736. Balance platform system dynamic properties

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Abstract. Lately mechanical vibrations problematic interesting increasing is observed, not only in the aspect of its harmfulness for human but also in the direction of its positive influence on human organism. During tests determining vibrations influence on human organism it was observed, that beside negative influence of vibration with frequencies close to the human intestines free vibrations frequencies there is also observed improvement of parameters in connection to muscular weakening especially in organs responsible for holding of proper posture. In case of balance platforms which are controlled vibration platforms there are used vibrations with low-frequency character (about 1Hz) where proper vibration control helps holding of correct posture by standing on it patient. In practice there are exists many balance platform construction solutions, notwithstanding there are solutions in which at basis of set static parameters and patients feet pressure mechanism perform motion moves by established in advance trajectory. To improve effectiveness of work and system control, balance platform movement wouldn't be dependent only from controllable patient position in relation to platform, but also from its height, mass and biofeedback parameters. In such system human body should be deal as biomechanical system with defined inputs and outputs. In the article basic dynamic properties are described.

Keywords: balance platform, posturography, dynamic properties, measurements.

Introduction

In the last years mechanical vibrations problematic interest increasing is observed, not only in aspects of its mischievousness for human but also in direction of its positive influence for human organism.

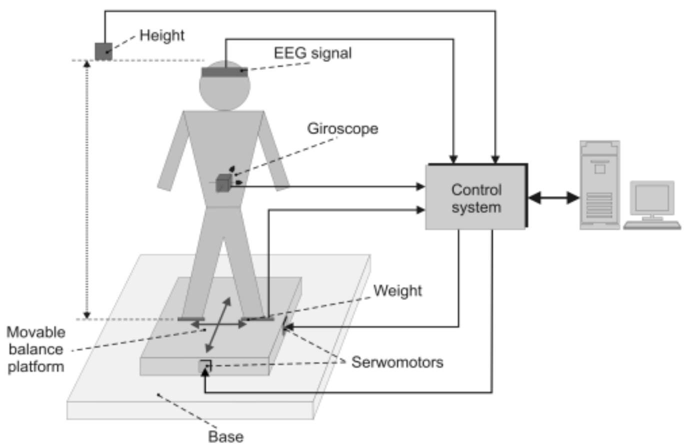

Fig. 1. Concept of the balance platform

During the tests which determine vibration influence for human body there were observations that besides of negative influence of low-frequency vibrations with range closed to human inner tissues free vibrations frequencies, there is positive improvement of muscles mechanical parameters especially for those parts responsible in holding correct posture of human body. This phenomenon is conduced to evolve two main trends of research. In first of them main accentuation was put on use of high-frequency mechanical vibrations during training process. Using of vibration training enforces muscles power, improves mobility, stimulate blood circulation in human body and allow for various types of pain mitigation. Vibration platform are used very often with high level of success in rehabilitation process, especially in osteoporosis where substantial increasing of bones mineral density was tested and verified [1, 2]. Those results are also verified in the way of well known scientific tests. In the second case of mentioned trends of research low-frequency (about 1Hz) character vibrations are used, where proper vibration control allow for holding of correct posture of the standing on a platform patients [3]. Its determines authors to start works over developing and constructing of balance platform of new type for which basic tests are presented in the article.

Conception of the balance platform is presented in Fig.1 [4].

Assumptions for the balance platform system

Authors in the article concentrate on system consisting the mechanism which moves in two directions *x* and *y* (Fig. 2.), because of posturoghaphy examinations, which rely on compensation movements registering performed in the straight posture and using platform for rehabilitation of patients with sense of stability disorders.

Fig.2. Constructed balance platform system

Movement in the *x* axis is realized as for a cart driven by servomotor. On mentioned cart two conveyor belts with separate driving motors are mounted. These belts are responsible for the perpendicular movement in axis *y*.

Usage of balance platform by patients with some kinds of movement disorders leads to number of medical limitations which have an influence on system construction.

Such limitations are with the maximum allowable values of frequencies and accelerations for which human can be exposed. In case of balance platforms, i.e. steered vibration platforms, there are used vibrations with low frequency characteristics (about 1 Hz), when proper control of the vibrations enables maintaining proper posture by the patient standing on it, as it was mentioned in the previous section.

Proposed system has also possibility of movement division in axis *y* for separate movement of each limb. Additionally each part can be solved separately as a uni-axial inverted pendulum.

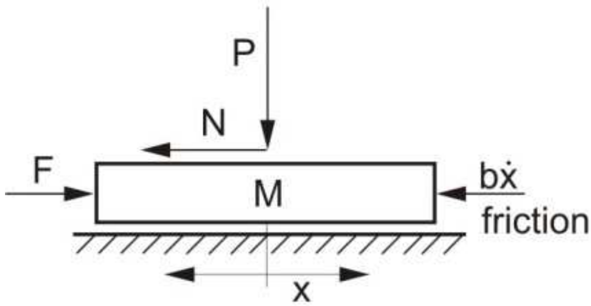

Fig. 3. System forces distribution of a cart in one direction

Summing the forces in the Free Body Diagram of the cart in the horizontal direction, we have following equation of motion:

$$M\ddot{x} + b\dot{x} + N = F \tag{1}$$

Mathematical model of balance platform

In the article mechanical system consists of two working perpendicularly parts driven by three separate electric servo-motors: one in the *y* axis and two independent in *x* axis, where each of them is responsible for motion of one limb. Servo-controllers for mechanical systems, such as machine tools and robots, are required to achieve high accuracy at high speed on a specified trajectory. A servo-control algorithm for high accuracy has to minimize or eliminate the effects of a response delay and friction, which mainly cause trajectory errors. Furthermore, when an advanced control algorithm is utilized, it is difficult for operators who are unfamiliar with it to adjust the control parameters.

Other parameter causing errors in the trajectory of moving platform modeled as *XY* table is the stiffness of the system transmitting servo-motor torque to the movement of balance platform. Since the stiffness of this system is not infinite, it can be simply modeled as a two-inertia system with constant stiffness.

However, the effective stiffness depends on the position of the table, but in the paper movement of the platform is limited to a small area, and the stiffness is considered to be a constant. Also there is a backlash in the mechanism, and the relationship between its torsional displacement and its load torque is modeled as a dead zone.

Mechanical equation of the two-inertia system can be in this moment expressed as [3]:

$$J_M \frac{d^2\Theta_M / K_2}{dt^2} + B_M \frac{d\Theta_M / K_2}{dt} = T_M - T_L, \tag{2}$$

$$T_L = \frac{K_s\left(\Theta_M - \Theta_L\right)}{K_2}, \tag{3}$$

$$J_L \frac{d^2\Theta_L / K_2}{dt^2} + B_L \frac{d^2\Theta_L / K_2}{dt} = T_L - T_D, \tag{4}$$

where:

T_M – motor torque,

T_L – load torque,

θ_M – motor position,

θ_L – plate position,

B_M and B_L – viscous frictional damping coefficients of the motor and the plate respectively,

T_D – load disturbance, which is applied at the table in the opposite direction of the load torque.

At the next stage torsional displacement should be estimated. In order to determine torsional displacement we should take some reasonable assumptions. It is based on the knowledge of the motor's inertia and the torque applied to the motor. If the backlash is ignored, the displacement $\Delta\Theta$ can be derived from the previous equations as:

$$\Delta\Theta = \Theta_M - \Theta_L = \frac{1}{K_s}\left(K_2 T_M - J_M \frac{d^2\Theta_M}{dt^2}\right) \tag{5}$$

This equation only requires the inertia of the motor, which can be easily obtained from a data sheet of the motor. The acceleration of the motor is obtained by differentiating the position of the motor twice. If the resolution of the encoder is low, the result may be too noisy to use. To overcome this problem, the following assumption is made:

$$\frac{d^2\Theta_M}{dt^2} = \frac{d^2\Theta_R}{dt^2} \tag{6}$$

where: θ_R – reference position.

If the tracking error of the motor is small enough, the previous assumption makes sense. From two previous equations the estimate $\Delta\hat{\Theta}$ is calculated as:

$$\Delta\hat{\Theta} = \Theta_M - \Theta_L = \frac{1}{K_s}\left(K_2 T_M - J_M \frac{d^2\Theta_M}{dt^2}\right) \tag{7}$$

where $\hat{K}_s$ is an estimate of the torsional spring constant K_s. This equation makes it possible to get the displacement simply, without any additional measuring instruments.

Balance platform dynamic properties identification

To create mathematical dynamic model from measured during experiment input-output data authors use Matlab System Identification Toolbox to determine at numerical way character of analyzed object. At the first stage set of carried out measurements for various loading conditions with fulfillment of Shannon's sampling theorem principles, especially for the low-frequency character of the process, input and output displacement signals were determined. Input signal corresponds to set value sent to the servomotor responsible for cart movement. Torque control of servomotor was used in this case. Output signal was measured at the proportional encoder implemented in a servomotor. At this basis using Matlab System Identification Toolbox authors perform an identification assuming that object has linear character. Cart system with servomotor was identified as first order inertial element with the limit of frequency at 0.92 Hz. So its transfer function can be presented as:

$$G(s) = \frac{1}{1.09s + 1} \tag{8}$$

Such object basic characteristics are presented at Fig. 4 and Fig. 5.

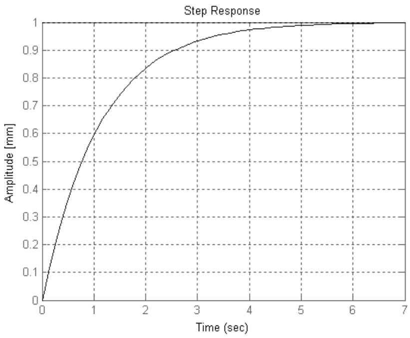

Fig. 4. Step response of a cart

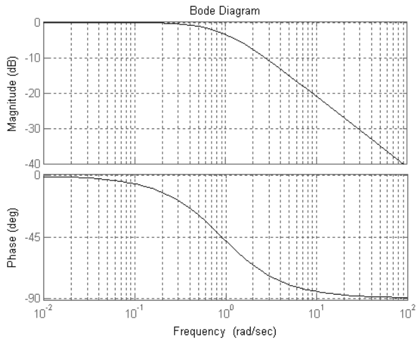

Fig. 5. Frequency characteristics of a cart

Conclusions

Presented in the paper testing of a balance platform cart is an introduction to determination of the whole balance platform model with an assumption that standing on it human can be treated as multi dimensional inverted pendulum. Presented simple linear model allows one to create more complicated model with an intention that it will be described as object with distributed parameters.

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