Control system structure design for object positioning system

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Abstract. Object positioning system is intended for load transposition. Its main feature is the control method which is based on operator muscle force. One of the most important object position system development problems is a control system design. The article presents the first step of this problem solution that consists of control system structure design.

1. Introduction

In many industries significant progress and economic efficiency are related to the level of handling mechanical engineering development, which is based on the widespread introduction of production processes automation, the elimination of manual handling and hand-labour.

There is a need for lifting and conveying machines creation and its application because of assembly quality increasing. Cranes are the particular case of those machines. A control of such equipment uses different ways: from crane cabin, using pendant switch, from operator station, etcetera [1, 2]. But sometimes a load positioning quality is increased by an operator muscle force (for example, when there is a need to install a car engine). That is why there is the necessity for an object positioning system (OPS) creation that helps with load transposition [3, 4].

2. The load positioning method

OPS is intended for load transposition. There is a huge amount of its design solutions. In common way developed OPS is a travel crane [3], shown in figure 1. The load hangs on the rope which is reinforced at the movable support and moves in space through actuators help. Units 1 and 2 are X and Y axis slides with actuators. They move load along the horizontal plane using bearing slides 3 and 4. Unit 5 is an elevation. Unit 7 generates control system feedback using information from sensor unit 6. That is why the load moves in space. The structure of sensor unit 6 includes two sensors of rope deflection from the vertical axis and one rope tension sensor.

The system allows one to position the object by one's own direct affecting, as well as to improve the accuracy of work due to the direct operation control.

OPS model in figure 2 describes the method of its control. The load hangs on the rope (figure 2 *a*). Operator defines load track from A to B using one's own muscle force $\overline{F}$, which is directly applied to the load (figure 2 *b*). This is the reason of rope deflection and tension changing (figure 2 *c*). The control system generates the actuator control signals using angle $\overline{\varphi}$ and rope tension $\overline{T}$. That's why the load moves according to the desired trajectory in space (figure 2 *d*).

IOP Conf. Series: Materials Science and Engineering **124** (2016) 012021 doi:10.1088/1757-899X/124/1/012021

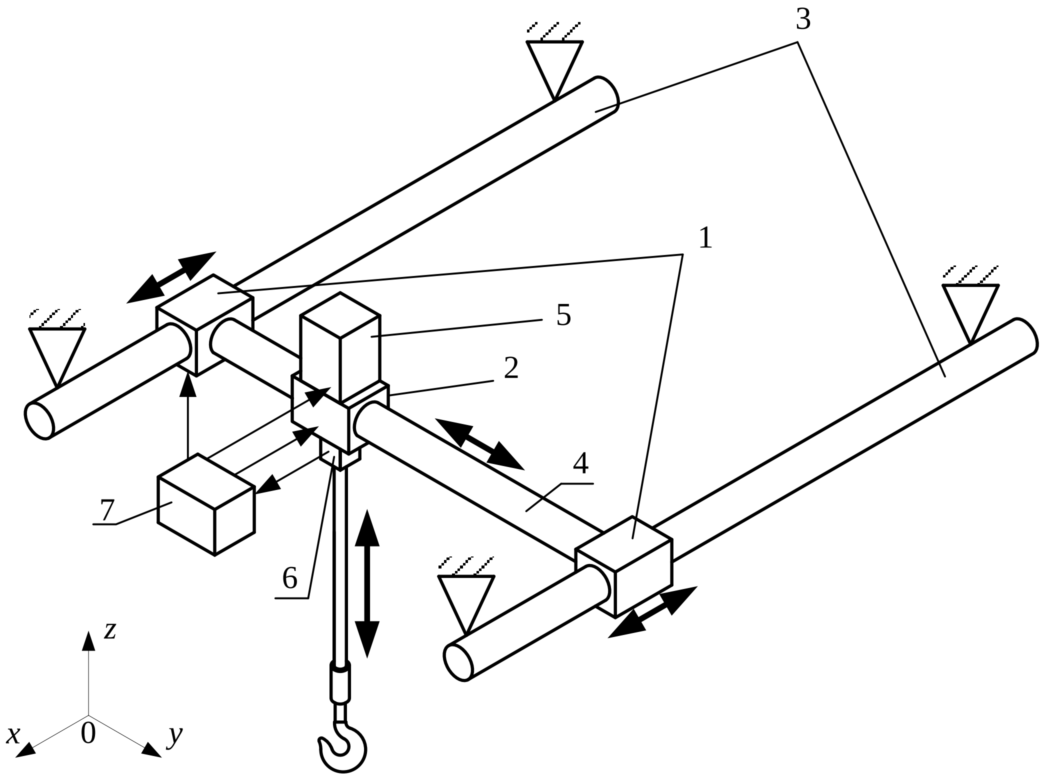

Figure 1. OPS principal scheme

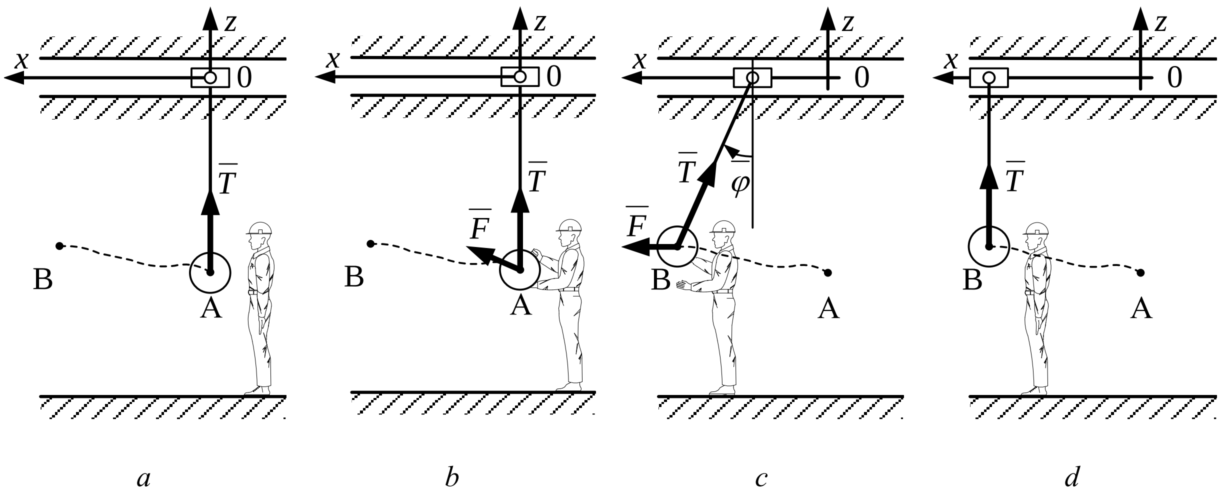

Figure 2.

The control system uses information of three measured OPS parameters. These parameters are rope tension $\overline{T}$ and rope deflection angles $\overline{\varphi}$ and $\overline{\psi}$ (figure 3). These parameters are generic coordinates, which are able to present the desired trajectory.

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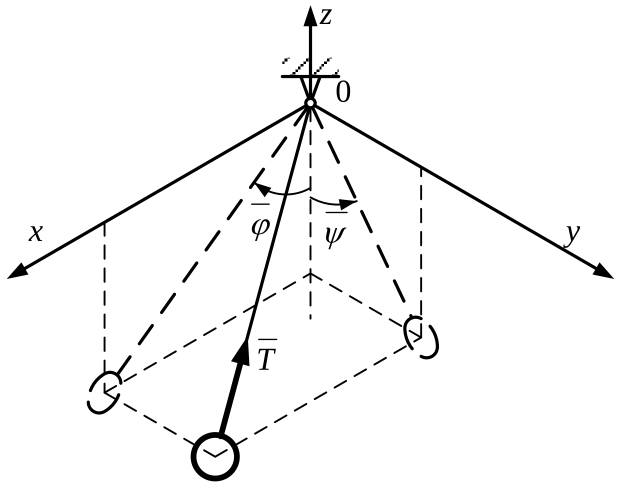


Figure 3. System measured parameters

3. Laboratory bench

The laboratory bench shown in figure 4 is created for OPS processes research. It is able to transpose load, which mass is between 1 and 20 kg. Benches' outline dimensions (LxWxH) are 2500x2500x2500 mm. Operating area (LxWxH) is 2000x2000x2000 mm.

Figure 4. Laboratory bench

4. Control system structure

4.1. Control object block schematic diagram of
OPS (Figure 5) is a multiple-input multiple-output control object, which diagram is shown in figure 5, where $\mathbf{U}(t)$ and $\mathbf{Y}(t)$ are associated matrix input and output.

The specification of the laboratory bench (figure 4) is the following:

$$\mathbf{U} = \left(u_{\dot{x}}(t) \quad u_{\dot{y}}(t) \quad u_{\dot{l}}(t)\right)^T \mathbf{Y} = \left(\varphi(t) \quad \psi(t) \quad T(t)\right)^T,$$

where l – rope length; $u_{\dot{x}}(t)$ and $u_{\dot{y}}(t)$ – control inputs of actuators that move load along the horizontal plane; $u_{\dot{l}}(t)$ – actuator control input, which changes the height of the load.

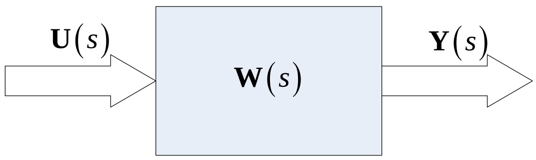


Figure 5. Control object

The following matrix transfer function describes the object math model:

$$\mathbf{W}(s) = \begin{pmatrix} W_{\varphi\dot{x}}(s) & W_{\varphi\dot{y}}(s) & W_{\varphi\dot{l}}(s) \\ W_{\psi\dot{x}}(s) & W_{\psi\dot{y}}(s) & W_{\psi\dot{l}}(s) \\ W_{T\dot{x}}(s) & W_{T\dot{y}}(s) & W_{T\dot{l}}(s) \end{pmatrix}. \tag{1}$$

According to the load positioning method [3, 4] load horizontal speeds $\dot{x}$ and $\dot{y}$ are determined by angles φ and ψ respectively.

Let us assume that $\Delta T = T - T_0$ (T_0 – rest load tension) determines load vertical speed ($\dot{l}$) direction and value. That is why decoupled circuits $\varphi \to \dot{x}$, $\psi \to \dot{y}$, $\Delta T \to \dot{l}$ are obtained. This is the reason that expression (1) transforms to

$$\mathbf{W}(s) = \begin{pmatrix} W_{\varphi\dot{x}}(s) & 0 & 0 \\ 0 & W_{\psi\dot{y}}(s) & 0 \\ 0 & 0 & W_{T\dot{l}}(s) \end{pmatrix} = diag\left(W_{\varphi\dot{x}}(s) \quad W_{\psi\dot{y}}(s) \quad W_{T\dot{l}}(s)\right). \tag{2}$$

The math model obtaining problem is to find transfer functions $W_{\varphi\dot{x}}(s)$, $W_{\psi\dot{y}}(s)$ и $W_{T\dot{l}}(s)$ using identification methods of single-input single-output systems (for example, [5]).

4.2. Control system block schematic diagram
An OPS model consists of three transfer functions according to expression (2). That is why the OPS control system has three control circuits and three controllers.

4.2.1. Control system block diagram for load horizontal motion
Load horizontal motion is determined by channels $\varphi \to \dot{x}$ and $\psi \to \dot{y}$ that are mathematically equal. That is why the control system block diagram (figure 6) is the same for each channel.

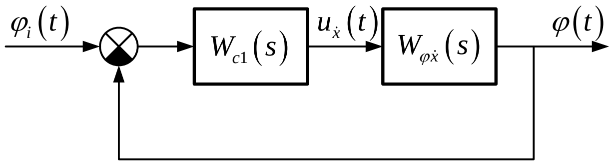


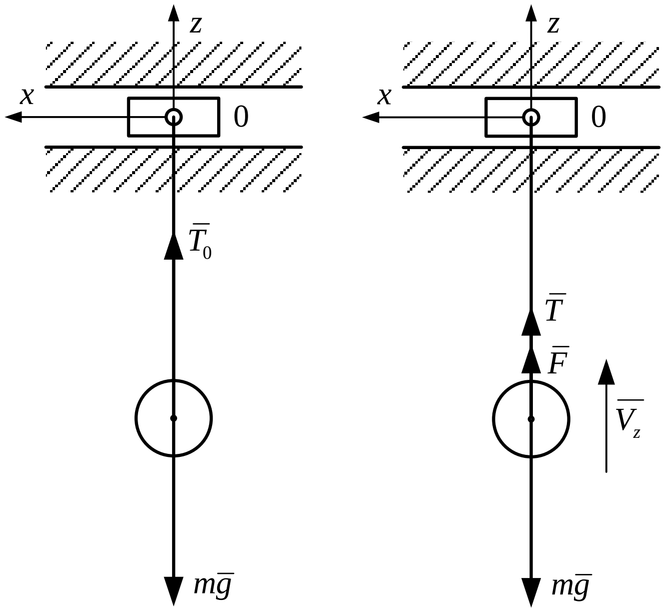
Figure 6. Control system block diagram of channel $\varphi \to \dot{x}$

In figure 6: $W_{\varphi\dot{x}}(s)$ – transfer function of channel $\varphi \to \dot{x}$; $W_{c1}(s)$ – controller transfer function; $\varphi_i(t)$ – control system input.

Such load horizontal motion control systems use angle errors. The control system input is $\varphi_i(t)=0$ when OPS is in an automatic control mode, but the load horizontal speed is determined by the error decay $\varphi_i(t)-\varphi(t)=e_\varphi \to 0$.

4.2.2. Control system block diagram for load vertical motion

According to the way of load positioning [3] the load vertical speed is determined by operator muscle force $\overline{F}$. But there is no possibility to measure force $\overline{F}$ and vertical speed $\overline{V_z}$ in OPS (figure 7).



a) Rest state *b)* Operator control

Figure 7. Load acted forces

Let us assume that $|F| \approx |\Delta T|$ and speed is determined by the expression

$$V_z(t) \approx \frac{1}{m}\int \Delta T \cdot dt, \qquad (3)$$

where *m* – load mass.

The expression (3) and our assumption $|F| \approx |\Delta T|$ mean that the designed control system is defined by the dependence $V_z = f(\Delta T)$, which describes a desired load track

IOP Conf. Series: Materials Science and Engineering **124** (2016) 012021 doi:10.1088/1757-899X/124/1/012021

The control system block diagram of channel $\Delta T \rightarrow \dot{l}$ (figure 8) is created on the basis of expression (3).

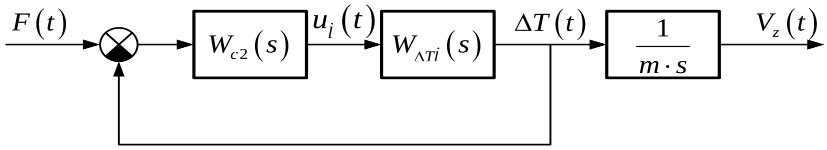


Figure 8. Control system block diagram of channel $\Delta T \rightarrow \dot{l}$

In figure 8: $W_{\Delta Ti}(s)$ – transfer function of channel $\Delta T \rightarrow \dot{l}$; $W_{c2}(s)$ – controller transfer function; $F(t)$ – operator muscle force.

5. Conclusion

This paper presents results of a small part of a project which aim is OPS creation and development. The article describes the way of load positioning through OPS and contains an OPS principle scheme. The main result of this paper is block diagrams of the control system, which is the first step of the control system design.

The next steps of OPS development are obtainment of a math model and a controller design on the basis of this paper material.

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