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Investigation on Noise Pollution Comprehensive Treatment of Distribution Transformer in Living Area

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Abstract: In the current paper, which deals with the noise pollution excited by distribution transformers in the living area, a comprehensive treatment scheme is put forward for the purpose of reducing the sound pressure level emitting into the environment. In accordance with the associated test standard, the sound pressure levels of distribution transformer and surrounding environment are not only tested but analyzed as well. The measurements were carried out with the frequency analysis of the 1/3 octave resolution, with the center frequencies at 125 Hz, 250 Hz, 400 Hz, and 500 Hz. As illustrated, on the basis of the measurement results, the frequency of noise at 500 Hz of distribution transformer causes the major noise pollution in the surrounding environment. This measurement result is in line with the noise frequency characteristics of distribution transformer. There are two transmission routes of noise: i) the noise excited by distribution transformer transmits by means of the wall of distribution room, and ii) part of noise spreads through the ground of distribution room. Accordingly, acoustic shield and vibration isolation device are applied for the reduction of the low frequency noise emitted through the above two paths. Aimed at applying the appropriate acoustic material and vibration mounting, the evaluation of the noise reduction and vibration absorption is carried out in accordance with the sound and vibration insulation theory. Following the noise treatment, the transformer and environment noise are measured again. The corresponding findings shed light on the fact that the sound level satisfied the requirement of limits of the ordinance. The proposed noise treatment scheme can be applied to the existing power distribution facilities for controlling the sound levels that reach a point where it is comparatively more unobjectionable.

Keywords: Acoustical enclosure; distribution transformer; noise pollution; treatment; vibration isolation pad

1 Introduction

Recently, in both the large and medium sized cities of China, for the limited land resources, increasing numbers of power distribution facilities are installed in either the first floor or the cellar of residential buildings. Thereafter, the vibration of distribution transformer transmits into resident families through the building structure, for instance, ground and wall, accordingly resulting into the annoying noise. The strict limits of government ordinance require distribution facilities to emit the low-level noise at each working frequency [1]. That is why it is deemed as quite urgent to develop the low-noise transformers or put forward some strategies for the effective reduction of vibration and noise of the existing distribution facilities.

In the foregoing investigation, some possible research and design methodologies of low noise transformer are discussed. They include the utilization of low magnetostriction core steel, in addition to the reduction of the operating flux in core, the usage of sound panels mounted on transformer tanks, and the application of low noise cooling system [2]. In [3], a novel accurate calculation methodology of vibration for power transformer by the FEM is put forward that has the potential of guiding the design of low noise transformer. In [4], the acoustic property and the soft magnetic property in distribution transformer with the amorphous alloy core are discussed and analyzed comprehensively.

Nonetheless, for the existing transformer substations, it is quite difficult to replace the transformer with the low-noise distribution transformer only when its lifespan ends. Also, the associated research has revealed the fact that a transformer is likely to have significantly different acoustic characteristics on-site versus that is measured in the factory [5, 6]. Speaking otherwise, the distribution transformer is capable of exciting the excessive noise on-site, despite the fact that the test of noise level is successfully passed in factory. Also, as reported, the sound pressure level of distribution transformer emitting into the environment is not constant but variates continually during a many-year operation of the electrical apparatuses installed at the power substations [7]. To summarize, investigating the reducing noise of distribution transformers emitting into the environment on-site is of engineering significance.

In the present paper, a comprehensive noise pollution treatment scheme, which applies acoustical enclosure and vibration isolation pad, is put forward. Moreover, the structure and parameters of enclosure and isolator are not just evaluated but selected appropriately. By means of the on-site noise level measurement at factory boundary and noise-sensitive building following the noise treatment, the noise emission values during both day-time and night-time satisfy the associated noise emission standard in China.

2 Problem Description

With regard to the specific analysis case, a 10-kV integrated distribution room locates in the first floor of residential building. In the integrated distribution room, three 630 kVA dry-type distribution transformers are in charge of the power supply for all of the residential areas. Recently, the inhabitants of this building have indicated that there is observed humming noise as the transformers are operating. Accordingly, the noise source treatment project is required to be carried out.

2.1 Structure of Distribution House

The layout of distribution facilities in the distribution room is presented in Fig. 1. The transformer model is termed as SCB9-630kVA/10. The cooling mode is AN/AF. The production and run time are in the month November, 2002.

2.2 Background

In the first half year of the year 2018, the inhabitants, who resided this building, complained that there was annoying noise emitted from distribution room, in particular, during the night time. The complaining user lived in the upper stair of distribution house. The relative position of the user's house and distribution room is presented in Fig. 2.

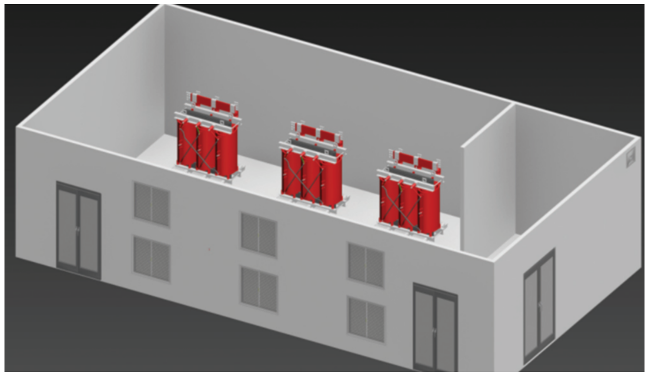


Figure 1: Layout of distribution room

Figure 2: Specific position of resident family and distribution room

3 On-Site Test and Analysis of Noise Level

For the purpose of capturing the primary sources of noise pollution, the measurement of the noise level on both noise-sensitive building and factory boundary (around the distribution room) is carried out.

3.1 Related Test Standard

In China, the maximum permissible noise levels at factory boundary and in noise-sensitive room are stipulated by the national government. The upper limits of noise emission during the daytime and night time are 55 dB and 45 dB, correspondingly.

With regard to the upper limit of noise in the noise-sensitive buildings, when the distance between factory boundary and building is below 1 m, the corresponding noise limit should be 10 dB lower as compared with that put forward in the factory boundary standard.

3.2 Measurement Method

The distribution transformer, factory boundary, and noise-sensitive building noises are measured through the use of the below instruments. The sound pressure level is measured using a meter type of B&K2250, made by the B&K Company. The device deals with taking the measurements of noise level with the accuracy that corresponds to Class I and for a frequency analysis of the signals in the band 1 Hz-20 kHz. A B&K4231 calibrator, which is made by B&K, is applied for calibrating the measuring instrument.

For safety reasons, the prescribed contour is spaced 1 m away from the principal radiating surface. For the height being smaller than 2.5 m, the prescribed contour is placed on a horizontal plane, which is located at the half height of transformer [8]. The level of sound pressure under investigation is measured at three measuring points (points #1, #2, and #3) distributed in front of the three transformers, which is presented in Fig. 3. The measurements of noise emitting into the environment by transformers under operation are taken for 20 seconds.

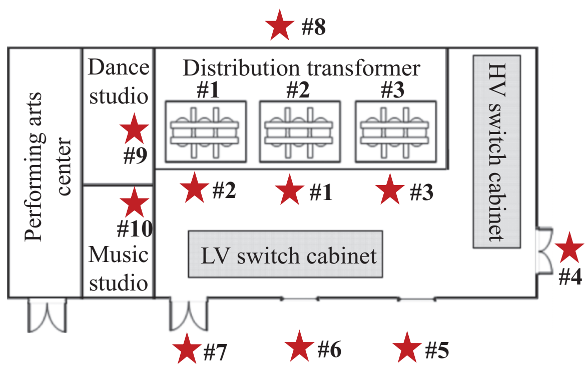


Figure 3: Layout of detecting plane

In accordance with the associated national standard in China, the factory boundary noise emitting into the environment by the transformer should be measured simultaneously. The corresponding distribution of measuring points (points #4, #5, #6, #7, and #8) is presented in Fig. 3.

The noise generated by transformers is likely to be transmitted through ground or wall, subsequently giving rise to noise in other rooms of the same building again. In this case, the dance studio and music studio of performing arts center are situated near the distribution room. That is why two test points are arranged in these two rooms, which are marked as #9 and #10 in Fig. 3.

3.3 Measurement Results

The noise level of three distribution transformers is measured in the distribution room, at factory boundary, and in noise-sensitive rooms, with the help of the sound pressure method. The measurement is carried out with A-weighted sound pressure level and 1/3-octave band.

Near distribution transformers, the measured noise level is between 60.3 dB and 63.75 dB. In addition, the 1/3-octave band spectrum is presented in Fig. 4. In accordance with the results, the peak values appear at

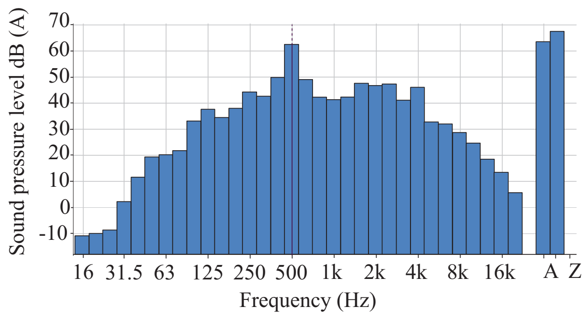


Figure 4: Frequency spectrum of noise measured 1 m away from transformer #1

125 Hz, 250 Hz, and 500 Hz, correspondingly; the maximum sound pressure level takes place at 500 Hz. In accordance with the analysis, the load noise of transformer makes primary contribution to these frequencies. It is created by the interaction of the leakage flux in the winding with winding current and augments with the load increment.

With regard to the test points #4 - #8, the measurement of boundary noise level is carried out during daytime and night time. The measurement results are listed in Tab. 1. During the daytime, the test values of all of the test points are qualified. Nevertheless, during the night time, except #8, the measurement values at the rest four points (points #4, #5, #6, and #7) are not qualified on the basis of the associated stipulation. The maximum noise excessive reaches 4.7 dB(A) at #4. As indicated by 1/3-octave band spectrum at position #4, the peak sound level appears at 500 Hz.

Table 1: Measurement of factory boundary noise

Measure point	Noise intensity dB(A)		Remarks
	Night	Day	
Limits	45	55	/
#4	49.6	52.4	Night excess
#5	48.6	51.2	Night excess
#6	47.3	53.3	Night excess
#7	47.7	52.5	Night excess
#8	43.2	50.3	Qualified

Aimed at checking the noise pollution level in noise-sensitive rooms, the measurement of the sound pressure levels of point #9 and #10 is carried out during the daytime and night time, whereas the measurement results are illustrated in Tab. 2 and Tab. 3, correspondingly. All through the daytime, the measured sound level is qualified at the entire frequency band. Nevertheless, during the night time, the noise levels are not qualified at 250 Hz and 500 Hz.

Table 2: Noise of sensitive spots during night time Unit: dB(A)

Point	L_{Aeq}	Frequency spectrum (Hz)					Remarks
		31.5	63	125	250	500	
Limits	30	69	51	39	30	24	/
#9	**34.6**	47.4	46.4	37.6	**32.0**	**33.5**	Not-qualified
#10	**33.1**	45.2	40.5	35.3	29.2	**31.5**	Not-qualified

Table 3: Noise of sensitive spots during daytime Unit: dB(A)

Point	L_{Aeq}	Frequency spectrum (Hz)					Remarks
		31.5	63	125	250	500	
Limits	40	76	59	48	39	34	/
#9	38.7	55.2	50.3	43.3	36.9	33.8	Qualified
#10	37.6	54.2	52.1	40.1	33.2	32.8	Qualified

4 Scheme Design of Noise Reduction

As evident from the measurement results presented above, the primary noise pollution sources are the three distribution transformers in distribution room. The impacting mechanism of noise pollution can be classified into two paths as hereunder:

1. Through air and wall, the transformer noise is transmitted into room of resident family.
2. The noise is excited by vibration. The vibration of distribution transformer disseminates through floor and wall to resident family. The air is excited by ground and wall again so that the noise is excited.

4.1 Evaluation of Noise Reduction and Vibration Absorption

For the purpose of designing the suitable sound insulation device, it is deemed as quite essential to access vibration absorption, together with evaluating noise reduction. In the course of measurement, just distribution transformer #2 is under operating condition. When all of the distribution transformers are in service simultaneously, there exists the maximum noise level. In accordance with the superposition principle of sound level, the calculation of the overall noise level can be made as hereunder:

$$L_p = 10\lg\left(\sum\nolimits_{i=1}^{N} 10^{0.1L_{pi}}\right) \quad (1)$$

where L_p indicates overall noise level, L_{pi} presents noise level from i-th individual noise source, and N denotes the number of noise sources.

In accordance with the investigation, the maximum equivalent noise level is approximately 67.5 dB and the peak value at 500 Hz is approximately 64.3 dB. In a bid to satisfy the noise emission requirement, the required noise reduction is illustrated in Tab. 4.

Another technique employed in the noise reduction is reducing transmissibility of vibrations of the transformers to ground, accordingly causing the lower ground and wall vibrations as well as sound radiation. The connections between clamping structure of transformer and ground should be designed for the provision of the effective vibration isolation. The vibration insulation efficiency (η) is adopted for the measurement of the vibration isolation capability. It is defined as hereunder:

Table 4: Estimator of noise reduction (SRI- sound reduction index)

No	Operating state	SRI(LA)/dB	SRI (500 Hz)/dB
1	Current state (1 transformer)	25	22
2	Max. noise source (3 transformers)	30	27

$$\eta = (1 - T_A) \times 100\% \tag{2}$$

where T_A denotes the transfer coefficient of excited force. The smaller value of T_A corresponds to the better vibration isolation capability. It refers to a function of the frequency ratio and damping ratio, whose expression is

$$T_A = \frac{\sqrt{1 + 4\varepsilon^2\lambda^2}}{\sqrt{(1-\lambda^2)^2 + 4\varepsilon^2\lambda^2}} \tag{3}$$

where $\lambda = f/f_0$ indicates the frequency ratio of transformer excited frequency (f) and natural frequency (f_0) of the entire system, ε denotes the damping ratio between damping coefficient of vibration isolation device and critical damping of the entire system.

Overall, in engineering applications, the optimal frequency ratio is between 2.5 and 5, whereas the optimal damping ratio lies between 0.05 and 0.2.

With regard to this case, the vibration level along vertical direction generated by transformer is quite small. That is why, as the analysis presented above suggests, once the insulation efficiency is larger than 80%, the requirement can be met.

4.2 Scheme of Noise Reduction

The underlying objective of the noise pollution treatment for this case is summarized as hereunder:

1. The noise level at factory boundary should be reduced to 45 dB at night and 55 dB at daytime;
2. The noise level at factory boundary at 500 Hz should be decreased by approximately 42%;
3. The vibration level of distribution transformers at 500 Hz should be decreased to approximately 20% of the original value.

Aimed at satisfying the stringent limits of the noise emitting quota, the application of the sound panels, sound enclosures, and vibration isolation device is made. These additional structures typically attain a substantial decline in not only transformer noise but also vibration. The sound enclosure includes soundproof door, sound boarding, soundproof window, and muffler. The overall structures both before and after the treatment are demonstrated in Fig. 5.

A single open door that has a soundproof window is applied so that the distribution transformer operating condition could be observed easily. The wall of sound enclosure is constructed by sound boarding and the associated parameters for the soundproof door and sound boarding are illustrated in Tab. 5.

(a)

(b)

Figure 5: Picture of distribution room before and after treatment. (a) Before treatment. (b) After treatment

Table 5: Performance parameters of soundproof door and sound boarding

Item	Performance parameters	
	Soundproof door	Sound boarding
LA average noise reduction	40 dB	38 dB
Noise reduction (500 Hz)	30 dB	30 dB
Fire-protection rating	B1	B1
Hydrophobicity	85%	85%
Life span	Over 20 years	Over 20 years
Ventilated area	1.5 m^2	–

Nonetheless, the application of acoustic enclosure is represented as less favorable for thermal and field maintenance considerations. Accordingly, cooling fans are deemed as essential for the improvement of the heat dissipation generated by transformers. The six cooling fans are installed on the top of the sound enclosure as presented in Fig. 6. In addition, the noise from additional cooling fans is typically decreased through the selection of the low-speed fans and the fans with sound-absorbing elements at the inlet and outlet both. Tab. 6 lists the associated related parameters.

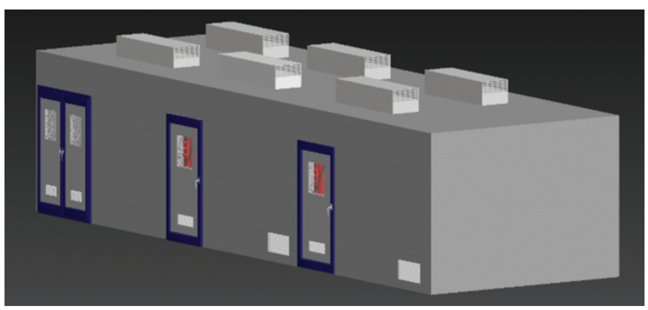


Figure 6: Sketch of acoustical enclosure

Table 6: Performance parameters of cooling fan

Item	Parameter	Remarks
L_A noise reduction	40 dB	/
Ventilation	2000 m^3/h	20 times/h
Fire-protection rating	B1	/
Life span	Over 20 years	/

Considering the duty type, together with the operating environment, and noise frequency band of distribution transformers, damping spring isolators are adopted. The load, natural frequency, and damping ratio of the selected damping spring isolator are 700 kg, 3 Hz, and 0.075, correspondingly. In accordance

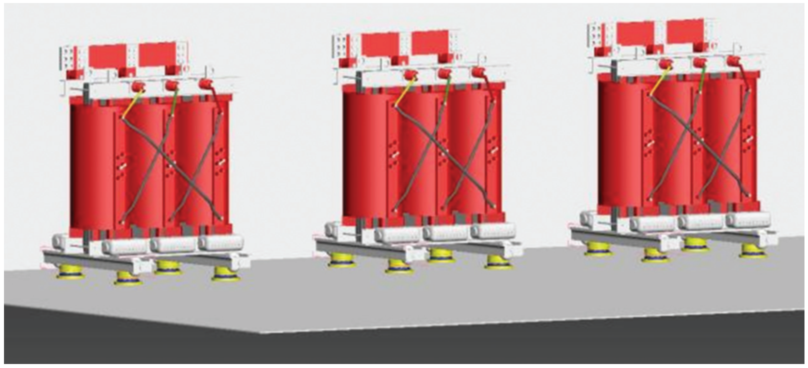


Figure 7: Absorber arrangement on transformer lampstand

with above parameters and the parameters of the transformer, the transfer coefficient (0.059) and vibration isolation efficiency (94.1%) can be evaluated by (2) and (1), respectively. Furthermore, the calculated vibration isolation efficiency is way better as compared with the required value, which is calculated from Section 4.1. Each distribution transformer weighs approximately 2000 kg. In this manner, four isolators for one transformer are considered as essential, whereas the isolators require symmetric installation on the basis of the force balance. The effect drawing of installation is demonstrated in Fig. 7.

5 Comparison of Treatment Effect

The values of sound pressure levels that take place around the distribution room (#1-#12) under this treatment are measured in the same manner. All through the measurement, only #1 transformer is under operation, referring to the same condition as earlier.

5.1 Noise Level Around Transformer

The distribution of measuring points is demonstrated in Fig. 3. Subsequent to the comprehensive treatment, the noise level out of the sound enclosure is approximately 50 dB. The noise level declines by approximately 10 dB. Figs. 8(a) and (b) indicate the measured frequency spectra before and after treatment, correspondingly. As evident from the frequency spectra, the noise level at 500 Hz has been decreased from 62 dB to 38 dB. It is illustrated that the proposed noise treatment scheme has the potential of lowering the noise level of this frequency band.

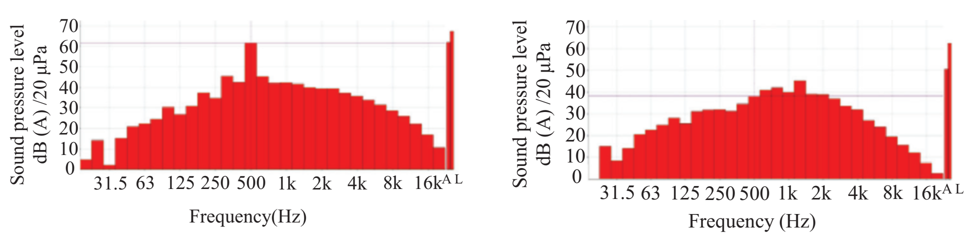


Figure 8: Noise spectrum comparison of points 1 m away from main transformer before & after noise treatment. (a) Before treatment. (b) After treatment

5.2 Noise Level at Factory Boundary

In accordance with the previous measurement results, during the night time, the noise levels at the test points #4-#7 are not qualified on the basis of the associated standard. Following the treatment, the same

Table 7: Measurement of factory boundary noise

Measurement spot	Limit	L_{Aeq} (dB) Day/55[1]	Night/45	Remarks
# 4	Before[2]	52.3	49.6	Not-qualified
	After[3]	49.3	43.8	Qualified
# 5	Before	52.1	48.6	Not-qualified
	After	48.4	44.0	Qualified
#6	Before	53.3	47.3	Not-qualified
	After	40.1	43.8	Qualified
#7	Before	52.5	47.7	Not-qualified
	After	48.3	44.1	Qualified
Background	Before	49.2	43.1	Qualified
	After	48.2	43.3	Qualified

[1] Category 1 functional area based on GB12348-2008 (Emission standard for industrial enterprises noise at boundary).
[2] The data is handled by background value revision based on GB12348-2008.
[3] The data is unhandled by background value revision.

measurement procedure is carried out and the measurement results are illustrated in Tab. 7. The noise levels of all of the measuring points are controlled in a reasonable level.

5.3 Noise Level in Noise-sensitive Room

In the noise-sensitive rooms (dance studio and music studio), the measurement of the 1/3-octave band spectrum of noise is carried out at the test points #8 and #9 during the night time. Fig. 9 and Fig. 10 shed light on the comparisons.

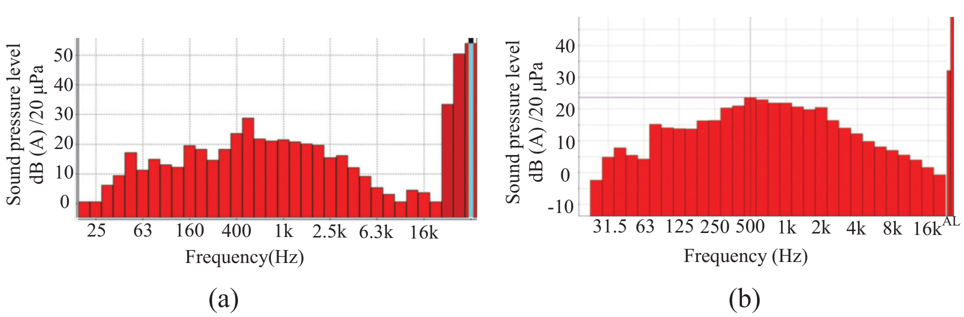
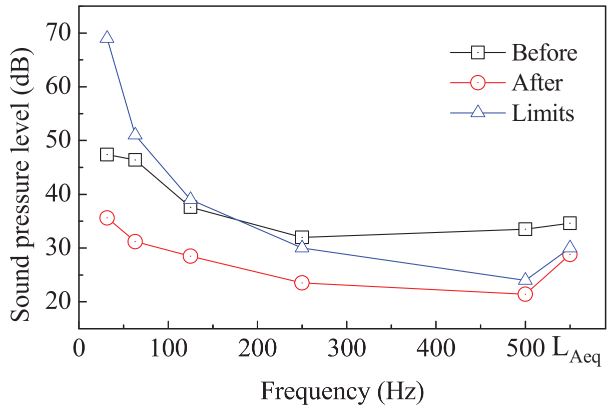
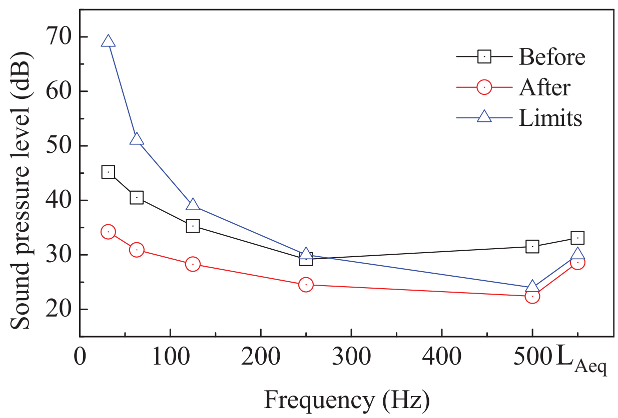


Figure 9: Night noise spectrum comparison of sensitive points (#8) before & after noise treatment. (a) Before treatment. (b) After treatment



(a)



(b)

Figure 10: Comparison of noise measurement for sensitive points (Night). (a) Point #8. (b) Point #9

6 Conclusion

The current paper puts forward a noise pollution comprehensive treatment scheme for the existing distribution room in the living area. The key achievements of this treatment effort are summarized as hereunder

1. As the sound absorption and vibration isolation theory puts forward, the evaluation of the reduction of noise and vibration is carried out. Both the acoustic enclosure material and vibration isolators are selected in a proper manner.
2. In accordance with the measurement results before and after the treatment, the equivalent noise level can be attenuated significantly at all of the test points.
3. In the course of the measurement, the 1/3-octave band spectrum of noise is recorded and the noise level at 500 Hz is weakened through the introduction of the suitable vibration isolator.

Even though the proposed noise treatment scheme is only applied to a specific actual case, the solution itself can be extended to the other existing distribution facilities as the noise level emitted into the environment is not qualified.

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