NUMERICAL CONTROL OF THE ELECTRICAL STEP-BY-STEP LINEAR MOTORS

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1. INTRODUCTION

The position, as output rate of the automatic systems is one of the most important adjustment parameters, by considering that the linear mechanical motion is encountered on most of the applications. The usage of the step-by-step linear motors in the positioning systems as execution elements have the advantage of developing a motor force and generating a linear motion with no mechanical transmission.

This work is presenting a positioning system in open circuit, equipped with step-by-step electric linear motor. Its block diagram is illustrated in fig. 1. An algorithm was also issued for the numerical control of the electrical step-by-step linear motor.

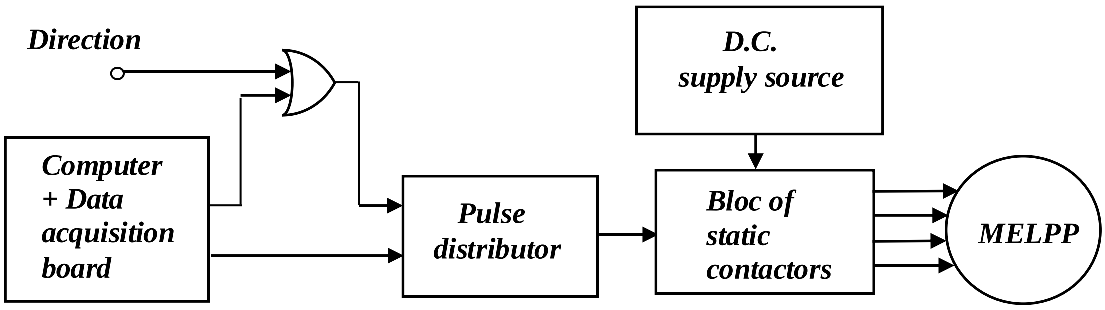


Figure 1. Positioning system in open circuit.

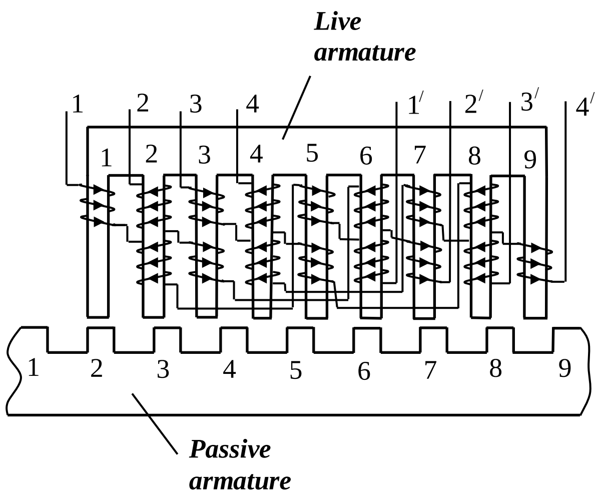
2. THE ELECTRIC STEP-BY-STEP LINEAR MOTOR

The electrical step-by-step linear motor is functioning on the principle of the minimum magnetic reluctance. It is composed of a live armature and a passive armature with a spatial juxtaposition of one to another, as shown in fig. 2. The passive armature consists of a flat material, magnetically permeable, that has several equidistant poles of identical width. The live armature consists of a yoke made of magnetic material including a series of parallel and equidistant poles, having the pole faces defined with identical width at one end. It is understood that the gap that actually is the width deemed for any face of a pole is an extension to a longitudinal direction of the live armature motion.

The distance between the faces of the pole live armatures is equal to the distance between the faces of the passive armature. Anyway, the width of the faces of the live armature poles differs from the width of the passive armature faces by a pitch that is proportional to the number of poles of the live armature. The pitch rate is calculated by means of the formula:

$$p = \frac{L}{M-1} \qquad (1)$$

where L means the pitch of the passive armature and M is the number of poles of the live armature. With a view to increasing the static force of synchronization of the electrical step-by-step linear motor, the live armature is made with a double number of poles. The excitation winding is mounted on each pole and is supplied from an electronic device furnishing, in a selective manner, energy to the excitation winding successively, so that the magnetic field being generated to produce a magneto-motor force between the associated faces of both armatures, thus resulting the motion of the live armature to a position of maximum magnetic flow and minimum magnetic reluctance, respectively. Once this position reached, an oriented force is created, with a view to keeping the live armature at the position of dead point until the next pulse. The excitation winding is made for four distinct phases. Each phase winding is made of four coils located on four different poles. The coils of a phase winding are located on four poles so that on each pole there are two coils of two sequent windings. Through such a location of the coils a each pole there are two coils of two sequent windings. Through such a location of the coils a magnetic circuit of minimum length is provided, through which the magnetic flow generated by the coils of one winding is closed. Thus, the static synchronization force resulted at the supply of one



phase winding will be doubled

Figure 2. The electric step-by-step linear motor

2.1. Establishing the expression of the static synchronizing force

In case of the rotary motors, the expression of the static synchronizing torque can be expressed as the derivate of the magnetic energy in function of the rotation angle of the rotor, [2], [3].

$$M_s = -\left(\frac{dW_m}{d\theta}\right)_{i=const.} \qquad (2)$$

where: W_m means the energy of the magnetic field.

$$W_m = \frac{k}{2}\int_{\Lambda}(wi)^2\, d\Lambda \qquad (3)$$

where k is a factor of proportionality and Λ is the magnetic permeability.

The expression of the static synchronizing torque will be:

$$M_s = -\frac{k}{2}(wi)^2\frac{d\Lambda}{d\theta}\,[Nm] \qquad (4)$$

where Λ is expressed in H and (wi) in A, or:

$$M_s = -5100(wi)^2\frac{d\Lambda}{d\theta}\,[gf.cm] \qquad (5)$$

In case of the linear motors the expression of the static synchronizing force can be established as follows: If in the formula of the static synchronizing torque the replacement $d\theta = \frac{dx}{r}$ (as $x = r\theta$) is done, it will result:

$$M_s = 5100(wi)^2\frac{d\Lambda}{dx}r \qquad (6)$$

The static synchronizing force is:

$$F_s = \frac{M_s}{r} = 5100(wi)^2\frac{d\Lambda}{dx}\,[gf] \qquad (7)$$

The maximum static synchronizing force can be found by replacing in the formula of above the rate of the magnetic permeability for $\theta = 45^0$.

3. THE DEVICE FOR THE MOTOR CONTROL AND SUPPLY

The device for control and supply of the electrical step-by-step linear motor is composed of:
- Computer equipped with data acquisition board;
- Pulse distributor; - Block of static contactors; D.C. supply source.

The train of control pulses and the pulse for selecting the motion direction are generated by the IBM-PC compatible numerical computer, equipped with the data acquisition board model AX 5411. The pulse distributor [4] takes over the train of standard control pulses along with the direction controls and supplies on the output m trains of pulses, distanced one to another by the angle $\theta_{pe} = 2\pi/m$ (electric pitch), where m means the number of phases of the electrical step-by-step linear motor. The signals of the pulse distributor are amplified by means of the static contactor block [4] for transmitting an adequate power to the motor. The D.C. supply source provides a maximum power of 200 W and a stabilized D.C. voltage adjustable at steps within 1 to 40 V D.C. at a maximum current rate of 5A. The data collection board AX 5411 included to the IBM-PC compatible computer has the following features: 16 analog-digital inputs, two digital-analog outputs, 24 numerical inputs and 24 numerical outputs. The control algorithm of the electrical step-by-step linear motor requires performance of the following steps:

- Initiating the data acquisition board;
- Selecting the motion direction;
- Selecting the numerical output channel

the control pulse train;

- Setting the generation frequency of the control pulses;
- Launching the control loop and the stop command;

Within the last step the following operations are done:

- Initiating the counter; - Calling the function for generating the control pulse;
- Incrementing the counter; - Testing the stop condition.

Based on this algorithm a program in TURBO C++ has been issued that was implemented to the positioning system in open circuit whose block diagram is shown in figure 1. The usage of the data acquisition board allows achieving a wide range of frequency for the control pulses.

4. EXPERIMENTAL RESULTS

The positioning system in open circuit with electrical step-by-step linear motor being built has the following features:

- Maximum synchronizing force, $F_{\max}$ = 5 N;
- Motor pitch, x = 5 mm; - Number of control windings: 4;
- Number of poles of the live armature: 9;
- Number of poles of the passive armature: 27;
- Supply voltage, U = 7 through 25 V D.C.; Rated current, I = 1 A.

Fig. 2 is showing a section through the two armatures of the motor and its winding system. The maximum synchronizing force varies in function of the current and voltage for a constant gap as follows: For a gap rate δ = 0.5 mm the results shown in table 1 have been obtained:

Table 1

F $[N]$	1.45	1.85	2.45	3.70	4.80
I $[A]$	0.36	0.5	0.6	0.82	1.1
U $[V]$	3	4	5	6	7

For a gap rate δ = 1 mm the results shown in table 2 have been obtained:

Table 2

F $[N]$	1.1	1.6	2.10	3.05	4.15
I $[A]$	0.36	0.5	0.6	0.82	1.1
U $[V]$	3	4	5	6	7

The static synchronization force decreases along with increasing the gap between the two armatures. The accuracy of the positioning system in open circuit is 5 mm, being equal to the pitch of the linear motor. A program in C++ has been issued and implemented through which the functioning of the electrical step-by-step linear motor has been verified at various transmission frequencies of the control pulses within the range $(1 \div 200)$ Hz.

5. CONCLUSIONS

The positioning system in open circuit is composed of an electronic control and supply device and an electrical step-by-step linear motor. This motor is composed of two armatures, the live armature and the passive armature. The motor pitch is 5 mm and the number of distinct control windings is 4. The static force for synchronization decreases while increasing the gap between the two armatures. The electronic control and supply device provides the sequent switching of the supply voltage ton the phase windings of the motor. The accuracy of the positioning system in open circuit is 5 mm, being equal to the pitch of the linear motor. The positioning system with electric linear motor can be used on machine tools, industrial robots technological lines, etc.

References

1. Catrina O., ş.a.: *Turbo C++ , Editura Teora Bucureşti, 1993.*

2. Kelemen A., ş.a.: *Motoare electrice pas cu pas, Editura Tehnică Bucureşti, 1975.*

3. Livinţi P.: *Motor liniar pas cu pas cu reluctanţă variabilă, A XIV-a sesiune de comunicări ştiinţifice a cadrelor didactice din Academia Navală "Mircea cel Bătrân " Constanţa, 25-27 mai 1995, vol. II, pag. 559-564.*

4. Livinti P., Stan G., Andone C.: *Conducerea cu calculatorul numeric a sistemelor de acţionare electrică cu motoare pas cu pas, A treia conferinţă internaţională de sisteme electromecanice şi energetice SIELMEN'01, Chişinău, 4-6 octombrie 2001, vol. III, pag. 135-138.*

5. Olah I., Mastacan L., Dosoftei C.: *Comanda virtuală a motoarelor pas cu pas, A doua conferinţă internaţională de sisteme electromecanice SIELMEC'99 , Chişinău, 8-9 octombrie 1999, vol. II, pag. 107-110*

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