ROTATION AND OSCILLATING MODES OF ASYNCHRONOUS MOTOR SUPPLIED FROM SINGLE-PHASE NET

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Abstract. A three-phase squirrel-cage asynchronous motor with one-phase power supply is researched. It is shown that switching supply voltage positive and negative half-cycles to stator windings in special sequence, the rotor of drive is rotating three times slower than switched to three-phase supply voltage. It is possible to make the oscillating regime of drive if the order of positive and negative half-cycles of the supply voltage are switched to stator windings. This can be achieved by microcontroller program not by changing power and control circuits. Also mechanical and other characteristics of drive are made in rotating and oscillating regimes.

Key words: asynchronous motor, oscillation regime, vibration, operating switch.

Introduction

There are different fields in national economy where devices are used that perform vibrations (vibrotransporting, vibrosorting, prepacking, polishing etc.). Mechanical vibration converters of such devices are driven by rotating electric drives to get vibrations. In order to decrease dimensions, weight, simplify the control system new technologies for gaining vibration without mechanical transmission are searched for. Practically, there are different types of drives used for gaining vibrations (asynchronous, synchronous, DC and step motors) and different control methods [1]. The proposed system in this paper is based on three-phase cage drive in vibration regime supplied by a one-phase voltage source.

Principle of operation

In the 80's of the last century RPI (now RTU – Riga Technical University) control method of three-phase asynchronous drive supplied by one-phase sinusoidal voltage source, was patented by colleagues of the department of electric drives [2]. Windings of stator phase are commutated with semiconductor switches in proper order to supply voltage positive or negative half cycle. The winding of phase A is switched when the positive voltage half cycle starts, winding of phase B is switched when the negative half-cycle starts, but next the positive half-cycle is switched to the winding of phase C. Next negative, positive and negative voltage is switched accordingly to windings of phases A, B and C. In the time of 3 half-cycles of voltage one full cycle is complete. The next such cycles are following. In such regime current that flows in stator windings creates pulsing rotating magnetic field in rotor windings. In time of each half-cycle the direction of the magnetic flow is perpendicular to the plane of the respective winding and the value of flow changes by sinus law. In the next half-cycle the value of flow is changing according to sine law, but the direction is changing by 60°. In the time of six half-cycle (3 periods) magnetic flow makes a full turn on 360°. This rotating field induces EMF in rotor windings. The electromagnetical moment that is created during in interaction of rotor current and magnetic flow makes the rotor to turn. In this regime the magnetic field rotates three times slower than drive switched at three-phase voltage supply. Respectively also the rotor turns three times slower. To change the rotation direction of the rotor of asynchronous drive, the magnetic field rotating direction should be changed to the opposite direction. In a three-phase system it can be done by changing over two wires that are connected to stator windings. Also in this case we can act similarly by changing over the voltage half-cycle switching order to stator phase B and C windings of drive.

The discussed control strategy can be modified that the rotor of drive does not rotate but works in oscillating regime [3, 4]. Previously discussed control strategy switching order of voltage half-cycles was A^+ - B^- - C^+ - A^- - B^+ - C^-. Here "+" means that the accordant winding is switched to positive half-cycle of voltage, but "-" negative voltage half-cycle. In the time of those three periods the magnetic flow direction changes on 360 electric degrees, but the rotor turns by 180°. If in the next 3 periods the switching order of the voltage half-cycle is A^+ - C^- - B^+ - A^- - C^+ - B^-, then the magnetic field and rotor rotate in reverse direction. In the time of six voltage half-cycles the rotor makes one full oscillation with rotation angle of 180^0 on each direction. The oscillation period is T_S=6T=120 ms. Oscillation frequency can be changed, by changing the rotor turning angle. Reducing the rotating angle, the oscillation frequency increases and oscillation period decreases. Increasing the turning angle, oscillation frequency decreases and the period increases. For example, if supply voltage half-cycles to stator is delivered in the following order: $A^+ - B^- - C^+ - A^- - B^+ - A^- - C^+ - B^- - A^+ - C^- - B^+ - A^- - C^+ - A^- - B^+ - C^-$, one oscillation continues for 8 voltage periods. The oscillation period T_S =160 ms, oscillation frequency f_S=6.25 Hz, rotating angle 240°.

Experimental model and connection diagram

There is three-phase cage drive used in experiments on two pole-pair. The connection diagram is depicted in Figure 1. The parameters of drive are: 0.55 kW, 220/380 V, 2.9/1.7 A, 1360 rpm, $\cos\varphi$=0.71, η=71%. Drive is supplied from 220V network through the autotransformer, to control voltage value. The stator windings are connected in wye connection. Each winding is connected to the voltage source with two anti-parallel optical thyristors. There are several measuring instruments in the scheme: the voltmeter is switched for measuring the input voltage, ammeter is for measuring current and wattmeter is for measuring the consumed power.

The control scheme provides a possibility to supply control impulses on thyristors in the proper moment for switching positive or negative voltage half-cycle to the accordant stator winding. The control scheme contains a microcontroller (ATtiny2313), where control programs are written, that can provide a possibility to operate the drive in rotation regime in both directions and in six different oscillation regimes.

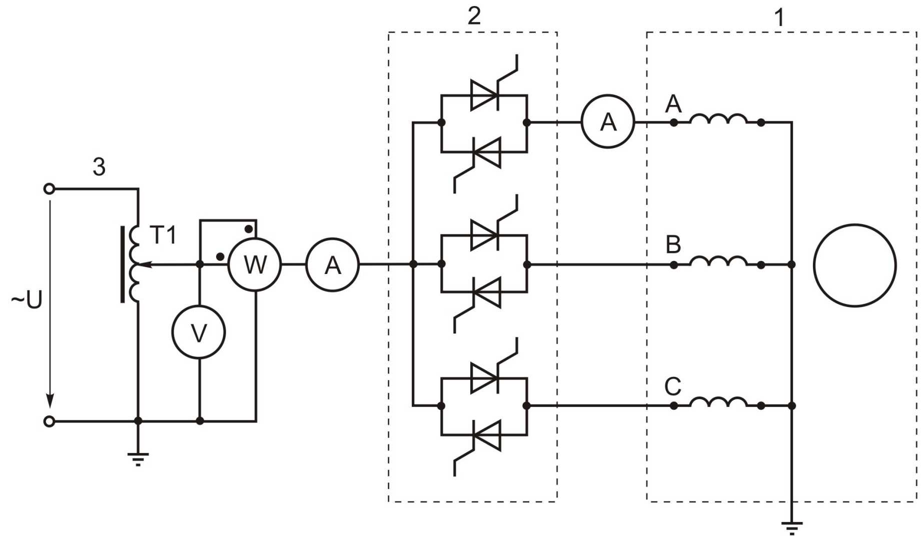

Fig. 1. **Asynchronous drive diagram:**
1 – asynchronous drive, 2 – semiconductor switch block, 3 – autotransformer

Experimental results in rotation case

It is experimentally proved that the motor operates in rotation and oscillation regimes. There are different characteristics made for rotation regimes, where the electromagnetic brake is used as a load. Experiments are made at lower voltage, because if the rotor of the drive is rotating slower, the cooling conditions become worse.

It is interesting that during no-load operation and in the regime with braked rotor the currents in the stator winding are almost equal. It is experimentally verified, that it is possible to start drive even if there is no supply voltage on one of the stator windings. As we know, it is not possible to start the three-phase asynchronous motor if one phase is lost at three-phase voltage supply.

Measurements are made of different parameters dependent on the load torque at different input voltages: 102 V, 9 V and 80 V. Figure 2 shows mechanical characteristics of drive. In no-load operation the rotating frequency of the drive at different voltages is 497 rpm that was prospective, because the magnetic field rotates with speed 500 rpm. Mechanical characteristics at different voltages are practically the same, they differ only coming closer to the critical moment that decreases if the supply voltage decreases.

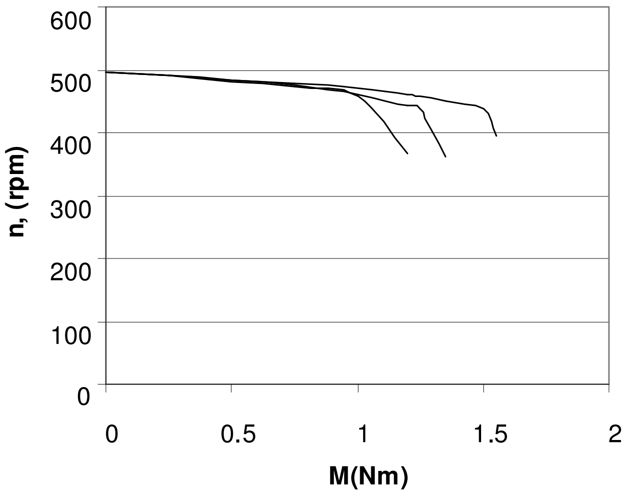

Fig. 2. **Mechanical characteristics of drive *n=f(M)***

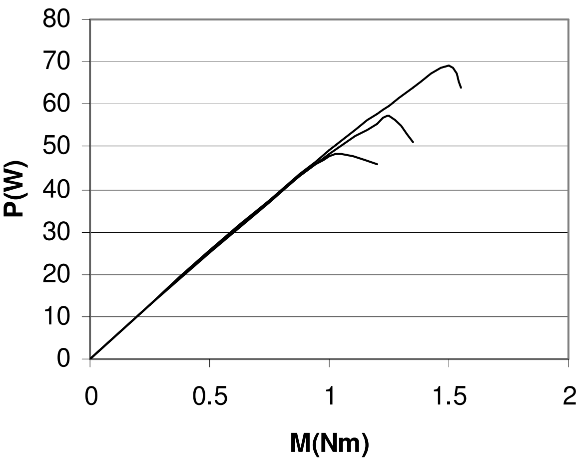

Fig. 3. **Output power P_2 dependent on load torque *M***

Figure 3 reflects the output power P_2 dependence on the load torque. P_2 grows proportionally to the torque M and is not dependent on the supply voltage while the torque is smaller than critical. Also other experimental results are obtained. The consumed power P_1 of the drive and current I in the stator winding grows if the voltage U is increased. If the voltage is constant then increasing the load torque M, P_1 and I decrease a little bit, but the power factor $\cos\varphi$ a little bit grows. If the load torque is smaller than critical, decreasing the supply voltage U, the efficiency ratio η increases.

Experimental results for oscillating regimes

Operating drive in oscillating regime the frequency of oscillations is the same as calculated but oscillating angle is much smaller than it is calculated theoretically. There is a moment of inertia for real drives. During switching in rotation regime there is a transient process and only after some time the drive is rotating with steady-state rotation frequency Ω_S. In a constant load case the rotation frequency changes by exponent

$$\Omega(t) = \Omega_S[1 - \exp(- t/T_{mex})], \tag{1}$$

where Ω_s – rotation frequency in steady-state regime, degree s^{-1};
T_{mex} – mechanical time constant, s.

If the rotor is oscillating the drive is all the time in the braking or starting regime and the rotation frequency Ω_S is newer reached. When the regime becomes quasi-stationary in one oscillation half – period the rotation frequency changes by exponent within $-\Omega_{OS}$ till Ω_{OS}, but in next half period within Ω_{OS} till $-\Omega_{OS}$ (Fig. 4). It is assumed that $\Omega_{OS} = \Omega_S\, k^{-1}$, where $k > 1$. In the first half-period

$$\Omega(t) = \Omega_S[1 - (k + 1)\exp(- t/T_{mex})/k] \tag{2}$$

Taking into account that $\Omega(0) = -\Omega_{OS}$, but $\Omega(0.5\,T) = \Omega_{OS}$, we get

$$\Omega(t) = \Omega_S[1-(2\exp(- t/T_{mex}) /(1+\exp(- t/2T_{mex})] \tag{3}$$

During the time interval from 0 till the moment the rotor of drive is braked, but in the interval from t` till $0.5T_{OS}$ is turned to the opposite direction. During the time interval from t' till $0.5T_{OS}+t'$ the rotor turns by angle α_{OS}, that is named as oscillating angle.

$$\alpha_{OS} = \int_{t'}^{T_{OS}/2+t'} \Omega(t)dt \tag{4}$$

Here t' is less than $0.25T_{OS}$. The longer is the oscillating period T_{OS}, the smaller is t' (relatively). Experimentally, the oscillating period was changed by changing the length of pause when voltage half-cycles are not connected to stator windings.

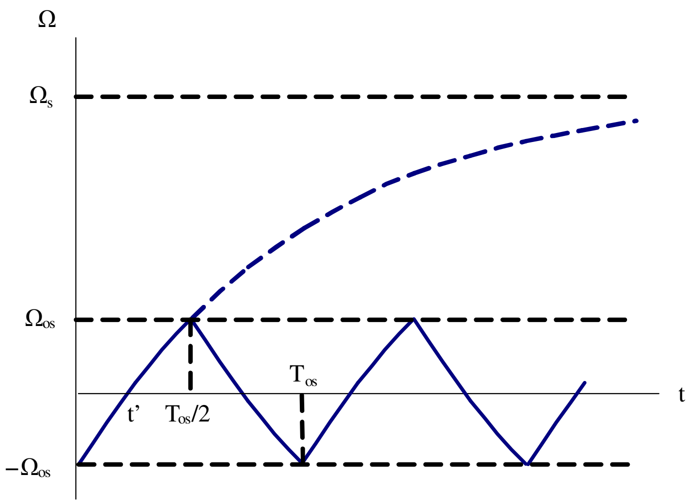

Fig. 4. **The changes of rotation frequency in oscillating regime**

If the oscillating period T_{OS} increases, the ratio k decreases the rotation frequency Ω_{OS} and the oscillation angle α_{OS} grows. It is assumed that the rotation speed of the drive in no load operation is n_S=1500 rpm, then Ω_S=3000 deg s^{-1}. Processing the data of the starting process for rotating case there is calculated the mechanical time constant T_{mex}=0.14 s. Ω_{OS} and α_{OS} the calculation results are generalized in Table 2.

Table 1

Voltage supply to stator windings during oscillating regimes

T_{OS}, s	**0.08**	**0.12**	**0.16**	**0.20**	**0.24**	**0.28**
1	A^+	A^+	A^+	A^+	A^+	A^+
2.	B^-	B^-	B^-	B^-	B^-	B^-
3.	C^+	C^+	C^+	C^+	C^+	C^+
4.	B^-	-	-	-	-	-
5.	A^+	-	-	-	-	-
6.	C^-	B^-	-	-	-	-
7.	B^+	A^+	-	-	-	-
8.	C^-	C^-	B^-	-	-	-
9.		B^+	A^+	-	-	-
10.		-	C^-	B^-	-	-
11.		-	B^+	A^+	-	-
12.		C^-	-	C^-	B^-	B^-
13.			-	B^+	A^+	A^+
14.			-	-	C^-	C^-
15.			-	-	B^+	B^+
16.			C^-	-	-	-
17.				-	-	-
18.				-	-	-
19.				-	-	-
20.				C^-	-	-
21.					-	-
22.					-	-
23.					-	-
24.					C^-	-
25.						-
26.						-
27.						-
28.						C^-

Table 2

Oscillating angle α_{OS} dependence on oscillating period T_{OS}

T_{OS}, s	0.08	0.12	0.16	0.20	0.24	0.28
Ω_{OS}, deg s^{-1}	425	633	834	1028	1212	1386
α_{OS}, deg	8.5	19.1	33.8	52.5	73.7	106.5

Operation of drive in the oscillating regime is experimentally proved to unloaded drive. The consumed power P of drive and current I dependent on oscillation period T_{OS} in 4 different supply voltage U values are measured. The result is given in Fig. 5.

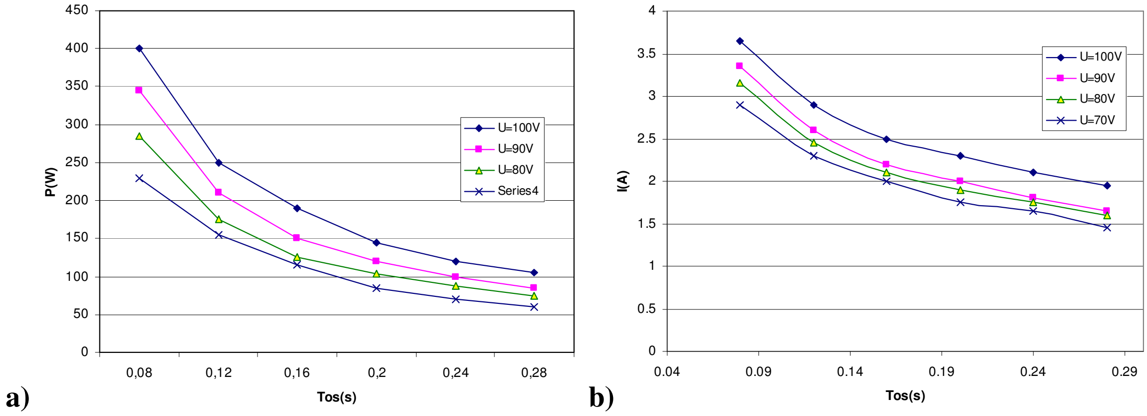

Fig. 5. **Consumed power P and current I dependent on oscillation period T_{OS}:**
a – $P = f(T_{OS})$; b – $I = f(T_{OS})$

If the oscillating period T_{OS} grows, the consumed power P and current I decrease. Also P and I decrease if the supply voltage is decreased.

Conclusions

1. The proposed model allows operating the cage drive both in rotating regime and in oscillation regime by connecting it to one-phase supply voltage.
2. The drive must be supplied with decreased voltage, not at the rated voltage.
3. The perspective for future could be using of drive in ocillating regimes. It is possible to change the rotor oscillation frequency and range by keeping the same power and control schemes – only microcontroller program is variable.

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