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Innovation of a Control Transformer Design

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Abstract **– The present article deals with an innovative design of a control transformer. It describes a conventional design of a control transformer and provides the basic theoretical information on control transformers which is available in the world technical literature, patents, as well as other available sources addressing this topic. Subsequently, the article describes a novel, original design and presents the related drawing documentation.**

Keywords **– control transformer, load current, electrical voltage, ferromagnetic core.**

1. Introduction

The technical design relates to a control transformer with a double-layer secondary winding. It may be used in all types of equipment in which voltage must be continuously regulated within the range from zero to a maximum value and which facilitate current collection up to a value determined by the maximum output of the control transformer.

2. Conventional Technical Design

Conventional control transformers are frequently used as the sources of continuously controllable voltage at a particular load current.

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Control transformers contain a ferromagnetic core, which may be of a cylindrical or toroidal shape.[1] As to the method of collection of the output power, they usually have a secondary winding with only one layer of a conductor on the surface of an isolated core around which the primary winding is wound. The conductors of the secondary winding are isolated on their surface, and along their surface a conductive (carbon) collector (sliding, pulley) is sliding. A position of the collector determines the amount of the output voltage. Collector is also used to supply the output current to the load. [1],[3]

A great technological problem which accompanies the manufacture of control transformers is the process of winding the secondary winding, especially when its conductor is of an angular shape (a tape conductor). A necessity of using a tape conductor follows from the need of winding all turns of the secondary winding in a single layer. In such a case, it must be wound "onto the edge", i.e. upright. This process requires a very skilled winder and a use of special preparations. A frame of such a coil must usually be shaped as a pipe, and this requires using a core with a cascaded shape. The resulting core is therefore of a complex shape and comprises multiple types of steel sheets of various profiles.[4] This results in low manufacturing productivity and a high labour input as an indicator of labour intensity. Moreover, the cost of such a product is rather high.

A discovery made in 1831 by a great scientist Faraday, regarding the principle of electromagnetic induction, brought a new perspective of several laws of electrotechnology. It is based on interactions between electromagnetic fields. 45 year later, a great Russian scientist P. N. Yablochkov registered a patent for an invention of a transformer. [2]

A classic definition is as follows: A transformer is an electrical device transforming the current of the primary winding with a certain voltage into the secondary winding with a different voltage. The induction effect occurs when the electromagnetic field changes; therefore, a transformer only works in the presence of voltage with alternating current. The transformation (transfer) runs through the conversion of electrical energy of the primary winding into a magnetic field, and then in the secondary winding the magnetic field is transformed back into electrical energy. If the number of turns of the secondary winding is higher than the number of turns of the primary winding, such a device is referred to as a step-up transformer.[5] When the windings are connected in a reverse order, such a device is a step-down transformer. A structural device that regulates voltage consists of a core and two windings. The core is formed of the plates made of electrical steel sheets. The primary and secondary windings, made of a copper wire of various diameters, are wound around a coil. A thickness of the winding conductor of the transformer depends directly on its output power. The core of the device may be a rod or armour. When this product is used in low-voltage networks, wires of various shapes are most frequently used as magnetic rods. [6]

The issues related to such control devices represent the subject of the following patents and technical literature: US3152311A, Inventor: N. N. Bojarski 3,152,311 Variable voltage transformer, Current Assignee: L R POWER CORP, Oct. 6, 1964 I311A;

US Patent PUS3445753 - Variable standard mutual inductance circuit with air core transformer and tap changing cascaded autotransformers, Inventor: Emanuel Maxwell, Current Assignee: Massachusetts Institute of Technology, 1966; GB9912205D0, United Kingdom, A variable transformer, 1999, Current Assignee: ABB AB; US Patent US2097770A, Transformer inventor: Morelisse Jan, Nov. 2, 1937. Filed Jan. 21, 1937 more continuous current Patented Nov. 2, 1937 UNITED STATES PATENT OFFICE Application January 21, 1937, Serial No. 121,614;

3. Innovated Design

All the above mentioned drawbacks are eliminated in a newly developed design of a control transformer with a double-layer secondary winding, which is wound in two layers, while the conductive surface of the outer (top) layer is accessible to a sliding collector. The inner (bottom) layer has the same number of turns and the same cross-section as the outer layer. The ends and beginnings of its windings are connected to the outer layer. The beginning of the inner secondary winding is connected to the beginning of the outer secondary winding and also to a respective terminal of the beginnings of the secondary windings. The end of the inner secondary winding is connected to the end of the outer secondary winding and also to a respective terminal of the ends of the secondary windings. [9]

A sliding collector is pressed against the isolated and oiled surface of the outer secondary winding. The collector is connected to the terminal by a cable. Such an arrangement of the secondary windings ensures that the coil of the inner secondary winding of the control transformer has the same voltage effect as if there was another (virtual) collector contacting also the surface of the inner secondary winding in the same position as the real collector on the coil of the outer secondary winding of the control transformer. The resulting effect is that the voltage drawn from such a control transformer is determined by the collector's position, and the collected current is determined by the sum of the cross-sections (areas) of the conductors of the outer as well as inner secondary windings at a given permissible current density. [8],[9]

The above described control transformer with a double-layer secondary winding exhibits the characteristics and parameters equal to those of a control transformer with a single-layer secondary winding. As a result of the maximum utilisation of the unified parts and the application of a double-layer secondary winding, it is possible to achieve a very low weight and small geometrical dimensions of such a product, when compared to conventional single-layer, parametrically equivalent functional models.[12] The control transformer with the above described design is easier to manufacture and more profitable. Conductors of the secondary coils exhibit as small ratio of the width to the thickness of the used angular conductor. The ratio may even be 1; it means that it is possible to wind the secondary windings with an angular (or spherical) profile of the conductor. This facilitates (so far almost unfeasible) winding of the secondary winding around the unified square coil frames with only a low labour demand. The costs of manufacturing control transformers with the design described herein are therefore significantly lower than the costs of conventional products. This new design is applicable to cylindrical, multi-cylindrical (shell, core), as well as toroidal shapes of cores for control transformers.

The design is explained in more detail in the drawings; Figure 1. shows a functional scheme of a control transformer with a double-layer secondary winding, and Fig. 2. shows the overall arrangement of the functional parts of the device. This figure also contains an example of an embodiment of this design and the defined protection requirements.[9],[7]

4. Example of an Embodiment of the Design

Fig. 1. depicts the principle of this design in form of a particular functional scheme of a control transformer with a double-layer secondary winding. The parameters and symbols have the following meanings:

11 – ferromagnetic core;

I_{21} – output current of the control transformer passing through the entire layer of the secondary winding and a CB section of the layer of the outer secondary winding (where it flows in the opposite direction);

I_{22} – output current of the control transformer passing through the AB section of the layer of the outer secondary winding;

N_{21} – number of turns of the layer of the inner secondary winding (of the control transformer);

N_{22} – number of turns of the layer of the outer secondary winding (of the control transformer);

U_{xx} – voltage in the demarcated relevant part of the winding.[9]

The following applies to the individual parameters at the secondary windings of the control transformer:

$$U_2 = U_{21} + U_{22} \quad (1)$$
$$U_{22} = U_2 - U_{21} \quad (2)$$
$$I_2 = I_{21} + I_{22} \quad (3)$$
$$I_{21} = I_{22} \quad (4)$$
$$N_{21} = N_{22} \quad (5)$$

If the load is connected to the output terminals which are connected to points A and B, current I_2 will pass through it at a voltage U_{22}. As for the layer of the outer secondary winding, formula (2) is definitely applicable and physically feasible. As for the layer of the inner secondary winding, it is evident that the voltage between the terminals which are connected to points A and C will be U_2. The absolute voltage effect of this coil, relative to the B terminal, is reduced by U_{21}, because the direction of the current I_{21} in the outer layer of the secondary winding is opposite to that of current I_{21} in the layer of the inner secondary winding.[9]

$$U_{22} = U_{22} + \text{abs}(U_{21}).\text{sign}(I_{21S}) + \text{abs}(U_{21}).\text{sign}(I_{21H}) = U_{22} + U_{21} - U_{21} \quad (6)$$

Where in sign(I_{21H}) is a symbol for current I_{21} in the layer of the winding of the outer secondary coil, and sign(I_{21S}) is a symbol for current in the layer of the winding of the inner secondary coil. The following formulas apply:[9]

$$\text{sign}(I_{21H}) = -\text{sign}(I_{21S}) \quad (7)$$
$$\text{abs}\, I_{21H}) = \text{abs}(I_{21S}) \quad (8)$$

Due to the aforementioned facts, the coil of the inner secondary winding of the control transformer will have a voltage effect expressed by formula (6), in line with formulas (7) and (8), as if there was another (virtual) collector B, being in contact with the surface of the inner secondary winding in the same position as the real collector on the coil of the outer secondary winding of the control transformer. [9],[10]

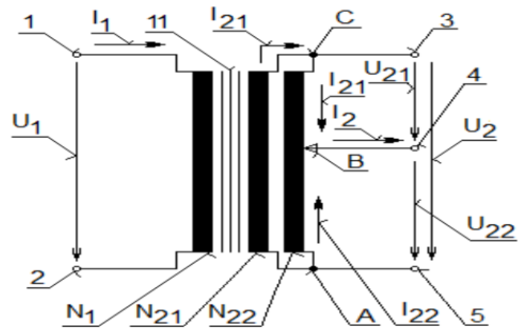

Figure 1. A functional scheme of a control transformer with a double-layer secondary winding

Figure 2. shows an example of an embodiment of this design and the overall arrangement of the functional parts of the device with an innovated design. The control transformer with a double-layer winding consists of a ferromagnetic core 1 with an isolating coil frame 7, around which the primary winding 2 is wound with an insulation layer 6. On top of it, there is an inner secondary winding 3 with an insulation layer 5, as well as the outer secondary winding 4. On the isolated conductive surface of this winding 4, there is a thin layer of transformer oil 23, a sliding collector 8 is pressed against this surface. The collector is connected by a cable 9 to the collector terminal 10**.** The beginning 20 of the inner secondary winding 3 is connected to the beginning 22 of the outer secondary winding 4 and to the terminal of the beginnings 12 by a connection 21. The end 17 of the inner secondary winding 3 is connected to the end 19 of the outer secondary winding 4, which is connected to the terminal of the ends 11 by a connection 18. The beginning of the primary winding 2 is connected by a connection 15 to the input terminal of the beginning 14 of the primary winding 2, and the end of the primary winding 2 is connected by a connection 16 to the input terminal of the end 13 of the primary winding 2.[9]

The control transformer with the design described herein may be used in all types of equipment in which voltage must be continuously regulated within the range from zero to a maximum value and with a possibility of collecting current up to the value determined by the maximum power of the control transformer.[9]

Legend to Figure 2.:

1. ferromagnetic core;
2. primary winding;
3. inner secondary winding;

4. outer secondary winding;
5. isolating layer;
6. isolating layer;
7. coil frame;
8. sliding collector;
9. collector cable;
10. collector terminal;
11. terminal of the ends;
12. terminal of the beginnings;
13. input terminal of the end;
14. input terminal of the beginning;
15. connection;
16. connection;
17. the end of the inner secondary winding 3;
18. connection;
19. the end of the outer secondary winding 4;
20. the beginning of the inner secondary winding 3;
21. connection;
22. the beginning of the outer secondary winding 4;
23. transformer oil layer.

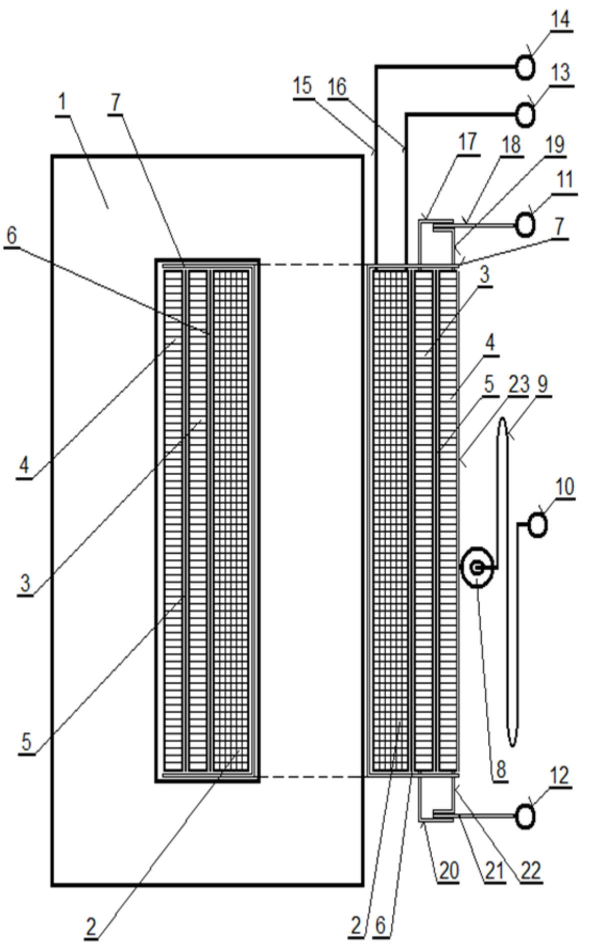

Figure 2. Overall arrangement of the functional parts of the innovated device

5. Conclusion and Industrial Applicability

Current technological achievements of our civilisation exhibit an exponential growth, and we are now witnessing emergence of new devices, as well as innovations of obsolete devices. There is an ongoing trend of consuming electrical energy and increasing the power of various types of equipment; such power needs to be transformed, depending on a distance and size of the transformed power, and this is facilitated by a transformer.[11] A transformer is an electrical device which transforms the supplied alternating voltage and current into other voltage and current values without changing the frequency, while concurrently carrying the active and reactive power from the primary network to the secondary network. It is based on the principle of electromagnetic induction, but without a rotary motion.[9] Transformers are used mostly in power engineering as step-up transformers in power plants where they increase voltage from a value appropriate for manufacturing into a value appropriate for the transmission, or as step-down transformers, which are used at terminal points of long-distance power distribution networks.

Control transformers with the design described herein may be used in all types of equipment in which voltage must be continuously regulated within the range from zero to a maximum value and which facilitate the current collection up to a value determined by the maximum output of the control transformer.

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