Influence of the Type of Acceleration Characteristic of the Stepping Motor for Efficient Power Usage

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Influence of the type of acceleration characteristic of the stepping motor for efficient power usage

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Abstract

The main goal of presented research is to confirm efficiency of nonlinear characteristic of frequency increase during start with full load of stepper motor. This paper discusses about characteristics commonly used during start of stepper motor and proposes nonlinear characteristic. Presented results are compared to criteria of total angular acceleration. Proposed acceleration characteristic use real torque-speed characteristic taken from stepper motor. Described method is applied to a machine that glues elements of complicated geometry. Usage of non-linear characteristic reduces productive time. Presented research was accomplished on prototype machine build for company, which produce seats for mass transportation. Due of diversity of elements in this process, the glue layer must always have the same parameters and setup time need to be as short as possible. Non-linear characteristic with variable frequency change is used to accelerate ball screw, which shift spraying system alongside machine.

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Keywords: stepper motor; control; stepping motor acceleration

1. Introduction

Different types of motors are applied for drives in automatic control engineering. One of these types was used in the prototype of manipulator for gluing the elements of seats for passenger transport services. This gluing process is manually performed and it is connected with a lack of repeatability of connection parameters of particular layers.

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The main aim of the designed automatic system of the manipulator is to improve this process and in consequence increase the strength of the connection and save some glue and compressed air.

Triaxial Cartesian drive is applied because of the element dimensions and complex shape of surfaces (digital representation). Stepper motors, BLDC motors, linear induction motors or pneumatic rodless actuators can be applied as a source of this drive.

The application of pneumatics for the drive of spraying system should guarantee the displacement of large masses in a short time [1]. It requires the installation of compressor with high efficiency.

The other solution is the application of linear induction motors. Depending on construction we can get high dynamics of motion and high values of forces [2]. The drawback of this solution is a motor weight which has a negative influence on inertia of manipulator drive system. Additionally, it is too expensive.

Ball screw drive was also analysed. Comparison between stepper motor and BLDC motor (BrushLess Direct-Current motor) was done. The application possibilities of stepper and BLDC motor do not show the problem from the point of view of operation characteristics [3–5].

Finally, the stepper motor was chosen as a drive due to weight, overall dimensions and economics – the selection was done on the basis of review of essential parameters of manufacturing process.

The investigations have been done with the application of special test stand, prototype of the machine equipped with triaxial manipulator for gluing (Fig. 1 and 2). Construction consists of frame 1 connected with two ball screws 5 which were driven by stepper motors ST5918L4508 from Nanotec company 4. These two screws are applied to displace traverse 3 with spraying system 8 along guides 6. Selection of proper stepper motor is very important due to requirement of the power for overcoming the resistance of power unit. Operation characteristic of head manipulator drive is connected with variable speeds in a wide range and variable values of force of inertia. The analysis of motor operation is done for one ball screw drive.

Stepper motor steering is done with the application of controller SMCI47-S-2 from Nanotec company which is supplied by voltage 48 V. The controller works in mode ¼ step (0.45°) and this causes the rotation of rotor with the defined angle which is forced by impulse generated by 32-bits microcontroller from ST company. This approach is possible to do because the construction of controller provides 95% of torque in a full-step operation [3]. Digital encoder NOE2 was applied to read the position of rotor. The aim of the investigations was the determination of limiting operation frequency of stepper motor where no steps are lost and determination of effective parameters of motor impetus.

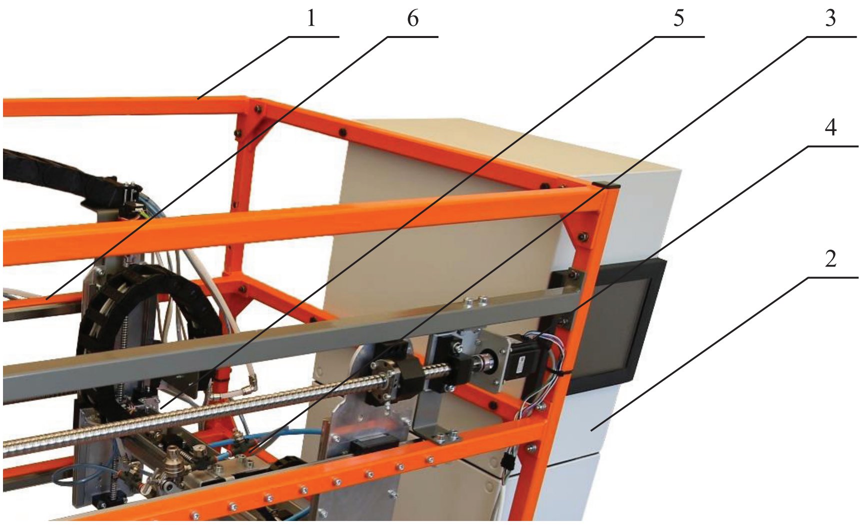

Fig. 1. View of drive axle: 1 – frame, 2 – steering box, 3 – traverse with spraying system, 4 – stepper motor, 5 – ball screw drive, 6 – guide.

2. Acceleration characteristic of stepper motor

Characteristic of frequency variation in function of supplying time of particular windings of stepper motor is described by the following relationship [3]:

$$f(t) = t \cdot p + f_s \tag{1}$$

where: f – frequency variation of windings supply (Hz), t – time (ms), p – increment (Hz.ms^{-1}), f_s – initial frequency (Hz).

Within a framework of the investigations the other characteristic was proposed – it should shorten the time of motor impetus. This characteristic is a supplement of characteristics of frequency increment which are given by controller producers for stepper motors [3, 6]. The basis of this characteristic is number of steps which take a part in motor impetus in function of time. Due to this fact it is possible to compare both characteristics of frequency variation. The analysed relationship is given by the following formulas:

$$\begin{cases} f(k) = \dfrac{(-1)\cdot\sqrt{r_1^2 - k^2} + r_1}{k_c} \cdot (f_d - f_s) + f_s, k \in < 0; r_1), & (2) \\ f(k) = \dfrac{\sqrt{r_2^2 - (k - r_2)^2} + r_1}{k_c} \cdot (f_d - f_s) + f_s, k \in < r_1; r_2 >, & (3) \\ k_c = r_1 + r_2, & (4) \end{cases}$$

where: f – frequency variation of windings supply (Hz), k – present step, r_1 – number of steps of first part, r_2 – number of steps of second part, k_c – total number of steps, f_d – target frequency (Hz), f_s – initial frequency (Hz).

Characteristics of frequency increment in function of step and time are presented in Fig. 2.

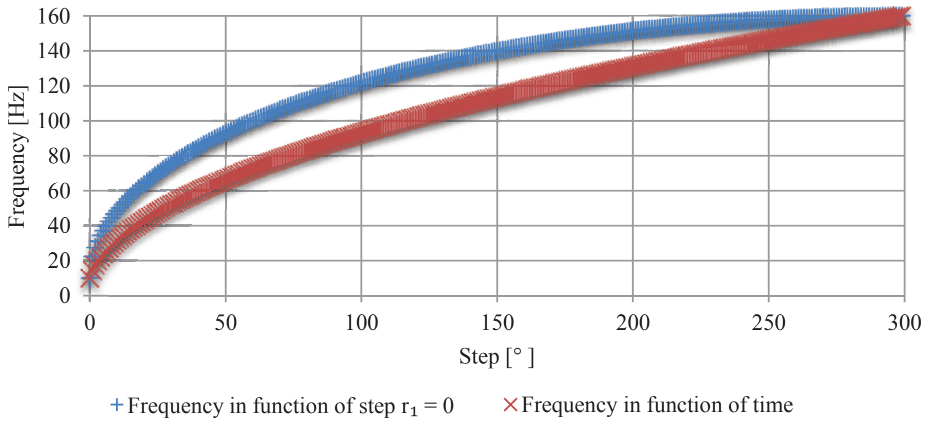

Fig. 2. Characteristics of frequency variation in function of time and step.

3. The investigation results

The aim of investigations was the determination of limiting maximal frequency where no steps are lost. On the basis of the results presented in Table 1 one can notice that the characteristics of frequency variations have not got any significant influence on maximal rotational speed of the motor. For frequency increments greater than 50 Hz.ms^{-1} the value of frequency for the given step and both characteristics is similar in every examined range of speed.

Table 1. Statement of limiting frequencies.

Type of characteristic	Basic increment of frequency p ($Hz.ms^{-1}$)	Maximal frequency (Hz)
Linear	10	14 500
	30	14 500
	50	14 500
Non-linear ($\frac{r_1}{r_2} = 0$)	10	15 000
	30	15 000
	50	14 500
Non-linear ($\frac{r_1}{r_2} = 1$)	30	6 000
Non-linear ($\frac{r_1}{r_2} = \frac{1}{5}$)	30	10 000
Non-linear ($\frac{r_1}{r_2} = \frac{1}{7}$)	30	12 000

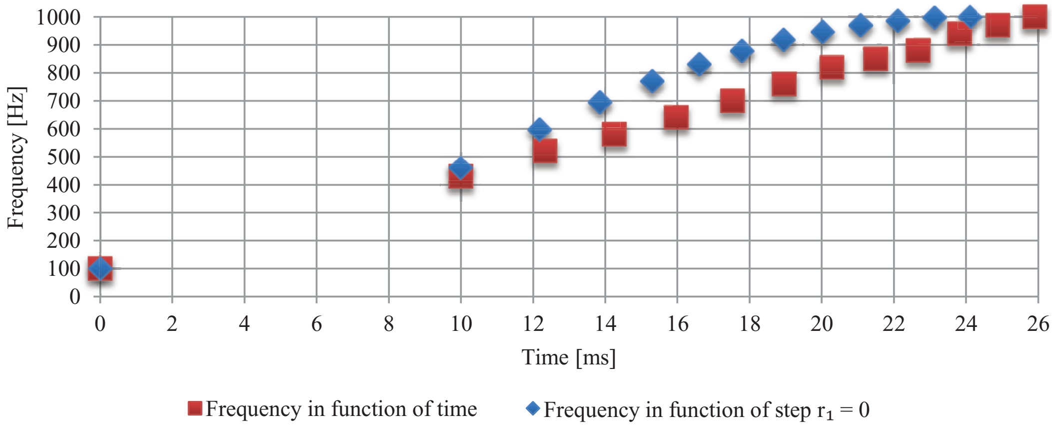

Fig. 3. Characteristics of motor impetus time for the given frequency 1000 Hz and increment 30 $Hz.ms^{-1}$ of characteristic in function of time.

Real time of obtaining the given rotational speed was also analysed (Fig. 3). As we can see both characteristics of low frequency of supply variation show small difference for time of motor impetus.

The characteristics for different ratios of parameters r_1 and r_2 and maximal frequency 10 kHz were also compared. Time for achieving the given speed is noticeably short. On the basis of Fig. 4 one can see that the speed of frequency variation depends on ratio between r_1 and r_2.

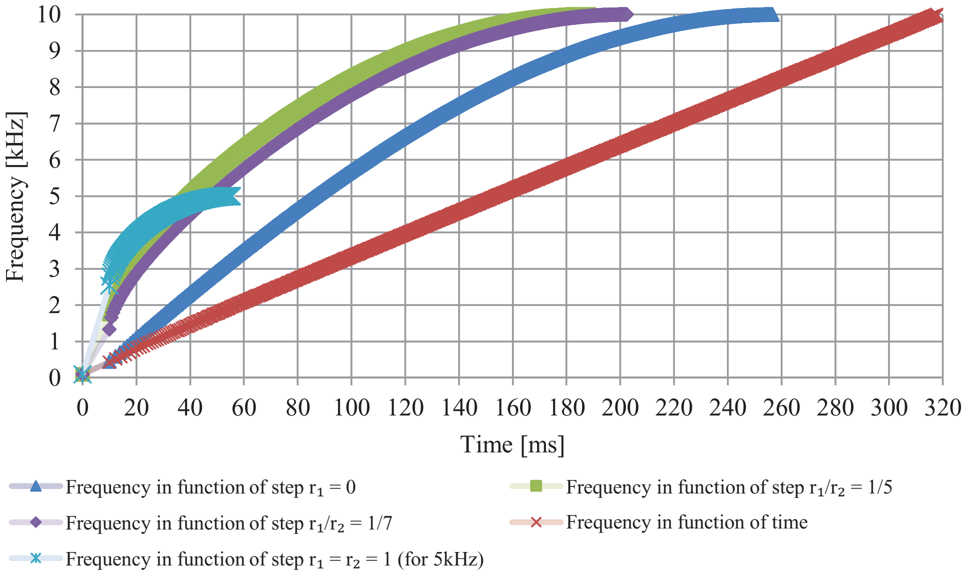

Fig. 4. Characteristics of frequency in function of time for variable values of step r_2.

4. Conclusions

On the basis of comparison of both types of characteristics of stepper motor acceleration we can notice the difference between times for achieving the given speed. This fact results from different parameters of variation of frequency increment during acceleration.

Characteristics in function of step for ratio $r_1/r_2 = 1$ show longer time of motor impetus. Frequency increments for last phase of acceleration have too high values and it causes the phenomenon of step loosing.

Characteristic of frequency variation with parameter $r_1 = 0$ has higher rotational speed than for case with linear frequency increment. This results from lower frequency variation in last phase of acceleration.

The investigations allowed to choose the proper parameters of motor impetus which provide undisturbed motor operation. The investigation results will be applied in steering program for gluing process and this will allow to effectively use the motor power. The obtained results will be used for further scientific works i.e. selection of effective parameters of operation of stepper motor in function of loading values.

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