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SUITABLE MOTORS FOR MECHANISM WITH ELECTRONIC CAMS

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Abstract

This paper deals with the servomotor selection to drive the mechanism using an electronic cam. The electronic cam works in a continuous cyclic motion. The mechanism is accelerated and decelerated and the servomotor of the electronic cam has to serve enough of drive torque (drive force) to ensure the required displacement law. The driving torque is not only influenced by external forces and dynamic torque of mechanism, but also the high amount of torque is consumed by accelerating of the servomotor rotor itself. The suitable displacement law influences the motor selection too.

The mechanisms in machines are driven by electromotors, such as asynchronous and synchronous motors. The selection of the suitable motor to drive the mechanisms using the electronic cam is important and it depends on the mechanisms and the displacement law. In this case the selection of suitable motor for simply crank mechanism will be shown. The motor is not only loaded by the dynamic forces of mechanism but also by the dynamic force of the rotor of the motor which satisfies the displacement law of the electronic cam.

1 Introduction

The mechanisms in machines are driven by motors. One of sort of motors used in machines are electro motors. These motors can be divided into several kinds – the asynchronous motors, synchronous servo motors, stepper motors etc. The motor selections depend on driven mechanisms, driven torques and on the requirements of movement.

The motor selection is simple in many cases, because the motor is selected according the maximum required torque, maximum required speed. Where is not required dynamic of mechanism, where is constant velocity,

The motor selection is not simple in case of electronic cams, where is required the high dynamic of the movement described by the displacement law.

2 Electronic cams and displacement law

The electronic cam represents several meanings but in this paper has one meaning. The electronic cam consists of combination of a motor and a gear unit and rotates according the displacement law. The trajectory of the displacement law depends on the request of technology, construction, dynamic behavior.

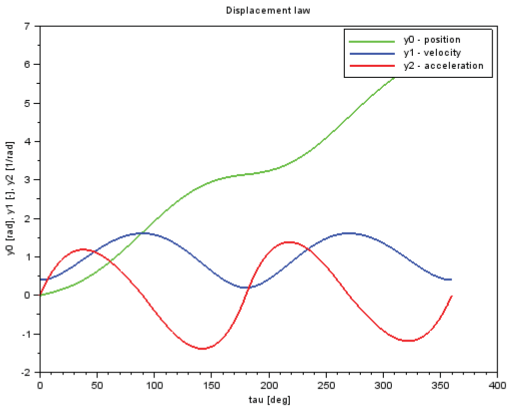

Fig. 1 Displacement law

The displacement law described the movement of rotor of motor. When designing of the displacement law of electronic cams are used the analogy of classic cams. The classic cams are designed by the several types of displacement law described by mathematical formulas. One of the displacement laws is presented in Fig. 1.

Some terms from classic cams are used in electronic cams. The virtual master exists and represents the main virtual position of the rotor and the speed of the virtual master represents the speed of mechanism. The virtual master is the analogy to rotation position of classic cam; the virtual speed is the analogy to speed of rotation of classic cam. The virtual master position represents the vector τ which depends on the speed of the machine and time (Eq. 2.1).

$$\tau = 60 \cdot n_M \cdot t, \qquad (2.1)$$

where:

τ – independent value of the displacement law, rotation of virtual master,

n_M – speed of the mechanism [rpm],

t – time [s].

The displacement law output value depends on the independent value of τ. The results of the displacement law are in position (green), velocity (blue) and acceleration (red). They are in norm forms because they are not dependent on the velocity of the virtual master. The norm form represents the shape of the displacement law, the velocity and the acceleration. Real values of velocity and acceleration depend on the angular velocity of the virtual master:

$$\omega_M = n_M \cdot \frac{\pi}{30}, \qquad (2.2)$$

$$\varphi_2 = y_0, \qquad (2.3)$$

$$\dot{\varphi}_2 = y_1 \cdot \omega_M, \qquad (2.4)$$

$$\ddot{\varphi}_2 = y_2 \cdot \omega_M^2, \qquad (2.5)$$

where:

y_0 – position of the displacement law,

y_1 – velocity of the displacement law in norm form,

y_2 – velocity of the displacement law in norm form,

ω_M – speed of the mechanism (virtual master) [s-1].

The shape of the displacement law could be described by mathematical formulas and could be modified by optimization or transformation.

3 Model of mechanism

In order to demonstrate the servomotor selection the exemplary mechanism was selected. The model of the mechanism is a simple crank mechanism (Fig. 2) which is used in many machines (packaging machine, manipulators, etc.). The useful of the selection of suitable motor is presented on the simple mechanism for the clear description.

3.1 Mechanism

The crank mechanism consists of a crank (2), rod (3) and mass (4). The motor is connected to the mechanism in point A. The mass (4) translate according the rotation of the crank (2). The description of the mechanism is in Eq. (3.1) – (3.3).

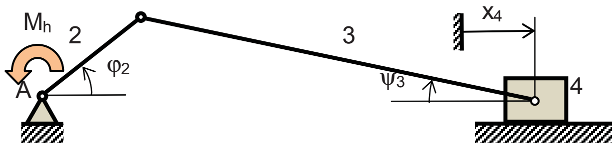

Fig. 2 Crank mechanism

These kinematics equations are for the mechanism:

$$x_4 = x_4(\varphi_2), \tag{3.1}$$

$$\psi_3 = \psi_3(\varphi_2), \tag{3.2}$$

$$\varphi_2 = \varphi_2(\tau), \tag{3.3}$$

where:

τ – independent value of displacement law, rotation of virtual master,

φ_2 – rotation of crank 2,

ψ_3 – rotation of rod 3,

x_4 – position of mass 4.

The movement of the mechanism is according the displacement law.

3.2 Dynamics of mechanism

Newton dynamic equations [2] were used to describe the model of the mechanism. The driving torque of the mechanism (Fig. 3) was computed from Eq. (3.6) and these forces describe the torque to movement of mechanism according the selected displacement law and the reaction forces.

$$M\ddot{x} = \sum F \tag{3.4}$$

$$M\ddot{x} = A \cdot R \tag{3.5}$$

$$R = inv(A)M\ddot{x} \tag{3.6}$$

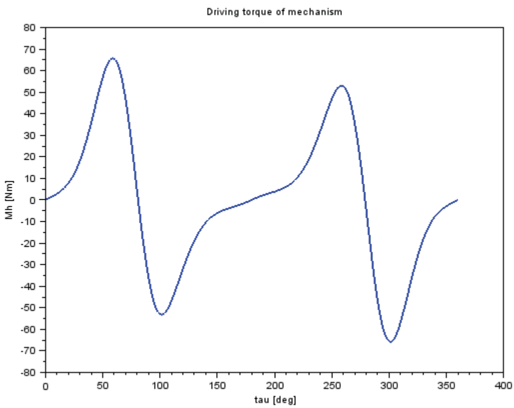

Fig. 3 Driving torque of the mechanism

4 Motor selection

The selection of the suitable servomotor depends on several parameters. In order to demonstrate the servomotor selection the servomotor of Yaskawa [3] and gear units of Stöber [4] were selected. The Yaskawa motors (Fig. 4) are described by the moment of inertia, rated torque, rated speed, maximum torque and maximal speed. The gear units are described by moment of inertia (related to input), gear unit ratio, maximal input speed. Both components have other parameters that are used for the selection of the suitable motor. But these other parameters are irrelevant in this case.

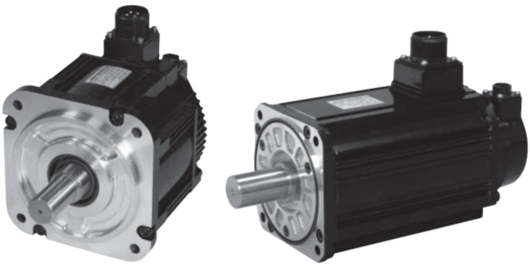

Fig. 4 Yaskawa motors (SGMGV, SGMSV)

4.1 Motor dynamics

The displacement law describes the kinematics of rotor and motion of the mechanism. The motor is described by the moment of inertia of rotor. The motor is loaded by the driving torque of mechanism and by its inherent dynamics. The dynamic load of the motor is the sum of the driving torque of mechanisms divided by the gear unit ratio and the driving torque of the motor plus the gear unit.

$$M_{rot} = (I_{rot} + I_{gear}) \cdot \ddot{\varphi}_2, \tag{4.1}$$

$$M_h = M_{rot} + \frac{M_{mech}}{i}, \tag{4.2}$$

where:

M_{rot} – driving torque of only the motor and the gear unit [Nm],

I_{rot} – moment of inertia of the motor [kg.m^2],

I_{gear} – moment of inertia of the gear unit (related to input) [kg.m^2],

M_{mech}– driving torque of the mechanism [Nm],

M_h – driving torque of whole mechanism [Nm].

Driving torques of the mechanism, the motor and the whole mechanism are in Fig. 5. The dynamics of the motor influences the resulting dynamics and the result of driving torque.

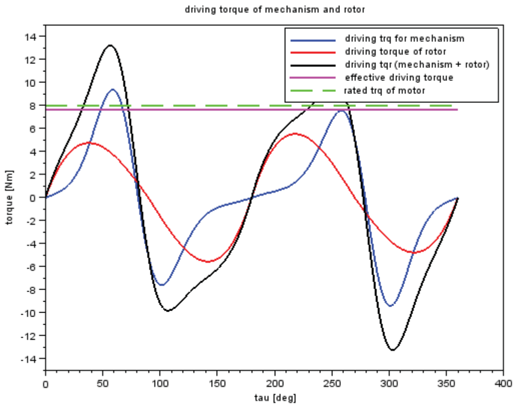

Fig. 5 Driving torque of the whole mechanism (motor + gear unit + mechanism), n_M = 300 rpm

Effective torque is computed for the driving torque of the whole mechanism

$$M_{ef} = \sqrt{\frac{M_1^2 \cdot t_1 + M_2^2 \cdot t_2 + \cdots + M_n^2 \cdot t_n}{t_1 + t_2 + \cdots + t_n}}, \qquad (4.3)$$

where:

M_{ef} – effective value of driving torque of whole mechanism,

M_i – driving torque of whole mechanism in time $t_{i,}$

t_i – time difference between values.

When the effective torque is within the rated torque, the servomotor can be used within the intermittent duty zone.

4.2 Motor selection

In order to show the differences between the different types of motor and gear unit a database of their parameters was built. The driving torques were computed to every combination of the motor and gear unit.

For low speed of n_M the dynamics is low and many types of motor and gear units are suitable. In Fig. 6 results are shown for n_M = 100 rpm. White squares are suitable combination of the motor and gear unit, black squares are not suitable combination of the motor and gear unit.

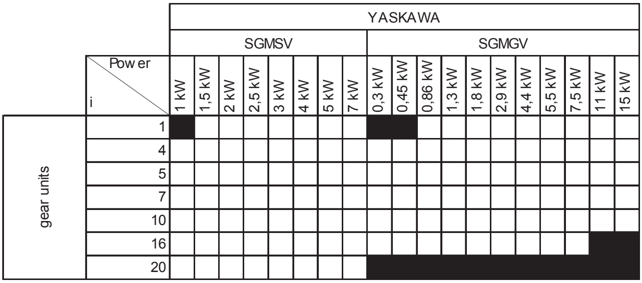

Fig. 6 Results of the selection of motor and gear unit, n_M = 100 rpm

(white - suitable, black - unsuitable)

When the speed increases, then the dynamics of the motor increases too. In Fig. 7 it is shown that the suitable motors are 2.5 kW and more powerful or equal than 4 kW in SGMSV types. It is shown that the motor of 3kW does not have enough power and has higher value of moment of inertia. This is main problem to select the suitable motor.

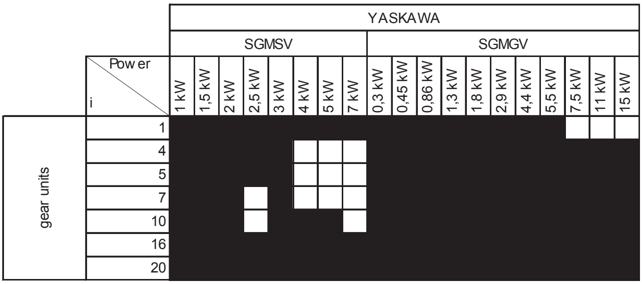

Fig. 7 Results of the selection of the motor and the gear unit, n_M = 300 rpm

In the case of electronic cam, the selection of suitable servomotor is very important. If the displacement law is changed, the other motors are suitable (Fig. 8). It depends on the mechanism and on displacement law.

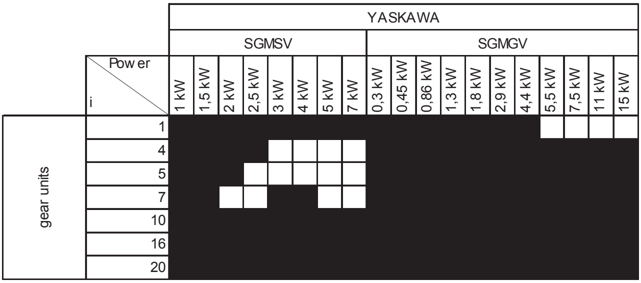

Fig. 8 Other results of the selection of the motor and the gear unit (other displacement law)

The high powerful motor is a possible solution in many cases, but a more powerful motor is more expensive and the power of the motor is not sufficiently utilized. The effective torque is equal 14.76 Nm in this case and rated torque of 7kW motor is 22.3 Nm.

The passive resistance is not taken into account in this selection.

5 Conclusion

Every motor has a different value of moment of inertia. This value produces a different driving torque of unloaded motor. The driving torque of the mechanism is independent on the motor selection. The selected gear unit changed the relation (ratio) between the moment of inertia of the servomotor and the moment of inertia of the mechanism. A more powerful motor has a higher moment of inertia and needs higher a driving torque of motor. In this case the more powerful motor does not satisfy the torque conditions.

In cases of electronic cams, selection of suitable servomotors is very important. The correct designed displacement laws are very important too. A bad displacement law is able to impair the motor selection.

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