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WORKING AREA OF THE HELICOPTER PAD STABILIZATION MECHANISM

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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 four independent cable 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 and transverse axis and the displacement of the deck along the transverse and vertical axis within the limits of the work area. The mechanism consists of four movable links on which the movable helicopter pad platform is located. As the linear actuators, trolleys moving along horizontal guides were used, powered by system of steel cables with four independent electric motors. In folded state the mechanism, take up appropriately little space under 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 speeds. For the adopted assumptions simulation was performed, confirming the predicted behaviour of the system. Based on the kinematic equations of system and taking in consideration collisions and geometrical limits, working area for the flat part of the mechanism was determined.

Keywords: *mechanical engineering, maritime engineering, mechanism design, safety*

1. Introduction

Marine and ocean-going ships are often equipped with a helicopter pad. Landing a helicopter on a moving ship during bad weather brings with it a number of dangers. The main threats may include; contact blades of the main rotor of the helicopter with helipad plate, uneven approach the helicopter relative to the ship moving by waves and damage of helicopter caused a hard hit on the landing platform.

There are solutions to support the landing of helicopters on the ship. The most widely used system is “CILAS HVLAS Helicopter Visual Landing Aid System” [13], which by means of gyro-stabilized helicopter indicator lights guides the helicopter on the correct approach path. There are also prototype systems such as the Prism Defence [14] system, which monitors the movement of the ship and at the moment when the conditions are right it gives a signal to the pilot to land.

Another solution is a conceptual system proposed by J. L. Sánchez López in 2012 [8]. Using a camera mounted on the helicopter system is observing the “H” symbol on the landing pad and without the participation of the pilot controls the helicopter during landing. There are also mechanical solutions. Patent US 2010 / 0224118A1 [12] describes a system which is able to move the landing pad along the transverse axis of the ship. The proposed solution [3] provides the use of 4 trolleys driven by cable drives. Trolleys using 4 independently operated supports stabilize the helipad. For further consideration included in this article, a patented [11] flat part of the mechanism was adopted [1, 2] (Fig .1).

A set of all possible platform positions is a working space of the mechanism that can be divided by the boundary surfaces of the peculiar positions in to subspaces corresponding to the particular configurations [5, 10]. Transition of the mechanism by peculiar positions is undesirable, due to increased load and reduced controllability [6]. When designing these mechanisms, it is planned to work in only one configuration. Significant limitations of the working space result from the possibility of link collisions between one another or to the platform or the base, and the limitations of the displacement ranges in the joints [7].

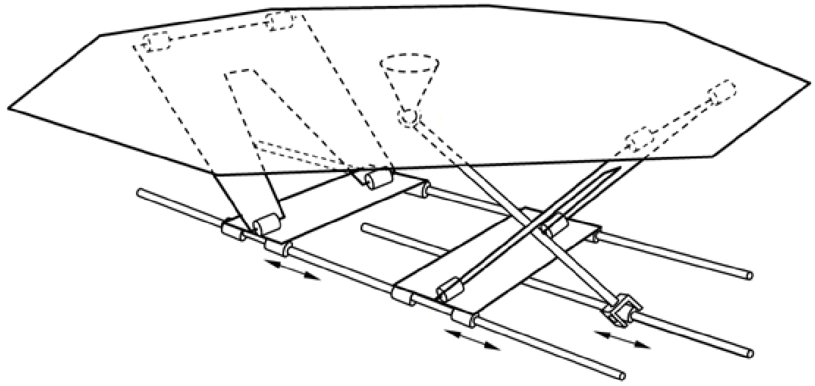


Fig. 1. Scheme of the helicopter pad stabilization mechanism [11]

2. Links position of the helicopter pad stabilization mechanism

Working area of the helicopter pad stabilization mechanism is defined as the set of all possible points that can be reached by the centre of the helipad (Fig .2) $O_{p,i}$. It is represented by a vector $\boldsymbol{r}_i(y_i, z_i)$ and the associated angle of inclination of the landing plate $\alpha \in (\alpha_{\min,i}; \alpha_{\max,i})$, under which you can set the landing pad relative to the deck. Working area is represented by a three-dimensional matrix $P(y, z, \alpha)$.

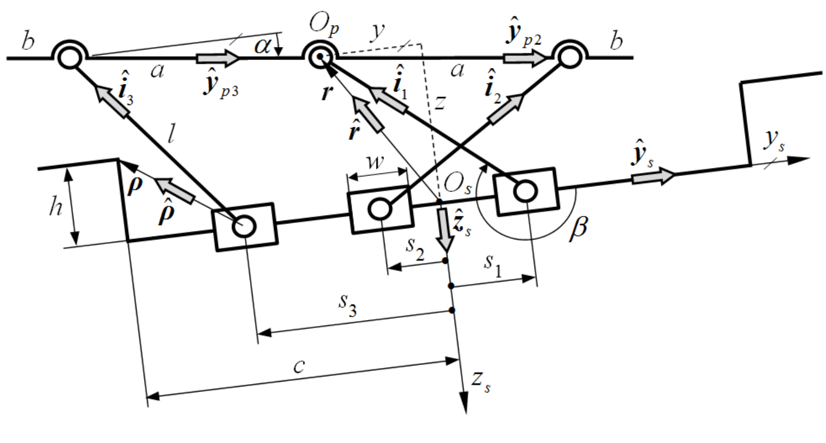


Fig. 2. Values used to describe the helicopter pad stabilization mechanism

To determine the working area, straight or reverse positions task can be used.

2.1. Straight positions task

Straight positions task is to set the coordinates; y, z of the vector $\boldsymbol{r}$ of helipad centre O_p and the inclination angle α for the preset positions of the trolleys; S_1, S_2 and S_3. Trolleys must meet the conditions of a non-collisional position on the prescribed section of the guide:

$$\left.\begin{array}{l} -c+2,5w<s_1<c-0,5w \\ -c+1,5w<s_2<c-1,5w \\ -c+0,5w<s_3<c-2,5w \end{array}\right\}, \tag{1}$$

where: c – distance from point O_p to the end of the trolley guide, w – the length of three trolleys.

The trolleys must also comply with the positions order conditions:

$$\left.\begin{array}{l} s_2-s_3>w \\ s_1-s_2>w \\ s_1-s_3>2w \end{array}\right\}. \tag{2}$$

A function of constraints was created (3) with one variable that temporarily allows a "break" in the pivot O_p, by which the platform unit vectors lying to the right and left $\hat{\boldsymbol{y}}_{p2}, \hat{\boldsymbol{y}}_{p3}$ may be in different directions. The desired alignment of the unit vectors occurs in the root-value of constraints function:

$$g(\beta)=1+\hat{\boldsymbol{y}}_{p2}\cdot\hat{\boldsymbol{y}}_{p3}, \tag{3}$$

where: β − inclination angle of the first plate support relative to the transverse horizontal axis of the ship $\hat{\boldsymbol{y}}_s$,

$$-\hat{\boldsymbol{y}}_{p2}=\frac{a^2-l^2+r_2^2}{2r_2a}\hat{\boldsymbol{e}}_2\pm\sqrt{1-\left(\frac{a^2-l^2+r_2^2}{2r_2a}\right)^2}\hat{\boldsymbol{j}}_2,\ \hat{\boldsymbol{y}}_{p3}=\frac{a^2-l^2+r_3^2}{2r_3a}\hat{\boldsymbol{e}}_3\pm\sqrt{1-\left(\frac{a^2-l^2+r_3^2}{2r_3a}\right)^2}\hat{\boldsymbol{j}}_3$$

$$r_2=\sqrt{l^2+(s_1-s_2)^2-2l(s_1-s_2)\cos\beta},\ r_3=\sqrt{l^2+(s_1-s_3)^2+2l(s_1-s_3)\cos\beta},$$

$$\hat{\boldsymbol{i}}_1=\cos\beta\hat{\boldsymbol{y}}_s+\sin\beta\hat{\boldsymbol{z}}_s,\ \hat{\boldsymbol{e}}_2=\frac{l\hat{\boldsymbol{i}}_1+(s_1-s_2)\hat{\boldsymbol{y}}_s}{r_2},\ \hat{\boldsymbol{e}}_3=\frac{l\hat{\boldsymbol{i}}_1+(s_1-s_3)\hat{\boldsymbol{y}}_s}{r_3},\ \hat{\boldsymbol{j}}_2=\hat{\boldsymbol{e}}_2\times\hat{\boldsymbol{x}}_s,\ \hat{\boldsymbol{j}}_3=\hat{\boldsymbol{e}}_3\times\hat{\boldsymbol{x}}_s$$

where:
l – length of three supports,
a – the distance between the centre of the landing pad O_p and the external joints of the helipad.

This constraint function can occur for an independent variable in the range: $0\le\beta\le2\pi$, its values are in the range; $0\le g(\beta)\le 2$. Node function (3) occurs in four forms: $g_{++}, g_{--}, g_{+-}, g_{-+}$ with different character set $\pm$ occurring in $\hat{\boldsymbol{y}}_{p2}$ and $\hat{\boldsymbol{y}}_{p3}$. Sought node function root-value is also tangent points to the absent axes. An exemplary course of the four forms of node functions is presented in Fig. 3. $l=5.34\,[m]$, $a=5.675\,[m]$, $s_1=4.967\,[m]$, $s_2=1.124\,[m]$.

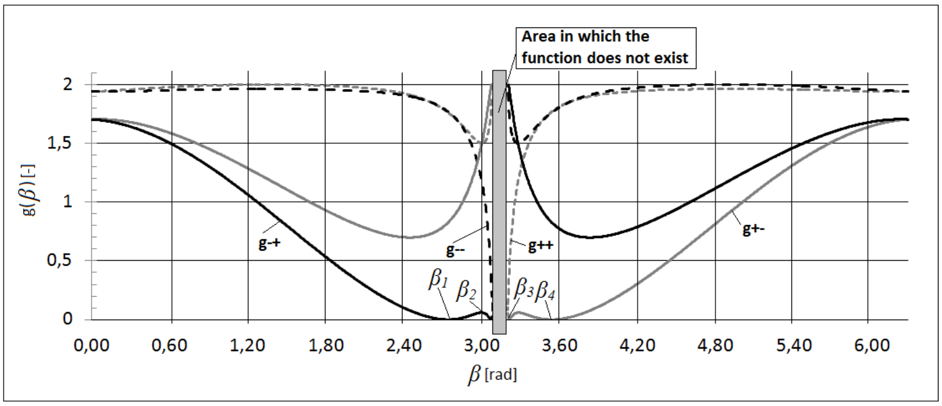
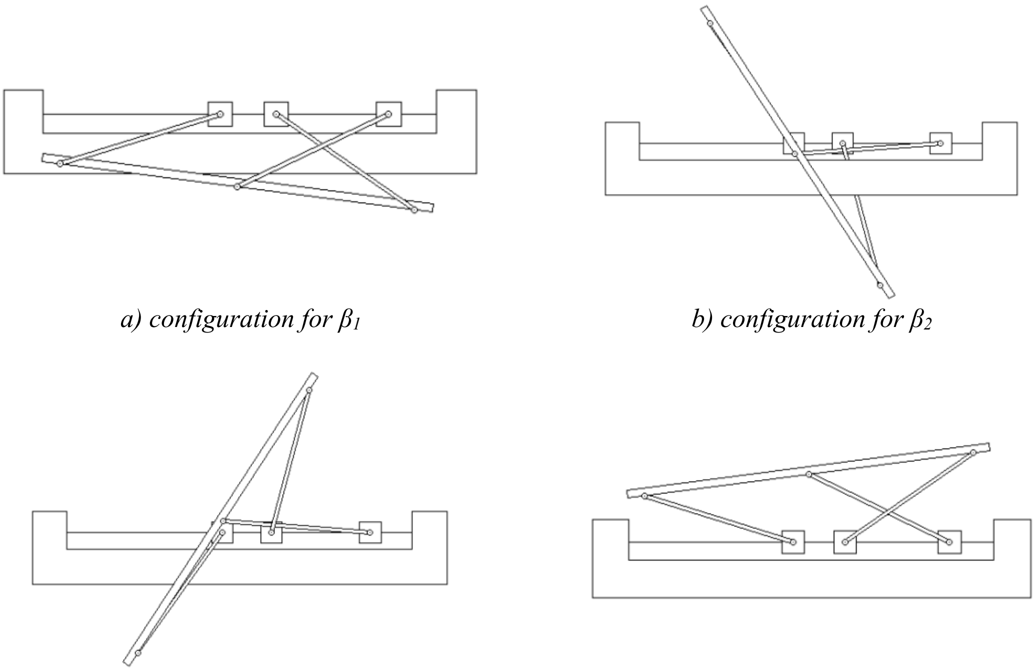


Fig. 3. Four forms of node functions g_{++}, g_{--}, g_{+-}, g_{-+}

On Fig. 3 there are four root-value $\beta_1 = 2.74\,[rad]$, $\beta_2 = 3.07\,[rad]$, $\beta_3 = 3.21\,[rad]$, $\beta_4 = 3.54\,[rad]$ which correspond to the four configuration of the mechanism for the straight positioning task shown in Fig. 4. The node function does not exist in its middle part and is symmetrical to the vertical straight $\beta = \pi$. The configuration, implemented in the analysed mechanism corresponds to the angle $\beta_4 = 3.54\,[rad]$, is presented on Fig. 4d.



a) configuration for β_1 *b) configuration for β_2*

c) configuration for β_3 *d) configuration for β_4*

Fig. 4. Mechanism configurations for four straight positions task solutions

Based on the value of the angle β all other values can be determined including: leader vector helipad centre O_p and the angle of inclination of the landing plate:

$$\boldsymbol{r} = y\hat{\boldsymbol{y}}_s + z\hat{\boldsymbol{z}}_s, \tag{4}$$

where: $y = s_1 + l\cos\beta$, $z = -l\sqrt{1-\cos^2\beta}$,

$$\alpha = \arccos(\hat{\boldsymbol{y}}_p \cdot \hat{\boldsymbol{z}}_s), \tag{5}$$

where: $\hat{\boldsymbol{y}}_p(\beta) = \pm\sqrt{1-\left(\dfrac{a^2-l^2+r_3^2}{2r_3a}\right)^2}\,\hat{\boldsymbol{j}}_3 + \dfrac{a^2-l^2+r_3^2}{2r_3a}\hat{\boldsymbol{e}}_3$.

The right and left edges of the landing site must be at most at the deck of the ship hight, which implies the condition:

$$z \pm (a+b)\sin\alpha < -h, \tag{6}$$

where:
b – the distance between the extreme joints under the landing plate and its edges,
h – the distance between the deck of the ship and the axles of the trolleys.

In addition, the left support can interfere with the left edge of the deck (Fig. 2). The exclusion of this collision describes the condition:

$$(\hat{\boldsymbol{\rho}} \times \hat{\boldsymbol{i}}_3) \cdot \hat{\boldsymbol{x}}_s > 0, \tag{7}$$

where: $\hat{\boldsymbol{\rho}} = \dfrac{-(c+s_3)\hat{\boldsymbol{y}}_s - h\hat{\boldsymbol{z}}_s}{\sqrt{(c+s_3)^2 + h^2}}$.

The inequality (7) can be reduced to a useful form:

$$\frac{h}{c+s_3} < \frac{z - a\sin\alpha}{y - a\cos\alpha - s_3}. \tag{8}$$

Using a straight positions task to determine the field of work of the helicopter pad stabilization mechanism is to calculate, for all positions of trolleys meeting the conditions (1) and (2), leader vector ***r*** of helipad centre; O_P and the inclination of the landing plate α. This requires finding the root-values of the constraints function (3) corresponding to the proper configuration of the mechanism. The resulting position of the link mechanism must meet the conditions (6) and (8).

2.2. Reverse positions task

Another possibility of obtaining a helipad mechanism working area is to use a reverse task, which is to determine the positioning of the trolleys; s_1, s_2 and s_3 for preset coordinates; y, z leader vector ***r*** of helipad centre O_P and the inclination of the landing plate α. A set of variable ranges has been adopted $y \in \langle -c + 0.5\,w - l + a, c - 1.5w + l - a \rangle$, $z \in \langle -h, -l + h \rangle$ and $\alpha \in \langle -\alpha_{\max}, \alpha_{\max} \rangle$, where $\alpha_{\max} = \arccos\left(\dfrac{l-h}{2a+b}\right)$. In this set, for each of the three variables y, z and α the positions of the trolleys are determined:

$$s_1 = y \pm \sqrt{l^2 - z^2}, \tag{9}$$

$$s_2 = y + a\cos\alpha \pm \sqrt{l^2 - [z + a\sin\alpha]^2}, \tag{10}$$

$$s_3 = y - a\cos\alpha \pm \sqrt{l^2 - [z - a\sin\alpha]^2}. \tag{11}$$

In order for the three variables y, z and α to be included in the working area, several conditions must be fulfilled. The values of the trolleys positions must be within the range of the real numbers, that is, the expressions under the roots (9), (10) and (11) must not be less than zero. Trolleys must meet collision-free conditions in the correct sequence of positions on the prescribed section of the guide, which requires that the conditions of (1) and (2). The right and left edges of the landing plate must be at most at the deck level (6) and the left support cannot interfere with the edge of the deck (8).

Eight reversed task solutions correspond to the eight configurations of the mechanism. This is due to sign $\pm$, which occurs three times in equations (9), (10) and (11). It was assumed to define the configuration as a system of three characters occurring sequentially in these equations. On Fig. 5. A set of mechanism configurations for the reverse positions task is shown (view from the stern of the ship).

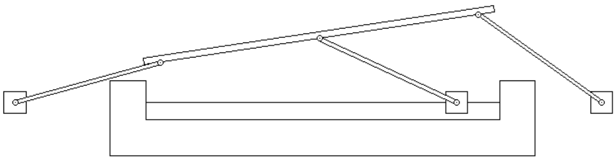
The configuration implemented by the mechanism is shown in Fig. 5h. From two methods for determining the working area of helicopter pad stabilization mechanism reverse position task was selected. It was selected because of the overt form for determining the position of trolleys under the same conditions that must be met for the position of the mechanism consideration.

3. Working area of the helicopter pad stabilization mechanism

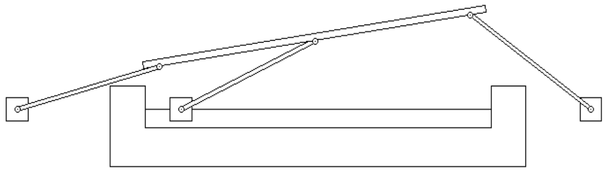
For numerical calculations, the following data were adopted: a=5.68[m], b=0.58[m], c=6.10[m], h=0.90[m], l=5.34[m], w=0.78[m]. Variables ranges are: $y \in \langle -5.38;\quad 4.60 \rangle [m]$

$$z \in \langle -0.90;\quad -5.34 \rangle [m],\ \alpha \in \langle -0.382;\quad 0.382 \rangle [rad]. \tag{12}$$

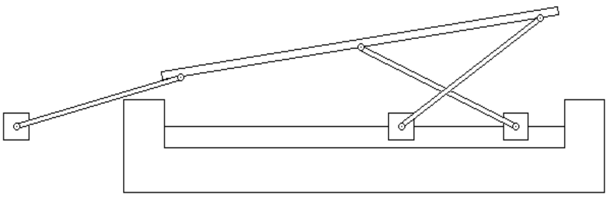
The working area is shown in Fig. 6. for eleven values of the angle α, Where the names of the surface fragments mean: I – working area of the mechanism, II – collision area of the third support with the inner edge of the deck, III – collision of the edge of the landing pad with the deck of the ship, IV – at least one trolley cannot be at the guide level, V – trolleys collide with each other or are not in proper order, VI – the trolleys do not fit on the guide section.



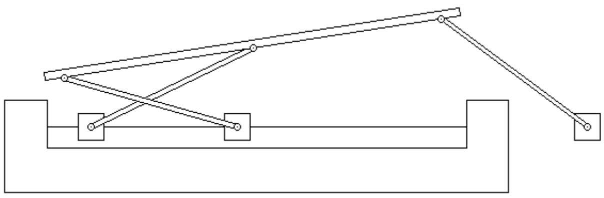
a) configuration − ++



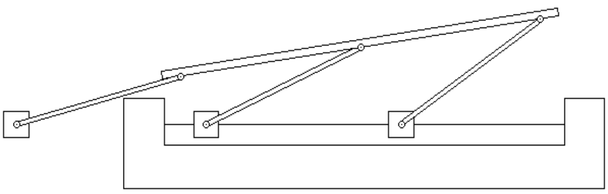
b) configuration − -+



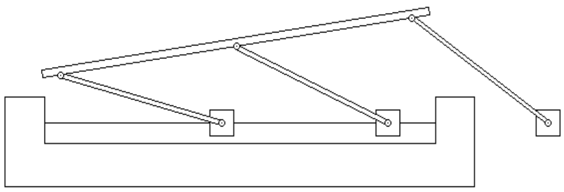
c) configuration − +-



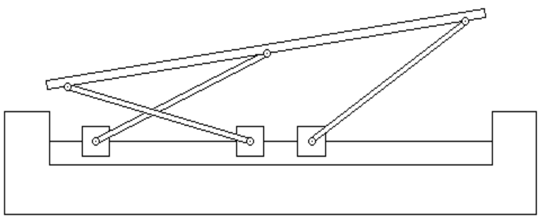
d) configuration − +-+



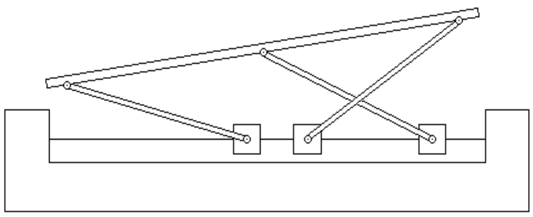
e) configuration − --



f) configuration − +++



g) configuration − +--



h) configuration − ++-

Fig. 5. Mechanism configurations for the reverse positions task

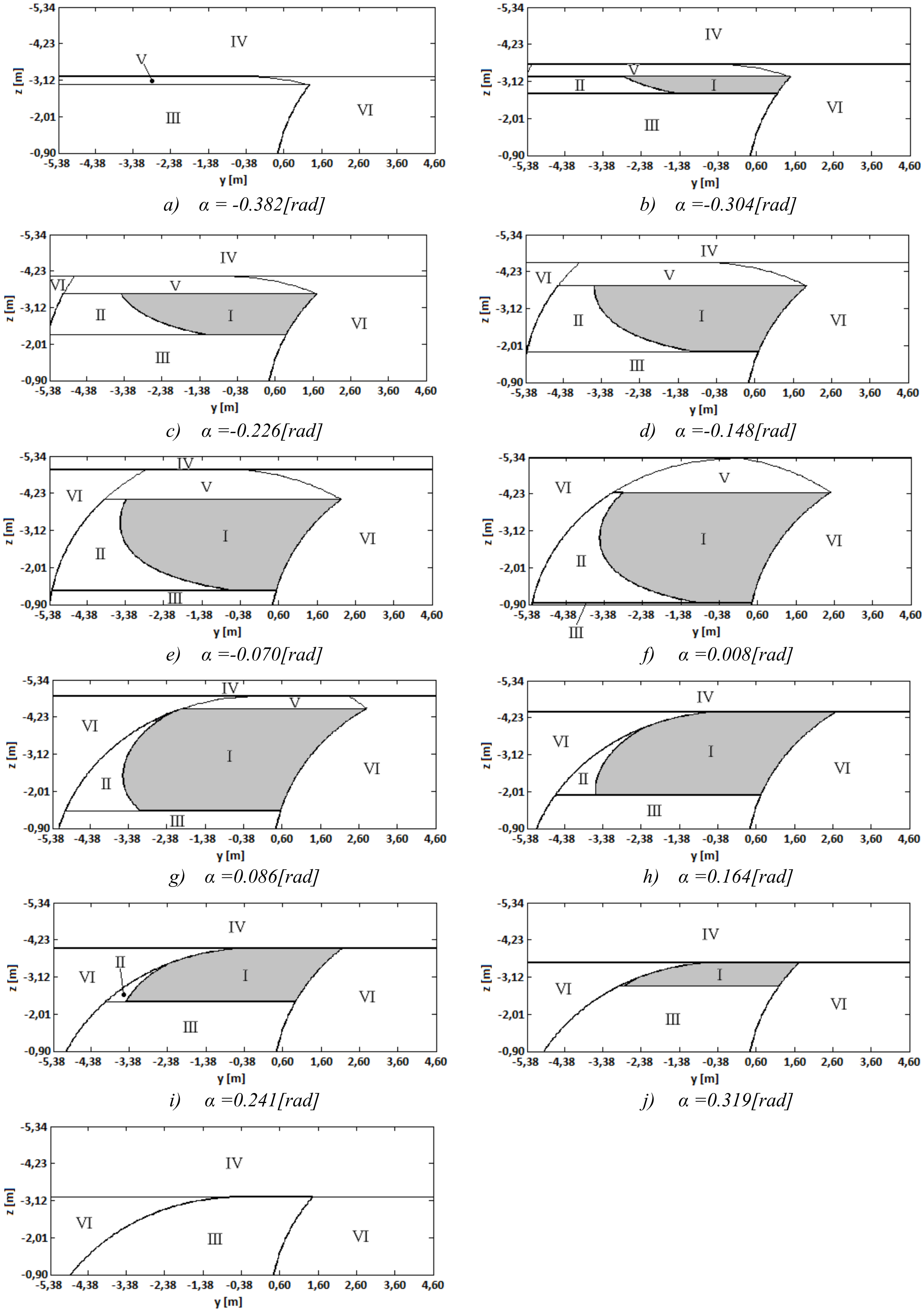
4. Conclusion

The basic way to control the movement of the trolley is through the fixed horizontal position of the landings in the earth-related system. If the helipad is approaching to the boundary of the working area, the landing pad braking control strategy must be implemented before it reach the boundary.

One of the basic criteria for evaluating the quality of mechanism is the size of its working area that can be used to synthesize the geometrical parameters of the landing supports, positions of the joints under the helipad and the range of movement of the trolleys on their guides.

The working area is slightly shifted to the left relative to the centre of the deck and the condition of no collision supports with the deck occurs only on the left. This is due to the asymmetrical position of the supports.

The helicopter pad stabilization mechanism working area range can be evaluate by, for example; manoeuvrability, time constant of its action and drives loads.



a) α = -0.382[rad]

b) α =-0.304[rad]

c) α =-0.226[rad]

d) α =-0.148[rad]

e) α =-0.070[rad]

f) α =0.008[rad]

g) α =0.086[rad]

h) α =0.164[rad]

i) α =0.241[rad]

j) α =0.319[rad]

k) α =0.382[rad]

Fig. 6. Working area for different values of the tilt angle α

References

[1] Brewczyński, D., Tora, G., *Dynamics model of stabilization mechanism for helicopter pad*, KONES, 2016.

[2] Brewczyński, D., Tora, G., *Dynamic positioning system of helicopter pad on the ship*, Journal of Kones, Vol. 21, No. 4, 21-27, 2014.

[3] Brewczyński, D., Tora, G., *Stabilization mechanism for helicopter pad with four degrees of freedom*, Journal of KONES, e-ISSN: 2354-0133, OI: 10.5604/12314005.1165947, 2015.

[4] Gogu, G., *Parallel mechanisms with decoupled rotation of the moving platformin planar motion*, J. Mechanical Engineering Science Proc. ImechE, Vol. 224, Part C, 710-720, 2010.

[5] Han, C., Kim, J., Kim, J., Park, F. C., *Kinematic sensitivity analysis of the 3-UPU parallel mechanism*, Mechanism and Machine Theory, 37, 787-798, 2002.

[6] Ider, S. K., *Inverse dynamics of parallel manipulators in the presence of drive singularities*, Mechanism and Machine Theory, 40, 33-44, 2005.

[7] Quennouelle, C., Gosselin, C. M., *Stiffness Matrix of Compliant Parallel Mechanisms*, Advanced in Robot Kinematics: Analysis and Design, 331-341, 2008.

[8] Sanchez-Lopez, J. L., Pestana, J., Saripalli, S., Campoy, P., *An Approach Toward Visual Autonomous Ship Board Landing of a VTOL UAV,* J Intell Robot Syst., 74:113-127, 2014.

[9] Zhao, J-S., Feng, Z.-J, Zhou, K., Dong, J.-X., *Analysis of the singularity of spatial parallel manipulator with terminal constraints*, Mechanism and Machine Theory, 40, 275-284, 2005.

[10] Zhu, Z., Li, J., Gan, Z., Zhang, H., *Kinematic and dynamic modeling for real-time control of Tau parallel robot*, Mechanism and Machine Theory, 40, 1051-1067, 2005.

[11] Patent P.407136, Tora, G., *Mechanizm stabilizujący ruchome lądowisko helikopterów*.

[12] Patent: US 2010/0224118, A1, *Helicopter Landing Platform Having Motion Stabilizer for Compensating Ship Roll and/or Pitch*, 2010.

[13] *CILAS HVLAS Helicopter Visual Landing Aid System* http://www.cilas.com/helicopter-visual-landing-aids.htm.

[14] *Prism Defence company that develops support systems for helicopters landing on the ships* http://www.prismdefence.com/index.html.