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Stray Magnetic Field around the Transformer

Abstract: Distribution transformers installed in residential buildings should not disturb residents' living comfort through noise, fire hazards and variable magnetic fields. The article presents the results of measurements concerning magnetic flux density having a frequency of 50 Hz in the space around oil-immersed transformers having a power of 1600 kVA, 800 kVA and 100 kVA as well as dry-type transformers having a power of 1600 kVA and 2500 kVA. Oil-immersed transformers generate magnetic induction at the same distance in the space outside the tank, approximately four times lower than that generated by dry-type transformers. Both in terms of oil-immersed and dry-type transformers, induction at a distance of 2 m away from the transformer is at the level of several μT and is approximately 10 times lower than values permissible for human presence. In terms of the variable flux density component of leakage, both oil-immersed and dry-type transformers can be installed in residential buildings.

Key words: distribution transformer, leakage magnetic flux density, measurement of leakage flux density

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1. Distribution transformers installed in residential buildings

Distribution transformers having rated power restricted within the range of 100 kVA to 2500 kVA are installed in urban areas. Transformer stations are installed on poles, in separate buildings or residential buildings. In towns and cities, the medium-voltage grid is cable-based. Transformer stations are located in buildings. In residential buildings, transformer rooms must satisfy the conditions specified in Regulation [1]. The question which arises is concerned with the benefits and risks posed by that situation to tenants.

The advantages resulting from installing transformer stations in residential buildings are the following:

- housing estate looks more aesthetic, without additional small transformer station buildings occupying free space in the estate,
- 400 V power distribution cables to apartments are shorter,
- tenants' apartments adjacent to the transformer station through the wall and ceiling are heated by transformer heat.

In turn, threats to living comfort are the following:

- noise and vibrations,
- in terms of oil-immersed transformers, the possibility of insulation fire,
- variable magnetic fields.

The aforementioned Regulation of the Minister of Infrastructure [1] § 182 governs the location of transformer stations in buildings intended for the permanent residence of humans:

- it is necessary to maintain a horizontal and vertical distance of at least 2.8 m from rooms intended for the permanent residence of humans,
- walls and ceilings should constitute fire divisions and be protected against the penetration of liquids and gases.

In addition, § 96. 1 and § 323 section 2 item 2 state that a technical room containing devices emitting noise or vibrations can be located in the direct vicinity of rooms intended for permanent residence of humans subject to the application of structural and material solutions protecting adjacent rooms against noise coming from systems and devices constituting the technical equipment of the building.

The PN-B-02151-2:2018-01 standard [2] specifies the permissible sound level for residential premises, i.e. 30 dB in rooms during daytime (6 AM–10 PM) and 25 dB at night as well as 35 dB in separate kitchens and sanitary facilities. In certain cases, the standard allows an increase in the sound level by 5 dB.

It is generally known that noise (acoustic waves) is generated by mechanical vibrations.

In the transformer, these vibrations are generated by the sheets in the core, winding and cooling devices. The transformer core is composed of sheets having a thickness restricted within the range of 0.35 mm to 0.2 mm. Micro-vibrations of the sheets in the core are generated by variable magnetic fields, i.e. magnetostrictive vibrations. The magnetostrictive vibration coefficient of the sheets is $\varepsilon \approx 1$ μm/m, whereas the frequency is $2f = 100$ Hz. The above-presented frequency is the fundamental frequency of noise, having harmonics (200, 300 and 400 Hz) with amplitudes decreasing to zero. This is low-frequency noise. The sheets in the core can also vibrate in the core braiding nodes if the core is not well pressed and fastened. If noise in rooms for humans exceeds the values provided in the PN-B-02151-2:2018-01 standard [2], the transformer room should be soundproofed. Other sources of noise are windings with flowing current, located in the stray magnetic field. Under normal transformer operating conditions, electrodynamic forces in the winding are not significant and are compensated by the elements compressing the winding. As a result, the winding is stiffened and does not vibrate. The vibrating winding can destroy the insulation precluding the transformer from lasting until the end of the guarantee period.

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Cooling devices in oil-immersed transformers are radiators. In distribution transformers, the circulation of oil is gravitational; there are no pumps which could generate vibrations and noise.

The risk of oil-immersed transformer fire does exist, yet it is very low. The fire can be triggered by a short circuit inducing arc, leading to the explosion of gases inside the tank. As a result, the tank could leak and the oil could ignite. For the sake of safety, investors often install (in buildings) dry-type transformers with non-flammable insulation.

The article presents the issue of the magnetic field in the space of a distribution transformer. The aforesaid field penetrates rooms adjacent to the transformer. The magnetic field became the subject of interest in the 1980s. In manufacturing plants (steelworks, mines, etc.), transformers and switching stations are located in shops (usually in repair shops). The switching station was located under rooms for electricians. The images on screens at that time were deformed, which drew attention to the magnetic field present in the room and generated by the transformer and the switching station.

2. Measurements of weak magnetic fields

The transformer is surrounded by the earth's magnetic field and the stray magnetic field generated by the transformer.

The earth's field is constant. At the measuring point of the transformer in Mikołów, the earth's field is as follows:

$$H_z = 24\ \text{A/M} \;\widehat{=}\; B_z = \mu_0 H_z = 4\pi\ 10^{-7} \cdot 24 \approx 30\ \mu\text{T} \qquad (1)$$

The stray magnetic field around the transformer is an alternating field having frequency f = 50 Hz. Regulation [4] specifies the permissible levels of the electromagnetic field parameters having a frequency of 50 Hz for areas designated for residential land development, i.e. electric field component $E_{bz} \leq 1000$ V/m and magnetic field component $H_{bz} \leq 60$ A/m.

Fig. 1. Magnetic induction meter: a) obverse and b) reverse

Magnetic induction in air corresponding to H_{bz} is as follows:

$$B_{bz} = \mu_0 H_{bz} = 4\pi 10^{-7} \cdot 60 = 75.36\ \mu\text{T} \qquad (2)$$

Magnetic induction measurements around the transformer which should be performed are at the level of µT. Induction is measured using equipment based on measurement probes, i.e. Hall generators or small coils containing thousands of turns. Hall generators can be used in measurements of both constant and variable induction. The measurement coils measure the magnetic flux penetrating the coil surface. Magnetic induction is determined in the centre of the coil surface. The measurement equipment based on coils has a higher measurement class and it was this equipment that was used in the measurements discussed in the article. The measurement device used in the tests was a TRACER space magnetic induction meter with a probe placed inside, in the area marked with the amplifier symbol. Measurements were performed within the nanotesla and microtesla measurement ranges. Photographs of the meter, i.e. its "obverse and reverse" sides are presented in Figure 1.

3. Magnetic induction distribution around the oil-immersed transformer

The study-related tests concerning the distribution of the variable magnetic induction component in the space around oil-immersed transformers involved transformers intended for installation in residential buildings. The nominal data of the transformers were the following [6]:

- Dyn1, S_N = 1600 kVA, U_{1N} = 22 kV, I_{1N} = 41.99 A, U_{2N} = 400 V, I_{2N} = 2309 A, 50 Hz.
- Dyn1, S_N = 800 kVA, U_{1N} = 11.4 kV, I_{1N} = 40.5 A, U_{2N} = 420 V, I_{2N} = 1099 A, 50 Hz.
- Dyn1, S_N = 100 kVA, U_{1N} = 11.4 kV, I_{1N} = 5.06 A, U_{2N} = 420 V, I_{2N} = 1137 A, 50 Hz.

The magnetic induction measurements were performed on the envelopes around the transformer in two planes, i.e. in the plane passing at half of the tank height and in the plane of the upper cover closing the tank, on the envelope at the radiators and the envelopes which were 0.5 m, 1 m, 1.5 m and 2 m away from the radiators. Figure 2 presents a 1600 kVA transformer with measurement points marked on its radiators. Point "1" is on the left, point "5" is on the right, whereas points "6" to "16" are marked sequentially on the other sides of the radiators in a counterclockwise manner. The measurement results are presented in induction diagrams as a function of distance, where each point on the diagram constitutes the mean (average) of 16 measurement points

$$B_{śr} = \frac{1}{16}\sum_{i=1}^{16} B_i \qquad (3)$$

The measurement of the variable component of background magnetic induction was performed on the envelope near the radiators. The value of the component was restricted within the range of $(2 \div 6)\cdot 10^{-2}$ µT, whereas the mean value amounted to $3.3\cdot 10^{-2}$ µT. The low value of background induction was not taken into account in the measurement results as it had little effect on the measurement results.

In relation to 1600 kVA, 800 kVA and 100 kVA transformers, Figures 3 through 5 present the results of induction measurement as a function of distance for the no-load and short circuit states.

Fig. 2. Measurement points 1–5 marked on the radiator of the 1600 kVA transformer

The highest values of the variable induction component were observed on the envelopes at the radiators at half of the tank height. In relation to the rated current (in the short circuit state), the value of induction did not exceed 50μT. On the envelope, at a distance of 2 m, none of the transformers subjected to the tests was characterised by induction exceeding 1 μT. It should be noted that the value of induction permissible for rooms with humans inside them amounts to 75 μT.

4. Magnetic induction distribution around the dry-type transformer

The tests concerning the distribution of variable magnetic induction in the space around dry-type transformers involved transformers intended for installation in residential buildings. The nominal data of the transformers were the following [5]:

- Dyn5, S_N = 1600 kVA, U_{1N} = 15.57 kV, I_{1N} = 41.99 A, U_{2N} = 400 V, I_{2N} = 2309 A, 50 Hz.
- Dyn5, S_N = 2500 kVA, U_{1N} = 15.75 kV, I_{1N} = 91.64 A, U_{2N} = 420 V, I_{2N} = 3608 A, 50 Hz.

Induction measurement points, located around the transformer, are marked in Figure 6. The distribution of induction

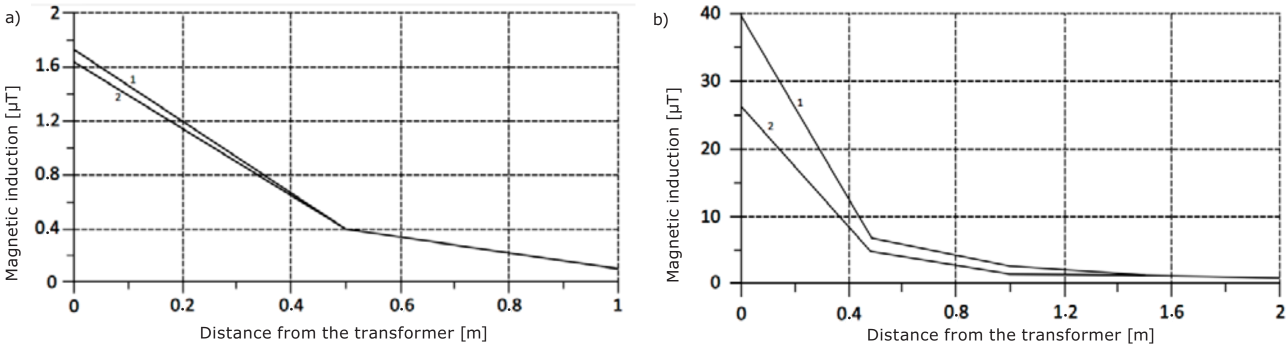

Fig. 3. Induction on the envelopes around the 1600 kVA transformer: a) in the no-load state and b) in the short-circuit state

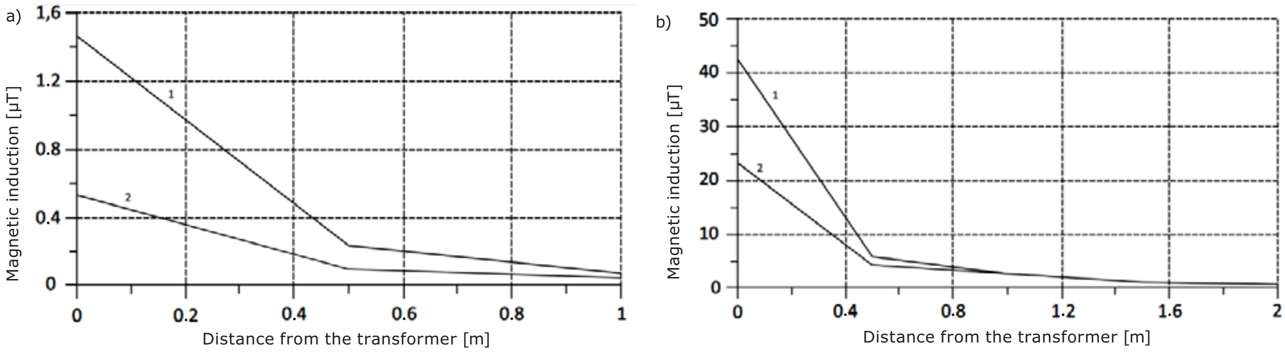

Fig. 4. Induction on the envelopes around the 800 kVA transformer: a) in the no-load state and b) in the short-circuit state

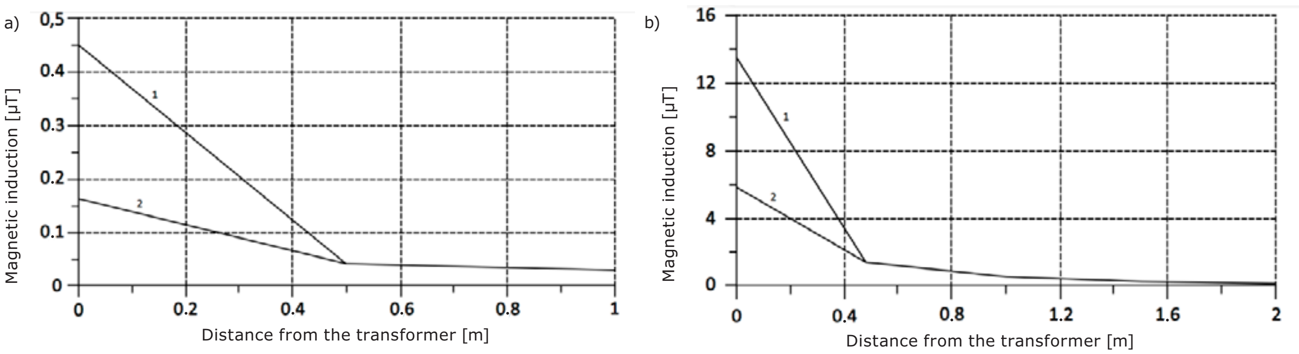

Fig. 3. Induction on the envelopes around the 1600 kVA transformer: a) in the no-load state and b) in the short-circuit state

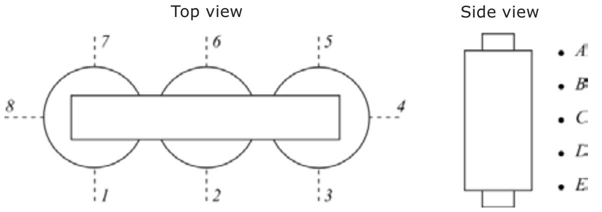

Fig. 6. Measurement points 1–8 and A–E in the space of the transformer

Table 1. [5]

Measurement at the height of column "1" at a distance of 0.5 m						
Transformer station	**Points**	**A**	**B**	**C**	**D**	**E**
1600 kVA	Induction [μT]	34	92	104	74	71
2500 kVA		25	110	148	97	47

checked first was that at the winding height. The induction measurement results presented in Table 1 concerned the 1600 kVA and 2500 kVA transformers. The measurements were performed at points at height A-E, in the short circuit state, in relation to nominal current, at the extreme column "1" at a distance of 0.5 m away from the winding.

The measurement results presented in Table 1 indicate that the highest value of magnetic induction was observed on the plane passing through half of the winding height and perpendicular to the winding.

The measurements of magnetic induction in the space of the transformer were performed on the envelopes around the transformer, lying on the plane perpendicular to the core and passing through half of its height. The first envelope with measurement points 1–8 was at a distance of 0.5 m away from the winding, whereas the remaining envelopes were located on the same plane and at a distance of 1 m, 1.5 m, 2 m and 2.5 m.

The measurement results are presented in induction diagrams as a function of distance, where each point on the diagram constitutes the mean value of 8 measurement points belonging to one envelope.

5. Summary

Distribution transformers installed in residential buildings should not disturb residents' living comfort through noise, fire hazards and variable magnetic fields. The article presents the results of measurements concerning magnetic flux density having a frequency of 50 Hz in the space around oil-immersed transformers having a power of 1600 kVA, 800 kVA and 100 kVA as well as dry-type transformers having a power of 1600 kVA and 2500 kVA. In oil-immersed transformers, magnetic fluxes in the space outside the tank are smaller than those in dry-type transformers. For instance, in the 1600 kVA oil-immersed transformer, the variable induction component at the tank amounted to 40 μT. In turn, in the dry-type transformed of the same power, at a distance of 0.5 m away from the winding, the value of induction amounted to 140 μT. As can be seen, the transformer tank effectively attenuates the transformer leakage flux. At the same distance in space outside the tank, oil-immersed transformers generate magnetic induction approximately four times lower

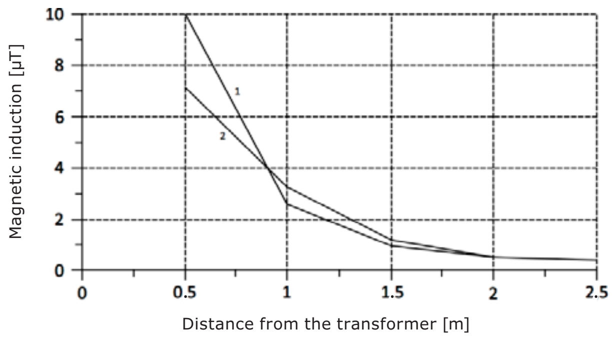

Fig. 7. Diagram of induction in the no-load state in the space of 1) 1600 kVA transformer and 2) 2500 kVA transformer

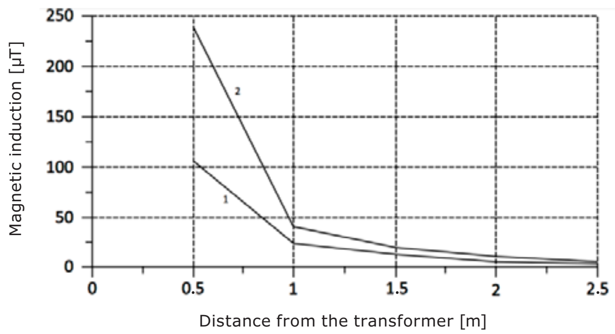

Fig. 8. Diagram of induction in the short circuit state in the space of 1) 1600 kVA transformer and 2) 2500 kVA transformer

than that generated by dry-type transformers. At a distance of 2 m away from both oil-immersed and dry-type transformers, induction generated by the transformer amounted to several μT and was approximately 10 times lower than the value permissible for rooms with humans inside them, specified in Regulation [4] for a distance of 2.8 m. From the variable magnetic induction component point of view, both oil-immersed and dry-type transformers can be located in residential buildings subject to provisions specified in Regulation [1].

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