Research on Vibration Test in Urban Indoor Substation

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Abstract. The problem of vibration and noise of urban indoor substations has become more and more socially concerned. The urban indoor substation of 110kV and its conjoined buildings were taken as the research object and the vibration tests of the transformer and each floor slab were respectively carried out. The sound vibration characteristics and sound transmission rules of the urban indoor substation were obtained through the time-frequency analysis and coherence analysis of the test data. The vibration spectrum of transformer body was mainly 100Hz together with its multiplying factors and the vibration characteristics of the floor slab were basically the same as those of the transformer body. It is crucial to control the vibration and noise transmission in the equipment floor of the urban indoor substation.

1. Introduction
The ultra-high voltage substations have been established in large cities across China and some of them even under residential buildings. The noise of power transformation equipment can be transmitted through space and buildings, and then transmitted in the proximate space within the residential buildings, which has affected the residents’ life, caused the residents to complain constantly and become highly socially concerned[1][2]. The urban indoor substation of 110kV, 220kV and even higher voltage classes have been numerous established in cities such as Beijing, Shanghai and Xi’an etc. across China, which has caused out of limits in environmental impact assessment on vibration and noise of some substations[3][4].

The floor slab vibration and indoor noise of building structures caused by operation of urban indoor substations must be considered during construction and operation of substations. Therefore, the urban indoor substation of 110kV and its conjoined buildings were taken as the research object so as to conduct field test of vibration as well as coherence analysis in the transformer room of substation and reinforced concrete composite floor slab in each floor. The test and analysis of the structural vibration of the relevant urban indoor substation concluded in this paper can provide a reference for the future design of structural vibration control in substations.

2. Test Plan of Vibration of Urban Indoor Substation

2.1. Overview of Substation
The urban indoor substation of 110kV was put into operation in January 2005. It was the secondary voltage load station of 110kV/10kV, designed and installed with 3 sets of main transformers with unit capacity of 50MVA. It was seamlessly built with the office building of one company. The mixed structure of steel-concrete frame was adopted as the building structure. The underground part had two
floors in which the basement floor 1 (B1) included the cable inter-layers. The basement floor 2 (B2) included a ventilator room, an electric reactor room, a capacitor room, and a warehouse etc. the over-ground floor 1 included 3 main transformer rooms (skip-floor F1-F3) and a switch gear room. the over-ground floor 2 and 3 included GIS rooms mainly. The over-ground part of the building included 8 floors (F4-F8) of office area with floor height of 3.8m and total building height of 31.6m. Figure 1 shows the layout plan of the first floor.

2.2. Sound Vibration Test and Arrangement of Test Points

The vibration of the urban indoor substation went through a field test so as to get hold of the vibration level as well as frequency spectrum characteristics in main functional areas such as the transformer room and GIS room. For this purpose, the following test contents were conducted according to the structural layout of the urban indoor substation and conjoined buildings.

The main vibration and noise source within the substation came from 1#, 2# and 3# main transformer rooms located in the first floor. The test points of vibration were arranged in transformer oil tank wall surface, transformer foundation, ground surface and wall. The vibration level in the main transformer room was tested. Two cross sections were set around the transformer in each main transformer room and then tested. Figure 2 shows the layout plan of test points in the main transformer room, in which ◆ represents the only vibration test point in the floor slab. ▲ represents the test points of vibration and noise of simultaneous acquisition in floor slab. and ● represents the test points of oil tank wall and wall vibration.
The test points of vibration were set up in each floor slab so as to control the vibration characteristics of floor slab in the building structure. The key task was to analyse the coherence test of transformer vibration response so as to further obtain the vibration transmission routes and attenuation rules of the building structure. In addition, for locations such as corridor, passageway, and equipment room, the test points of vibration were selectively set up on the floor slab and wall to test the vibration level and analyse the frequency spectrum characteristics.

Totally 173 vibration test points were arranged in the test of urban indoor substation. In addition, multiple vibration transmission channels were set up in each set of main transformer. The coherence between different test points and vibration source of main transformer in each floor were investigated. The acquisition equipment was the 24-bit network-distributed acquisition instrument of YSV8016 type with sampling frequency of 6400Hz. The acceleration sensors of YA-22 and YSV2303S types as well as sound pressure sensor of YSV5001 type were adopted for vibration probes.

3. Analysis on Test Results of Transformer Sound Vibration

Because 1# and 2 main transformers belong to the same type, this paper only analyses the relevant test data of different test points in 1# and 3# main transformer rooms. Figure 3 shows the layout map of test points in 1# main transformer room. The vibration acceleration was collected from the transformer oil tank wall, foundation, indoor floor slab and wall. The basic characteristics of indoor vibration of transformer room could be obtained through the time-domain analysis of signals and Fourier spectrum analysis. In order to represent the vibration level, the vertical Z-vibration level is defined as follows:

$$La = 20 \log \frac{a}{a_0} (dB)$$  \hspace{1cm} (1)

In which, $a$-Effective value of accelerated speed (root mean square value), $a_0$-Take $10^{-6}$m/s$^2$ as reference value.

Select several key test points from vibration transmission lines in 1# and # 3 main transformers to analyze the vibration data. Figure 3 shows the test site of the 1# main transformer. Figure 4 and Figure 5 show the time domain of key test points and spectrograms in 1# and # 3 main transformers respectively.

**Fig. 3 Test Site of 1# Main Transformer**
The analysis of the above Figure 4 and Figure 5 shows:

(1) There are regular attenuation on vibration amplitude in vibration transmission paths of the main transformer, including the decrease of vibration frequency amplitude and decrease of frequency spectrum composition.

(2) The main transformer body has the largest vibration amplitude and the 1# and 3# main transformers have relatively close vibration amplitudes. The vibration amplitude in floor slab of the main transformer room is slightly reduced. It can be seen from the spectrum of vibration signals that the two spectrum ranges are the closest.

(3) The vibration amplitude in the lower B1 floor slab of the main transformer is significantly higher than that of in the upper floor of the main transformer. This shows that the upwards-transmitted energy attenuation of the vibration is relatively higher. Further analysis is made in the subsequent paragraphs of this paper based on the floor change rules.
Table 1: Vibration Amplitude and Z Vibration Level in Test Points of 1# Main Transformers

| NO. of Test Point | Effective Value (m/s²) | Vibration Level (dB) | 100Hz Z Vibration Level (dB) | Test Point Position                        |
|------------------|-------------------------|----------------------|-----------------------------|--------------------------------------------|
| XG_F1V60         | 0.084                   | 98.82                | 64.26                       | 1# main transformer body (vertical ground) |
| XG_F1V61         | 0.054                   | 94.59                | 73.32                       | Floor slab in 1# main transformer          |
| XG_B1V10         | 0.019                   | 85.76                | 64.13                       | B1 floor slab in 1# main transformer       |
| XG_F4V9          | 0.032                   | 70.21                | 46.22                       | Floor slab right above 1# main transformer |

Table 1 shows the vibration acceleration amplitude and Z vibration level in the test points of 1# main transformers. It can also be obtained that the vibration amplitude in transformer body is the largest in the main transformer room. The ground vibration amplitude in the adjacent floors decreases and the influence of vibration transmitted to the lower floor slab is higher than that of the upper floor slab.

Figure 6-7 show the cross-power spectrum and coherence function of vibration signals in body vibration V60 and the adjacent test points. It can be found that the correlation coefficient is quite high and can reach above 0.9 and even 0.99. This means the coherence between the signals is good and there is a causal relationship on the transmission path, namely, the vibration of each point comes from the
vibration excitation of the main transformer. The test points on the vibration transmission paths of the main transformer have the same change rules, which are not repeated here.

4. Conclusion
The following conclusions can be obtained through testing and analysing the vibration in the urban indoor substation of 110kv and conjoined structure. Through analysing the test data of vibration correlation within the main transformer room, it can be found that the correlation coefficient in the test points of vibration transmission paths can reach at least 0.9 and most can reach 0.99, which indicates that the data signals tested from B1 to F2 almost entirely come from the vibration excitation of the main transformer. Frequency component is also consistent and the frequency range focuses on 100Hz-500Hz.

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