CALCULATING MATHEMATICAL EXPRESSIONS OF **LINEAR ELECTROMAGNET WITHOUT THE STOP WITH TRAPEZOID SHAPED CROSS SECTIONAL AREA TRAPEZOIDAL CROSS-SECTION *CONTROL WINDING* (III)**

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Abstract

This work presents calculating mathematical expressions and additional algorithms from corresponding literature that enable calculating and designing a linear electromagnet without a stop with or without an external magnetic wire, with any shape (cylinder, ball, etc.) and different cross-sectional areas of anchor. The shaped of the control winding's cross section is trapezoid.

Аннотация

В работе представлены математические выражения, в которых, при добавлении алгоритма и математических выражений из соответствующей литературы, можно рассчитать и спроектировать линейный электромагнит без стопа с внешним магнитопроводом или без него, с любым видом якоря (цилиндр, шар и т.д.) и с различными площадями поперечного сечения. В электромагните поперечное сечение обмотки управления имеет трапециевидную форму.

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Keywords: calculation, project, linear electromagnet, *trapezoidal cross-section* winding, anchor, electromagnetic force.

Ключевые слова: расчет, проект, линейный электромагнит, обмотка трапециевидной сечением, якорь, электромагнитная сила.

Foreword: Till lately the cross section of the control winding (CW) of electromagnetic systems was rectangle. But during recent years we imported CW with trapezoid cross section to the field of electromechanics. Its usage in different systems proved its privileges above the tradition windings with rectangle shaped cross section. There are many scientific articles and certificates of invention [1-10].

In the presented work we observe the main calculating principals and approaches of linear electromagnet without a stop (LEWS) with trapezoid cross-sectioned CW. The calculation and automated design system of LEWS with rectangle cross-sectioned CW is presented in the published works [11, 12]. As the space of the work is limited only the calculating expressions and approaches that are unique for LEWS with trapezoid shaped cross-sectioned CW are presented.

Fig. 1 illustrates the structure of the linear electromagnet without the stop (LEWS) and the letter notations of the main dimensions, where 1 is the CW with trapezoid shaped cross section, 2 is the feromagnetic anchor, 3 is the external magnetic wire. The anchor may be of any shape-cylinder (as in the image), ball, etc, and may have different cross sectional areas. The explanations of the physical meanings of the main letter notations can be found in work [11]. In the Fig. 1, h_1 and h_2 are correspondingly shorter and longer bases of the trapezoid-the heights of the CW.

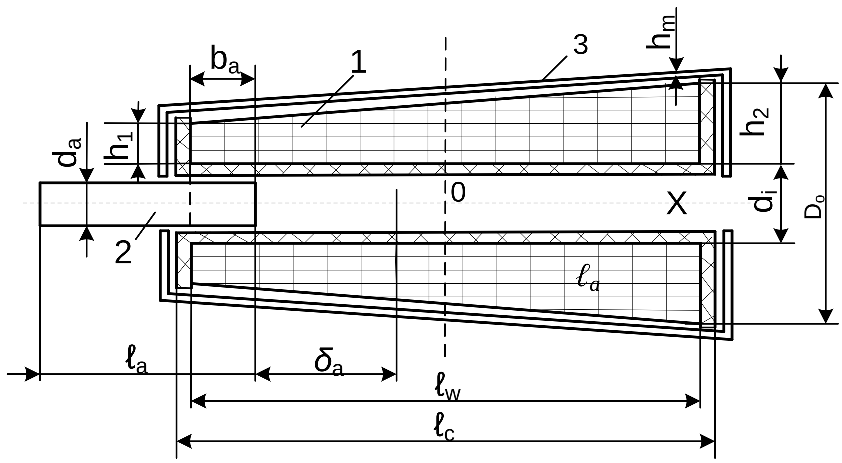
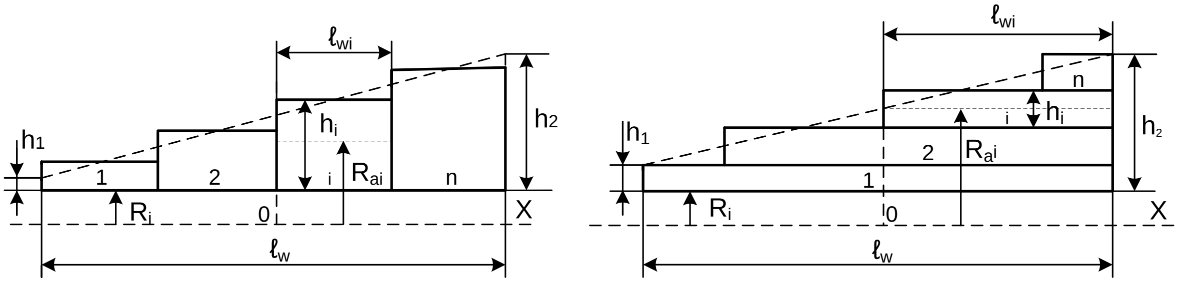


*Fig. 1. T*rapezoidal cross-section *CW The structure of the LEWS and letter notations of the main dimensions*

Problem settings and method justification.

The main task of the calculation is to find the induction value of the magnetic field in certain points of b_a axis along X axis of the CW. For this the whole CW is divided into n basic windings with rectangle shaped cross sections. The division can be made using either horizontal or vertical cross sections (Fig. 2). The image illustrates the logic of CW division. The principle of overlaying is used to find the total induction value of the magnetic field.

In the presented work the vertical division of the CW is used.



a. *b.*

Fig. 2. Examples of division of CW with trapezoid shaped cross section into windings with rectangle shaped cross section.

a. vertical division, b. horizontal division

In order to increase the preciseness of the calculations b_a part of the anchor is divided into parts considering the structural features of the anchor. Here the example of cylindrical anchor is observed.

In case of the cylinder, to simplify the calculations, b_a length of the anchor is divided into m equal parts $\Delta_{aj}=b_a/m$, j=1...(m+1) (Fig. 3):

Let's observe mathematical algorithm of calculation of magnetic field's induction divided along X axis of the CW.

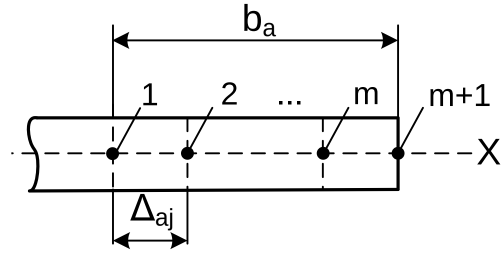


Fig. 3. The division of b_a into m equal parts

The $B'_{(0i)_j}$ induction value of magnetic field of each i-th (i=1...n) basic winding, in each X_j point on the symmetry axis of the whole CW, is calculated using the following formula

$$B'_{(0i)_j} = \mu_0 \frac{F_{wi}}{2\ell_{wi}} \left[\frac{0,5\ell_{wi}-X_j}{\sqrt{R_{ai}^2+\left(0,5\ell_{wi}-X_j\right)^2}} + \frac{0,5\ell_{wi}+X_j}{\sqrt{R_{ai}^2+\left(0,5\ell_{wi}+X_j\right)^2}} \right], \quad (1)$$

where F_{wi} is the magnet moving force (MMF) of i-th winding

$$\sum_{i=1}^{n} F_{wi} \approx F_w, \quad (2)$$

$$F_{wi} = \frac{2F_w}{\ell_w(h_1+h_2)} S_{wi}, \quad (3)$$

F_w is the MMF value of the whole CW,

S_{wi} is the area of the i-th winding

$$S_{wi} = h_{mi} \frac{\ell_w}{n}, \quad (4)$$

h_{mi} is the height of the i-th winidng

$$h_{mi} = h_1 + (2i-1)\frac{h_2-h_1}{2n}, \quad (5)$$

X_j is the distance between j-th point and symmetry axis of the whole CW

$$X_j = (i-0,5)\frac{\ell_w}{n} - (j-1)\Delta_{aj}, \quad (6)$$

j is the number of the calculated point,

R_{ai} is the avarage radius of the i-th winding

$$R_{ai} = \frac{1}{2}(d_i + h_{mi}). \quad (7)$$

Total induction value of the magnetic field in each j-th point is equal to the sum of induction values of the magnetic field in n basic windings

$$B'_j=\sum_{i=1}^{n} B'_{(0i)_j}. \quad (8)$$

The average length of the spirals of the whole CW is calculated in the following way

$$l_{aw} = 2\pi\left[R_i + \left(\frac{h_1+h_2}{4}\right)\right], \quad (9)$$

and the cooling area

$$S_c = 2\pi\sqrt{l_w^2 + (h_2 - h_1)^2}[R_i + h_m], \quad (10)$$

where

$$h_m = \frac{h_2+h_1}{2}. \quad (11)$$

Using the mentioned expressions and logics one can get expressions for the horizontal division of the CW.

The rest of the expressions for the complete calculations of the LEWS are the same as for the LEWS with CW with rectangle shaped cross section, which can be found in literature [11], and for the automated design in the literature [12].

Conclusion. Using the mentioned expressions and corresponding literature one can calculate and design a linear electromagnet without a stop with or without an external magnetic wire with any armature (cylinder, ball, etc.), with different trapezoid shaped cross sectional areas, and with control winding.

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Literature

1. Hovhannisyan A., Grigoryan *A.*, Sargsyan V., *Khachatryan V.* The Applications of the trapezoid control coil in electromechanics // Wykształcenie i nauka bez granic: Materiały IX międzynarodowej naukowi-praktycznej konferencji.- 2013.- V. 46.- P. 50-55.

2. Оганесян А.Т., Григорян А.Х., Хачатрян Ш.Д., Хачатрян В.А. Особенности обмотки управления трапециевидного сечения в электромеханических системах // "Научно-теоретический и практический журнал Уральский Научный Вестник". Серия: Технические науки, Современные информационные технологии, Химия и химические технологии.- 2014, № 21 (100).- С. 79-83.

3. Оганесян А.Т. Расчет тягового электромагнитного усилия длинноходового электромагнита без стопа // MATERIALS OF THE I INTERNATIONAL SCIENTIFIC AND PRACTICAL CONFERENCE «SCIENCE AND EDUCATION - 2014» Volume 20, Technical sciences Belgorod - Sheffield Science and Education LTD. 2014, P. 43-47.

4. Оганесян А.Т., Григорян А.Х., Хачатрян Ш.Д., Апетян Н.В**.** Особенности обмотки трапециевидного сечения в электромагнитной системе //

Электротехника: сетевой электронный научный журнал.- 2015, Т. 2, №2.- С. 50-52.

5. Оганесян А.Т., Григорян А.Х., Хачатрян Ш.Д. Влияние внешнего магнитопровода на магнитное поле обмоток прямоугольного и трапециевидного сечений // Актуальные проблемы гуманитарных и естественных наук.- М., 2015.- №12, ч. 2.- С. 169-174.

6. Оганесян А.Т., Григорян А.Х., Хачатрян Ш.Д. Исследование и сравнительный анализ плотности электромагнитной энергии обмоток прямоугольного и трапециевидного сечений / ВЕСТНИК ИНЖЕНЕРНОЙ АКАДЕМИИ АРМЕНИИ.- 2016.- Т. 13, № 1.- С. 44-48:

7. Patent of RA 2349A. The reed relay / A.T. Hovhannisyan, *A.Kh.* Grigoryan, V. G. Sargsyan.- 2010.

8. Patent of RA 2572A. The linear electromagnet / A.T. Hovhannisyan.- 2011.

9. Patent of RA 2609A. Electromagnet / A.T. Hovhannisyan.- 2012.

10. Patent of RA 2708. The electromagnetic linear accelerator / A.T. Hovhannisyan.- 2013.

11. **Hovhannisyan A.T.** SYSTEM OF DESIGN AND CALCULATION OF LINEAR ELECTROMAGNET WITHOUT THE STOP (I) / Сборник публикаций научного журнала "Chronos" поматериалам XXXIII международной научно-практической конференции: «Естественные и технические науки в современном мире».- М: Научный журнал "Chronos", 2018.- С. 18-24.

12. **Hovhannisyan A.T., Grigoryan A.Kh., Yenokyan K.R., Babayan A.N.,** Khachatryan V.H. AN AUTOMATED SYSTEM OF DESIGN AND CALCULATION OF LINEAR ELECTROMAGNET WITHOUT THE STOP (II) / Сборник публикаций научного журнала "Chronos" поматериалам XXXIII международной научно-практической конференции: «Естественные и технические науки в современном мире».- М: Научный журнал "Chronos", 2018.- С. 24-29.