ISSN 1330-3651
UDC/UDK 621.873.01 : 519.863

ULTRA-LIGHT TELESCOPIC CRANE/PLATFORM MECHANISMS FEATURE ANALYSIS

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Preliminary notes

Based on the research of mechanical properties of fine-granular high-strength steels and the obtained results, the design of prototype ultra-light telescopic crane was performed. The article presents the analysis results of the crane drive mechanism. The geometric synthesis of shapes and sizes of four joint was performed based on the maximum and minimum slope of each arm and on the minimum weight. Feedback of optimal shape of each mechanism's stick was implemented by the variant solutions evaluation methods. The detailed calculation of stress and strain in each mechanism's stick was performed by finite element method.

Keywords: *Ultra-light telescopic crane/platform, mechanisms, mechanisms' synthesis, optimization*

Analiza značajki mehanizama ultralake teleskopske dizalice/podesta

Prethodno priopćenje

Temeljem istraživanja mehaničkih svojstava sitnozrnatih visokočvrstih čelika i dobivenih rezultata izvršeno je projektiranje prototipa ultralake teleskopske dizalice. U članku su prikazani rezultati analize pogonskog mehanizma dizalice. Izvršena je geometrijska sinteza oblika i dimenzija četverozgloba na temelju maksimalnog i minimalnog nagiba pojedine ruke i minimuma masa. Ocjena optimalnog oblika pojedinog štapa mehanizma provedena je metodama vrednovanja varijantnih rješenja. Detaljan proračun naprezanja i deformacija u pojedinim štapovima mehanizma izvršen je metodom konačnih elemenata.

Ključne riječi: *Ultralaka teleskopska dizalica/podest, mehanizmi, sinteza mehanizama, optimiranje*

1 Introduction
Uvod

Ultra-light telescopic cranes are designed for people working at height where they perform different maintenance jobs: e.g. glass facades of buildings, frescos in the religious facilities, transmission lines, lighting poles etc. It is also possible to use them to manipulate different types of small goods in manufacturing facilities, warehouses, energy facilities etc. The maximum setting-up height is 30 m.

The drive can be manual, hydraulic, electric or combined. The most common drive is a combined electro-hydraulic one, because of the possibility of automatic control and driving with security the crane's functions. Driving the crane can be achieved from the ground or from the working crane's basket [1].

2 Structural features of the crane
Konstrukcijske značajke dizalice

The basic crane's features arise from its use, and these are:

- low weight (less than 3 tones)
- minimum pressure on the base
- small dimensions of the foldable transport position, in order to pass through narrow passages/doors
- application of fine-granular high-strength steel.

2.1 Low weight of crane
Mala masa dizalice

The crane must have a minimum mass from several reasons:

- Possibility of pulling by car.
- Minimal pressure on the background,
- Entering into rooms, whose background structure is not designed for the increased load.

To reduce the mass of crane, in addition to specific construction operations, the fine-granular high-strength steels StE 680 and StE 960 were selected [1]. Based on the research of mechanical, metallographic, tribological and other properties and based on the results, the design of telescopic crane/platform was carried out.

2.2 Drive of crane
Pogon dizalice

The crane is self-propelled because it possesses own drive for starting in the workspace. The crane is autonomous because it does not require the external power source. For its transport from one worksite to another it a tow truck is necessary which is in the form of a passenger car with limitation of drawn mass size.

From the minimum conditions of mass, dimensions and form a special problem is set to the crane's drive. From the analysis of forces in the crane's arms, a solution with four-joint with electro-hydraulic drive controlled by electronics was found.

3 Analysis of mechanism
Analiza mehanizma

3.1 The connection between the geometric parameters of the mechanism
Veza između geometrijskih parametara mehanizma

The mechanism, whose scheme is shown in Figure 1, is a mechanism for rotating the basket and the upper arm (Figures 2 and 3). The mechanism shown in Figure 4 is used to start the lower arm.

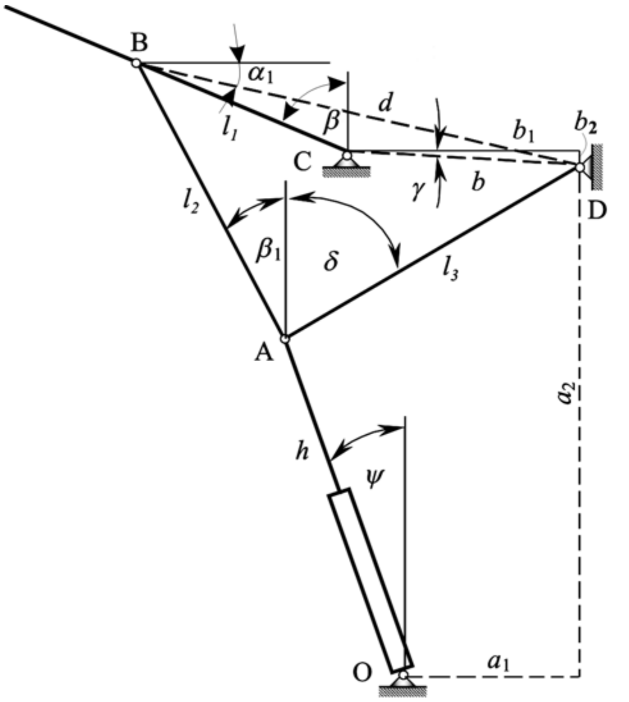

Figure 1 *Scheme of four-joint mechanism*
Slika 1. *Shema četverozglobnog mehanizma*

3.1.1
Analysis of four-joint mechanism
Analiza četverozglobnog mehanizma

Drives for the rotation of the upper arm and the basket have the form of four-joint mechanism.

The connection between geometric sizes of four-joint mechanism can be concluded from Figure 1. Geometric synthesis of shapes and dimensions of the four-joint is performed on the maximum and minimum inclination of each arm, and on minimum masses [2, 3]. l_1, l_2 and l_3 are lengths of sticks of mechanism.

The values of a, b and d together with the angles α_1, β, β_1, δ and ψ determine the geometry of supports, h is the length of the drive cylinder. The angle β is the entry value which comes from the working conditions and purpose of the crane/platform. During the calculation of geometry, some of these values result from the calculation of other physical features and they are included as the known values.

$$\tan\alpha_1 = \frac{b_2 + l_1 \cdot \cos\beta}{b_1 + l_1 \cdot \sin\beta}, \tag{1}$$

$$d = \frac{b_1 + l_1 \cdot \sin\beta}{\cos\alpha_1}, \tag{2}$$

$$\sin(\delta - \alpha_1) = \frac{d^2 + l_3^2 - l_2^2}{2 \cdot d \cdot l_3}, \tag{3}$$

$$\sin\beta_1 = \frac{d \cdot \cos\alpha_1 - l_3 \cdot \sin\delta}{l_2}, \tag{4}$$

$$\tan\psi = \frac{l_3 \cdot \sin\delta - a_1}{a_2 - l_3 \cdot \cos\delta}, \tag{5}$$

$$h = \frac{a_2 - l_3 \cdot \cos\delta}{\cos\psi}. \tag{6}$$

3.1.2
Analysis of lower arm drive
Analiza pogona donje ruke

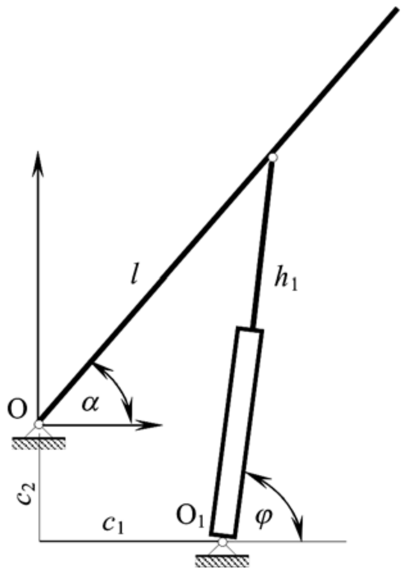

Figure 2 *Scheme of lower arm drive*
Slika 2. *Shema pogona donje ruke*

The values c_1 and c_2, together with angles α and φ, determine the geometry of supports. The length of drive cylinder is h_1. The angle α is input value which comes from working conditions and purpose of the platform/crane. From Figure 2 it is possible to write the connection between the geometric values of the drive mechanism.

$$\begin{aligned} l \cdot \cos\alpha - h_1 \cdot \cos\varphi - c_1 &= 0 \\ l \cdot \sin\alpha - h_1 \cdot \sin\varphi + c_2 &= 0, \end{aligned} \tag{7}$$

$$\tan\varphi = \frac{l \cdot \sin\alpha + c_1}{l \cdot \cos\alpha - c_1}, \tag{8}$$

$$h_1 = \frac{l \cdot \sin\alpha + c_2}{\sin\varphi}. \tag{9}$$

3.2
Forces in elements of mechanism
Sile u elementima mehanizma

For dimensional control it is necessary to determine the maximum force in some sticks of mechanisms depending on the inclination angles of lower and upper arm. Forces F_B and F_D are in B and D of four-joint mechanism. M_B is the moment in the point B from its own gravity, inertial forces, conductive and wind action on the structure. F_{C1} and F_{C2} are the forces acting on the drive cylinders.

$$F_B = \frac{M_B}{l_1 \cdot \sin(\beta + \beta_1)}, \tag{10}$$

$$F_D = \frac{\cos\beta_1 \cdot \tan\psi - \sin\beta_1}{\cos\delta \cdot \tan\psi + \sin\delta} \cdot F_B, \tag{11}$$

$$F_C = \frac{F_D \cdot \cos\delta - F_B \cdot \cos\beta_1}{\cos\psi}. \tag{12}$$

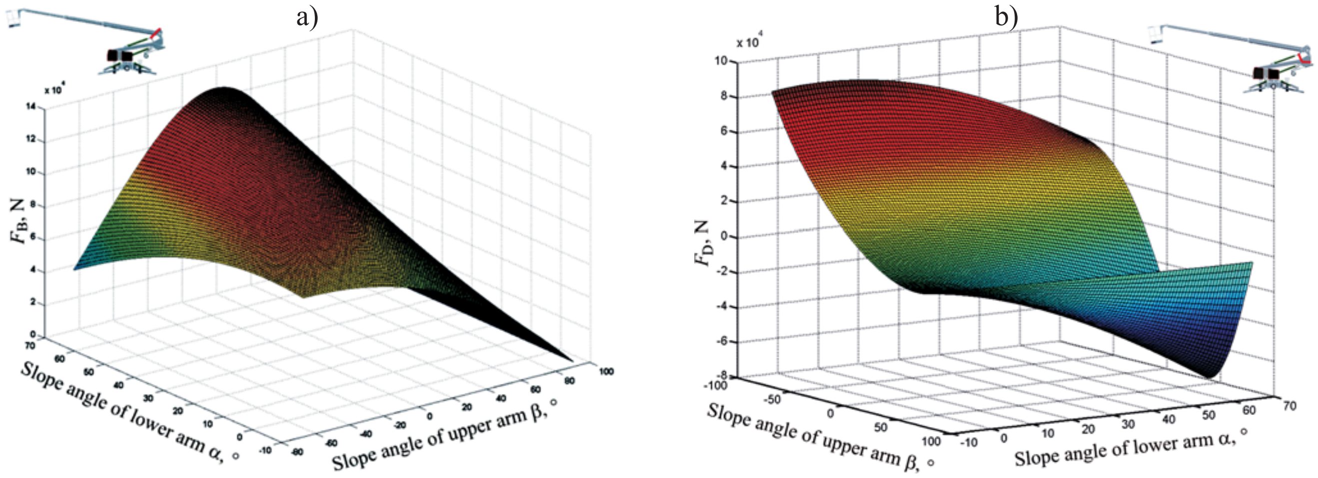

Figure 3 *Force changes in B mechanism (a) and in D mechanism (b) for the arm lifting*
Slika 3. *Promjena sile u B mehanizma (a) i u D mehanizma (b) za podizanje ruke*

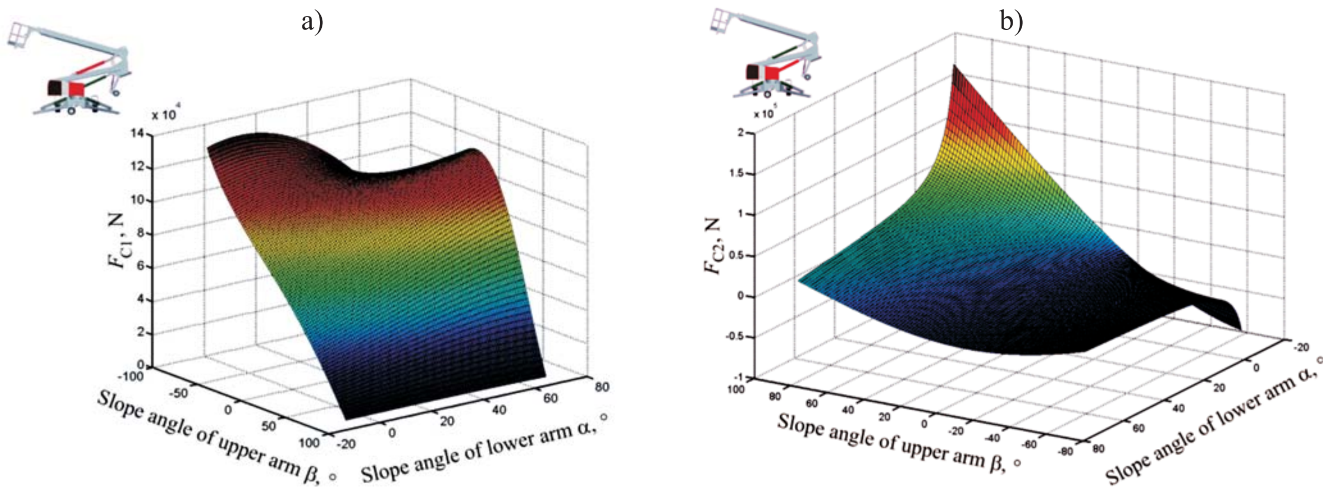

Figure 4 *Force changes in the cylinder 1 for the rotation of the upper arm (a) and in the cylinder 2 for the rotation of the lower arm (a)*
Slika 4. *Promjena sile u cilindru 1 za zakretanje gornje ruke (a) i u cilindru 2 za zakretanje donje ruke (a)*

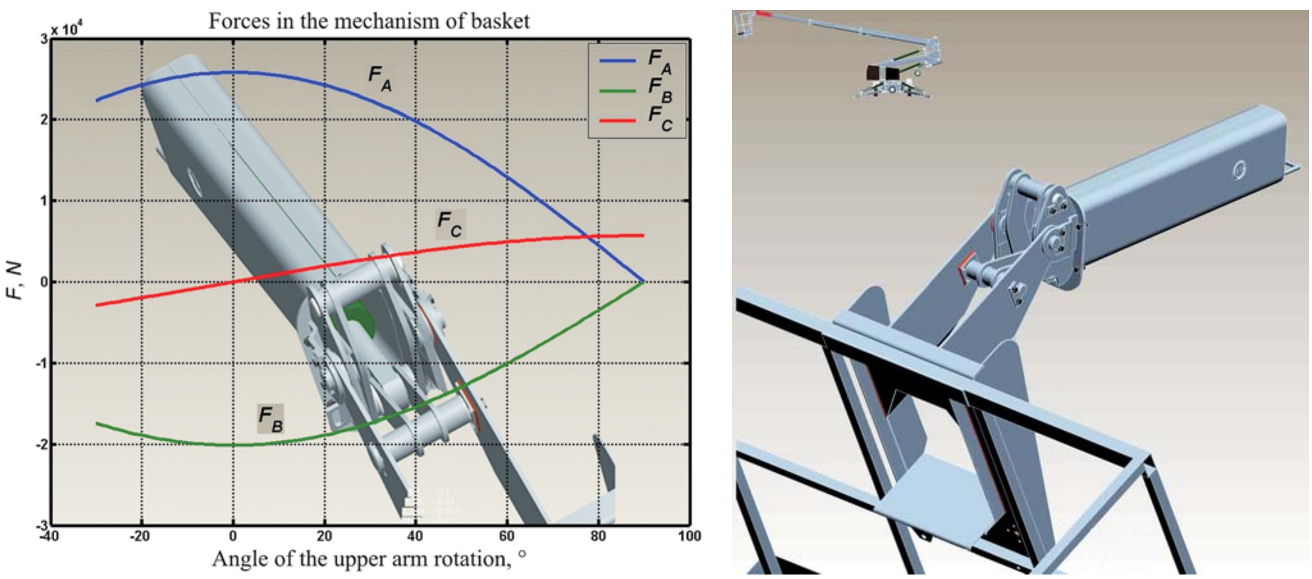

Figure 5 *Forces in the mechanism for rotating the basket*
Slika 5. *Sile u mehanizmu za zakretanje korpe*

The method of determining the maximum forces acting on individual elements of the crane is performed depending on the taken angles of the crane arm. Inertial forces are not directly taken into account because the velocity of basket motion is very small. Furthermore the engaging of individual actuators is regulated electronically so that the acceleration is very small. The dynamic effects on the crane are taken into account through the dynamic plug-in prescribed by the standard EN 280:2001 (6.1.4.4) [4]. The results of analysis of the forces that act on individual elements of the crane's mechanism are shown in Figure 3 and Figure 4.

The form of each stick is determined from the conditions of minimum crane's dimensions with the fact that the selection of optimal form is carried out by evaluation methods of variant solutions [5, 6].

Detailed calculation of stresses in some sticks of mechanism is performed by finite element method.

Some problems appeared in applying the finite element method. For example, with known elements and applying known theoretical relations how to determine all values required for the analysis of described continuous system. Ten-nodal isoparametric tetrahedral 3D elements are used to describe the elements of construction and generation of mesh elements [7]. Examples of analysis of some elements of the mechanism are shown in Figures 6 and 7. Figure 3 shows the strains of basket by different ways of loading. Figures 4 and 5 show the stresses and strains for one of the crane segments. Figure 6 shows the schedule of stresses and strains quantities of the crane's upper and lower base.

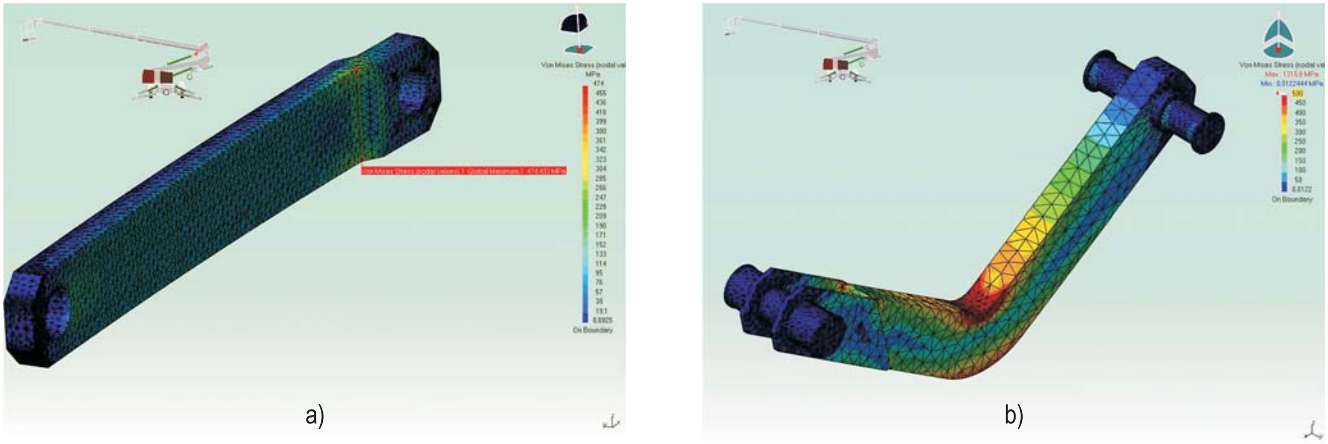

Figure 6 *Analysis of stresses in the sticks of the mechanism of the upper arm: a) - in a straight stick, b) – in a curved stick*
Slika 6. *Analiza naprezanja u štapovima mehanizma gornje ruke: a) – u ravnom štapu, b) – u zakrivljenom štapu*

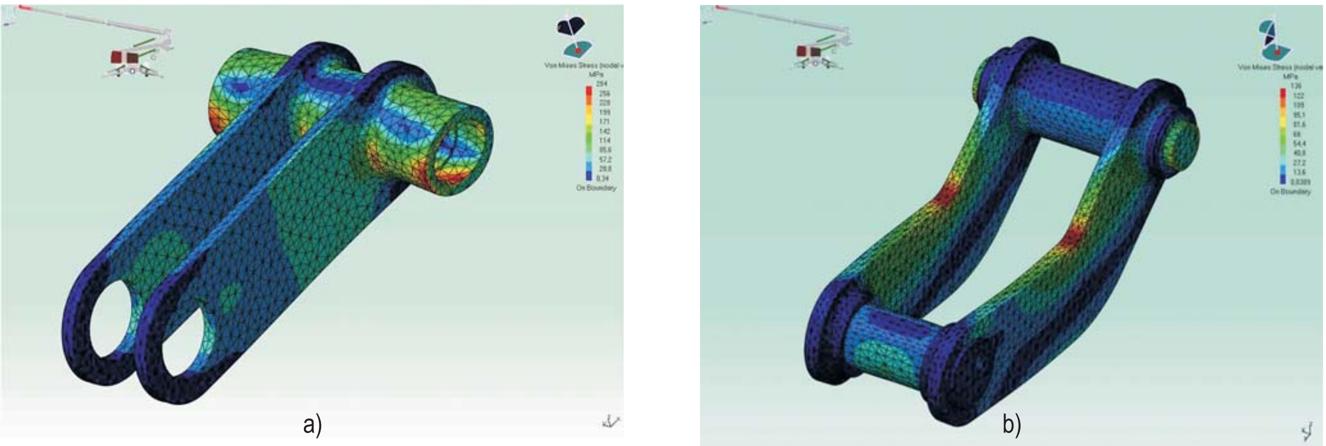

Figure 7 *Disposition of stresses in the basket rotation mechanism: a) - in a straight stick, b) – in a curved stick*
Slika 7. *Raspored naprezanja u mehanizmu zakretanja korpe: a) – u ravnom štapu, b) – u zakrivljenom štapu*

4 Analysis of results
Analiza rezultata

Figures 3 and 4 show the forces variation in the sticks of mechanism for the platform drive. From these figures it is evident that the forces in the B and D of mechanism decrease with increasing the slope angle. Thus can be conclude that it is better to lift first the lower arm, and then to rotate and draw the upper arm. The forces on the driving cylinders of mechanisms are also lower and if it is possible the work can be performed electronically only by the raised lower arm. From Figure 4 is also visible that the force in the cylinder of the lower arm increases rapidly and goes to the singularity if the slope angle amounts to $\beta<0$. Furthermore, it is evident that the mechanism does not work singularly. Singularities are located outside of the mechanism so for the upper and the lower arm work that for the basket rotation. Forces in the mechanism for rotating the basket are shown in Figure 5. The possibility of going into the singular area of mechanism is limited by cylinder's stroke, end-switches and electronic control of the platform operating.

Figure 8 Production and testing of prototypes in the workshop
Slika 8. Izrada i testiranje prototipa u radionici

5 Conclusion
Zaključak

Based on the analysis it can be concluded that the different variants of work can be performed by the crane. The paper presents an example of development and structural analysis of the drive mechanisms of ultra-light crane. The aim of this study was to get the optimal design of light crane, as well as detailed analysis of the stresses of each crane's mechanism elements. Some innovative and design solutions (Figure 8) with optimized variant solutions were used in the design process.

Acknowledgment: This article resulted from technological project supported by the Ministry of Science, Education and Sports of the Republic of Croatia TP-05-152-05. The authors thank all participants in the project who provided presentation of project solution in this article.

6 Literature
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