Study on inductive method of vibration normalized spectrum of equipment on the communication tower

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Abstract. In today's society, communication is becoming more and more important. However, communication equipment is subjected to the vibration caused by wind in communication tower for a long time. In this paper, the inductive methods of vibration normalized spectrum for the equipment on the tower are introduced. Combined with the characteristics of communication tower, based on the current national military standards and some related papers, the random vibration environment data from communication tower can be inductive and processed. The energy distribution of the spectrum is compared with that of the European standard. The measured spectrum by induction is used in engineering tests, it also has laid a foundation for improving the reliability of the relevant equipment on the communication tower.

1. Introduction

With the development of communication technology, as an important carrier of communication equipment, communication towers have been developed and established in various regions. As the communication tower is outdoors for a long time, the vibration environment will affect the communication equipment installed at the top of the tower, and the communication will inevitably be interfered, such as the antenna installed at the top of the tower, RRU and other equipment. In order to examine and improve the safety performance and structural reliability of the equipment under different wind vibration environments, the appropriate vibration environment spectrum is compiled, the data is applied to the vibration environment test, and the actual vibration environment is simulated by using the shaking table, which is of great significance to the reliability research of the equipment installed on the top of the communication tower.

In the early vibration test, the experimental magnitude was concluded from the measured data of the product, and then the reference spectrum was obtained by summarizing it. Due to the lack of sufficient data resources, they are often processed and summarized according to the data of a type of product. The inductive reference spectrum is lack of pertinence, and there is a big difference with the actual working environment, and can’t effectively evaluate the working condition of the product under the actual situation. Then, according to the measured data in MIL-STD-810D, the corresponding reference spectrum of random vibration test was formulated in China. At present, the relevant vibration environmental specifications and standards include: international commercial IEC 60721 series standards and national environmental conditions GB/T 2423, military equipment of the United States military standard IL-STD-810F and the national military standard GJB 150A-2009[1].

In order to improve the stability and reliability of the communication equipment installed on the top
of the tower, it is necessary to process and summarize the vibration environment data. In accordance with GJB/Z 126-99 "Methods of Summing up the Measurement Data of Vibration and Impact Environment" and the data characteristics of communication tower, as well as the relevant manuals of data processing, the author proposes a method of data processing and summing up for random vibration environmental test data of communication tower based on different wind speeds[2-3].

2. Acquisition of vibration data
In order to make the data universal, 32 stations are set up in the country for data collection. The vibration sensors are arranged at the two connections of the pole with the antenna, one up and one down. In order to accurately test the vibration of the communication equipment, the wind speed and direction sensor is installed at the top of the antenna pole to test the level of the wind force received by the antenna, as shown in Figure 1. The sampling frequency was set as 1000Hz, and the vibration was collected twice a day for 10 minutes each time. The vibration was obtained by collecting data in three directions of X, Y and Z. Figure 2 shows the time-domain signal of sample data after DC removal, and the frequency-domain signal, which shows the frequency band range of the energy distribution.

3. Preprocessing of vibration data
Before data processing, the original data should be tested for periodicity, stationarity, normality and ergodic properties in order to meet the requirements of data analysis and processing[4].

Figure 1. the Sensors on the Tower.

Figure 2. Time Domain & Frequency Domain.
3.1. Eliminating abnormal signals
First of all, the signal should be visually checked for abnormal phenomena. Sometime the signal abnormality caused by equipment reasons, like an impact signal significantly larger without damping attenuation process[5]. Those needs to be removed as abnormal data.

3.2. Data inspection
Firstly, normal test is carried out on the data. QQ graph is a commonly used normal test method. The quantile of the standard normal distribution is the abscissa and the sample value is the ordinate. The scattered points in the QQ graph are approximately near a straight line, indicating that the data conform to normal distribution, Histogram is another normal test. As can be seen from the figure, the distribution of sample amplitude approximately follows normal distribution as shown in Figure 3.

![Figure 3. Data Inspection.](image)

4. Induction of vibration environmental spectrum

4.1. Parameter hypothesis estimation of measurement data
After analyzing the sample data, the corresponding PSD was obtained as $\tilde{G}_k(q)(q=1, 2, \ldots, Q; k=1, 2, \ldots, N)$, where $Q$ is the number of simples, $N$ is the number of line spectrum. The frequency band is divided according to the distribution of characteristic sample PSD along the frequency axis.

4.1.1 Parameter Estimation. $x_k(q)$ is given as (1), transform $\tilde{G}_k(q)$, which is considered to be normally distributed. According to equation (2), we can get the mean $\overline{X}_k$ and variance estimates $S_k^2$ of the samples $x_k(q)$.

$$x_k(q) = \sqrt{\tilde{G}_k(q)}(k = 1, 2, \ldots, N; q = 1, 2, \ldots, Q)$$  \hspace{1cm} (1)

$$\overline{X}_k = \frac{1}{Q} \sum_{q=1}^{Q} x_k(q) \quad (k = 1, 2, \ldots, N)$$  \hspace{1cm} (2)

$$S_k^2 = \frac{1}{Q-1} \sum_{q=1}^{Q} [x_k(q) - \overline{X}_k]^2$$

4.1.2 Hypothesis Testing. Statistical parameter $F(k, k+1)$ and $t(k, k+1)$ can be calculated as equation (3). Assuming that the PSD of the adjacent spectral lines $k$ and $k+1$ of the feature samples belong to the same population, then $F(k, k+1)$ obeys the F distribution with ($Q-1, Q-1$) degree of freedom, and $t(k,k+1)$
obeys the central T distribution with \( 2(Q-1) \) degree of freedom. Under the given confidence coefficient \((1-\alpha)\), if equation (4) is true, then the hypothesis is true. The PSD of the adjacent spectral lines \( k \) and \( k+1 \) of the samples belong to the same population; otherwise, they do not belong to the same population.

The adjacent spectral lines belonging to the same population are merged in the same frequency band to form \( H1 \) frequency band. The spectral line numbers of the two endpoints of the \( h \) frequency band are \( k_h1 \) and \( k_h2 \) \((h =1, 2, \cdots, H1)\), and the number of spectral lines is \( N_h = kh2-kh1+1 \). \( \sqrt{G_h(q)} \) in the same frequency band are approximation to obey normal distribution.

\[
\begin{align*}
F(k, k + 1) &= \frac{S_k^2}{S_{k+1}^2} \\
t(k, k + 1) &= \frac{X_k - X_{k+1}}{\sqrt{S_k^2 + S_{k+1}^2}} (k = 1,2,\cdots, N)
\end{align*}
\] (3)

\[
\begin{align*}
F_{\left(\frac{Q-1}{Q}, \frac{Q-1}{Q}\right)} \leq F(k, k + 1) \leq F_{\left(\frac{Q-1}{Q}, \frac{Q-1}{Q}\right)}: \frac{Q-1}{Q} \leq t(k, k + 1) \leq t_{2\left(\frac{Q-1}{Q}\right)}
\end{align*}
\] (4)

4.2. Estimation of the normalized spectrum

4.2.1 the Factor of upper tolerance limits. According to equation (5), we can get the mean \( \bar{X}_h \) and variance estimates \( S_h^2 \) of the samples \( x_k(q) \) in the same frequency band \( H \).

\[
\begin{align*}
\bar{X}_h &= \frac{1}{Q \cdot N_h} \sum_{q=1}^{Q} \sum_{k=k_{h1}}^{k_{h2}} x_k(q) \\
S_h^2 &= \frac{1}{Q \cdot N_h - 1} \sum_{q=1}^{Q} \sum_{k=k_{h1}}^{k_{h2}} (x_k(q) - \bar{X}_h)^2
\end{align*}
\] (5)

According to equation (6), the factor of upper tolerance limits \( F_{12} \) with confidence coefficient of \((1-\alpha)\) and quartiles of \( \beta \) was calculated.

\[
F_{12} = \frac{\sqrt{Q \cdot N_h - 1}}{Q \cdot N_h} + Z_\beta \frac{\sqrt{Q \cdot N_h - 1}}{\bar{X}_h \cdot F_{12} \cdot S_h^2}
\] (6)

4.2.2 Estimation of upper tolerance limits. The estimation of the upper tolerance limits of the sample \( G_h(q) \) in frequency band \( h \) is given by the formula (7).

\[
G_h = [\bar{X}_h + F_{12} \cdot S_h^2] (h = 1,2,\cdots, H1)
\] (7)

In log-log coordinates, the adjacent flat spectra obtained by equation (7) are connected by straight lines to obtain the random vibration specification spectrum \( G \) under vibration environmental conditions with confidence coefficient of \((1-\alpha)\) and quartiles of \( \beta \). Then the normalized spectrum is obtained through the envelope with the line, shown as Figure 3. At present, the spectrum in ETSI EN300 is usually used in the random vibration test of communication equipment, but this spectrum is the universal spectrum of communication equipment\[7\]. Due to the low natural frequency of the tower, through comparison, it is found that the measured spectrum energy is mainly concentrated in the frequency band of 5-10Hz, which is consistent with the reality.
5. Conclusion
According to the characteristics of the communication equipment on the tower, the corresponding vibration normalized spectrum is summarized. The energy distribution of normalized spectrum obtained by the method in this paper is closer to the reality. Using the normalized spectrum, the reliability of the product can be improved effectively by random vibration test.

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