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DYNAMIC POSITIONING SYSTEM OF HELICOPTER PAD ON THE SHIP

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Abstract

Helicopter pad located on the ship significantly increase the operational capabilities of military and civilian ships. During the storm, especially side tilts of the ship hinder or even prevent the safe use of the helicopter pad. It is proposed to apply the system placed between the deck of the ship and landing site plate, driven by three independent linear drives located under the deck. The task of the system will be preventing from transferring to Helicopter pad the tilt of the ship around the longitudinal axis and the displacement of the deck along the transverse and vertical axis within the limits of the work area. The mechanism consists of the three movable pillars with the plate on top, which is the movable helicopter pad platform. As the linear actuators, plates moving along a horizontal guide were used, powered by system of steel cables with three independent electric motors. In folded state the mechanism, take up appropriately little space in the deck area. For the assumed extreme amplitudes of the ship motion, minimum dimensions of the mechanism links that meets the requirement to work in one configuration and lack of collisions were determined. Kinematic relationships were created indicate which mechanical quantities should be measured in real time to determine the momentary drives speed. For the adopted assumptions simulation was performed, confirming the predicted behaviour of the system. Based on the dynamics equations of system, drives loads, their power and individual links and joints load were determined.

Keywords: *Mechanical Engineering, Maritime Engineering, Kinematic Analysis, Mechanism Design*

1. Introduction

Seas and oceans ships are often equipped with a helicopter pad. The use of these helicopter pads is limited by the weather conditions. During the storm, large amplitude low-frequency ship tilts prevent a safe helicopter landing.

There are systems, which support pilots in the landing approach and the landing. An example is a system for tracking and guiding the helicopter on the correct approach path using warning lights "COLAS HVLAS Helicopter Visual Landing Aid System" [8]. The pilot during approaching to the landing is trying keeping the path of the helicopter in the displayed green beam of light sent by the stabilized transmitter from the ship's deck. The helicopter position is tracked by the system and information about the possible need to modify the approach is send to the pilot.

Another system, proposed by JL Sánchez López [7], is based on optical tracking of the position of the symbol “H” on the pad by a camera placed on a helicopter and automatic control landing approach. Image analysis allows for automatic identification of the helicopter position and orientation in space relative to the helicopter pad.

The system proposed by Prism Defence [2] (Fig. 1), examine the boundary conditions for safe helicopter interaction with the ship. As you might guess, the system relies on movement measurements of the ship, helicopter, ship nearest surroundings and use this data in real-time to predict the right moment for the landing when appropriate conditions occur for a long enough time.

The above helicopter landing support system may be supplemented by a system of movable landing, which reduces vibrations caused by rocking of the ship. The U.S. patent 2010/0224118 A1 presents a system of movable landing moving along the transverse axis of the ship.

Fig. 1. Helicopter landing attempt on a ship during the storm [2]

It is proposed to apply the active vibration reduction system of landing (AVRSL) for helicopters, which moves HELICOPTER PAD simultaneously in three degrees of freedom relative to the deck of the ship, causing a reduction in its movements, consisting of four sub-systems cooperating with each other.

1. The mechanism supporting landing plate. The main element of the mechanism is movable platform with helipad on in. The platform is supported by links of the mechanism, which will allow its simultaneous movement relative to the ship in the assumed direction.
2. Motors. Moves links is to the AVRSL mechanism. Due to the expected load and speed plans to use electric drives with rope motion transfer. Motors are equipped with drivers, inflicts momentary speeds calculated in the control system.
3. Measurement Subsystem. Ship subjected to extortion from the sea, performs spatial movement, which is measured using the set of sensors. As the value of the AVRSL control displacement and speed of the drives was selected. Direct measurement enables calculation of the deviation used in the control process.
4. Control Subsystem. It is planned to use deviations of the drives positions and their derivatives for controlling AVRSL with feedback. In the control system, the expected load and the required drives speeds are calculated in real time based on the measured motion of the machine frame.

2. Scheme of the movable helipad mechanism

The mechanism shown in Fig. 2, which is to be placed between the deck and the landing plate, is proposed. The platform 7 is supported by two moving plates 5 and 6 and the movable lever 4. Lever 4 and plates 5 and 6 are moved by the trolleys 1, 2 and 3. Trolleys 1, 2 and 3 drives on three rectilinear guides 0 attached to the hull of the ship. Dual pivot joint D_α, D_β and F_α, F_β connects landing platform with plates 5 and 6. From the other side plates are connected to the trolleys 2 and 3 by dual pivot joint B_α , B_β and C_α , C_β. Lever 4 is connected to the trolley 1 by cardan joint A and with the platform 7 by ball joint E. Rectilinear guides 0 are oriented transversely to the longitudinal axis of the ship.

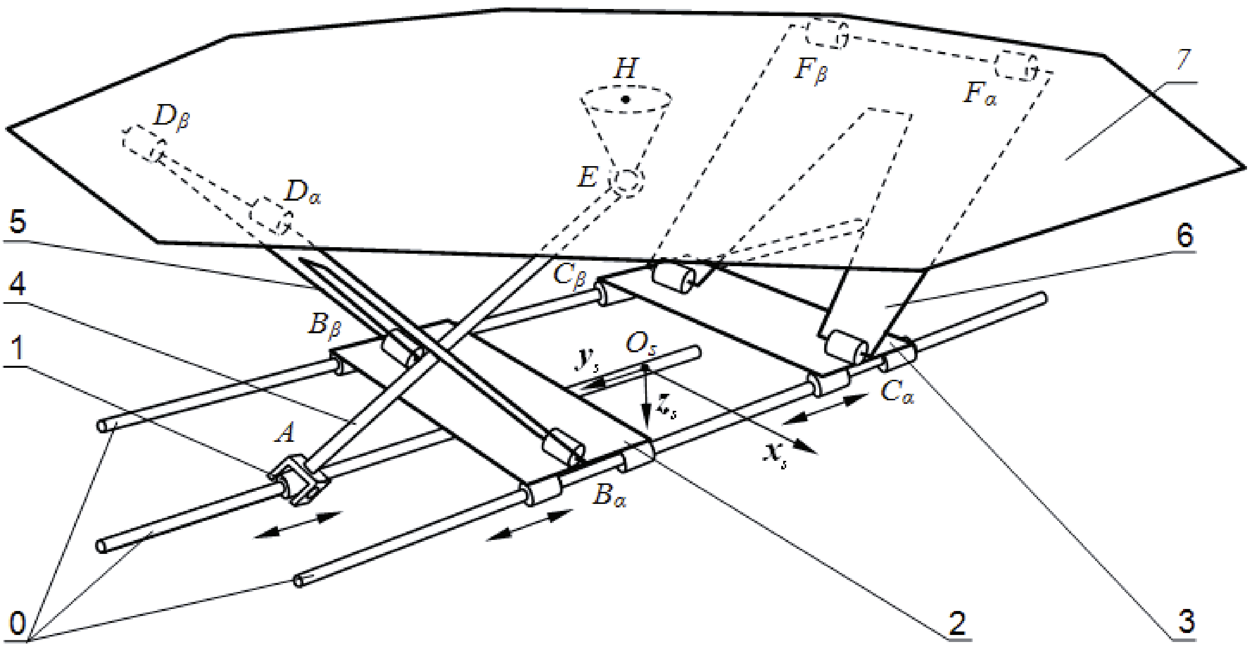

Fig. 2. Scheme of active vibration reduction system for helicopter pad on the ship (submitted as the invention to UP RP nr P.407136)

The mechanism of movable helicopter landing in the folded state occupies the minimum space under the plate. Provided space will house the trolleys 1, 2, 3, and lever and supporting plates 4, 5, 6, which are tilted to the plane of the deck at a slight angle.

In future development stages linear drives will move trolleys 1, 2 and 3. Trolleys will roll on rollers placed on three sides of the guides. This solution will prevent trolleys of detachment from the guides. It is considered the transfer of power by ropes hooked permanently to the cylinder, which, together with tensioner and motors can be placed on the side of the deck (Fig. 3).

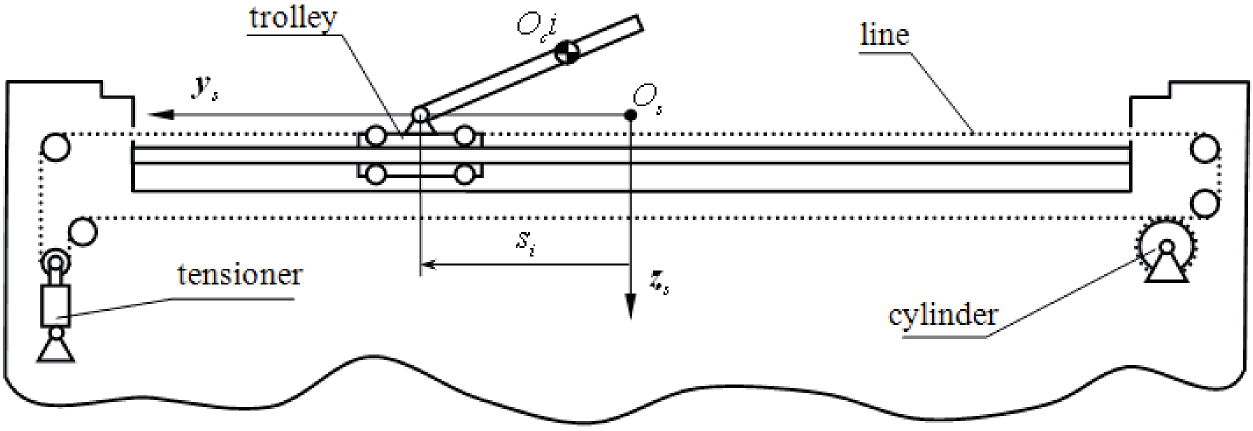

Fig. 3. Scheme of the trolley linear drive system

3. Kinematic and dynamic model of the AVRSL mechanism

For the preliminary analysis, the active vibration reduction system for helicopter pad can be considered as a flat mechanism (Fig. 4), moving in the plane $y_s z_s$ of the reference system $\{O_s x_s y_s z_s\}$ connected with the ship. Independently controlled drive mechanism causes simultaneous reduction of the helipad vibration in three degrees of freedom: rotation around the longitudinal axis x_s shifts along the transverse axis y_s and vertical axis of the ship z_s.

Adopt a strategy for behavior of the helipad during helicopter landing allows determining the kinematic relationships in the area of position and velocity. Since the mechanism of AVRSL has three degrees of mobility, should be a minimum of three terms. Helipad angular position relative to the ship's body will be determined by the need to set the helipad perpendicular to the direction of gravity. Knowing the location of the helicopter in helipad reference system can impose a condition to follow the centre of the landing for the projection perpendicular to the plane of the centre of the helicopter-landing pad. The vertical displacement of the landing can be adapted to the vertical displacement of the helicopter in order to obtain a controlled and smooth process of moving these objects to each other.

At the same time, we need to take into account the approach of a mechanism to border of the work field and the possibility of a collision landing plate with deck landing, resulting in the occurrence of these cases, the limited movement of the platform. Having measured the tilt of the ship and the location of the helicopter, we can specify the expected position of the platform relative to the ship through the imposed position of extreme points of the platform L_p and P_p relative to the extreme points of the ship's deck L_s and P_s. Setting the extreme points of landing plate in accordance with radius vectors $\boldsymbol{r}_L$ and $\boldsymbol{r}_P$ allows to determine the radius vector of the centre O_p of helipad reference system in ships reference system $\boldsymbol{r}_{O_sO_p}$ and axis unit vector of the helipad reference system $\boldsymbol{i}^o_{py}$, $\boldsymbol{i}^o_{pz}$. Time derivatives of the above figures enable the determination of the linear velocity vector of centre of the platform relative to the centre of the ships reference system $\boldsymbol{v}_{O_p} = [v_{O_p,y}, v_{O_p,z}]$ and component of angular velocity of helipad relative to the longitudinal axis of the ship $\omega_{7,x}$.

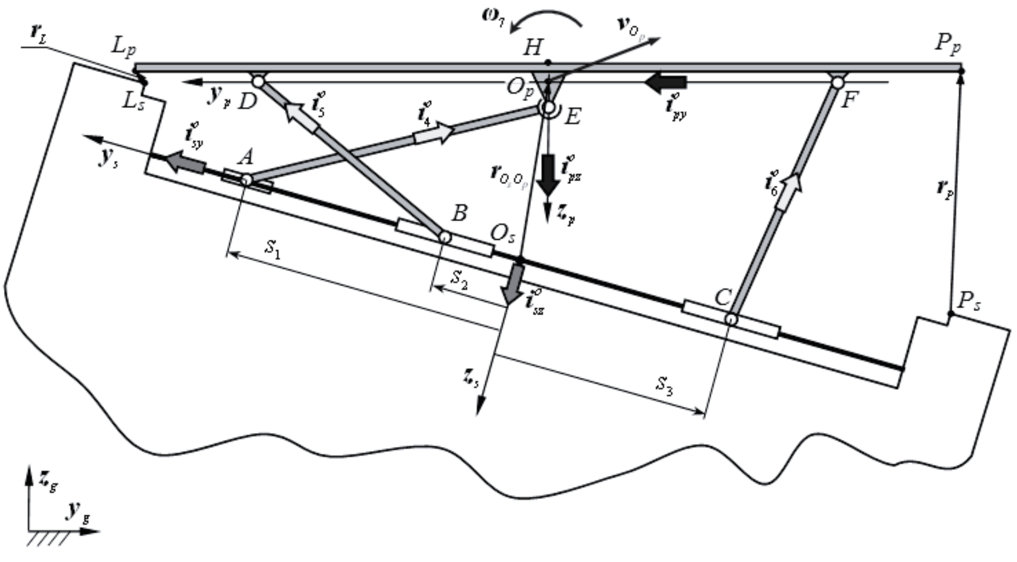

Fig. 4. Unit vectors system of active vibration reduction system for helicopter pad on the ship

Links of considered mechanism form polygons: O_sAEO_p, O_sBDO_p, O_sCFO_p, (Fig. 4), which can be described by equations:

$$s_1\boldsymbol{i}^o_{sy} + l_4\boldsymbol{i}^o_4 - l_{O_pE}\boldsymbol{i}^o_{pz} = \boldsymbol{r}_{O_sO_p},\quad s_2\boldsymbol{i}^o_{sy} + l_5\boldsymbol{i}^o_5 - l_{O_pD}\boldsymbol{i}^o_{py} = \boldsymbol{r}_{O_sO_p},\quad s_3\boldsymbol{i}^o_{sy} + l_6\boldsymbol{i}^o_6 + l_{O_pF}\boldsymbol{i}^o_{py} = \boldsymbol{r}_{O_sO_p}, \tag{1}$$

where:

l_4, l_5, l_6, l_{O_pD}, l_{O_pE}, l_{O_pF} – known length,

$\boldsymbol{i}^o_{sy} = [0,1]$ – unit vector aft axis y_{es} in ships reference system,

s_1, s_2, s_3, $\boldsymbol{i}_4^o$, $\boldsymbol{i}_5^o$, $\boldsymbol{i}_6^o$ – determined from the (1) coordinates of the momentary positions of the trolleys in the ships reference system and supports unit vectors.

On the basis of the time derivative of the equation (1) momentary speed of drives executing the adopted movement strategy are:

$$v_1 = \frac{(\boldsymbol{v}_{O_p} - l_{O_pE}\omega_{7,x}\boldsymbol{i}_{py}^o)\cdot\boldsymbol{i}_4^o}{\boldsymbol{i}_{sy}^o\cdot\boldsymbol{i}_4^o},\quad v_2 = \frac{(\boldsymbol{v}_{O_p} + l_{O_pD}\omega_{7,x}\boldsymbol{i}_{pz}^o)\cdot\boldsymbol{i}_5^o}{\boldsymbol{i}_{sy}^o\cdot\boldsymbol{i}_5^o},\quad v_3 = \frac{(\boldsymbol{v}_{O_p} - l_{O_pF}\omega_{7,x}\boldsymbol{i}_{pz}^o)\cdot\boldsymbol{i}_6^o}{\boldsymbol{i}_{sy}^o\cdot\boldsymbol{i}_6^o}, \tag{2}$$

where $\boldsymbol{i}_{py}^o, \boldsymbol{i}_{pz}^o$ – axis unit vector y_p and z_p of landing platform reference system.

For each moving link of the AVRSL mechanism can be formulated:

$$\boldsymbol{v}_{O_c,i} = \boldsymbol{J}_i\,\boldsymbol{v}\,, \tag{3}$$

where:

$\boldsymbol{v}_{O_ci} = [v_{O_ci,y} \quad v_{O_ci,z} \quad \omega_{i,x}]^T$ – matrix of the centre of mass velocity and angular velocity of the *i* link ($I = 1,...,7$) ,

$\boldsymbol{J}_i$ – Jacobian matrix transformation of trolleys velocity into linear velocity of centre of the mass and angular velocity *i* link,

$\boldsymbol{v} = [v_1 \quad v_2 \quad v_3]^T$ – trolleys velocity matrix.

The basis for determining the forces acting on the trolleys on the direction of their movement is equation derived from the principle of virtual work:

$$\boldsymbol{v}^T\boldsymbol{F}_n + \sum_{i=1}^{7}\boldsymbol{v}_{O_ci}^T\boldsymbol{B}_i = 0\,, \tag{4}$$

where:

$\boldsymbol{F}_n = [F_1 \quad F_2 \quad F_3]^T$ – matrix of forces acting on the trolleys,

$\boldsymbol{B}_i = [P_{bi,y} \quad P_{bi,z} + G_i \quad M_{bi,x}]^T$ – matrix interactions of inertial and gravitational force.

Taking into account equation (3) according to equation (4) gave the explicit designation of the forces acting on the trolleys:

$$\boldsymbol{F}_n = -\sum_{i=1}^{7}\boldsymbol{J}_i^T\boldsymbol{B}_i\,. \tag{5}$$

The force obtained from the equation (5) with trolleys velocities are used to determine momentary power developed by the trolleys. These are the basic data for the design of the propulsion system of the rope motion transmission.

4. Results

In the program, 2D Working Model a model of AVRSL mechanism was made. Trolleys 1, 2 and 3 performed momentary velocity based on equation (2). The simulation was made without the participation of the helicopter on the assumption landing locked horizontally in the inertial system and that the execution of trolleys speed was immediate and accurate.

Adopted parameters of force are from waving sea. The movement of the ship in transverse direction; amplitude s_{ymax} = 0.19 [m], frequency f_y = 0.11 [Hz]. The movement of the ship in the vertical direction, displacement amplitude s_{zmax} = 0.55 [m], frequency: f_z = 0.12 [Hz]. The movement of the ship around the longitudinal axis, displacement amplitude $\alpha_{x\max} = 9$ [°], frequency: f_x = 0.11 [Hz].

For AVRSL mechanism the following data were assume. Landing platform width 22 [m]. Length of the support lever l_4 = 6 [m] and length of the support plates $l_5 = l_6$ = 5 [m]. Landing weight m_p = 15000 [kg], the weight of the supporting lever m_4 = 500 [kg], weight of the support plates $m_5 = m_6 = 1000$ [kg], mass of the supporting lever trolley $m_1 = 300$ [kg], mass of the supporting plates trolleys $m_2 = m_3 = 500$ [kg].

The simulation showed the correctness of the AVRSL action. For the method used for determining the speed of trolleys landing was still, during movement of the ship. In addition, set the time courses of loads (Fig. 5), trolleys velocities (Fig. 6), power developed by trolleys (Fig. 7) and reaction forces in platform joints *D*, *E* and *F* (Fig. 8.).

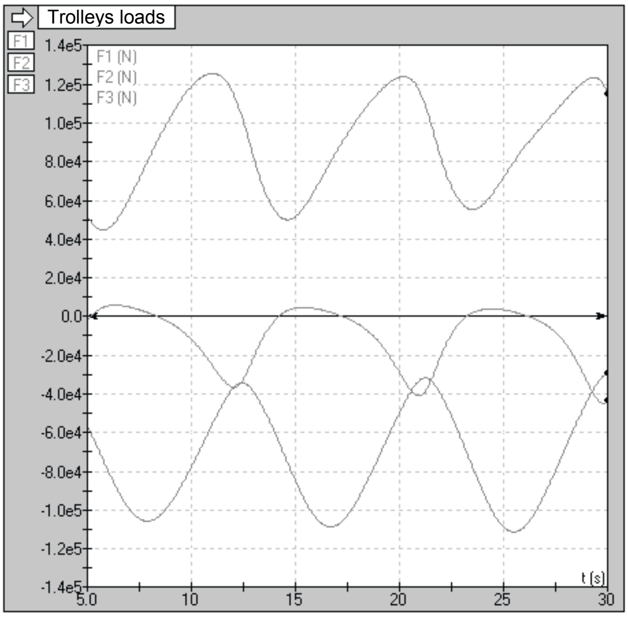

Fig. 5. Time course of trolleys loading forces on the direction of their movement

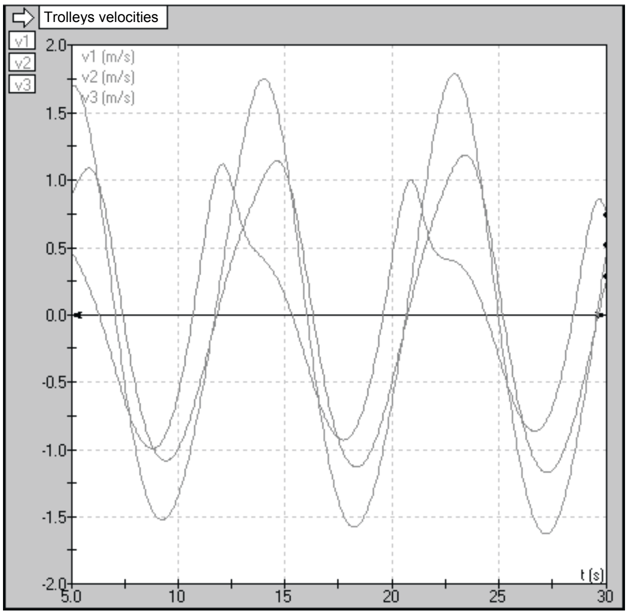

Fig. 6. Time course of trolleys speed

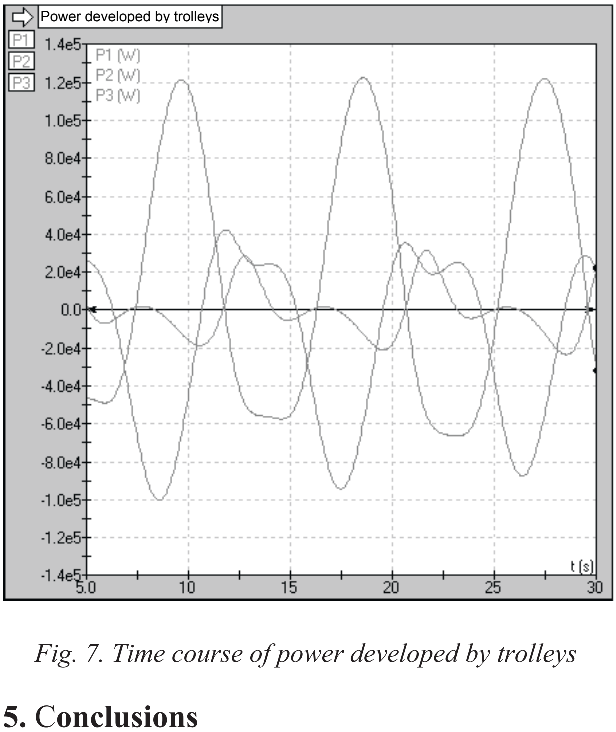

Fig. 7. Time course of power developed by trolleys

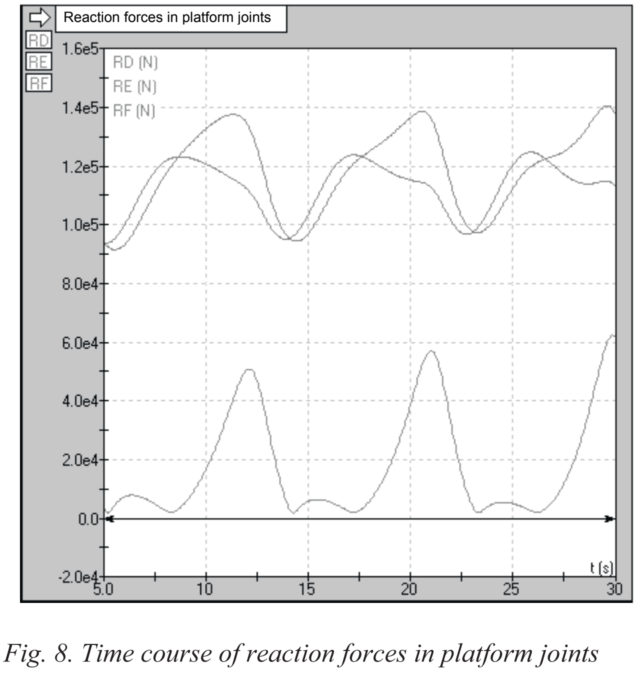

Fig. 8. Time course of reaction forces in platform joints

5. Conclusions

In order to increase the safety of the helicopter landing on the ship during the difficult weather conditions, the paper proposes an active vibration reduction system of landing. Preliminary simulations have shown that a vibration can be significant reduced along the transverse axis and the vertical axis and angular vibrations around longitudinal landing axis during the ships tilts.

Designated time course of load, speed and power developed by the trolleys show that can be used, for example, the electric drive for the rope motion transfer on the trolleys.

Further work will refer to the design of the control system takes into account the characteristics of the engine and the properties of the rope and the modeling of helicopter contact with the landing. It seems appropriate to consider the spatial AVRSL mechanism performing additional rotation around the transverse axis of the ship.

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