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THE METHOD FOR SPEED-UP CONTROL OF STEPPING MOTORS STARTING CHARACTERISTICS

A new method has been developed for controlling the dependence of stepping motors starting torque on the supply voltage frequency, which provides the increased speed of response through full automation of the measuring process.

Keywords: *starting torque, stepping motor, control, measurements, speed of response, MathCAD, .NET Framework.*

Introduction

One of the basic stepping motor (SM) characteristics is the dependence of starting torque on the control pulses frequency. It determines the range of loading torque values at which the motor can be started without the loss of steps for different supply voltage frequencies. Therefore, this characteristic is the main indicator of SM loading ability in the process of starting and stopping [1, 2].

While testing SM it is important to perform the task of measuring its characteristics. For this purpose a number of methods are used. They are based on manual control of the motor torque in the range of the supply voltage starting frequencies [1]. However, with the development of measuring techniques and evolving of new SM types the existing measuring methods and facilities, based on them, do not satisfy current requirements and objects being controlled. Therefore, improvements and development of new approaches to measuring starting characteristics are of great current importance. First of all it is necessary to carry out analysis of the known methods and determine their main shortcomings which prevent them from further efficient application.

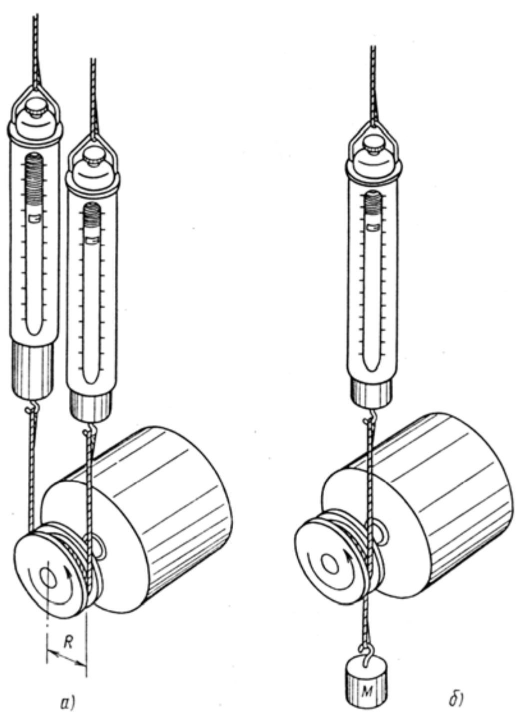


Fig. 1. SM staring torque measurements using dynamometer scale
(a – two scales, b – one scale)

Analysis of he known methods and facilities for SM starting characteristics measurements

Most known is the method of measuring SM starting characteristics, using string dynamometer as a torque sensor (fig. 1). In this case it is important to balance SM rotor with the additional loading torque created by means of another dynamometer (fig. 1a) or a weight, suspended to the pulley on a steel filament [1].

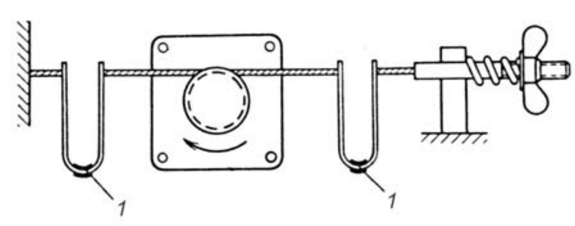


Fig. 2. SM staring torque measurements using strain sensors 1

Though the weight creates a constant loading torque, string with the weight stretches and vibrates as a result of SM motor vibrations. Therefore, loading torque and corresponding dynamometer readings will be unstable, which reduces the accuracy of measurements. Besides, the presence of a man in the measuring process causes additional subjective error and makes automation of measurements impossible.

Strain sensors are also used for starting torque measurement instead of spring dynamometers (fig. 2). Under such conditions SM torque is equal to the difference between the readings of strain sensors connected into bridge circuits [1].

In this case loading torque is created due to the friction force of the rope that is not constant and depends on the shaft rotation speed which changes in transition from one stable position to the next one.

Piezoresistive method allows measuring SM starting torque with high precision as well as its convenient transformation. In order to measure starting characteristic, loading torque is gradually increased until the motor is unable to start at the given frequency, i. e. SM torque is insufficient to overcome the resistance. Under such conditions torque balance is registered visually by the operator, which makes automation of the measuring process impossible.

Besides, the above-mentioned methods and facilities, though solving the problem of starting torque measurement, do not consider the problem of control in terms of the measured values correspondence to the established norms [3]. Therefore, taking into account the above-mentioned shortcomings, the problems of SM torque measurements and starting characteristics control, search for new approaches and technical solutions is required, foremost at methodological level.

Thus, the purpose of this work is to accelerate the process of SM starting torque measurements.

Having analyzed the above-discussed methods and facilities, we distinguished the tasks to be accomplished in order to solve the problem of SM starting characteristics control:

1. To establish the criterion of SM falling out of synchronism at the moment of its starting under overload conditions.
2. To perform mathematical modeling of SM starting characteristic;
3. To develop a method for speed-up control of SM starting torque.

Development of the speed-up SM starting torque control method

As it was stated above, the main feature of SM starting process is its ability to be in synchronism under given load and supply voltage frequency. The maximum possible load torque for the entire frequency range is considered to be SP starting characteristic. The maximum motor torque is achieved at the limit of the motor falling out of synchronism and so it is important to determine it. With the facilities, considered above, this is done through visual observations, which is unsatisfactory taking into account the principle of measurements automation. Therefore it is necessary to work out a new criterion that will make it possible to carry out this operation in the automatic mode. For this purpose we shall perform mathematical modeling of SP operation under starting conditions, using the model presented in [1, 4]:

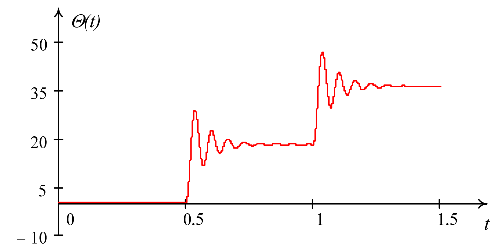
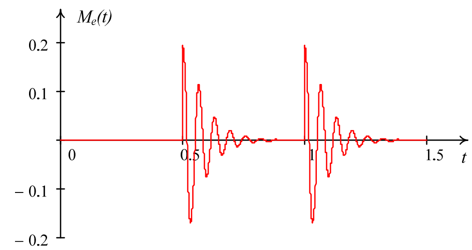
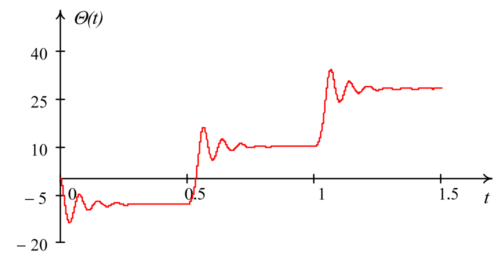
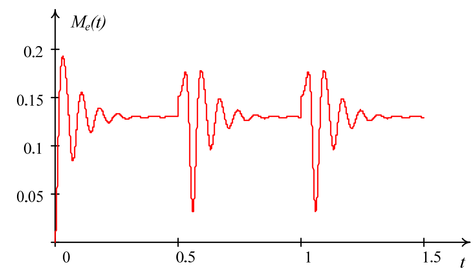
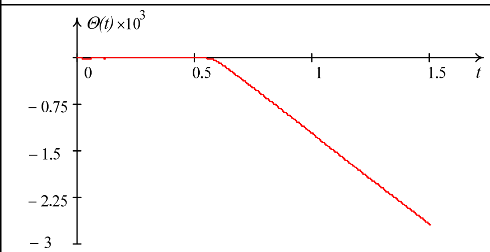
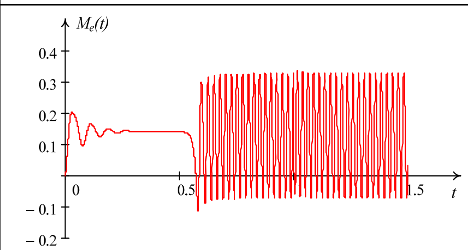
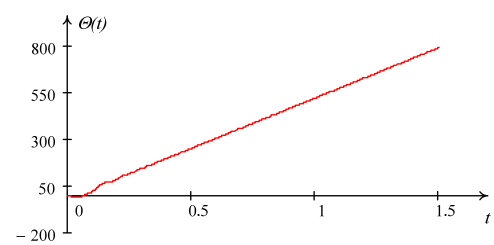
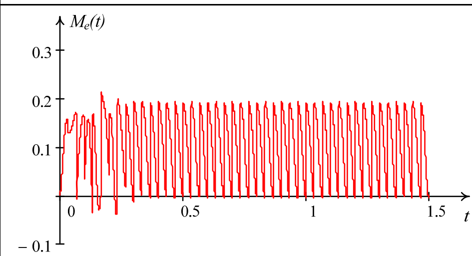
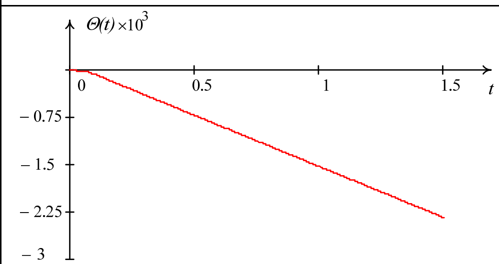
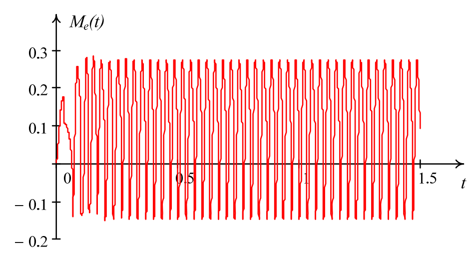
$$\begin{cases} J\dfrac{d^2\theta}{dt^2} + D\dfrac{d\theta}{dt} + pn\Phi_m i_A \sin(p\theta) + pn\Phi_m i_B \sin(p(\theta-\lambda)) - M_H = 0, \\ V_{gA} - r\cdot i_A - L\cdot\dfrac{di_A}{dt} - M\dfrac{di_B}{dt} + \dfrac{d}{dt}\left[n\Phi_m \cos(p\theta)\right] = 0, \\ V_{gB} - r\cdot i_A - L\cdot\dfrac{di_B}{dt} - M\dfrac{di_A}{dt} + \dfrac{d}{dt}\left[n\Phi_m \cos(p\cdot(\theta-\lambda))\right] = 0, \\ M_n = -nN_r\Phi_M\cdot[i_A\cdot\sin(N_r\cdot\theta) + i_B\cdot\cos(N_r\cdot\theta)], \end{cases} \quad (1)$$

where V_{GA}, V_{GB} – supply voltages, phases A and B correspondingly; i_A, i_B – currents in the phase windings; $n\Phi_m$ – flux linkage; L – self-inductance of every phase; M – mutual inductance; r – stator winding resistance; N_r – rotor teeth number; p – the number of pole pairs; n – the number of winding coils; J – moment of inertia; D – viscous friction coefficient; θ – angle of rotor rotation relative to stator; λ – SM stator teeth pitch; M_n – SM electromagnetic moment; M_H – loading torque.

Using research cited in [3], we shall present the results of solution (1) in MathCAD application package for diphase SM of M35SP-6 type in three operation modes at different frequencies of supply voltage f_U (table. 1).

Table 1

SM transients modeling

Mode	Rotation angle transient $\theta(t)$	Starting torque transient $M_{\ddot{\imath}}(t)$
Idling $M_H = 0$ $f_U = 1$ Hz		
Nominal loading $M_H = \sqrt{2} \cdot M_{\max}$ $f_U = 1$ Hz		
Overloading $M_H > \sqrt{2} \cdot M_{\max}$ $f_U = 1$ Hs		
Nominal loading $M_H = \frac{M_{\max}}{2}$ $f_U = 15$ Hz		
Overloading $M_H > \frac{M_{\max}}{2}$ $f_U = 15$ Hz		

As shown in Table 1, SM revolves in reverse direction due to the loading torque that exceeds $\sqrt{2} \cdot M_{\max}$ ($M_{\max}$ – maximal synchronizing torque). It is the evidence of the fact that with given supply voltage SM torque is insufficient for starting and the applied load exceeds the starting torque. Under such conditions boundary loading torque value

$$M_{\text{n. max}} = \sqrt{2} \cdot M_{\max} \tag{2}$$

is the maximal starting torque for this frequency.

Overload operation mode is characterized by SM falling out of synchronism, starting torque values being different for different frequencies. However, rotary angle transient process is alike, which is characterized by swift SM shaft rotation in the direction of the loading torque action. Obviously, this formulation does not give a clear picture of the conditions of SM falling out of synchronism under overload conditions. From table1 it is clear that for idling and loading modes, in the low frequencies range, the rotor also changes sharply the rotation direction, which also is the evidence of ambiguousness of this statement. Therefore its perfection is required so that SM hold-off condition would be not only precise but also could be subsequently used as a starting torque control means.

Under SM overload conditions, not only the factor of swift shaft rotation in the direction of the loading torque action is important, but also the duration of such rotation. In the transition from one angular position to the next one, duration of vibrations does not exceed the supply voltage half-period. At the moment of hold-off (table1) SP rotation angle does not change its direction and its duration obviously exceeds the supply voltage half-period.

Thus, main criterion of SM falling out of synchronism under overload conditions is shaft rotation in the direction of load action within the time t_n, that exceeds supply voltage half-period T_U / 2, i. e.

$$t_{n.} > \frac{T_U}{2}. \tag{3}$$

Realization of this criterion is possible due to software processing of the rotation angle transient process after previous measurement transformation by the angle sensor.

Starting characteristics belong to the class of rotation curves which are shown as a start area in fig. 3. General theory, that describes these characteristics [1, 5], has a number of shortcomings: dead and instability zones, determined experimentally, are not taken into account; presence of assumptions and simplifications in the calculation of analytical relationship $M(f)$. Therefore, the task of starting characteristics mathematical modeling is of great current importance.

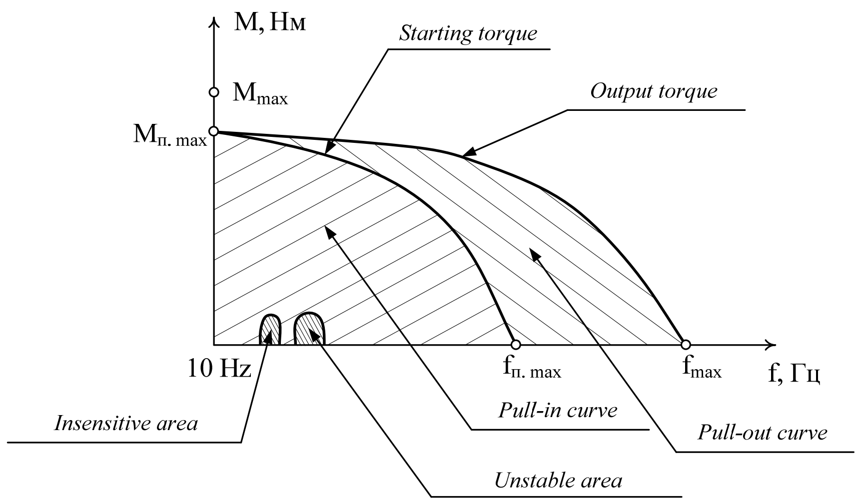


Fig. 3. Starting and output SM characteristics

The main idea of modeling SM starting torque dependence on the supply voltage frequency lies in determination of this characteristic, i. e. it is necessary to determine such maximal loading torque for each supply voltage value in the starting range, where SM remains in synchronism and can rotate in the prescribed direction and then stop. This operation is possible after solving mathematical model (1) with the application of the developed criterion of SM falling out from synchronism.

Thus, the following algorithm of starting torque determination is suggested (fig. 4). After finding the minimal supply voltage frequency f = 1Hz and maximal starting torque $Mn._{max}$ (2) from system (1), solution for SM rotation angle $\theta(t)$ is found. Then such areas of $\theta(t)$ dependence are found, where the first derivative is negative, i. e. the direction of shaft rotation is opposite to the prescribed one.

By comparing the duration of the obtained areas t_n with the supply voltage half-period $T_U / 2$, it is determined whether SM starting torque is sufficient to overcome the load. If it is insufficient and inequality (3) is satisfied, loading torque Mn is reduced by a pre-set step and the process of rotation angle transient calculation is repeated. The process continues until inequality (3) is violated and SP can start without the loss of steps and its torque exceeds the loading torque for given frequency value. Then the previous torque value will be the maximal starting torque for this frequency.

After storing the current values of torque and frequency, frequency is increased by the pre-determined step and rotary angle is calculated for given frequency and load values. Calculation process is repeated until current loading torque value approaches zero. Then starting characteristic is plotted using the stored values.

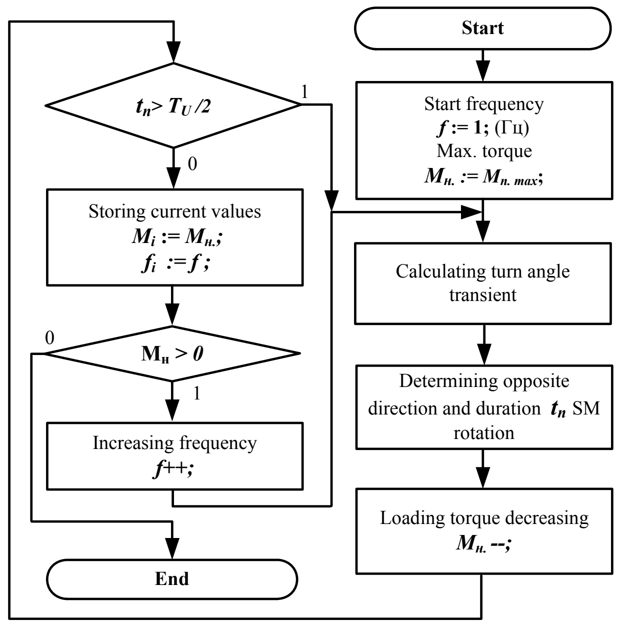


Fig. 4. Algorithm of SM starting torque modeling

Due to the complicated cyclic calculations of the non-linear differential equations set, MathCAD application package can not be fully used for the developed algorithm realization. That is why the developers of this application package offer MathCAD Automation Interface (MAI), that provides realization of MathCAD capabilities for dynamic computations and data processing with appropriate adjustment with the help of external programming facilities [6].

Using modern .NET Framework 2.0 technology [7, 8], a computer program has been developed on the basis of the presented algorithm (fig. 4) that performs modeling of the starting characteristic for SM with the pre-defined parameters or type (fig. 6).

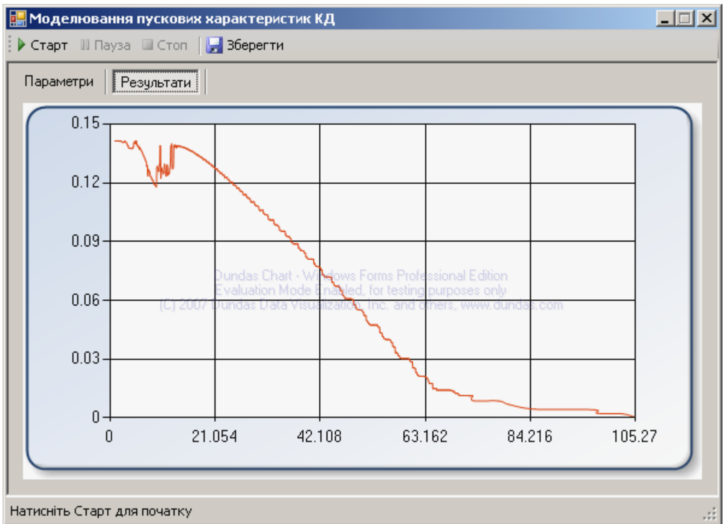


Fig. 6. Results of SM M35SP-6 starting characteristic modeling

From fig. 6 it is clear that the obtained starting torque dependence on SM supply voltage represents theoretical starting characteristic (fig.3) with low-frequency resonance dips being taken into account, which makes it possible to adjust measuring process in the course of the starting torque control. Besides, using starting characteristic it is important to determine SM pick-up frequency that will be the maximal supply voltage frequency for the motor to be able to start without the loss of steps [1, 2].

The presented approach to the starting characteristics modeling enables not only mathematical description of these relationships, but also representation of the starting torque measuring process. First of all this is important in terms of methodology because makes it possible to represent the developed approach to mathematical modeling in the form of measurement method that consists in the following.

SM starting characteristic control is based on the discrete measurements of its torque in the supply voltage starting range under stepwise load reduction beginning from the maximal value $M_{n.\ max}$) until the moment when the motor will be able to start. This moment is determined using the criterion of SM falling out of synchronism (3) by comparing the time of SM shaft rotation in the direction opposite to the prescribed one with the supply voltage half-period. Processing of the obtained starting torque values for all supply voltage frequencies in the form of starting characteristic is required for finding the pick-up frequency and establishing of SM quality class. Thus, we have obtained the method for speed-up control of SM starting characteristics that makes it possible to accelerate measurements through full automation of the processes of adjustment and supervision over the measurement control and data processing system.

Conclusions

In this work a new method for speed-up control of stepping motors starting characteristics has been developed. It consists in the automated discrete torque measurement in the starting range of the supply voltage frequency with further processing and normalization. Above all, this method makes it possible to accelerate the measurements. Besides, due to automation the accuracy of SM starting torque control is increased because human factor is excluded.

As a result of the analysis of the existing methods and facilities for starting torque measurements it was found that one of the main problems is to determine the moment of SM falling out of synchronism. In order to solve this problem a new criterion was suggested that is based on comparing the time of SM shaft rotation in the direction, opposite to the prescribed one, with the supply voltage half-period.

For the development of speed-up control method, mathematical modeling of SM starting characteristics is suggested, which enables measurement process representation.

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