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To the theory of mechanisms subfamilies

A Fomin^{1,2}, L Dvornikov¹, M Paramonov¹ and A Jahr³

¹ Siberian State Industrial University, 42, Kirova st., Novokuznetsk, 654007 Russia

² IT SB RAS, 1, Ac. Lavrentieva ave., Novosibirsk, 630090, Russia

³ Düsseldorf University of Applied Sciences, 23 31/32, Gebäude, Düsseldorf, 40225, Germany

E-mail: alexey-nvkz@mail.ru

Abstract. The principles of formation of mechanisms subfamilies based on the usage of different kinds of kinematic pairs within the families of mechanisms are substantiated in the current paper. The division of mechanisms into subfamilies allows defining not only fundamental differences in the structure of mechanisms, but also provides the necessary foundation for the synthesis of new structures. 57 subfamilies of mechanisms have been totally distinguished. Among them, 31 subfamilies – within the zero family, 15 subfamilies– within the first family, 7 subfamilies – within the second family, 3 subfamilies – within the third family and 1 subfamily– within the fourth family. There were separately viewed planar mechanisms of the third family with three general imposed constraints and spatial mechanisms of the second family with two general imposed constraints in terms of their subfamilies. New methods of kinematical and dynamical investigations of mechanisms might be developed according to their analytical equations describing structural organization of different subfamilies of mechanisms.

1. Introduction

The creation of any mechanical system begins with the definition of its structural parameters. This procedure is called a structural synthesis. Despite of sufficient scientific developments in mechanisms and machines science, this part is less investigated.

The synthesis of newly designed structural schemes of mechanisms has been intuitively carried out, using previous experience, by layering the structural groups of zero mobility, called Assur groups [1]. Such solution is not always rational-functional because it does not consider all possible options.

The problem of how to develop the structural schemes with specified number of links and mobility in the system is a multivariate task. This is due to the fact that with the same number of links and kinematic pairs we can find a number of structural schemes differing from each other in structure and in types of kinematic pairs. To solve such problems, it is advisable to consider the structure in terms of the mechanisms imposed constraints and the possible usage of kinematic pairs with different numbers of relative motions.

Professor Artobolevsky I.I. suggested the classification of all the mechanisms into families in 1936 [2]. The number of constraints imposed on mechanism (m) was taken as a general criterion, which enters the universal formula of mobility of kinematic chains described by Professor Dobrovolsky V.V. [3]

$$W_m = (6 - m)n - \sum_{k=5}^{k-m=1} (k - m) p_k, \quad (1)$$



where W_m – number of degrees of freedom of a mechanical system, n – number of movable links, p_k – class of kinematic pairs from 5 to 1. The mechanisms as systems with one degree of freedom ($W_m=1$), are studied in the current investigation. The introduction of parameter m , accepting positive integer values from zero to four, allowed revealing five families of mechanisms.

2. Classification of mechanisms depending on the number of general imposed constraints

The zero family includes only classically spatial mechanisms without imposed constraints. Links of these mechanisms have motions of a general nature, they are connected by kinematic pairs of all five classes from p_5 to p_1 . A structural formula with $m=0$ introduced in the equation (1) will be written as follows

$$W_0 = 6n - 5p_5 - 4p_4 - 3p_3 - 2p_2 - p_1. \quad (2)$$

and called ‘Malishev’s formula’. The mechanism of the zero family is shown in Figure 1 [4].

The first family ($m=1$) includes spatial mechanisms with one general imposed constraint and it is described by the dependence

$$W_1 = 5n - 4p_5 - 3p_4 - 2p_3 - p_2. \quad (3)$$

The mechanisms of this family include all classes of kinematic pairs except five-degree-of-freedom pairs of the first class p_1 . Figure 2 provides an angled transmission mechanism which functions within the first family.

Spatial mechanisms of the second family (Figure 3 [5]) with two general imposed constraints ($m=2$) are constructed by only three classes of pairs: three-, two-, one-degree-of-freedom pairs

$$W_2 = 4n - 3p_5 - 2p_4 - p_3 \quad (4)$$

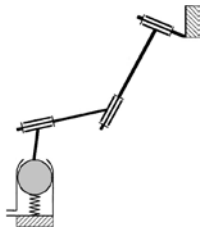


Figure 1. Spatial four-bar jointed mechanism ($m=0$)

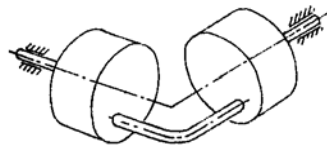


Figure 2. Angled mechanism ($m=1$)

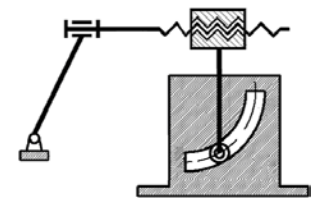


Figure 3. Spatial four-bar mechanism ($m=2$)

The mechanisms of the third family, planar or spherical, have three general imposed constraints and mobility formula (1) is written with $m=3$ as following

$$W_3 = 3n - 2p_5 - p_4 \quad (5)$$

Figure 4 provides a planar four-bar cam mechanism [6] of the third family, which has three imposed constraints.

The fourth family ($m=4$), where only wedge and screw mechanisms with four imposed constraints might be synthesized, is organized only by kinematic pairs of the fifth class

$$W_4 = 2n - p_5. \quad (6)$$

There is a mechanism of the fourth family presented in Figure 5 [7].

Thereby the number of general imposed constraints (m) allows the synthesis of mechanisms within five different families in accordance with their structural formulas of mobility (2) - (6), considered numbers of relative motions of links in the Cartesian spaces of coordinates and composition of kinematic pairs.

At the same time one should note the existence of multi-family mechanisms in the technique, which simultaneously includes kinematic chains of different families [8]. Figure 6 shows a kinematic scheme of the multi-family mechanism, which includes the mechanism of the second family ($m=2$)

formed by links 1, 2, 3, 4 and 7, and the mechanism of the fourth family ($m=4$) made of links 5, 6 and 7.

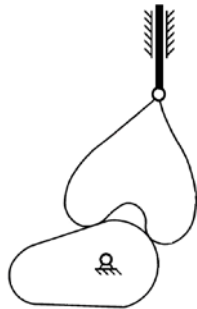


Figure 4. Four-bar cam mechanism ($m=3$)

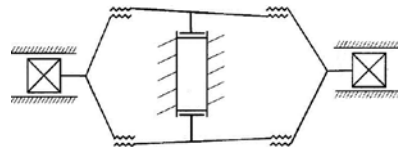


Figure 5. Progressive motion reducer ($m=4$)

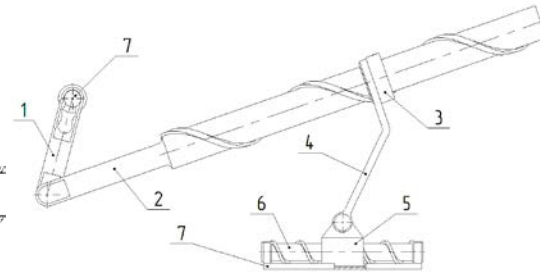


Figure 6. Multi-family mechanism ($m=3.5$)

The number of degrees of freedom of this mechanism can not be defined with the use of only one formula (2) - (6). It is calculated in accordance with the kinematic chains included in the mechanism's scheme. In this case, for the part of the second family we have mobility

$$W_2 = 4 \cdot 4 - 3 \cdot 5 = 1,$$

and for the part, belonging to the fourth family, mobility equals

$$W_4 = 2 \cdot 2 - 3 = 1.$$

To sum up total mobility of this mechanism is calculated as

$$W_{2,4} = W_2 + W_4 = 2,$$

which means that input motions are set for two links in the mechanism (for links 1 and 6).

3. Mechanisms subfamilies, their structural formulas

The mechanisms have more specific distinctions according to the composition of the applied kinematic pairs of different classes. In this connection it was offered to distinguish different subfamilies of mechanisms. Let us address to the formulas of mechanisms families (2) - (6).

It is possible to distinguish 31 subfamilies with different composition of kinematic pairs within the zero family of mechanisms, which are described by structural formula (1). The most complex subfamily is the first one, describing the equation

$$W_{0(1)} = 6n - 5p_5 - 4p_4 - 3p_3 - 2p_2 - p_1,$$

when the simplest one is the 31st, which includes only five-degrees-of freedom pairs p_1

$$W_{0(31)} = 6n - p_1.$$

The mechanisms of the first family include 15 subfamilies. The most complex among them is the first one, which contains pairs p_5, p_4, p_3 and p_2

$$W_{1(1)} = 5n - 4p_5 - 3p_4 - 2p_3 - p_2,$$

and the simplest one is the fifteenth, which contains only two-degrees-of-freedom pairs p_2

$$W_{1(15)} = 5n - 2p_2.$$

Only kinematic pairs of three classes – three-, two- and one-degree-of-freedom (p_5, p_4 and p_3) are used in the mechanisms of the second family. So, seven different subfamilies within the second family might be defined. Their structural formulas are provided here

$$W_{2(1)} = 4n - 3p_5 - 2p_4 - p_3, \quad W_{2(3)} = 4n - 3p_5 - p_3, \quad W_{2(5)} = 4n - 2p_4 - p_3,$$

$$W_{2(2)} = 4n - 3p_5 - 2p_4, \quad W_{2(4)} = 4n - 3p_5, \quad W_{2(6)} = 4n - 2p_4,$$

$$W_{2(7)} = 4n - p_3.$$

There are three subfamilies within the third family. Pairs p_5 and p_4 are simultaneously used in the first subfamily, while the second and the third subfamilies include either pairs p_5 or p_4 separately

$$W_{3(1)} = 3n - 2p_5 - p_4, \quad W_{3(2)} = 3n - 2p_5, \quad W_{3(3)} = 3n - p_4.$$

As the links of mechanisms of the fourth family connect among themselves in pairs of the fourth class, a singular subfamily within the fourth family has been found out. This subfamily is described by the structural formula of the following view

$$W_{4(1)} = 2n - p_5.$$

It tumbles to a fact that condition $W_m=1$, which means creation of a mechanism with a singular degree of freedom, cannot be provided in each subfamily. For instance, the sixth subfamily of the second family, which is organized only by kinematic pairs of the fourth class and is described by dependence

$$W_{2(6)} = 4n - 2p_4,$$

does not allow the synthesis of a mechanism because the coefficients before n and p_4 are even numbers, so condition $W_{2(6)}=1$ cannot be reached. Only mechanical systems with zero or grade mobility within this subfamily might be constructed.

4. Synthesis of elementary planar mechanisms of the third family within their subfamilies

Let us address to the mechanisms of the third family, which includes three subfamilies. The simultaneous use of one-degree-of-freedom (p_5) and two-degree-of-freedom (p_4) kinematic pairs is the indispensable condition for the first subfamily, which is described by the formula

$$W_{3(1)} = 3n - 2p_5 - p_4$$

with $W_{3(1)}=1$, we have $n = (2p_5 + p_4 + 1)/3$, where a minimal number of movable links of the mechanism will be equal to two ($n=2$) with a minimal number of kinematic pairs, which are $p_5=2$ and $p_4=1$. According to these parameters the cam mechanism with a higher kinematic pair 'cam-follower' is shown in Figure 7.

Only one-degree-of-freedom pairs of the fifth class might be applied in the second subfamily. Introducing $W_{3(2)}=1$ into the equation of the second subfamily, written as

$$W_{3(2)} = 3n - 2p_5,$$

and then expressing n , like $n = (2p_5 + 1)/3$, it is possible to find minimal values for n and p_5 which are 3 and 4. Figure 8 provides the simplest mechanism of the third family second subfamily – a four-bar jointed mechanism. The last expression for n has the solution when $n=1$ and $p_5=1$, which in fact describes the structure of a driving link – a crank or a slider.

Let us move to the third subfamily. It is formed only by four-degrees-of-freedom pairs p_4 . To express parameter n from structural formula $W_{3(3)} = 3n - p_4$ like $n = (p_4 + 1)/3$, we find that the minimal values are $n=1$, $p_4=2$. The mechanism synthesized by this solution is shown in Figure 9 [9].

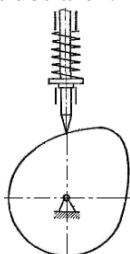


Figure 7. Three-bar cam mechanism

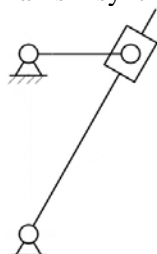


Figure 8. Link gear

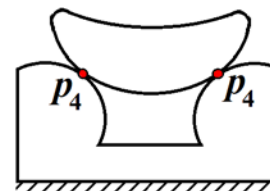


Figure 9. Two-bar mechanism with higher kinematic pairs

Despite the fact that the mechanisms of the third family (Figure 7-9) have the same number of imposed constraints ($m=3$) and their links move in plane, these mechanisms differ in structure and functioning as they are organized by different types of kinematic pairs.

5. Subfamilies of mechanisms of the second family in the view of their structure

Let us move from planar mechanisms to spatial ones and examine subfamilies of the second family. The first subfamily, described by dependence

$$W_{2(1)} = 4n - 3p_5 - 2p_4 - p_3,$$

simultaneously includes pairs p_5 , p_4 and p_3 . Setting $W_{2(1)}=1$, we express a parameter of the number of movable links like $n = (3p_5 + 2p_4 + p_3 + 1)/4$, where a minimum value for n is 2 (when parameters p_5 , p_4 and p_3 possess minimum values). In this way sum $(3p_5 + 2p_4 + p_3 + 1)$ shall equal to 8. It is possible only when $p_5=1$, $p_4=1$, $p_3=2$. Let us present the scheme of a spatial mechanism of the first subfamily constructed in accordance with the found parameters in Figure 10.

Two kinds of kinematic pairs might be used in the second subfamily, they are p_4 (fourth class) and p_5 (fifth class). From the structural formula of this subfamily

$$W_{2(2)} = 4n - 3p_5 - 2p_4$$

it follows that the simplest mechanism (with a minimum number of links) is such mechanism which includes two movable links ($n=2$), one pair of the fifth class ($p_5=1$) and two pairs of the fourth class ($p_4=2$). Figure 11 shows a kinematic scheme of this mechanism

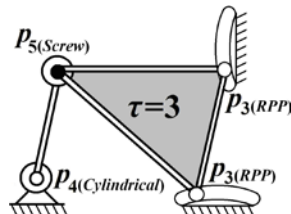


Figure 10. Three-bar linkage

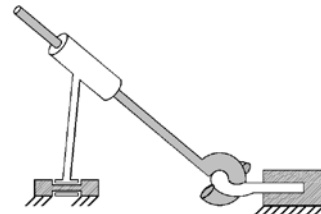


Figure 11. Three-bar linkage

The third subfamily includes mechanisms with three- (p_3) and one-degree-of-freedom kinematic pairs (p_5). From the structural formula of this subfamily

$$W_{2(3)} = 4n - 3p_5 - p_3$$

It has been found that the minimum number of movable links of mechanism will be $n=2$, the numbers of kinematic pairs are $p_5=2$ and $p_3=1$. This mechanism is shown in Figure 12.

The mechanisms of the fourth subfamily contain kinematic pairs of the fifth class p_5 only. Using their structural formula of mobility

$$W_{2(4)} = 4n - 3p_5$$

we have found that the simplest mechanism here is the mechanism with four movable links ($n=4$). Then it is possible to use only five pairs ($p_5=5$). The mechanism constructed with this solution is shown in Figure 13 [10].

It is impossible to apply one-degree-of-freedom kinematic pairs (p_5) in three residuary subfamilies of mechanisms of the second family. The mechanisms of the fifth subfamily are organized by pairs of the fourth p_4 and third p_3 classes. The formula of mobility of this subfamily

$$W_{2(5)} = 4n - 2p_4 - p_3$$

with $W_{2(5)}=1$ gives the solution $n=1$, $p_4=1$ and $p_3=1$. The kinematic scheme of the mechanism that corresponds to this solution is shown in Figure 14.

It was mentioned above that it is not possible to create mechanisms in the sixth subfamily as it is impossible to provide one number of degrees of freedom ($W_{2(6)}=1$). So, let us turn to the seventh subfamily, which is constructed by three-degrees-of-freedom kinematic pairs. The first solution of the equation

$$W_{2(7)} = 4n - p_3$$

with $W_{2(7)}=1$ is $n=1$, $p_3=3$. This describes a two-bar mechanism with one movable link and one fixed link connected by three pairs. Let us present the scheme of the mechanism in Figure 15.

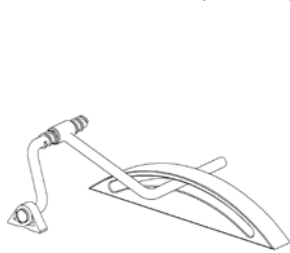


Figure 12. Three-bar linkage

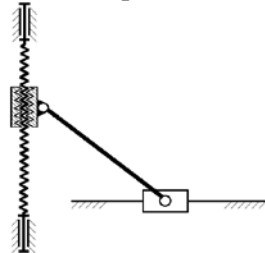


Figure 13. Press mechanism

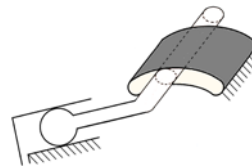


Figure 14. Two-bar linkage

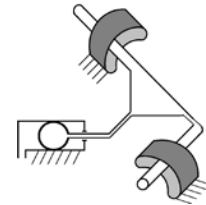


Figure 15. Two-bar linkage

Thereby all diversity of the mechanisms of the second family with two general imposed constraints is created within six different subfamilies. The kinematic schemes of the mechanisms demonstrated in Figure 10-15, have individual design features because of the usage of different kinematic pairs.

6. Conclusions

The division of mechanisms into families, offered in this paper, appreciably simplifies the problem of a mechanisms classification and a structural synthesis task and allows the introduction of more precise parameters of the constructed mechanical system.

The algorithms of a kinematical and dynamical analysis of linkages shall be developed according to their analytic equations.

The theory of mechanisms subfamilies might be developed in the direction of the synthesis of new kinematic chains, in which pairs are located in different sequences with the opportunity to change the complexes of relative motions of kinematic pairs. For example, with the appliance of kinematic pairs of the fifth class it is possible to use screw, rotate or prismatic pairs. This approach allows a structural synthesis of new mechanisms within families and subfamilies of the mechanisms.

Acknowledgments

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References

- [1] IFToMM Terminology, <http://www.iftomm.org>
- [2] Artobolevski I I 1939 *Prikladnaya matematika i mehanika*, **11(4)**
- [3] Dobrovolski V V 1936 *AN USSR*
- [4] Dvornikov L T and Obryadin A S 2012 Four-bar jointed mechanism. RU Patent 2446331
- [5] Dvornikov L T Fomin A S 2010 Spatial four-bar mechanism with screw pair and roller moving in a slot. RU Patent № 94515
- [6] Dvornikov L T Ermolaeva N Yu 2012 *RU Patent* 2456491
- [7] Dvornikov L T and Baklushin D S 2007 *RU Patent* 2295080
- [8] Dvornikov L T 1997 *Proc. VI scientific and practical conference of the problems of metallurgical and mining machines Novokuznetsk* 15
- [9] Adamovich N O 1998 Doctoral thesis Structural synthesis, kinematics and statics of planar non-Assur mechanisms
- [10] Ozol O G 1984 *M.: Nauka* 432