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Investigation of Supply Posibilities of Mechatronic Actuator

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Introduction

There are a lot of electrical drives with oscillating links, for instance, piston-pumps, compressors, hammers. Usually rotating electrical motors may be used in these drives after rotating movement is changed to oscillating one. On purpose to reduce overall dimensions, mass and to increase efficiency the drives without movement change links are being created. Oscillating electrical motors can be used in such drives [1].

The parameters of oscillating drives can be changed and these drives can be supplied by several ways:

- Supplying the drive from the source of sinusoidal voltage: to change amplitude of supplying voltage; to change frequency of supplying voltage – it can be realised by autonomous controlled generators or frequency converters; to change the firing angle of controlled diode (thyristor) in motor windings circuit [2].
- Supplying the drive from the source of rectangular voltage [3] by modulating [4]: changing value of voltage; changing frequency of voltage; changing relative width of impulses etc.

Research method

This paper deals with oscillating linear pulsating current synchronous motor mechatronic drive (further – drive), which principal scheme is shown in Fig.1.

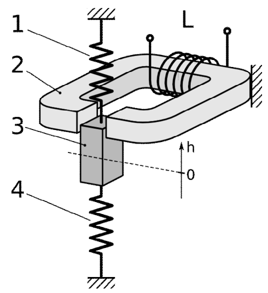

Fig. 1. Mechatronic device: 1, 4 – springs; 2 – core of stator; 3 – moving part

In the stator of the drive is magnetic core (Fig. 1, 2). Moving part (Fig.1, 3) of the drive is mounted to the stator using spring units (Fig. 1, 1 and 4). Moving part can only creep along the spring units. Working principle of the drive: when current flowing in one of the windings, magnetic field is generated in magnetic core, which attracts the moving part toward self-part; when current decreases, moving part is returned to initial position; if current in windings is beating, moving part is pulling to the one or other magnetic core alternately – moving part oscillates.

Supply voltage rectangular shaped is formed the windings of the drive connecting to the constant voltage source using analogue switches. During the work, when analogue switches disconnect circuit, electromotive is induced in winding. It can damage the switches. Therefore protective circuits are created – they help to damp part of energy stored in magnetic field. In this case two ways of connection of windings analysed in this article are possible:

- Winding of the motor is shunted by diode (further "shunted diode") (Fig. 2). When analogue switch disconnects winding supply circuit, electromotive, induced in winding, opens diode. Current flowing in composed circuit is damped in passive elements (such as the resistance of the winding).

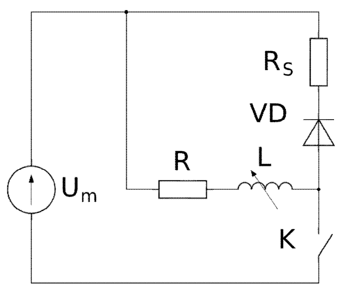

Fig. 2. Electric circuit diagram of the drive, when windings are shunted by diode and additional resistance

- Winding of the motor is switched in diagonal of the bridge (further "bridge") (Fig. 3). When analogue switches disconnect winding supply circuit (as in mentioned above case), diodes are opened by induced electromotive, which is created in winding circuit, current flowing in composed circuit appears. In this case part of energy, stored in magnetic field, is returned to supply source.

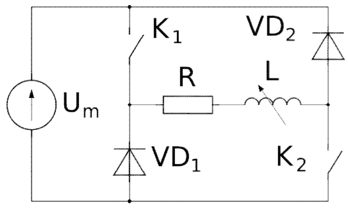

Fig. 3. Electric circuit diagram of the drive, when winding is switched in diagonal of the bridge

Efficiency of mentioned above drives on purpose to establish, which one is preferable in this work is analysed.

Method of investigation

The drive was analysed by mathematical modelling and doing physical experiment. In both cases the dynamic model of the drive with one degree of freedom was accepted – stator of the drive connects with infinite mass.

Making mathematical model of the drive these assumptions were taken: supply source (U_m in Fig. 2 and Fig. 3) is ideal; semiconductor diodes (VD in Fig. 2; VD_1, VD_2 in Fig. 3), analogue switches (K in Fig. 2; K_1, K_2 in Fig. 3) are ideal; resultant scheme of winding of the drive – active resistance of winding and inductance of winding, which depends on coordinate of moving part of the drive, are connected in series (respectively, R and L in Fig. 2 and Fig. 3); dependence of inductance of winding on coordinate of moving part of the drive is linear.

The drive was investigated by numerical modelling using software „GNU Octave“ [5]. First order differential equation, which describes the drive

$$\begin{cases} \dfrac{\mathrm{d}i_L}{\mathrm{d}t} = \dfrac{1}{L(h)}\left(u - i_L R - i_L v \dfrac{\mathrm{d}L(h)}{\mathrm{d}h}\right), \\ \dfrac{\mathrm{d}h}{\mathrm{d}t} = v, \\ \dfrac{\mathrm{d}v}{\mathrm{d}t} = \dfrac{1}{m}\left(F_{em} - R_{mch} v - ch\right); \end{cases} \tag{1}$$

here i_L – current in winding; $L(h)$ – inductance of winding of the drive, which depend on coordinate of moving part; u – voltage of source, which is connected to the winding of the drive and depend on mode of analogue switches; R – active resistance of the winding of the drive; F_{em} – electromagnetic force acting the moving part of the drive; m – mass of moving part; h – coordinate of moving part in the central position $h=0$; v – speed of moving part of the drive; R_{mch} – mechanical resistance of the drive; c – resilience of springs of the drive.

Electromagnetic force in (1) equation system

$$F_{em} = \frac{1}{2} i^2 \frac{\mathrm{d}L}{\mathrm{d}h} \ . \tag{2}$$

Inductance of the winding of the drive can be described by linear dependence

$$L(h) = L_0 + kh \ ; \tag{3}$$

here L_0 – inductance, when moving part of the drive is in the central position; k – coefficient of proportion.

Derivative of inductance depending on coordinate

$$\frac{\mathrm{d}L}{\mathrm{d}h} = k \ . \tag{4}$$

In the case, when the winding is shunted by diode, voltage of source, which is connected to the winding

$$u = \begin{cases} U_m, & \text{when switch } K \text{ is on,} \\ 0, & \text{when switch } K \text{ is off.} \end{cases} \tag{5}$$

Voltage, mentioned above in case, when winding is switched in diagonal of the bridge

$$u = \begin{cases} U_m, & \text{when switches } K_1 \text{ and } K_2 \text{ are on,} \\ -U_m, & \text{when switches } K_1,\ K_2 \text{ are off, and } i_L > 0, \\ 0, & \text{else.} \end{cases} \tag{6}$$

In the winding of the drive, when it is shunted by diodes, current has high constant component, which is decreased by additional resistance connected to shunted diode circuit in series. The resistance damps part of energy, which is stored in the winding. Modeling the case of the drive with additional resistance R_s (Fig. 2) in the 1 system of equations expression of current is transformed

$$\frac{\mathrm{d}i_L}{\mathrm{d}t} = \frac{1}{L(h)}\left(u - i_L\left(R + R_{ADD}\right) - i_L v \frac{\mathrm{d}L(h)}{\mathrm{d}h}\right), \tag{7}$$

here

$$R_{ADD} = \begin{cases} 0, & \text{when switch } K \text{ is on,} \\ R_S, & \text{when switch } K \text{ is off.} \end{cases} \tag{8}$$

Results of investigation

The drive, when windings were shunted by diode and the case, when winding were switched in diagonal of the bridge, were investigated by physical experiment and mathematical modeling. The drive was supplied from the constant 100 V voltage source. Relative width of impulses $\varepsilon = 0{,}25\ldots0{,}5$ was changed and frequency of commutation was constant, $f = 50\text{Hz}$.

It was noticed, that in the winding of the drive, where the winding is shunted only by diode, constant component of the current is big enough. On purpose to reduce it and to make it closer to the “bridge” type drive (for comparison of parameters), it was inserted additional resistance in series to the shunted diode R_s (Fig. 2).

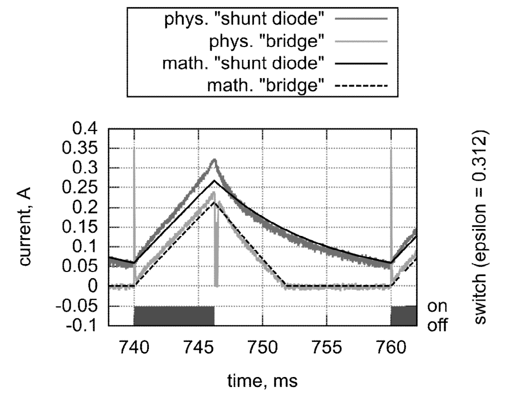

Fig. 4. Currents in one of the windings of the drive, when relative width of impulses $\varepsilon = 0{,}312$

Experimental and modelling curves of currents of the windings are depicted in Fig. 4.

From the presented graph can be noticed, that the currents in winding of the drive, which are obtained by mathematical modelling are close to the currents, which were measured by physical experiment.

Graphs of parameters, obtained by experimental and modelling mode, are depicted in Fig. 5, 6.

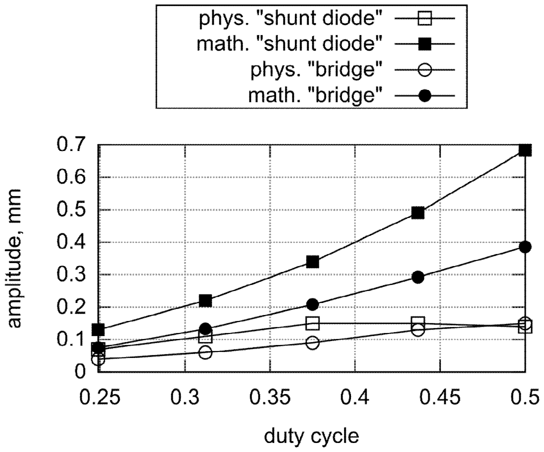

Fig. 5. Dependencies of oscillating amplitude of the moving part of the drive on relative width of commutation impulses

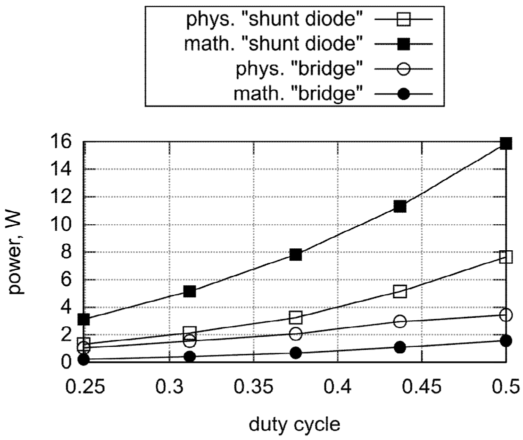

Fig. 6. Dependence of an input electric power of the winding on relative width of commutation impulses

From these graphs can be noticed that oscillating amplitude of the moving part, when the winding is shunted by diode, is bigger than in case, when winding is switched in diagonal of the bridge. But the first drive has used much more power than the other one.

The curves of current and drops of voltage of the drive, measured in circuits during physical experiment, when the winding is shunted by diode, are depicted in Fig. 7–9.

The curves of current and drops of voltage of the drive, measured in circuits during physical experiment, when the winding is switched in diagonal of the bridge, are depicted in Fig. 10, *a), b), c)* , when ε=0,375. From these graphs can be noticed that part energy is lost in active elements (diodes, transistors).

In the Table 1 the powers of both drives are presented: P_{input} – input power of the drive, $P_{winding}$ – power in the winding, P_{diode} – power losses in diodes, P_{switch}– power losses in the switches.

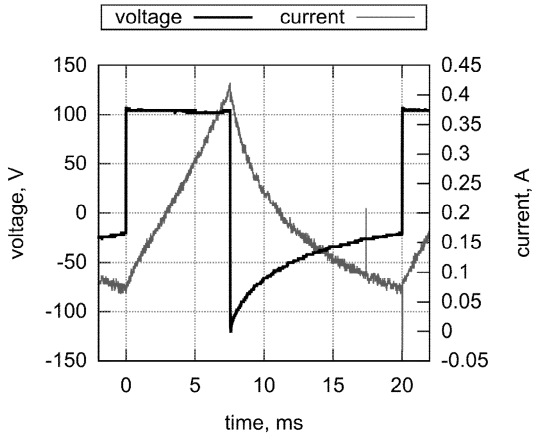

Fig. 7. Current and voltage in winding (ε=0,375)

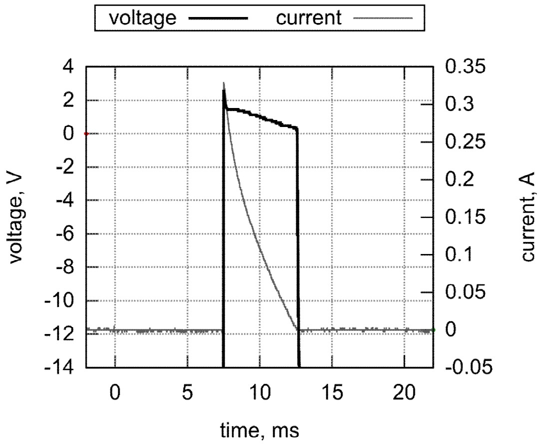

Fig. 8. Current ant voltage in diode (ε=0,375)

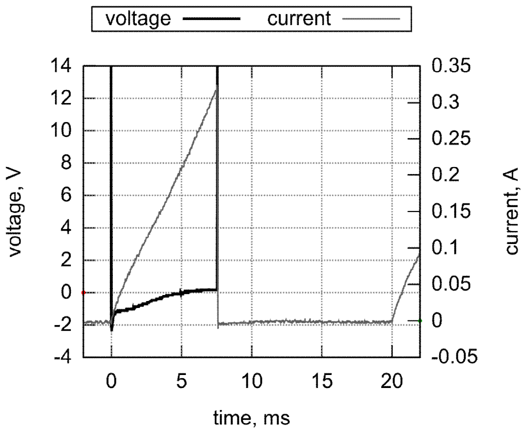

Fig. 9. Current and voltage in transistor (ε=0,375)

Table 1. The powers of the drives

	„shunt diode" drive	„bridge" drive
P_{input}, W	7,03	3,53
$P_{winding}$, W	6,09	3,44
P_{diode}, W	0,0575	0,131
P_{switch}, W	0,0228	0,0389
Power balance, %	12,0	7,5

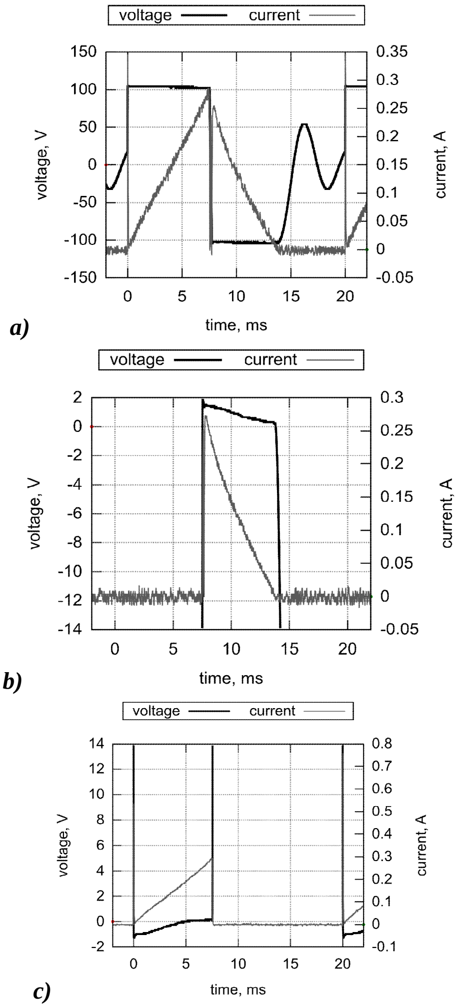

Fig. 10. Current and voltage in winding *a),* diode *b),* transistor c*)*

Conclusion

Efficiency of the drives, which windings are shunted only by diodes is very low, because constant component of current in their windings is high. It may be improved by including additional resistance with the shunted diode by series.

The highest power rates have drives, which windings are switched in diagonals of the bridges, because constant component of current in winding is smaller than of the drive, which windings are shunted by diodes. In these drives recuperation of energy to the accumulative element (capacitor) is possible.

Otherwise, in the windings of the drive, when they are shunted by diodes, the constant component of the current was decreased by additional resistance, which is connected by series with the shunted diode. In addition, in that type of drive less semiconductor elements are included (diodes, transistors), where part of energy is lost.

On purpose to analyze relevance of comparison drives, it is needed to examine them from economic standpoint.

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Synchronous mechatronic drive of pulsating current of oscillating linear motor, which is supplied from rectangular voltage source, is analysed. Efficiency of the drives are analysed on purpose to establish, which drive is preferable. Mathematical modelling and physical experiment were made. It was obtained, that the highest power rates have the drives, when the windings are switched to the diagonals of bridges. It is noticed that part of energy is lost in semiconductor elements. It is concluded to investigate these drives more detail. Il. 10, bibl. 5 (in English; summaries in Lithuanian, English, Russian).

В. Янкунас, Д. Эйдукас, Э. Гусейновене, В. Циртаутас. Исследование возможностей электрического питания механотронного привода прямолинейного движения // Электроника и электротехника. – Каунас: Технология, 2009 – № 5(93). – С. 25–28.

Исследуется механотронный привод прямолинейного движения пульсирующего тока, питаемый импульсным напряжением постоянной амплитуды. Энергетические параметры исследуются стремясь определить наилучший привод. Совершены физические эксперименты и математическое моделирование. Установлено, что наилучшие энергетические свойства имеют приводы, обмотки которых включены в диагонали мостов. Замечено, что часть энергии теряется в полупроводниковых элементах. Ил. 10, библ. 5 (на английском языке; рефераты на литовском, английском и русском яз.).

V. Jankūnas, D. Eidukas, E. Guseinovienė, V. Cirtautas. Mechatroninės tiesiaeigės pavaros elektrinio maitinimo galimybių tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 5(93). – P. 25–28.

Tiriama švytuojamosios tiesiaeigio judesio pulsuojamosios srovės sinchroninė mechatroninė pavara, maitinama pastovios amplitudės stačiakampe įtampa.Tiriami minėtų pavarų energetiniai rodikliai ir siekiama nustatyti tinkamesnę pavarą. Atlikti fiziniai eksperimentai bei matematinis modeliavimas. Nustatyta, kad aukščiausi energetiniai rodikliai yra tų pavarų, kurių apvijos jungiamos tiltelių įstrižainėse. Pastebėta, kad pavaros puslaidininkiniuose elementuose prarandama dalis energijos. Nuspręsta detaliau ištirti lyginamųjų pavarų tinkamumą. Il. 10, bibl.5 (anglų kalba; santraukos lietuvių, anglų ir rusų k.).