ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2011. No. 4(110)
ELEKTRONIKA IR ELEKTROTECHNIKA

ELECTRICAL ENGINEERING
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ELEKTROS INŽINERIJA

# Investigation of Energetic Parameters of Oscillating Synchronous Pulsating Current Motors

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## Introduction

Oscillating pulsating current motors are distinguished for simple construction, cheapness, and high power parameters [1]. The article deals with the main regime of oscillating pulsating current motor when power supply of a motor is a source of sinusoidal or rectangular voltage. While using sinusoidal power supply, is possible to change: amplitude of voltage ($U_m$=var) by special schemes, firing angle of thyristors in motors windings ($\alpha_{tir}$=var) forming one-way pulses of current, and frequency ($f_t$= var) by frequency converters. The easiest way is to change thyristor firing angle since extra equipment and special schemes are not needed. It is possible to use amplitude frequency control which may be realized by combining particular methods [2–6].

While supplying a motor from rectangular power supply, is possible to change: duration of pulses, frequency of pulses of voltage, when amplitude and width of separate parts of pulses are constant, value of voltage also to combine a few control methods.

## Object, aim and method of research

The object of research is oscillating linear synchronous pulsating current motor in compressor drive, Fig. 1. The drive is symmetrical therefore modeling is made for only one winding of a motor.

System consists of: mover 1 which also is a piston of compressor; two electromagnets 2 interacting with the mover and creating electromagnetic force $F_{elm}$ giving cause for the mover (piston) to move. Windings 3 through thyristors are mounted on electromagnets and connected to alternative voltage. Systems' work depends on thyristor firing angle α which may be changed from $0^0$ to $180^0$.

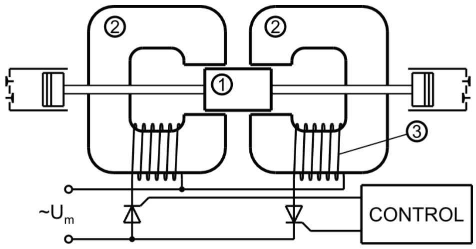



**Fig. 1.** System of the oscillating linear synchronous pulsating current (OLSPC) motor-compressor

The aim of research is to obtain characteristics and power parameters of OLSPC motor and to compare them when a motor is supplied by different power sources while changing thyristor firing angle α, frequency of power supply *f* and a load. Matlab software was used while mathematical modeling. Mathematical model was made taking into account mass, friction, stiffness of system, resistances and inductance of the windings, and type of power supply (sinusoidal or rectangular).

While mathematical modeling, some assumptions were accepted: OLSPC motor is symmetrical; active resistance of winding of the motor is constant, inductance is changing according sinusoidal law and depends on a position of a mover; magnetical losses are evaluated approximately by active resistance *r* of winding which is connected in parralell to inductance; a load of a motor is linear and evaluated by complex mechanical impedance $\underline{Z}$; oscillations of the mover are sinusoidal.

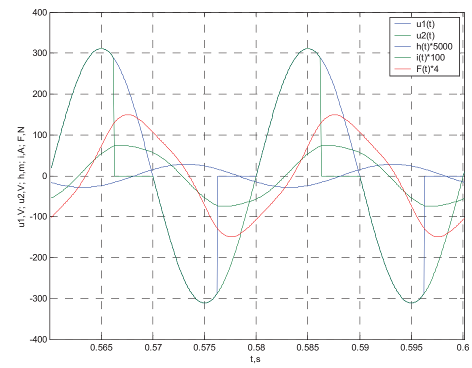
System of differential equations:

$$
\begin{cases}
\dfrac{\mathrm{d}i_{L1}}{\mathrm{d}t} = \dfrac{1}{L_1(h)}\left(\dfrac{r_2}{r_1 + r_2}u(t) - \dfrac{r_1 r_2}{r_1 + r_2}i_{L1} - k_1 v i_{L1}\right); \\
\dfrac{\mathrm{d}i_{L2}}{\mathrm{d}t} = \dfrac{1}{L_2(h)}\left(\dfrac{r_2}{r_1 + r_2}u(t) - \dfrac{r_1 r_2}{r_1 + r_2}i_{L2} - k_2 v i_{L2}\right); \\
\dfrac{\mathrm{d}v}{\mathrm{d}t} = \dfrac{1}{m}\left(\dfrac{1}{2}{i_{L1}}^2 k_1 + \dfrac{1}{2}{i_{L2}}^2 k_2 - Rv - ch\right); \\
\dfrac{\mathrm{d}h}{\mathrm{d}t} = v; \\
L_{1,2} = L_0 \pm K \sin\left(\dfrac{h}{H_\mathrm{m}}\dfrac{\pi}{2}\right);
\end{cases}
\quad (1)
$$

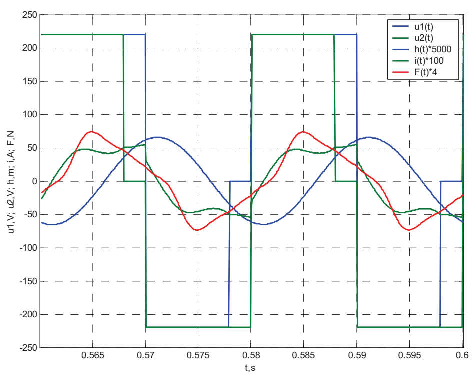
where $u(t)$ – power supply; $r_1$ – active resistance of windings; $r_2$ – equivalent resistance of magnetic losses; $i_{L1}$, $i_{L2}$ – inductive currents; $m$ – mover mass; $c$ – stiffness; $h$ – coordinate of oscillation; $H_\mathrm{m}$ – amplitude of oscillations; $R$ – mechanical resistance; $L_0$ – initial inductance; $k_1$, $k_2$ – transfer characteristics of inductance: $k_1 = \dfrac{\mathrm{d}L_1}{\mathrm{d}h}$, $k_2 = \dfrac{\mathrm{d}L_2}{\mathrm{d}h}$, , $K = \dfrac{L_{\min} - L_{\max}}{2\sin\frac{\pi}{2}}$ – coefficient of inductance $L_{\min}$, $L_{\max}$ – minimum and maximum values of inductance.

## OLSPC characteristics when power supply is sinusoidal and rectangular

While supplying OLSPC motor by sinusoidal and rectangular voltage, steady state characteristics are shown in Fig. 2.



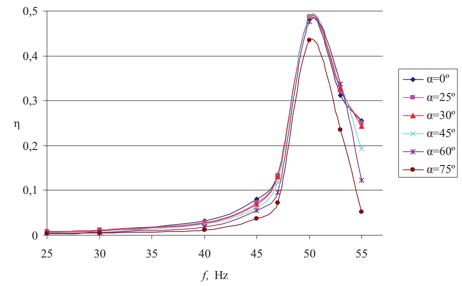

a)



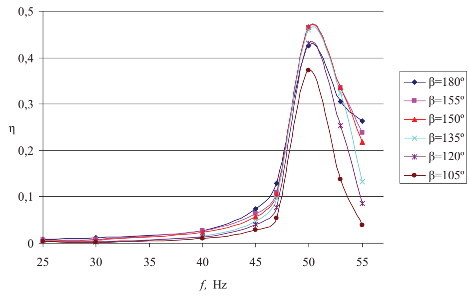

b)

**Fig. 2.** The curves of steady state: $u_1 = f(t)$, $u_2 = f(t)$, $h = f(t)$, $i = f(t)$, $F_\mathrm{elm} = f(t)$, a) voltage is sinusoidal, $f = 50$ Hz, $\alpha = 0^0$, b) voltage is rectangular, $f = 50$ Hz, $\beta = 180^0$

Form of the curves of velocity, coordinate of mover also current in common circuit and electromagnetic force $F_\mathrm{elm}$ are close to sinusoidal. Using modeling results of the OLSPC motor power characteristics were formed, when thyristor firing angle α is from 0º to 75º, the load $R = 4$ Ns/m, frequency is from 25 to 55 Hz and a load is not matched to the supply voltage frequency (Fig. 3, Fig. 4).

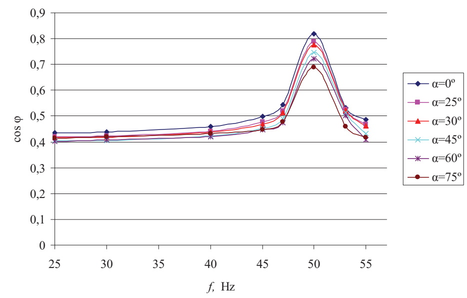



a)

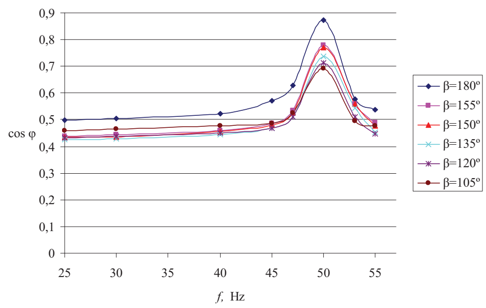



b)

**Fig. 3.** Efficiency $\eta = f(f)$ when supply voltage is a) sinusoidal, b) rectangular, $R = 4$ Ns/m




a)




b)

**Fig. 4.** Characteristics of power factor $\cos\varphi = f(f)$ when supply voltage is a) sinusoidal, b) rectangular $R = 4$ Ns/m

In a case when a load is matched to the supply voltage frequency, change of the power characteristics of the motor is not so significant. Calculating results of efficiency $\eta$ and power factor $\cos\varphi$ are shown in Table 1 and Table 2. Efficiency and power factor increase when thyristor firing angle decreases.

When power supply is rectangular form pulses width of pulse may be changed with the aim to determine influence of width pulse modulation to the parameters of a motor. Width of pulse of voltage, frequency and the load were changed while mathematical modeling. For comparison data when the motor is supplied from rectangular voltage width of pulses are taken from π, i.e. β = 180º(for sinusoidal voltage it corresponds to thyristor firing angle α = 0º) to 105º (for sinusoidal voltage it corresponds to thyristor firing angle α = 75º). Influence of the load (mechanical load is matched) to the motor characteristics is shown in Figures 5, 6. Stiffness is recalculated as well.

**Table 1.** Power factor cos*φ* when *R* = 4 Ns/m

| Form of supply voltage and firing angle | Frequency of supply voltage, Hz | | | | |
|---|---|---|---|---|---|
| | 25 | 40 | 47 | 50 | 53 |
| Sinusoidal 0° | 0,814 | 0,816 | 0,809 | 0,817 | 0,804 |
| Rectangular180° | 0,848 | 0,864 | 0,872 | 0,871 | 0,867 |
| Sinusoidal 25° | 0,820 | 0,783 | 0,778 | 0,787 | 0,772 |
| Rectangular 155° | 0,787 | 0,776 | 0,779 | 0,779 | 0,772 |
| Sinusoidal 30° | 0,819 | 0,774 | 0,768 | 0,776 | 0,760 |
| Rectangular 150° | 0,777 | 0,769 | 0,770 | 0,769 | 0,763 |
| Sinusoidal 45° | 0,796 | 0,744 | 0,741 | 0,746 | 0,726 |
| Rectangular 135° | 0,756 | 0,748 | 0,774 | 0,737 | 0,737 |
| Sinusoidal 60° | 0,765 | 0,732 | 0,723 | 0,721 | 0,698 |
| Rectangular 120° | 0,752 | 0,743 | 0,726 | 0,714 | 0,708 |
| Sinusoidal 75° | 0,747 | 0,726 | 0,698 | 0,689 | 0,659 |
| Rectangular 105° | 0,771 | 0,741 | 0,705 | 0,693 | 0,687 |

**Table 2.** Efficiency *η* when *R* = 4 Ns/m

| Form of supply voltage and firing angle | Frequency of supply voltage, Hz | | | | |
|---|---|---|---|---|---|
| | 25 | 40 | 47 | 50 | 53 |
| Sinusoidal 0° | 0,592 | 0,481 | 0,464 | 0,483 | 0,474 |
| Rectangular180° | 0,338 | 0,375 | 0,402 | 0,426 | 0,415 |
| Sinusoidal 25° | 0,609 | 0,479 | 0,469 | 0,486 | 0,477 |
| Rectangular 155° | 0,493 | 0,444 | 0,449 | 0,464 | 0,446 |
| Sinusoidal 30° | 0,609 | 0,479 | 0,471 | 0,488 | 0,476 |
| Rectangular 150° | 0,494 | 0,449 | 0,452 | 0,466 | 0,447 |
| Sinusoidal 45° | 0,584 | 0,476 | 0,475 | 0,489 | 0,472 |
| Rectangular 135° | 0,488 | 0,459 | 0,451 | 0,459 | 0,432 |
| Sinusoidal 60° | 0,540 | 0,475 | 0,472 | 0,477 | 0,456 |
| Rectangular 120° | 0,474 | 0,456 | 0,425 | 0,432 | 0,395 |
| Sinusoidal 75° | 0,488 | 0,464 | 0,437 | 0,435 | 0,402 |
| Rectangular 105° | 0,448 | 0,422 | 0,371 | 0,372 | 0,327 |

Power parameters are the best close to resonant frequency. When width of pulses is bigger (the highest is π, i.e., when *β* = 180º) efficiency diminishes but power factor is higher.

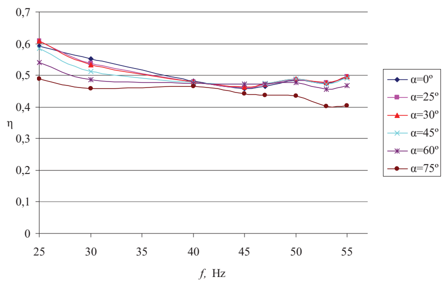



**Fig. 5.** Efficiency η = *f*(*f*) when supply voltage is sinusoidal (*R* = 4 Ns/m)

In Figures 5–7 characteristics when *R* = 4 Ns/m, and frequency *f* various from 25 to 55 Hz are shown in a case when a load is matched to the supply voltage frequency.

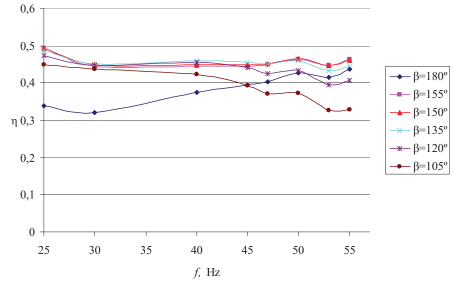
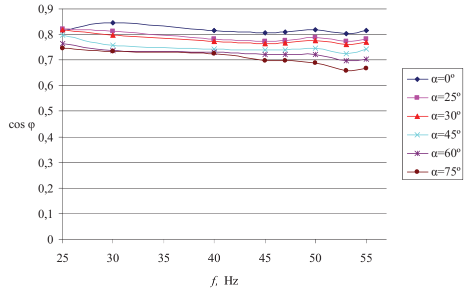
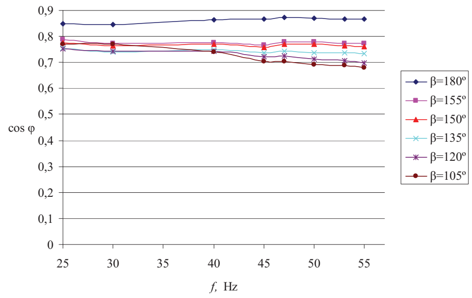



**Fig. 6.** Efficiency *η* = *f*(*f*) when supply voltage is rectangular (*R* = 4 Ns/m)




a)




b)

**Fig. 7.** Power factor cosφ = *f*(*f*) when supply voltage: a) sinusoidal, b) rectangular *R* = 4 Ns/m

When the load increases, thyristor firing angle and frequency grow, efficiency and power factor decrease significantly, duration of transient process is less. So when the load grows, character of power parameters changes, work of the motor and the drive will be influenced by decreasing slope of characteristics. Power characteristics when the load *R* = 20 Ns/m and a load is matched to the supply voltage frequency, are shown in Figures 7, 8.

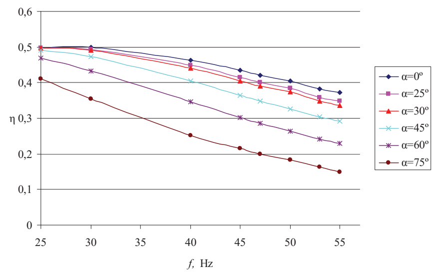



**Fig. 8.** Efficiency η = *f* (*f*) when supply voltage is sinusoidal and *R* = 20 Ns/m

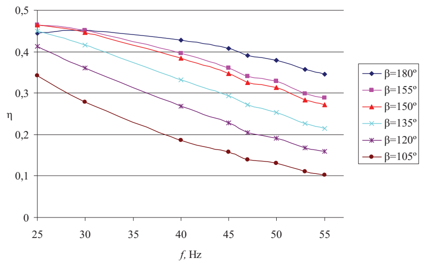



**Fig. 9.** Efficiency $\eta = f(f)$ when supply voltage is rectangular and $R = 20$ Ns/m

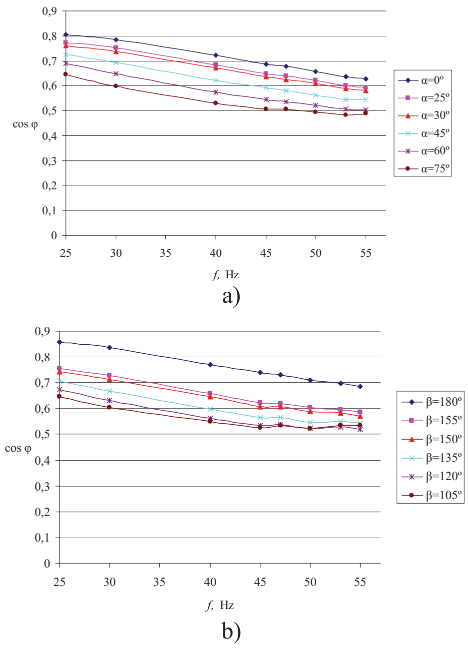



**Fig. 10.** Power factor $\cos\varphi = f(f)$ when supply voltage: a) sinusoidal, b) rectangular $R = 20$ Ns/m

While increasing load, efficiency is higher when frequency increases, slope of characteristic is not clear. Decreasing width of pulses and increasing frequency, efficiency diminishes significantly. Power factor almost does not depend on frequency, but while increasing width of pulses power factor is higher. It is possible to conclude that work of the device is more efficient in the area of the resonant frequency.

## Conclusions

1. While OLSPC motor is supplied by rectangular voltage, the highest efficiency is obtained when width of pulses and a load are the biggest. Decreasing width of pulses when frequency grows, efficiency decreases significantly.
2. While OLSPC motor is supplied by sinusoidal voltage, when increasing a load, efficiency and power factor decreases significantly while increasing thyristor firing angle and frequency. So loading a motor slope of characteristics decreases, it also influences a work of a motor. Higher efficiency may be obtained while supplying a motor by sinusoidal voltage, when a load is not matched to the supply voltage frequency.
3. While supplying a motor by sinusoidal voltage, higher efficiency may be obtained (independent on a load) when a load is matched to the supply voltage frequency, but power factor is less in comparison while supplying by rectangular voltage.

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Received 2011 01 18

**L. Urmoniene, S. Gecys, E. Guseinoviene, V. Cirtautas. Investigation of Energetic Parameters of Oscillating Synchronous Pulsating Current Motors // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 4(110). – P. 17–20.**

This paper deals with oscillating linear synchronous pulsating current motor compressor drive supplied by sinusoidal and rectangular voltage. While creating mathematical model of the motor for investigation, Matlab software was used for solving of differential equations. Modeling results while supplying motor by sinusoidal and rectangular voltage and changing firing angle α of thyristor, frequency of voltage *f* and a load *R*. Characteristics and energetic parameters of oscillating linear pulsating current motor were obtained and analyzed. Ill. 10, bibl. 6, tabl. 2 (in English; abstracts in English and Lithuanian).

**L. Urmonienė, S. Gečys, E. Guseinovienė, V. Cirtautas. Švytuojamųjų sinchroninių pulsuojamosios srovės variklių energetinių parametrų tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 4(110). – P. 17–20.**

Straipsnyje tiriamas švytuojamasis tiesiaeigio judesio pulsuojamosios srovės sinchroninis variklis kompresoriaus pavaroje, maitinamas sinusine ir stačiakampe įtampa. Sudarant variklio matematinį modelį panaudojama skaitinio modeliavimo programa Matlab diferencialinėms lygtims spręsti. Pateikiami modeliavimo rezultatai, gauti maitinant variklį skirtingos formos įtampomis ir keičiant tiristoriaus atidarymo kampą, maitinimo įtampos dažnį ir apkrovą. Gautos švytuojamojo tiesiaeigio judesio pulsuojamosios srovės variklio charakteristikos ir analizuojami energiniai parametrai. Il. 10, bibl. 6, lent. 2 (anglų kalba; santraukos anglų ir lietuvių k.).