

THE APPROACH TO STABILITY DETERMINATION OF SINGLE AXIS POSITIONING REGULATION FOR THE MODEL OF TTT MANIPULATOR

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Original scientific paper

The various models of manipulators are commonly used in industry plants and technologies. Possibility of applying and comparing such new methods is presented for actuator control. For produced TTT (Translation-Translation-Translation) manipulator it is necessary to determine standard catalogue information. The main issue in usage of such manipulators is stabile positioning regulation. The test survey is conducted with various mechanical loads, mainly concentrated in close surrounding of standard mechanical load used for simulations of industry models. Results of the highest available stabile speed of stepper motor are presented for the worst axis case of the model of TTT manipulator. The stability determination is conducted up to double standard mechanical load. The result of highest stabile motor speed can be applicable on all other axis with no influence on stability, since experiment is conducted on most mechanically loaded axis.

Keywords: automation, stability mode, translation manipulator

Pristup određivanju stabilnosti pozicioniranja pojedine osi modela TTT manipulatora

Izvorni znanstveni članak

Razni modeli manipulatora često se koriste u industrijskim pogonima i tehnologijama. Prikazana je mogućnost uporabe i usporedbe novih metoda upravljanja aktuatorima. Za izvedeni TTT manipulator neophodno je utvrditi standardne kataloške podatke. Glavna karakteristika pri upotrebi ovakvih manipulatora je njihov stabilan odziv u regulaciji pozicioniranja. Pokusno mjerenje provodi se s različitim mehaničkim opterećenjima, uglavnom koncentriranih u okolini standardnog mehaničkog opterećenja korištenog za simulaciju modela industrijskih pogona. Prikazani su rezultati provedenog eksperimenta najveće dostupne stabilne brzine koračnog motora za najopterećeniju os modela TTT manipulatora. Određivanje stabilnosti provedeno je do dvostrukog standardnog mehaničkog opterećenja. Najveću utvrđenu stabilnu brzinu motora moguće je koristiti za sve ostale osi bez utjecaja na stabilnost obzirom da je eksperiment proveden za mehanički naopterećeniju os.

Ključne riječi: automatizacija, stabilan režim rada, translacijski manipulator

1 Introduction

The portal manipulators are used as a part of industry production plants for serial production of large and heavy products. The most common usage is at the end of product line, usually for palletisation of products. The portal derivation of manipulator, as opposite to rotary derivation [1, 2, 3], is characterized as very robust and able to manipulate with far heavier loads. Gantry manipulators can also be used in various other usages, such as plasma cutting materials, waterjet cutting materials, milling, laser treatment [4, 5, 6, 7, 8, 9], etc. The real prototype model of TTT manipulator is used in this research for stability characterization. The single worst axis case can be selected, and measured results can be applied as highest possible error for the whole model. It can be expected that other axis will have lower errors than the error on highly loaded axis, in this case x axis.

2 The prototype of model of TTT manipulator

The robotic TTT manipulator is type of robot which produces three translator movements. Therefore, its name stands for translation-translation-translation manipulator. The whole manipulator can be parsed to three subsystems since it produces three translations, x -axis, y -axis and z -axis, stand and head respectively. Therefore, the movement can be described using Cartesian system. The robotic TTT manipulators of gantry derivation are used in industry for arranging objects, boxes, bags, etc. Although most common usage is for palletisation, TTT manipulators are also used for object transfer in serial industry with tracks, from one machine to another or for

machine serving applications. The simplified schematic of a TTT manipulator is presented in Fig. 1.

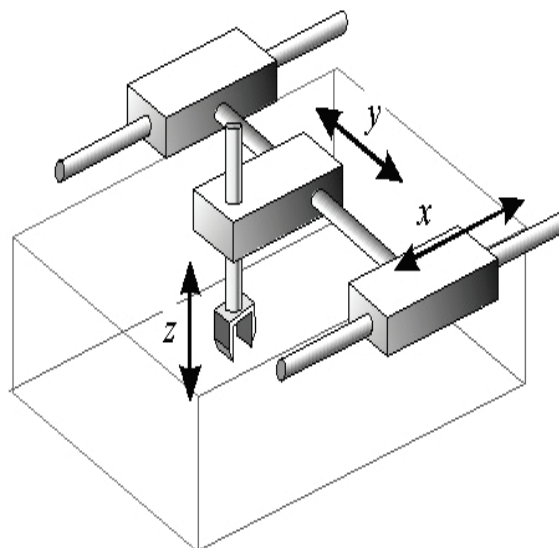


Figure 1 Block model of TTT manipulator

The common dynamic model of three-axis Cartesian manipulator with TTT derivation in horizontal plane can be described by linear differential Eqs. (1), (2) and (3).

$$m_1 \cdot \ddot{x} + d_1 \cdot \dot{x} + k_1 \cdot x + k_{12} \cdot (x - y) = \tau_1 \quad (1)$$

$$m_2 \cdot \ddot{y} + d_2 \cdot \dot{y} + k_2 \cdot y + k_{12} \cdot (y - x) + k_{23} \cdot (y - z) = \tau_2 \quad (2)$$

$$m_3 \cdot \ddot{z} + d_3 \cdot \dot{z} + k_3 \cdot z + k_{23} \cdot (z - y) = \tau_3 \quad (3)$$

Where m_i , d_i and k_i for $i = 1, 2, 3$ are parameters of mass, viscous friction and elasticity. The coefficients k_{12} and k_{23} are used to describe interdependence of robot joints. The control functions are described by τ_i for $i = 1, 2, 3$. The positioning for TTT manipulator is used in this research, so it is necessary to describe main technical properties of used manipulator. The physical values of m_i , d_i and k_i for $i = 1, 2, 3$ are used to describe dynamic of Cartesian manipulator, and are presented in Fig. 2.

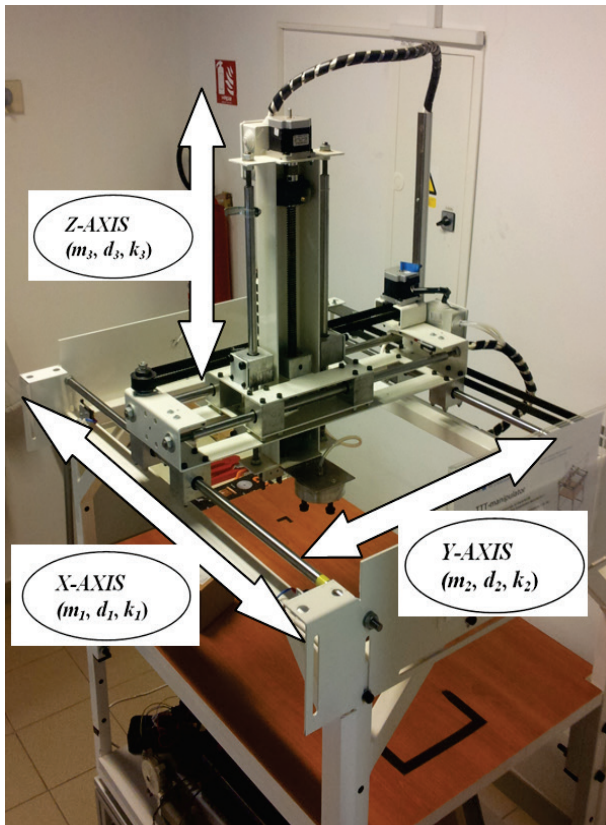


Figure 2 The parameters of mass, viscous friction and elasticity on x, y and z-axis for the model of TTT manipulator

The x-axis linear movement for single rotation of the motor shaft is one length of plane range as provided by Eq. (4), with diameter of 38 mm. The used stepper motors have $1,8^\circ$ of shaft revolution per each control impulse. Therefore the movement in x-axis per each control impulse can be provided by Eq. (5). The transmission ratio in y-axis is equal to transmission ratio in x-axis since pulleys that have both the same diameter and same settings for stepper motors are used. The translation in z-axis for one motor shaft revolution is equal to rise of trapezoidal spindle (Tr16x4). Therefore, for each rise of 4 mm can be calculated per each control impulse as provided by Eq. (6).

$$O = 2 \cdot r \cdot \pi = 2 \cdot 19 \cdot \pi = 119,38 \text{ mm.} \tag{4}$$

$$l_x = l_y = \frac{1,8^\circ}{360^\circ} \cdot 119,38 = 0,597 \text{ mm/step.} \tag{5}$$

$$l_z = \frac{1,8^\circ}{360^\circ} \cdot 4 = 0,02 \text{ mm/step.} \tag{6}$$

The program package SolidWorks can be used for modelling of TTT manipulator. The standard elements of

TTT manipulator are provided from vendor catalogue. The manipulator drive is made with three stepper motors, while pneumatic head and vacuum pump are used for object manipulation. The x-axis of TTT manipulator is presented in Fig. 3. It consists of four skaters (part 2), portal sheets (part 1 and part 3), two guides in y-axis (part 7), and drive for y-axis (part 4, part 5 and part 6).

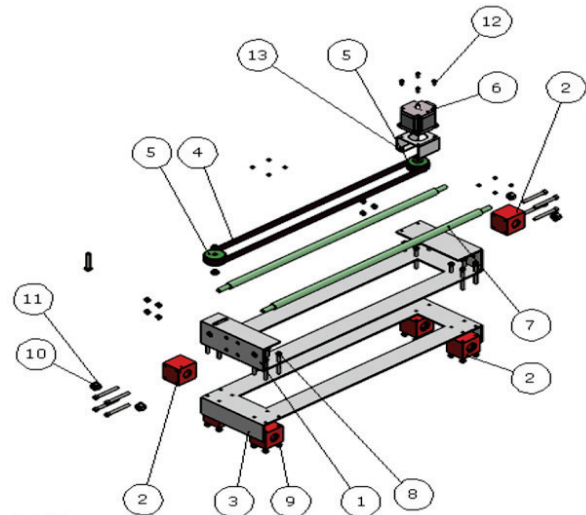


Figure 3 The x-axis for the model of TTT manipulator

The y-axis of TTT manipulator is presented in Fig. 4. The main parts of which it consists are four skaters (part 3), portal sheets (part 1), and four guides in y-axis (part 2).

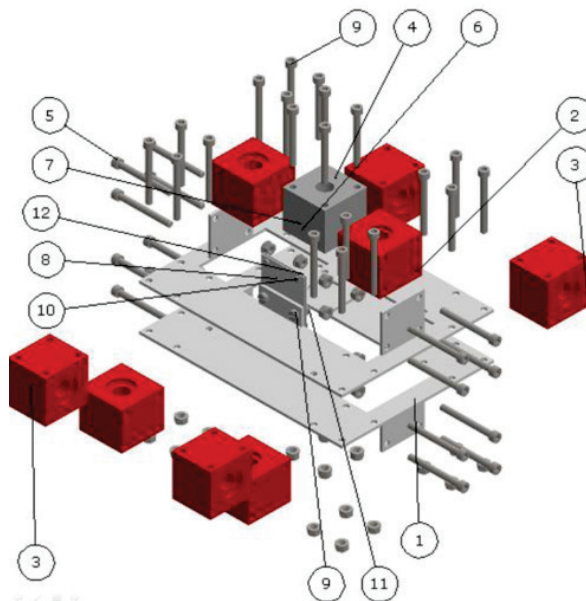


Figure 4 The y-axis for the model of TTT manipulator

The z-axis of TTT manipulator is presented in Fig. 5. The main parts from which it consists are stepper motor (part 3), guides (part 2), housing (part 1), pneumatic head (part 6), and vacuum pump (part 11).

The prototype for model of TTT manipulator presented in Fig. 6 is equipped with automation system provided by Siemens Simatic S7-200 CPU 224. The hardware datasheet of used PLC (Programmable Logic Controller) is available in [10]. The S7-200 is sufficient

for this application since there are no communication demands, and higher technologies, such as S7-1200 [11], are redundant. The selected PLC module is equipped with 10 digital outputs and 14 digital inputs. Used DC/DC/DC technology can provide very high speed of pulse train output signals (up to 10 kHz) through electronic transistors used as digital switches. Therefore, it is possible to derive all necessary control signals for stepper motor drive, as used in. Each motor is controlled by three digital signals: pulse train output, direction selection and half/full step mode of operation, as presented in Fig. 7. Additional digital control signal is provided for pneumatic grab.

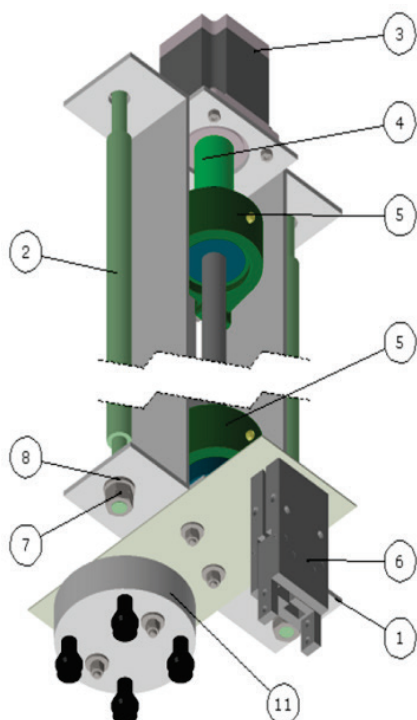


Figure 5 The z-axis for the model of TTT manipulator

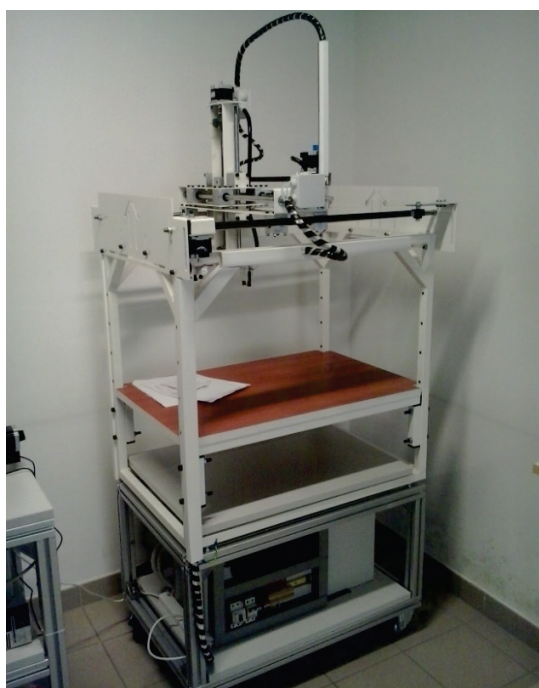


Figure 6 The prototype for model of TTT manipulator developed in Technical College in Bjelovar

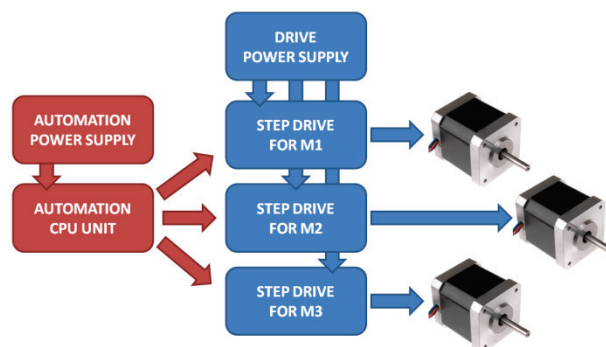


Figure 7 Block diagram of automation system

The model of TTT manipulator is provided as complete autonomous system with single power supply line and full current protection equipment for all used electrical modules. Inside electrical installation power supply is divided in two sections, for automation system and for stepper drives. The front of electrical automation system installation is presented in Fig. 8. The control signals are divided in groups for each actuator. The stepper drive of M1 is provided with pulse output from Q0.0, direction selection from Q0.3 and half/full step mode from Q0.6. Also, the stepper drive of M2 is provided with pulse output from Q0.1, direction selection from Q0.4 and half/full step mode from Q0.7. Finally, the stepper drive of M3 is provided with pulse output from Q0.2, direction selection from Q0.5 and half/full step mode from Q1.0. The pneumatic/vacuum grab placed on the top of manipulator head is controlled by single digital signal provided from Q1.1.

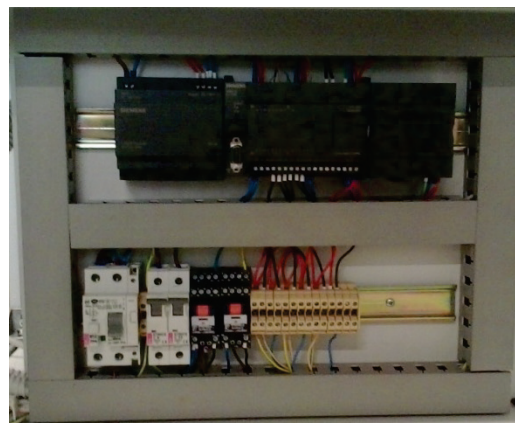


Figure 8 Front of prototype for model of TTT manipulator automation panel in S7-200 technology

The output control signals are also controlled for safety by input digital information provided by limit switches. These signals are used to override every attempt of basic regulation loop to produce movement outside of the model of TTT manipulator operating space. The limit switches are always used with higher priority than any other input reference of stepper drive regulation. The input signals are divided in groups by model of TTT manipulator movement axis, as provided in [12, 13, 14]. In x-axis input signals I0.2 and I0.3 are used respectively for left and right limit switch. Also, in x-axis input signals I0.4 and I0.5 are used in the same manner for limiting movement to back and forward. Finally, in z-axis input signals I0.6 and I0.7 are used as low and high limit

switch. All of output and input control signals are presented in Fig. 9.

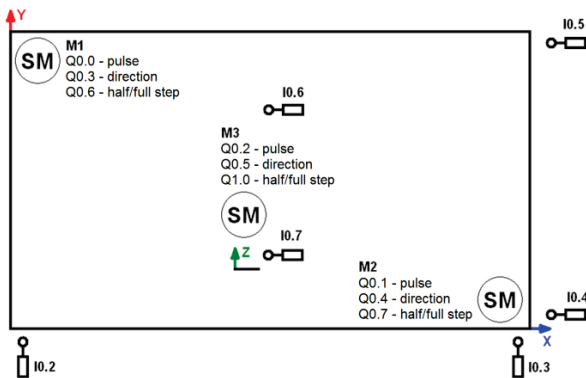


Figure 9 Actuators and sensors on the model of TTT manipulator

3 Measuring of movement stability characteristic

Standard catalogue information about TTT manipulators is presented for each axis maximum speed. In this case the most interesting characteristic is stability in movement for each axis, since the model of TTT manipulator is provided with stepper motors. These motors are good solution if mechanical load does not introduce fault in open loop position regulation. Measuring of position regulation error is presented in this section, which will provide nominal data for the model of TTT manipulator. The measurement is conducted on *x*-axis in order to determine maximum speed with stable position regulation, since *x*-axis carries other axis and therefore is mechanically most loaded. All other axis will have significantly better nominal data. The total working distance of *x*-axis is 600 mm.

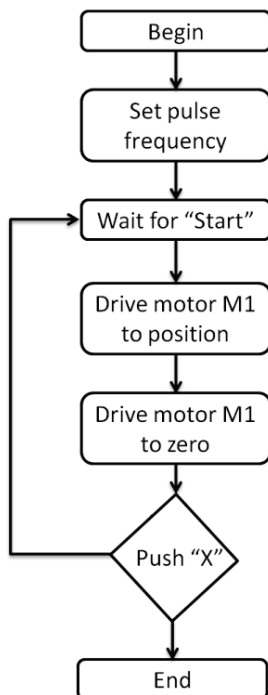


Figure 10 The block diagram of PLC program

The automation system is adjusted in order to conduct measuring procedure. The program is made for PLC station which will allow measurement of position error in

each set of motor speed and mechanical load. The stepper motor is driven from home position to preset position and back to home position by the same number of steps, with no pause while changing the movement direction. In this way the mechanical load will in case of overload because the *x* axis belt to slide through pulleys. The block diagram of PLC program for measuring procedure is presented in Fig. 10.

The communication with PLC while conducting the measurement procedure is made through SCADA application presented in Fig. 11. All functionalities used for this application are described in [15]. The preset values of movement in each axis are provided through input textboxes *Pomak n*, where *n* determines axis of movement.

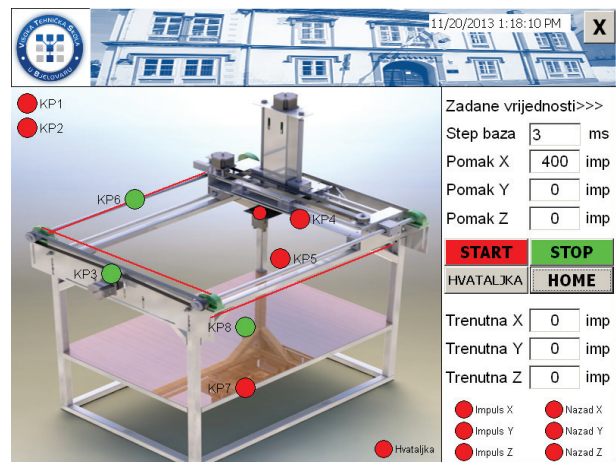


Figure 11 The SCADA application for measuring of positioning error in each axis for the prototype for model of TTT manipulator

The mechanical construction and mechanical gear determine the accuracy of positioning system in stable mode. The provided speed of stepper motor is considered stable if movement of mechanical parts is inside positioning error tolerance. The speed of stepper motor can be considered as stable if positioning error is inside range of $\pm 1,5$ mm. The measured impulse frequency for stepper motor is provided by highest resolution which the PLC can produce since the shortest time period in PLC is 1 ms. Therefore, when determining the smallest time step on timer it will produce impulse with 1 ms ON and 1 ms OFF, which is total time of 2 ms or frequency of 500 Hz. The next available frequency is provided with impulse of 2 ms ON and 2 ms OFF, which is total time of 4 ms or frequency of 250 Hz. The measuring impulse frequencies for stepper motor are respectively provided till 50 Hz.

4 Results of stability determination for the model of TTT manipulator

The measured stability characteristic can be provided for different mechanical load of the model of TTT manipulator. In this research mechanical load was provided with high resolution from 2,0 kg till 3,0 kg, since 2,5 kg is standard mechanical load used for simulation of real industry plant using the model of TTT manipulator. Two more specific stability characteristics are measured and presented in, idle (0,0 kg) and double standard mechanical load (5,1 kg). The positioning error is measured in cm, and conclusion of stability derived by

comparing with specified tolerance ($\pm 1,5$ mm). The last column will have value of "Yes" if positioning error is less than 1,5 mm and "No" if more than 1,5 mm.

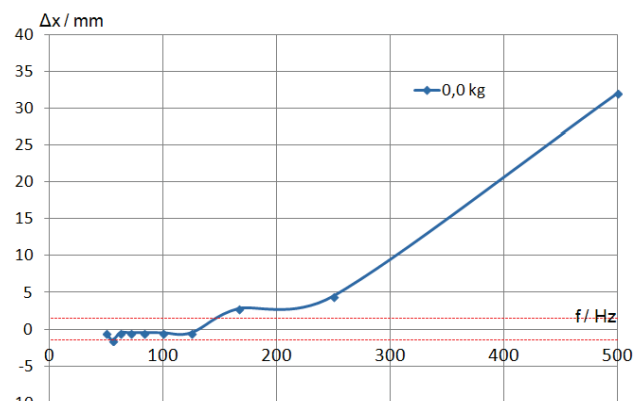


Figure 12 Positioning error diagrams for x-axis, load of 0,0 kg

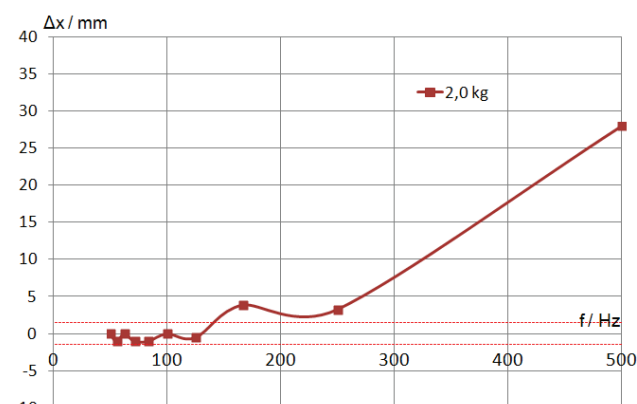


Figure 13 Positioning error diagrams for x-axis, load of 2,0 kg

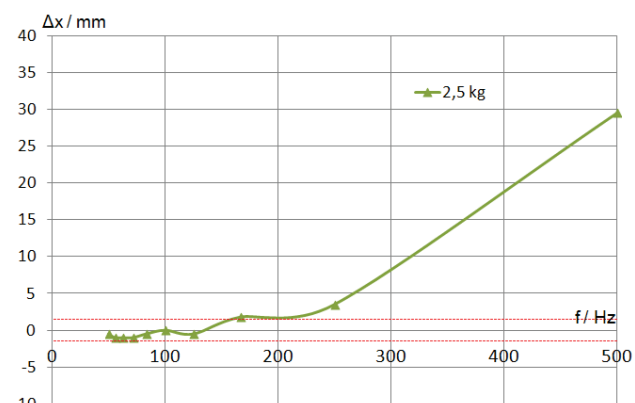


Figure 14 Positioning error diagrams for x-axis, load of 2,5 kg

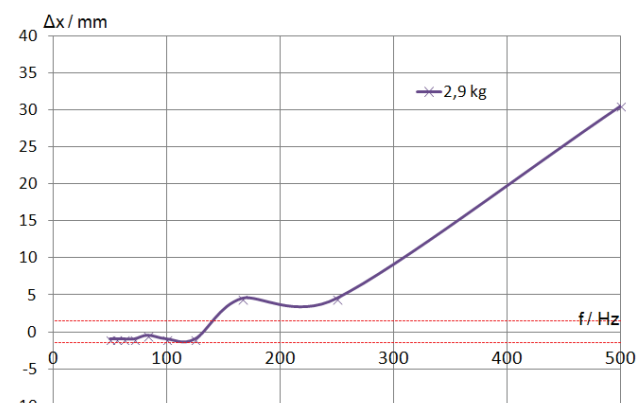


Figure 15 Positioning error diagrams for x-axis, load of 2,9 kg

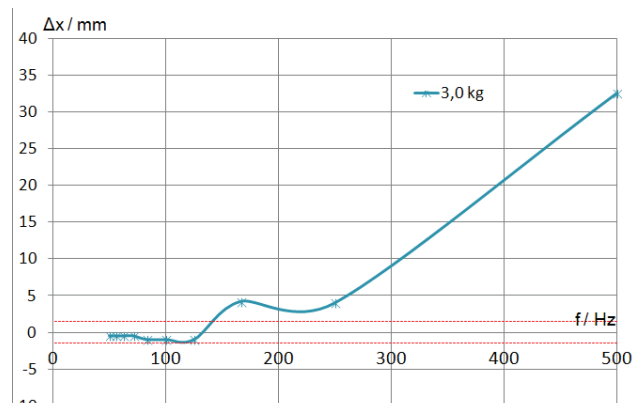


Figure 16 Positioning error diagrams for x-axis, load of 3,0 kg

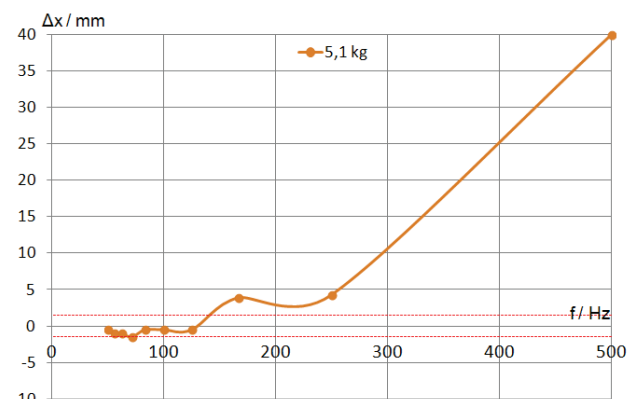


Figure 17 Positioning error diagrams for x-axis, load of 5,1 kg

All measured stability characteristics for different mechanical loads are presented in Figs. 12 ÷ 17. Each characteristic in diagram presents positioning error of described measuring procedure for different speed of stepper motor.

From presented stability characteristics it can be concluded that in stability mode positioning error is almost identical for any given mechanical load. The measured positioning errors rapidly increase from 150 Hz to higher pulse frequency for stepper motor. Therefore, it can be concluded that x-axis is stable for 125 Hz and any mechanical load in range from 0,0 kg till 5,1 kg.

5 Conclusion

The model of TTT manipulator is configured to enable simulation of industry plant technologies which use manipulators in production process. Stepper motors used for axis drives enable open-loop positioning with high precision if applied speed has stable positioning response presented as result in this research. The used mechanical load in simulations is below limit of mechanical load capacity, and can be used with no possibility to produce non-stable positioning if maximum speed of stepper motor is limited to 125 Hz. The highest stable stepper motor speed should be used as an upper limit in all regulators applied to the model of TTT manipulator.

6 References

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