

Research on some auxiliary mechanisms used in passenger cars

Daniela Antonescu¹, Daniel Iozsa², Ovidiu Antonescu³ and Gh. Fratila⁴

¹ "Iuliu Maniu" High School, Bucharest, Romania, e-mail: daniela.mihalache@yahoo.com

² Dept. of Road Vehicles, Politehnica University of Bucharest, Romania

³ Dept. of Mechanism and Robot Theory, Politehnica University of Bucharest, Romania

⁴ Dept. of Road Vehicles, Politehnica University of Bucharest, Romania

Abstract. The paper presents the results of researches on the topological structure and geometrical analysis of the planar mechanisms with articulated bars, which are used for actuating the doors of cars. The main five types of car doors with rotate movement (folding) are presented, being described both as constructive structure and mode of operation, through suitable kinematic schemes. Some innovative solutions for vehicle door actuating mechanisms aim to use as little space as possible, which is beneficial for car parking. There are three types of car door movements: rotation, sliding and planar rotational-sliding. Most of the cars are equipped with folding doors, where the rotate movement is limited and operates horizontally. Almost all sliding doors are placed on the rear of the car (only for passengers, not for driver). Unlike rotate doors, the sliding doors require a minimum lateral space, which is an advantage, especially in parking places. In the end of the paper, a kinematic analysis of the canopy 4-bar mechanism has been performed, in order to increase the passenger comfort on the access into the vehicle.

1. Introduction

The automotive market is dominated by conventional vehicle doors (fig. 3a) with only one degree of mobility [1, 8], which represents a major discomfort for the passengers [2, 7], especially to parking on a tight surface or on a steep terrain. For moderated slopes, this issue specific for the vehicle doors has been overcome by means of using a variable movement of the door [2, 13]. Through an actuating device, for instance an electro-pneumatic actuator, the comfort and safety in operating the door can be increased. Thus, a collision prevention system can be developed using obstacle detection sensors. The use of multi-DOF (Degree Of Freedom) vehicle doors has been proposed, allowing an improved comfort on the access into the vehicle. In figure 1 three types of unconventional vehicle doors are presented.



Figure 1. Unconventional car doors (*a* – suicide, *b* – scissors, *c* – gull wings) [11, 12]

2. The mechanism of the vehicle rotate door

The vehicle rotate door is mounted to the car body by means of some hinges (figure 2a) that are rotate kinematic joints, whose axis is usually vertical.

2.1. Vehicle rotate doors with vertical axis

The vehicle hinge is a rotate joint R single or double in car doors or, at least, double in freight vehicle doors.

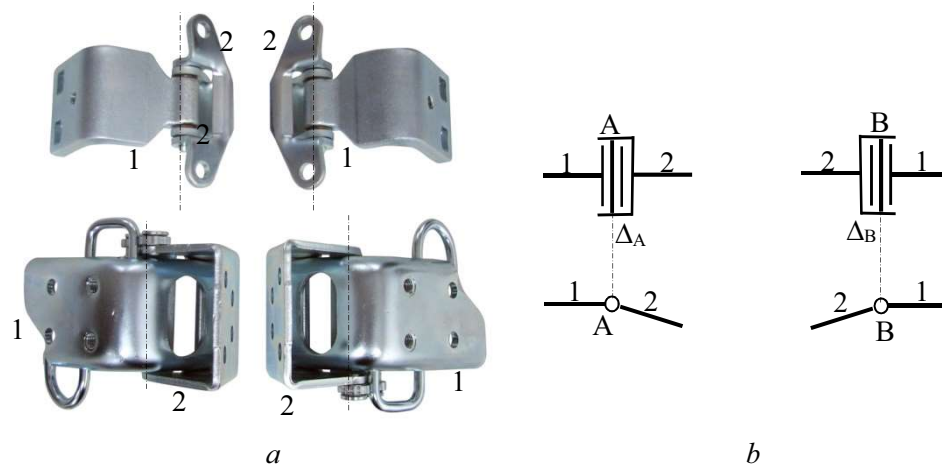


Figure 2. Photos [12] of two pairs of hinges (a) and the kinematic schemes of two rotate joints (b)

The technical design solutions for hinges (figure 2a) vary a lot among manufacturers, but the schematic representation of them is that of a rotate kinematic joint R (figure 2b). In reality, the hinge axis (Δ_A , Δ_B) is not strictly vertical (figure 2b), the angle formed with the vertical axis being small and measured in a transversal vertical plane (figure 3a). Anyway, they are considered with vertical axis – figure 3a.



Figure 3. Conventional vehicle rotate doors [11, 12] with vertical axis hinges (a) and front vehicle rotate door with inclined axis hinges (b)

2.2. Vehicle rotate doors with longitudinal-horizontal axis

In this case the vehicle door rotates by 90° in a transversal-vertical plane, around a horizontal axis of longitudinal direction (figure 4). Usually, this design solution is used to some coupe and sport vehicles (figure 4a) or only to the rear doors of some passenger cars (figure 4b).



Figure 4. Doors [12] with horizontal axis, type *gull wings*: “coupe” (a) and at rear (b)

In order to maintain open the vehicle door, one or two devices type gas dampers are used (figure 4, 5).

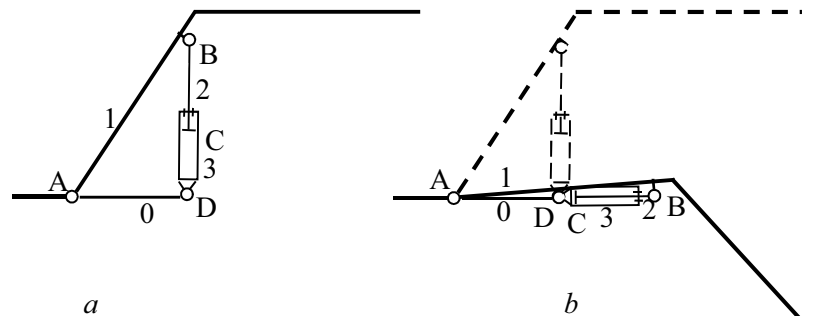


Figure 5. The vehicle door mechanism in open (a) and closed (b) positions

The rotate joint A is the symbolic representation of the vehicle door hinge, whose rotate axis is horizontal, in longitudinal position related to the vehicle body (figure 5). In the open position of the door (figure 5a) the damper (piston 2 and cylinder 3) is in vertical position, and in the closed position of the door (figure 5b) the damper end up horizontally along a transversal direction.

Note that the damper has the actuator role due to the fluid pressure in cylinder 3, and its structure is a kinematic chain type dyad (0, 1, 2 and 3) with a structure RTR (figure 5a).

2.3. Vehicle rotate doors with inclined axis

Some of these vehicle doors have only a single hinge, whose axis is in a longitudinal-vertical plane (figure 6b), the inclining angle being about 45° .

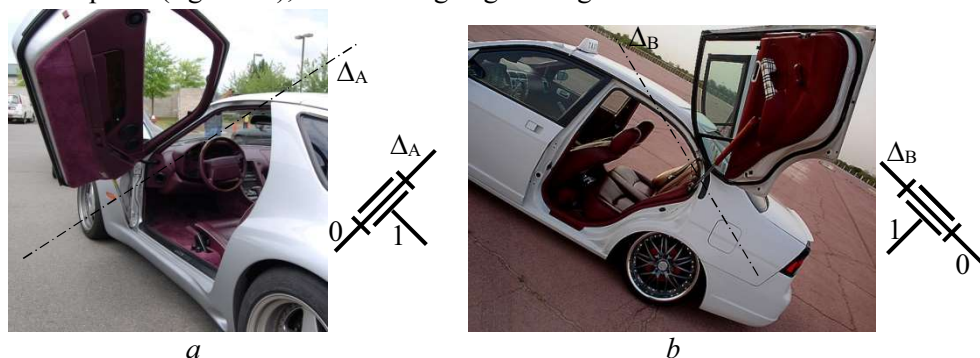


Figure 6. Photos [11] of the vehicle rotate doors with inclined axis, type *butterfly*: “coupe” (a) and “sedan”, at rear (b)

The vehicle door hinge makes the connection between the body 0 and the door 1, being graphically represented as a kinematic rotate joint $R(0,1)$, whose axis is denoted with Δ_A (figure 6a) or Δ_B (figure 6b).

The inclined position of the hinge axis allows the rotation of the door in an inclined plane, this advantage permitting the passenger to get in/out the vehicle more easily in a narrow lateral space between the two parked vehicles (figure 6a).

2.4. Vehicle rotate doors in a longitudinal-vertical plane

These vehicle doors rotate by maximum 60° (figure 7) in a longitudinal-vertical plane, having a horizontal rotate axis on a transversal direction with respect to the body.

The rotate angle of the door appears in a real dimension in a longitudinal plane (figure 7b), in respect of which the rotate axis is perpendicular.



Figure 7. Photos [12] with rotate doors in a longitudinal-vertical plane, type *scissors*: front/rear (a) and only in front (b)

In the case of actuating the vehicle door for opening, first the door performs a sliding motion toward outside (figure 8a), along a transversal direction, then the rotate motion in a longitudinal plane completes the task.



Figure 8. The scheme of the open kinematic chain $LC(0+1+2)$ [1]: T+R for opening (a) and R+T for closing (b)

The kinematic element 1 slides on the cylinder surface of the vehicle body 0, moving along with the door 2 by s_{10} in respect of a transversal direction Δ_{21} (figure 8).

When the vehicle door 2 is closing, first the door rotates by φ_{21} in a counter clockwise direction (figure 8b), and then it slides by s_{10} along the axis Δ_{21} .

Note that in order to open both the vehicle doors on the same side (figure 7a), the front door (AA_0) must slide more than the rear door (BB_0), as it can be observed in figure 9.

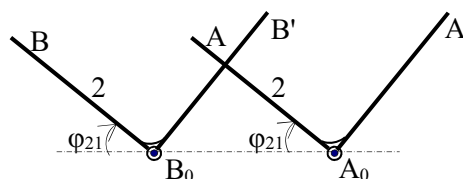


Figure 9. The kinematic scheme of the two same-side vehicle doors in open position

2.5. Vehicle rotate doors in a transversal plane

This type of vehicle door has a curved shape, having a cylindrical outer surface (figure 10), which it allows to roll into a circular guide under the body floor.

Note that these doors have no hinges, the opening/closing movement being performed through rotation in a transversal-vertical plane.

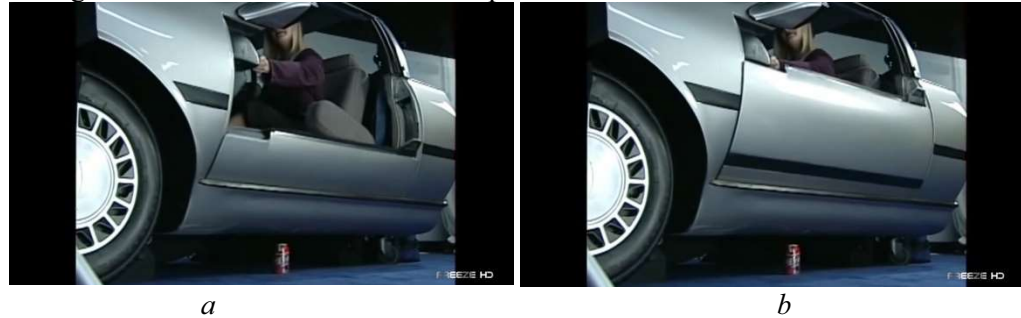


Figure 10. Photos [11] of vehicle rotate door in two positions of closing phase

Note that the outer of the vehicle door is a cylindrical surface as the car side body is. Before the beginning of the door opening, its window lowers in the bottom (open) position. The rotation of the vehicle door is performed by means of an actuation electric system. The disadvantage of this kind of door is that it occupies too much room from vehicle inner space, but the advantage is obviously in parking places.

3. The vehicle sliding doors

These vehicle sliding doors are placed in front (figure 11 - coupe) and at rear (station wagon), being guided by means of longitudinal-horizontal slots.

Usually, the guiding slots are positioned at top, bottom and middle parts of the vehicle body.



Figure 11. Photo [11] of a vehicle sliding door

If the actuating of the vehicle sliding door is often and the driver is not willing to get out every time, the using of an electric adjusting mechanism is recommended [3]. The door opening is frequent when the vehicle, for instance a minibus, is used for urban passenger transportation, or a city van which delivers goods has the sliding door on the opposite side of the vehicle regarding the driver's seat, and the driver has to remain at steering wheel all the time. Since the vehicle rotate door can be actuated pneumatically, the sliding door is more suitable to be driven electrically. The opening/closing mechanism of the vehicle sliding door is using a cable as the driving component (figure 12).

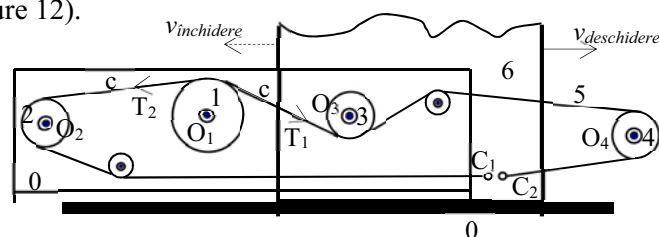


Figure 12. Kinematic scheme of the cable mechanism for actuating the sliding door

The mechanism actuation is performed by an electric motor which drives the reel 1 as driving element, on which the cable 5 is reeled having two branches tensioned with the forces T_1 and T_2 (figure 12). The pulleys 2, 3, 4 and the others are assembled on the body 0, and the cable ends are fixed on the sliding door in the points C_1 and C_2 . When the reel 1 rotates in counter clockwise, the branch tensioned with the force T_1 (by the point C_2) moves the door 6 to the right for opening, or when the reel 1 rotates in clockwise, the branch T_2 linked to point C_1 drives the door 6 to the left for closing.

4. Articulated planar mechanisms used as hinges

4.1. The four-bar mechanism

The four-bar mechanism is used to lift/lower the vehicle roof which forms a single piece along with the doors and the windshield, named “canopy roof” (figure 13).



Figure 13. Photos [11] of the *canopy* sport cars with a double 4-bar mechanism

Early mechanism was an articulated parallelogram (figure 13a), the roof performing a circular sliding motion. Late-on the linkage became a general four-bar mechanism (figure 13b) which allows a planar rotational-sliding movement of the canopy roof.

The four-bar mechanism is type planar linkage A_0ABB_0 (figure 14), on which the coupler 2 (AB) forms a rigid part along with the canopy roof.

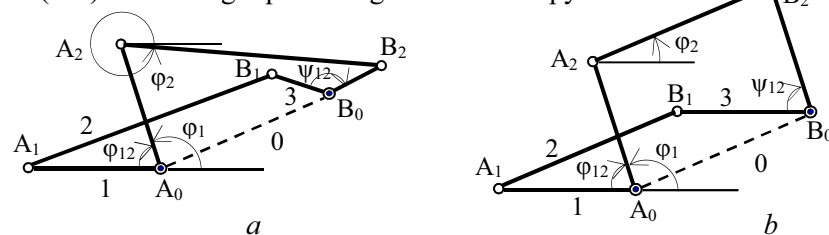


Figure 14. Four-bar mechanism [1, 5] - general case (a) and type parallelogram (b)

The fixed articulations A_0 and B_0 belong to the vehicle body, and about which the rockers 1 and 3 rotate by the angles ϕ_{12} and ψ_{12} in a vertical plane (figure 14a). In the particular case of the parallelogram mechanism (figure 14b) the coupler 2 performs a circular sliding motion alongside of the circle arcs A_1A_2 and B_1B_2 . Actually, the four-bar mechanism (figure 15) is double, having the rockers 1 and 3 dephased in a transversal plane.

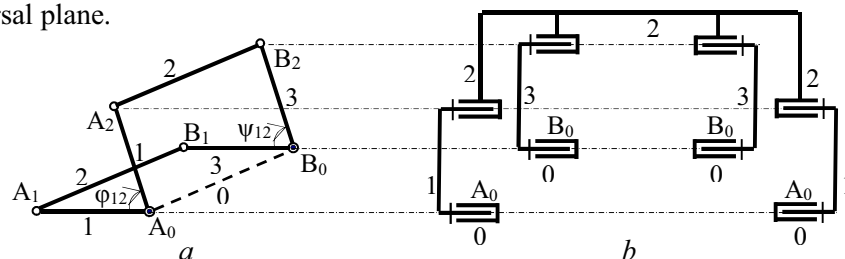


Figure 15. Parallelogram mechanism scheme - side view (a) and transversal view (b)

4.2. The bi-contour mechanism (Watt)

The Watt mechanism is an articulated planar linkage [1, 5] with two closed contours (figure 16a) and it is obtained by amplification of the 4-bar mechanism A_0ABB_0 with a kinematic chain type dyad $LD(4,5)$ (figure 16b).

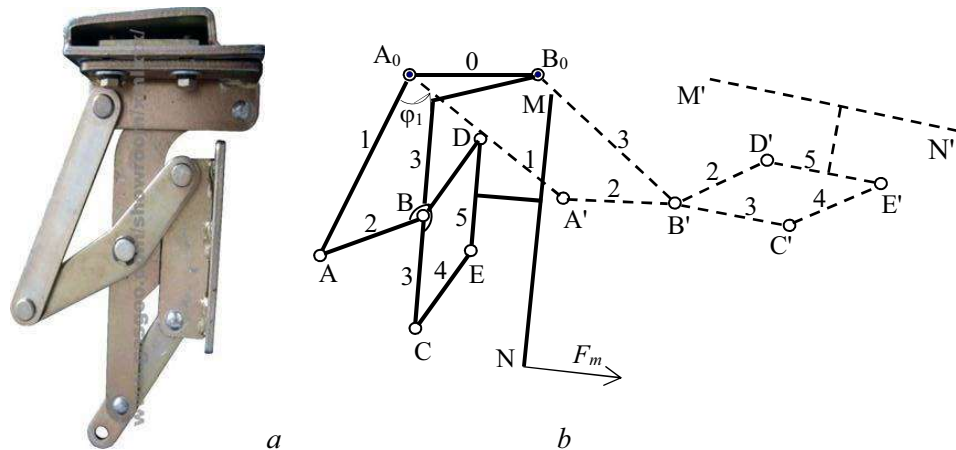


Figure 16. Photo of the Watt mechanism (a) and its kinematic scheme (b)

5. Kinematics of the Canopy 4-bar mechanism

In figure 17 a computer program for calculation of the kinematics of canopy 4-bar mechanism is displayed. The TurboPascal 6.0 software for developing the programming source file has been used.

```

CANOPY - Notepad
File Edit Format View Help
program mec_RRR; {kinematics of mechanism type canopy for n1=10 rpm !}
uses crt;
const l1=0.2; l2=0.6; l3=0.35; l0=0.6; l0p=0.2; xB0=0.6; yB0=-0.2;
var A2, B2, C2, t21, t22, f121, f122, A3, B3, C3, t31, t32, f131, f132: real;
    f11, om1, f12, f13, om2, om3, ep2, ep3, u: real;
    xB, yB, xA, yA: real;
    i: integer; f: text;
function rg(u: real): real;
begin
  rg:=u*180/pi; end;
function gr(u: real): real;
begin
  gr:=u*pi/180; end;
begin
  assign(f, 'D(2_3).lst'); rewrite(f);
  om1:=(10*pi)/30;
  writeln(f);
  writeln(f, '          TABLE OF RESULTS - D(2_3)');
  writeln(f, '          f11    f12    om2    ep2    f13    om3    ep3');
  writeln(f, '          -----');
  for i:=0 to 36 do
  begin
    f11:=(i*pi)/18;
    A2:=2*l2*(l1*cos(f11)-l0);
    B2:=2*l2*(l1*sin(f11)+l0p);
    C2:=2*l1*(l0p*sin(f11)-l0*cos(f11))+sqr(l1)+sqr(l2)-sqr(l3)+sqr(l0)+sqr(l0p);
    t21:=(-B2+sqr(sqr(A2)+sqr(B2)-sqr(C2)))/(C2-A2);
    t22:=(-B2-sqr(sqr(A2)+sqr(B2)-sqr(C2)))/(C2-A2);
    f121:=2*Arctan(t21);
    f122:=2*Arctan(t22);
    f12:=f122+2*pi;
    A3:=2*l3*(l0-l1*cos(f11));
    B3:=2*l3*(l0p+l1*sin(f11));
    C3:=2*l1*(l0p*sin(f11)-l0*cos(f11))+sqr(l1)-sqr(l2)+sqr(l3)+sqr(l0)+sqr(l0p);
    t31:=(-B3+sqr(sqr(A3)+sqr(B3)-sqr(C3)))/(C3-A3);
  end
end

```

Figure 17. Canopy 4-bar mechanism software for kinematic calculation

As it can be observed in figure above, a programming loop for the calculation of displacement, velocity and acceleration of the vehicle roof has been compiled and ran. Due to the fact that the velocity of actuating the canopy roof is low (10 rpm), it is shown only the angular displacement of the car roof (φ_2 – link 2, fig. 14a) in figure 18. As it can be observed in figure 18, the range of canopy roof angular displacement is about 40° from the closed position to the maximum open position. This means that the

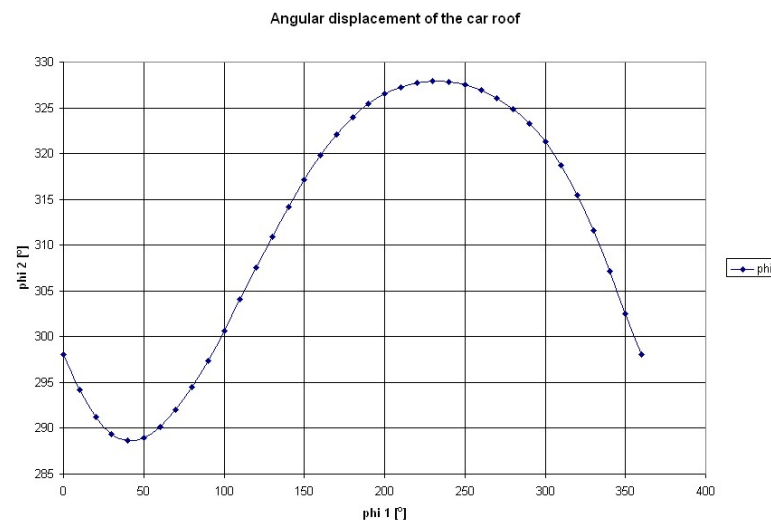


Figure 18. Variation of the angular displacement of the canopy roof

mechanism offers a pretty good comfort for the passenger to enter into the car. Yet, there is still some discomfort comparing to the classical rotate door with vertical axis. The greater is this angle, the better comfort it offers.

6. Conclusions

The most used types of vehicle doors are with rotate motion (hinges). Yet, the sliding doors are more and more present in passenger cars, not only in minibuses and vans. Following this idea, the paper presents the main five types of vehicle doors with rotate motion, the sliding door and, in the end, two linkage types used as door hinges. Some of the solutions are designed to save as much space as possible in narrow parking places. The sliding doors are the best from this point of view, but the disadvantages of them are the low safety, poor maneuvering and reliability, and the high-cost.

The paper ends with the developing of software for kinematic analysis of the 4-bar mechanism used in Canopy sport cars. It can be used in optimizing the angle of canopy roof for increasing the comfort when the passengers get in/out the car.

7. References

- [1] Antonescu O Antonescu P 2016 *Mechanism and Machine Science*, Politehnica Press
- [2] Fratila G 1977 *Calculation and construction of the automobiles* (RO), E.D.P., Bucharest
- [3] Horwitz Alexander Netanya 2005 *Sliding door mechanism for vehicles*, EP1548221 A2
- [4] Lichtenheldt W 1970 *Konstruktionslehre der Getriebe*, Akad. Verlag, Berlin
- [5] Manolescu N I et al. 1972 *Mechanism and Machine Theory* (RO), E.D.P., Bucharest
- [6] Mass J Kern S 2007 *Mechatronic vehicle door assistant*, IEEE/ASME International Conference on Advanced Intelligent Mechatronics, pp. 1-5
- [7] Mondir C 1998 *Dacia vehicles - diagnosis, maintenance, repairing* (RO), E.T., Bucharest
- [8] Oprisan C Popovici G A 2001 *Mechanisms* (in Romanian - RO), Ed. Tehnica, Chisinau
- [9] Strolz M Morti A et al. *Development, Control and Evaluation of an Actuated Car Door*, Journal IEEE, pp. 1-11
- [10] Tomohiko N Hiroiyuki S 1993 *Opening and closing device of door for vehicle*, JP05112128A
- [11] https://en.wikipedia.org/wiki/List_of_cars_with_non-standard_door_designs
- [12] https://en.wikipedia.org/wiki/Vehicle_door
- [13] <https://www.carid.com/lambo-doors.html>