SELECTED ENGINEERING PROBLEMS
NUMBER 7
INSTITUTE OF ENGINEERING PROCESSES AUTOMATION
AND INTEGRATED MANUFACTURING SYSTEMS

Mateusz SUMERA, Mariusz Piotr HETMAŃCZYK[1]*

[1]Institute of Engineering Processes Automation and Integrated Manufacturing Systems,
Faculty of Mechanical Engineering, The Silesian University of Technology, Gliwice, Poland
*mariusz.hetmanczyk@polsl.pl

THE LABORATORY STAND FOR OPTIMIZATION OF SWING VALUES OF THE PHYSICAL PENDULUM – CONFIGURATION

Abstract: The article shows main features of the laboratory stand used for testing and optimization of swing values of the physical pendulum. Mechanical design, electrical protection arrangements and overall configuration were also described. The main goal was to develop the physical pendulum model driven by a synchronous servomotor (providing high rotational speed, efficiency and dynamic of operating parameters). Described model refers to industrial overhead cranes, especially in cases where unfavourable phenomenon of fluctuations of manipulated objects exists.

1. Introduction

Transportation and manipulation of physical objects suspended on flexible connectors require usage of specialized algorithms implemented in control systems (e.g. damping of angular displacement, reliable and fast readjustment of control parameters etc.). In the considered case a manipulated object can be treated as the physical pendulum (i.e. system in which the rigid body can perform a movement around the axis of rotation O, not passing through the centre of mass S, under the influence of gravitational forces). A resultant of gravitational forces which act on the elementary mass of the pendulum is proportional to the weight of the pendulum (Fig. 1). Oscillations of the physical pendulum belong to the periodic movement i.e. changes of the physical quantities recurring at regular time intervals [1,2].

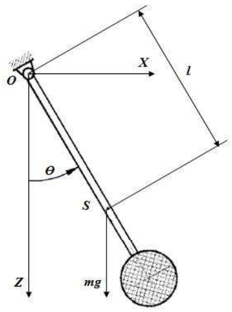

Fig.1. A schematic diagram of a physical pendulum [2]

The equations of motion of the physical pendulum pulled out from the equilibrium position by an Θ angle could be described by the following features [1,2,5,6]:

- a torque derived from the force of gravity:

$$M = -mglsin\Theta$$

- equation of motion:

$$I_0 \frac{d^2\theta}{dt^2} = -mglsin\theta$$

- simplification - reducing movement of the pendulum for small deflections (a few degrees) allows to expression angular values by means of the radian measure (i.e. sinθ≈θ):

$$\begin{cases} \frac{d^2\theta}{dt^2} + \frac{m \cdot g \cdot l}{I_0} = 0 \\ \omega_0 = \sqrt{\frac{m \cdot g \cdot l}{I_0}} \end{cases}$$

- oscillation period of the pendulum (in case of small angles of swings):

$$\begin{cases} T = \frac{2\pi}{\omega_0} \\ T = 2\pi \cdot \sqrt{\frac{I_0}{m \cdot g \cdot l}} \end{cases}$$

where:

M - moment of force $[Nm]$,
m - mass of a physical pendulum $[kg]$,
g - gravitational acceleration $[\frac{m}{s^2}]$,
l - distance between a centre of gravity and an axis of rotation $[m]$,
Θ - tilting angle [°],
I_0 - moment of inertia of a pendulum terms to the pivot axis $[kgm^2]$,
ω - angular frequency $[\frac{1}{s}]$,
T - oscillation period $[s]$.

Due to occurrence of additional forces acting on oscillator (e.g. air resistance, friction, dynamic forces caused by rapid change of speed and direction) a phenomenon of pendulum movement damping exists. In the real systems described features may have an impact on [3,4]:

- bevelling of gantry bridges - causing occurrence of additional stresses in structures (especially inside guides) and uneven weight distribution of crane construction (with special emphasis on supporting elements and guides),
- lack of precision in manipulation of loads to designated locations,

- complex process of manually elimination of adversely fluctuations, leading to machine damage and dangerous operational states.

2. The mechanical design of the laboratory stand

The frame and supporting elements have been made of aluminium extrudes sections with dimensions 45x45 millimetres (Fig. 2). The drive unit has been built through the use of a high precision rolled ball screw (the Bosch Rexroth BASA/40x10Rx6 model, Fig. 2) with the nominal diameter equals 40 millimetres and the 10 millimetres thread pitch.

The screw is characterized by high work precision as a result of small clearances existing between a single flange nut (FEM-E-C type, Fig. 2) and the ball screw (stabilized by using two bearing blocks).

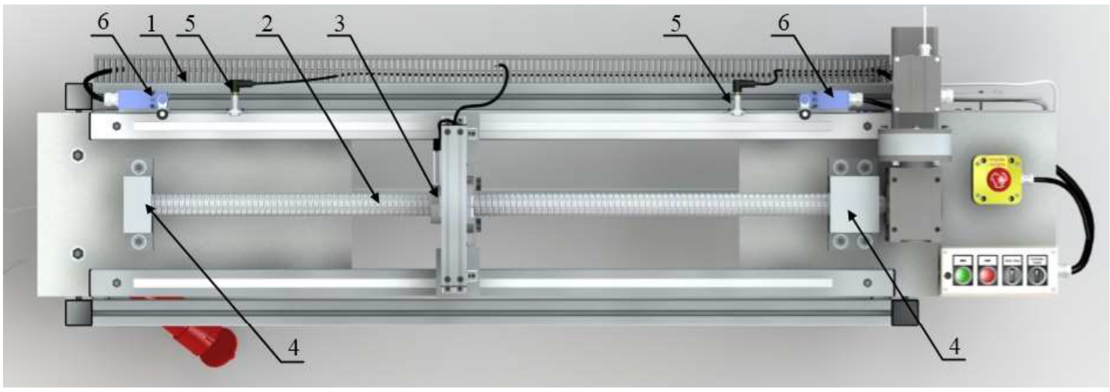

Fig.2. Top view of the 3D model, where: 1 - a cable tray, 2 - the high precision rolled ball screw, 3 - the nut, 4 - bearing blocks, 5 - inductive sensors, 6 - mechanical limit switches

A frame of the physical pendulum has been made of aluminium extrudes sections (cross-sectional dimensions equal 20x40 millimetres) and dedicated coupling brackets. The assembly has been placed on high precision guides (Fig. 2) allowing accurate and stable positioning realized on the motion plane.

The driven saddle is moved by a nut with mounting flange. Total length of guides equals 1139 millimetres, however, due to the spacing of the bearing blocks the total useful distance is limited up to 1100 millimetres.

The laboratory stand has undergone modernizations in order to satisfy stated assumptions. The first stage of the modernization concerned a durable fixation between the DFS56M servomotor and applied worm gear (made by the Chiaravalli, CHM-50 model). Such correction arises from size differences between diameters of mounting flanges and spacing of mounting holes (Fig. 3).

Frame of the physical pendulum was characterized by insufficient stiffness, this phenomenon was visible especially in cases of forced swings with simultaneous linear movements. Therefore, mounting brackets of the top sections were replaced by rigid screw fixings. To strengthen mechanical connections between vertical profiles and profiles of the driven saddle, additional stabilizing brackets were used (Fig. 4).

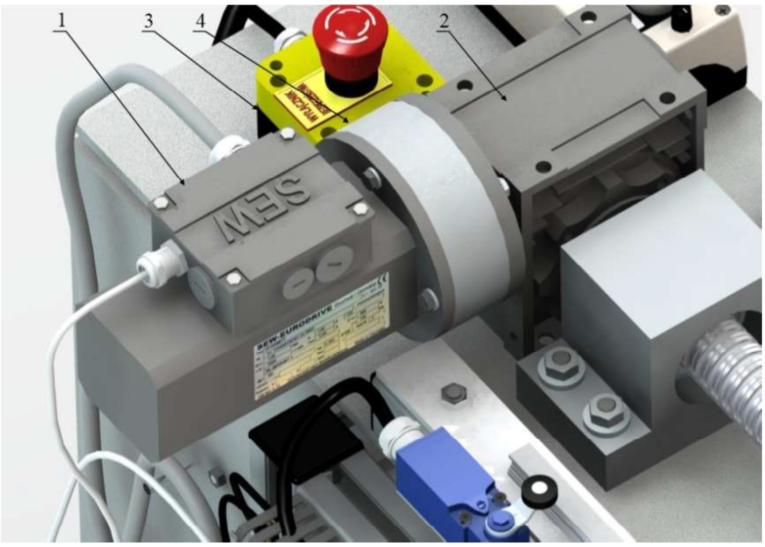

Fig. 3. View of complete drive system, where: 1 - electric servomotor, 2 - worm gear, 3 - safety switch, 4 - mounting adapter

Strengthening was made also between sections located on the sledges, which due to their construction are susceptible to deformation (on grounds of oscillations and rapid movements).

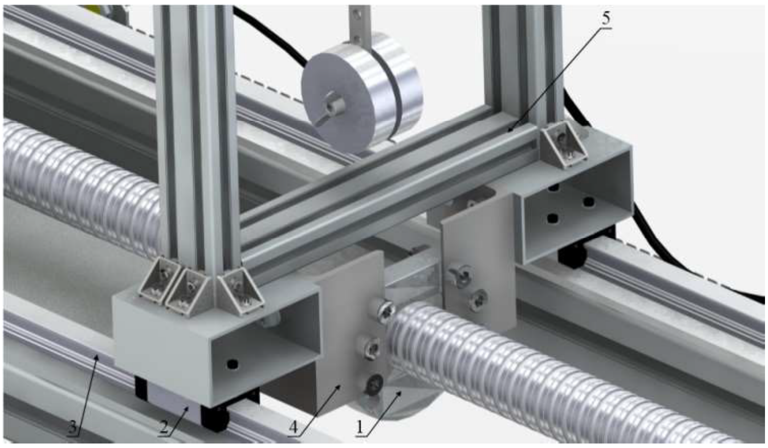

Fig.4. View of linear powertrain system, where: 1 - the single flange nut, 2 - a linear bearing, 3 - guides 4 - fasteners, 5 - a cross profile

The construction of the pendulum (Fig. 5) has been made of a flat steel bar with holes for changing the height position of test masses. Load are two aluminium discs with holes in axis, screwed on opposite sides of an arm.

Improvement of motion properties of the pendulum has been obtained by usage of rolling bearings in rotary joints (Fig. 5). This solution allows for an elimination of movement resistances, lateral looseness and vibrations. Rigidity of the structure and a lack of interferences caused by misalignment of the pendulum structure are essential aspects that guarantee the correctness of inclination measuring.

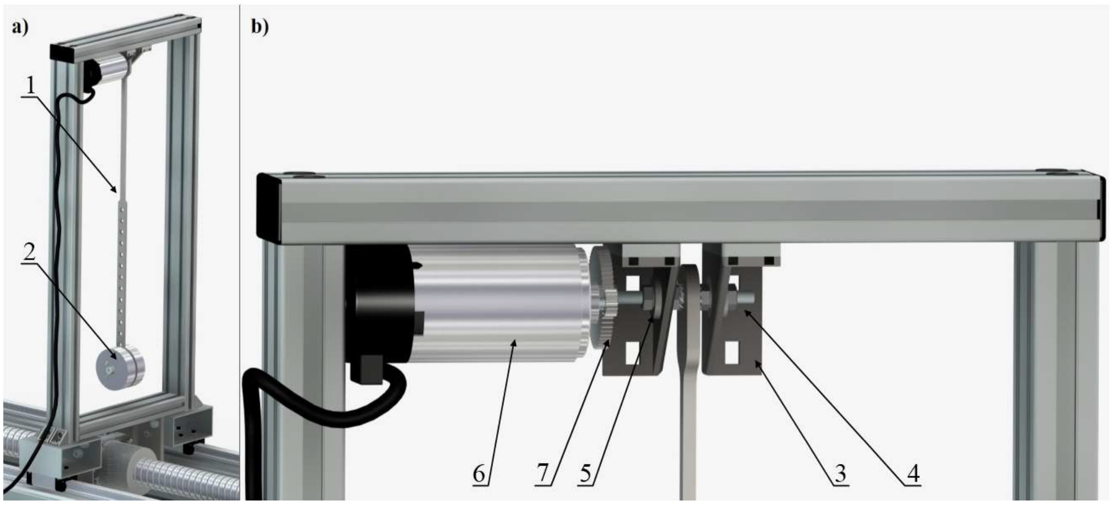

Fig. 5. View of the physical pendulum model: a) the frame, b) the clamping unit, where:
1 - the frame of the pendulum, 2 - test masses, 3 - mounting brackets, 4 - rotary axis, 5 - ball bearings,
6 - an encoder, 7 - a gear

In figure 5b an assembly of the sensor for measuring an inclination angle of the physical pendulum was shown.

3. Protection and electrical system

Described laboratory stand belongs to a teaching equipment what implicates a necessity of usage of additional safeguards against uncontrolled movement of a drive (especially at the top speed leading to a collision of the pendulum with one of the bearing blocks). For this purpose safety system has been equipped with two inductive sensors (TURCK model BI4-M12-AP6X-H1141, Fig. 6) with outputs configured as NO (Normally Open).

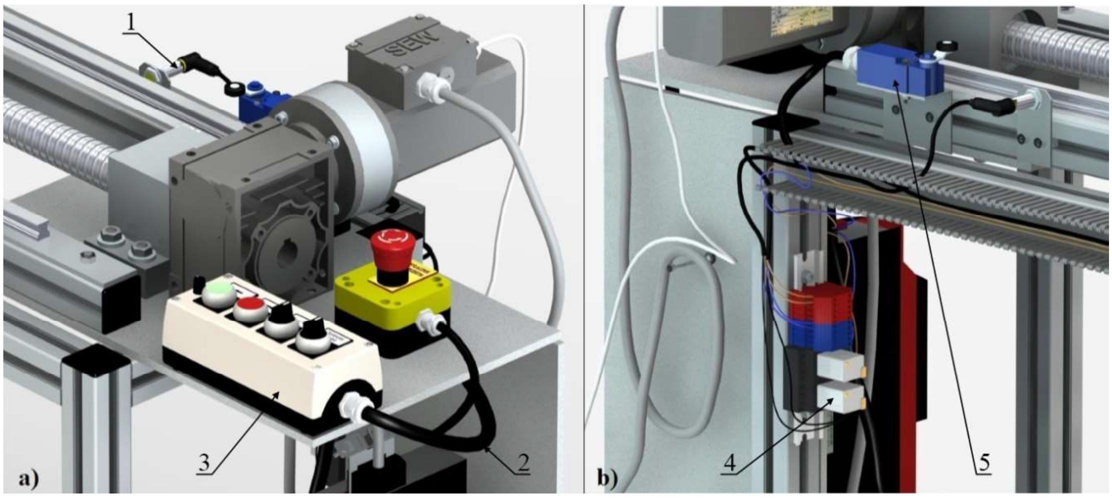

Fig. 6. View of the control system configuration: a) top view, b) view of the power module, where:
1 - inductive sensors, 2 - cable covers, 3 - a control box, 4 - relays, 5 - a limit switch

These sensors were programmed as non-contact bumpers, acting at the time of entry and detection of driven saddle (the control algorithm jumps immediately to emergency stop mode or change direction).

Such connection does not provide a secure execution of safety function in case of loss of communication with the PLC controller or other perturbation in control algorithm. Inductive sensors are connected directly to the binary inputs of the frequency inverter through relays. Due to the fact that they perform safety functions are required normally closed outputs. For this reason relays have been used.

This disadvantage was eliminated by a series connection of additional limit switches (Fig. 6) to the inputs X17 in the frequency converter, which serves as a safe disconnection of torque STO (Safe Torque Off).

4. Conclusions

In order to simulate a process of damping (in terms of different control algorithms realized by electric motors operated via frequency inverters) the model used to study a swing position of the physical pendulum was constructed. Described laboratory stand belongs to a teaching equipment but enables testing of advanced algorithms for damping of oscillations (elements hung on susceptible connectors).

The laboratory stand has been equipped with doubled safety functions (inductive sensors and XCKN2118P20 mechanical limit switches, produced by the Telemechanique), which are configured as NC (Normally Closed). Taken serial connection of two limit switches and safety button, prevents collisions.

References

1. Magiera A.: Physical laboratory. Krakow: Institute of Physics of Jagiellonian University, 2012.
2. Mianowski B.: Determination of the period of small and large swings of physical pendulum. Lodz: Publishing House of Technical University of Lodz, 2009.
3. Nowak A.: Modelling of dynamics driving bridge crane, taking into account the rebound phenomenon. Gliwice: The Silesian University of Technology Publishing House, 1995.
4. Kosucki A.: Research cargo transportation using associated movements of overhead cranes mechanisms. Lodz: Scientific Papers of the Technical University of Lodz, 2013.
5. Adams M.L.: Rotating Machinery Vibration: From Analysis to Troubleshooting (2nd Edition). New York: CRC Press, 2009.
6. Bently D.E., Hatch C.T.: Fundamentals of Rotating Machinery Diagnostics (Design and Manufacturing). USA: ASME Press, 2003.