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Some Aspects of the Structure of Planar Mechanisms

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Abstract: The machine is a technical system made up of distinct kinematic component parts (called kinematic elements) which, following the imprinting of movements imposed on an element or elements (considered as leading elements), cause movements to all other kinematic elements in order to execute a useful mechanical thing, or transforming some form of energy into mechanical energy. It follows from the previous definition, three essential characteristics of the machine: the machine is a technical system; its kinematic elements have determined (desmodromic) movements; either to perform either a useful mechanical thing, calling it a lucrative machine, or transforming some form of energy into mechanical energy, bearing the name of a motor car. The lucrative machines are cars, locomotives, motor wagons, presses, machine tools, pumps, compressors, agricultural machines, lifting and transporting machines, etc. The motor vehicles are external combustion (Stirling, Watt) or internal combustion engines (Lenoir, Otto, Diesel, Wankel, star), turbines, hydraulic motors, reaction engines, pneumatic motors, electromagnetic), ionic engines, energy beam or LASER motors, etc. The most used mechanisms in machine building were and still maintain those that operate in a plane or in parallel planes. For this reason, new analytical methods have been developed and developed to determine all the essential aspects of these mechanisms in order to improve the design of machine components. For this reason, it is necessary to present a general presentation of the mechanism of the design of the mechanisms, the present paper dealing only with the first aspect, namely the structure of the planar mechanisms. The most common mechanisms are planar, with bars, toothed, with cams, with a mortar cross, with chains, with belts, with tracks, with bolts, with liquids (hydraulic or sonic), with air (pneumatic). However, spacecraft with universal cardan shaft (universal joint) and cardanic transmission, with hyperboloidal gears (with cross axles), with pivots (spherical couplings), especially steering and suspension mechanisms, tripod mechanisms, mechanisms with space cams, screw and nut mechanisms, robots, serial and parallel systems, steppers, etc. The mechanism, as we have already shown, is composed of kinematic elements connected by kinematic joints (or couplings).

Keywords: Machines, Mechanisms, Industrial Robots, Automation, TTT Manipulator, Design, Joints or Couplings, Structure, Elements

Introduction

The machine is a technical system made up of distinct kinematic component parts (called kinematic elements) which, following the imprinting of movements imposed on an element or elements (considered as leading elements), cause movements to all other kinematic elements in order to execute a useful mechanical thing, or transforming some form of energy into mechanical energy. It follows from the previous definition, three essential characteristics of the machine:

- The machine is a technical system
- Its kinematic elements have determined (desmodromic) movements
- Either to perform either a useful mechanical thing, calling it a lucrative machine, or transforming some form of energy into mechanical energy, bearing the name of a motor car

The lucrative machines are cars, locomotives, motor wagons, presses, machine tools, pumps, compressors, agricultural machines, lifting and transporting machines, etc.

The motor vehicles are external combustion (Stirling, Watt) or internal combustion engines (Lenoir, Otto, Diesel, Wankel, star), turbines, hydraulic motors, reaction engines, pneumatic motors, electromagnetic), ionic engines, energy beam or LASER motors, etc.

Note: Engines may also be classified as lucrative machines, but only complex ones (complex work machines) called aggregates.

The development and diversification of machines and mechanisms with applications in all fields requires new scientific researches for the systematization and improvement of existing mechanical systems by creating new mechanisms adapted to modern requirements, which involve increasingly complex topological structures.

The modern industry, the practice of designing and building machinery is increasingly based on the results of scientific and applied research.

Each industrial achievement has backed theoretical and experimental computer-assisted research, which solves increasingly complex problems with advanced computing programs using increasingly specialized software (Aversa *et al*., 2016a; 2016b; 2016c; 2016d; 2017a; 2017b; 2017c; 2017d; Mirsayar *et al*., 2017; Cao *et al*., 2013; Dong *et al*., 2013; De Melo *et al*., 2012; Garcia *et al*., 2007; Garcia-Murillo *et al*., 2013; He *et al*., 2013; Lee, 2013; Lin *et al*., 2013; Liu *et al*., 2013; Padula and Perdereau, 2013; Perumaal and Jawahar, 2013; Petrescu and Petrescu, 1995a; 1995b; 1997a; 1997b; 1997c; 2000a; 2000b; 2002a; 2002b; 2003; 2005a; 2005b; 2005c; 2005d; 2005e, 2016a; 2016b; 2016c; 2016d; 2016e; 2013; 2012a; 2012b; 2011; Petrescu *et al*., 2009; 2016 a-e; 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; Petrescu and Calautit, 2016a; 2016b; Reddy *et al*., 2012; Tabaković *et al*., 2013; Tang *et al*., 2013; Tong *et al*., 2013; Wang *et al*., 2013; Wen *et al*., 2012; Antonescu and Petrescu, 1985; 1989; Antonescu *et al*., 1985a; 1985b; 1986; 1987; 1988; 1994; 1997; 2000a; 2000b; 2001).

The mechanism is a technical system consisting of distinct kinematic component parts (called kinematic elements), which have determinate and periodic movements, intended to transmit and/or transform the initial motion (given by one or more input elements) to the final element(s).

The mechanism thus fulfills the first two essential characteristics of the machine.

Mechanisms can be operated either separately or as devices included in winch machines or engines.

It should be noted that a machine generally contains several mechanisms.

The mechanism has kinematic elements and kinematic couplings.

Below are some mechanisms.

The most common mechanisms are planar, with bars, toothed, with cams, with a mortar cross, with chains, with belts, with tracks, with bolts, with liquids (hydraulic or sonic), with air (pneumatic). However, spacecraft with universal cardan shaft (universal joint) and cardanic transmission, with hyperboloidal gears (with cross axles), with pivots (spherical couplings), especially steering and suspension mechanisms, tripod mechanisms, mechanisms with space cams, screw and nut mechanisms, robots, serial and parallel systems, steppers, etc.

(a) (b)

Fig. 1: Mobile components of a thermal engine

Fig. 2: Components of a V engine

(a) (b)

Fig. 3: Bar mechanisms: (a) mec. piston; (b) mec. quadrilateral

(a) (b)

Fig. 4: Flat plane mechanisms with bars: (a) mec. with swinging rod; (b) mec. slide swing

(a) (b)

Fig. 5: (a) mecanismul transportor cu cruce; (b) mecanismul unui motor clasic în V

Figure 1a shows the pin connected to the piston (via a bolt) and Fig. 1b shows the engine shaft (or crank) which together constitutes the three movable elements of a thermal motor or compressor. In Fig. 2 we can see the main part of a classic engine crank in V (missing crankshaft).

In Fig. 3 there are presented two flat bars: (a) The whip-crank-piston mechanism; (b) planar (or articulated) quadrilateral mechanism.

In Fig. 4 there are presented two other planar mechanisms with bars: (a) The oscillating rod mechanism; (b) oscillating slide mechanism.

(a) (b)

Fig. 6: (a) the mechanism of a Lenoir engine (two-stroke engine); (b) the mechanism of a classic gearshift (manual)

(a) (b)

Fig. 7: (a) Cardan or universal joint mechanism (the cardan cross); (b) The two-beginner Malta cross crossing mechanism

(a) (b)

Fig. 8: (a) planetary mechanism; (b) rotating cam mechanism and translatable stick

In Fig. 5, two other flat bars are presented: (a) The cross conveyor mechanism; (b) Engine mechanism in V.

In Fig. 6, two other mechanisms are presented: (a) The mechanism of a Lenoir engine (two-stroke engine); (b) Mechanism of a classic gearshift (manual).

In Fig. 7, two other mechanisms are presented: (a) Cardan or universal joint mechanism (cardan cross); (b) The two-beginner Malta cross crossing mechanism.

In Fig. 8 two other mechanisms are presented: (a) the planetary mechanism; (b) the rotary cam mechanism and the translatable bar.

Materials and Methods

The mechanism, as we have already shown, is composed of kinematic elements connected by kinematic joints (or couplings).

Definition: "The kinematic couple is the permanent, direct and mobile link between two kinematic elements."

The classification of kinematic couplings can be done according to four main criteria: Geometric, cinematic, constructive and structural.

The Geometric Criterion

Geometrically, there are inferior and superior kinematic couplings.

The lower kinematic couplers are those where the contact between the elements is made on a surface. This surface may be cylindrical, conical, spherical, planar, helical, etc.

The lower kinematic couplers are reversible, the surfaces in contact being geometrically identical, the relative movement of the elements not changing regardless of which of them is fixed or movable, conducting or driven.

The higher kinematic couplers are those where the contact between the elements is made by a line or a point. The line may be straight or curved (arc of circle).

The higher kinematic couplers are irreversible. The best example is that of the wheel rail coupler (Fig. 9).

In case the rail 2 is fixed and the wheel 1 rolls the contact point I will describe the cyclode C12. If wheel 1 is fixed and rail 2 rolls, contact I will describe the evolution of E21 (Antonescu, 2000).

The Kinematic Criterion

From a cinematic point of view, we distinguish planar couplings and space couplings.

The planar kinematic couplets allow component elements only for plane movements (in one plane, or in several parallel planes between them).

Spatial kinematic couples allow spatial movement of space elements (there is at least one point that cannot be framed by moving it in only one plane).

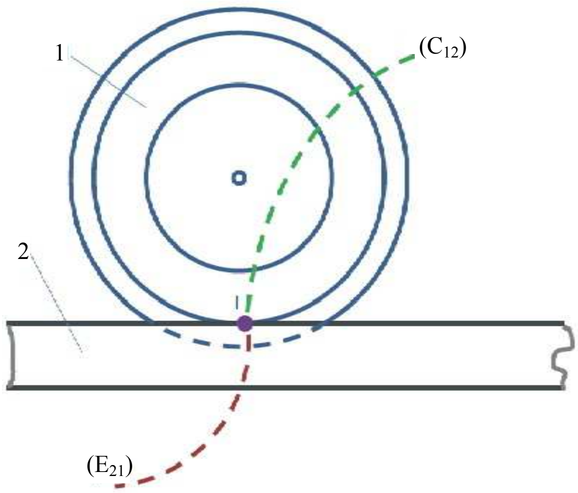


Fig. 9: High-wheel-rail superior coupling

Constructive Criterion

From a constructive point of view, the closed kinematic couplers and open cinematic couplings are distinguished.

Closed kinematic couplers are those in which the coupling of the coupling elements is made by steer guidance and the two coupling elements can not be separated without dismantling or breaking.

Open kinematic couplers are those where contact between the coupling elements is made directly by external forces (weight, electromagnetic, voltage, elastic, etc.) and the two coupling elements can be easily and directly separated without dismantling or breaking.

Structural Criterion

Structurally, kinematic couples are divided into five classes, depending on the number of degrees of freedom abducted, C1-C5.

If we denote the number of degrees of relative freedom that the kinematic coupler permits (l = 1,5) and with k the number of stopped movements (restricted by coupling), (k = 1,5), we can write the relations (1):

$$\begin{cases} l + k = 6 \\ l = 6 - k \\ k = 6 - l \end{cases} \tag{1}$$

The kinematic coupling class will be given by k (number of restrictions imposed by the coupling).

For Class 1 couples, which have a single restriction and 5 freedoms, the sphere coupling in the upper (space, open, C1) plane is shown. For second-class couples, we have the sphere in the cylinder (upper, space, closed, C2) and the cylinder on the plane (upper, space, open, C2). At third class couples, we have the sphere in the sphere (lower, space, closed, C3), the sphere in the cylinder, with a finger (upper, space, closed, C3) and plane (lower, flat).

In fourth class couplings, we have a torch that guides another torch (upper, space, closed, C4) and cylinder in the cylinder (lower, space, closed, C4). Here too we can remember the upper couplers with cams, toothed wheels, with a bolt, a cross from Malta, a universal or universal joint (Fig. 10), the tripods (planetary ones, Fig. 12), the Thompson coupler (Fig. 11) with constant speed, or ball (Fig. 13), etc.

For fifth class couplings, we have the rotation coupler (lower, flat, closed, C5) and the translation coupler (lower, flat, closed, C5). However, we can also remember the nutnut coupling (Fig. 14).

By definition, kinematic couples bind two kinematic elements between them, but no less than two.

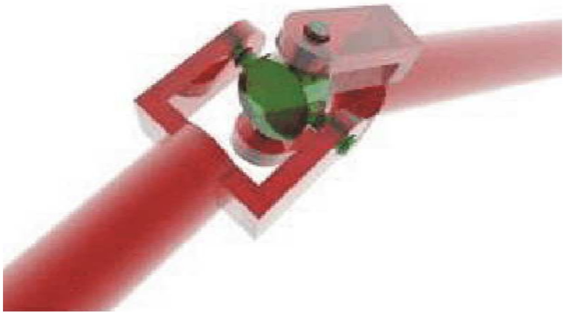


Fig. 10: Cardan cross or universal joint

Fig. 11: The Thompson couple

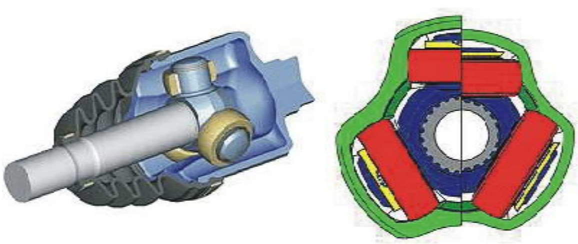


Fig. 12: The tripod couple

In some classifications, therefore, normal couplings are called simple and complex (or compound or multicouple) are referred to as couplers that violate the definition consisting of multiple elements, but also from multiple links. Such a coupling has always p-1 bonds and p elements and has the radial elements (in parallel, Fig. 15a), in series (Fig. 15b), or mixed (Atkinson *et al*., 1986). It is considered to be a single composite couple and it analyzes all its movements given by the freedoms gathered from all the simple component couplings (Fig. 16). Thus, the coupling of Fig. 16 is composed of four distinct kinematic elements and three simple couplings. In the table in Fig. 17 are presented the axonometric constructive schematic of the elementary couplings.

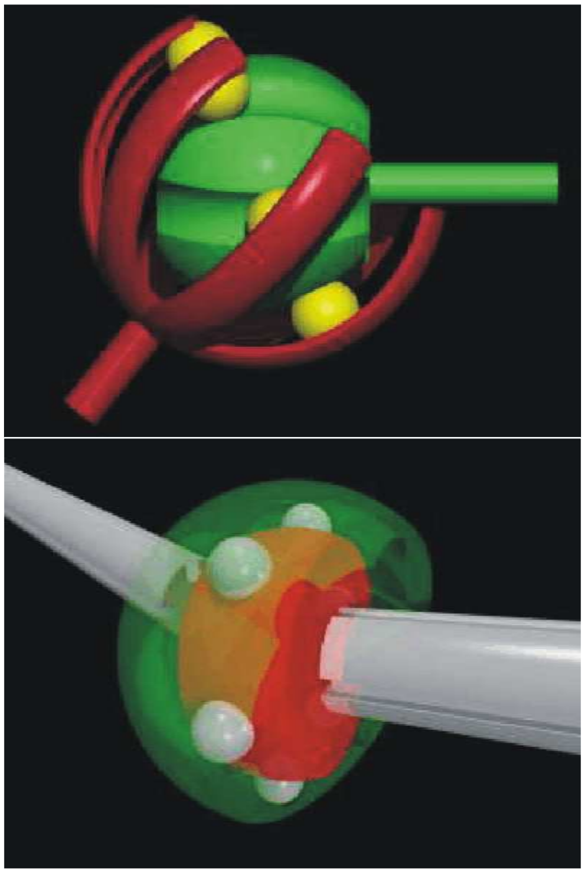


Fig. 13: Constant speed coupling (ball coupling)

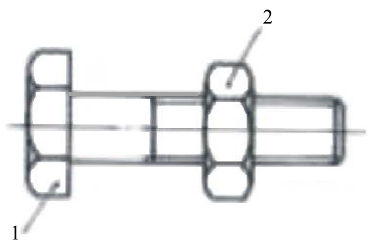
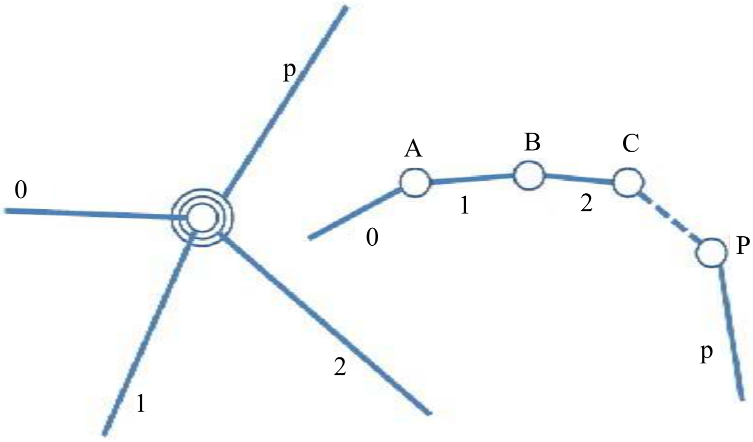


Fig. 14: Screw-nut coupling



(a) (b)

Fig. 15: Complex couplers

Fig. 16: Complex couplers

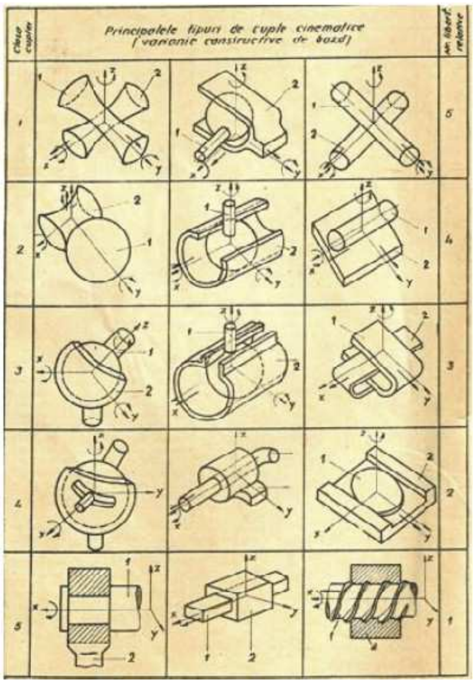


Fig. 17: Table with axonometric constructive representations of elementary couplings

Results

The structural analysis of plane mechanisms will be followed, being the most common mechanisms. It is intended to determine the mode of formation of the mechanism, specifying the number and type of component kinematic elements and couplings, the degree of mobility of the mechanism, as well as the class to which it belongs (for this purpose the kinematic scheme, the structural scheme and the block diagram or connections).

Figure 18a shows a schematic diagram of a planar mechanism with bars. Figure 18b shows the kinematic schematics of the planar mechanism in Fig. 1, a simplified scheme that helps to study the mechanism (cinematic, structural, cinetostatic, dynamic, etc ...).

In Fig. 19 shows how to determine kinematic elements starting from the leading element 1 which performs a complete rotation (crank movement) and in Fig. 20, the kinematic coupler of the mechanism is identified and the complete kinematic schema with identified kinematic elements and kits will appear in Fig. 21.

The kinematic elements and couplings have already been intuitively identified on the drawing so that the tables of the couplings and the kinematic elements can easily be drawn, showing how each coupling is formed by connecting two elements (the resulting fifth-class coupling, which can be rotation - R or translation - T), but also how many links each element has (see table in Fig. 22).

The degree of mobility of the planar bar mechanism is determined by formula (2):

$$\begin{aligned} M_3 &= 3 \cdot m - 2 \cdot C_5 - C_4 = 3 \cdot m - 2 \cdot i - s \\ &= 3 \cdot 7 - 2 \cdot 10 - 0 = 21 - 20 - 0 = 1 \end{aligned} \tag{2}$$

where, m is the number of movable elements (in the present case $m = 7$), $C_5 = i$ = the number of fifth or fifth class couplings, comprising both the *R* and the *R* couplers (for the given mechanism $i = 10$) and $C_4 = s$ represents the number of fourth or upper class couplings (camshaft couplings, toothed gears, Malta cross, contact profiles, etc.), (in the case of the upper coupler not present, s = 0).

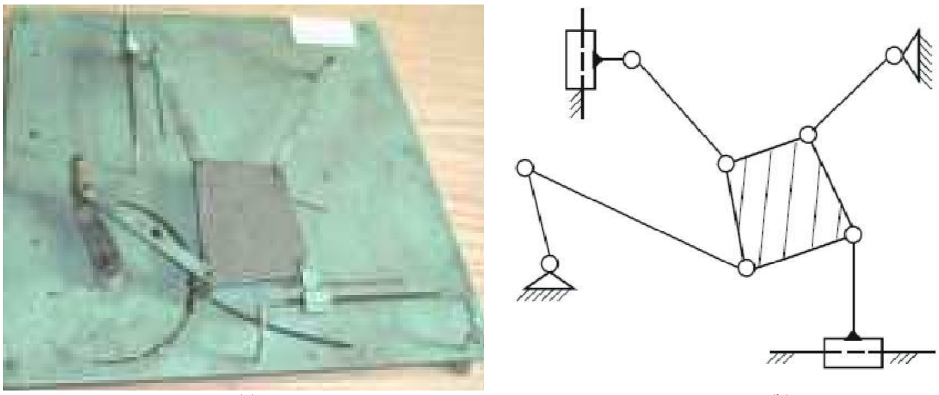

(a) (b)

Fig. 18: (a) Schematic drawing of the planar mechanism with bars (b) The kinematic scheme of the mechanism

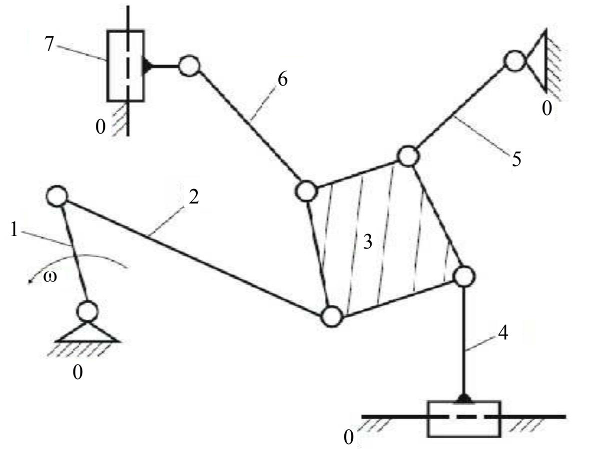


Fig. 19: How to determine kinematic elements starting from the leading element 1

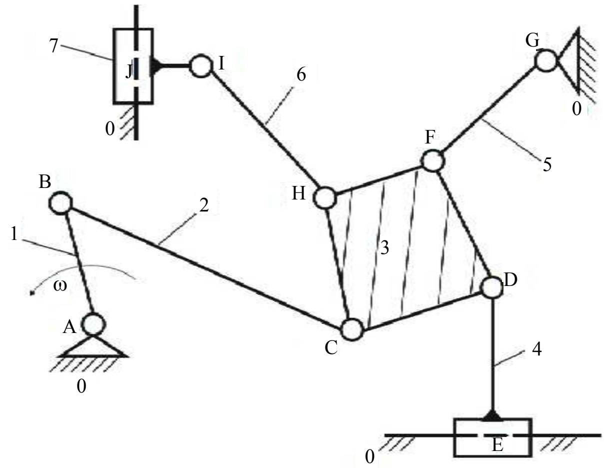


Fig. 21: The complete kinematic schema

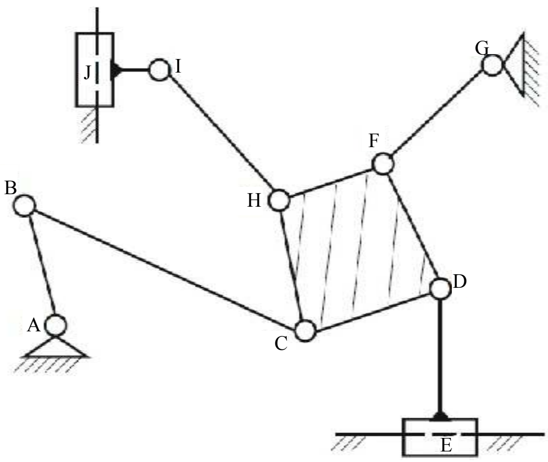


Fig. 20: The kinematic coupler of the mechanism is identified

Couple table

A(0,1)R
B(1,2)R
C(2,3)R
D(3,4)R
E(4,0)T
F(3,5)R
G(5,0)R
H(3,6)R
I(6,7)R
J(7,0)T

Elements table

0(A,E,G,J)IV	A E G J
1(A,B)II	A B
2(B,C)II	B C
3(C,D,F,H)IV	C H D F
4(D,E)II	D E
5(F,G)II	F G
6(H,I)II	H I
7(I,J)II	I J

Fig. 22: The kinematic elements and couplings

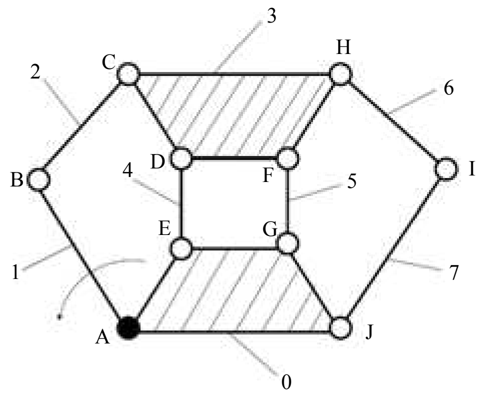


Fig. 23: The structural scheme of the mechanism

The structural diagram of the mechanism is built from the kinematic element table. It starts from the fixed element (0). After drawing it with the potential kinematic couplers (in the present case A, E, G, J), the first movable kinematic element (element 1) is attached to the frame, taking care to match the coupler A from the frame to that of element 1 Add the coupling B to it; then stick the elements 2, 3, 4 and 5 always matching the respective couplers. Add items 6 and 7; all kinematic elements and couplings are noted, after which the structural diagram is ready (see Fig. 23). Important observation: In the structural scheme, all the couplings are inferior (after the kinematic equation of the upper ones) and all are equally circular, as if only rotating, even if some of them are translation. Active couplers (motors) are black.

The mechanism connection scheme (Fig. 25) consists of rectangular blocks connected to each other. Goes to block 0, representing the fixed element that has only output buttons (A, E, G, J). The first linked button is A, which represents both the output of block 0 and the input to block 1 (EC driver element, or ME element moto). For 1 button B is output and for triad (2,3,4,5) it is input, just like the buttons (E and G). The triad has three inputs (B, E, G) and three inner couplings (C, D, F); An output coupler H is added, which becomes an inlet coupling for diada D (6,7), just like the coupling J coming out of the frame. Diada always has two input couplers (in this case, H and J) and an inner coupler (at the given mechanism, coupling I). No diaphragm (6, 7) is added to any output coupler so that the mechanism is fully studied.

Determining the structural formula is done using the structural scheme (divided into structural groups), or by using the connection scheme.

For the exemplary mechanism the structural formula reads.

Z (0) + EC (1) + T (2,3,4,5) + D (6,7) or Z (0) + ME (1) (6,7) or MF (0,1) + T (2,3,4,5) + D (6,7), i.e., zero pole + Guide element 1 (Moto Element), 1) to which triad T (2,3,4,5) and diada D (6,7) are added.

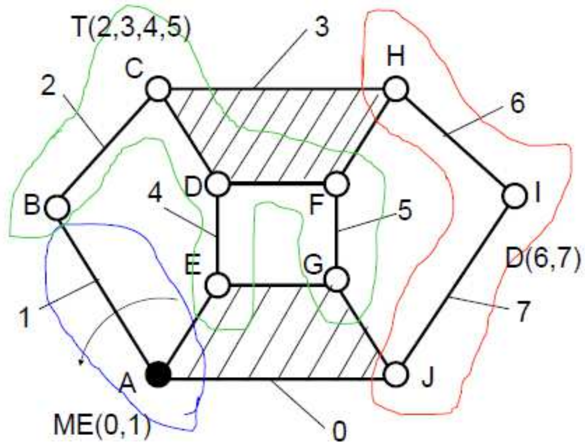


Fig. 24: The structural scheme of the bar mechanism divided into the structural groups: One can see a triad T (2,3,4,5) and a dyad D (6,7)

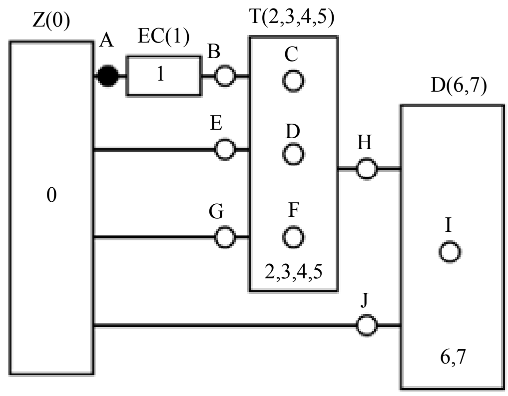


Fig. 25: Scheme of connection of the mechanism

The simplest structural group is diada.

A structural group (or Assuric) must not change the degree of mobility of the mechanism to which it is added; in other words the structural group has the degree of mobility equal to zero. For Flat Mechanisms, flat structural groups are used, which are synthesized according to the structural formula.

After equating the higher kinematic couplers, the formula takes the form (3):

$$3 \cdot m - 2 \cdot i = 0 \tag{3}$$

In Table 1 we give a few pairs of numbers that satisfy the relation (3), pairs by which the flat Assurice structural groups, containing only the couplers *i*, will be constructed.

The simplest structural group is dyad (see the first cell in Fig. 26). It consists of two kinematic elements (both of which have the rank II, that is, both the element 1 of length AB and the element 2 of length BC each have only two kinematic couplings, so each is of the order II).

In any structural group, the class of the group is given by the highest deformable closed contour, or by the highest ranked kinematic element.

There is no outline in the diadem, so its class is given by the highest rank element. Since both elements of a dyad have the second rank, it follows that the dyad class is also II.

The order of a structural group is given by the input couple of the group, couples which are also called semi couples or potential couples (since they only conclude when the structural group links to a mechanism).

Each structural group has (a + b) couplings:

- Inputs (semi couples) (they give the order of the group)
- inner couplings
- Output couplers (semi couples); these can be added in unlimited number or even absent, they are not represented on the definition of a structural group, they are added but are not part of the respective structural group

Diada has two input (potential) couplings, (in Fig. 26, marked with A and B), so the order of any dyad is 2. Each diadem also has an inner coupler (in the table in Fig. 26, it is marked with C).

In conclusion, the dyad is the simplest class II class of the 2nd order, having 2 elements and three couplings (two of which are semi couples because they are the input and the third is the inner one).

Table 1: Pairs of numbers that satisfy the relationship (3)

M	2	4	6	…
i	3	6	9	…

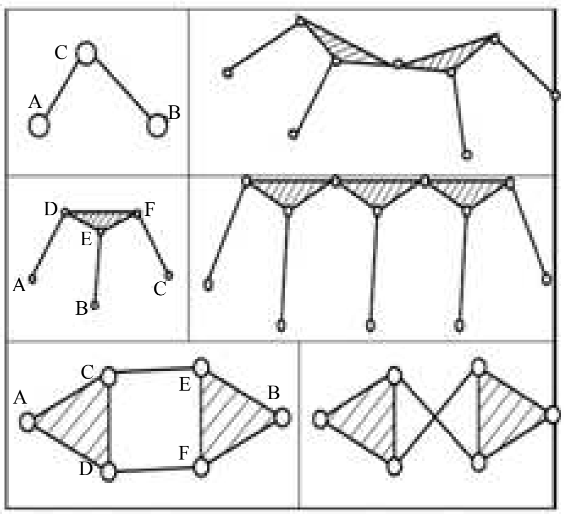


Fig. 26: Several schemes of simple (usual) structural groups

In the table of Fig. 26, the triad is immediately below the diadem. It has four elements and six kinematic couplings, of which 3 (three) are external input couplers (A, B, C) and three are inner couplers (D, E, F). The triad does not have any deformable contour, so its class will be given by the highest rank element. As it has three elements of rank II and one of rank III (triangle), it follows that any simple triad has the third class.

The order of the triad is given by the input couples (three in number), so the triad has the order 3.

Also, with four movable elements and six couplings, another structural group, namely tetrad, can be constructed (see the entire column on the left, the third row in the table in Fig. 26).

Tetrada has a definite deformable contour of IV, so it is a class IV class structure.

Since four couplings are internal and only two inputs (A and B), the tetrad is of the order 2.

In the same table on the right of the tetrad can be seen a tetrad in the cross, which is also the fourth class, the 2nd order.

In row 1, the second column, you can see a double triad (with 6 elements and 9 cups), it is also class III, but of the 4th order.

Below it is a triple triad (with 8 elements and 12 couplings), with a 3rd order, 5th order.

There are also pentas, hexas, etc ... but the usual ones are only: Dyad, triad or double triad and normal tetrad or a cross tetrad.

Discussion

For the mechanisms with five movable kinematic elements and a fixed one with one driving element (motor) two types of structural schemes can be obtained: (James) Watt (Fig. 27) or (George) Stephenson (Fig. 28).

However, we choose the fixed and leader elements in the Watt scheme to obtain two dyads. On the Stephenson scheme, we can get two dyads, but we can reach a triad if we choose the fixed and leading elements in a certain way (for example, in the structural scheme of Fig. 28, the movable element 5 must be chosen as the leading element, triad 1,2,3,4).

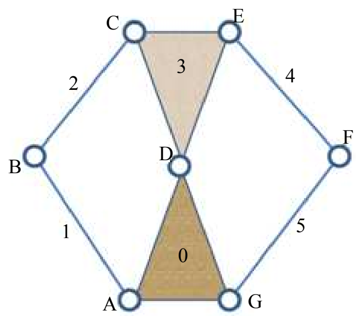


Fig. 27: Watt structural diagram

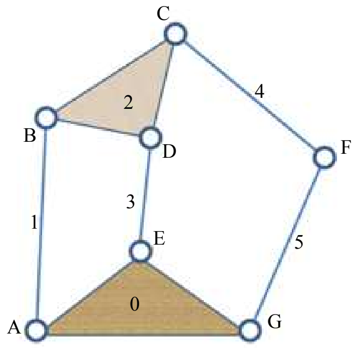


Fig. 28: Stephenson Structural Scheme

Conclusion

The machine is a technical system made up of distinct kinematic component parts (called kinematic elements) which, following the imprinting of movements imposed on an element or elements (considered as leading elements), cause movements to all other kinematic elements in order to execute a useful mechanical thing, or transforming some form of energy into mechanical energy. It follows from the previous definition, three essential characteristics of the machine: The machine is a technical system; its kinematic elements have determined (desmodromic) movements; either to perform either a useful mechanical thing, calling it a lucrative machine, or transforming some form of energy into mechanical energy, bearing the name of a motor car.

The lucrative machines are cars, locomotives, motor wagons, presses, machine tools, pumps, compressors, agricultural machines, lifting and transporting machines, etc. The motor vehicles are external combustion (Stirling, Watt) or internal combustion engines (Lenoir, Otto, Diesel, Wankel, star), turbines, hydraulic motors, reaction engines, pneumatic motors, electromagnetic), ionic engines, energy beam or LASER motors, etc.

The most used mechanisms in machine building were and still maintain those that operate in a plane or in parallel planes. For this reason, new analytical methods have been developed and developed to determine all the essential aspects of these mechanisms in order to improve the design of machine components. For this reason, it is necessary to present a general presentation of the mechanism of the design of the mechanisms, the present paper dealing only with the first aspect, namely the structure of the planar mechanisms.

The most common mechanisms are planar, with bars, toothed, with cams, with a mortar cross, with chains, with belts, with tracks, with bolts, with liquids (hydraulic or sonic), with air (pneumatic).

However, spacecraft with universal cardan shaft (universal joint) and cardanic transmission, with hyperboloidal gears (with cross axles), with pivots (spherical couplings), especially steering and suspension mechanisms, tripod mechanisms, mechanisms with space cams, screw and nut mechanisms, robots, serial and parallel systems, steppers, etc.

The mechanism, as we have already shown, is composed of kinematic elements connected by kinematic joints (or couplings).

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Author’s Contributions

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Ethics

This article is original and contains unpublished material. Authors declare that are not ethical issues and no conflict of interest that may arise after the publication of this manuscript.

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