Original Research Paper

# Structural-Topological Synthesis of Planar Mechanisms with Rods and Wheels

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**Abstract:** Today, robots are increasingly present in the machine building industry, sometimes even in some sections to replace workers altogether, due to the high quality of their work, repetitive, without stopping or pausing, without any manufacturing and assembly scuffs. Additionally, robots do not get sick, do not require medical leave or rest, work faster and better than humans and also support toxic environments from dyers, general assemblies, etc. Generally, robots have increased the quality and productivity of work and have not even created a union to defend their claims, demanding increased wages for them and larger holidays. Interestingly, a robot is working without a break, but without salary, without breaks, without complaining about working conditions in the plant. It has come to the effect that the big car manufacturers and even others, have entire sections in which only robots work. They do not have to worry about each other, do not quarrel, do not complain, do not cry, do not ask for the salary, do not require leave, they do not want free days and can work with high returns and Saturday and Sunday, if necessary on three shifts without a break. The importance of implementing robots can no longer be challenged. They have so increased the quality of work and the production of an enterprise that they can no longer give up their help. Workers have reclassified themselves and work only in more friendly workplaces, or in other workplaces, such as supermarkets, in better conditions, with higher wages, with several days off and they are also pleased and all this is due to production and additional gains from higher sales due to the robot work in large factories. We can clearly state that robots have improved our lives considerably. Thanks to them, a new free day was introduced for almost all working people, Friday, in addition to Saturday and we may soon be able to introduce another free day, but we have to choose whether it is Monday or Thursday. In this paper we present the mechanisms with bars and gears, which are planetary mechanisms for robot automation and mechatronics, structurally-topological. The gears and gears consist of at least one movable articulated bar and one of the cylindrical, tapered or hipoidal gears. Only gears with circular or straight toothed gears, in which the relative position of the rotation or translation axes does not change, shall be considered. The topological structure of the gears and gears is characterized by a kinematic chain with articulated bars and at least one kinematic chain with gears. The kinematic chain may be chain open (with a fixed rotation joint) or closed chain (with at least two fixed joints). The kinematic chain with gears is attached to the kinematic chain with bars so that at least two gear wheels have centers in the bars of the bars and some wheels may be integral with the bars. In practice, some of these gears with gears and gears are known as planetary gears with cylindrical, conical or hipoidal gears.

**Keywords:** Robots, Mechatronic Systems, Structure, Topology

## Introduction

Today, robots are increasingly present in the machine building industry, sometimes even in some sections to replace workers altogether, due to the high quality of their work, repetitive, without stopping or pausing, without any manufacturing and assembly scuffs.

Additionally, robots do not get sick, do not require medical leave or rest, work faster and better than humans and also support toxic environments from dyers, general assemblies, etc.

Generally, robots have increased the quality and productivity of work and have not even created a union to defend their claims, demanding increased wages for them and larger holidays. Interestingly, a robot is working without a break, but without salary, without breaks, without complaining about working conditions in the plant.

Robots can work on three shifts, that is, permanently, but not by shifting them like people did, but always remaining the same robots deployed in operation, nonstop, for days, without breaks, without rest, without problems.

It has come to the effect that the big car manufacturers and even others, have entire sections in which only robots work. They do not have to worry about each other, do not quarrel, do not complain, do not cry, do not ask for the salary, do not require leave, they do not want free days and can work with high returns and Saturday and Sunday, if necessary on three shifts without a break.

The importance of implementing robots can no longer be challenged. They have so increased the quality of work and the production of an enterprise that they can no longer give up their help. Workers have reclassified themselves and work only in more friendly workplaces, or in other workplaces, such as supermarkets, in better conditions, with higher wages, with several days off and they are also pleased and all this is due to production and additional gains from higher sales due to the robot work in large factories.

We can clearly state that robots have improved our lives considerably. Thanks to them, a new free day was introduced for almost all working people, Friday, in addition to Saturday and we may soon be able to introduce another free day, but we have to choose whether it is Monday or Thursday.

People, in the beginning, were taught by the trade union bosses to chase and sabotage the robots, to ruin them and not to accept them. Today things are clear and the robots work quietly in the big companies and factories for the sake of everyone, so now we can all accept the silence of the automation, the robotics, the electronics, without letting us be fooled by the union leaders, who slowly slow down and they will calm down.

If we like it or not like, robots have already stolen all our hard works places.

Anthropomorphic robots are, as I have already said, in most of the most widespread and widely used works worldwide today, due to their ability to adapt quickly to forced work, working without breaks or breaks 24 h a day, without unpaid leave without asking for food, water, air, or salary. Anthropomorphic robots are supple, elegant, easy to configure and adapted to almost any required location, being the most flexible, more useful, more penetrating, easy to deploy and maintain. For the first time, these robots have asserted themselves in the automotive industry and especially in the automotive industry, today they have penetrated almost all industrial fields, being easily adaptable, flexible, dynamic, resilient, cheaper than other models, occupying a volume smaller but with a major working space. They can also work in toxic or dangerous environments, so used in dyeing, chemical cleaners, in chemical or nuclear environments, where they handle explosive objects, or in military missions to land or sea mines, even if they were banned to use, because there are still countries around the globe that use them, such as Afghanistan.

The most used today's industrial robots, is built. The importance of the study of anthropomorphic robots has also been signaled, being today the most widespread robots worldwide, due to its simple design, construction, implementation, operation and maintenance. In addition, anthromomorphic systems are simpler from a technological and cheaper point of view, performing a continuous, demanding, repetitive work without any major maintenance problems. The basic module of these robots was also presented geometrically, cinematically, of the forces, of its total static balancing and of the forces that arise within or after balancing. In the present paper we want to highlight the dynamics of the already statically balanced total module. It has been presented in other works and studied matrix spatially, or more simply in a plan, but in this case, it is necessary to move from the working plane to the real space, or vice versa, passage that we will present in this study. In the basic plan module already presented in other geometric and cinematic works, we want to highlight some dynamic features such as static balancing, total balancing and determination of the strength of the module after balancing. Through a total static balancing, balancing the gravitational forces and moments generated by the forces of gravity is achieved, balancing the forces of inertia and the moments (couples) generated by the presence of inertial forces (not to be confused with the inertial moments of the mechanism, which appear separately from the other forces, being part of the inertial torsion of a mechanism and depending on both the inertial masses of the mechanism and its angular accelerations. Balancing the mechanism can be done through various methods. Partial balancing is achieved almost in all cases where the actuators (electric drive motors) are fitted with a mechanical reduction, a mechanical transmission, a

sprocket, spiral gear, spool screw type. This results in a "forced" drive balancing from the transmission, which makes the operation of the assembly to be correct but rigid and with mechanical shocks. Such balancing is not possible when the actuators directly actuate the elements of the kinematic chain without using mechanical reducers (Antonescu and Petrescu, 1985; 1989; Antonescu *et al.*, 1985a; 1985b; 1986; 1987; 1988; 1994; 1997; 2000a; 2000b; 2001; Aversa *et al.*, 2017a; 2017b; 2017c; 2017d; 2017e; 2016a; 2016b; 2016c; 2016d; 2016e; 2016f; 2016g; 2016h; 2016i; 2016j; 2016k; 2016l; 2016m; 2016n; 2016o; Berto *et al.*, 2016a; 2016b; 2016c; 2016d; Cao *et al.*, 2013; Dong *et al.*, 2013; Comanescu, 2010; Franklin, 1930; He *et al.*, 2013; Lee, 2013; Lin *et al.*, 2013; Liu *et al.*, 2013; Mirsayar *et al.*, 2017; Padula and Perdereau, 2013; Perumaal and Jawahar, 2013; Petrescu, 2011; 2015a; 2015b; Petrescu and Petrescu, 1995a; 1995b; 1997a; 1997b; 1997c; 2000a; 2000b; 2002a; 2002b; 2003; 2005a; 2005b; 2005c; 2005d; 2005e; 2011a; 2011b; 2012a; 2012b; 2013a; 2013b; 2016a; 2016b; 2016c; Petrescu *et al.*, 2009; 2016; 2017a; 2017b; 2017c; 2017d; 2017e; 2017f; 2017g; 2017h; 2017i; 2017j; 2017k; 2017l; 2017m; 2017n; 2017o; 2017p; 2017q; 2017r; 2017s; 2017t; 2017u; 2017v; 2017w; 2017x; 2017y; 2017z; 2017aa; 2017ab; 2017ac; 2017ad; 2017ae; 2018a; 2018b; 2018c; 2018d; 2018e; 2018f; 2018g; 2018h; 2018i; 2018j; 2018k; 2018l; 2018m; 2018n).

In this paper we present the mechanisms with bars and gears, which are planetary mechanisms for robot automation and mechatronics, structurally-topological.

## Materials and Methods

The rods and gears consist of at least one movable articulated bar and one of the cylindrical, tapered or hipoidal gears. Only gears with circular or straight toothed gears, in which the relative position of the rotation or translation axes does not change, shall be considered. The topological structure of the gears and gears is characterized by a kinematic chain with articulated bars and at least one kinematic chain with gears. The kinematic chain may be chain open (with a fixed rotation joint) or closed chain (with at least two fixed joints). The kinematic chain with gears is attached to the kinematic chain with bars so that at least two gear wheels have centers in the bars of the bars and some wheels may be integral with the bars. In practice, some of these gears with gears and gears are known as planetary gears with cylindrical, conical or hipoidal gears.

The gearing of these gears in these complex mechanisms is carried out in the form of series, parallel, or both parallel-series trains.

The system is made according to the articulated plan cinematic chain, which can be made as an open or closed kinematic chain.

*Flat-Bellows and Gears with Open Kinematic Chain*

They are divided into elementary mechanisms (with a single articulated bar) and layered complex mechanisms with at least two articulated bars. The gears and gears of the first category are called planetary mechanisms, being used as planetary mechanical transmissions.

In turn, the elementary mechanisms are made with a central wheel with the fixed rotation axis (Fig. 1) and with two central wheels (Fig. 2), whose axes coincide with the fixed axis of the articulated bar.

Elementary mechanisms with a central wheel (Fig. 1) have a central wheel marked with a Fig. 1 and a satellite wheel 2 with the mobile shaft. The bar is numbered 3 and the joints are marked with letter $A_0$ (double joint) or A (simple joint).

The two wheels 1 and 2 form a cylindrical gear, which is external (Fig. 1a) or interior (Fig. 1b and 1c). Each toothed wheel is represented by the rolling circle, which in the kinematic schematics symbolizes a continuous line.

The mobility of this gear with bars and gears is equal to 2, which is deduced from the structural-numerical formula (1):

$$M = \sum_{m=1}^{5}\left(m \cdot C_m\right) - \sum_{r=2}^{6}\left(r \cdot N_r\right) \qquad (1)$$

In formula (1) the following notations were used:

- Is the functional class of the kinematic couple (degree of freedom)
- Is the number of kinematic couplings of class $m$
- Is the rank of the space associated with a closed cinematic contour
- Is the number of closed kinematic contours independent of $r$

The total number $N_c$ of the closed contours is calculated using formula (2):

$$N_c = \sum_{m=1}^{5} C_m - n \qquad (2)$$

In the formula (2), the total number of moving kinematic elements in the mechanism is denoted by $n$.

In the case of elementary gears with bars and gears (Fig. 1), the kinematic elements are in the form of a bar and a gear wheel and the kinematic couplers are rotation ($m = 1$), represented by plane and roto-translational joints ($m = 2$), represented by cylindrical gears.

Following the kinematic schemes (Fig. 1) the following numerical values are identified (3):

$$m = 1, \ C_1 = 3; \ m = 2, \ C_2 = 1; \\ r = 3, \ n = 3, \ N_3 = 1 \qquad (3)$$

With these numerical values introduced in the formula (1) the expression (4) is obtained:

$$M = (1 \cdot 5 + 2 \cdot 1) - 3.1 = 2 \qquad (4)$$

By immobilizing the crank wheel, the mechanism will have $M = 1$ mobility, in which case the bar 3 may be a driving member and the toothed wheel 2 will become a driven member.

In this case, a point on the wheel 2 will describe an epicicloid curve (Fig. 1a), a hypo-cycloid (Fig. 1b) or a pericicloid (Fig. 1c).

The central two-gear center gears (Fig. 2) are obtained from the previous ones by the addition of a gear wheel 4 which engages the wheel 2' integral with 2.

Since a toothed wheel is structurally topological equivalent to a diadem cinematic chain, the mobility of the new mechanisms (Fig. 2) is preserved, so $M = 2$.

The mobility value is calculated by the formula (1) in which the numerical values specific to this two-wheel center mechanism (5) are introduced:

$$m = 1, \ C_1 = 4; \ m = 2, \ C_2 = 2; \ r = 3, \ n = 4, \ N_3 = 2 \qquad (5)$$

Thus, the mobility of the elementary mechanisms presented above results (6):

$$M = (1 \cdot 4 + 2 \cdot 2) - 3 \cdot 2 = 2 \qquad (6)$$

The two cylindrical gears are both external (Fig. 2a), one inner and the other outside (Fig. 2b) or both interiors (Fig. 2c).

When installing the second central wheel 4, account is taken of the geometric condition that the distance between the axes of the two gears is the same (7):

$$m_{12} \cdot (z_1 \pm z_2) = m_{2'4} \cdot (z_{2'} \pm z_4) \qquad (7)$$

Complex gears with stacked bars and toothed wheels are obtained by overlaying the elementary mechanisms previously analyzed.

Overlaying refers to the kinematic chain with bars, which can have two bars (Fig. 3a) or several bars (Fig. 3b).

In the kinematic analysis of the two-bar mechanism (Fig. 3a), it should be noted that the wheel 3 is integral with the $A_0A$ bar and the wheel 2 is integral with the bar AB. These solidarizations are highlighted in both projections, both in the axial plane and in the transverse projection, corresponding to the plane of the gears and gears.

There are four outer cylindrical gears, two at each level, which requires verification of the following deduced relationships from the equal distance between axes (8-9):

$$m_{12} \cdot (z_1 + z_2) = m_{45} \cdot (z_4 + z_5) \qquad (8)$$

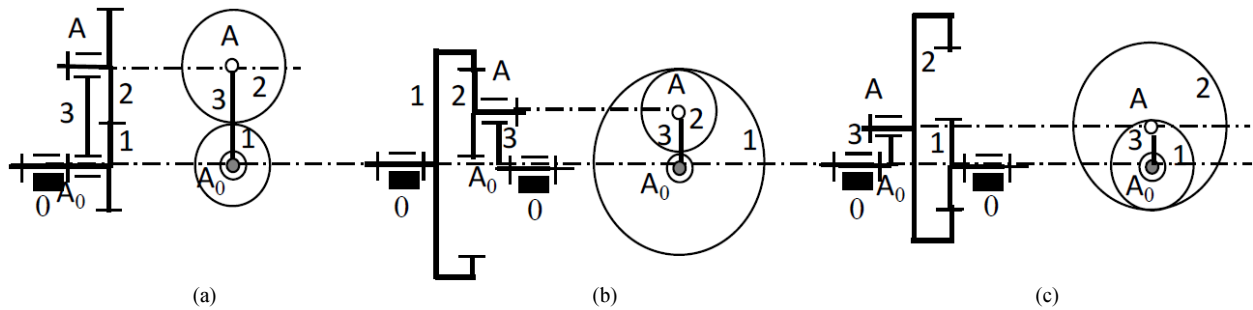$$m_{56} \cdot (z_5 + z_6) = m_{36'} \cdot (z_3 + z_{6'}) \qquad (9)$$



(a)          (b)          (c)

**Fig. 1:** The elementary mechanisms are made with a central wheel with fixed rotation axis
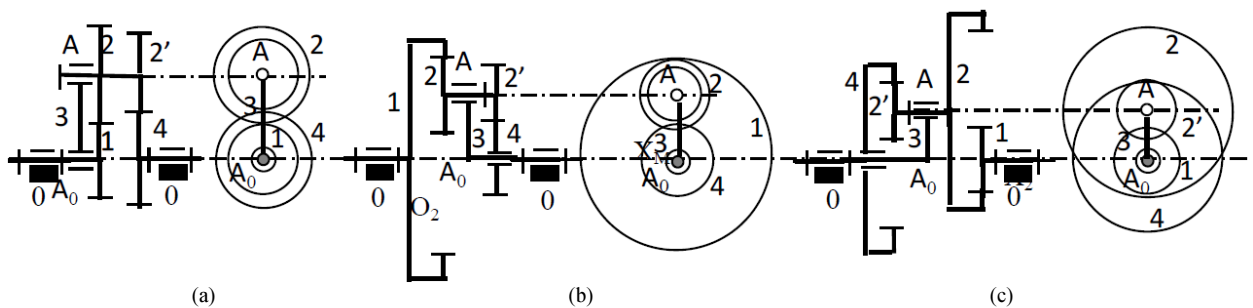


(a)          (b)          (c)

**Fig. 2:** The elementary mechanisms are made with two central wheels
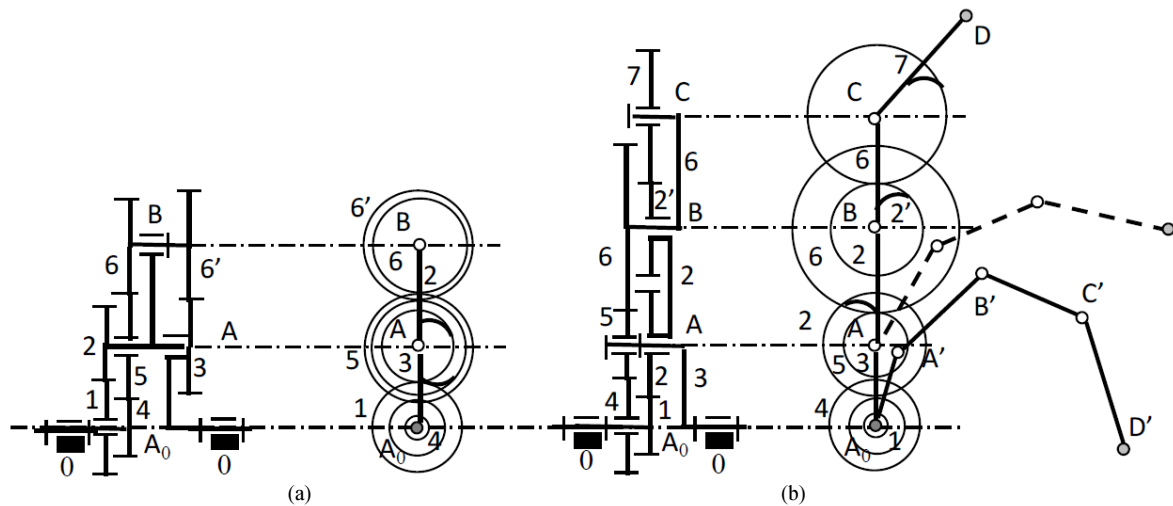
**Fig. 3:** Overlaying refers to the kinematic chain with bars, which can have two bars (Figure 3a) or several bars (Figure 3b)

The mobility of the simple flatbed mechanism (Fig. 3a) is $M = 2$, this being calculated by means of formula (1), in which purpose the specific numerical values are determined (10):

$$m = 1, \ C_1 = 6; \ m = 2, \ C_2 = 4; \\ r = 3, \ n = 6, \ N_3 = 4. \tag{10}$$

With these data entered in the formula (1) the relationship (11) results:

$$M = (1 \cdot 6 + 2 \cdot 4) - 3 \cdot 4 = 2 \tag{11}$$

The composite block mechanism (Fig. 3b) is composed of the A0ABCD open-kinematic kinematic chain (in which the last CD is integral with the toothed wheel 7) and the kinematic chain with gears located in planes parallel to the main chain.

It is noted that the gears 2 and 2' are integral with the bar AB and the toothed wheel 6 is integral with the articulated link bar BC.

For the first two cylindrical gears, mounted in parallel to the zero level, there is the relation (8), taking into account the notations identical to those in the kinematic scheme analyzed above.

The mobility of the overlayed mechanism (Fig. 3b) is $M = 3$, which is verified using formula (12):

$$M = (1 \cdot 7 + 2 \cdot 4) - 3 \cdot 4 = 3 \tag{12}$$

In formula (12) the following numerical values specific to the analyzed mechanism (13) were introduced:

$$m = 1, \ C_1 = 7; \ m = 2, \ C_2 = 4; \\ r = 3, \ n = 7, \ N_3 = 4 \tag{13}$$

The geometric structure of this complex mechanism (Fig. 3b) corresponds to a redundant planar manipulator with three mobilities, at which point D can reach D' on a given trajectory.

## Results

### Straight Mechanism with Flat Bars and Gears

These planar mechanisms have, as a main chain with bars, a kinematic contour of the articulated quadrilateral, articulated pentalator, articulated hexalator, etc. The kinematic chain with toothed wheels is attached to the bar chain by positioning each circular wheel with the center in a polygonal contour joint.

The chain mechanism with quadrilateral bars is made with two, three or four gears, these being distinct kinematic elements or being solidly mounted with certain bars of the closed kinematic contour. In some situations, toothed wheels are also used with the centers placed at certain points on the bars, other than their joints.

Where appropriate, the articulated quadrilateral is crank-type, double crank and double swing (with simple and complex variants).

The kinematic chain with the crankshaft (Fig. 4) is further considered to be attached to the kinematic chain with two, three or four gears, respectively one, two or three cylindrical outer or inner gears.

Assuming that the mobility of the complex gear with bars and toothed wheels is $M = 1$, one of the gears of the gears attached solidarizes with one of the articulated bars 1, 2 or 3.

Variant 1 (Fig. 4a) is obtained when wheel 2 is integral with rod 2 of length AB = 12 and gear wheel 4 has a fixed rotation axis in B0 being a driven wheel.

Because the toothed wheel 4 is a distinct kinematic element, equivalent to a zero mobility chain diadem, by

adding it to the articulated quadrant (0, 1, 2, 3) and $A_0ABB_0$ respectively, the mechanism mobility is preserved.

For verification, mobility is calculated with the general formula (1), where the numerical values specific to this complex mechanism are introduced (Fig. 4a), (14-15):

$$m = 1, \quad C_1 = 5; \quad m = 2, C_2 = 1;$$
$$r = 3, n = 4, N_3 = 2 \tag{14}$$

$$M = (1 \cdot 5 + 2 \cdot 1) - 3 \cdot 2 = 1 \tag{15}$$

The distance between the axes of the two gear wheels 2 and 4 of the external cylindrical gear that is mounted on the rocker 3, of length $B_0B = 13$, must fulfill the geometric condition (16):

$$a_{24} = BB_0 = \frac{1}{2} m_{24} \cdot (z_2 + z_4) \tag{16}$$

Variant 2 (Fig. 4b) has two cylindrical gears mounted on bars 2 and 3, where wheel 1 with center in A is integral with crank 1 of length $A_0A = 11$ and wheels 4 (4') and 5 are elements distinct cinemas, having centers in B and B0 respectively. The two toothed wheels 4 (4') and 5 are equivalent to two diadic chains, which preserve the mobility of the quadrilateral mechanism M = 1.

Variant 3 (Fig. 4c) comprises three cylindrical gears mounted on bars 1, 2 and 3, wherein the toothed wheel 0 with the center in $A_0$ is integral with the base of the quadrilateral. Wheels 4 (4'), 5 (5') and 6 are distinct elements which equate to three diadic chains, so that $M = 1$ mobility is preserved.

Chain mechanisms with pentalaters can be made with one or more cylindrical gears attached to the articulated pedal (Figure 5), in which, in order to obtain the mobility one (M = 1), two conditions are introduced which aim at the solidarity of two wheels toothbrushes with distinct bars.

It is noted that from each of the above-mentioned variants, by attaching another rod of the articulated pentatal there are obtained two other variants of gears and gears, which means 9 distinct variants.

Variant 1 (Fig. 5a) is obtained by using two toothed wheels (with teeth numbers $z_3$ and $z_0$) having the centers in the C and C joints of the bar 4 and solidarized by the movable bar 3 and the fixed 0 respectively.

In this way the engagement of the two wheels is equivalent to the introduction of an additional link between bars 3 and 0, which is equivalent to a bar and two articulations whose mobility is -1.

The mobility of the resultant mechanism (Fig. 5a) is that of the articulated pentatal ($M = 2$), to which is added the mobility of the inserted engagement connection (-1), i.e., M = 2-1 = 1.

The same result is obtained by computing the mobility of the complex mechanism with the structural - topological formula (2.1), whose particular form is (17):

$$M = C_1 + 2C_2 - 3N_3 = 5 + 2 \cdot 1 - 3 \cdot 2 = 1 \tag{17}$$

The mounting condition of the two toothed wheels (Fig. 5a) is (18):

$$a_{30} = CC_0 = \frac{1}{2} m_{30} \cdot (z_3 + z_0) \tag{18}$$

If the bar 1 is a leading element, the complex mechanism is of Class 3, which can be determined by highlighting the triad once the upper coupling coupler is replaced by a binary bar (with two joints).

Following the two other kinematic schemes obtained from variant 1 (Fig. 5a and 6a) by changing the base, they each represent a complex mechanism of class 2 (Fig. 6b) and a complex class 4 mechanism (Fig. 6c).

Variant 2 (Fig. 5b) is obtained from the bi-mobile articulated catenary chain by attaching the toothed wheel chain with two cylindrical gears mounted on the bars 3 and 4. Between the wheels with the centers in the joints $B$ and $C_0$ (integral with the bars 2 and 0) finds the toothed wheel 5 (5') with the center in $C$, which is a distinct cinematic element.

The mobility of the complex mechanism is calculated by the formula (1), (19):

$$M = C_1 + 2C_2 - 3N_3 = 6 + 2 \cdot 1 - 3 \cdot 3 = 1 \tag{19}$$

where, the following replacements were made (20):

$$m = 1, \quad C_1 = 6; \quad m = 2, \quad C_2 = 2;$$
$$r = 3, \quad n = 5, \quad N_3 = 3 \tag{20}$$

The mounting conditions of the two cylindrical gears are (Fig. 5b; 21-22):

$$a_{25} = BC = \frac{1}{2} m_{25} \cdot (z_2 + z_5) \tag{21}$$

$$a_{05'} = C_0C = \frac{1}{2} m_{05'} \cdot (z_0 + z_{5'}) \tag{22}$$

And from this kinematic scheme (Fig. 5b and 7a) of class 4, two other distinct kinematic schemes are obtained, by changing the base, one of class 3 (Fig. 7b) and the other of class 4 (Fig. 7c).

Variant 3 (Fig. 5c) results from the bimobal pentalater chain by the attachment of a kinematic chain of gears with three cylindrical gears mounted on the bars 2, 3 and 4.

The gears with the centers in the joints $A$ and $C_0$ are integral with the bars 1 and 0 respectively and the gears 5 (5') and 6 (6') with the centers in the joints $B$ and $C$ are distinct kinematic elements.

Mobility is $M = 1$, which is verified using formula (1; 23):

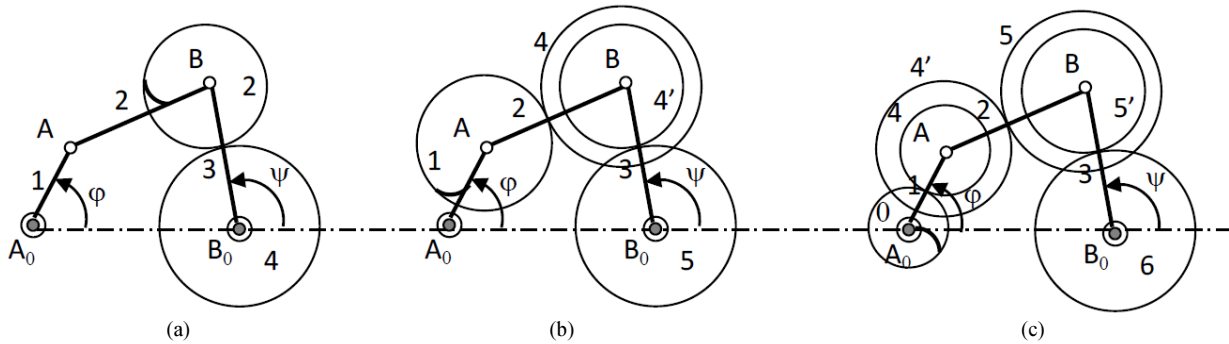$$M = C_1 + 2C_2 - 3N_3 = 7 + 2 \cdot 3 - 3 \cdot 4 = 1 \qquad (23)$$



(a)         (b)         (c)

**Fig. 4:** The kinematic chain with the crankshaft (Fig. 4) is further considered to be attached to the kinematic chain with two, three or four gears, respectively one, two or three cylindrical outer or inner gears
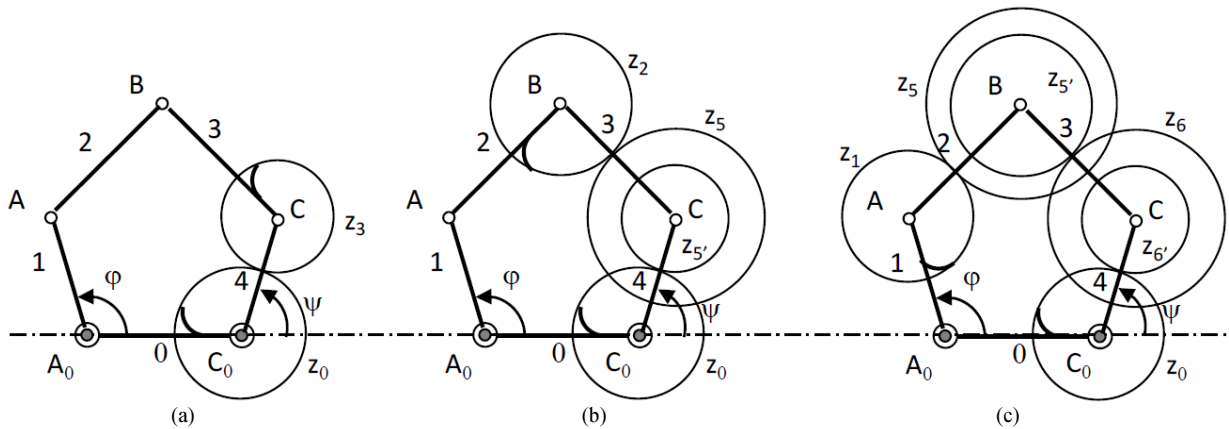


(a)         (b)         (c)

**Fig. 5:** Chain mechanisms with pentalaters can be made with one or more cylindrical gears attached to the articulated pedal, in which, in order to obtain the mobility one ($M = 1$), two conditions are introduced which aim at the solidarity of two wheels toothbrushes with distinct bars
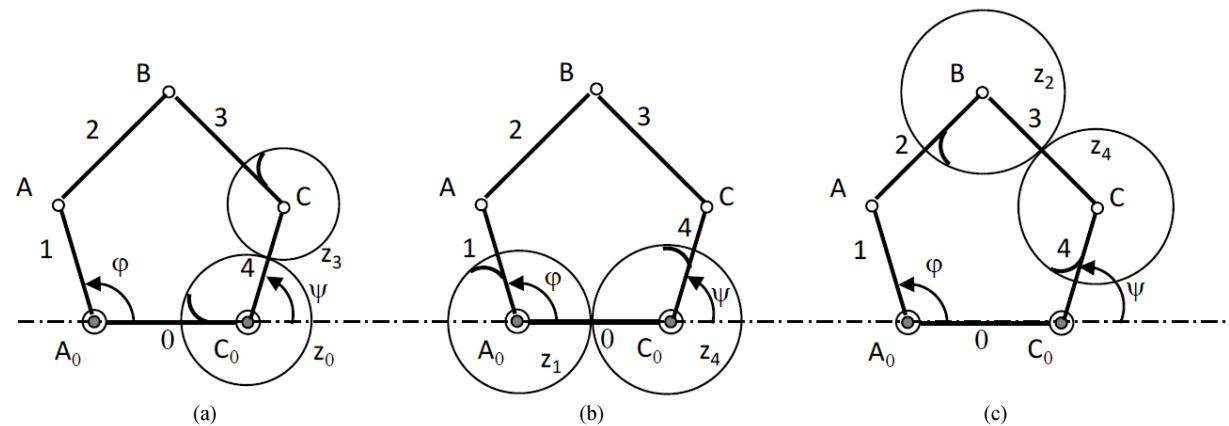


(a)         (b)         (c)

**Fig. 6:** Following the two other kinematic schemes obtained from variant 1 (Fig. 5a and 6a) by changing the base, they each represent a complex mechanism of class 2 (Fig. 6b) and a complex class 4 mechanism (Fig. 6c)
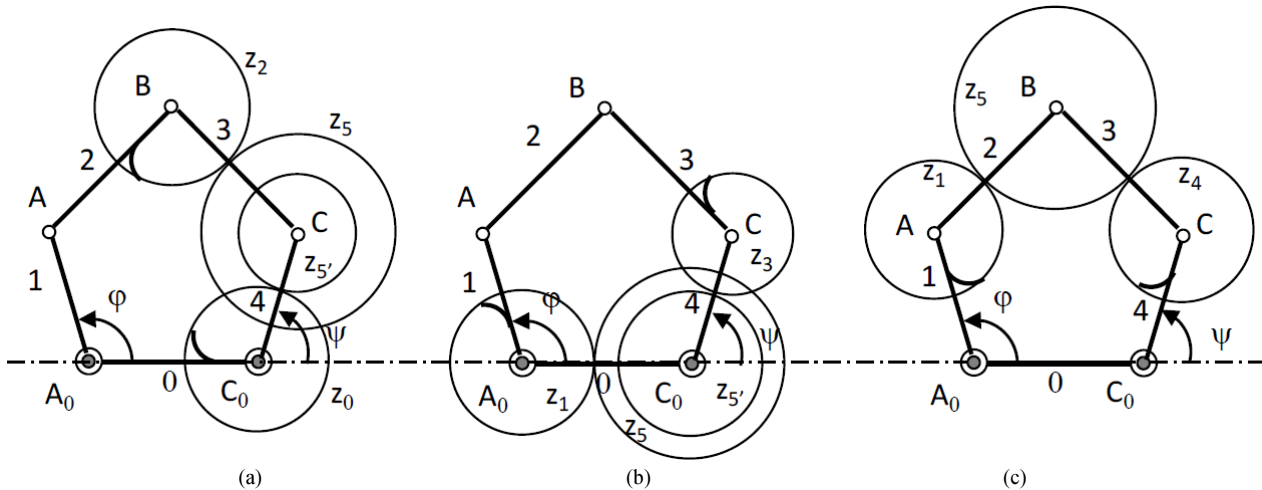
**Fig. 7:** From this kinematic scheme (Fig. 5b and 7a) of class 4, two other distinct kinematic schemes are obtained, by changing the base, one of class 3 (Fig. 7b) and the other of class 4 (Fig. 7c)
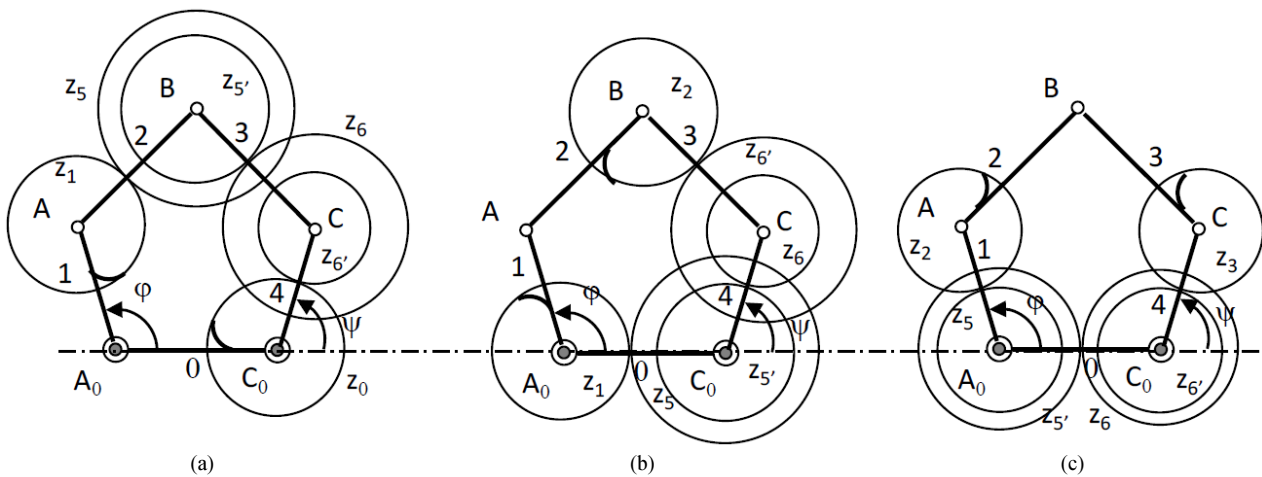


**Fig. 8:** From this kinematic scheme (Fig. 5c and 8a) of class 4 ord. 4, two other kinematic schemes are obtained by changing the base, one by one. 4 ord. 3 (Fig. 8b) and the other one. 7 ord. 4 (Fig. 8c)

From this kinematic scheme (Fig. 5c and 8a) of class 4 ord. 4, two other kinematic schemes are obtained by changing the base, one by one. 4 ord. 3 (Fig. 8b) and the other one. 7 ord. 4 (Fig. 8c).

The hexal-type chaining mechanisms are obtained by attaching a chain of gears with two or more gears to an articulated hexalator (Fig. 9), in which, in order to achieve a unitary mobility ($M = 1$), at least four wheels are solidarized with the bars.

Three kinematic schemes of such complex gears with bars and gears, each having two cylindrical gears, were considered (Fig. 9).

If equal gears are used, the first and third kinematic schemes (Fig. 9a and 9c) show a geometric symmetry, in which case the bar 3 performs a rectilinear translation motion.

Moreover, under the above-mentioned conditions and with the second kinematic scheme (Fig. 9b), the rectilinear translation of the rod 3 is obtained, even if the topological structure is not symmetrical.

The mobility of these complex mechanisms is $M = 1$, which is verified by the calculation of formula (1; 24):

$$M = C_1 + 2C_2 - 3N_3 = 6 + 2 \cdot 2 - 3 \cdot 3 = 1 \qquad (24)$$

*Chain Mechanisms with Hexagonal and Octagonal Bars*

For these mechanisms there is an example of a kinematic scheme with a symmetrical geometric structure (Fig. 10).
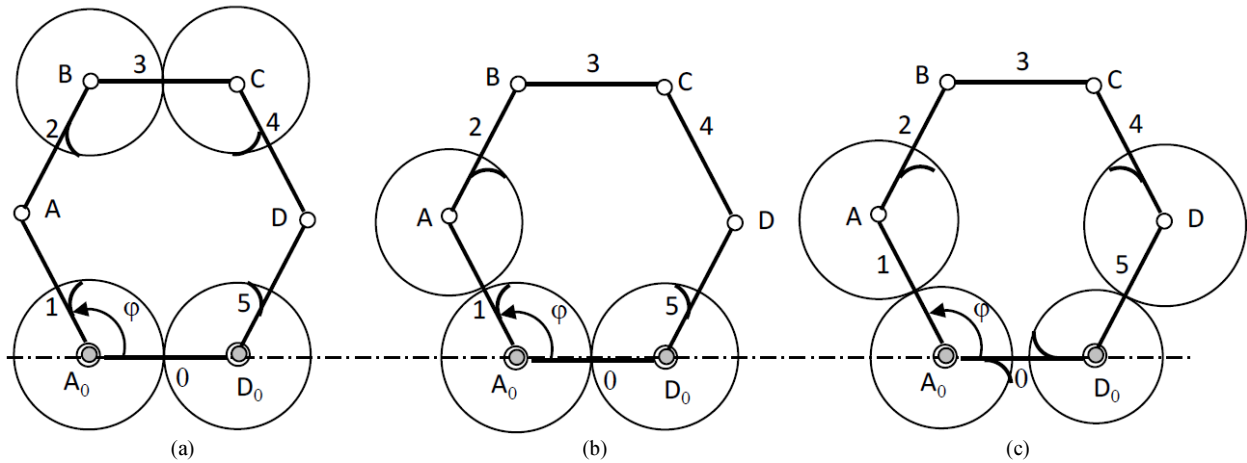
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**Fig. 9:** The hexal-type chaining mechanisms are obtained by attaching a chain of gears with two or more gears to an articulated hexalator (Fig. 9), in which, in order to achieve a unitary mobility ($M = 1$), at least four wheels are solidarized with the bars. Three kinematic schemes of such complex gears with bars and gears, each having two cylindrical gears, were considered (Fig. 9). If equal gears are used, the first and third kinematic schemes (Fig 9a and 9c) show a geometric symmetry, in which case the bar 3 performs a rectilinear translation motion. Moreover, under the above-mentioned conditions and with the second kinematic scheme (Fig. 9b), the rectilinear translation of the rod 3 is obtained, even if the topological structure is not symmetrical
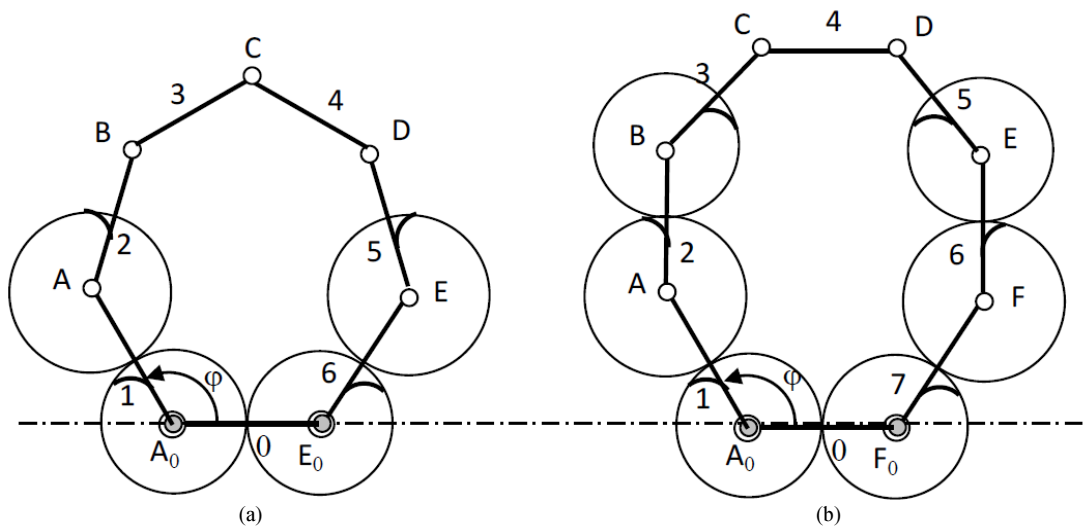


**Fig. 10:** The complex heptagonal chain mechanism (Fig. 10a) is made with three gears, one with fixed axes (1, 6) and two with movable axes (1, 2) and (5, 6). The octagonal chain complex mechanism (Fig. 10b) consists of five gears mounted symmetrically to the vertical symmetry axis of the octagon. Both mechanisms have mobility one $M = 1$.

The complex heptagonal chain mechanism (Fig. 10a) is made with three gears, one with fixed axes (1, 6) and two with movable axes (1, 2) and (5, 6).

The octagonal chain complex mechanism (Fig. 10b) consists of five gears mounted symmetrically to the vertical symmetry axis of the octagon. Both mechanisms have mobility one M = 1.

For planar mechanisms of this kind we will stop at this point and in another paper we present the topology of the spatial mechanisms with bars and gears, which is much more complex than the similar planes already presented.

Next, all figures based on the previous chapter, already announced in this chapter, Fig. 4-10 will be shown.

## Discussion

The rods and gears consist of at least one movable articulated bar and one of the cylindrical, tapered or hipoidal gears. Only gears with circular or straight toothed

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gears, in which the relative position of the rotation or translation axes does not change, shall be considered. The topological structure of the gears and gears is characterized by a kinematic chain with articulated bars and at least one kinematic chain with gears. The kinematic chain may be chain open (with a fixed rotation joint) or closed chain (with at least two fixed joints). The kinematic chain with gears is attached to the kinematic chain with bars so that at least two gear wheels have centers in the bars of the bars and some wheels may be integral with the bars. In practice, some of these gears with gears and gears are known as planetary gears with cylindrical, conical or hipoidal gears.

The gearing of these gears in these complex mechanisms is carried out in the form of series, parallel, or both parallel-series trains.

The system is made according to the articulated plan cinematic chain, which can be made as an open or closed kinematic chain.

Flat-bellows and gears with open kinematic chain are divided into elementary mechanisms (with a single articulated bar) and layered complex mechanisms with at least two articulated bars. The gears and gears of the first category are called planetary mechanisms, being used as planetary mechanical transmissions.

In turn, the elementary mechanisms are made with a central wheel with the fixed rotation axis (Fig. 1) and with two central wheels (Fig. 2), whose axes coincide with the fixed axis of the articulated bar.

Elementary mechanisms with a central wheel (Fig. 1) have a central wheel marked with a Fig. 1 and a satellite wheel 2 with the mobile shaft. The bar is numbered 3 and the joints are marked with letter A0 (double joint) or A (simple joint).

The two wheels 1 and 2 form a cylindrical gear, which is external (Fig. 1a) or interior (Fig. 1b and 1c). Each toothed wheel is represented by the rolling circle, which in the kinematic schematics symbolizes a continuous line.

The mobility of this gear with bars and gears is equal to 2, which is deduced from the structural-numerical formula (1). By immobilizing the crank wheel, the mechanism will have $M = 1$ mobility, in which case the bar 3 may be a driving member and the toothed wheel 2 will become a driven member.

In this case, a point on the wheel 2 will describe an epicicloid curve (Fig. 1a), a hypo-cycloid (Fig. 1b) or a pericicloid (Fig. 1c).

The central two-gear center gears (Fig. 2) are obtained from the previous ones by the addition of a gear wheel 4 which engages the wheel 2' integral with 2.

Since a toothed wheel is structurally topological equivalent to a diadem cinematic chain, the mobility of the new mechanisms (Fig. 2) is preserved, so $M = 2$.

The mobility value is calculated by the formula (1) in which the numerical values specific to this two-wheel center mechanism (5) are introduced.

Complex gears with stacked bars and toothed wheels are obtained by overlaying the elementary mechanisms previously analyzed.

Overlaying refers to the kinematic chain with bars, which can have two bars (Figure 3a) or several bars (Figure 3b).

In the kinematic analysis of the two-bar mechanism (Figure 3a), it should be noted that the wheel 3 is integral with the A0A bar and the wheel 2 is integral with the bar AB. These solidarizations are highlighted in both projections, both in the axial plane and in the transverse projection, corresponding to the plane of the gears and gears.

There are four outer cylindrical gears, two at each level, which requires verification of the following deduced relationships from the equal distance between axes (8-9).

The composite block mechanism (Fig. 3b) is composed of the A0ABCD open-kinematic kinematic chain (in which the last CD is integral with the toothed wheel 7) and the kinematic chain with gears located in planes parallel to the main chain.

It is noted that the gears 2 and 2' are integral with the bar AB and the toothed wheel 6 is integral with the articulated link bar BC.

For the first two cylindrical gears, mounted in parallel to the zero level, there is the relation (8), taking into account the notations identical to those in the kinematic scheme analyzed above.

The mobility of the overlayed mechanism (Fig. 3b) is $M = 3$, which is verified using formula (12).

These planar mechanisms have, as the main chain with bars, a kinematic contour of the articulated quadrilateral, articulated pentalater, articulated hexalator, etc. The kinematic chain with toothed wheels is attached to the bar chain by positioning each circular wheel with the center in a polygonal contour joint.

The chain mechanism with quadrilateral bars is made with two, three or four gears, these being distinct kinematic elements or being solidly mounted with certain bars of the closed kinematic contour. In some situations, toothed wheels are also used with the centers placed at certain points on the bars, other than their joints.

Where appropriate, the articulated quadrilateral is crank-type, double crank and double swing (with simple and complex variants).

The kinematic chain with the crankshaft (Fig. 4) is further considered to be attached to the kinematic chain with two, three or four gears, respectively one, two or three cylindrical outer or inner gears.

Assuming that the mobility of the complex gear with bars and toothed wheels is $M = 1$, one of the

gears of the gears attached solidarizes with one of the articulated bars 1, 2 or 3.

Variant 1 (Fig. 4a) is obtained when wheel 2 is integral with rod 2 of length AB = 12 and gear wheel 4 has a fixed rotation axis in B0 being a driven wheel.

Because the toothed wheel 4 is a distinct kinematic element, equivalent to a zero mobility chain diadem, by adding it to the articulated quadrant (0, 1, 2, 3) and $A_0ABB_0$ respectively, the mechanism mobility is preserved.

For verification, mobility is calculated with the general formula (1), where the numerical values specific to this complex mechanism are introduced (Fig. 4a), (14-15).

Variant 2 (Fig. 4b) has two cylindrical gears mounted on bars 2 and 3, where wheel 1 with a center in A is integral with crank 1 of length $A_0A = 11$ and wheels 4 (4') and 5 are elements distinct cinemas, having centers in B and $B_0$ respectively. The two toothed wheels 4 (4') and 5 are equivalent to two dyadic chains, which preserve the mobility of the quadrilateral mechanism M = 1.

Variant 3 (Fig. 4c) comprises three cylindrical gears mounted on bars 1, 2 and 3, wherein the toothed wheel 0 with the center in A0 is integral with the base of the quadrilateral. Wheels 4 (4'), 5 (5') and 6 are distinct elements which equate to three dyadic chains so that M = 1 mobility is preserved.

Chain mechanisms with pentalaters can be made with one or more cylindrical gears attached to the articulated pedal (Fig. 5), in which, in order to obtain the mobility one (M = 1), two conditions are introduced which aim at the solidarity of two wheels toothbrushes with distinct bars.

It is noted that from each of the above-mentioned variants, by attaching another rod of the articulated pentalater there are obtained two other variants of gears and gears, which means 9 distinct variants.

Variant 1 (Fig. 5a) is obtained by using two toothed wheels (with teeth numbers $z_3$ and $z_0$) having the centers in the C and C joints of the bar 4 and solidarized by the movable bar 3 and the fixed 0 respectively.

In this way, the engagement of the two wheels is equivalent to the introduction of an additional link between bars 3 and 0, which is equivalent to a bar and two articulations whose mobility is -1.

The mobility of the resultant mechanism (Fig. 5a) is that of the articulated pentalater (M = 2), to which is added the mobility of the inserted engagement connection (-1), i.e., $M = 2-1 = 1$.

## Conclusion

The rods and gears consist of at least one movable articulated bar and one of the cylindrical, tapered or hipoidal gears. Only gears with circular or straight toothed gears, in which the relative position of the rotation or translation axes does not change, shall be considered. The topological structure of the gears and gears is characterized by a kinematic chain with articulated bars and at least one kinematic chain with gears. The kinematic chain may be chain open (with a fixed rotation joint) or closed chain (with at least two fixed joints). The kinematic chain with gears is attached to the kinematic chain with bars so that at least two gear wheels have centers in the bars of the bars and some wheels may be integral with the bars. In practice, some of these gears with gears and gears are known as planetary gears with cylindrical, conical or hipoidal gears.

The gearing of these gears in these complex mechanisms is carried out in the form of series, parallel, or both parallel-series trains.

The system is made according to the articulated plan cinematic chain, which can be made as an open or closed kinematic chain.

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## Author's Contributions

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## Ethics

Authors should address any ethical issues that may arise after the publication of this manuscript.

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