quality can be improved by reducing the resistance in parallel with the loudspeaker circuit [8]. The speaker's impedance should match the impedance of the amplifier or audio output that drives it to achieve the best sound quality. Mismatched impedances can lead to distortion of the audio signal, loss of power, and degradation of sound quality.

3.3 Impedance Curve

A more in-depth understanding of the speaker's impedance can be known from the speaker's impedance curve in the actual situation. The loudspeaker impedance contains resistance, capacitance, and inductance, of which the capacitor's impedance and inductance will change nonlinear according to the alternating current of different frequencies. Hence, the impedance curve of the loudspeaker is nonlinear. The impedance has not only the magnitude but also the phase Angle. The phase angle of the impedance can affect the localization of the sound. After the RLC circuit, the size and phase Angle of the voltage signal will change, and the frequency of the input voltage will have different effects on the size and phase Angle. Loudspeakers may experience impedance peaks at certain frequencies. These peaks can cause resonance or sound quality problems. To make the speaker work normally and have the best sound quality, it should be ensured that the speaker is within the corresponding operating frequency [8]. The loudspeaker's rated impedance, resonant frequency, etc., can also be obtained from the impedance curve of the loudspeaker [7]. To make it easier for speakers to cope with different frequencies, some speakers are connected to impedance converters, such as transformers, that adjust the impedance to match the speaker to the audio source. Of course, converters also impact sound quality, so their performance needs to be analyzed and considered.

3.4 Frequency Response

From the speaker's impedance curve, it can be known that the actual impedance of the speaker usually changes with the frequency. The frequency characteristic of the loudspeaker means that when the frequency of the input electrical signal voltage changes, the impedance of the corresponding component will also change so that the sound pressure generated by the loudspeaker will change with the change of the input voltage frequency of the loudspeaker [8]. Understanding the impedance and frequency characteristics of the loudspeaker can help analyze the frequency response of the loudspeaker. Frequency response is a key factor affecting sound quality because it affects sound balance and accuracy. Generally, the speaker's impedance is large at low frequencies, so the attenuation of the electrical signal at low frequencies is greater than that at high frequencies. In the case of low frequency, the sound will appear thicker, and in the case of high frequency, the speaker's power is relatively high. It can be seen from the relationship between the speaker frequency response and the speaker impedance curve that the lower limit of the speaker frequency response curve is the resonant frequency on the impedance curve, and the small peak in the high-frequency region of the impedance curve corresponds to the high-frequency peak of the speaker frequency response curve [7]. The loudspeaker designer must know the maximum power that each can handle by examining the loudspeaker's impedance curve and frequency response.

4. Summary

Harmonic distortion mainly determines the sound quality of the loudspeaker. Many factors lead to harmonic distortion of the loudspeaker, such as the influence of the uneven magnetic field of the magnet mentioned earlier and the interference of the external magnetic field will affect the force on the voice coil. Due to the limited technical level of the loudspeaker at the time of production, the choice of magnetic materials may also affect the harmonic distortion. The conversion process of the loudspeaker from electricity to sound is nonlinear, which increases the confounding of harmonics, resulting in the poor sound quality of the loudspeaker [8]. Therefore, when designing and using these devices, the characteristics of the magnetic circuit system need to be considered to ensure that the sound quality reaches the required level. Any unevenness, interference, or variation can negatively affect sound quality, requiring proper analysis and control. In general, due to the nonlinear behavior of the internal components of the loudspeaker, the sound quality of the loudspeaker is closely related to the impedance of the circuit. Impedance matching, analysis of impedance curves, and understanding of frequency response can all help design speakers with better sound quality. Speaker manufacturers also typically provide information about speaker impedance characteristics to help audio engineers and users better understand and optimize sound quality[9,10].

5. Conclusion

Research shows that there are many factors related to speaker sound quality. When designing a speaker, the choice of the composition structure of the speaker, the external environment when the speaker is used, and the interaction of the internal components of the speaker will affect the sound quality of the speaker to a certain extent, affecting the audio experience of the speaker user. Because the operation of the internal components of the loudspeaker is nonlinear, the optimization of the loudspeaker has a certain particularity, and the performance improvement of one aspect may lead to the decline of the performance of the other. Optimizing and balancing every aspect of the speaker to present the best effect for the speaker requires the speaker designer's careful decision. This study provides a new view for the designer of loudspeakers, and the future design needs to be optimized based on the characteristics of loudspeaker sound quality.

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