THE STRUCTURE AND SIMULATION OF THE RETRACTABLE CAR HARDTOP MECHANISM

Ph.D. Eng. Ovidiu ANTONESCU, Politehnica University of Bucharest,
oval33@hotmail.com
Ph.D. Eng. Ioana POPESCU, Iuliu Maniu Highschool of Bucharest,
ioana.popescu@yahoo.com
Eng. Daniela ANTONESCU, Iuliu Maniu Highschool of Bucharest,
daniela_mihalache@yahoo.com

Abstract: *The paper presents two kinematic schemes of the mechanisms of retractable car hardtops. Each hardtop is divided into three parts (segments), which overlap in the area provided by the car boot. The mechanisms consist of articulated bars, mounted in two parallel planes. Both kinematic schemes have been built by using dyadic type kinematic chains, assembled in a specific order. The first kinematic scheme is driven by a pneumatic actuator mounted on the middle segment, while the extreme segments move and overlap with the middle segment. The second kinematic scheme is electrically driven from the bottom by means of an articulated parallelogram.*

Keywords: retractable hardtop, kinematic scheme, articulated mechanism, pneumatic actuator, kinematic simulation.

1. The kinematic scheme of the plane articulated mechanism with an oscillating cylinder

Let us consider a car hardtop [5, 6] divided into three parts P_1, P_2 and P_3, where the P_2 segment is in the middle (fig. 1). An oscillating cylinder is mounted on this P_2 segment.

From here, motion is transmitted to the P_1 segment (to the left) and to the P_3 segment (to the right). Thus, the P_2 segment is a fixed reference element (fig. 2).

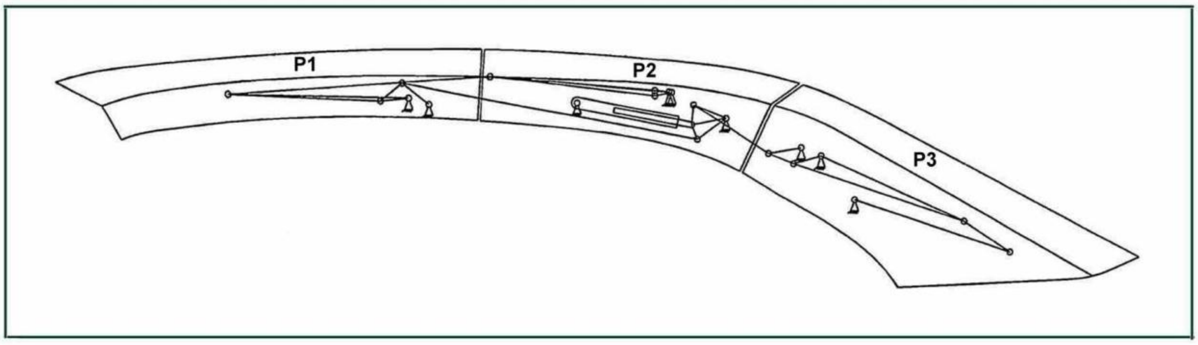


Fig.1. The retractable car hardtop with three rigid segments P_1, P_2 and P_3

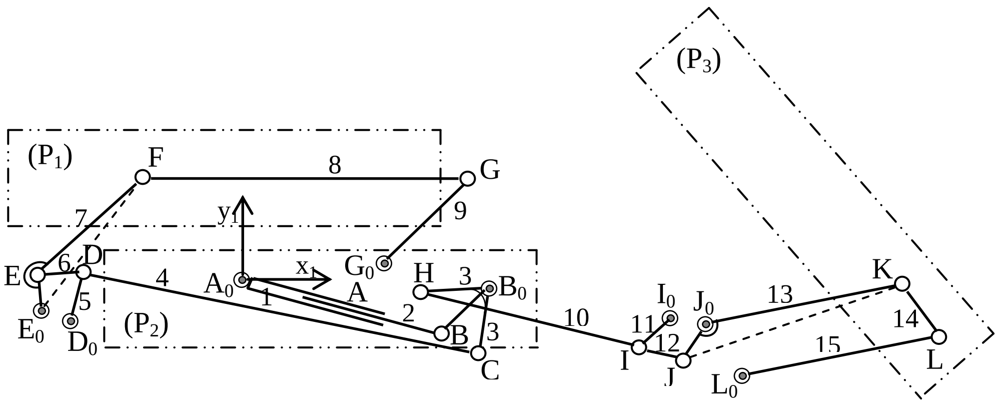


Fig.2. The kinematic scheme [1] of the plane mechanism provided with an actuator cylinder [7]

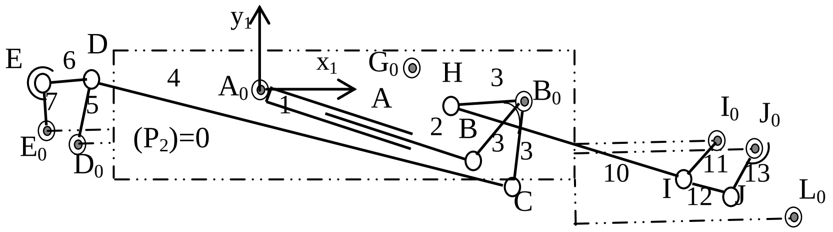


Fig.3. P_2 segment as fixed element and the position of the fixed articulations

The following fixed articulations are situated in the P_2 segment plane (fig.3): A_0 (of the oscillating cylinder 1), B_0 (of the equalizing bar 3), G_0 (of the equalizing bar 9), D_0 (of the equalizing bar 5), E_0 (of the equalizing bar 6), I_0 (of the equalizing bar 11), J_0 (of the equalizing bar 13), L_0 (of the equalizing bar 15).

Thus, the other fixed articulations (situated in the P_2 segment plane) are positioned as to the fixed articulation A_0 (fig. 2) by means of the following Cartesian coordinates:

$x_{B_0} = -47{,}5mm;\ y_{B_0} = -5mm;\ x_{D_0} = -47mm;\ y_{D_0} = -2mm;$

$x_{E_0} = -54{,}5mm;\ y_{E_0} = -0{,}0mm;\ x_{G_0} = 27{,}5mm;\ y_{G_0} = 8mm;$

$s_{I_0} = 72{,}5mm;\ y_{I_0} = -14mm;\ x_{J_0} = 79mm;\ y_{J_0} = -16mm;$

$x_{L_0} = 91mm;\ y_{L_0} = -30{,}5mm;$

The values of the constant lengths of the articulated bars are (fig. 2 and 3):

$BB_0 = CB_0 = HB_0 = l_3 = 11{,}5mm;\ BC = l'_3 = 5mm;\ BH = l''_3 = 6{,}5mm:$

$CD = l_4 = 97mm;\ DD_0 = l_5 = 11mm;$

$DE = l_6 = 9mm;\ EE_0 = l_7 = 9{,}5mm;\ E_0F = l''_7 = 60{,}5mm;$

$EF = l'_7 = 51{,}5mm;\ FG = l_8 = 85mm;$

$GG_0 = l_9 = 56mm;\ HI = l_{10} = 28{,}5mm;$

$II_0 = l_{11} = 11mm;\ IJ = l_{12} = 9mm;$

$JJ_0 = l_{13} = 9{,}5mm;\ J_0K = l'_{13} = 50mm;\ JK = l''_{13} = 48mm;$

$KL = l_{14} = 18mm;\ LL_0 = l_{15} = 53mm;$

The variable length corresponds to the move of rod 2 in piston 1 (fig. 2 and 3):

$A_0B = 40 - 55mm.$

The mobility of the plane articulated mechanism (fig. 2) can be determined with the formula [1, 8, 9, 10]:

$$M_3 = 3n - 2C_5 - C_4 \qquad (1)$$

In formula (1) we identify the kinematic scheme mechanism (fig. 2):

$n = 15$ mobile kinematic elements;

$C_5 = 22$ mono-mobile kinematic couplings (class 5);

$C_4 = 0$ bi-mobile kinematic couplings (class 4);

When replacing these numerical values in formula (1), we obtain:

$$M_3 = 3 \times 15 - 2 \times 22 - 0 = 1 \qquad (2)$$

By using compressed air in cylinder 1, rod 2 moves linearly in the cylinder, rotating the equalizing bar 3 against the fixed articulation B_0.

From bar 3 via the C and H articulations, motion is transmitted to bars 4 and 10 towards bars 9 and 15, as actuated kinematic elements located at the ends of the corresponding dyadic chains. It should be noticed that bars 8 and 14 (fig. 2) are made rigid by the P_1 and P_3 segments of the car hardtop. The following structural formula shows the univocal motion transmission [1]:

$$MM = MA(0,1) + LD(2,3) + LD(4,5) + LD(6,7) + LD(8,9) + LD(10,11) + LD(12,13) + LD(14,15) \qquad (3)$$

By means of an Inventor program [2, 3, 4], we obtained the simulation of the analysed mechanism in three different positions (fig. 4, fig. 5).

a *b*

Fig.4. Mechanism simulation in the initial position (a) and in the intermediary position (b)

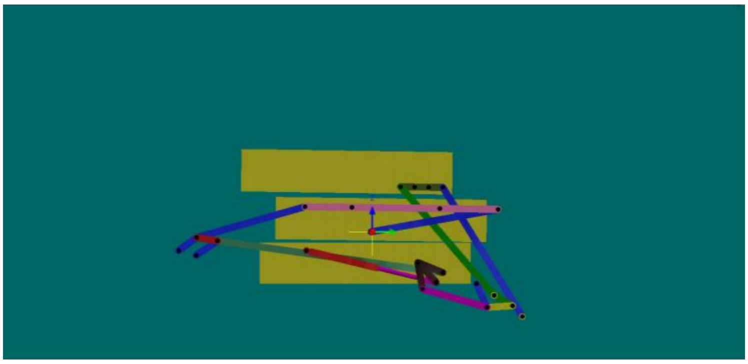


Fig. 5. Mechanism simulation in the folded position

At the end of the first simulation stage (fig. 5), the three segments of the hardtop overlap in the order P_3, P_1 and P_2 from top to bottom.

In the second stage, the P_2 segment (with the P_1 and P_3 segments on top), moves within the boot area by means of the paralellogram mechanism $A_0^*A^*B^*B_0^*$ (fig. 6).

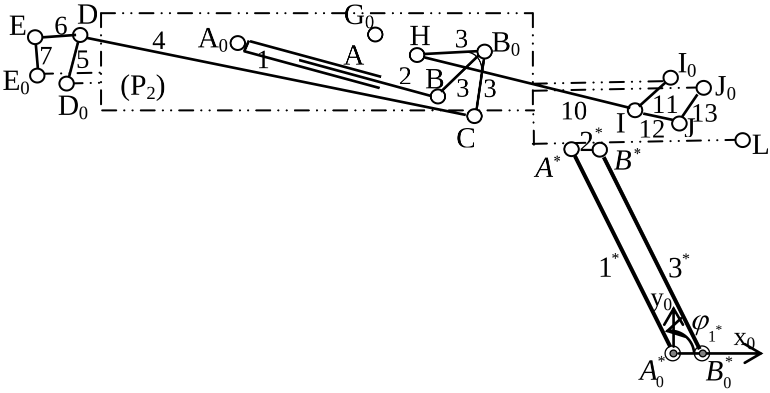


Fig.6. Kinematic scheme [1] of the parallelogram mechanism used for actuating the three overlapped segments

The mobility of the parallelogram mechanism is activated only after piston 2 has been blocked in cylinder 1 (fig. 6). The characteristic sizes of the articulated parallelogram $(01^*2^*3^*)$ are (fig. 6): $A_0^*B_0^* = A^*B^* = 6{,}5mm;\ A_0^*A^* = B_0^*B^* = 95mm.$

In the initial position (fig. 6), the lean angle of bar 1^* has the maximum value $\varphi_{1^*} = 125^0$, while, in the final position, it reaches the minimum value $\varphi_{1^*} = 0^0$.

2. The kinematic scheme of the retractable mechanism of the 3-segment hardtop

Let us consider the kinematic scheme of the plane articulated mechanism of a retractable hardtop [11, 12] with three segments (fig. 8). Bar 2 has, left of point A, four articulations D, F, I and L, and, left of point B, three articulations T, R and U.

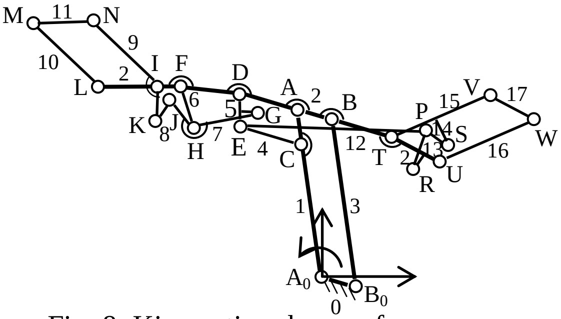


Fig. 8. Kinematic scheme of the retractable mechanism [13]

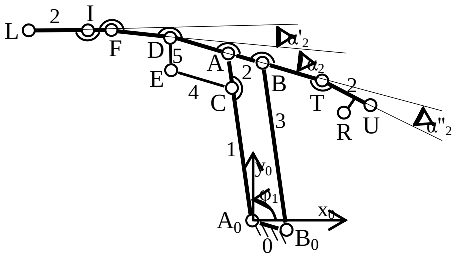


Fig. 9. Kinematic scheme of the first 2 closed contours [1]

The structure of the plane articulated mechanism includes an articulated parallelogram A_0ABB_0. On bar 2 (reciprocating rod), dyadic kinematic chains have been mounted, to the left and to the right, in a specific order (fig. 8).

The mechanism mobility can be determined by means of the formula:

$$M_3 = 3n - 2C_5 - C_4 \qquad (4)$$

where the following notations have been used (fig. 8):

$n = 17$ kinematic elements (articulated rods numbered from 1 to 17);

$C_5 = 25$ 5-class kinematic couplings (mono-mobile plane rotations), of which two articulations are fixed (A_0 and B_0) and the other 23 are mobile;

$C_4 = 0$ class-4 kinematic couplings (plane roto-translations).

By replacing this numerical data in formula (4) we obtain

$$M_3 = 3\times 17 - 2\times 25 - 0 = 1 \tag{5}$$

In terms of actuator for the analysed mechanism (fig. 8) we can use bar 1 or bar 3. Checking the kinematic scheme (fig. 8), we obtain the structural – topological equation [1] necessary for the composition of the motor mechanism with the actuator mechanism $MA(0,1)$ and the dyadic kinematic chains LD:

$$\begin{aligned} MM = MA(0,1) + LD(2,3) + LD(4,5) + LD(6,7) + LD(8,9) + LD(10,11) + \\ + LD(12,13) + LD(14,15) + LD(16,7) \end{aligned} \tag{6}$$

Let us consider the system of Cartesian axes centred in the fixed articulation A_0 and measure the coordinates of point B_0: $x_{B_0} = 7mm;\ y_{B_0} = -3mm;$ The characteristic lengths of the bars are (fig. 9): $A_0A = B_0B = l_1 = 49mm;\ A_0B_0 = AB = l_2 = 7{,}5mm;$

We should notice that the shape of bar 2 is a polygonal contour with the edges in F, D and T (fig. 9). The three angles are: $\alpha_2 = 15^0,\ \alpha_2' = 10^0,\ \alpha_2'' = 15^0.$

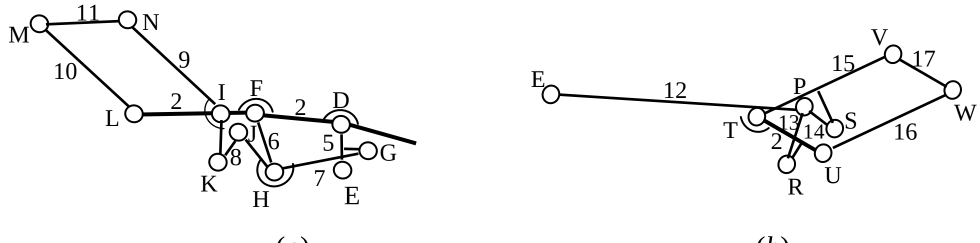
The characteristic lengths of the segments along the polygonal contour are (fig. 9):

$AD = l_2' = 10mm;\ DF = l_2'' = 22mm;\ FI = l_2''' = 5mm;\ IL = l_2'''' = 20mm;$

$BT = l_2''''' = 10mm;\ TU = l_2'''''' = 12mm;\ TR = 4mm;\ RU = 10{,}5mm.$

The characteristic lengths of bars 4 and 5 are (fig. 9):

$CE = l_4 = 10mm;\ AC = DE = l_5 = 6mm.$



(*a*) (*b*)

Fig.10. The left (a) and right (b) poly-contour kinematic chains [1]

The characteristic lengths values of the left kinematic chain (fig. 10a) are:

$EG = l_5' = 4mm;\ DG = l_5'' = 8mm;\ HG = l_7 = 22mm;\ HJ = l_7' = 7{,}5mm;\ \angle(GHJ) = \alpha_7 = 146^0;$

$JK = l_8 = 5mm;\ KI = l_9 = 6{,}5mm;\ IN = l_9' = 29{,}5mm;\ \angle(KIN) = 148^0;$

$LM = l_{10} = 29{,}5mm; MN = l_{11} = 20mm.$

The characteristic lengths values for the right kinematic chain are (fig. 10b):

$EP = l_{12} = 30mm;\ PR = l_{13} = 7{,}5mm;\ PS = l_{14} = 4mm;\ ST = l_{15} = 6mm;$

$TV = l_{15}' = 32mm;\ SV = l_{15}'' = 27{,}5mm;$

$UW = l_{16} = 32mm; VW = l_{17} = 12mm;$

The P_1 segment is connected to bar 11 (fig. 11), the P_2 segment is fixed to bar 2, while the P_3 segment is made rigid to bar 17.

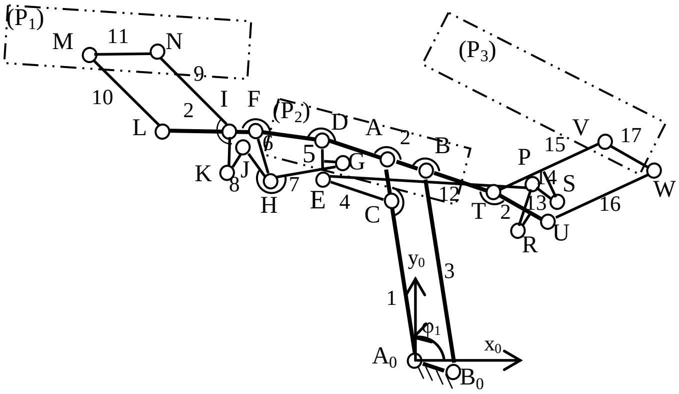


Fig.11. Kinematic scheme of the retractable hardtop mechanism when folding begins

The mechanism simulation (fig. 12) takes place by varying the φ_1 angle (fig. 10) from about 100^0 (the initial position) to around 10^0 (folded position).

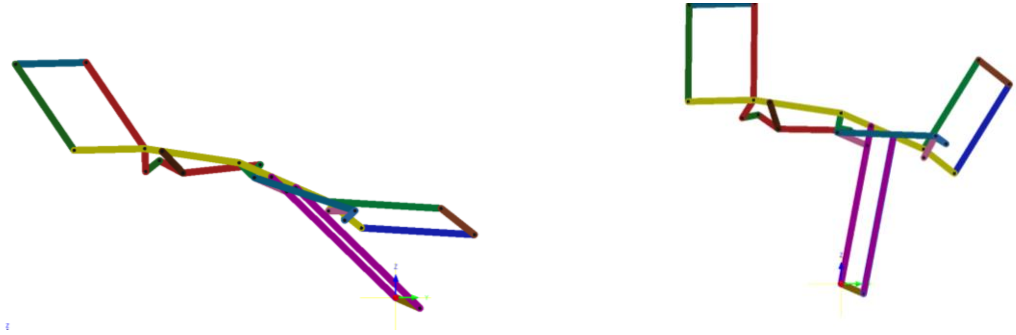


Fig. 12. Simulation of the retractable mechanism in the intermediary position

3. Conclusions

The two kinematic schemes of the plane mechanisms under consideration are two different options for retractable car hardtops made of three segments.

The first kinematic scheme of the retractable car hardtop mechanism has partial mobility as the two actuators drive in different stages. The second kinematic scheme of the retractable car hardtop mechanism has total mobility as the actuator drives all the articulated rods.

Both kinematic schemes consist of dyadic type kinematic chains, and two double articulations can be identified. The retractable hardtops mechanisms operate in two parallel planes, so that two electric syncronous motors are used for driving them.

References

[1] Antonescu, O., Antonescu, P., *Mechanism and Machine Science, course book*, Politehnica Press, Bucharest, 2016;

[2] Stăncescu, C., *Inventor Parametrical and Adaptive Modelling*, FAST Press, Buch., 2009;

[3] Stăncescu, C-tin., Manolache, D.S., Pârvu, C., Ghionea, I.G., Matei, M.T., *Autodesk Inventor Aided Design*, Fast Press, Bucharest, 2008;

[4] *** *Autodesk Inventor Professional 2014 - Software;*

[5] Patent US 7287801 B2, *Convertible top mechanism with inwardly articulating rearmost lateral rails;*

[6] Patent US 5772274 A, *Motorized drive system for a convertible roof of an auto vehicle;*

[7] Patent US 6336673 B1, *Convertible vehicle;*
[8] Popescu I., Luca L., Cherciu M., *Structura si cinematica mecanismelor. Aplicatii.* Editura Sitech Craiova, 2013.
[9] Popescu I., Luca L., Mitsi S., *Geometria , structura si cinematica unor mecanisme*. Editura Sitech, Craiova 2011.
[10] Luca L., Popescu I., *Generation of aesthetic surfaces through trammel mechanism,* Fiability & Durability, No 1, supplement, 2012, pp.55-61.
[11] Vella, Matt, *Convertible with Hard Tops*, The Wall Street Journal, Retrieved 3.02. 2014;
[12] Merlis, Bob, *Lucy Loved Ford's First Hard Top Convertible,* GreatersTV.com., 2008;
[13] Vaghn, Mark, *2007 Mazda MX-5 Miata Power Retractable Hardtop,* 2011.