SIMULATION OF LINEAR ELECTRIC MOTOR FOR ELECTROMECHANICAL PRUNER

Sergey ANTONOV [1], Gennady NIKITENKO [1]

[1]*Department of Using Electric power in Agriculture, Russian Stavropol State Agrarian University*

Abstract
Gardening is a complex system for the production of berries and fruits, which includes material, financial and labor resources aimed at obtaining the maximum economic effect. Electromechanical pruners based on linear electric motors have several advantages over manual, pneumatic and hydraulic. The use of linear electric motors is one of the promising areas for the development of electric hand tools. The analysis of existing designs of linear electric motors revealed a number of drawbacks. These disadvantages are low efficiency, large mass and size, low armature thrust. The proposed electric motor has the design features of the magnetic system of the stator and the armature. Features are a combination of the design parameters of the magnetic pole of the stator and the armature magnetic circuit. They allow you to increase the power of the armature thrust, increase the efficiency, reduce the weight and size of the electric motor. One of the main tasks in the design of a linear electric motor is to obtain the maximum value of the armature thrust force. To do this, it is necessary to conduct its computer simulation, in order to determine the rational design of the magnetic system. The main factor is the design features of the magnetic system in the air gap, where the energy of the stator magnetic field is converted to the force of the armature. The design parameters affecting the magnitude of the thrust force of the armature determined the bevel angle of the magnetic pole of the stator and the bevel angle of the armature magnetic circuit. The combination of these parameters in different combinations allows you to get a rational design of the magnetic system of a linear electric motor with the maximum value of the armature thrust force.

Key words: *Linear motor; thrust force; magnetic system; pruner.*

INTRODUCTION

Get high productivity, durability, winter hardiness of trees, regulate growth, as well as product quality allows timely and high-quality pruning of trees.
Detailed pruning of tree branches is done by hand. To increase labor productivity when pruning of branches, we can use mechanization and electrification of works. The analysis of the existing devices of increasing in labor productivity allowed developing the following classification (Fig. 1.).

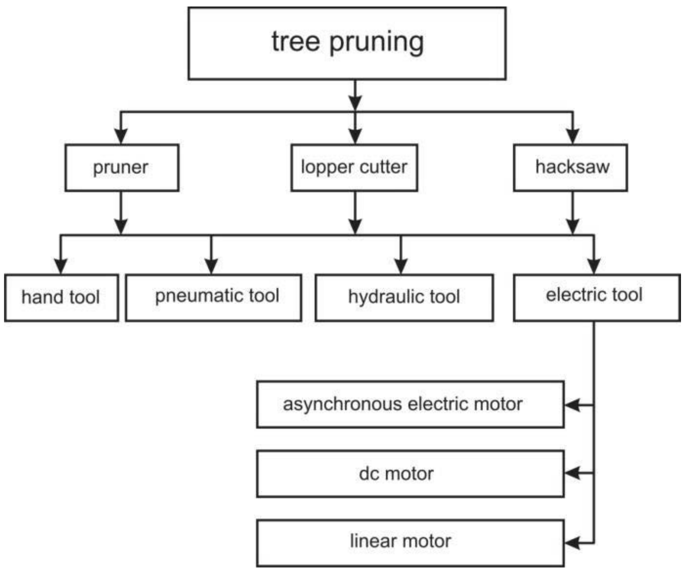


Fig. 1 Classification of mechanization process of trees pruning

Each of the considered tool types has positive and negative sides. The most promising is the use of electrified hand tools for trees pruning (*Hedrick, 1922; Csanády, Magoss, 2013*).
For branches pruning, there are many electromechanical pruners manufactured by industry. These are such as: Makita 4603PW, Makita DVP361Z, Bosch Ciso, Electrocoup F3010, HDP08G, etc. (Fig. 2.)

a) b)
Fig. 2 Electromechanical pruners: a **-** HDP08G; b **-** Electrocoup Infaco

All considered models of electric pruners use direct current motors to drive blades. One of the disadvantages of these engines is high power consumption. This leads to the use of a large mass and overall dimensions battery for powering the electric motor (*Antonov, Nikitenko, Grinchenko, Molchanov, & Avdeeva, 2018*). The main task in the development of a linear electric motor, for hand tools, is to obtain the maximum value of the armature thrust force. To obtain this force of armature thrust it is necessary to optimize the design of the magnetic system of a linear electric motor.

MATERIALS AND METHODS

The linear electric motor (Fig. 3.) consists of a stator (1), which contains a magnetic body (2), a magnetizing coil (3), a non-magnetic frame (4), an upper magnetic pole (5), the cross section of which has the shape of a rectangular trapezium, an end magnetic pole (6), a bolt (7) and a lower magnetic pole (8), having a sample in the form of a cylinder, fixed by bolt (9) to the magnetic body (2), and a non-magnetic insert (10). An armature (11) of a linear electric motor consists of an upper magnetic circuit (12) having the shape of a truncated cone, a lower magnetic circuit (13), non-magnetic bushing (14) put on a non-magnetic rod (15). The armature (11) is mounted in the stator (1) by means of a non-magnetic frame (4) and the non-magnetic insert (10), which are sliding bearings. The return spring (16), the washer (17) and the nut (18) are required to return the armature (11) to its original position.

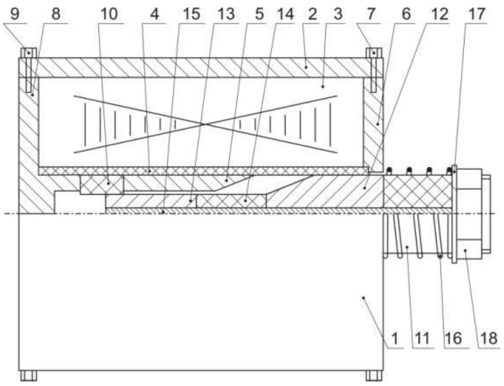


Fig. 3 Linear electric motor: 1 is a stator; 2 is a magnetic body; 3 is a magnetizing coil; 4 is a non-magnetic frame; 5 is an upper magnetic pole; 6 is an end magnetic pole; 7 is a bolt; 8 is a lower magnetic pole; 9 is a bolt; 10 is a non-magnetic insert; 11 is an armature; 12 is an upper magnetic circuit of the armature; 13 is a bottom magnetic circuit of the armature; 14 is a non-magnetic bearing; 15 is a non-magnetic rod; 16 is a return spring; 17 is a washer; 18 is a nut

The proposed linear electric motor works as follows (Fig. 4.): in the absence of power supply to the magnetizing coil (3), the armature (11) takes the upper position under the action of the return spring

(16). When voltage is applied to the magnetizing coil (3), a current creating a magnetic flux Φ starts to flow through it and closes through the magnetic body (2), the end magnetic pole (6), the upper magnetic circuit (12), the upper magnetic pole (5), the lower magnetic circuit (13) and the lower magnetic pole (8).

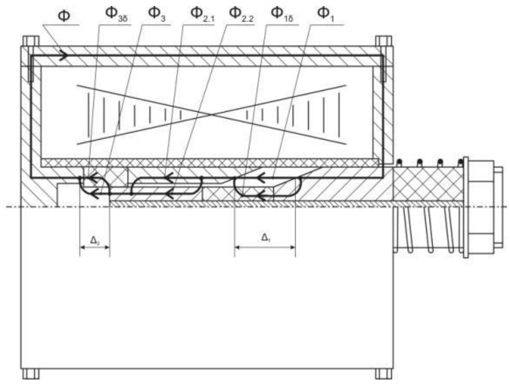


Fig. 4 Magnetic fluxes of linear motor

The magnetic flux Φ in the air gap Δ_1 is divided into magnetic fluxes Φ_1 and $\Phi_{1\delta}$, and in the air gap of length Δ_2 it is divided into magnetic fluxes Φ_3 and $\Phi_{3\delta}$. The magnetic fluxes $\Phi_{2.1}$ and $\Phi_{2.2}$ pass through the upper magnetic pole (5) and the lower magnetic circuit (13). Separation of the magnetic fluxes Φ_1 and $\Phi_{1\delta}$, Φ_3 and $\Phi_{3\delta}$ is possible due to the magnetic resistances commensurability of the air gap and the non-magnetic insert (14). As a result of the passage of magnetic fluxes Φ_1, Φ_3, an electromagnetic force appears, which causes the displacement of the armature (11).
The simulation of a linear electric motor begins with the calculation of magnetic fields. The main characteristic of a magnetic field is magnetic induction, which is a vector quantity. To calculate the magnetic system, we use a two-dimensional magnetostatic problem. The Poisson equation describing the magnetic state of an electric motor in partial derivatives and cylindrical coordinates (r, z). It is recorded as follows:

$$\frac{\partial}{\partial r}\left(\nu\frac{1}{r}\partial r(rA)\right)+\frac{\partial}{\partial z}\left(\nu\frac{1}{r}\frac{\partial}{\partial z}(rA)\right)=J \quad (1)$$

where $\nu=\frac{1}{\mu_0\mu}$ - specific magnetic resistance;
r, z - cylindrical coordinates;
J - current density;
A - vector magnetic potential.

When building a model on the internal and external borders of areas, the following types of boundary conditions are possible.
Dirichlet condition, which sets on the part of the border the known vector magnetic potential A_0, at the top or on the edge of the model. This boundary condition determines the behavior of the normal induction component on the boundary. This condition is most often used to specify a zero value or a complete attenuation of the magnetic field at a border remote from the sources (2).

$$rA_0=a+bzr+\frac{cr^2}{2} \quad (2)$$

where a, b, c - constant values for each edge.
To analyze the calculation results, it is necessary to operate with the following local and integral quantities.

Magnetic induction vector ($B=rotA$)

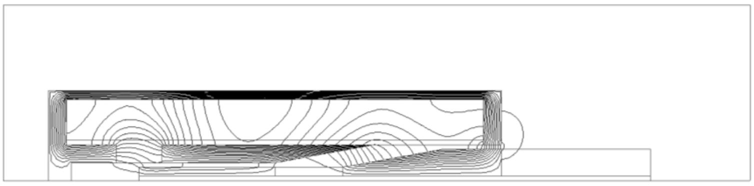
$$B_z=\frac{1}{r}\frac{\partial(rA)}{\partial r},\ B_r=-\frac{\partial A}{\partial z} \quad (3)$$

The total magnetic force acting on the anchor of a linear electric motor is determined by the formula:

$$F = \frac{1}{2}\oint\left(H(n \cdot B) + B(n \cdot H) - n(H \cdot B)\right)dS \qquad (4)$$

Where n - unit vector of the outer normal to the surface.
On the basis of the above formulas, the calculation of the magnetic static field, which is incorporated in the algorithms for calculating the ELCUT program, is constructed. To solve linear problems, the iterative method of conjugate gradients is used.

RESULTS AND DISCUSSION
The purpose of modeling a linear electric motor is to determine the thrust force of the armature. To simulate magnetic fields, we use the professional version of the ELCUT program (*Antonov, Gabriyelyan, Mastepanenko, Zorina & Nozdrovicky, 2016*). As a result of the calculation, we obtain a picture of the magnetic fluxes distribution (Fig. 5.).
a)



b)

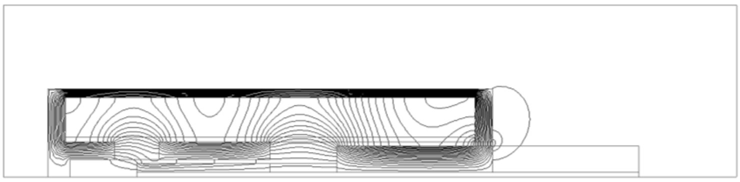


Fig. 5 Calculation result of the magnetic system of the linear motor program ELCUT: a – $\alpha = 10^0$, $\beta = 10^0$; b – $\alpha = 90^0$, $\beta = 90^0$

The main task of modeling a linear electric motor is to rationalize the design of the magnetic system, in order to obtain maximum values of the armature thrust force. The main factor influencing the magnitude of the armature thrust force is the value of the magnetic fluxes Φ_1 and Φ_3 in the air gaps Δ_1 and Δ_2. To rationalize the design of the magnetic system, we change the inclination angle of the magnetic pole of the stator 5 (α) and the inclination angle of the upper magnetic circuit of the armature 12 (β) (Fig. 6a.) from 10^0 to 90^0 at a pitch of 10^0.

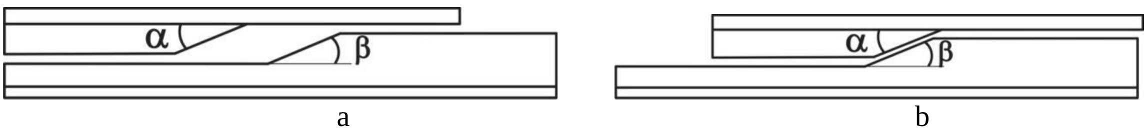


Fig. 6 Magnetic system modeling of a linear electric motor: a - at the beginning of the working stroke; b - at the end of the working stroke

Based on the design features of the magnetic system and the dynamics of the armature (11) relative to the magnetic pole of the stator (5), it is necessary to take into account when modeling their joint at the end of the working stroke (Fig. 6.b). This means that the angle α must be equal to the angle β.
Modeling results of the magnetic system of the linear motor pruner are shown in Table 1.

Tab. 1 Calculation result of the armature thrust force (F_a) of a linear electric motor, N

inclination angle of the magnetic pole of the stator (α) and the upper magnetic circuit of the armature (β) α - β								
10^0-10^0	**20^0-20^0**	**30^0-30^0**	**40^0-40^0**	**50^0-50^0**	**60^0-60^0**	**70^0-70^0**	**80^0-80^0**	**90^0-90^0**
55,52	52,66	45,61	43,31	43,29	41,59	40,972	39,33	38,33

Considering the obtained data, it should be noted that with an increase in the inclination angle of the upper magnetic circuit of the armature (β) and the inclination angle of the magnetic pole of the stator (α) from 10^0 to 90^0, the armature force F_a decreases from 55.52 to 38.33 N. The maximum value of the armature thrust force is calculated as F_a = 55.52 N.

CONCLUSIONS

The use of a linear electric motor for electrified pruners, as compared to direct current motors, will reduce the mass and dimensional parameters of the device.

Modeling of a linear electric motor in the ELCUT program allowed us to confirm the pattern of magnetic fluxes distribution. Conformity of changes in the armature thrust force, from the inclination angles of the magnetic system elements of a linear electric motor was studied. Based on the obtained results, it can be concluded that the maximum value of the armature thrust force $F_a = 55{,}52N$ is obtained at $\alpha = 10^0$ and $\beta = 10^0$.

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Corresponding author:

Ing. Sergey Antonov, Ph.D., Department of Using Electric power in Agriculture, Russian Stavropol State Agrarian University, Chekhova 37, ap.118, Stavropol, Stavropol Territory, 355013, Russian Federation, phone: +79283054566, e-mail: antonov_serg@mail.ru