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Synthesis of Elevator Mechanisms in X with Complex Triad Type Kinematic Chains

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Abstract: *The mechanisms of the elevators in X usually have a simple structure with hinged, scissor-type bars, having one or more levels. In the last period, models of elevators with articulated bars in X with complex structure with triad type kinematic chains were made. For such an elevator with triadic chains, a construction diagram (dimensioned drawing) is presented, after which the kinematic diagram of the plane mechanism with articulated bars and guided rollers is executed. The structural-topological analysis aims at the mobility calculation and is complemented by a frictionless static calculation.*

Keywords: *Elevator mechanisms, kinematic analysis, complex triad, kinematic chains.*

1. Introduction

Elevators with articulated bars in X are flat structures mounted in parallel with one or more levels, being operated with hydraulic or pneumatic cylinders. These lifts are used more and more in car services, for lifting vehicles for current repairs below at the bottom.
In most of them, elevators with articulated bars in X are used for work at height (fig. 1, 2), at the top of which there is a platform, on which workers work [1,2,3,4].

Fig. 1. X lift scissor with two levels

Fig. 2. X lift scissor with 3 and 4 levels

Being built for higher heights, these elevators are operated with relatively long hydraulic actuators [5,6,7].
For working at lower heights (fig. 3, 4) non-articulated X-lifts with two levels are used, where the work table is moved vertically with a mechanical screw actuator.

Fig. 3. X lift with non-articulated bars

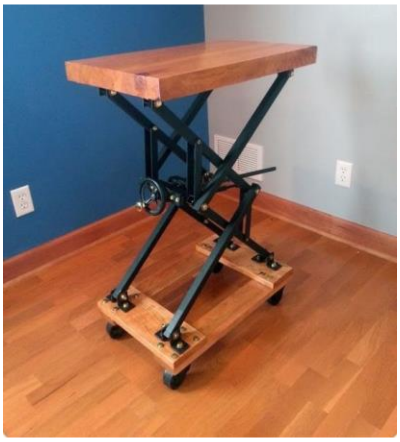

Fig. 4. X lift with non-articulated bars with two levels

It is noted in these elevators that the X-shaped bars are not articulated with each other, the respective bars being opposite and unequal in a deltoid quadrilateral (fig. 3), respectively opposite equal bars and articulated by the horizontal actuator provided with a screw (fig. 4).
These height-adjustable tables are mounted on the elevator with non-X-articulated bars, but articulated at the base on a four-wheeled carriage (fig. 5).
There is also the solution of making an elevator mechanism with articulated bars (fig. 6) and a single level, having in its structure two dyadic chains denoted LD (2,3) and LD (4,5).

Fig. 5. Non-articulated X-lift with 2 levels

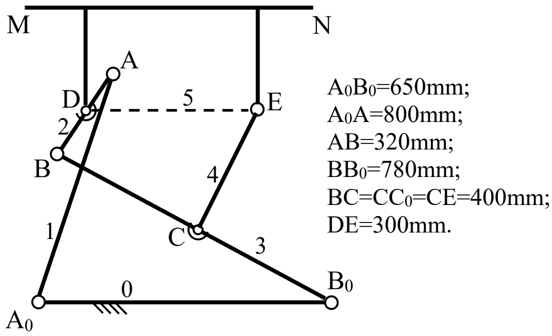

Fig. 6. Dyadic chain elevator kinematic diagram sketch

2. Structural analysis of the X-bar elevator with complex chains

The dimensioned construction diagram (fig. 7) of an articulated X scissor elevator mechanism [8] is followed, after which the appropriate kinematic diagram (fig. 8) with articulated bars is deduced.

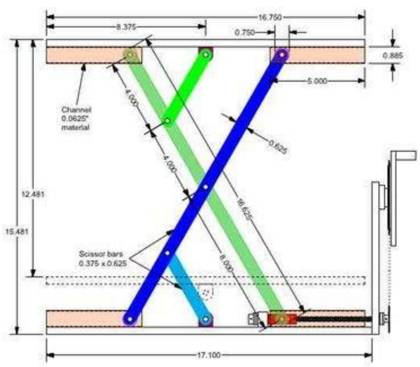

Fig. 7. Construction scheme of the elevator

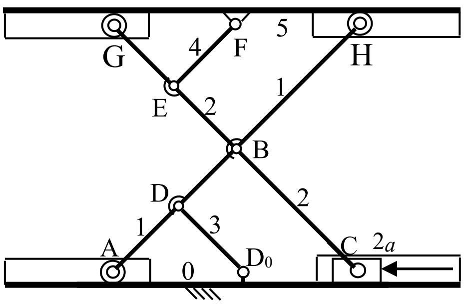

Fig. 8. Kinematic scheme of the complex mechanism

The construction diagram (fig. 7) also shows the screw actuator, which is driven by a toothed belt transmission, on the lower right.
Check the mobility of this flat mechanism (fig. 8) equipped with four upper roller-type couplings in the guide, two of which are at the base (A and C) and two at the top (G and H).
Mobility M_b of the lifting mechanism (fig. 8) is calculated with the formula:

$$M_b = 3n - 2C_5 - C_4 \tag{1}$$

where the following notations were used:

$n = 5$ elements (noted on the diagram, fig. 8), 1 skate and 3 rollers with centers in A,G,H;
$C_5 = 9$ kinematic rotation couplings (planar joints);
$C_4 = 3$ planar rototranslation kinematic couplings (the 3 rollers in the respective guides).

Substituting these numbers in formula (1) yields:

$$M_b = 3 \cdot 9 - 2 \cdot 10 - 3 = 4 \tag{2}$$

Note that 3 mobilities are the independent rotations of the rollers in A, G and H in the horizontal guides, and the 4th mobility corresponds to the independent movement of the motor element 2a. This leading element can be represented by a patina in joint C (fig. 8).
As an actuator in the analyzed elevator (fig. 8) a screw 1a can be used which screws into the plate 2a and rotates in a transverse bearing C0 (fig. 9).

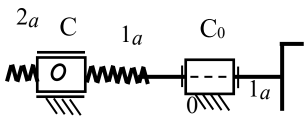

Fig. 9. Kinematic diagram of the screw actuator

If this screw actuator (fig. 9) is included in the kinematic diagram of the X-joint elevator (fig. 8), the mechanism is no longer planar, since the lead screw 1a rotates in another plane, to move the slide-nut 2_a on its horizontal axis.
In the elevating mechanism with skid actuator (fig. 8), the calculation of mobility can also be done with the formula:

$$M_b = \sum_{m=1}^{5} m C_m - \sum_{r=2}^{6} r N_r \tag{3}$$

The meaning of the notations in formula (3) is:

m - the mobility of a kinematic couple, like this (fig. 8), for *m=1,* C_1=10 and for *m=2,* C_2=3;
r - the rank of the space adjacent to an independent closed kinematic contour, thus (fig. 8) *r=3* and N_3=4;

With these data, from formula (3) it follows:

$$M_b = (1 \cdot 10 + 2 \cdot 3) - 3 \cdot 4 = 4 \tag{4}$$

The 4 mobilities correspond to the independent rotations of the rollers in the three horizontal guides (A, G, H), and the fourth mobility is the actuation of the elevator (not shown on the kinematic diagram). If in the joint in C (replacing skid 2_a) is assembled the screw actuator (fig. 9), the mobility of this mechanism is deduced from formula (3):

$$M_b = 1 \cdot 3 - 2 \cdot 1 = 1 \tag{5}$$

Thus, the mobility of the elevator in complex X (fig. 10), obtained by assembling the screw actuator (fig. 9) to the mechanism of the elevator in X (fig. 8) is calculated with formula (3):

$$M_b = (1 \cdot 12 + 2 \cdot 3) - (3 \cdot 4 + 2 \cdot 1) = 4 \tag{6}$$

The result obtained in (6), of the 4 mobilities, 3 mobilities are of the 3 rollers with centers in A, G, H, and the fourth mobility corresponds to the rotation of screw 1a (fig. 9), provided with a crank.

3. Topological structure of the complex X-bar elevator mechanism

The structural - topological formula of the motor mechanism articulated plane (fig. 8) has the expression:

$$MM = MF(0,2_a) + LTr(2,1,3) + LTr(4,5) \tag{7}$$

In the structural formula (7) it was noted with - the Motor Mechanism (with the specified driving element), for example the skate 2a from the joint C (fig. 8) in translational movement in the horizontal guide.

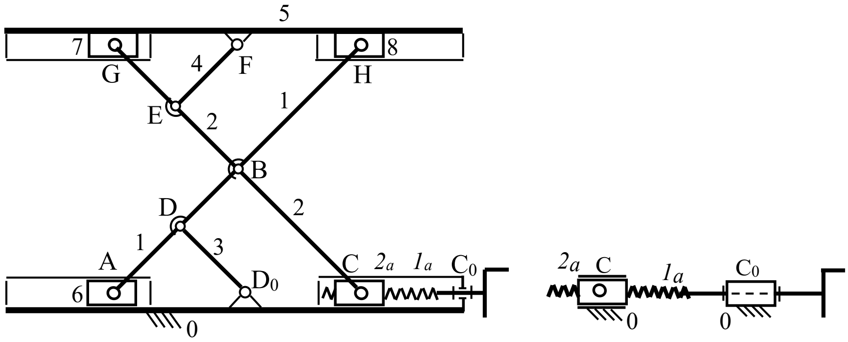

Fig. 10. Kinematic diagram of the complex elevator with screw actuator (2 variants)

This skid 2_a which translates (under the action of a driving force) is defined as *MF,* i.e. Fundamental Mechanism.
To this *MF(0,2$_a$)* is added the first triadic kinematic chain *LTr(2,1,3),* which consists of bars 2(BC), 1(AB), 3(DD_0) and the roller in joint A (fig. 8), roller equivalent to a translation skid 6 (fig. 10), representing the 4th kinematic element of the triad.
The last triadic kinematic chain is *LTr(4,5)* together with the 2 rollers in the joints G and H, which can be replaced by two skids(7 and 8) horizontally guided (fig. 10, 11).

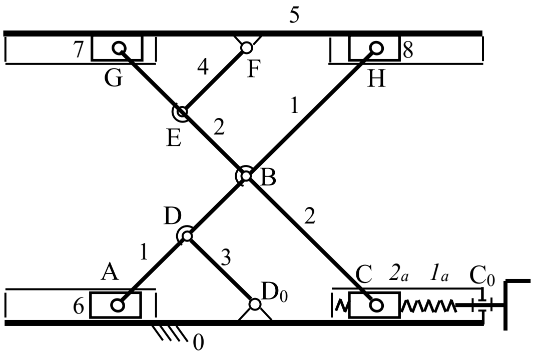

Fig. 11. Kinematic diagram of X elevator with screw actuator

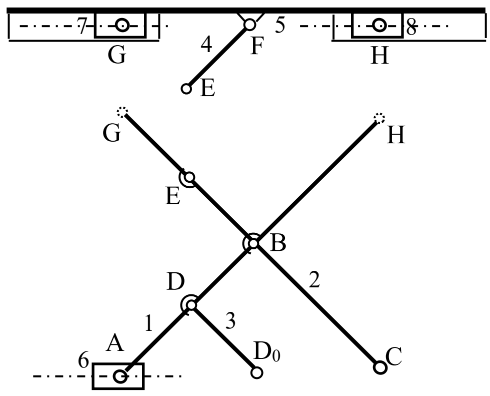

Fig. 12. Isolated triad chains

In this case (fig. 11), the two triad-type kinematic chains are represented explicitly, with the central element 1 and 5 respectively (fig. 12): triad LTr(1,2,3,6) with a translational couple (6,0) and triad LTr(4,5,7,8) with two translational couples (5,7) and (5,8).
Analyzing the kinematic diagram of the complex elevator (fig. 8, 10, 11), the geometric conditions can be observed: AB=BC=2DD_0 (for the first triad) and BG=BH=2EF (for the second triad).
It should be noted that both triadic chains (fig. 12) are simple triads, having in their structure 4 kinematic elements and 6 monomobile kinematic couples.

4. Static calculation of the elevator mechanism with complex structure

The static calculation is performed in two stages, at the level of the two triad-type kinematic or kinetostatic chains, a structure that is statically determined (fig. 12).

4.1. Static calculation of the triad Tr (4,5,7,8)

The resisting force is imposed by two equal components F_r which acts on the bar 5, in two points M and N symmetrical to the joint F which is the middle of the bar 5 (fig. 13).

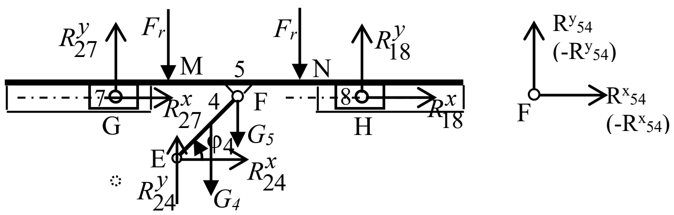

Fig. 13. The triadic chain LTr(4,5,7,8) as a statically determined structure

The reactions in the three outer joints (semicouples) E, G, H of the triad (fig. 13) are introduced (figured) through the two components of the respective reaction (on the x and y axes).
In the inner joint F (active couple) both components (positive and negative) are shown on the right side of figure 13.
Reactions from translational couples (5,7) and (5,8) are listed in G and H, in vertical direction (perpendicular to bar 5): $R^y_{57}(-R^y_{37})$, $R^y_{58}(-R^y_{58})$.
For a kinematic element in the plane, 3 balance equations can be written, so for the 4 component elements of the triad, 12 static balance equations are deduced.
Consider the force of gravity G_4 of bar 4 acting at its middle and the weight force G5 of the bar 5 placed in the joint F (fig. 13). The weight of skids 6, 7 and 8 is neglected.
With these specifications, the static balance equations (two projection equations and one moment equation) of the four kinematic elements 4,5,7,8 can be written (fig. 13):

$$\text{(el. 4)}\quad \begin{aligned} & R^x_{24} + R^x_{54} = 0 \\ & R^y_{24} + R^y_{54} - G_4 = 0 \\ & R^x_{24} \cdot l_4 \cdot \sin\varphi_4 - R^y_{24} \cdot l_4 \cdot \cos\varphi_4 + G_4 \cdot 0{,}5 l_4 \cos\varphi_4 = 0 \end{aligned} \tag{8}$$

It should be noted that the angle is formed by bar 4 with the horizontal from point E (fig. 13).

$$\text{(el. 5)}\quad \begin{aligned} & -R^x_{54} = 0 \\ & -R^y_{54} + R_{75} + R_{85} = G_5 + 2F_r \\ & R_{75} \cdot GH - (R^y_{54} + G_5) \cdot FH - F_r \cdot (MH + NH) = 0 \end{aligned} \tag{9}$$

$$\text{(el. 7)}\quad \begin{aligned} & R^x_{27} = 0 \\ & R^y_{27} - R_{75} = 0 \\ & (R^y_{27} - R_{75}) \cdot 0 = 0 \end{aligned} \tag{10}$$

$$\text{(el. 8)}\quad \begin{aligned} & R^x_{18} = 0 \\ & R^y_{18} - R_{85} = 0 \\ & (R^y_{18} - R_{85}) \cdot 0 = 0 \end{aligned} \tag{11}$$

From the sets of equations (9), (10), (11) the null horizontal components are obviously deduced.

4.2. Static calculation of the triad Tr (1,2,3,6)

The kinematic scheme of the triad is considered, Tr (1,2,3,6), loaded with the external forces known as the weight forces of bars 1, 2, 3 and the skate 6 (fig. 14).
For the static balance of the triadic chain the reactions from joints G and H are introduced, through which bars 1 and 2 take over the forces F_r from platform 5 (fig. 13). In the joint D_0 the two components of the reaction of base 0 against bar 3 are introduced (fig. 14).

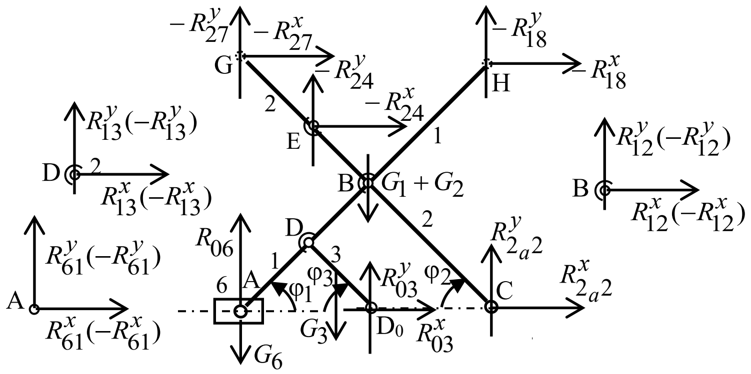

Fig. 14. The triadic chain LTr(1,2,3,6) as a statically determined structure

Also, in point A, the reaction is shown R_{06} of base 0 versus skid 6, and in joint C, the two components of the reaction of the motor skid 2_a against bar 2 are introduced.
For the three internal (active) joints in A, B and D (fig. 14) the reaction from the respective kinematic couple is represented by the positive and negative *x* and *y* components.
With these clarifications, regarding the known external and internal forces (unknown reactions), acting on each component kinematic element (fig. 14), the static balance equations can be written as follows:

$$\text{(el. 1)}\quad \begin{aligned} & R_{61}^{x} - R_{13}^{x} - R_{12}^{x} - R_{18}^{x} = 0 \\ & R_{61}^{y} - R_{13}^{y} - R_{12}^{y} - R_{18}^{y} - G_1 = 0 \\ & -R_{13}^{x} \cdot AD \cdot \sin\varphi_1 - R_{12}^{x} \cdot AB \cdot \sin\varphi_1 - R_{18}^{x} \cdot AH \cdot \sin\varphi_1 + G_1 \cdot AB \cdot \cos\varphi_1 = 0 \end{aligned} \qquad (12)$$

$$\text{(el. 2)}\quad \begin{aligned} & R_{2_a2}^{x} + R_{12}^{x} - R_{24}^{x} - R_{27}^{x} = 0 \\ & R_{2_a2}^{y} + R_{12}^{y} - R_{24}^{y} - R_{27}^{y} - G_2 = 0 \\ & R_{12}^{x} \cdot BC \cdot \sin\varphi_2 - R_{24}^{x} \cdot CE \cdot \sin\varphi_2 - R_{27}^{x} \cdot CG \cdot \sin\varphi_2 - G_2 \cdot BC \cdot \cos\varphi_2 = 0 \end{aligned} \qquad (13)$$

It should be noted that $\varphi_1 = \varphi_2 = \varphi_3 = \varphi_4$, geometry of the elevator in X (fig. 14) highlighting the symmetrical position of bars 1 and 2, and bar 3 is parallel to bar 2 and bar 4 is parallel to bar 1.

$$\text{(el. 3)}\quad \begin{aligned} & R_{03}^{x} + R_{13}^{x} = 0 \\ & R_{03}^{y} + R_{13}^{y} - G_3 = 0 \\ & R_{13}^{x} \cdot DD_0 \cdot \sin\varphi_3 + R_{13}^{y} \cdot DD_0 \cdot \cos\varphi_3 - G_3 \cdot 0{,}5 \cdot DD_0 \cdot \cos\varphi_3 = 0 \end{aligned} \qquad (14)$$

$$\text{(el. 6)}\quad \begin{aligned} & -R_{61}^{x} = 0 \\ & R_{06} - R_{61}^{y} - G_6 = 0 \\ & (R_{06} - R_{61}^{y}) \cdot 0 - G_6 \cdot 0 = 0 \end{aligned} \qquad (15)$$

Observing the last set of three equations (15), from the balance of element 6 it follows

$R_{61}^{x} = 0$ and $R_{06} - R_{61}^{y} = G_6$

5. Conclusions

The first part of the work highlights the X-bar elevators, some of which are placed on wheeled carts, manually operated or automatically programmed as mobile robots.
Most elevators in X have articulated scissor bars with one or more levels so that the work platform can rise to greater heights.
For relatively low heights there are elevators in X where the bars are not articulated and are manually operated with screw actuators.
All elevators with articulated X bars have a simple dyad-type structure, made of two scissor-type mechanisms, functioning in parallel as an articulated spatial system.
The second part of this scientific paper presents the kinematic diagram of an X-articulated plane elevator with a complex triad type structure.
The mobility of the elevator mechanism with articulated bars in X is checked and the method of actuation through a mechanical screw actuator is analyzed.
Two complex kinematic chains of simple triad type (four component elements and four rotational or translational couples) were identified.
The paper ends with a static analysis of the two statically determined chains, which was achieved by writing the equilibrium equations for each of the four component elements.
Thus, for each triadic chain, a system of 12 scalar equations with 12 unknowns represented by the components of the reactions in the joints or translational couplings was written.

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