TẠP CHÍ KHOA HỌC
TRƯỜNG ĐẠI HỌC QUY NHƠN

Nghiên cứu đặc tính động của động cơ không đồng bộ tuyến tính đơn biên ba pha ứng dụng trong thang máy

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TÓM TẮT

Động cơ không đồng bộ tuyến tính có mạch từ hở nên từ thông không liên tục từ cực này đến cực khác mà nó bị cắt ra ở đoạn đầu và đoạn cuối làm từ trường trong động cơ mất đối xứng cũng như dòng điện xoáy trong mạch thứ cấp gây ra sức từ động không sin và gọi là hiệu ứng đầu cuối và dòng xoáy. Việc ứng dụng loại động cơ này trong thang máy cũng đã được quan tâm, tuy nhiên để thực hiện tốt và phát triển loại mô hình truyền động này thì cần có nền tảng nghiên cứu về đặc tính làm việc của động cơ, đặc biệt là đặc tính động. Bài báo đề cập đến vấn đề nghiên cứu đặc tính động của động cơ không đồng bộ tuyến tính đơn biên ba pha ứng dụng trong thang máy trong các trường hợp không mang tải, mang tải, tần số thay đổi và nguồn điện mất đối xứng. Phương pháp mô phỏng trên phần mềm Matlab được sử dụng trong nghiên cứu này.

Từ khóa: *Động cơ không đồng bộ tuyến tính, truyền động thang máy chở khách, mô hình động.*

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Study on dynamic characteristics of three-phase single-side linear induction motor used in elevator

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ABSTRACT

Linear induction motor has open magnetic circuits, so the flux is discontinuous from one pole to the other where it is cut off at the beginning and at the end, making the magnetic field in the motory asymmetric as well as the eddy currents in the secondary circuit cause non-sinusoidal magneto-motive force and is called end effect and eddy current. The application of this motor type in elevators has been of great interest, but to perform well and develop this drive type, it is necessary to have a research background on the working characteristics of motor, especially the dynamic characteristics. The paper deals with the study of dynamic characteristics of three-phase single-side linear induction motor used in elevator in the no-load and loaded elevator, variation of frequency and asymmetric power supply. The simulation method on Matlab software is used in this study.

Keywords: *Linear induction motor, passenger elavator drives, dynamic model.*

1. INTRODUCTION

Elevator is a specialized equipment to transport of passengers, goods, materials, etc. in vertical direction. The characteristics of transport by elevator compared to other means of transportation are the time of a small transport cycle, large transportation frequency, continuous opening and closing of the machine.

Structure diagram of elevator using linear induction motor (LIM), drive winch with cable sheave by friction is shown in Figure 1.[1] The winch is located above the elevator shaftway which run along the entire height of the building. On the load-bearing structure along the elevator shaftway, there are guide rails attached to the counterbalance unit and the elevator cabin which are hung on the two ends of the lifting cables thanks to the suspension system. The suspension system is intended to ensure that the individual lifting cables are of equal tension. The lifting cable is squeezed through the cable grooves of the friction pulley of the winch. When the LIM operates, the towing winch operates, the friction pulley rotates and transmits motion to the lifting cable, the elevator cabin goes up or down on the guide rails along the elevator shaftway, LIM rests on guide rails along the length of the secondary part.

Linear induction motor has open magnetic circuits, so the flux is discontinuous from one pole to the other where it is cut off at the beginning and at the end, making the magnetic field in the motor asymmetric as well as the eddy currents in the secondary circuit cause non-sinusoidal magneto-motive force and this is called end effect and eddy current. In Figure 2,[2-4] these effects are modeled and simulated on the basis of mathematical model,[5] and finite element method 3D.[6]

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The content of the paper presents a dynamic model of a three-phase single-side linear induction motor (SLIM) used in elevators taking into account the components of end effects and eddy currents, thereby surveying the thrust and velocity responses when starting the system in the cases of no-load, load-carrying, variation of frequency and asymmetrical power supply. This can be considered as the basic foundation for the study of the SLIM to develop and implement an appropriate control model. The simulation method on Matlab software is used in this study.

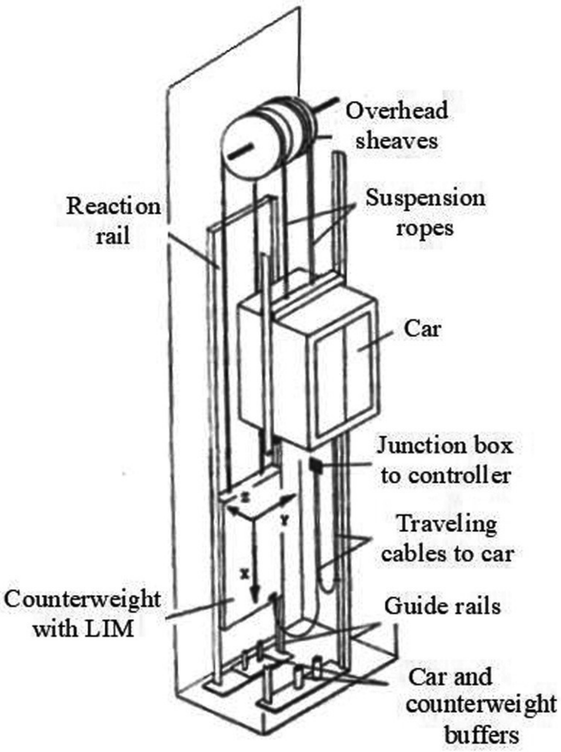

Figure 1. Passenger elevator model using the LIM

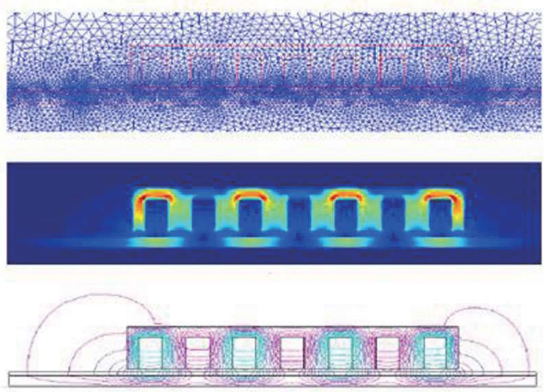

Figure 2. Flux density distribution inside the LIM

2. SLIM MODEL TAKING INTO ACCOUNT THE COMPONENTS OF END EFFECT AND EDDY CURRENT

Components reflect end effects:[4] $L_m.(1\text{-}f(\xi))$

with $\xi = \dfrac{l.R_r}{L_r.v}$ và $f(\xi) = \dfrac{1-e^{-\xi}}{\xi}$ (1)

When the SLIM is moving, in the secondary side

When the SLIM is moving, in the secondary side aluminum plate exists an eddy current component and causes loss.

and causes loss.

$$P_{dx} = R_r.I_\mu{}^2 \frac{1-e^{-\xi}}{\xi} = I_\mu^2 R_r f(\xi) \quad (2)$$

The characteristic component for this loss is

The characteristic component for this loss is $R_r.f(\xi)$, and it is connected in series in the magnetization branch as shown in Figure 3.

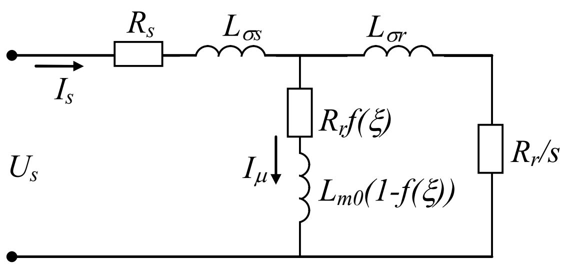

Figure 3. Equivalent circuit of LIM

On the αβ coordinate system. The dynamic model of the SLIM is described as follows:

$$\begin{cases} \dfrac{di_{s\alpha}}{dt} = -D'i_{s\alpha} + B'\psi_{r\alpha} + \dfrac{\pi}{\tau}vC\psi_{r\beta} + Au_{s\alpha} \\ \dfrac{di_{s\beta}}{dt} = -Di_{s\beta} + B\psi_{r\beta} - \dfrac{\pi}{\tau}vC\psi_{r\alpha} + Au_{s\beta} \\ \dfrac{d\psi_{r\alpha}}{dt} = F'i_{s\alpha} - E'\psi_{r\alpha} - \dfrac{\pi}{\tau}v\psi_{r\beta} \\ \dfrac{d\psi_{r\beta}}{dt} = Fi_{s\beta} - E\psi_{r\beta} + \dfrac{\pi}{\tau}v\psi_{r\alpha} \\ F_e = \dfrac{3}{2}\dfrac{p}{2}\dfrac{\pi}{\tau}.k_F.(\psi_{r\alpha}i_{s\beta} - \psi_{r\beta}i_{s\alpha}) \\ \dfrac{dv}{dt} = m(F_e - F_L) \end{cases} \quad (3)$$

In there:

$$A = \frac{L_r - L_m.f(\xi)}{(L_s - L_m f(\xi)).(L_r - L_m f(\xi)) - (L_m(1-f(\xi)))^2}$$

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$$B = \frac{R_r.L_m(1-f(\xi))}{(L_r - L_m f(\xi))}.$$

$$.\frac{1}{L_s - L_m f(\xi)).(L_r - L_m f(\xi)) - (L_m(1-f(\xi)))^2}$$

$$C = \frac{L_m(1-f(\xi))}{(L_s - L_m f(\xi)).(L_r - L_m f(\xi)) - (L_m(1-f(\xi)))^2}$$

$$B' = \left[R_r.f(\xi) - \frac{L_m(1-f(\xi))}{L_r - L_m f(\xi)}(R_r + R_r f(\xi))\right].$$

$$.\frac{1}{L_s - L_m f(\xi)).(L_r - L_m f(\xi)) - (L_m(1-f(\xi)))^2}$$

$$D = \frac{R_s.(L_r - L_m f(\xi))^2 + R_r.(L_m(1-f(\xi)))^2}{(L_r - L_m f(\xi))}.$$

$$.\frac{1}{L_s - L_m f(\xi)).(L_r - L_m f(\xi)) - (L_m(1-f(\xi)))^2}$$

$$D' = \left[\begin{array}{l} R_s + R_r f(\xi) - \dfrac{2.R_r f(\xi).L_m(1-f(\xi))}{L_r - L_m f(\xi)} + \\ + \dfrac{(R_r + R_r f(\xi)).(L_m(1-f(\xi)))^2}{(L_r - L_m f(\xi))^2} \end{array}\right].$$

$$.\frac{L_r - L_m f(\xi)}{(L_s - L_m f(\xi)).(L_r - L_m f(\xi)) - (L_m(1-f(\xi)))^2}$$

$$E = \frac{R_r}{L_r - L_m.f(\xi)}; \quad E' = \frac{R_r + R_r f(\xi)}{L_r - L_m.f(\xi)}$$

$$F = \frac{R_r.L_m(1-f(\xi))}{L_r - L_m.f(\xi)}$$

$$F' = \frac{(R_r + R_r f(\xi)).L_m(1-f(\xi))}{L_r - L_m.f(\xi)} - R_r f(\xi)$$

$$k_F = \frac{L_m(1-f(\xi))}{L_r - L_m f(\xi)} \quad (4)$$

$$F_e = m\dot{v} + nv + F_L \quad (5)$$

$$L_m = 3L_{m0}/2;\ L_s = L_m + L_{\sigma s};\ L_r = L_m + L_{\sigma r} \quad (6)$$

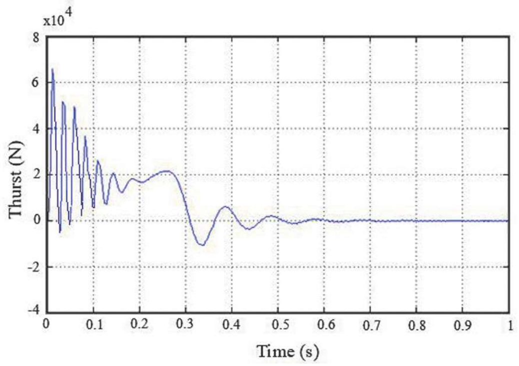
Here: $R_s(R_r)$, $L_s(L_r)$ - resistance and inductance components of the primary (secondary); $L_{\sigma s}(L_{\sigma r})$ - dissipation inductance of primary (secondary) part; L_m - mutual inductance between primary and secondary; L_{m0} - maximum mutual inductance between primary and secondary; $u_{s\alpha}$, $u_{s\beta}$ - components along the α and β axes of the voltage vector; $i_{s\alpha}$, $i_{s\beta}$ - components along the α and β axes of the current vector; $\psi_{r\alpha}$, $\psi_{r\beta}$ - components along the α and β axes of the flux vector of secondary part; v – velocity of primary part; F_e - electromagnetic thrust of the motor; F_L - load force; m - mass; n - coefficient of friction; l- primary part length.

3. DYNAMIC CHARACTERISTICS OF THREE-PHASE SINGLE-SIDE LINEAR INDUCTION MOTOR USED IN ELEVATOR

Simulation is performed on Simulink/Matlab with the parameters of the SLIM applied in the elevator:[7] Rated line voltage 400 V; I_{1dm} = 201.6 A; F = 16 kN; f = 50 Hz; velocity 10 m/s; a = 2 m/s^2, total weight of cabin and bearing m_{cabin} = 500 kg; Number of passenger in one cabin 5 and average weight of each passenger 75 kg; s_{dm} = 10%; R_s = 0.00356 Ω; R_r = 0.2055 Ω; X_s = 0.1371 Ω; X_m = 1.1795 Ω.

3.1. In case of no-load:

The primary or stator moves along the secondary of a SLIM and no-load (cabin, passenger), the thrust, velocity, stator current responses as shown in Figures 4 and 5. The obtained results show that factors such as end effects and eddy currents have a great influence on the dynamic characteristics of the SLIM. The maximum transient thrust value in the case of the end effect and eddy current is only 58 kN (decreased by 4.13%) and the maximum thrust value is 18 kN (decreased by 12.19%) compared to not considered. The value of the maximum current amplitude in the first cycle is slightly changed. Start-up time is longer.



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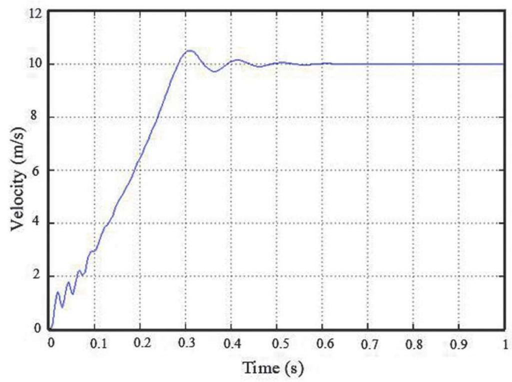

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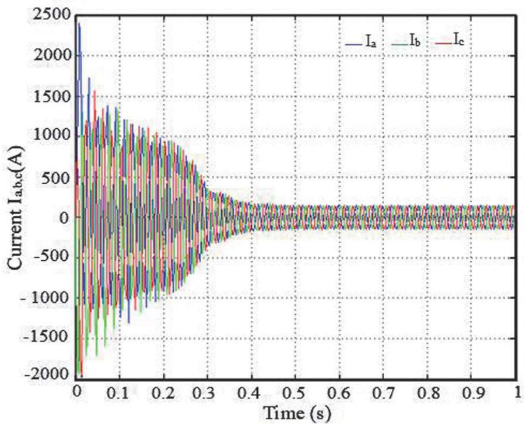

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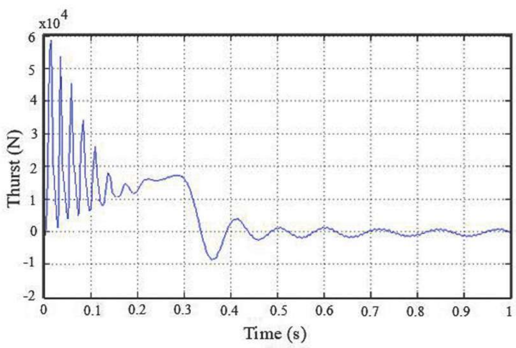
Figure 4. Thrust response a) velocity b) stator current c) at no-load in the absence of end effect and eddy current



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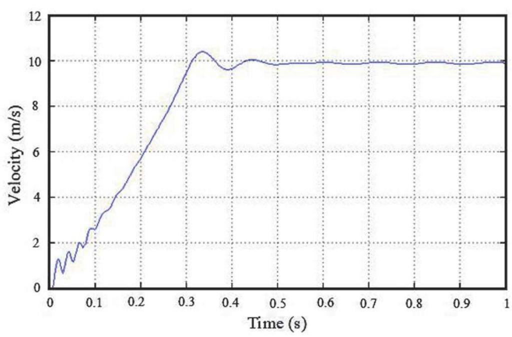

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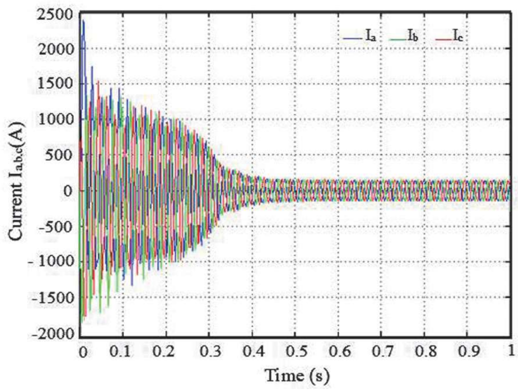

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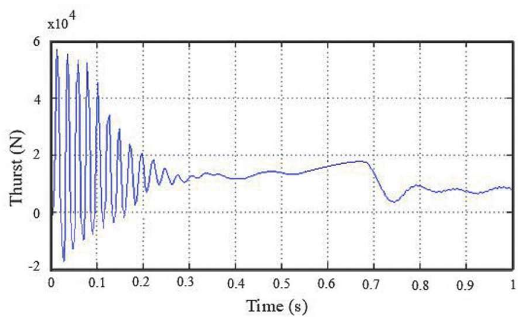
Figure 5. Thrust response a) velocity b) stator current c) at no load in the case of end effect and eddy current

During the operation of SLIM, end effect and eddy currents phenomena always occur simultaneously, causing synergistic effects on dynamic characteristics. Therefore, the investigation of the characteristics in the following cases is carried out on the model that takes this phenomenon into account.

3.2. In case of load-carrying:

The primary part moves along the secondary and the full load (cabin and passenger) and load 57.14% (cabin and no passenger).

When starting the SLIM with a large load, the start-up time is prolonged. For example, the starting time at full load is 0.7 s which is larger than 0.3 s with load 57.14%. Note that starting the SLIM with a large load will be very difficult, even if it doesn't start, the load force of the elevator belongs to the type of energy of potential force, the motor can be pulled back at the moment the force reaches its minimum value. The maximum transient thrust value as well as the maximum thrust value are not changed when changing the load force.



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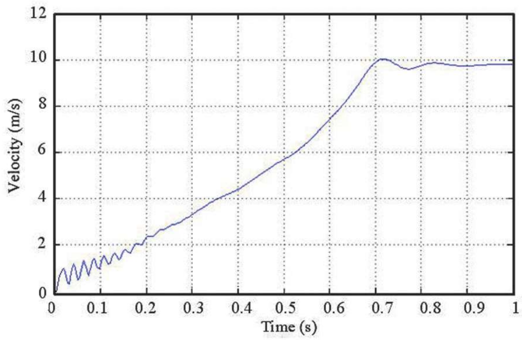

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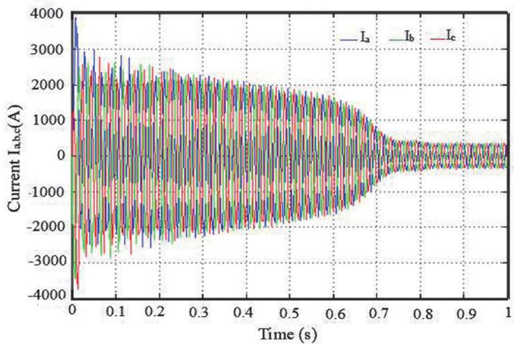

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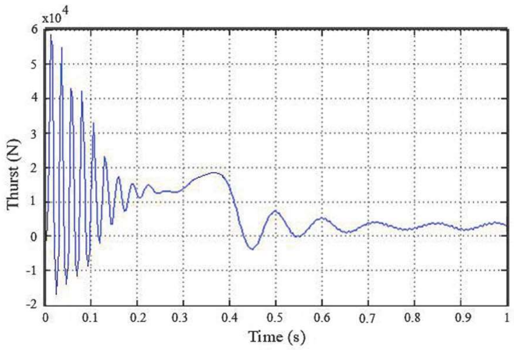
Figure 6. Thrust response a) velocity b) stator current c) at full load



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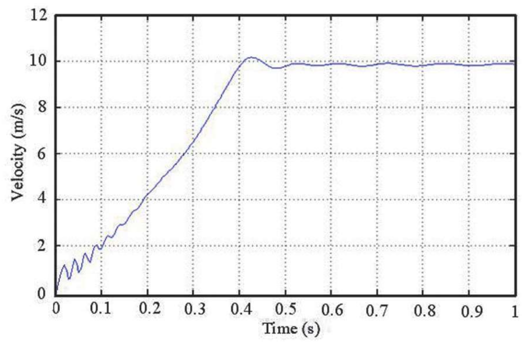

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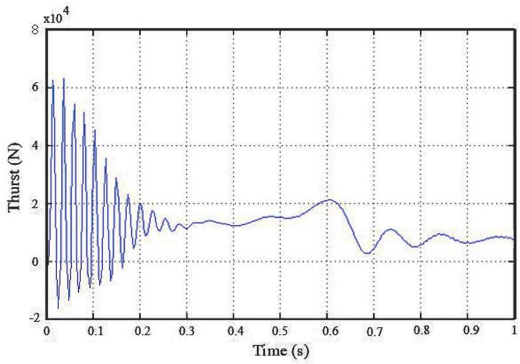
Figure 7. Thrust response a) velocity b) at load 57,14%

3.3. In case of power supply frequency reduced by 1%:

Investigate the dynamic characteristics of the motor in case the power supply frequency is reduced by 1% (49.5 Hz) compared to the 50 Hz power frequency as shown in Figure 8. The speed of the motor is reduced, the maximum transient force value in this case is 61 kN (increase of 3.28%) and the maximum thrust value is 20.5 kN (increase of 4.88%) compared to the case of Figure 6 (59 kN and 19.5 kN) this can be explained that the effect of end effectphenomenon in the SLIM is also reduced in the working area of lower speed.



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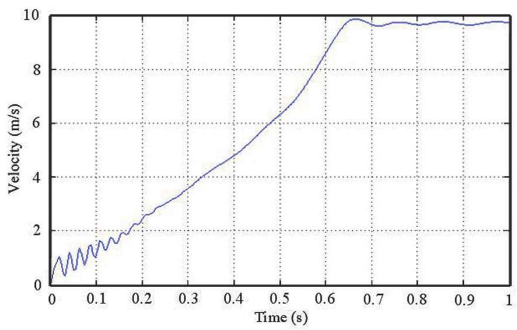

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Figure 8. Thrust response a) velocity b) at full load and power supply frequency reduced by 1%

3.4. In case of asymmetrical power supply:

Considering another case related to the symmetry of the power supply for the motor, the phase A voltage is reduced by 5% compared to the remaining 2 phase voltage. The results in Figure 8 shows that the current in phase A has a larger amplitude than the other two phases, the start up time is extended to 0.8 s and the thrust and speed response fluctuate at steady state, which can cause "jerk" when operating the elevator system.

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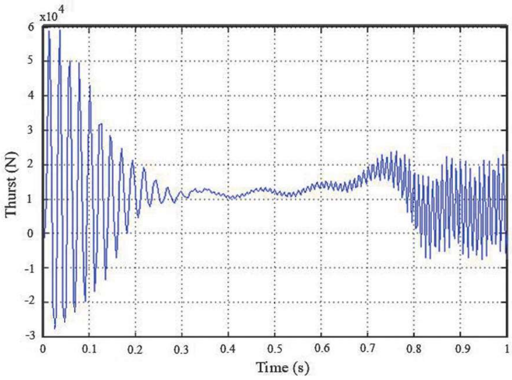

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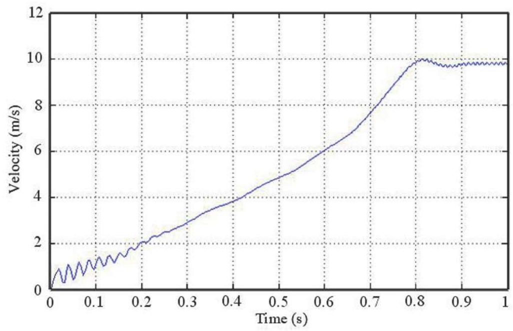

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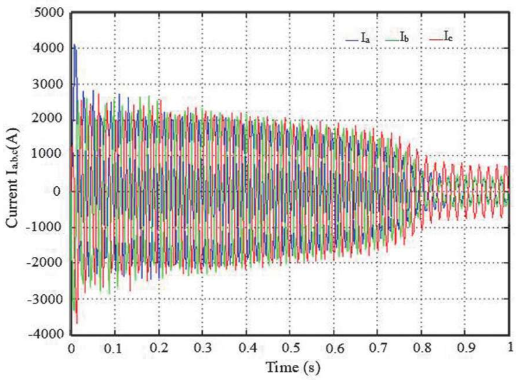

c)

Figure 9. Thrust response a) velocity b) stator current c) at full load and asymmetrical power supply

4. CONCLUSION

- End effect and eddy current in the SLIM have a certain influence on the working state of the motor, reduce the magnitude of the thrust, and change the shape of the dynamic thrust characteristics single - side linear induction motor.

- The dynamic characteristics of the SLIM are considered in the following cases: no load, low load, full load, variable frequency, and asymmetrical voltage source. The results show that the dynamic characteristics change with the changes of the working state of the motor.

- The issue of using a SLIM for the passenger elevator drive system has opened up the prospect for the application of this motor to loads of potential energy nature. The system attains the criteria of velocity, fast response time as well as safety requirements when operating.

- In present practice, the motor velocity regulation is usually combined with the inverter, and the dynamic characteristics of the motor in this case need to be further studied.

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