Research progress on human feel test method of Substation low frequency noise

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Abstract. Low frequency noise has the characteristics of slow attenuation, strong penetration and long propagation distance. Compared with other types of environmental noise with the same equivalent sound level, the subjective annoyance of low frequency noise in substation is higher, which easily leads to the problem of public complaints. In order to quantify people's subjective and objective feelings of noise, researchers established the relationship between subjective perception and objective parameters through human perception test. In this paper, the development history of low frequency noise human perception test method and the present situation are investigated, and a feasible human perception test method suitable for substation low frequency noise is put forward.

1. Development History of Human perception Test

The research on the human perception test method of low frequency noise originated in 1960s, when the United States and the former Soviet Union carried out a detailed and rigorous study on the high sound level low frequency noise of aerospace equipment. Subsequently, infrasound has attracted the attention of the public because of its sensational effect, and low-frequency noise has also attracted people's attention. In 1977, Vasudevan carried out field investigation and laboratory human feeling research on complaints of low-frequency noise. In 1978, Challis pointed out that the original noise evaluation method can not be well applied to low-frequency noise. Then Broner began to study and explore the evaluation method of low frequency noise. In 1999, WHO put forward the problem of low frequency noise in social life noise, which made people begin to pay attention to the low frequency noise pollution around them.

In addition to low frequency characteristics, substation noise also shows strong tone characteristics. For the subjective annoyance of low frequency noise with tonal components, researchers obtained many useful conclusions through different experiments. Landstrom studied the relationship between subjective annoyance of low frequency, intermediate frequency, high frequency noise and exposed sound level and tone composition in different workplaces. The results show that the influence degree of tone on subjective annoyance is affected by noise frequency characteristics and sound pressure level, and under the same B weighted sound pressure level, The noise with tonal components is more
troublesome, and the subjective annoyance increases with the increase of tonal components. Jeon tried to improve the indoor sound quality by changing the noise spectrum of air conditioning noise. It was found that the subjects preferred sounds without tonal components, and the sounds with higher energy at 250–630 Hz were more acceptable. However, the research of Alayrac showed that for substation noise with 100 Hz and its harmonic frequency, the subjective annoyance of substation noise with high sound energy at 100 Hz at the same A sound level is lower.

In 1978, Broner and Leventhall measured the personal annoyance functions of 20 subjects using 10 kinds of low frequency noise as sound sources. In the study, they hypothesized the psychophysiological function as a simple energy function by \( \Psi = k \varepsilon^\beta \). where, \( \psi \) is the psychophysiological evaluation, \( \varepsilon \) is the stimulation intensity, \( \beta \) is the subjective significant index. The results show that the range of individual index is 0.045–0.400. In 1987, Meller studied the isometric annoyance curves of pure tones with frequencies of 4 Hz, 8 Hz, 16 Hz, 31.5 Hz and 1000 Hz, and the subjective annoyance obtained by marking them on the axis of the line. It can be seen that the low frequency sound can only be heard when it is maintained at a high sound level, and once it can be heard, its annoyance will increase rapidly with the increase of sound pressure level. The results showed that when the subjective annoyance increased from 0 to 150, the pure sound pressure level of 4 Hz increased to 10 dB, and the pure tone of 8 Hz and 16 Hz was 20 dB, 31.5 Hz increased to 40 dB. In recent years, the research on low frequency noise effect, evaluation method and its control technology has become a hot research topic in the field of environmental acoustics and noise control at home and abroad.

2. Present situation of Human perception Test method

There have been a lot of research on subjective and objective perception test methods and prediction models of low frequency noise at home and abroad. The related studies show that the equivalent continuous A sound level (L\(_{Aeq}\)) and loudness (N) all underestimate the subjective annoyance of low frequency noise to a certain extent, in addition to L\(_{Aeq}\) and loudness, many other acoustic characteristics of noise are also important factors affecting the subjective annoyance of low frequency noise. The psychological effects of L\(_{Aeq}\) with the same and other characteristics may be significantly different. Alayrac studied the subjective annoyance of some industrial noise sources, including transformer noise, analyzed the relationship between noise subjective annoyance and L\(_{Aeq}\), loudness level LN, \( I_{A,1/3oct,100Hz} \) (excluding the A sound level of 1/3 times frequency band at 100Hz), and considered that \( I_{A,1/3oct,100Hz} \) is suitable for evaluating the subjective annoyance of noise with 100Hz as the main frequency component. The linear regression model is as follows:

\[
I_{A,1/3oct,100Hz} = 10 \log(10^{0.1L_{Aeq} - 0.0L_{A,100Hz}})
\]

From the psychoacoustic point of view, Zwicker and Fastl establish a nonlinear calculation model of noise subjective annoyance based on the psychoacoustic parameters such as loudness (N), roughness (R), sharpness (S), sloshing (F) and so on, as shown below. The psychoacoustic annoyance (PA) calculated by the model has no upper limit. In addition, many scholars use psychoacoustic parameters to establish multiple linear regression models for predicting sound pleasure or annoyance.

\[
PA = N_5 (1 + \sqrt{w_S^2 + w_{FR}^2})
\]

\[
w_S = \begin{cases} 
(S - 1.75) \cdot 0.25 \log(N_3 + 10) & S > 1.75 \\
0 & S \leq 1.75 
\end{cases}
\]
In order to quantify people's subjective and objective feelings of sound, researchers proposed some single-dimensional and psychoacoustic measures to describe the characteristics of sound, such as Loudness, Roughness, Sharpness, Fluctuation and so on. When these indexes are mentioned, for different sounds, as long as the Jury Testing is used to compare the numerical values of these indexes, the specific subjective feelings of the corresponding sounds can be judged. There are several commonly used analysis methods, which need to choose the appropriate methods according to the actual problems in practical application.

Ranking method is one of the most convenient methods in subjective evaluation. The listener was asked to compile a set of numbered sound samples (1, 2, 3... n) sorted by several different indicators (such as preference degree, annoyance degree), and sound samples are played continuously. The number of sound samples evaluated by sequencing method is relatively small, and about 6 sound samples are generally used. For the samples number is large, the sorting work will be very complicated because of different arrangement and combination. The main drawback of this method is that it can not give a relative measure, it just draw a conclusion that sound A is better than sound B, it can obtained the result of how much better. Therefore, the results of sorting method can not be used to compare with the objective evaluation results. Sorting method is usually used to evaluate the final results of several sound designs.

Paired Comparison method, also known as AM comparison method, is to play sound samples in pairs, according to which the listener makes related comparative evaluation. By comparing the two kinds of signals, the human ear can distinguish the small differences between the two auditory events. However, human hearing can not obtain absolute sound level, loudness and other parameters, but according to sound events to form their own reference sound image, so as to compare the heard sound with the reference sound. Therefore, comparative comparison is relative evaluation, not absolute evaluation, listeners can make evaluation without scruples, suitable for those who have no experience. The disadvantage of pairwise comparison method is that when there are more samples, the number of comparisons is more, which can easily cause the fatigue of evaluators. Moreover, correlation analysis often contains multiple variables, and the number of evaluators needed to obtain the accurate coefficient of multiple regression analysis is also large.

Scoring is a common method, which uses objective score to record the different responses of listeners to sound. The listener should comment on the sound heard within the range of the set score (such as 0~10). In the evaluation, the sound samples are played sequentially and cannot be replayed. Therefore, this method is characterized by simplicity and rapidity, and the scoring results can be obtained directly. However, for the lack of experience, it will be difficult for untrained listeners to achieve satisfactory results. Its main shortcomings include that the subjective numerical evaluation is almost impossible to compare with the objective evaluation results. Only the influence trend of the two can be obtained, and the use of this evaluation method will cause difficulties for the untrained subject, and the objective factors of the evaluator should be taken into account when using it.

Semantic differential method is to let the listener use some adjectives to evaluate the sound samples subjectively. These adjectives are often pairs of polar adjectives (a pair of adjectives with opposite meaning), such as heavy-light, smooth-rough, strong-weak and so on. Put them on each side and use some metric evaluators, five, seven or more. The listener can choose one from the above table to represent his or her feelings. This method can be used on many occasions, and the effect is often good, very suitable for those who are inexperienced and untrained. Polar words are used to describe the polar outline of noise. For different types of noise, semantic adjectives must be specially designed and verified by subjective evaluation.

3. Experimental Design of Human perception of low Frequency noise in Substation

The accurate expression of human feelings is the key to the success of this study. There are many
factors related to the results of human perception test, and the choice of each factor will directly or indirectly affect the results of human perception test. How to ensure the reliability of the test data and how to truly reflect the subjective feeling of the subjects to the low frequency noise of the substation are the key and difficult points.

In order to solve the above difficulties, human experiments will be designed from test conditions, test systems, test methods and test parameters. First of all, with regard to the experimental conditions, the study will ensure that the background sound level of the human sensory test is not higher than that of the 20dB (A), volunteers with normal hearing (63, 125, 250, 500, 1000, 2000, 4000 and 8000Hz hearing threshold should not exceed 20dB); For the test signal, the real sound and artificial synthetic sound of low frequency noise in substation are classified according to voltage level or equipment type, and the local resonance frequency caused by the structure of human ear canal is adjusted in the test system. For the test system, the high fidelity playback system will be used to ensure the consistency of the test signal playing. For the subjective evaluation test method of human perception, the subjective evaluation methods, including multi-sample grouping method, grade scoring method, psychology, cognition, emotion difference analysis, blind test and non-blind test contrast test, will be studied in order to understand the influence of subjective evaluation method on human feeling and determine the relevant test parameters. The general implementation steps of human perception test are as follows:

The substation noise samples with different voltage levels (500kV and above) are obtained by using the artificial head data acquisition system, and the 5 s of each sample which is least interfered by other noise is intercepted as the experimental sample. In order to make the subjective annoyance evaluation results of different subjective evaluation experimental groups comparable, substation noise samples were grouped, and several pink noise were added as reference sound samples to calibrate the experimental results within the group. The loudness of the reference sound samples was set from small to large, and the loudness level range was between the minimum loudness and the maximum value of each group of sound samples, and all the sound samples were randomly sorted three times.

In order to reach out to the elderly, middle-aged, young-aged and young-aged groups, the subjects were asked to have normal visual acuity or normal corrected visual acuity by recruiting volunteers (1:1 male/female ratio, 10 to 70 years of age, initially according to 300 to 500 persons) to the local volunteer associations. Before the experiment began, the subjects were asked to read the relevant experimental instructions carefully, and the experimenter explained the experiment process and matters needing attention to the subjects. After each sound sample had been played, the subjects evaluated the degree of annoyance of the sounds they heard using the 11-level digital scale, where "0" means "no trouble at all" and "10" means "extreme trouble".

In order to verify the evaluation results of noise annoyance based on listening experiment, the annoyance evaluation based on social acoustics survey is carried out in a small range. Typical substation noise sampling points (including substation plant boundary, environmental sensitive target and representative equipment) were selected as site noise evaluation points, and volunteers (male to female ratio 1:1, age 10~70 years old) were recruited as respondents. The respondents needed to evaluate the noise annoyance at each site noise evaluation point.

The questionnaire of noise annoyance can be divided into four parts. First part is the basic information of the respondents, including sex, age, occupation, educational level, living time and so on, Second part is the investigation area acoustic environment related problems, including the most important sound source in the surrounding environment, whether the substation and the equipment can be seen around the place of residence. The third part is the subjective attitude of the respondents to the sound environment related problems in the survey area, including the degree of noise annoyance, noise sensitivity, the influence attitude to the substation environmental landscape and the overall attitude to the substation, and the fourth part is the interference of noise to the sleep of the respondents and the self-reported health status of the respondents. Most of the questions in the questionnaire (such as the degree of noise annoyance) were rated 5 descriptive scales. Noise at the evaluation point of synchronous sampling during investigation.
Spearman correlation analysis was used to analyze the correlation between related factors and the degree of noise disturbance, sleep disturbance and so on, and chi-square test was used to check whether there was significant difference in the percentage of noise disturbance population in different sound level groups. Taking the basic information (sex, age, living time), noise sensitivity, attitude to substation environmental landscape, overall attitude and outdoor sound level as independent variables, whether they were annoyed by substation noise as dependent variables, logistic regression analysis was used to screen the independent variables which had significant influence on substation noise annoyance. Hosmer-Lemeshow test was used to test the goodness of fit of logistic regression model. P > 0.05 showed that there was no significant difference between the model data and the observed data, and the fitting effect of the model was good. When P < 0.05, there was significant difference in double tail test.

4. Conclusion
The accurate expression of human feelings is the key point for the success in the study. There are many factors related to the results of human perception test, and the choice of each factor will directly or indirectly affect the results of human perception test. How to ensure the reliability of the test data and how to truly reflect the subjective feeling of the subjects to the low frequency noise of the substation are the key and difficult points. In this paper, the research and development history of low frequency noise human perception test method and the present situation at home and abroad are investigated, and a feasible human perception test method suitable for substation low frequency noise is put forward.

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