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DYNAMIC IDENTIFICATION OF A HIGHSPEED MECHATRONICAL POSITIONING STRUCTURES

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Abstract: *The positioning structures have a significant place in the modern manufacturing systems. The aim in the modern machines is involved with a continuous growth in a machine performance, without loose of the positioning accuracy in a high dynamics operations. The goal for this solution is in defining and optimizes the dynamics performance parameters of the structure into the design process.*

Key words: *mechatronics, positioning, error, structure, dynamics, simulation.*

1. INTRODUCTION

The mechatronics positioning structures are taking a significant place in a high variety of manufacturing applications like abrasive waterjet, plasma or laser cutting machines. These cutting processes are characterized by high dynamic movements of the cutting head (up to 50 m/min), high accelerations (up to 2g), and high positioning accuracy (up to ±0.05mm).

To reach a high performance structure for the concrete application, the dynamical identification of the positioning structure of the driving system has to be obtained. Identifying the dynamical properties and the positioning accuracy of the structure in the design phase makes the development process time and cost effective.

The lack of the complete information about the identification approach in the literature and unsatisfactory information about the mechanical structure parameter relations reduce the efficiency of the design processes.

The aim is to clarify the system identification process. For this the following tasks belonging to the identification process clarification have to be achieved:

- the properties and the correct choice of the concrete positioning structure and driving system (not enough clarified);
- the complete simulation model of the positioning structure using the driving system parameters;
- the complete information about the dynamic identification approach defining the positioning error;
- the field of the systematical error based on the simulation model results (not found in the literature).

The realization of the described tasks is possible using simulation models and the virtual prototype of the positioning structure. To generate the virtual prototype, the CAD model of the structure is needed, and also the simulation model in MATLAB/Simulink or in other similar software are required.

2. DEFINING THE PROPERTIES OF THE POSITIONING STRUCTURE

The mechanical structure is based on two main components:

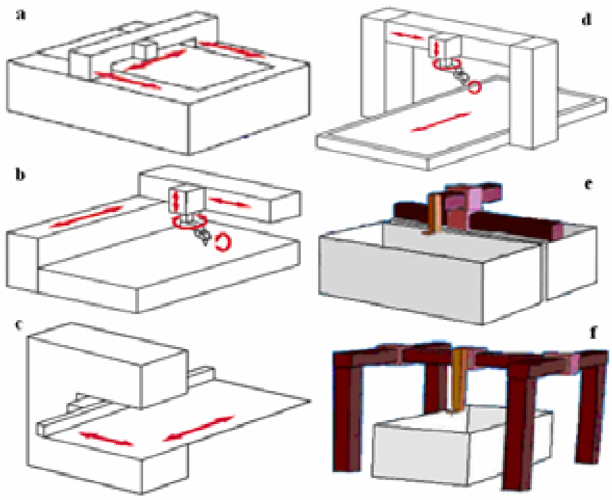

Fig. 1. Types of the positioning structures.

- type of the positioning structure;
- type of the driving system.

2.1. Types of the positioning structures.

There are different types of positioning structures that are applied in the manufacturing machines:

- "Moving gantry" structure (Fig. 1a);
- Bracket structure (Fig. 1b);
- Fixed tool – movable workpiece (Fig. 1c);
- Portal structure (Fig. 1d);
- Crossed structure (Fig.1e);
- Hanging structure (Fig.1f).

The "moving gantry" structure provides high dynamic performance, using the relatively easily moving parts. The bracket and crossed structure are applied in small machines with limited dynamic capabilities.

The portal and hanging structure are applied in big machines, and the fixed tool structure is a relatively old with a limited usage.

The correct choice of the type of the positioning structure results in a reasonable balance between the dynamic performance of the structure, positioning accuracy, structure stiffness, access to the working area etc.

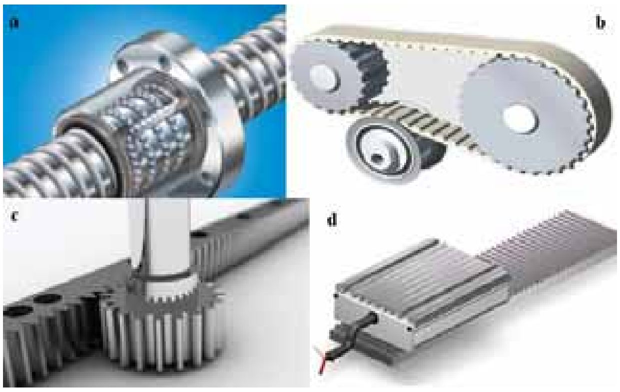

Fig. 2. Types of high speed linear driving systems.

[8, 11]. There is not a single solution, that assures in the maximum degree all of the design requirements. Also, making the correct choice needs to take in account the specific features for the working processes (pollution, vibrations, temperature, etc).

2.2. Types of the high-speed linear drives.

There are a different types of driving systems applied in the high speed positioning systems. They depends on the type of the driving technology, achieved positioning accuracy, dynamical capabilities, etc.

The common types of the plasma, laser or waterjet cutting machines have strokes in the range 0.5–3 m. The drive mechanisms used in these machines are:

- ballscrew drives (Fig. 2a);
- tooth belt drives (Fig. 2b);
- rack/pinion drives (Fig. 2c);
- linear motor drives (Fig. 2d).

The ballscrew drives provide high positioning accuracy with high speed capabilities. They are influenced by the cleanness of the working environment and have a relatively high price. Tooth belt drives [12] provide a low cost maintenance, high pollution durability, smooth run, and high reliability. They are applied in structures with a modest precision. The rack and pinion drives are used in low precision and low dynamics applications. Their accuracy depends on the rack and pinion precision. They are influenced by the pollutions, generated by the working process. The linear motor drives are used in very high dynamics applications with high precision requirements like pick-and-place machines. Their price is very high compared to other driving systems.

In the laser cutting machines, the required positioning accuracy is higher and the usage of the ballscrew drives is efficient. In a low precision, high dynamics application like waterjet or plasma cutting processes, the usage of the rack and pinion and the tooth belt drives is advisable [4].

Commonly, the positioning structures have a driving system working in parallel, for a better performance. In the literature, the model of the parallel drives is missing.

3. SIMULATON MODEL OF THE POSITIONING STRUCTURE WITH PARALLEL DRIVES

The simulation model of the structure is a model of a mathematical description of the structure. It contains the information related to the mass and inertial properties of

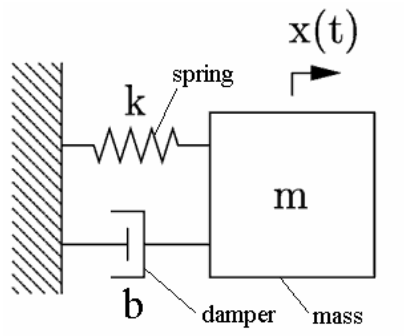

Fig. 3. Mass-spring-damper model.

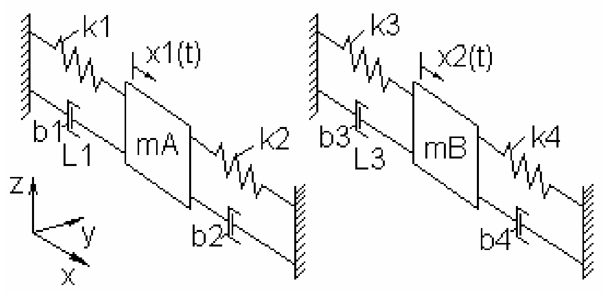

Fig. 4. Dual mass model of the parallel structure

the movable parts that have influence on the dynamic behavior of the structure. The model implements also the stiffness and the damping properties of the elements. They are defined as concentrated mass points, connected to the ground through spring and damper, like the mass-spring-damper model shown on the Fig. 3 [2, 9].

The mathematical description of the dynamical behavior of the structure corresponds with the eq. 1.

$$m\ddot{x} + b\dot{x} + kx = F(t) \tag{1}$$

In the positioning structures, the mass distribution depends on the system current configuration. The single mass model is not enough detailed to represent the system behavior properly.

Therefore, the dual mass model of the parallel positioning structures is generated. It contains two single mass models with different masses and inertial characteristics. The general overview of dual mass model is represented on the Fig. 4.

Using MATLAB/Simulink, the simulation model of the parallel drives positioning structure is generated (Fig. 5).

The model takes in account the flexibility of the moving gantry (Fig. 6) and the stiffness and damping coefficients of the driving systems separately.

The inertial force applied on the moving gantry is acting on the center of mass. Its actual position depends on the current configuration of the system moving parts.

Therefore, the parallel drives are loaded separately. As a result, they are moving in a different way. To identify the movements, the positioning sensors are applied on the gantry head and the supports. The simulation model is especially suitable for the representation of the structures equipped with parallel tooth belt drives. To verify the model, the real structure is explored.

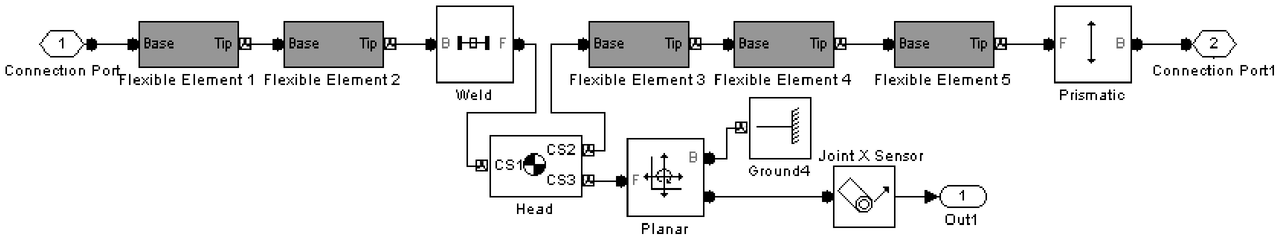

Fig. 6. Flexible gantry structure.

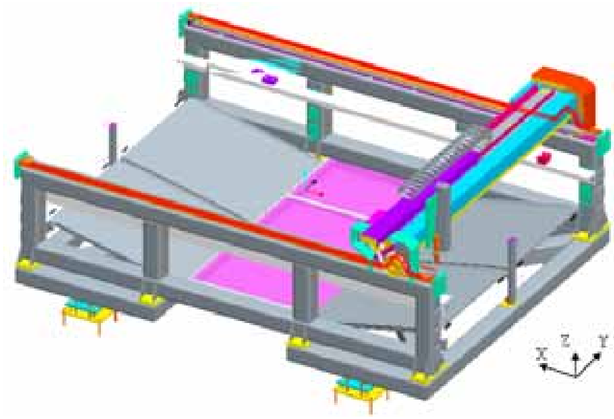

Fig. 7. Mechanical structure with parallel drives.

4. ANALYSIS OF THE POSITIONING STRUCTURE WITH TOOTH BELT DRIVES

The structure from example is a "moving gantry" type (Fig. 7), with two "Ω-drive" systems. The gantry is made of construction steel with normalized cross section of 200 × 200mm and a wall thickness of 6.3 mm.

The predefined requirements the mechanical structure have to provide are:

- max. velocity V=20m/min;
- acceleration 1g (9.81m/s^2);
- positioning accuracy ±0.1mm.

The calculation of the inertial force is according eq. 2

$$F_a = \left(m_s + m_p + 2.m_i\right).a,\left[N\right], \qquad (2)$$

where:

- m_s = 140 kg – mass of the moving parts;
- m_p = 4.8 kg – mass of the driver pulley;
- m_i = 0.8 kg – mass of the idler pulley;
- a = 9.81 m/s^2 – acceleration of the moving gantry.

The calculation of the necessary pull up force is done according to the eq. 3

F_a = (140+4.8+2×0.8)×0\9.81 = 1 436 N. (3)

The calculated pull up force is applied in the simulation model in the form of a step function. It represents the dynamic load on the structure in the transient processes.

4.1. Defining the mass and inertial properties of the structure

The structure is with variable configuration [3], thus the mass and inertia properties on the support points of the gantry are variable. As a result, the two parallel tooth belt drives are separately loaded and moved. Partially it

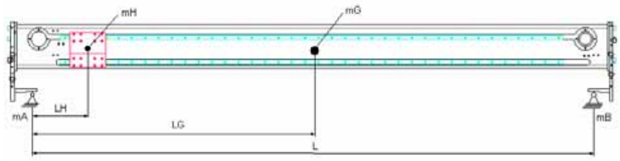

Fig. 8. Moving gantry model.

Table 1

Mass distribution

LH	270	520	770	1020
mA	93	90	87	84
mB	70	73	76	79
LH	1270	1520	1770	2020
mA	81	78	75	72
mB	82	85	88	91

is able to compensate this, using two separately controlled driving motors. Figure 8 represents the moving gantry geometry with its support points *A* and *B*.

On the figure the distances *LH* from support *A* to the gravity center of the cutting head *mH* and *LG* from *A* to the gravity center of the moving gantry *mG* are marked. The distribution of the moving masses between the supports *A* and *B* depending on the cutting head gravity center position is represented in the Table 1. The mass distribution between the supports is obtained for eight discrete positions of the head along the *Y* axis.

The values of the mass properties are applied individually in the simulation model, depending of the structure configuration.

4.2. Defining the parameters of the tooth belt drives.

The structure is equipped with the tooth belts HTD14M-40Steel, defined from the manufacturer's documentation [1, 7].

- shape of the teeth – HTD;
- teeth pitch p = 14 mm;
- belt width b = 40 mm;
- material of the reinforcement cords – steel.

The HTD type provides better load distribution on the teeth in mesh compared to other types [5, 6, 9].

Calculating the tooth belt stiffness is according the eq. 4.

$$k_{1/2} = c_{sp}.\frac{b}{L_{1/2}},\left[N/mm\right], \qquad (4)$$

where:

- $k_{1/2}$ – stiffness of the tooth belt sides;
- c_{sp} = 51 560 N/mm - specific stiffness coefficient, taken from the manufacturer's documentation[6];

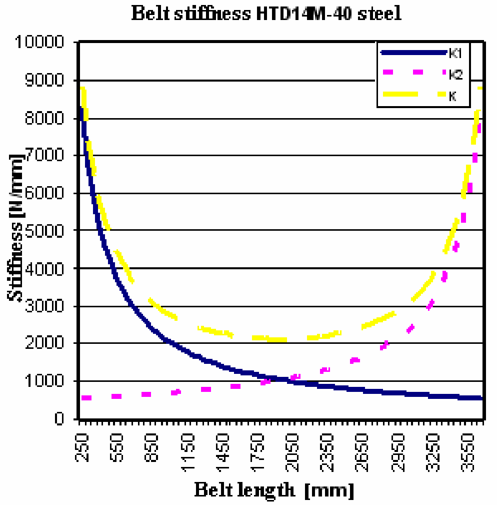

Fig. 9. Stiffness of the tooth belt drive.

- b = 40 mm- width of the belt;
- L_1 = 250÷3650 mm – length of the first side;
- L_2 = 3650÷250 mm – length of the other side;

The stiffness of the belt sides along the working stroke is represented in Fig. 9.

The results from the belt stiffness calculations are applied in the simulation model. The results from the simulation model are processed to generate the positioning error model of the working area.

5. POSITIONING ERROR MODEL OF THE STRUCTURE

The error model represents the graphical representation of the systematic positioning error in the working area of the structure (Fig. 10).

The model represents a nonuniform distribution of the positioning error in the working area. The value of the positioning error is in range of 0.2–0.35mm. It is possible to compensate for the errors using the generated filed of error. There are two ways to compensate the errors. First way is based on the optimization of the parameters of the mechanical structure:

- using the gantry from a lightweight material – aluminium alloys;
- using a stiffer tooth belts;
- apply two separate driving motors instead of one;

The other way is to compensate the error using the control system capabilities:

- use of the feedback control functionality – position, acceleration and velocity feedback, or both;

apply the adaptive intelligent control.

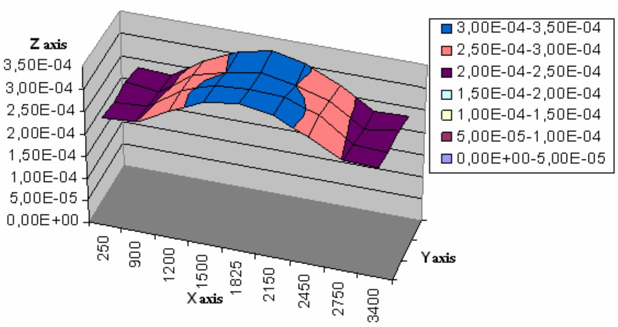

Fig. 10. Positioning error model of the structure.

6. CONCLUSIONS

The dynamic identification of the parameters of the mechatronics positioning structures has an important role in the design process. Using the virtual prototype accelerates the design process and verifies the mechanical compatibility of the assembled parts. Also, it is a base of defining the simulation model. Taking the information from the virtual prototype is helpful in making the correct decision. Verifying the results in the design phase is shortening the product design cycle and reducing the design costs. The main advantages the identification process provides are:

- defining the dynamical performance and position accuracy of the structure in the development phase;
- comparison of the obtained results and predefined requirements in the design phase;
- simulating the structure using easy configurable and reconfigurable simulation model according to the current requirements;
- testing the structure on extreme working conditions, causing the damage in the real structure;

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