How to cite this article:

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Title of article: "Use of structural synthesis of mechanisms for dynamic simulation in Autodesk Inventor"

Mechanik, No. 2(2019)DOI: <https://doi.org/10.17814/mechanik.2019.2.24>

Use of structural synthesis of mechanisms for dynamic simulation in Autodesk Inventor

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The use of structural synthesis of mechanisms for dynamic simulation in Autodesk Inventor is presented. The stages of preparation for dynamic simulation (in particular the creation of connections between links) and the method of an intermediate chain enabling the creation of complete sets of structural solutions are presented. The procedure is illustrated by two examples.

KEYWORDS: structural synthesis, dynamic simulation, mobility of the mechanism, intermediate chain method

Introduction

The initial stage of designing the mechanisms constituting assemblies and sub-assemblies of machines is the proper selection of their structural diagrams. In many cases, structural modification of existing kinematic systems or a solution based on a random idea can lead to the use of irrational solutions. The designer should have a full set of theoretically possible structural schemes, because this determines the selection of the most favorable kinematic system [3].

The publication [1] presents the structural synthesis and classification of parallel manipulators. Methods for creating structural solutions with one or more platforms were presented, and they were classified by type of platforms and connections. The work [2] presents the method of structural synthesis of flat or spatial parallel mechanisms. It enables the creation of structural schemes, and the end result is a complete set of possible solutions of the spatial parallel mechanism for the required mobility. The work [3] provides an overview of issues in the field of the structure of mechanical systems. The authors discussed the methods of creating sets of possible solutions for kinematic systems and presented a catalog of selected types of mechanisms, sorted by type of active and passive cell. The work [4] presents the methodology for designing parallel manipulators. Structural synthesis of kinematic chains with six degrees of freedom was performed, creating a generic chain that can be reconfigured for additional solutions.

The purpose of this paper is to demonstrate how to use the hash chain method in the Dynamic Simulation module of Autodesk Inventor.

Autodesk Inventor dynamic simulation module

The first stage of dynamic simulation in Autodesk Inventor is to prepare the 3D model for analysis. It consists in separating the elements of the mechanism into fixed and mobile links and creating bonded groups, i.e. connections of elements that move together. The next step is to define the types of connections between the links of the analyzed mechanism.

In the Autodesk Inventor dynamic simulation module, the constraints are divided into: standard, rolling, sliding, 2D contact and force. Most standard connections have equivalents in the classification of kinematic pairs and can be created using automatic conversion of assembly bonds. Other types of connections are only created manually.

Classification of kinematic pairs is presented in tab. I [6], and in tab. II [7] - standard connections that occur in the Dynamic Simulation module.

TABLE I. Classification of kinematic pairs [6]

Class	Form 1	Form 2	Form 3
I
II
III
IV
V

TABLE II. Standard connections of the Dynamic Simulation module [7]

Connection name	Connection symbol	Equivalent in table I	Description
spatial		it is not a kinematic steam	rotation around axis <i>y</i> and <i>z</i> offset along the axis <i>x</i> , <i>y</i> and <i>z</i>
point-plane		class I form 1	rotation around axis <i>y</i> and <i>z</i> offset along the axis <i>x</i> and <i>z</i>
point-line		class II form 1	rotation around axis <i>x</i> , <i>y</i> and <i>z</i> offset around axis <i>z</i>
line-plane		class II form 2	rotation around axis <i>y</i> and <i>z</i> offset along the axis <i>x</i> and <i>z</i>
spherical		class III form 1	offset along the axis <i>x</i> , <i>y</i> and <i>z</i>
flat		class III form 3	rotation around axis <i>y</i> offset along the axis <i>x</i> and <i>z</i>
cylindrical		class IV form 2	rotation around axis <i>z</i> offset along the axis <i>z</i>
rotary		class V form 1	rotation around axis <i>z</i>
prismatic		class V form 2	offset along the axis <i>z</i>
weld		it is not a kinematic steam	no shift and rotation

Mechanism synthesis - intermediary chain method

In each mechanism (fig. 1), the base *O*, active part *C*, passive part *B* and intermediate link chain *U* [3] can be distinguished. Mobility *W* of the mechanism can be calculated from:

$$W = W_C + W_U + W_B \quad (1)$$

where: *W_C* - active cell mobility, *W_U* - intermediate chain mobility, *W_B* - passive member mobility.

When the number of degrees of freedom for *W*, *W_C* and *W_B* is known, the mobility of the intermediate chain can be calculated:

$$W_U = W - W_C - W_B \quad (2)$$

The mobility W of the flat kinematic chain is:

$$W = 3 \cdot n - 2 \cdot p_5 - p_4 \quad (3)$$

where: n - number of mobile cells, p_5 - number of class V kinematic pairs, p_4 - number of class IV kinematic pairs.

In turn, the mobility of the spatial mechanism is determined by the formula:

$$W = 6 \cdot n - \sum_{i=1}^5 i \cdot p_i \quad (4)$$

where: i - kinematic pair class, p_i - number of kinematic pairs of class i .

Using the relationships (3) or (4) on the mobility of the mechanism, for the mobility of the intermediate chain, determined from equation (2), a formula is obtained that for flat mechanisms takes the form (5), and for spatial mechanisms - the form (6):

$$3 \cdot n - W_U = 2 \cdot p_5 + p_4 \quad (5)$$

$$6 \cdot n - W_U = \sum_{i=1}^5 i \cdot p_i \quad (6)$$

The numbers n and p_i are natural numbers, therefore equations (5) and (6) allow the determination of a certain number of variants of structural solutions of the intermediate chain U [3].

Fig. 1. Concept of building a mechanism with an intermediate chain (O - base, C - active part, B - passive part, U - intermediate link chain) [3]

Flat mechanism - slide clamp

Fig. 2 shows a 3D model of a slide clamp.

In the dynamic simulation module, one prismatic connection (base - slide) and three rotary connections (base-lever, lever-connector, connector-slide) were created. The mobility calculated from the formula (3) is $W = 1$.

Fig. 3 presents a 3D model of the intermediate chain used in the original solution.

Fig. 2. 3D model of a slide clamp (1 - base, 2 - lever, 3 - connector, 4 - slide)

Fig. 3. 3D model of the intermediate chain of the slide clamp for the primary solution

After inserting the last connection, a message about excessive binding of the mechanism (by three degrees of freedom) appears. This is due to the fact that in the dynamic simulation module all mechanisms are treated as spatial. When the actual mobility of the mechanism W is known, the number of passive constraints r can be calculated:

$$r = W' - W \quad (7)$$

In the analyzed mechanism, the mobility calculated from the formula (4) is $W = -2$, the real mobility is $W' = 1$, and the number of passive constraints is $r = 3$.

In the dynamic simulation module, the number of passive constraints was called the degree of reduction, while the actual mobility - the degree of movement.

The program constantly checks the status of connections and informs the user about redundant connections. After clicking the Mechanism Status icon and expanding the window, one can see a replacement of the lever-connector rotational pair with a point-line pair (fig. 4). This exchange eliminates passive bonds. The mobility calculated from formula (4) is then $W = 1$ ($n = 3$, $p5 = 3$, $p2 = 1$, $p4 = p3 = p1 = 0$), and the number of passive constraints $r = 0$.

Using the intermediate chain method, in equation (2), substitute $W = 1$, $WC = 1$ and $WB = 1$. The calculated required mobility of the intermediate chain is $WU = -1$. After introducing the limit $n = 1$ and $p1 = 0$ and inserting into equation (6) $WU = -1$, the solutions given in tab. III.

Zależności i status mechanizmu

Informacje o modelu

	Początek	Koniec
Stopień redukcji (r)	3	0
Stopień ruchu (dom)	1	1
Liczba brył	4	
Liczba brył ruchomych	3	

OK Anuluj

Zamknięte łańcuchy kinematyczne

Łańcuch 1 / 1

Połączenia początkowe	Wiązania nadmiarowe	Połączenia końcowe
$r = 3$ $dom = 1$	Tx Ty Tz Rx Ry Rz	$r = 0$ $dom = 1$
Obrotowe: 3 (Dźwignia kpl: 1, Łącznik kpl: 1)		Punkt-linia
Obrotowe: 2 (Korpus kpl: 1, Dźwignia kpl: 1)		Obrotowe
Obrotowe: 4 (Łącznik kpl: 1, Suwak kpl: 1)		Obrotowe
Pryzmatyczne: 1 (Korpus kpl: 1, Suwak kpl: 1)		Pryzmatyczne

Fig. 4. Dependencies window and mechanism status for the original solution

TABLE III. Variants of the solution of the intermediate chain of the slide clamp

No..	n	p_5	p_4	p_3	p_2
1	1	1	0	0	1
2		0	1	1	0
3		0	0	1	2

The lever-connector pair rotary pair suggested by the program for point-line pair is in the tab. III marked with number 1. The solution marked with number 2 was chosen as rational - its 3D model is shown in fig. 5.

Fig. 5. 3D model of the intermediate chain of the slide clamp for the selected solution

After inserting a rotary connection (base-lever), cylindrical (lever-connector), spherical (connector-slider) and prismatic (base-slider) and after clicking the Mechanism status icon in the dynamic simulation module, the window shown in fig. 6 appears.

Fig. 6. The Dependencies window and the status of the mechanism for the clamp with the intermediate chain shown in fig. 5

The proposed solution is a mechanism without passive ties. Such mechanisms are characterized by [6]:

- insensitivity to execution errors,
- easy assembly and repair,
- partial or complete elimination of break-in.

Spatial mechanism - parallel manipulator

The intermediate chain method can also be used to design a parallel manipulator. Then in equation (2) $W = 3$, $W_C = 0$ and $W_B = 6$. Assuming that the intermediate chain will consist of three identical chains ($W_U = 3W_L$), the mobility of a single chain can be calculated:

$$W_L = \frac{W - W_C - W_B}{3} = -1 \quad (8)$$

After using the relationship (6) and introducing restrictions $n \leq 3$, $p_1 = 0$, $p_2 = 0$, eight possible solutions of the intermediate chain are obtained, presented in tab. IV.

Fig. 7 shows a selected 3D model of a parallel manipulator. It is based on a stationary plate 1 with bearing elements and motors driving the active links 2. Cardan joints 3 connect the members 2 with the passive links 4 and the members 4 with the working platform 5.

The solution presented in fig. 7 (when the cardan joint is treated as a class IV kinematic chain pair [5]) in tab. IV is marked with number 6.

TABLE IV. Variants of resolving the intermediate manipulator intermediate chain

Lp.	n	p ₅	p ₄	p ₃
1	3	3	1	0
2		2	0	3
3		1	2	2
4		0	4	1
5	2	2	0	1
6		1	2	0
7		0	1	3
8	1	0	1	1

Fig. 7. 3D model of the parallel manipulator (1 - fixed plate being the base of the manipulator, 2 - active links, 3 - cardan joints, 4 - passive links, 5 - working platform)

Summary

The application of the intermediate chain method allows the selection of rational structural solutions of kinematic chains from all possible configurations of kinematic pairs, forming the working mechanisms of machines and devices. Combination of kinematic pairs classification and mechanism mobility determination with elements of the Autodesk Inventor Dynamic Simulation module explains and specifies the use of proposed variants of structural solutions. In addition, it increases the creation possibilities and facilitates the correct selection of kinematic pairs of specific classes - for both flat and spatial mechanisms. In the process of designing elements, assemblies of machines and mechanisms, it is an effective tool supporting the work of the designer.

REFERENCES

- [1] Alizade R., Bayram C. "Structural synthesis of parallel manipulators". *Mechanism and Machine Theory*. 39, 8 (2004): 857–870.
- [2] Bałchanowski J. "General method of structural synthesis of parallel mechanisms". *Archives of Civil and Mechanical Engineering*. 16, 3 (2016): 256–268.
- [3] Gronowicz A., Miller S. „*Mechanizmy. Metody tworzenia zbiorów rozwiązań alternatywnych. Katalog schematów strukturalnych i kinematycznych*”. Wrocław: Oficyna Wydawnicza Politechniki Wrocławskiej, 1997.
- [4] Ibarreche J.I., Hernández A, Petuya V., Urizar M., Macho E. "Multioperation capacity of parallel manipulators basing on generic kinematic chain approach". *Mechanism and Machine Theory*. 116, 8 (2017): 234–870.
- [5] Miller S. „*Układy kinematyczne. Podstawy projektowania*”. Warszawa: Wydawnictwa Naukowo-Techniczne, 1988.
- [6] Olędzki A. „*Podstawy teorii maszyn i mechanizmów*”. Warszawa: Wydawnictwa Naukowo-Techniczne, 1987.
- [7] Stasiak F. „*Zbiór ćwiczeń AutodeskInventor 2018. Kurs Professional*”. ExpertBooks, 2018