Mathematical Modeling and Parameters Identification of the Mechatronical System Used in the Constructed Hexapod Robot

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Abstract. We present both design and test results of the servodrive (electric motor and its control system) used in the constructed hexapod-type walking robot. We are aimed on the construction analysis of the servo, modeling and functioning of the electronic feedback action in the applied type of the engine. The carried out research also includes a block diagram presenting working scheme of the used servo. In particular, we describe a control method of eight servodrives using only one control signal. The obtained results present the relationship between the current used by the system and the value of a specified torque generated by each servodrive. We illustrate and discuss the accuracy of the positioning of the particular drive depending on the applied dynamic load. The obtained results supported by analysis of the gait of the biologically inspired six-legged walking robot (Geotrupes stercorarius) allow to preliminary determination of the average energy required to realize given robot tasks. In addition, the maximum speed and the permissible load for the gait of the hexapod as well as the repeatability of the individual steps performance during the movement of the robot are also estimated.

Keywords: servo, control, servo characteristic, six-leg robot.

1 Introduction

Nowadays mechatronics become large part of both research and everyday life. Morover many of us come in contact with mechatronic devices often unconsciously. Designed and produced robots find their use not only in industry [3], but also in daily life. Design of every robot combines elements such as power supply, control systems, sensors and motors. Those last elements have huge influence on the robot performance and efficiency, especially on its movement precision, speed and power consumption. There is a lot of operation [6] describing both direct-current and alternating current motor drives. In literature there are reported results mostly of the numerical calculations [7], where main characteristics used in analysis are given by manufacture's. In this paper we are presenting results of the research based on the servos operating that are commonly used in small robotics. The summary consists of the results analysis in comparison to data provided by the manufacturer.

J. Awrejcewicz et al. (eds.), *Mechatronics: Ideas for Industrial Applications*,
Advances in Intelligent Systems and Computing 317, DOI: 10.1007/978-3-319-10990-9_46

2 The Servodrive Construction

The servo is a closed loop drive system with a position feedback, in which the input signal is a rectangular voltage control with variable frequency, while the output signal is a physical quantity (position, velocity, acceleration). Fig. 1 shows a functional block diagram of the servo [5].

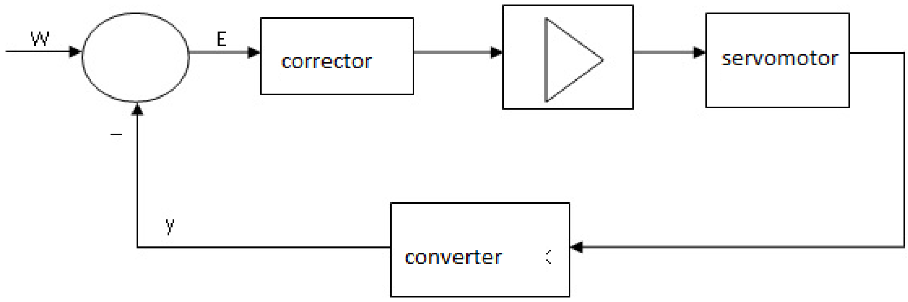

Fig. 1. Servos construction scheme

The set-point input signal is compared to the pre-processed output signal and the resulting error is being transmitted to a correction term and subsequently amplified. The correction signal is applied to the actuator which angular position is the output value of the system. The purpose of the system is to eliminate the difference between the actual servo position and current position set-point. The servo shows the structure of a typical closed-loop control system.

The construction of the servodrive consists of a DC motor, control system and gearbox. Due to the gearing ratios being very big (about 1:171) – it provides considerable torque in relation to the mass, such as in case of Servo TowerPro MG-995 with a mass of only 55 g and the torque of 1.3 Nm with an angular velocity of 6.16 rad/s (according to the manufacturer). The disadvantage of most servodrives is the fact that due to the use of an rotational potentiometer with a limited angle range (the resistance change corresponds to the angular rotation) its motion is limited to 180°.

3 The Servodrive Control

In the designed robot the microprocessor (CPU) was applied that belong to 8-bit AVR controllers family. The CPU is clocked at a low speed of only 16 MHz, so the complex structure of the robot implies the usage of systems aiding its work. In the following case the external timing circuit is applied to speed up the operation frequency. This kind of the control system, can be connected even to a large number of sensors and still has enough computing power and ROM memory to generate control signals for at least 18 servos. Application of a specially designed electronic circuit, allows us to control the entire system in real time, as it reduces the computational loading of the processor by choosing which servo should be supplied with an input signal according to the set sequence. For this purpose the switching system was designed that enables simultaneous control of 32 servos with just three 16-bit PWM signals. Because the servo control signal is generated at a frequency of 50 Hz and is filled in a time domain for 0–2.5 ms (Fig. 2), it was possible to increase the frequency of generating a control signal to 400 Hz and create a loop to generate this signal. One cycle of the PWM signal lasts for 20 ms and consists of eight high states of 2.5 ms length, each correspond to a different servo. The signal generated by the microcontroller is transmitted by the timing circuit, which is intended to choose a particular servodrive. The system clock impulses are used to control the demultiplexer, which system allows to select a specific servo and to supply it with a control signal.

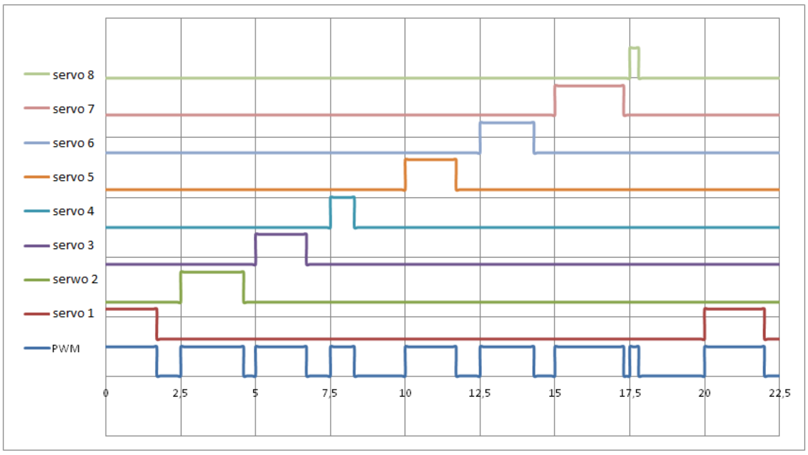

Fig. 2. The PWM signal division for each servo

4 Results

In order to compare the results of a computer simulation of the real six-legged robot it was necessary to carry out tests on the servos used in the project. The research was being conducted on the servodrives TowerPro MG-995 commonly used in model making. To determine necessary mechanical parameters, following technical characteristics declared by the producer were used:

- metal gear, double ball bearing and complete set of relevant (large and strong) servo arms, washers and screws equipped;
- rotational speed ratio 0.20 sec/60° (6.0 V voltage supply);
- power: 11 kg/m (6.0 V voltage supply);
- mass: 55.2 g;
- dimensions: 40.6 mm × 19.8 mm × 37.8 mm;
- power supply voltage range: 4.8–7.2 V.

For the need of the analysis a special research set-up was constructed, allowing to measure the current consumption of the servo and the driving torque generated by the servo at the same moment [1]. To test the speed ratio and the positioning accuracy of the servo under variable dynamic loading the another measurement set-up was also constructed. Each measurement was performed on several different servos. The position measured data for current characteristics was collected by the conversion circuit (PWM signal to analog) and then processed by the National Instruments DAQ multimodule NI-6001 using the NI LabVIEW software.

5 The Driving Torque Measurement

The results show the relation between the current consumed by a servo and the torque generated at the output of the gear shaft [2]. To obtain a real time characteristic of the servos, the linear intensity values of an electronic integrator was necessary. As shown in the following test results below, the servo consumes the largest current only with the coexistence of the high state of the control signals. Fig. 3 illustrates the measurement results after applying different loads to the servo.

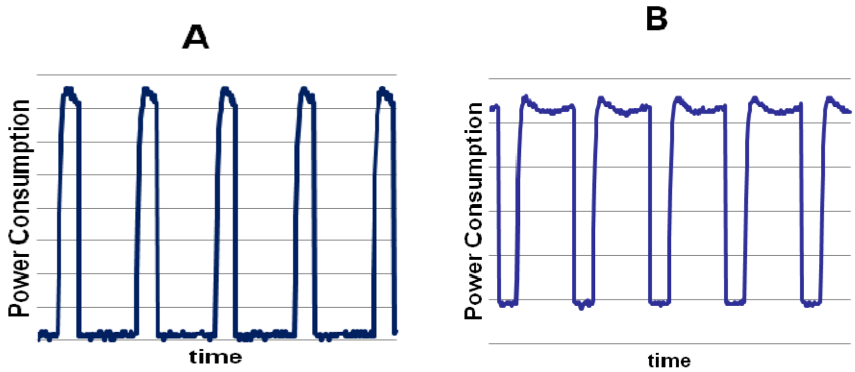

Fig. 3. The signal power for variable load A – low loaded, B – high loaded servo

Integrating filter was used to convert the pulse signal into an analog signal. It is generally based on the following equations:

$$y_{\min} \rightarrow for\ 0 < t < DT; \quad y_{\max} \rightarrow for\ 0 < DT < t < T \tag{1}$$

$$\bar{y} = \frac{1}{T}\int_0^T f(t)dt \tag{2}$$

$$\bar{y} = Dy_{\max} + (1 - D)y_{\min} \tag{3}$$

The obtained solution shows that the current consumed by the servo is dependent on the signals value (the minimum and maximum values of the signal). Introduced electronics allowed to study the servo in real time. The results integration yielded by the filter usage are presented in Fig. 4.

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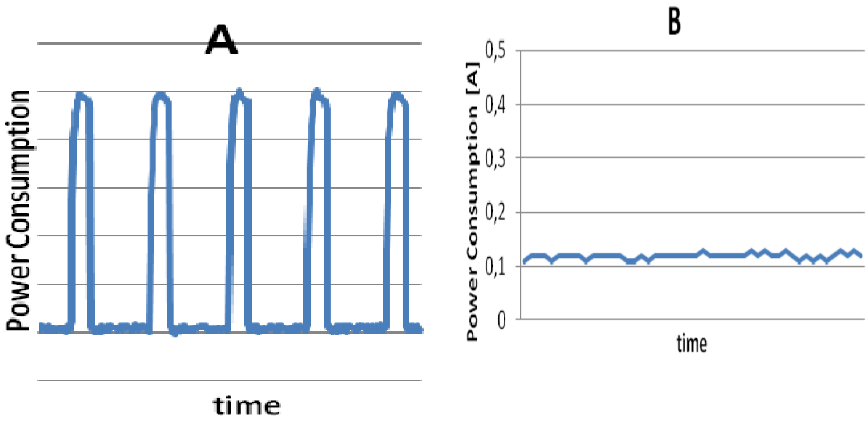

Fig. 4. Power consumption by the servo, A – before conversion, B – after conversion

6 Servodrives' Current vs. Torque Characteristics

The measuring system consisted of a force sensor and adjustable arms to differentiate the distance of the loading weigh from the output shaft. The graphs include the results of four servos for the various arms lengths.

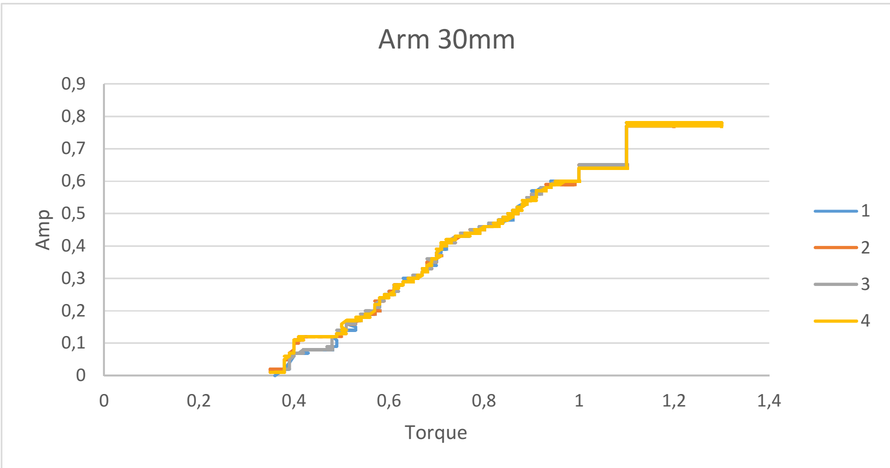

Fig. 5. The dependence between the current drawn by the servo and the torque generated on the arm of 30 mm

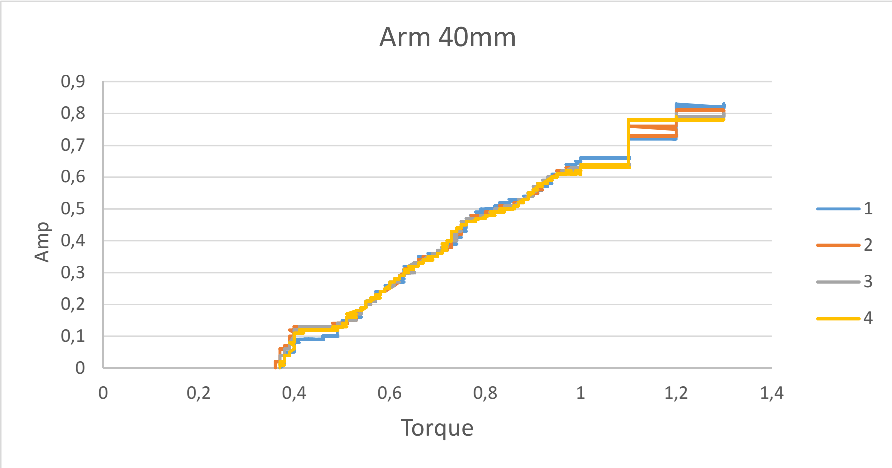

Fig. 6. The dependence between the current drawn by the servo and the torque generated on the arm of 40 mm

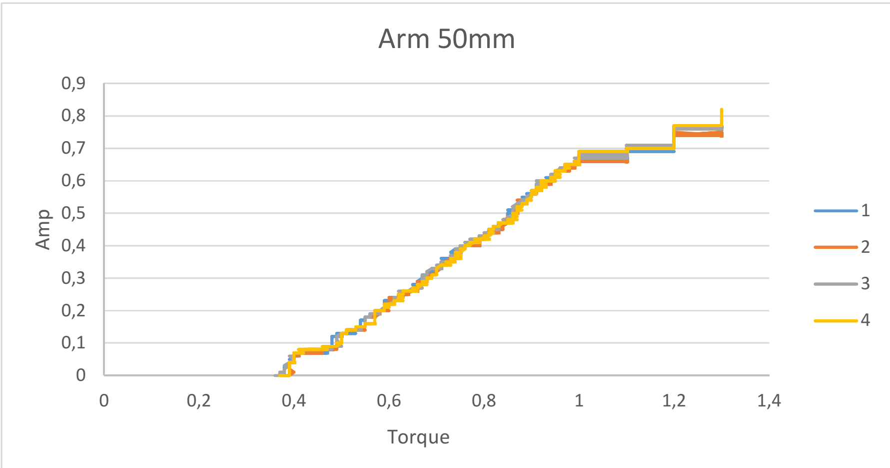

Fig. 7. The dependence between the current drawn by the servo and the torque generated on the arm of 50 mm

Analysing the graphs shown in Figures 2–4 it can be said that maximum torque generated by the servo is almost equaled to 0.8 Nm while the current consumed at the same time moment is at about 1.2 A. In order to avoid damage of the servomotor, the research was carried out only until the servo current exceeded 1.3 A. However, it was also found that the maximum current of the servo was at the level of 1.5 A, but the generated torque did not exceed more than 0.8 Nm. Basing on the determined data, the current vs torque characteristic can be described with a linear equation of the current function:

$$M = 0.846\, I - 0.23. \tag{4}$$

As shown in the graphs above, the servo holds the locking torque, which is a result of the high gear ratios application, at the value of 0.1 Nm. This occurrence often helps to achieve the reduction of the energy consumption while maintaining a fixed servo position.

7 Servodrives' Angle vs. Time Characteristics

The graphs shown in Figures 8 and 9 show the results of the angular velocity of the investigated servomotors (estimated average angular position of all examined drives vs. time). In order to perform these studies, the PWM signal generator system was designed. It allows to measure the minimum time displacement of the servo between two extreme positions. Speed has been measured for both rotation directions: clockwise and anti-clockwise. The test results are presented in the figures below.

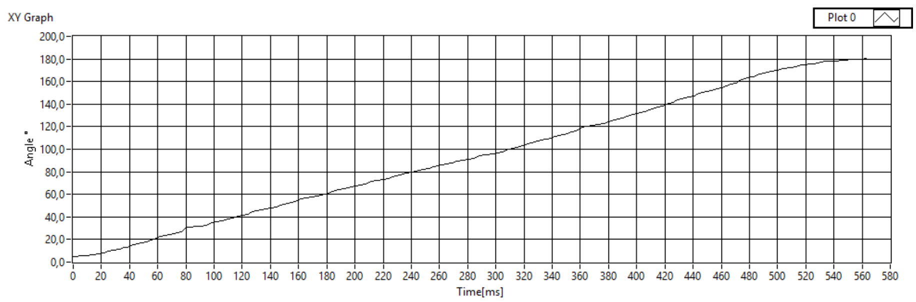

Fig. 8. The angular position vs. time for a clockwise rotation

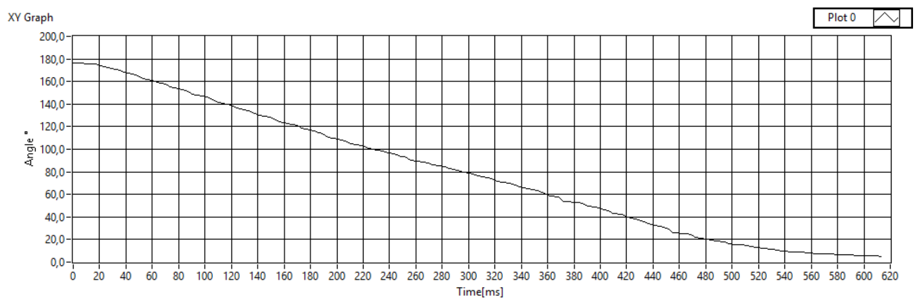

Fig. 9. The angular position vs. time for a anti-clockwise rotation

Basing on the results obtained in this study, the calculated mean speed of the servo rotation is at about 5.2 rad/s. It is larger for clockwise rotations (5.4 rad/s), while for reverse rotation it is equaled to 5 rad/s.

8 Positioning Accuracy

Conducted a study containing hundreds of measurement points, which helped to determine the accuracy and repeatability of the positioning[4].

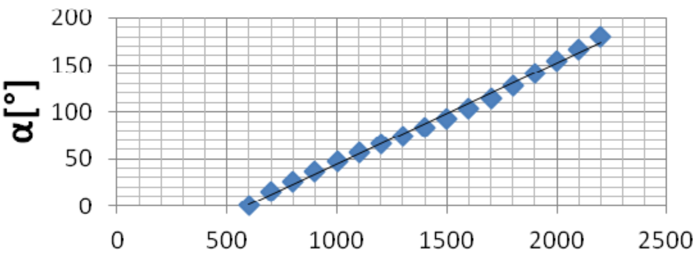

Fig. 10. Relation between the angle of the servo and PWM signal width

The graph shown above (Fig. 10) indicates that the servo positioning accuracy is at about 0.1 of the obtained signal satisfies the equation [p] from the angle [α] obtained on the shaft servo-mechanism.

$$\alpha = 0.1074\ p - 62.74 \tag{5}$$

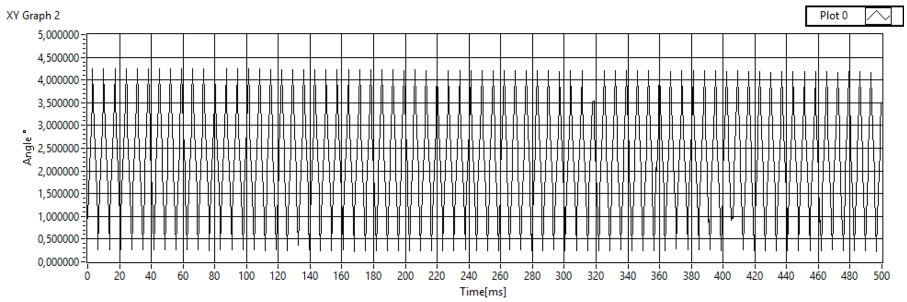

Fig. 11. Servo positioning repeatability results for the 50 g

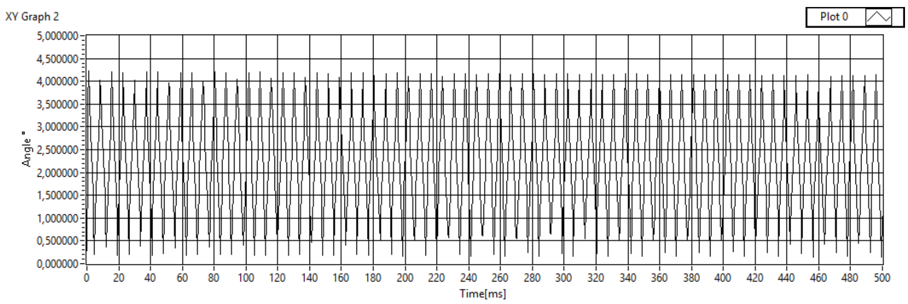

Fig. 12. Servo positioning repeatability results for the 200 g

Figures 11 and 12 show the repeatability achieved by servo position for different loads. Repeatability of servo positioning with small loading was calculated on 99 %. For the greatest load amounting to 200 g, on the shoulder length of 100 mm, the accuracy of achieving position was estimated on 98 %. Mentioned values in a time domain are shown on the Fig. 12.

9 Conclusions

The servo modeling is increasingly used both in research works, industrial applications, robotics as well as in rehabilitation constructions. It is widely used thanks to its small overall dimensions and the ability to generate a relatively large torque. The investigated servo control system does not require any computer with high speed and processing power. Obtained relation between control signal and the angular position of the servomotors' output shafts suggest that it is possible to use Denavit-Hartenberg notation for calculations of the final position of the manipulators effectors (driven by servomotors). Comparison of the obtained results with those stated in characteristics card shown that while the mean values of angular speed of servo are comparable, the torque generated by the engine is only half that was declared.

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