STRUCTURAL ANALYSIS, GEOMETRY AND STATICS OF A COACH UNFOLDING MECHANISM

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Abstract: *Starting from the constructive scheme of the mechanism, the kinematic scheme is drawn in three distinct positions (folded, middle and unfolded). By means of this scheme the mobility of the mechanism is calculated and the structural-topological formula of it is obtained. In the last section of the paper an algorithm of geometric calculus has been elaborated, starting from a kinematic link articulated to the base, element which is considered the driving component.*

Keywords: coach unfolding mechanism, kinematic scheme, mobility, static calculation.

1. General Aspects

A constructive scheme of a coach unfolding mechanism has been considered [3]. This scheme is in three distinct positions: folded when the coach is used as a coach (fig. 1.1) and unfolded when the coach becomes a bed (fig. 1.2).

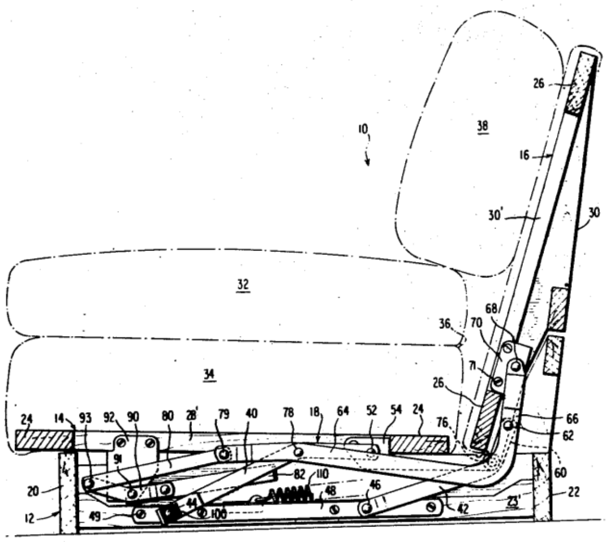

Fig. 1.1. Constructive scheme of the coach mechanism in folded position [3]

According to the constructive scheme of the coach mechanism in folded position (fig. 1.1) a curved shape of some kinematic elements configured as articulated bars, has been remarked.

Two kinematic components as bars of the mechanism are articulated to the base (fixed element) which is represented by the rigid rectangular frame of the coach (fig. 1.2).

In the unfolded position with maximum extension (fig. 1.2) the mechanism is totally as one piece, since the contact with the floor of the last element of the kinematic chain is made. In order to facilitate the manual actuating of the mechanism from unfolded to folded position, a tensioned spring force is used.

Specifically to this unfolded position are two kinematic components of the mechanism that are articulated each other and end up into a lineated position one from the other in the horizontal position of the coach as bed (fig. 1.2).

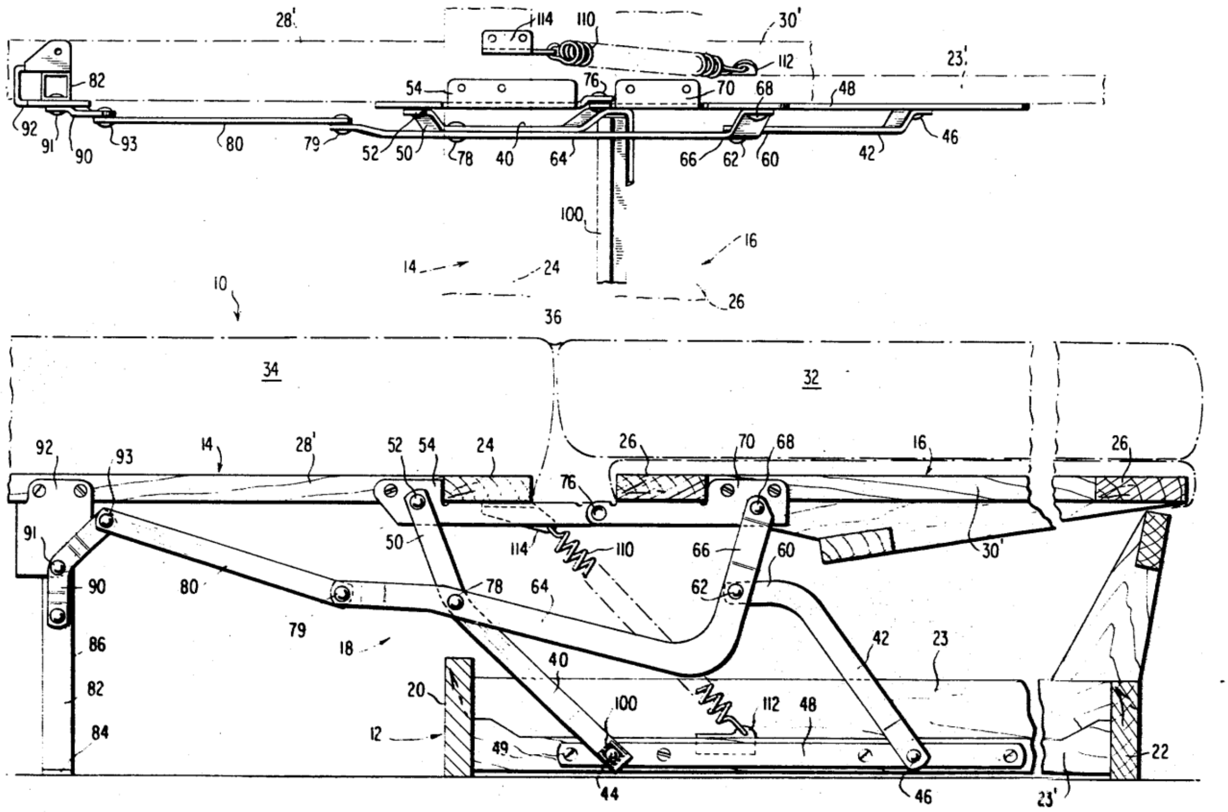

Fig. 1.2. Constructive scheme of the coach mechanism in unfolded position (maximum extension) for reconfiguring (transforming) into bed [3]

The two mattresses are one over the other in the folded position of the coach (fig. 1.1) but in the unfolded position the upper mattress is rotated in the vertical plane and ends up in a lineated position in respect to the lower mattress (fig. 1.2).

2. Topological and geometric structure of the reconfigurable mechanism

Starting from the constructive scheme of the coach mechanism in middle position (fig. 1.2) the kinematic scheme (fig. 2.1), in which the kinematic elements and joints are symbolically represented, has been drawn.

The kinematic elements are numbered by Arab figures (0, 1, 2, ..., 7) and the kinematic joints are marked by Latin capital letters (*A*, *B*, *C*, ..., *M*, *N*).

Since some kinematic elements (2, 3) are depicted as curved bars (fig. 1.3), these are represented in the kinematic scheme (fig. 2.1) as continuous straight lines and dashed lines too.

The mobility of the planar mechanism with jointed bars has been calculated by the formula [1]:

$$M = 3n - 2C_5 - C_4 \qquad (2.1)$$

In formula (2.1) the following parameter values have been used (fig. 2.1): $n = 7; C_5 = 10; C_4 = 0$.

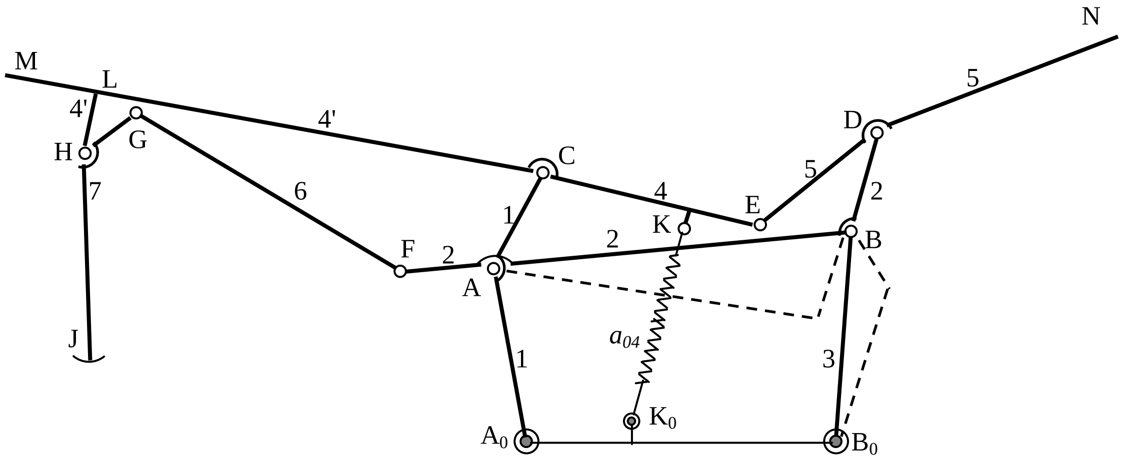

Fig. 2.1. Kinematic scheme of the coach reconfigurable mechanism in bed-coach configuration (middle position)

The outcome after the calculation by formula (2.1) is:

$$M = 3 \times 7 - 2 \times 10 - 0 = 1 \qquad (2.2)$$

Considering the bar 1 as driving element (actuator) articulated to the base, the structural-topological formula of the “motor” mechanism is [1]:

$$MM = MA(0,1) + LD(2,3) + LD(4,5) + LD(6,7) \qquad (2.3)$$

In reality the driving element is bar 4 through point *M* where the actuating force of the user for folding and unfolding the mechanism is applied. The folded position of the coach is represented in fig. 2.2.

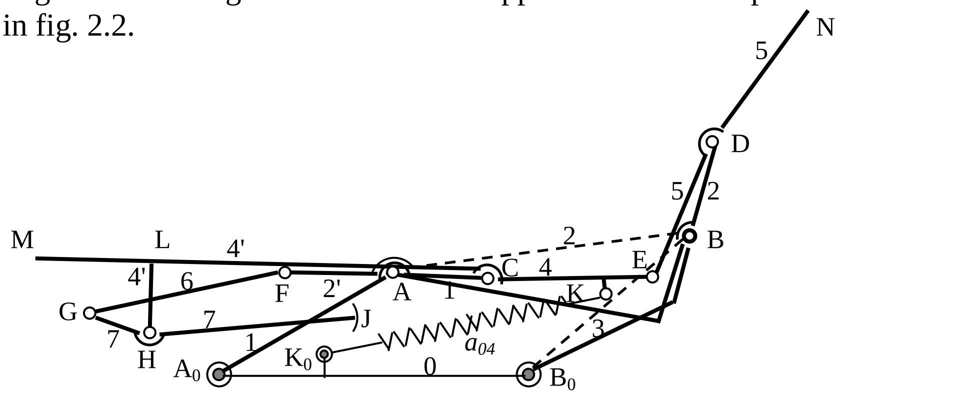

Fig. 2.2. Kinematic scheme of the coach mechanism in folded configuration

In the unfolded position of the coach the point *J* (end of bar 7) touches the floor while on the bar 4 is acting, as resistance force, the helical spring tension a_{04} which links the mobile point *K* of the bar 4 to the fixed point K_0 (fig. 2.3).

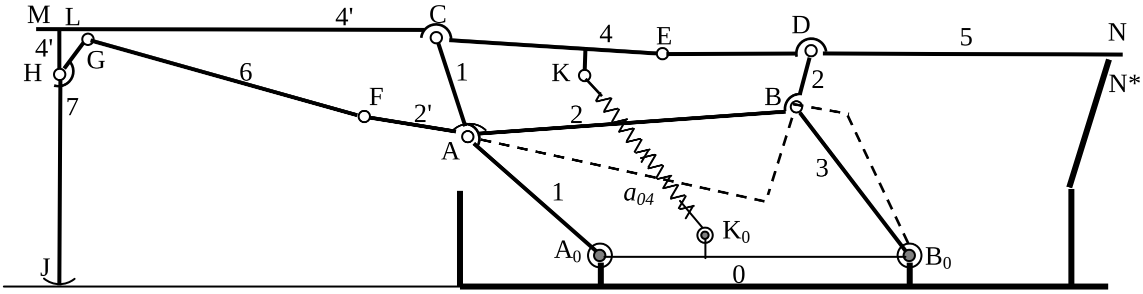

Fig. 2.3. Kinematic scheme of the coach mechanism in unfolded position (bed configuration)

In the unfolded position the end of the bar 5, represented by point *N*, props on the end *N** of the bed-coach base (fig. 2.3).

3. Kinematic geometry of the coach reconfigurable mechanism

By means of these geometric parameters the angular positions of all kinematic elements of the mechanism, in one instantaneous random position, can be calculated (fig. 3.1).

A 4-bar contour A_0ABB_0 (fig. 3.1) with oriented sides (according to the sketched angles) has been considered, and for which the following vector equation has been written [1, 2]:

$$\overrightarrow{A_0A} + \overrightarrow{AB} - \overrightarrow{B_0B} - \overrightarrow{A_0B_0} = 0 \tag{3.1}$$

If the position of the bar 1 is imposed by φ_1 angle, the vector equation (3.1) becomes:

$$\overrightarrow{AB} - \overrightarrow{B_0B} = \overrightarrow{A_0B_0} - \overrightarrow{A_0A} \text{ or } \vec{l}_2 - \vec{l}_3 = \vec{l}_0 - \vec{l}_1 \tag{3.2}$$

In this form the vector equation (3.2) is equivalent with two scalar equations:

$$l_2 \cdot \cos\varphi_2 - l_3 \cdot \cos\varphi_3 = l_0 - l_1 \cdot \cos\varphi_1; \tag{3.3}$$

$$l_2 \cdot \sin\varphi_2 - l_3 \cdot \sin\varphi_3 = -l_1 \cdot \sin\varphi_1. \tag{3.4}$$

By means of these equations the values of the angles φ_2 and φ_3 can be calculated (as <90° angles).

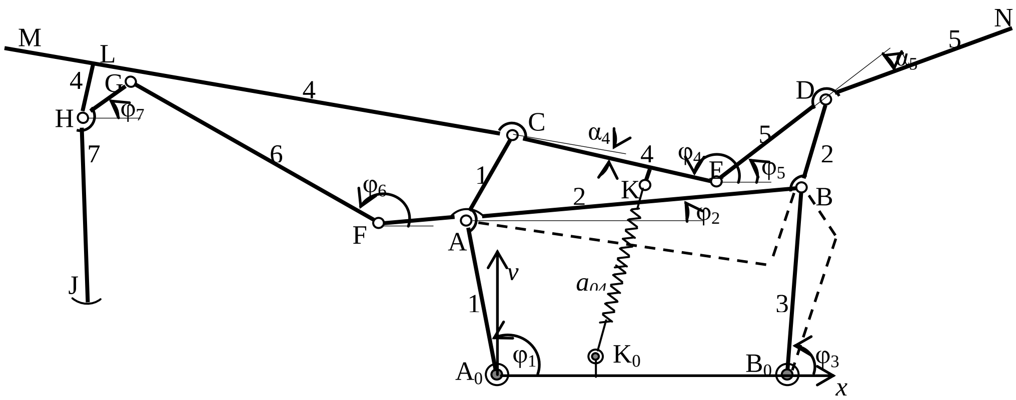

Fig. 3.1. Kinematic scheme showing the positioned components

In this phase the coordinates of the points *C* and *D* have been calculated (fig. 3.1):

$$x_C = l_1'' \cdot \cos(\alpha_1 + \varphi_1);\ y_C = l_1'' \cdot \sin(\alpha_1 + \varphi_1); \qquad (3.5)$$

$$x_D = l_3'' \cdot \cos(\alpha_3 + \varphi_3);\ y_D = l_3'' \cdot \sin(\alpha_3 + \varphi_3); \qquad (3.6)$$

By means of *CDE* triangle the φ_4 and φ_5 angles have been calculated:

$$l_4 \cdot \cos\varphi_4 - l_5 \cdot \cos\varphi_5 = x_C - x_D; \qquad (3.7)$$

$$l_4 \cdot \sin\varphi_4 - l_5 \cdot \sin\varphi_5 = y_C - y_D. \qquad (3.8)$$

In the next phase the analytical relations of the articulations *F* and *H* are (fig. 3.1):

$$x_F = x_A + l_2''' \cdot \cos\varphi_2;\ y_F = y_A + l_2''' \cdot \sin\varphi_2; \qquad (3.9)$$

$$x_H = x_C + l_{4'}' \cdot \cos(\alpha_4 + \varphi_4);\ y_H = y_C + l_{4'}' \cdot \sin(\alpha_4 + \varphi_4); \qquad (3.10)$$

The angles φ_6 and φ_7 can be calculated by means of *HGC* triangle (fig. 3.1):

$$l_6 \cdot \cos\varphi_6 - l_7 \cdot \cos\varphi_7 = x_H - x_F; \qquad (3.11)$$

$$l_6 \cdot \sin\varphi_6 - l_7 \cdot \sin\varphi_7 = y_H - y_F. \qquad (3.12)$$

The Cartesian coordinates of the point *J* have the following aspects (fig. 3.1):

$$x_J = x_H - l_7'' \cdot \cos(\alpha_7 - \varphi_7);\ y_J = y_H - l_7'' \cdot \sin(\alpha_7 - \varphi_7) \qquad (3.13)$$

For the points *M* and *N* the Cartesian coordinates have been deduced (fig. 3.1):

$$x_M = x_C + MC \cdot \cos(\alpha_4 + \varphi_4);\ y_M = y_C + MC \cdot \sin(\alpha_4 + \varphi_4); \qquad (3.14)$$

$$x_N = x_D + DN \cdot \cos(\varphi_5 - \alpha_5);\ y_N = y_D + DN \cdot \sin(\varphi_5 - \alpha_5). \qquad (3.15)$$

4. Static calculus of the coach mechanism in unfolded position

A kinematic scheme of the coach mechanism in unfolded position (fig. 2.3, 4.1), in which the point *J* reaches the floor forming a superior kinematic joint, is considered.

The mobility of the mechanism in this extreme position (fig. 4.1) has been calculated by formula [1]:

$$M = 3n - 2C_5 - C_4 \qquad (4.1)$$

By analyzing the kinematic scheme in this particular position (fig. 4.1), the following structure parameters have been identified: $n = 7;\ C_5 = 10;\ C_4 = 1$

By means of formula (4.1) results:

$$M = 3 \times 7 - 2 \times 10 - 1 = 0 \qquad (4.2)$$

In this extreme position, in which the bars 4 and 5 are horizontal, the planar articulated mechanism becomes rigid, being a determined static planar system.

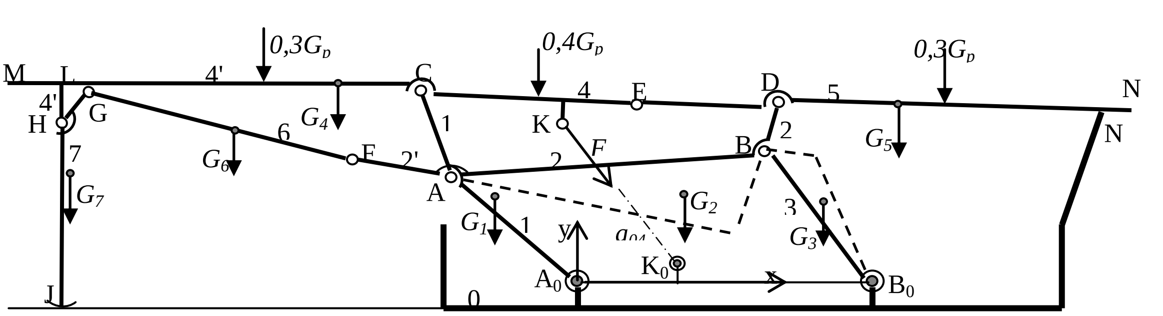

Fig. 4.1. Kinematic scheme of the coach mechanism in extreme unfolded position

The exterior forces that act on this rigid kinematic chain are three: the elastic force F_r of the helical spring a_{04} (applied in the point K), the gravity force G_p of the person lying horizontally on the mattress (which lies on the bars 4 and 5) and the gravity force G_i of each bar.

In this planar kinematic chain structure (with complex make-up) there were not been identified any determined static simple kinematic chains [1] of type dyadic, triadic, tetradic, etc. Further, each kinematic element has been isolated, introducing in each joint two components of the reaction force corresponding to coordinate axes (fig. 4.2).

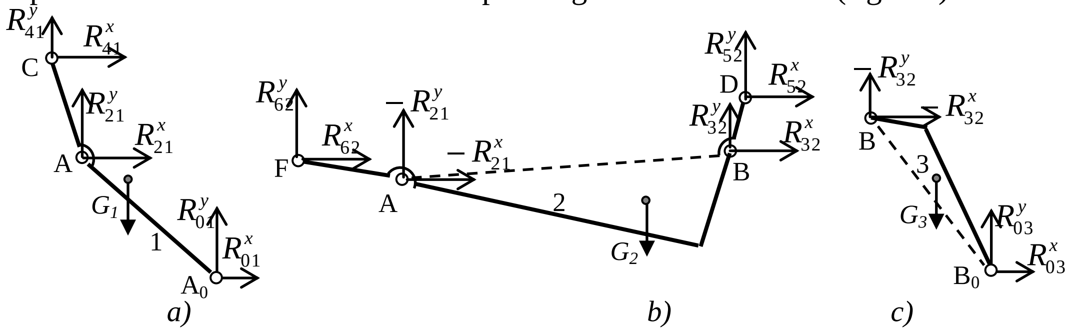

Fig. 4.2. Static balance of the bars 1, 2 and 3

Regarding the gravity force G_p (applied in three points) numerical values within 100 daN and 200 daN have been considered.

5. Conclusions

The coach reconfigurable mechanisms are, in most cases, planar linkages. Taking in consideration the width of coaches, these mechanisms are designed as double spatial structures operating in parallel planes. From the study of constructive solutions, presented in various patent documents, the kinematic structures are consisting of many articulated bars in complex geometric configurations.

These mechanisms can be compared with the planar manipulators having staged kinematic chains and being manually actuated by the last element. In the paper a constructive scheme of a planar manipulator-mechanism has been considered. The mobility of it has been deduced by calculation, the outcome being equal by one.

Starting from a certain element considered the driving component, an algorithm of angular displacement calculus of the kinematic elements, by using the analytical method of vector contours, has been presented. The paper ends with a calculus of the reaction forces applied in articulations according to two outer forces (the gravity force of the person which lies on the unfolded coach and the resistance force of a helical spring).

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