TOPOLOGICAL STRUCTURE OF CONNECTING MECHANISMS IN THE ELECTRIC GRID

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Abstract: *The paper presents the main types of mechanisms used within the connecting systems from the high- and low-voltage electric grid. The purpose is the accurate construction of the kinematic diagrams of the mechanisms of electrical connection. For the low voltage connecting systems the topological structure of three kinematic schemes of articulated plane mechanisms is analysed. The structural-topological analysis is extended to other three kinematic schemes of simple plane mechanisms used as high voltage connecting systems. The structural-topological study is then applied to the complex plane mechanisms used as high voltage separators.*

Keywords: topological structure, kinematic scheme, mobility, connecting mechanism, electric grid.

1. ARTICULATED PLANAR MECHANISMS USED FOR LOW VOLTAGE CONNECTING SYSTEMS

Connecting systems normally use plane mechanisms with articulated bars [1,3,6,7], or in the simplest form of a single equalizing bar articulated frame (fig. 1.1) or in the shape of an articulated quadrangle (fig. 1.2, 1.3).

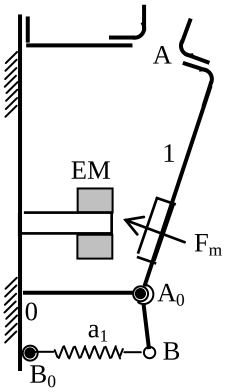

Fig. 1.1. Balanced mech. B;

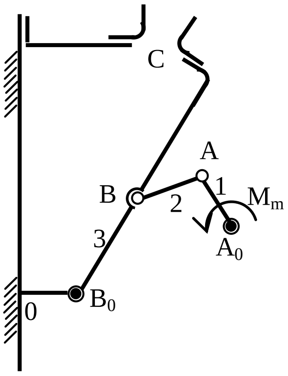

Fig. 1.2. Quadrilateral mechanism;

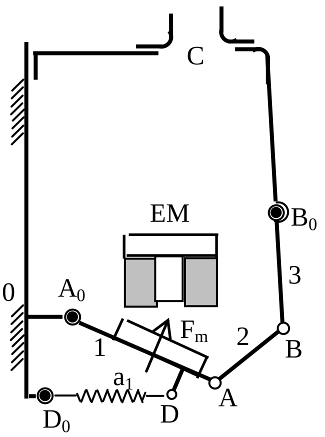

Fig. 1.3. Quadrilateral mech. B-B

The equalizing bar mechanism (fig. 1.1) shows the a_1 arc as the resistance force, opposing to the electromagnetic force F_m of EM, and it is one of the oldest solutions of electromagnetic relay switch [20] for small nominal currents. The quadrangle mechanism (fig. 1.2) is mechanically driven by the coupling M_m, by means of the crank 1, till the bars 1 and 2 are placed one continuing the other, which corresponds to the extreme position of the equalizing bar 3, when connection C is made.

The quadrangle type mechanism (fig. 1.3) is driven by the electromagnet EM till the bars 1 and 2 are one continuing the other, and the connection in point C is obtained in the extreme position of the equalizing bar 3. The arc a_1 acts as the resistance force and can open connection C if electric power is no longer supplied into the EM.

The mobility of the equalizing bar mechanism (fig. 1.1) shall be determined with the formula for plane mechanisms [5]:

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

From the kinematic scheme the following values stand out: $n = 1, C_5 = 1, C_4 = 0$.

Replacing these numbers in the formula (1) we obtain: $M_3 = 3\times1 - 2\times1 - 0 = 1$

The mobility corresponds to the rotation motion of the bar 1 (the equalizing bar) around the axis of the fixed articulation A_0. The connection in point *A* results from the rotation of bar 1, which can be obtained with the attraction driving force F_m. Interrupting the power supply into the EM results in breaking the connection in *A* assisted by the arc in tension a_1.

The mobility of the crank – equalizing bar mechanism (fig. 1.2) or of the equalizing bar - equalizing bar mechanism (fig. 1.3) is determined with the formula (1), where the numerical values are introduced: $n = 3, C_5 = 4, C_4 = 0$.

The following mobility results from replacement: $M_3 = 3\times3 - 2\times4 - 0 = 1$

The only independent motion is the rotation of bar 1 by means of the driving torque M_m (fig. 1.2) or by means of the driving force F_m (fig. 1.3), which leads to the connection in C.

2. SIMPLE PLANAR MECHANISMS USED FOR HIGH VOLTAGE CONNECTING SYSTEMS

We consider the kinematic scheme (fig. 2.1) related to the mechanism of a low oil power switch, for really high voltage with breaking arcs [1,3].

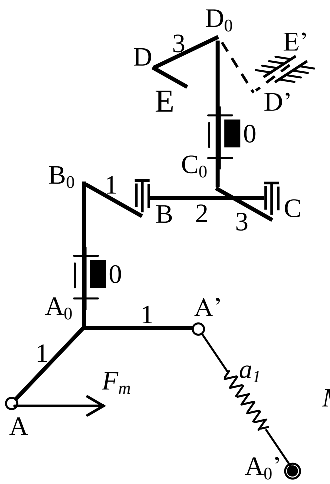

Fig. 2.1. Quadrangle mechanism.

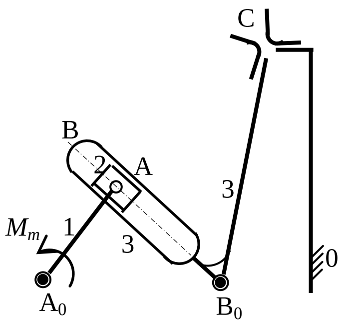

Fig. 2.2. Slipper mechanism.

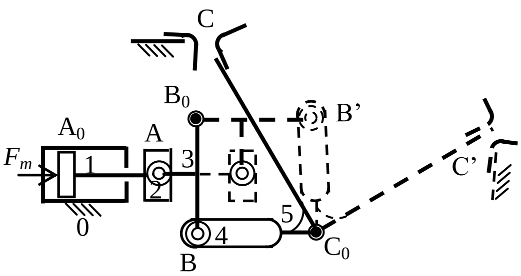

Fig. 2.3. Roller mechanism.

The mobile connection 3 has a rotating motion in an upper horizontal plane, and a part of it, DE, gets into the fixed connection. The articulated quadrangle B_0BCC_0 (fig. 2.1) receives the motion in the A_0A arm that is rotating in a lower horizontal plane of force F_m. Disconnection is obtained by means of the arc a_1 that is tensioned in the D'E' position.

The mobility of the mechanism is determined by means of the formula (1) in which we introduce the structural numerical parameters: $n = 3, C_5 = 4, C_4 = 0$. $M = 3\times 3 - 2\times 4 - 0 = 1$.

This value verifies the unambiguous determined motion of the mechanism with a single leading element 1. With regard to the slipper mechanism (fig. 2.2), guiding in the oscillating crank lever 3, the topological structure is the same as for the previous mechanism (fig. 2.1).

The difference consists in the existence of a translational coupling between the slipper 2 and the crank lever 3. The mechanism is actuated by means of the M_m coupling, and the connection position C must be reached in the extreme position of the bar 3, which corresponds to the angle (A_0AB_0) of 90^0.

The roller mechanism (fig. 2.3) is driven by a translational piston 1 actuated by the force F_m of the compressed air. We should notice that the rollers 2 and 4 (articulated by the equalizing bar 3) are connected to the upper part with the corresponding guide on the rod 1 respectively on the oscillating crank lever 5.

The mobility of the mechanism is determined by means of the formula (1) where we introduce the numerical values identified on the kinematic diagram (fig. 2.3): $n = 5, C_5 = 5, C_4 = 2$. Thus, we obtain for the mobility the value $M = 3\times 5 - 2\times 5 - 2 = 3$.

One of the three mobilities corresponds to the translational motion of the leading piston 1. The other two mobilities are represented by the independent rotary motions of the rollers 2 and 4. The connection in point C is obtaine din the left position of the piston 1, where the angle B_0BC_0 is 90^0, or in the right position of piston 1, where the angle $B_0B'C_0$ is equal to 90^0. The position of the connecting point C changes, and it can be placed in point C' in the right part of the figure (fig. 2.3).

3. COMPLEX PLANAR MECHANISMS USED AS AUTOMATED PNEUMATIC SWITCHES

These planar mechanisms with a complex structure are used as separators (switches) for three-phase high voltage power lines [1,2,3]. We consider the kinematic scheme (fig. 3.1) of an automated switch of 35 KW [3], which is pneumatically driven by means of a double piston with a rack bar, or by a roller guided in a crank lever.

From piston 1, driven by force F_m, by means of the rack bar gear (1) – geared sector (2), motion is transmitted to the articulated quadrangle (2, 3, 4). Thus, by means of the reciprocating rod 3, the rotation of bar 2 is transmitted to the equalizing bar 4, through the articulation D.

Following the kinematic chain, from the equalizing bar 4, through the reciprocating rod 5 with the articulations E and F, motion is transmitted to the translating rod 6 at the end of which there is the mobile connecting point K_1 of the first phase of electric power.

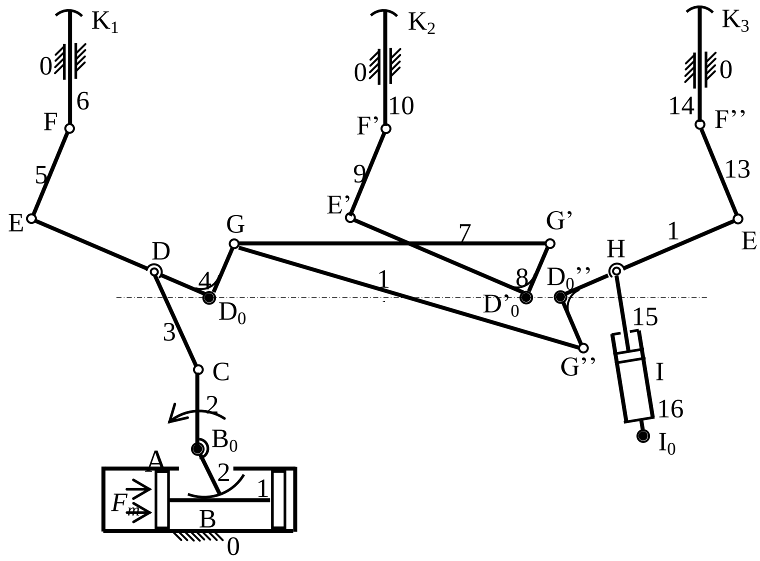

Fig. 3.1. Kinematic scheme of the three-phase connecting complex mechanism

Together with reaching the final position of rod 6, we obtain the synchronous displacement of rods 10 and 14, corresponding to the mobile connecting points K_2 and K_3 of the other two phases of the high voltage electric power.

From the equalizing bar 4, through the double articulation G, motion is transmitted to the articulated bars 7 and 11, and then to the equalizing bars 8 and 12.

On the way to the mobile connecting point K_2 we identify the articulated quadrangle $D_0GG'D'_0$ or through the component elements (0,4,7,8). Also, the kinematic way to the mobile connecting point K_3 contains the anti-quadrangle $D_0GG''D_0''$ (0, 4, 11, 12). The equalizing bar 12 is linked to a buffer made up of the kinematic elements 15 (piston rod) and 16 (cylinder). On the kinematic scheme (fig. 3.1) we identify the following numerical values of the parameters in the formula (1): $n = 16, C_5 = 23, C_4 = 1;\ M = 3 \times 16 - 2 \times 23 - 1 = 1.$

Mobility shows that the mechanism can be driven by a single leading element, piston 1.

The motion flow can be traced by means of the structural – topological formula of the drive mechanism motor *MM* for each contact K_1, K_2 and K_3, starting from the actuator mechanism MA(0,1). Thus, the structural – topological formula for the contact K_1 is

$$MM = MA(0,1) + LD(e_{12},2) + LD(3,4) + LD(5,6) \qquad (2)$$

In the second phase of the contact $K_{2,}$ the structural – topological formula becomes

$$MM = MA(0,1) + LD(e_{12},2) + LD(3,4) + LD(7,8) + LD(9.10) \qquad (3)$$

For the third contact K_3, the structural – topological formula is written

$$MM = MA(0,1) + LD(e_{12},2) + LD(3,4) + LD(11,12) + LD(13.14) + LD(15,16) \qquad (4)$$

In formulas (2, 3, 4) we noted as e_{12} the imaginary kinematic element equivalent to the superior kinematic joint made by the gear formed of the rack 1 and the geared sector 2. We should mention that the dyadic chain LD(15,16) of the RTR type is a sort of hydraulic buffer.

4. MECHANISM OF THE HIGH VOLTAGE THREE-POLE SEPARATOR

We take into consideration the kinematic scheme (fig. 4.1) of the mechanism of a separator for voltages higher than 60 kV.

Actuation of the contact bars in points K_1, K_2 and K_3 is carried out by means of the mechanism of a quadrangle of the equalizing bar – lever type (A_0ABB_0) through lever 1.

The three contacts are obtained in the extreme position of the equalizing bar 3, when lever 1 and the reciprocating rod 2 are one following the other.

From the equalizing bar 3, through the articulation C, the rotary motion of the former (clockwise) is transmitted through the reciprocating rod 4 to the equalizing bar 5 that is rotating, trigonometrically, until the bars b_3 and b_5 reach a vertical position (in contact K_2).

From the equalizing bar 3 the motion is transmitted, to the left and to the right, by means of articulated quadrangles to the equalizing bars 3’ and 3’’ with the fixed articulations B_0’ and B_0’’. Between the upper and lower axes of the fixed articulation B_0 and D_0 respectively B_0’, D_0’ and B_0’’, D_0’’ we mount insulators. Following the kinematic scheme of the separator mechanism (fig. 4.1) we infer the numerical values $n = 15, C_5 = 23, C_4 = 0$ that we introduce in the formula (1), resulting in $M = 3\times 15 - 2\times 23 - 0 = -1$

This result corresponds to a rigid structure, so that the mechanism should be an undetermined static system. In reality, the mechanism operates on the basis of only one leading element 1, and the result above is due to the double link between the equalizing bars 3, 3’ respectively 3 and 3’’. Thus, the reciprocating rods 7 and 7’ are mounted parallel to the reciprocating rods 6 and 6’, which does not introduce additional geometric conditions.

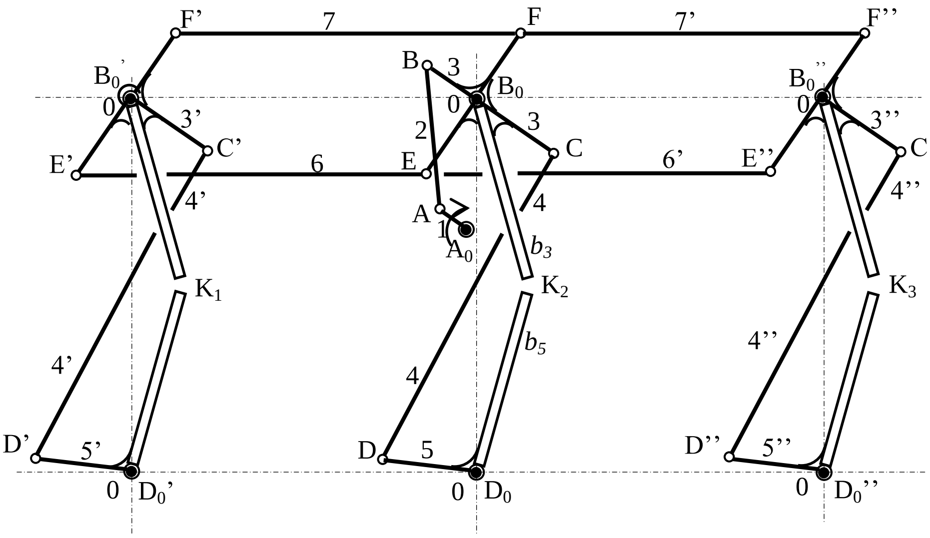

Fig. 4.1. Kinematic scheme of the three-pole separator mechanism

From a geometrical point of view, the mechanism can operate without bars 7 and 7’, case in which the structural parameters are: $n = 13, C_5 = 19, C_4 = 0$. Introducing the numerical values in the formula (1) we obtain $M = 3\times 13 - 2\times 19 - 0 = 1$

Indeed the mechanism transmits the unambiguous determined motion from the leading element 1 to the led elements 3, 5 respectively 3', 5' and 3'', 5''. The structural-topological formula of the drive mechanism is

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

5. THE MECHANISM OF THE SINGLE-COLUMN SEPARATOR (WITH ROLLER AND CRANK LEVERS)

The kinematic scheme of the mechanism (fig. 5.1) shows that the drive uses a pneumatic actuator p with a double piston 1 [3].

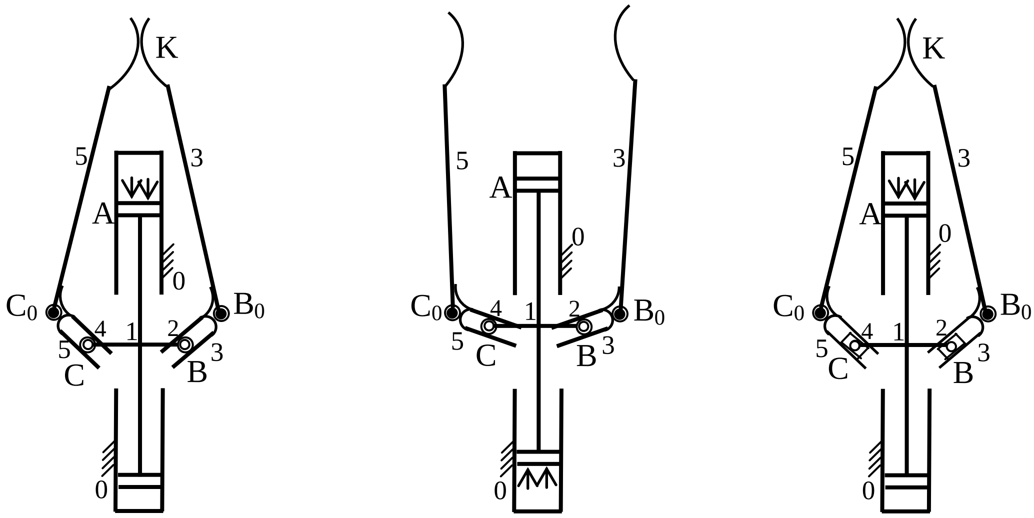

Fig. 5.1. Kinematic scheme of the single-column mechanism

We notice that the mechanism with a symmetrical structure has two rollers 2 and 4 guided in the corresponding crank levers 3 and 5.

Is identified $n = 5$ mobile kinematic elements; $C_5 = 5$ class kinematic couplings (mono-mobile) out of which a translational coupling A(0,1) and 4 rotary couplings B(1,2), C(1,4), B_0(3,0) and C_0(5,0); $C_4 = 2$ are 4 class kinematic couplings (bi-mobile) of plane rotary translation. Introducing these numerical values in the formula (1) we obtain

$$M = 3 \times 5 - 2 \times 5 - 2 = 3 = 1 + 2$$

We should notice that two of the three independent motions of the mechanism are passive mobilities, represented by the rotation of each of the rollers 2 and 4 around their centre.The available independent motion is the translational motion of the double piston 1 in the fixed pneumatic cylinder, vertically mounted.

The structural – topological formula of the drive mechanism analysed above is

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

The kinematic scheme in the position of closed contact K (fig. 5.1a) corresponds to the up-and-down displacement of piston 1, and the separating position of the two bars b_3 and b_5 (fig. 5.1b) corresponds to the up-and-down displacement of piston 1.

By replacing the plane upper kinematic couplings (2,3) and (4,5) with one equivalent element $e_{23}(2)$ respectively $e_{45}(4)$, we obtain the equivalent kinematic diagram (fig. 5.1c).

In this equivalent kinematic diagram all the kinematic couplings are class 5, or translational (0,1), (2,3), (4,5), or rotary (1,2), (3,0) and (1,4), (5,0).

We should mention that, for the constructive diagram of the pneumatic separating mechanism, we shall provide locking bolts for the two equalizing bars 3 and 5 especially due to the weight of the double piston 1.

6. CONCLUSIONS

The mechanisms related to electric switch systems are plane mechanisms with articulated bars, having a simple topological structure in the case of low electric voltages. The mobility of these mechanisms is usually carried out by means of electromagnets.

For high electric voltages, the plane mechanisms used are based on kinematic diagrams with single contour lines articulated bars, driven by spiral arcs.

For three-phase power lines, the mechanisms used are carried out as complex plane structures with parallel kinematic chains. These mechanisms are pneumatically driven, and are provided with a pneumatic buffer for one of the three phases.

We carried out an equivalent kinematic scheme, both for the pneumatic actuator and for the parallel final kinematic chains. The structural topological analysis of the mechanism of a three-phase separator shows that the kinematic diagram uses serial quadrangle mechanisms.

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