Araştırma Makalesi / Research Article

Kuru Tip Trafoların Çevresel Gürültü ve Titreşim Seviyelerinin Değerlendirilmesi ve Çözüm Alternatiflerinin Belirlenmesi: İstanbul Durum Çalışması

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Öz
Günümüzde evlerde kullandığımız cihazlardan, endüstride gerçekleştirilen kompleks üretim faaliyetlerine kadar enerji ihtiyacı her geçen gün artış göstermektedir. Artan enerji ihtiyacıyla birlikte elektriksel donanımlara olan ihtiyaç da artmaktadır. Enerji iletim ve dağıtımının temeli olarak niteleyebileceğimiz güç transformatörlerinin de kullanım alanlarında bu kapsamda artış görülmektedir. İyi bir elektrik altyapısı bağlamında düşünüldüğünde transformatörlerin sayısı kadar konumu da önem arz etmektedir. Yapılan çalışmada; güç transformatörlerinden kaynaklanan çevresel gürültü ve titreşimin, transformatörün yerleştirildiği binadaki insanlara olan etkisinin belirlenmesi ve bu etkinin azaltılmasına yönelik alınabilecek önlemlerin ortaya konmasına çalışılmıştır. Elde edilen veriler değerlendirildiğinde, transformatörden kaynaklanan çevresel gürültü ($L_{gece(kaynak)}$=65 dBA) ve titreşimin (1-3.15 Hz aralığı) Çevresel Gürültünün Değerlendirilmesi ve Denetimi Yönetmeliği'nde gürültü (L_{gece}= 55 dBA) ve titreşim için belirlenen sınır değerleri aştığı ve azaltılması gerektiği belirlenmiştir. Bu kapsamda Marshall Day Acoustics Firması tarafından üretilen INSUL Versiyon 6.2 Programı kullanılarak transformatörün konumlandırıldığı hacimde çevresel gürültü ve titreşimin azaltılması için gerekli yalıtım çalışması projelendirilmiştir.

Anahtar kelimeler: Insul, Gürültü, Transformatör, Titreşim.

Evaluation of Environmental Noise and Vibration Levels of Dry Type Transformers and Determination of Solution Alternatives: Istanbul Case Study

Abstract
Today, energy requirements are increasing day by day, from the devices we use at home to the complex production activities that are carried out in the industry. The need for electrical equipment is also increasing with increasing energy requirements. The use of power transformers, which can be specified as the basis of energy transmission and distribution, also increases in this scope. When it considered in the context of good electric infrastructure, location of the transformers is as important as the number of transformers. In this study; environmental noise and vibration originated by the power transformer located in the building and measures to be taken were determined in order to determine and reduce the environmental effect of the transformer on the people. When obtained data was evaluated, it was determined that the environmental noise ($L_{night(source)}$=65 dBA) and vibration (1-3.15 Hz range) caused by the transformer exceeded the noise (L_{night}= 55 dBA) and vibration limit values given in the Environmental Noise Assessment and Management Regulation and reduction required. In this context, by using INSUL Version 6.2 Program produced by Marshall Day Acoustics Company, insulation work was performed to reduce environmental noise and vibration in the volume where the transformer was located.

Keywords: INSUL; Noise, Transformers, Vibration.

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Geliş Tarihi: 29.01.2019, Kabul Tarihi: 01.07.2019

1. Introduction

One of the significant problems that seriously threaten people's environment and physiology is environmental noise [1-3]. Noise is defined as an unpleasant, unwanted, disturbing sound [1-4]. Nowadays, increases in rapid industrialization and therefore mechanization, increased traffic load due to widespread highways, increased prevalence of airway transportation and intense activities of construction make noise is a significant environmental problem [5-7]. Environmental noise is not only a phenomenon that is related to the sense of hearing, but it is also known that individuals who are exposed to noise are physiologically and psychologically affected, and their bodily balance is disturbed [8].

In order to reduce the negative effects of environmental noise on those who are exposed and achieve limit values that are indicated in legislation, it is needed to develop ergonomic methods. For this purpose, it has become a necessity for industrialists to develop and implement noise control systems [9-10].

Today, activities such as industry, transportation and construction cause vibration in addition to noise. The vibration that originates from the sources mentioned above and spreads through solid, flued and gaseous environments is defined as mechanical oscillation movements that are felt in the human body [11].

While vibration creates physical and psychological distress in people, there are also useful practices related to it in terms of structural analyses in civil engineering [12]. Due to their use in power systems, noise levels of transformers have become important topics of research. In the literature, the sources of noise in power transformers are discussed under 3 different main categories as "Core Noise", "Load Noise" and "Fan and Pump Noise." Dry Type transformers are preferred as they are relatively more environment-friendly and practical [13].

While transformers are functioning, they may lead to vibrations in their environment based on their location and usage capacity.

In order to prevent transformer-based noise and vibration from affect human health and equipment safety, the reasons for these should be accurately determined and relevant solutions should be produced. There are domestic and international standards that have been created towards determining noise that happens/might happen in transformers. In the time period of this study, it was observed that the standards IEC 60076-10 and IEEE Std. C57.12.90 were being used for determining noise levels, and the standard TS EN 60076-10 which is based on these two standards was active in Turkey.

While there is no standard for bringing an upper limit to restrict noise that originates from transformers, it is needed to achieve the limit values that are defined in the Directive for Analysis and Inspection of Environmental noise that was effective during the course of the study in the residential areas that are affected by transformer-based environmental noise and vibration [11]. In addition to this, regarding the levels of noise that disturb people, the effects of noise on human health are defined by the standards TS 9315 ISO 1996-1/T1 and TS ISO 1996-2/T1 [14-16].

2. Study Area

In the scope of the study, the noise and vibration effects of a transformer that was installed into the ground floor of a building on the residents were determined, and insulation project planning was carried out to reduce these effects. Because, especially people who had been living upstairs of the transformer in that apartment complained about noise and vibration of the transformer at night time.

The characteristics of the dry type transformer that was examined for its noise and vibration effects in the scope of the study are given in Table 1.

Table 1. Characteristics of the examined transformer

Characteristic	Unit	Value
Power	kVA	2000
Primary Voltage	kV	36/0.40
Type	-	Dry Type
Year of Production	-	2010
Dimensions (W x D x H)	meter	1.15 x 2.12 x 2.50

The central transformer unit mainly consists of two attached volumes in the ground floor of apartment. The first of these volumes is the low voltage volume on the right side including the control room, and the other volume is the volume on the left side containing the dry type transformer. There is no insulation on the walls of the two volumes. This apartment is reinforced concrete building. Figures 1, 2, 3 and 4 show the appearance of these volumes from inside and outside.

Figure 1. The transformer center from outside

Figure 2. Transformer center from inside **-**1 (control room**)**

Figure 3. Transformer center from inside **-**2 (control room)

Figure 4. Transformer center from inside **-**3 (transformer room)

2.1. The Devices and Measurement Standards Used in The Scope of The Study

The measurements were carried out with a Svan 958A 4-channel portable noise and vibration analyzer and based on the provisions of the standard "TS ISO 1996-2: Definition and Measurement of Acoustic-Environmental Noise, Part 2, Obtaining Data Regarding Noises in Field Usage – Description, Measurement and Analysis of Acoustic-Environmental Noise" [17].

2.2. Transformer Center Noise and Vibration Measurements

A detailed measurement process was carried out in compliance with the Environmental Noise Assessment and Management Regulation (ENAMR) in order to determine the effects of the transformer in enclosed and open spaces in its close proximity in terms of noise and vibration. In order to determine human exposure, all noise measurements were made at a 1.5 height from the floor [11]. The measurement process lasted from 23:00 at night to 06:00 in the morning. Device automatically gave the minimum and maximum noise levels and also calculated the equivalent noise level which defines the total sound energy over the 7 hours measurement period.

In the first part of the study, while the transformer was not working, measurements were made to determine the background noise, in front of the transformer center, outside in the bedroom of the apartment that is located about 3 meters above the ground right over the transformer center where the transformer noise is felt the most in the same building. The background noise measurements when the transformer was off are given in Table 2.

Table 2. Environmental noise measurements when the transformer was off (dBA) (background)

No	Measurement Point	Min. Noise L_{min}		Eq.Noise L_{eq}		Max. Noise L_{max}	
		(dBA)	(dBC)	(dBA)	(dBC)	(dBA)	(dBC)
1	Next to transformer	47	56	52	60	64	64
2	Bedroom	29	32	31	45	41	62

Results indicate that there was an important variability in terms of backround noise because of the human activities in the street. After determining the background noise, the transformer was turned on. After this, noise and vibration measurements were taken from the same points to determine the increase created in the background noise and vibration levels by the transformer. The results are in Table 3, Figure 5 and Figure 6. Results indicated that transformer had an important negative contribution to noise level.

Table 3. Environmental noise measurement results (dBA and dBC) (transformer is on)

No	Measurement Point	Min. Noise L_{min}		Eq. Noise L_{eq}		Max. Noise L_{max}	
		(dBA)	(dBC)	(dBA)	(dBC)	(dBA)	(dBC)
1	Next to transformer	64	64	65	70	66	71
2.1	Bedroom	38	51	41	52	59	75
2.2	Bedroom	42	52	42	53	54	66
2.3	Bedroom	43	52	43	53	47	47
2.4	Bedroom	43	52	44	52	46	55

The bedroom where the measurements were taken from was defined as an area of "very sensitive usage" based on ENAMR Article 4 and Clause r. So, the measurement results that show the distribution of the noise measurements in cases where the transformer was on and off based 1/3 octave band analysis are given below. This way, it is possible to see the frequency ranges that contribute the most to the increase in the levels of background noise and should be eliminated by insulation. (RMS indicates the noise standard deviations for each sound tonnes)

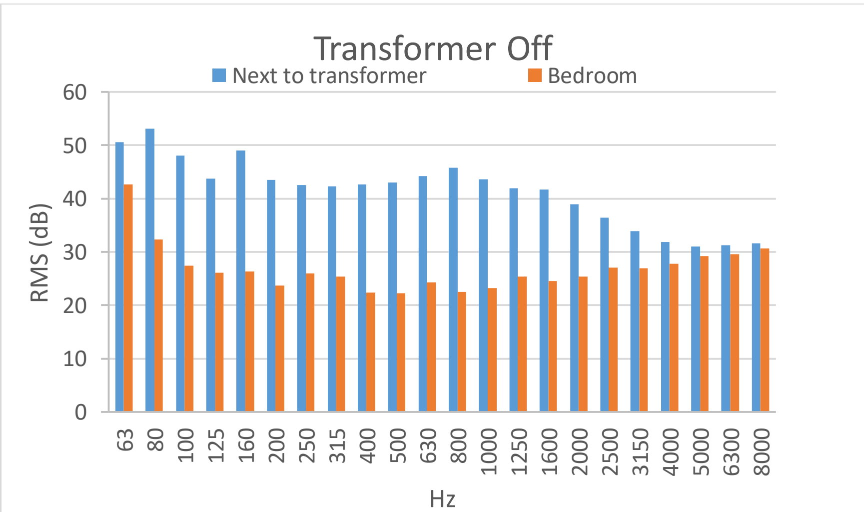


Figure 5. Environmental noise measurements based on 1/3 octave analysis (transformer off)

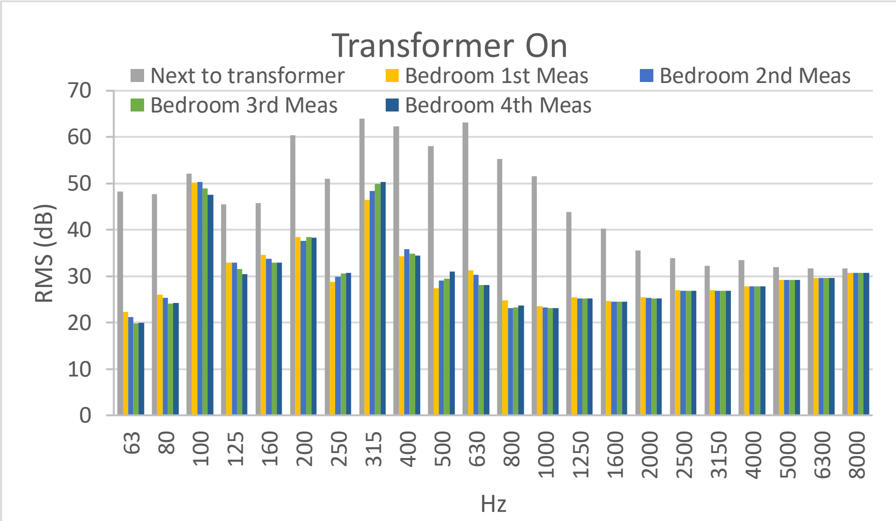


Figure 6. Environmental noise measurements based on 1/3 octave analysis (transformer on)

According to Figure 5 and 6 it was seen that most significant sound tones were 315-400 and 630 Hz in terms of noise pollution related with the transformer. When it was on most important contribution to the noise came from these tones.

Considering the background measurement when the transformer was off and the measurements when it was on, the L_{night} values of the measurement points were calculated (Table 4). This value is the average A-weighted long-term sound volume energy that is used to express a night-long discomfort that causes lack of sleep. The values are given in the Table 4.

Table 4. The L_{night} values for the noise levels outside

Parameter	**Unit**	**Measurement Point**
		Next to the Transformer
L_{night} (background)	dBA	52
L_{night} (source)		65

To determine and assess the effects of the transformer in the enclosed environment, 4 vibration rate measurements were made in parallel to the noise measurements in the bedroom, and Table 6 shows the measurement results and limit values based on frequency distributions.

The transformer center, due to its location, is considered to be in the scope of “areas where residential places are prevalent among areas where commercial structures sensitive usage areas are found together” based on ENAMR Appendix-7 Table 4 [11]. In this case, the limit value that needs to be achieved next to the transformer is L_{night}= 55 (dBA). If the measurement results given in Table 5 are compared to the limit value, it is seen that the transformer satisfies the limit value next to it when it is not working, while it does not satisfy this value when it is on.

Regarding interior noise, ENAMR Article 22 Clause b includes the provision “The level of environmental noise, which is transmitted to the environment through air or transferred to sensitive usage areas through shared separation elements, upholster, ceilings or walls from each business, workshop, shop and similar establishments in a way that may affect sensitive usage areas, cannot exceed the background noise level by more than 5 dBA in terms of L_{eq} noise levels” [11].

ENAMR Appendix-7 Table 9 has the provision that: “Regarding the internal noise levels, the L_{eq} = 35 dBA limit values should not be exceeded in the case of closed windows where there is no activity in the usage area” [11].

Table 5 shows that the increase in noise levels was higher than 5 dBA in all measurements in comparison to the background while the transformer was working. Moreover, all measurements were higher than the limit value of 35 dBA.

ENAMR Article 25 Clause c states that: “In buildings that are used as residences or offices, the vibrations to be caused by machinery and equipment such as electric motors, pumps and fans cannot exceed the limit values that are given in Appendix-7 Table-8.

Table 5. Comparison of inside measurements to background values

Parameter	Unit	Measurement Point			
		Bedroom			
		1st Meas.	2nd Meas.	3rd Meas.	4th Meas.
L_{eq}	dBA	41	42	43	44
L_{eq} (background)		31	31	31	31
Increase		10	11	12	12

For the machinery and equipment that exceed these values, the vibrations that are measured in the building are reduced to values below the limit values by taking technical measures, mainly vibration insulation. These limit values are also used regarding the vibrations that will be created in areas of highly sensitive and sensitive usage created by railway and highway transportation vehicles near such areas" [11]. Table 6 shows that the rates of vibration in the frequency range of 1-3.15 occasionally exceeded the limit values, and therefore, the requirements of the regulation could not be achieved. In this sense, it was projected that the insulation alternative to be employed for eliminating inconveniences related to the noise in the source would also eliminate the vibration that occurs at low frequencies and occasionally exceeds limit values.

Table 6. Bedroom vibration rate measurement results (while the transformer was working)

Vibration Frequency (Hz)	Limit Value (mm/s)	Measurement Results for the Bedroom (mm/s)														
		Background			1st Measurement			2nd Measurement			3rd Measurement			4th Measurement		
		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	1.50	2.13	7.31	30.80	3.65	3.33	12.74	0.16	0.16	0.17	0.16	0.16	0.17	0.16	0.16	0.17
1.25	1.46	2.30	6.58	29.82	2.35	2.07	9.66	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.20
1.6	1.40	0.88	1.91	8.94	1.67	0.73	3.64	0.08	0.09	0.09	0.08	0.09	0.09	0.08	0.09	0.09
2	1.33	0.38	0.80	3.84	1.25	0.49	2.66	0.07	0.08	0.08	0.07	0.07	0.08	0.07	0.07	0.08
2.5	1.24	0.27	0.50	2.20	0.98	0.78	2.68	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
3.15	1.13	0.08	0.14	0.61	0.52	0.38	1.76	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
4	0.99	0.09	0.14	0.67	0.39	0.30	0.99	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
5	0.82	0.07	0.09	0.36	0.21	0.18	0.64	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
6.3	0.59	0.03	0.05	0.21	0.13	0.12	0.44	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
8	0.30	0.03	0.04	0.17	0.09	0.10	0.35	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
10		0.03	0.03	0.08	0.05	0.08	0.27	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
31.5		0.01	0.02	0.04	0.03	0.04	0.12	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
40		0.01	0.01	0.02	0.02	0.03	0.08	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
50		0.01	0.01	0.02	0.02	0.02	0.06	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
63		0.01	0.01	0.02	0.01	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
80		0.01	0.01	0.04	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
100		0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

2.3. Insulation Calculations for the Transformer Center

A two-step process was carried out to eliminate airborne noise, structureborne noise and vibrations by insulation work in the transformer.

2.3.1. Controlling Airborne Noise

The design details and mounting schema of the noise panel that is needed to be installed on the ceiling and walls of the transformer center are given in Figure 7.

The loss of sound transmission to be created on the airborne noise that is spread from the transformer center by the projected noise panel design was modelled by using the INSUL Version 6.2 software developed by the firm Marshall Day Acoustics. Its a quick and accurate tool for predicting the sound insulation of walls, floors and ceilings. It has gradually developed into a unique tool that incorporates the best of many research papers published over the last 15 to 20 years.

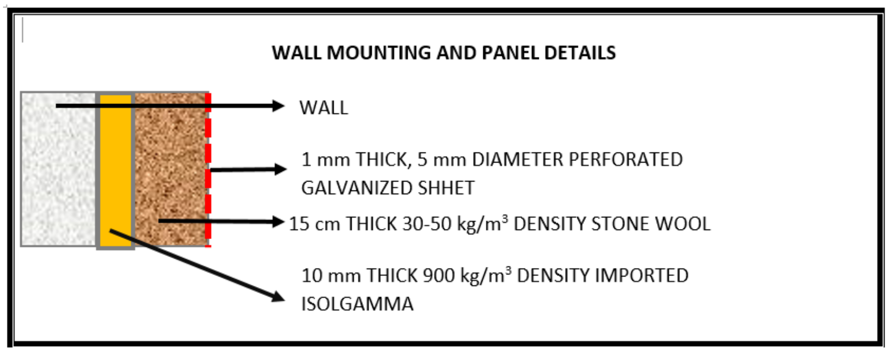


Figure 7. Features of the design that was developed for transformers

The results of the modelling study that was carried out towards the absorption of the components of noise by the panel design are given in Figure 8. By the design to be implemented on the ceiling and internal side walls of the transformer center, it was projected that an average sound transmission loss (noise isolation) level of 62 dB would be achieved depending on the frequency characteristics and the surroundings of the source of the noise according to Insul 6.2.

2.3.2. Controlling Structureborne Noise and Vibrations

Figure 9 shows the details of the design that needs to be implemented in transformer centers with the purpose of controlling the structureborne noise and vibrations that originate from the transformer. The software output of the projects design that shows the transformer-related vibration insulation capacity of the design is shown in Figure 10. According to the modeling software outputs, it was projected that the design to be implemented on the floor of the transformer would achieve 95% insulation. The insulator to be applied was determined as: rubber isolators (MASON EAFM 8852 Green preferred). If the approximate mass of the transformer is taken as 4980 kg, 74 pieces of the insulator needs to be applied.

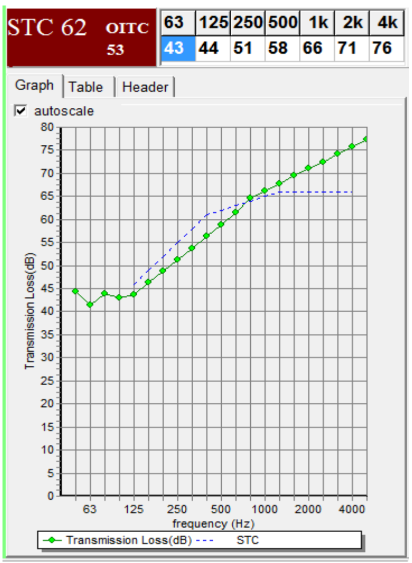


Figure 8. The sound transmission loss characteristics (STC) of the design developed for transformers based on frequency

2.3.3. Controlling Noise on The Ventilation Grills

The last part of the project planning process to be implementing for controlling the noise that spreads from the transformer center towards outside consists of the implementation to be used in the ventilation grills of the transformer center. The detailed drawing of the design to be implemented on the transformer grills is given in Figure 11. With the projected double-grill structure, it was estimated by means of INSUL Version 6.2 that a sound transmission loss (noise) isolation of 26 dB could be achieved depending on the frequency characteristics of the source of the noise and the environment. Sound transmission loss characteristics (STC) of the design developed based on frequency was given at the right side of Figure 11. The width and the height of the grill need to be determined with the aid of manufacturer or implementor during implementation and based on the need for ventilation.

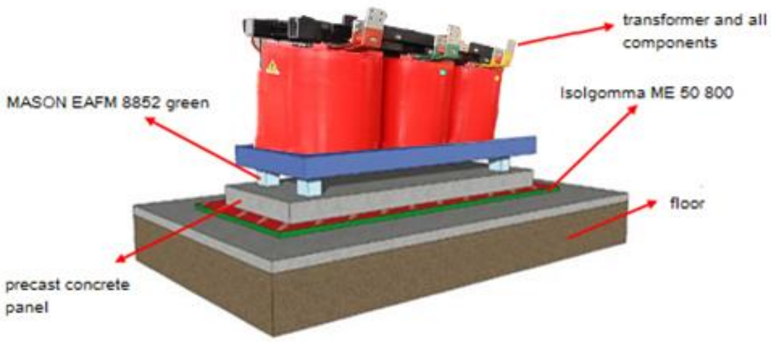


Figure 9. The characteristics of the design developed for transformers

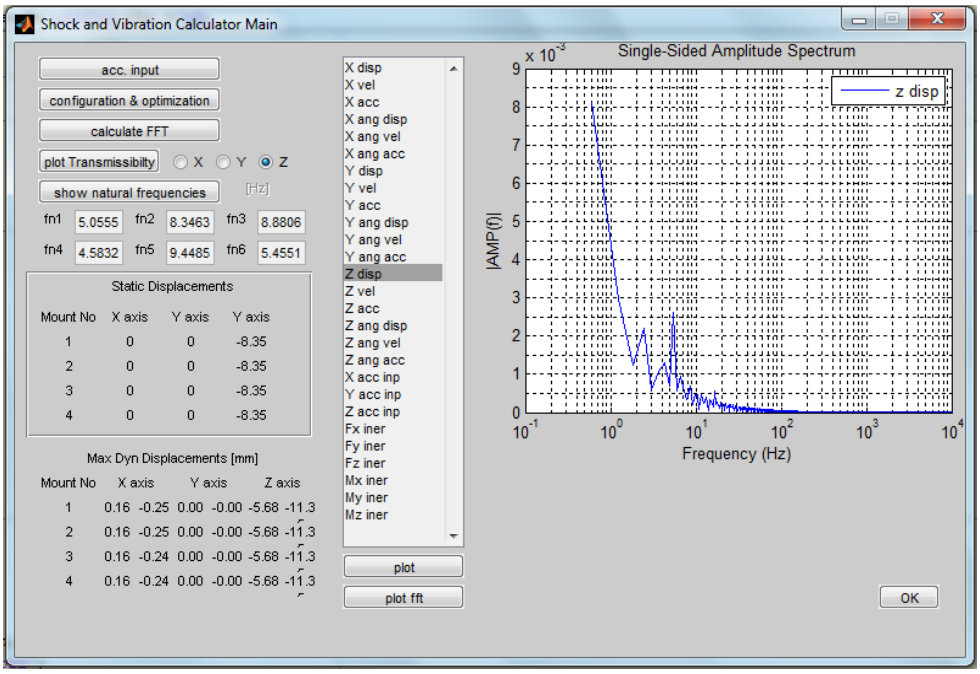
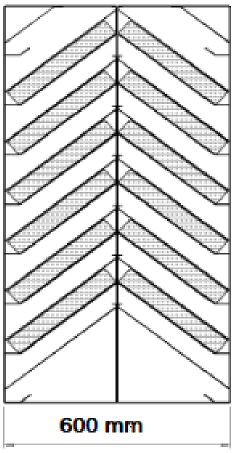


Figure 10. The frequency-dependent Vibration Insulation characteristics of the design developed for transformers



Octave Band Centre Frequency (Hz)

125	250	500	1k	2k	4k	8k
11	13	19	30	32	30	27

STC: 26 dBA

Figure 11. The ventilation grill design that was developed for transformers and the transmission loss (TL) values that in needs to satisfy

3. Conclusions

The study observed the noise and vibration effects of a dry type transformer that was installed into the ground floor of a building that is located in a residential area. The negative effects of building transformers in a residential area and related issues on people's health and psychology should be minimized. Therefore, after determining the effects, an insulation project planning process was carried out to reduce these noise- and vibration-related effects and achieve the limit values stated in the scope of ENAMR. The INSUL Version 6.2 software developed by the firm Day Acoustics was used for project planning.

The project planning process was designed with 2 steps. For the first step, the insulation project to be implemented on the ceiling and interior side walls of the transformer center was planned, and its effectiveness was tested with the help of the software mentioned above. According to the software outputs, it was projected that a sound transmission loss (noise insulation) of 62 dB could be achieved by the design in question depending on the frequency characteristics of the source of the noise and the environment.

In the second step, it was aimed to control the structureborne noise and vibration. As a result of the analysis on the modeling software mentioned above, it was projected that a 95% reduction could be achieved in vibration by using the design. Additionally, it was projected that a noise reduction of 26 dB could be achieved by the precaution to be taken for the ventilation grills on the door of the transformer center.

Consequently, while it is possible to reduce noise and vibration by taking precautions, the most effective solution would be building such equipment with high levels of noise and vibration effects in locations that are far from residential areas and centers that are designated for these.

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