

PRACTICAL ASPECTS REGARDING THE DESIGN AND MANUFACTURING OF SINGLE-PHASE POWER TRANSFORMERS AND AUDIO-FREQUENCY TRANSFORMERS

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Abstract: The paper presents a practical methodology for designing low-power transformers, covering all essential aspects from power calculation to winding and core dimensioning. Emphasis is placed on technical accuracy, efficiency considerations, and ensuring the proper fit of windings within the transformer core, making this guide suitable for both network and audio-frequency transformers.

Keywords: Electromagnetic induction, turn ratio, magnetic core, winding, lamination.

1. INTRODUCTION

Transformers are circuit elements based on the phenomenon of electromagnetic induction, designed to transfer electromagnetic energy at a voltage V_1 and current I_1 from a primary circuit to deliver it at a voltage V_2 and current I_2 to another circuit, called the secondary [6], [9], [12], [16]. It is important to note that transformers are not sources of energy or power, even if the voltages or currents obtained in the secondary can reach values hundreds or thousands of times higher than those in the primary circuit [17], [19]. The energy extracted from the primary circuit (connected to the power supply) is found in the secondary circuit at approximately 95–98%, the difference being lost as core and winding conductor losses. An increase in voltage in one coil compared to the other coil is always achieved at the expense of the current, which decreases roughly in the same ratio, and vice versa [1], [4], [11], [14], [18].

The efficiency (or performance) of the transformer depends on numerous factors, including the quality and geometry of the iron core, the shape and dimensions of the windings, and the diameter of the winding conductors used. In low-power mains

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transformers, the most commonly used magnetic cores are E-I laminations made of cold-rolled silicon steel, which provide an electromagnetic energy transfer efficiency η between 0.95 and 0.98 [8], [10], [21].

Based on the phenomenon of electromagnetic induction, transformers can operate only with alternating current. When the frequency of the voltage applied to the primary winding is low (tens or hundreds of Hz), the secondary voltage has the same waveform and frequency. As the frequency of the voltage applied to the primary winding increases, the ferromagnetic material of the transformer core increasingly resists its magnetization and demagnetization cycle, resulting in a gradual decrease in efficiency.

If a mixture of voltages with different amplitudes and frequencies is applied to the primary winding terminals (as in the output of an audio-frequency amplifier), the secondary signal will be distorted due to the reduced high-frequency transfer efficiency. This highlights the importance of the quality of the transformer's core material. For transformers designed to operate at higher frequencies (including audio-frequency transformers, where high efficiency and compact size are desired), cores are made of permalloy or other high-quality ferromagnetic materials [15], [20], [23].

This paper will present a practical and simplified method for calculating low-power mains transformers and audio-frequency adapting transformers. The calculation steps include determining the rated power, the parameters of the laminated ferromagnetic core, the number of turns of each transformer winding, and the diameters of the winding conductors for each coil.

2. POWER CALCULATION

To quantitatively express the fundamental law of transformers, let us denote by V_1 , I_1 , N_1 , the rated voltage, rated current, and number of turns of the primary winding, and by V_2 , I_2 , N_2 , the rated voltage, rated current, and number of turns of the secondary winding (Figure 1). The transformer's turns ratio k_T is then defined as:

$$k_T = \frac{V_1}{V_2} = \frac{N_1}{N_2} \quad (1)$$

The rated power of a transformer is defined as the product of the rated voltage and rated current of the primary winding:

$$P = V_1 \cdot I_1 \quad (2)$$

If losses are neglected, the power S is fully transferred to the secondary circuit and can be expressed by the equation:

$$P = V_2 \cdot I_2 \quad (3)$$

From equations (2) and (3) it follows:

$$V_1 \cdot I_1 = V_2 \cdot I_2, \text{ or } \frac{V_1}{V_2} = \frac{I_2}{I_1} = k_T \quad (4)$$

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The first step that must be precisely determined before constructing a transformer is its intended purpose. This requires knowing the maximum voltage and current values of the secondary winding, V_2 and I_2 . We will consider three common practical cases:

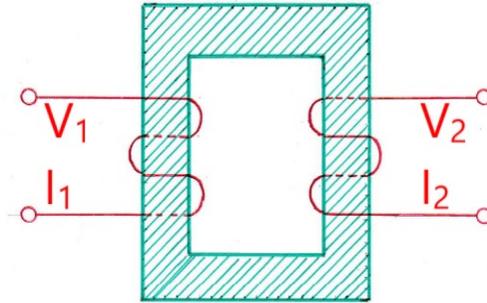


Fig.1. Transformer with a single secondary winding

- a) single secondary winding (Figure 1). If there is a single secondary winding delivering the maximum voltage V_2 and maximum current I_2 , the power of the secondary will be:

$$P_2 = V_2 \cdot I_2 \quad (5)$$

- b) Multiple separate secondary windings (Figure 2, a). If there are multiple secondary windings that must operate independently, delivering maximum voltages $V_2^1, V_2^2, \dots, V_2^n$ and maximum currents $I_2^1, I_2^2, \dots, I_2^n$, the total secondary power is calculated by summing the powers of each secondary winding individually:

$$P_2 = P_2^1 + P_2^2 + \dots + P_2^n = V_2^1 \cdot I_2^1 + V_2^2 \cdot I_2^2 + \dots + V_2^n \cdot I_2^n \quad (6)$$

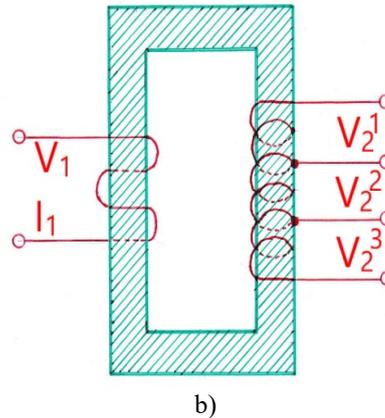
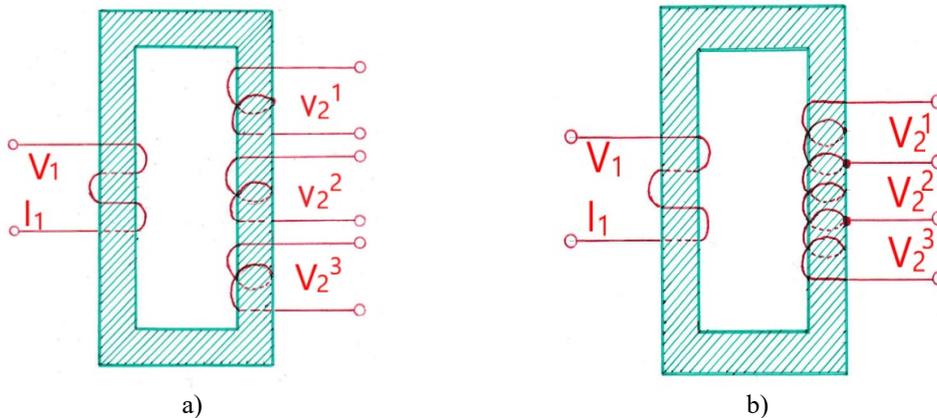


Fig.2. Transformer: a) with multiple separate secondary windings; b) with single secondary winding with multiple taps

Example: If the secondary has one winding of 230 V / 2 A and another winding of 120 V / 4 A, the total power is: $P_2 = 230 \cdot 2 + 120 \cdot 4 = 460 \text{ VA} + 480 \text{ VA} = 940 \text{ VA}$.

In practice, there are situations where not all secondary windings need to supply electric energy simultaneously [16], [22].

Knowing this operating mode is important because it can lead to a reduction in the transformer size and, consequently, manufacturing costs. Returning to the example above and assuming that the 230 V and 120 V voltages are used alternately, never simultaneously, the transformer power can be considered as the largest power among the two windings, i.e., 480 VA.

- c) Single secondary winding with multiple taps (Figure 2, b). In this case, the secondary power is calculated based on the maximum voltage of the entire winding and the current that must be delivered, using equation (5). Here, the maximum voltage will be the sum of the voltages between the winding ends and the intermediate taps, while the maximum current will be the same through all sections, which are connected in series.

After calculating the rated power P_2 of the secondary winding, the rated power of the primary winding P_1 can be determined, considering the transformer efficiency, which ranges between 0.95 and 0.98:

$$\eta = \frac{P_2}{P_1} = 0,95...0,98 \quad (7)$$

from which it follows:

$$P_1 = \frac{P_2}{0,95...0,98} = (1,02...1,05) \cdot P_2 \quad (8)$$

3. CALCULATION OF THE MAGNETIC CORE CROSS-SECTION

As previously mentioned, for low-power transformers, the magnetic cores are most often constructed using E + I laminations (Figure 3). A review of the technical literature shows that these laminations are further classified according to certain dimensional characteristics, with catalogs available to facilitate the correct selection of lamination types and the transformer design.

Regarding the lamination stack, two essential characteristics must be known: the core cross-section and the window dimensions. At this stage, it is assumed that the material of the laminations is already known (silicon steel sheet, hot- or cold-rolled). The cross-section s of the magnetic core is obtained by multiplying the thickness c of the lamination stack by the width b of the central limb of the E-lamination, expressed in centimeters (Figure 4). The resulting cross-section is expressed in square centimeters.

Knowing the cross-section is mandatory because the maximum power P transferred from the primary winding to the secondary winding depends directly on the core cross-section [9], [24].

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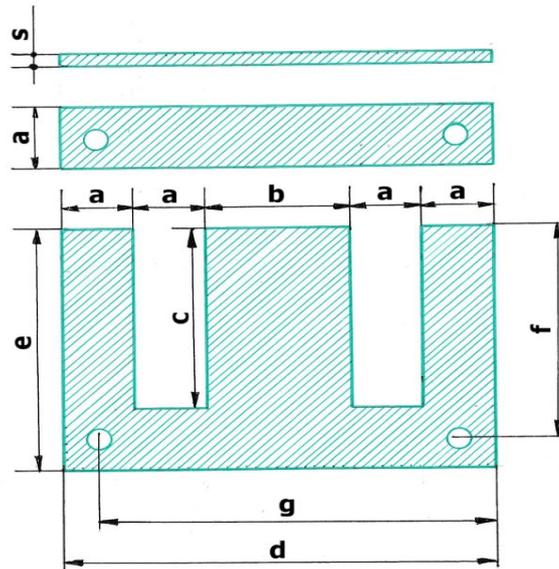


Fig.3. E + I -type lamination

For high-quality ferromagnetic materials (e.g., cold-rolled silicon steel), this relationship is expressed by the equation:

$$s = \sqrt{P} \quad (9)$$

When the magnetic core is made from lower-quality laminations, such as plain iron or annealed steel, a proportionality factor greater than 1 is introduced in the equation (9), typically ranging between 1,1 and 1,6:

$$s = (1,1 \dots 1,6) \cdot \sqrt{P} \quad (10)$$

The other essential characteristic of the magnetic core is the window, which represents the empty space inside the lamination stack after assembly, located between the central limb and one of the side limbs. In E + I laminations, there are two equal windows, one on each side of the central limb. These empty windows accommodate the transformer casing, which houses the primary and secondary windings. The window dimensions are considered after completing the winding calculations (number of turns and conductor diameters) to verify that the designed windings physically fit within the casing and the window space.

Once the minimum required cross-section of the magnetic core is established using equations (8) or (9), the corresponding lamination stack is selected. Special attention must be paid to ensure that the chosen core cross-section is never smaller than the calculated value. Conversely, a much larger cross-section than required ensures proper transformer operation but results in a larger physical size and higher conductor consumption, increasing manufacturing costs. If the difference between the transformer rating and the total load connected to the secondary winding is significant, the

transformer may operate with a lower power factor due to the increased proportion of reactive power in the total apparent power.

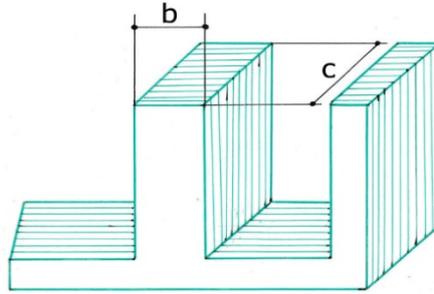


Fig. 4. E-laminations stack

Adjustment of the cross-section can be easily achieved by increasing or decreasing the stack thickness (i.e., the number of laminations used). In practice, it is advisable, as far as reasonably possible, for the cross-section $b \cdot c$ to be square, i.e., $b=c$. By adhering to this criterion, the length of each turn is minimized, since among all rectangles with a given area s , the square has the smallest perimeter. This reduces conductor length, lowers the winding's electrical resistance, and consequently decreases energy losses due to voltage drop.

4. CALCULATION OF WINDINGS

As previously demonstrated, the ratio of voltages in the primary and secondary windings is equal to the ratio of the number of turns of these windings- equation (1). At first glance, one might deduce that, to achieve a voltage transformation from V_1 to V_2 , any pair of values for the number of turns N_1 and N_2 could be chosen, as long as their ratio satisfies this equation. In reality, this is entirely incorrect because a specific number of turns cannot handle any arbitrary voltage. For a given number of turns, there is a maximum voltage that can be transformed efficiently while ensuring safe operation. This limitation is imposed by the magnetization conditions of the transformer core (the magnetic flux density depends on the number of turns of the primary winding, the current flowing through it, and the size and quality of the magnetic core) [13].

Based on accumulated practical experience in designing and operating transformers, a simple and precise empirical relationship has been established for determining the number of turns per volt:

$$N_{\text{turns/V}} = \frac{55}{s} \quad (11)$$

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where s is the magnetic core cross-section, and 55 is a constant dependent on network frequency and core quality. This constant can take the value 50 for high-quality silicon steel laminations and may increase up to 60 for lower-quality magnetic materials such as ordinary iron sheets [5].

Knowing the number of turns per volt for the selected core, the number of turns for the transformer windings can be calculated:

$$N_1 = U_1 \cdot N_{\text{turns/V}}; N_2 = U_2 \cdot N_{\text{turns/V}} \quad (12)$$

When the secondary coil contains multiple separate windings, this calculation is applied individually for each voltage.

Example: A transformer with a magnetic core cross-section of 5 cm² requires windings with $N_{\text{turns/V}} = \frac{55}{5} = 11$ turns per volt. For a secondary winding that must deliver 24 V, the number of turns is calculated as $N_2 = 24 \cdot 11 = 264$ turns.

5. SIZING OF WINDING CONDUCTORS

The next step in the calculation consists of determining the minimum diameters for the winding conductors. To achieve this, the maximum currents in the primary and secondary windings must first be determined, using the following equations:

$$I_1 = \frac{P_1}{V_1} \quad I_2 = \frac{P_2}{V_2} \quad (13)$$

Example: If the supply voltage of the primary winding is $V_1 = 230$ V and the maximum power of the primary, determined from previous calculations, is $P_1 = 200$ VA, then the current in the primary winding is: $I_1 = \frac{200}{230} = 0,87$ A, approximately 0,9 A.

It is known that when an electric current flows through a conductor, part of the applied voltage is lost due to the conductor's electrical resistance. Physically, this loss appears as heat because of the Joule effect. This voltage drop also implies a loss of power, directly proportional to the conductor's resistance and the square of the current flowing through it ($P = R \cdot I^2$).

Table 1. Winding calculation data

d (mm)	s (mm ²)	I _{max} (mA)			n _s (turns/cm ²)		n ₁ (turns / cm)
		j= 2A/ mm ²	j= 2,5A/ mm ²	j= 3A/ mm ²	without insulation between layers	with insulation between layers	
0,15	0,01707	35,3	44,2	53	2880	2260	55
0,18	0,02545	51	63,7	76,5	2050	1730	47,5
0,2	0,03142	62,9	78,6	94,8	1715	1465	43,4
0,22	0,03801	75	95	114	1460	1210	39,2
0,25	0,04909	98	123	147	1140	978	35

0,28	0,06158	122	151	185	925	813	31,5
0,3	0,07069	141	177	212	807	722	29,6
0,35	0,09621	192	240	289	594	530	25,3
0,4	0,126	252	315	378	470	350	22,5
0,45	0,159	318	398	477	371	277	19,9
0,5	0,196	392	490	590	300	234	18,1
0,55	0,2376	475	594	713	246	190	16,4
0,6	0,2827	566	707	848	209	162	15,1
0,65	0,3312	662	888	993	180	142	14,1
0,7	0,3848	770	960	1150	153	125	13,1
0,75	0,442	882	1110	1331	134	110	12,3
0,8	0,503	1000	1256	1510	127	95,5	11,4
0,85	0,569	1140	1420	1700	106	87	11
0,9	0,636	1270	1590	1910	93	78	10,2
0,95	0,710	1420	1775	2130	84	70	9,8
1	0,785	1570	1960	2360	75	65	9,3
1,2	1,131	2260	2730	3400	52	40,5	7,7
1,4	1,54	3080	3850	4620	39	30,7	6,7
1,5	1,767	3530	4420	5300	33,5	26,5	6,2

To keep voltage drops in the windings within acceptable limits, the electrical resistances of these conductors must be as low as possible, especially when higher currents are involved. The resistance R of a conductor is directly proportional to its length l and the resistivity ρ of the material, and inversely proportional to its cross-section s :

$$R = \rho \cdot \frac{l}{s} \quad (14)$$

In transformer windings, the lengths are well defined, the number of turns is precisely calculated, and the length of a turn is dictated by the magnetic core cross-section. The resistivity of winding conductors (usually copper) is well known. Therefore, the only variable that can be adjusted to reduce winding resistance is the conductor's cross-section s .

In practice, the minimum cross-section of the winding conductor (and thus the minimum diameter) for a given current is determined using the current density j . For small transformers, a current density of 2...2,5 A/mm² is generally accepted for copper. Higher values (3...4 A/mm²) may be used in cases such as:

- Secondary windings with a small number of turns in transformers installed outdoors, benefiting from natural or forced ventilation;
- Transformers with intermittent operation, with short periods of load alternating with rest periods.

Given a current density j , the conductor cross-section s in mm² is calculated as:

$$s = \frac{I}{j} \quad (15)$$

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where I is the maximum current in the winding (A). The calculated section of the wire is considered the minimum, and the result is always rounded up to the nearest standardized conductor size.

Example: For a maximum winding current of 1 A and a current density $j=2.5$ A/mm², the conductor cross-section is $s=0.4$ mm². Knowing that manufacturers provide conductor diameters without insulation, the conductor diameter d is:

$$s = \frac{\pi \cdot d^2}{4} = 0,785 \cdot d^2 \quad (16)$$

The inverse equation can be written:

$$d = \sqrt{\frac{4 \cdot s}{\pi}} \approx 1,13\sqrt{s} \quad (17)$$

Returning to the stated example, the diameter of the conductor with a cross-section of 0,4 mm² will be $d \approx 1,13\sqrt{0,4} = 0,714$ mm. The immediately higher standardized diameter for this value is 0,75 mm, which is the value that will be chosen for making the coil.

To eliminate the extensive calculations required by the preceding equations, tabulated data are commonly employed in practice, providing the main winding parameters for each standardized conductor diameter. By combining equations (15) and (17), a direct correlation is established between the maximum allowable current I (A) and the minimum diameter of the uninsulated winding conductor d (mm):

$$d = 1,13 \sqrt{\frac{I}{j}} \quad (18)$$

In equation (18), the current density j is taken in A/mm², and for value $j = 2$ A/mm², often used in practice, the wire diameter can be calculated using the approximative formula:

$$d \approx 0,8 \sqrt{I} \quad (19)$$

If the required diameter is not available, the winding can be made using two or more smaller conductors in parallel, ensuring that the sum of their diameters without insulation is at least equal to the minimum diameter calculated [1].

Based on the calculation performed, Table 1 was prepared, from which the windings data can be directly extracted.

6. DETERMINING THE SPACE OCCUPIED BY WINDINGS

The next step in designing the transformer is an approximate calculation of the total space occupied by the transformer windings. Neglecting this step may have unpleasant consequences, as there is a risk that the windings will not fit on the core.

The total space occupied by the windings practically represents the area of the winding's cross-section. To calculate this approximately, all winding data must be known in advance: total number of turns, conductor diameters, and type of insulation between layers and windings. Therefore, the choice of the core package and, implicitly, the casing is made only after the winding calculations are completed, because a given core package may have a sufficient power rating but a window that is too small for the designed windings [3].

Until now, we have used the conductor diameter without insulation. From this point forward, the insulated conductor diameter, denoted d_{is} , is considered. Key notions here are turns/cm and turns/cm².

To determine how many turns of a given conductor fit in 1 cm of length (column n_1 in Table 1), proceed as follows: wrap 20 turns of the conductor as tightly as possible around a pencil with a circular section, without gaps. Measure the winding length L in mm. The number of turns/cm n_1 is calculated proportionally:

$$\begin{array}{l} 20 \text{ turns} \dots\dots\dots L \text{ (mm)} \\ n_1 \text{ turns} \dots\dots\dots 10 \text{ (mm)} \end{array}$$

from which:

$$n_1 \text{ (turns/cm)} = \frac{200}{L} \tag{20}$$

The choice of 20 turns is arbitrary for ease of calculation and more precise measurement of L . If the conductor is very thin, 30–40 or more turns may be used.

If a micrometer is not available, the insulated conductor diameter can also be determined proportionally:

$$\begin{array}{l} 20 \text{ turns} \dots\dots\dots L \text{ (mm)} \\ 1 \text{ turn} \dots\dots\dots d_{is} \text{ (mm)} \end{array}$$

from which:

$$d_{is} \text{ (turns/cm)} = \frac{L}{20} \tag{21}$$

The cross-sectional area s_{is} of a conductor with diameter d_{is} can be approximately calculated as:

$$s_{is} \approx 0,8 \cdot d_{is}^2 \tag{22}$$

To calculate the total space occupied by the windings, proceed as follows:

- multiply the number of turns of each winding by the conductor's cross-section s_{is} ;
- sum the results for all transformer windings; the final result represents the effective total cross-sectional area occupied by the conductors;

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- to account approximately for space losses due to turn shape, insulation between layers, and uneven winding, multiply the result by a factor between 2 and 3. The resulting value approximates the minimum window area of the magnetic core, expressed in mm².

Example: A transformer has four windings with the following numbers of turns and conductor diameters:

- N₁ = 1430 turns, d_{is} = 0,44 mm;
- N₂ = 4000 turns, d_{is} = 0,2 mm;
- N₃ = 35 turns, d_{is} = 0,98 mm;
- N₄ = 45 turns, d_{is} = 0,8 mm.

The magnetic core is an E+I lamination package with a window area of 5 cm x 2,5 cm = 12,5 cm² = 1250 mm² and we aim to determine whether the 4 transformer's windings will fit within the mentioned window. Calculating the space occupied:

- Winding 1: 0,8 · 0,44² · 1430 = 250 mm²;
- Winding 2: 0,8 · 0,2² · 4000 = 128 mm²;
- Winding 3: 0,8 · 0,98² · 35 = 27 mm²;
- Winding 4: 0,8 · 0,8² · 45 = 23 mm².

Total cross-sectional area is: 250 + 128 + 27 + 23 = 428 mm², which is nearly three times smaller than the core window area. Therefore, the four windings fit comfortably in the chosen magnetic core.

7. DIMENSIONS OF E+I LAMINATIONS

In general, technical literature indicates a transformer core by the type of lamination (E6, E10, etc.) and the stack thickness. To deduce the relevant dimensions, it is necessary to know certain dimensional correlations. For this study, refer again to Figure 4 from Chapter 3 of this work, which shows the notations used for different dimensions of E+I laminations. The number following the letter E when specifying the lamination type represents the dimension a in Figure 4, expressed in millimeters. There are precise relationships between the dimensions a, b, c, d, e, f and g (for example, b=2a, d=6a, etc.). Numerical values of these dimensions in millimeters for several commonly used laminations are shown in Table 2. The column indicating the weight of a lamination is subdivided according to the lamination thickness s (0.35 mm or 0.5 mm) [2].

Using the notations from Figure 4, the core window area can be calculated as: Using the notations from Figure 4, the core window area can be calculated as:

$$S_{\text{window}} = a \cdot 3a \cdot 10^{-2} = 0,03 \cdot a^2$$

The factor 10⁻² accounts for the fact that the dimension a is expressed in millimeters. For example, an E8 lamination (a=8 mm) has a window area: 0,03 · 8² = 2,4 cm².

If h denotes the thickness (or height) of the lamination stack in millimeters, the cross-sectional area of the magnetic core is calculated as:

$$S_{\text{core}} = h \cdot 2a \cdot 10^{-2} = 0,02 \cdot h \cdot a$$

Table 2. Dimensions and weight of some common types of E + I laminations

Dimensions (mm)							Weight (g)	
a	b=2a	c=3a	d=6a	e=4a	f=3,5a	g=5a	s=0,35	s=0,5
5	10	15	30	20	-	-	1,2 0,4	1,7 0,57
6,4	12,8	19,2	38,4	25,6	-	-	2,07 0,66	3,04 0,97
8	16	24	48	32	-	-	3,08 1,03	4,53 1,59
10	20	30	60	40	35	50	4,95 1,61	7,1 2,36
12,5	25	37,5	75	50	43,75	62,5	7,28 2,52	10,7 3,7
14	28	42	84	56	49	70	9,4 3,16	13 4,63
16	32	48	96	64	56	80	12,4 4,14	18 6,21
18	36	54	108	72	63	90	15,6 5,2	23 7,6
20	40	60	120	80	70	100	24,3 6,4	28,3 9,4
25	50	75	150	100	87,5	125	30 10,5	44 14,5
32	64	96	192	128	112	160	50 16,5	73 23,6

Returning to the E8 lamination example, a stack of E8 laminations with thickness $h=10$ mm has a core cross-section of: $10 \cdot 8 \cdot 0,02 = 1,6 \text{ cm}^2$.

8. CALCULATION OF AUDIO FREQUENCY ADAPTER TRANSFORMERS

Audio frequency adapter transformers belong to the category of special transformers. Unlike mains transformers, which serve as the connection element between two power networks with different voltages, audio frequency transformers are used in public address systems, with the main role of matching the output impedance of the audio power amplifier stage with the transmission line impedance of the audio signal to the system's loudspeakers [11].

Public address systems are sound reinforcement installations designed for use in public spaces frequented by a wide audience and consist of audio equipment such as speakers, microphones, mixers, audio signal sources, public announcement generators, and so on.

The most common public address systems include:

- radio-distribution networks, through which a program transmitted by a radio station is delivered via subscriber lines simultaneously to a variable number of special speakers, called radio-distribution speakers, located at individual subscribers' residences;

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- radio-amplification systems, which transmit radio programs, music, announcements, etc., to crowded spaces such as classrooms in educational institutions, airports, train stations, bus terminals, shopping centers, and similar locations [7].

The audio signals handled and transformed by audio frequency transformers fall within the audio frequency spectrum, ranging from 20 Hz to 20 kHz. Typically, an audio frequency adapter transformer operates within a much narrower signal frequency range, between 100 Hz and 12 kHz. This limitation occurs because, as the audio signal frequency increases, the transformer's magnetic core increasingly opposes the very rapid magnetization-demagnetization cycles. This phenomenon can be mitigated by constructing the magnetic core from high-quality magnetic alloy laminations (for example, permalloy).

For audio adaptation transformers, the method and calculation formulas used to determine the core and winding parameters differ somewhat from those for mains transformers [12].

The rated power of a step-up audio adapter transformer, which receives the signal at its primary from the output of the final amplification stage, is determined using the relation:

$$P = P_{sp} \cdot n_{sp} \quad (23)$$

where:

- P_{sp} is the rated power of a subscriber's speaker;
- n_{sp} is the total number of speakers connected to the radio-distribution / radio-amplification network.

The next step is to determine the output voltage of the amplifier's final audio unit, V_g :

$$V_g = \sqrt{P \cdot Z_a} \quad (24)$$

where:

- P is the rated power of the audio amplifier in watts (W);
- Z_a is the output impedance of the audio amplifier in ohms (Ω), measured at a frequency of 1000 Hz.

Knowing the audio output voltage V_g and the nominal voltage of the transformer secondary, which is equal to the audio line voltage V_{al} indicated on the technical data plates of the speakers, the transformation ratio of the transformer k_T can be calculated:

$$k_T = 1,1 \cdot \frac{V_{al}}{V_g} \quad (25)$$

where 1.1 is a correction factor that accounts for power losses in the secondary winding relative to the primary winding.

The cross-section sss of the transformer's magnetic core is determined using the equation:

$$s = 16 \cdot \sqrt{\frac{P}{f_j}} \quad (26)$$

where f_j is the lower limit of the audio signal frequency in the transformer's secondary. In the absence of other information, f_j is taken as 100 Hz.

Considering a magnetic induction $B \leq 5000$ Gs, the number of turns per volt for the transformer windings, $n_{\text{turns/V}}$ is determined using the formula:

$$n_{\text{sp/V}} = \frac{10^8}{4,44 \cdot f_j \cdot B \cdot S_{fe}} \quad (27)$$

Knowing the turns per volt, the number of turns of the primary winding n_1 can be calculated, as well as the number of turns n_2 of the secondary winding:

$$n_1 = n_{\text{turns/V}} \cdot V_g \quad (28)$$

$$n_2 = n_1 \cdot k_T \quad (29)$$

The next step is determining the conductor diameters for the transformer windings. First, the maximum primary current I_1 is determined:

$$I_1 = \sqrt{\frac{P}{Z_a}} \quad (30)$$

The diameter d_1 of the primary winding conductor is:

$$d_1 = 0,65 \cdot \sqrt{I_1} \quad (31)$$

The diameter d_2 of the secondary winding conductor is:

$$d_2 = \frac{d_1}{\sqrt{k_T}} \quad (32)$$

9. CONCLUSIONS

Based on the theoretical analysis and the presented calculation relations, it is confirmed that the sizing and design of transformers depend directly on the electrical operating conditions for which they are intended. Thus, although power transformers and audio-frequency matching transformers belong to the same family of electromagnetic devices, they employ distinct calculation methodologies in order to correctly satisfy the requirements of their specific applications.

In the case of the single-phase power network transformer, its use at the supply network frequency (also called "industrial frequency") of 50 Hz requires that the proper transfer of power from the primary winding to the secondary winding is the main requirement for its operation. A judicious correlation between the rated power of the

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secondary winding and the rated power of the load is the premise for operation under a power factor as close as possible to its limit value ($\cos\varphi = 0.9$) established by the Order no. 76 of November 2, 2016 of the National Energy Regulatory Authority.

For audio-frequency matching transformers used in public address networks and sound distribution systems, the primary concern is not power transfer itself, but the correct impedance matching between the output unit of the power amplifier and the transmission line driving the distributed loudspeakers. The role of the turns ratio and spectral characteristics in maintaining audio signal fidelity is emphasized, along with the need to use high-quality magnetic materials in order to limit losses at higher frequencies within the audio spectrum.

The obtained calculation results confirm that core sizing, determination of the number of turns, selection of conductor cross-sections, and correlation with the level of magnetic induction must be approached integratively to simultaneously achieve efficiency, thermal stability, and distortion-free operation. The accuracy of these steps is essential for the reliability of the transformer and for the optimal operation of the electronic or electrotechnical system in which it is integrated.

In conclusion, the design of transformers — regardless of their application category — remains a multidisciplinary process in which knowledge of electromagnetism, electrical engineering, electronics, and material science must be rigorously combined. The precise application of calculation relations ensures the development of high-performance, energy-efficient, and operationally stable equipment capable of meeting the technical, economic, and safety requirements imposed by modern applications.

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