LINEAR SYNCHRONOUS MOTOR WITH TRAVELLING WAVE-EXCITATION

(1) Dr. Ferenc Tóth, (2) Norbert Szabó
(1), (2) University of Miskolc, Department of Electrical and Electronic Engineering
(1) (2) University of Miskolc, H 3515 Miskolc-Egyetemvaros
(1), (2) Phone: 00 36 46 566 111 /12 59Fax: 00 36 46 563 447
email: (1) elktoth@gold.uni-miskolc.hu, (2) elkszabo@gold.uni-miskolc.hu

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1.Introduction

Derivation Of The Linear Machines is usually carried out from the construction of conventional rotary machines. Accordingly if a conventional rotary machine is cut by a radial plane to the axis and unrolled we can obtain an electrical machine with two parallel plane surfaces separated by airspace. In this way, a number of different type of linear machines can be developed depending on the type of the initial rotary machine, we can speak about linear induction motor (LIMs), linear synchronous motors (LSMs), and direct-current linear motors (DCLMs). The result is a flat linear motor that produces linear force. Terms used at the rotary machines "stator" and "rotor" at the linear machines correspond to the primary and secondary, respectively. It is clear that were motion over a considerable distance is required with a constant power, either the primary or the secondary member must be elongated. Such elongation leads to the major classes of linear machines which may be designated as "short primary" and "short secondary". The alternating current linear synchronous motor can be obtained, if a wound-rotor induction motor is cut by a radial plane and unrolled. (It is considered as a double-sided stator configuration without secondary part.) The arrangement described above assumed that both parts consist of electrical conductors in slots in a laminated steel core, which is the usual arrangement in a rotary machine. If the primary windings and the secondary windings are exited from the same supply then two moving magnetic fields are produced, under proper circumstances, in same direction. If the secondary can move, then a force is established, that is put the secondary in motion and the poles of the two parts will be positioned opposing one another (this is the synchronous standing state). In the case if, for example, the frequency of the supply in secondary part is changed and the frequency of the supply in primary part remains constant, in this moment a force will be developed and the secondary will move with a velocity determined by the difference between the frequencies. As this kind of arrangement and supply of linear machines cannot be found in the technical literature the method is patented. [1]

1.1 Basic connection in Finite-element calculating method

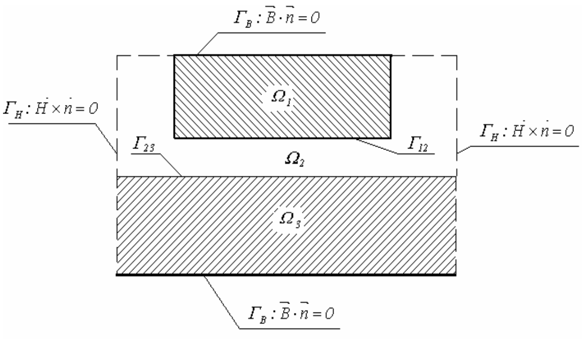
We determinate the motor important parameter with the help of finite element method. The allotted task solution did in the following steps with the finite-element method. First of all the examine piece, or spatial- (two dimension case plane) partial, dissociation to range-part so-called finite-element. Finite-element interface, respectively sign significant point inside so-called node, where we took some nodal parameter. The nodal parameter in most cases the replacement value was the task typical function in the nodes. The typical function approximate in partly (range-part). The approximate functions were polynomial mostly, which come about the nature of the task need to satisfaction the conditions. Take approximate function in every range-part finite element interface node parameter use interconnect.

The substitution of approaching concern the whole body into the given function of the typical function, transform the functioned function into node parameters function..

The linear algebraic equation system solution gives the value of the node parameters.

Knowledge of node parameters use elementary approximate polynomial any points of the body determinable the characteristic function, respectively the derive quantity (e. magnetic inductio n). [2, 3]

Linear synchronous motor with travelling wave-excitation two dimension calculation model accordingly above enumerated principle the 1. figure show dissociation of the range and terminal period. In the 1. figure we note that what kind of margin condition consider the external rim of the whole range. Inside the range the W_1 is the either deexcitation, W_3 is the other deexcitation, while the W_2 is the airspace between the two part, the $\vec{n}$ vector is surface normal of this range.



1. figure.

Between the W_1 and the W_3 range the following equations are valid:

$$rot\,\vec{H} = \vec{J}_{1(vagy\ 3)} \qquad (1)$$

$$div\vec{B} = 0 \qquad (2)$$

$$\vec{H} = n(B)\vec{B} \qquad (3)$$

Inside the W_2 range are:

$$rot\,\vec{H} = 0 \qquad (4)$$

$$div\,\vec{B} = 0 \qquad (5)$$

$$\vec{H} = n_0\,\vec{B} \qquad (6)$$

where $n = 1/m$ the magnetic reluctance. The formulas below are available in the G_{12} margin transition:

$$\vec{n} \times (\vec{H}_1 - \vec{H}_2) = 0 \qquad (7)$$

$$\vec{n} \cdot (\vec{B}_1 - \vec{B}_2) = 0 \qquad (8)$$

$$\vec{n} \cdot \vec{J}_1 = 0 \qquad (9)$$

Similarly the G_{23} margin transition are:

$$\vec{n} \times (\vec{H}_2 - \vec{H}_3) = 0 \qquad (10)$$

$$\vec{n}(\vec{B}_2 - \vec{B}_3) = 0 \qquad (11)$$

$$\vec{n} \cdot \vec{J}_3 = 0 \qquad (12)$$

Figure 1. show margin face:

$$\vec{n} \cdot \vec{B} = 0 \text{ in the } G_B \text{ at margin} \qquad (13)$$

$$\vec{n} \times \vec{H} = 0 \text{ in the } G_H \text{ at margin} \qquad (14)$$

Magnetic vector potential as usual to choose in two dimension tasks for the typical function of the node parameters.

As known with the help of the vector potential represent magnetic induction,

$$rot\,\vec{A} = \vec{B} \qquad (15)$$

With knowledge of the known vector-transformations using the (15) and the(3) the(1) can be expressed in the following way:

$$rot(n \cdot rot\vec{A}) = grad(n) \times rot\vec{A} + n \cdot grad(div\vec{A}) - n \cdot \Delta\,\vec{A} = \vec{J}_{1(or3)} \qquad (16)$$

Apply the (16) equation to on element of the examined domain, it is possible that inside the element the, n reluctance value is permanent, furthermore with the Coulomb measure ($div\,\vec{A} = 0$) the (16) become simple considerably::

$$n \cdot \Delta\vec{A} = -\vec{J}_{1(or\ 3)} \qquad (17)$$

The (17) is the expression of the Poisson equation solution by given limit can be reduced to a variable problem solution. In case of plane-problem the

$$I = \int_{\Omega}\left(\frac{n}{2} rot^2\,\vec{A} - \vec{J}\,\vec{A}\right) d\Omega - \oint_{\Gamma} \vec{A}\,\vec{J}_{\Gamma} dl \rightarrow \min \qquad (18)$$

we look for the value of $\vec{A}$ vector-potential belong to integral extreme of [4].
Examining two dimension case we have to consider only the z direction components of the vector-potential and the current density, so the(17) is reduced to the following scalar equation:

$$n\,\Delta\,A = -J \qquad (19)$$

If we exam the(18) equation with Dirichlet type limit-condition, then on the limit-surface the A tangent component is prescribe , and if it zero, then on the right side of the (18) equation found second integral is zero, so (20) integral expressed to one finite-element

$$I_e = \int_e \left[\frac{n}{2}(grad\ A)^2 - JA\right] dx\,dy \rightarrow \min \qquad (20)$$

has got extreme, if the along the curve border the W surface the A varies as it is prescribed (In the appendix we introduce the connection between energy-process and the energy-functional in the current-machines.) The (20) equation has got extreme value, when its first variation is zero. Constitute (20) the derivative as (A) of magnetic vector-potential, we can write on the i[th] node of e element:

$$\frac{\partial I_e}{\partial A_i} = \int_e \frac{\partial}{\partial A_i}\left[\frac{n}{2}(grad\,A)^2 - JA\right] dxdy = \int_e \left\{\frac{n}{2}\left[\frac{\partial A}{\partial x}\cdot\frac{\partial}{\partial A_i}\left(\frac{\partial A}{\partial x}\right) + \frac{\partial A}{\partial y}\cdot\frac{\partial}{\partial A_i}\left(\frac{\partial A}{\partial y}\right)\right] - J\frac{\partial A}{\partial A_i}\right\} dxdy = 0 \quad (21)$$

Where the A can be obtained from A_i vector-potential values, which are in the node of the vector-potential element. By the task, which is delineated, we divided the examined quadrangular domains to finite- elements, by which in a quadrangular element the vector-potential value can be expressed from the geometric measures and the vector-potential values of nodes:

$$A(z,h) = N_i(z,h)A_i + N_j(z,h)A_j + N_k(z,h)A_k + N_l(z,h)A_l = [N]\{A\} \qquad (22)$$

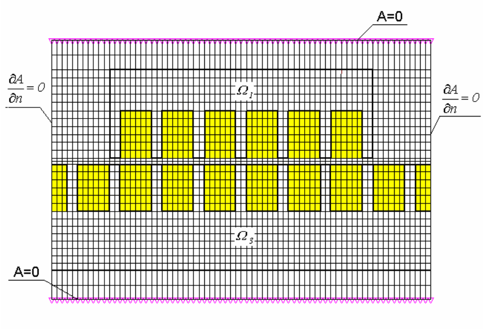
where $N_{i,j,k,l}$ is form-factor connected with geometric measures and position of finite- element [5], $A_{i,j,k,l}$ is the value of vector-potential in the summit of quadrangular substituting (22) for (21), then doing the pointed deriving and integrating, we get to an algebraic equation system, which usually is given in matrix form.

$$[\underline{\underline{K}}]^e \{\underline{A}\}^e = \{\underline{\underline{C}}\}^e \qquad (23)$$

where, $\{\underline{A}\}^e$ is the pillar matrix of magnetic vector-potential values of nodes connected with element, $[\underline{\underline{K}}]^e$ is the factor matrix, which contains the geometric measures between nodes and the values, which determine the position of node, $\{\underline{\underline{C}}\}^e$ is the pillar matrix of current-density values connected nodes.

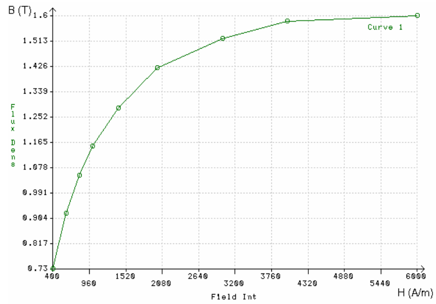
Solved the (23) equation by all element of the examination W domain, we get in the nodes of domain the values of magnetic vector-potential, so we can consider more space-description values.

We used the COSMOS/M ESTAR program package to the solution the task above mentioned, by which on the 1.figure mentioned task realization in ESTAR program, the finite element distribution and the border conditions are shown by 2. figure.



2. figure Two dimension –model with quadrangular formed finite-element distribution

By the calculation we considered the non-linearity of iron components in the W_1 and W_3 domains. In 3. figure we can see the B-H magnetic curve of the iron, which has been taken into the program as data.

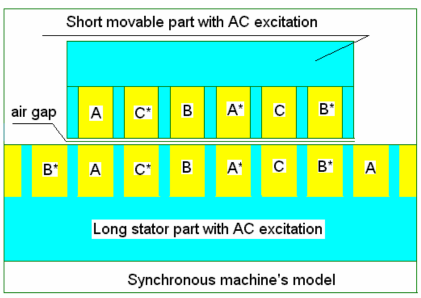


3. figure The curve of iron B-H applied in the program

1.2 Introduction of calculated results

The calculations were run with transient analysis program, we supposed, that the excitation of long armature (the W_3 domain) - as the 4. figure shows - is alternating current. The place values of calculated results we introduce in two typical status of synch operation, neutral operation status in a close status, and the maximum load in close status. (The close attribute refer to the values, we got between the neutral and the maximum load and we have possibility to introduce them) The 4a shows the place-values of calculated values: magnetic vector-potential, magnetic induction, hauling power and attractive power.

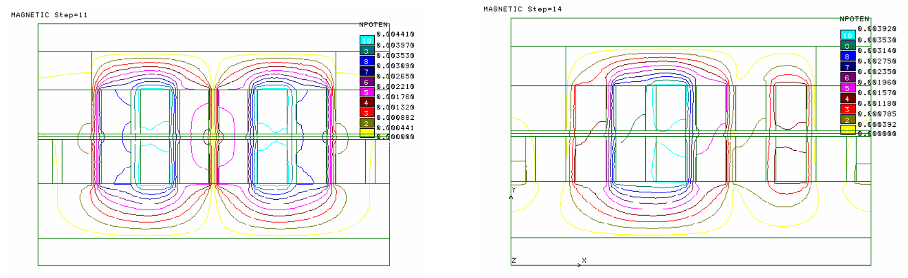
At first we introduce those results, which shows the values close to the synch status. The 4. figure shows the geometric arrangement of taken engine-model, if the long vertical-part has got A.C. excitation.



4. figure Geometric arrangement of engine model taken to calculation

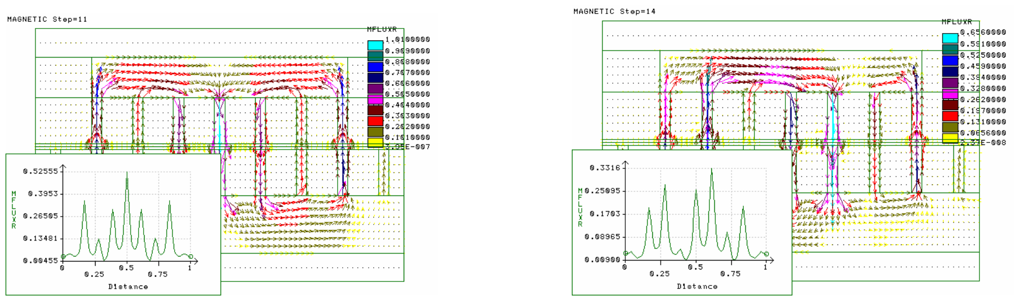
1.3 The results of the proceeding wave excitation engine.

The changes of more important typical of place-values in the neutral state of engine (a, figures), in the maximum hauling power state (b, figures)



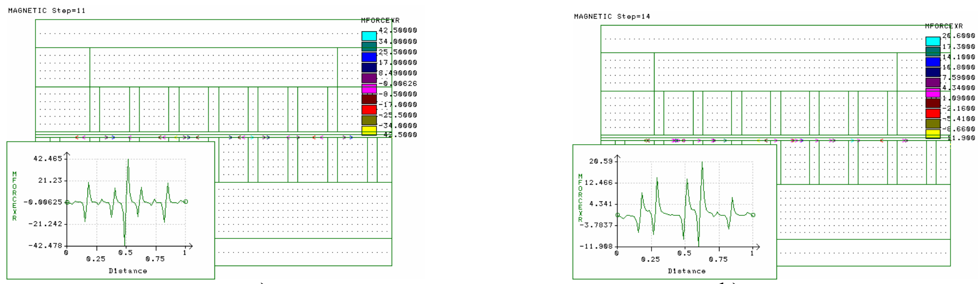
a) b)

5. figure The value of the magnetic vector-potential in node of finite-element: a) neutral, b) status close to dump point



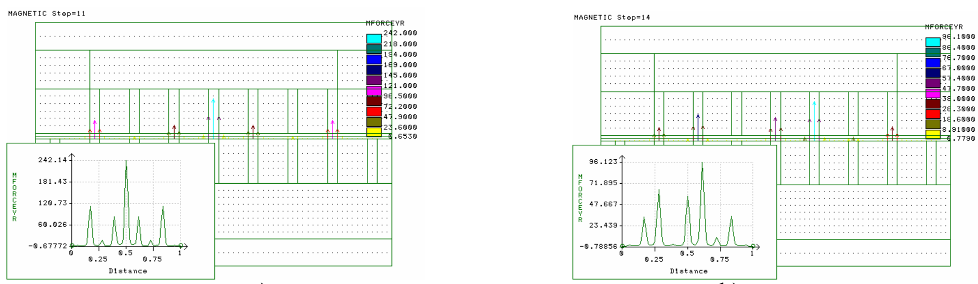
a) b)

6. figure The value of the magnetic induction in node of finite-element: a) neutral, b) status close to dump point



a) b)

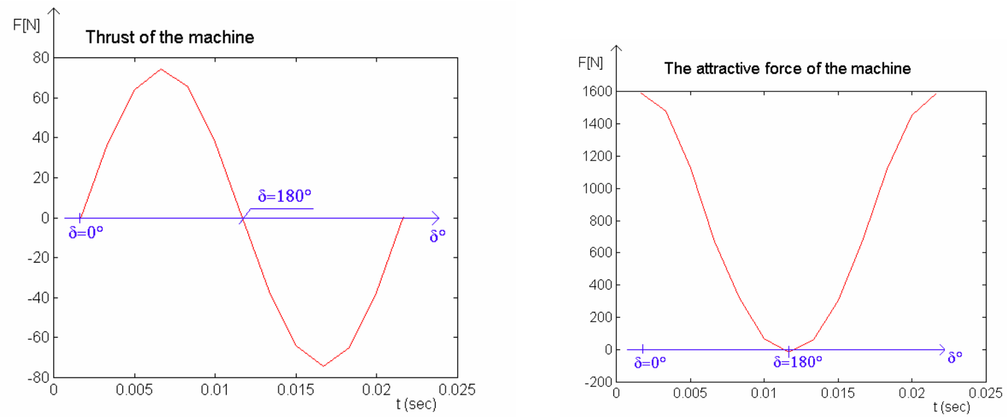
7. figure The values in node of hauling power acted on the long car-case: a) in status close to neutral, b) status close to dump point



a) b)

8. figure The values in node of attractive power acted on the long car case: a) neutral, b) status close to dump point

The calculation where run with transient analysis program like earlier from the output file we can know the average hauling power values. These values was drawn with MATLAB program. The average value of hauling power is shown in 9.a figure, 9.b figure near angular variation, while the attractive power average value is shown in 9.b. figure.

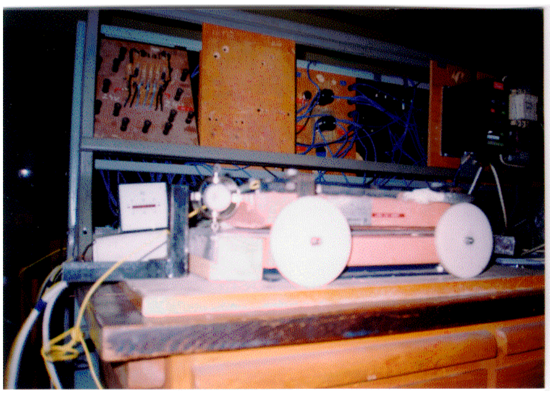


a) b)

9. figure The average a) hauling power, b) attractive power on 1 m wide engine determined with calculation

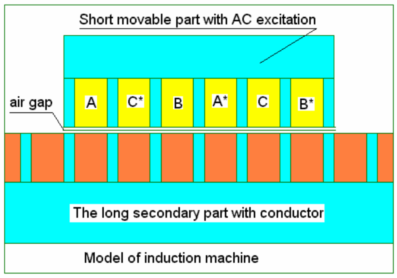
1.4 Supporting of calculated results with experiment

We used the 9 laboratory model shown in 10. figure to the measurement, where we used cross linear engine. We fixed the first engine, while the second can move on wheel. The two one-sided inductor was added up to atomic battery, then measured from synchronous point 363 N. If now we bind the one inductor from power supply and we close the battery shoe short (additional winding with linear induction motor),the value of hauling power in this status 21 N. The ratio of the measured values is 17,3 .



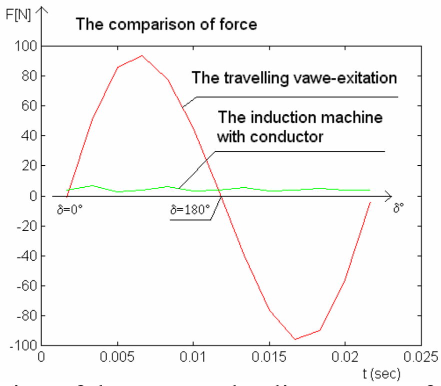
11. figure Laboratory measuring station

We had to make the engine model with winded secondary part to compare the ratio of calculated results. Unfortunately because of the bounded amount of our program we couldn't make the finite element calculating model of real laboratory model, only the induction engine model as the 4. figure shows. The 12. figure shows the geometric arrangement of winded secondary linear induction motor.



12. figure The geometric arrangement of the induction engine

The 15. Figure shows the hauling power of the winded secondary induction engine in standing position 12. figure and the travelling-wave excited induction engine 4. figure. We get near the calculated values the following ratio: 74,4 N/4 N= 18,6 . In spite of the fact, that the parameters of the engine- to the measuring and calculation- are different , the rations gives very similar values, which justify the simulation results.



15. figure. The comparing of the average hauling power of 1 meter wind engines

2. Conclusion

In this article we introduce by a small speed (or middle speed) linear synch engine a excitation method and arrangement that hasn't been examined except the author in the bibliography by linear engine. The author called this engine arrangement: travelling-wave engine. If we compare the travelling-wave engine with the linear induction engine which has got similar parameters, then the travelling-wave engine has got many advantage opposite the induction engine: it originate much bigger hauling-power, the longitudinal direction final-effect, the cross direction final-effect is similar by the rotating machines, the magnetic air-gap smaller than by the induction engines. So the efficiency, the performance-factor. The variation of the engine-speed and direction can be simply solved, at braking the energy get back to the network. It's disadvantage against the induction engine is that the whole path-length must be made winded and a one winded part must be fed from variable frequency inverter. But the mentioned disadvantages apply once at the investment.

3. Reference

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