TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 60, Issue IV, November, 2017

MOBILE CAM MECHANISMS SYNTHESIS USING THE CHARACTERISTIC POINTS. PART I: – THEORETICAL NOTIONS AND CALCULATION ALGORITHMS

Claudia-Mari POPA, Dinel POPA, Nicolae-Doru STĂNESCU, Nicolae PANDREA

Abstract: *The paper is structured in two parts. In the first part, the one in discussion, simple and complex mobile cam mechanisms are presented, as well as their domain of usage. The paper highlights the advantages of graphical methods and suggests the usage of characteristic points in solving the synthesis problems of mobile cam mechanisms, with the assistance of a CAD software. The considerable number of graphical constructions are made with AutoCAD with the help of AutoLisp functions. A calculation algorithm and an AutoLisp function are proposed, which will be used in the second part of the paper, in three applications, to obtain the cams of simple mechanisms and the complex mobile cam mechanisms.*

Key words: *Mechanism, cam, follower, synthesis, characteristic points, function, AutoLisp, AutoCAD.*

1. INTRODUCTION

Cam mechanisms are simple mechanisms, used almost in all technical fields, due to the fact that they provide any displacement law of the driven element – the follower.

A simple cam mechanism has 2 elements, cam and follower (Fig. 1), and the mechanisms with more then 2 elements are called complex cam mechanisms.

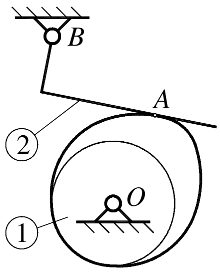

Fig. 1. Simple mechanism with mobile cam.

Complex cam mechanisms are obtained by amplifying a simple cam mechanism with a structural group: dyad (Fig. 2), triad (Fig. 3), tetrad (Fig. 4).

In [4] there is provided an adaptive distribution mechanism for adjusting the valve stroke 7, continuously, depending on the load and speed (Fig. 5). The functioning principle of this mechanism, (Hara's Mechanism), for a given position of the control lever *DE*, is the following: at the rotation of cam 1 jointed at *O*, the oscillating follower 2 jointed at *B* in rotating and through the shoe 4 (with relative circular displacement towards the follower), the lever 3 and the pushing rod 5 is produced the rotation movement of the rocker 6 jointed at *I* and via the point to point contact *J* a translation movement is sent to the valve 7 with the guiding *K*. Structurally speaking, the mechanism is obtained from a simple mechanism with mobile cam, the elements 1 and 2, amplified with two dyads: *EFG* (the elements 3 and 4) respective *GHI* (the elements 5 and 6).

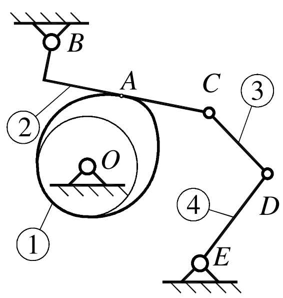

Fig. 2. Mobile cam mechanism amplified with a dyad.

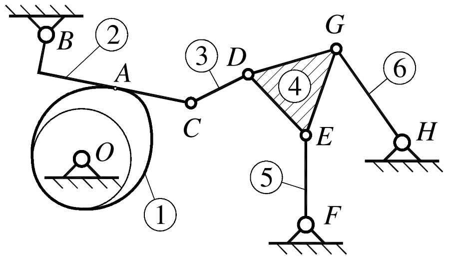

Fig. 3. Mobile cam mechanism amplified with a triad.

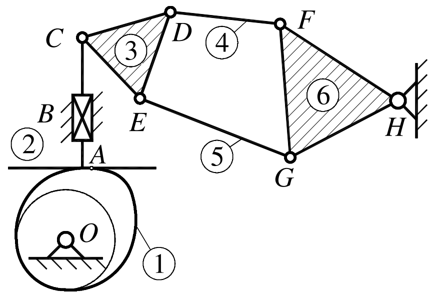

Fig. 4. Mobile cam mechanism amplified with a tetrad.

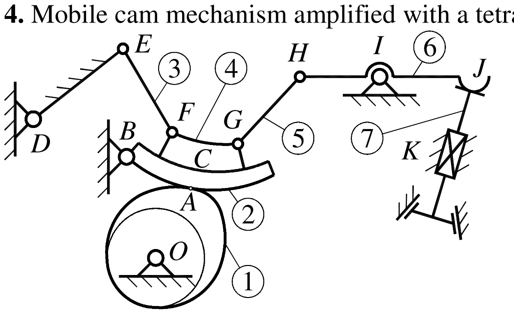

Fig. 5. Mechanism with adaptive distribution.

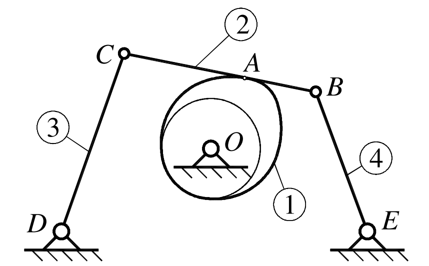

Fig. 6. Articulated four-bar cam mechanism.

Also, in the category of complex mechanisms with mobile cam is the mechanism in Fig. 6. Driving the rod 2 of the jointed four-bar mechanism *EBCD* is made by the cam 1. So, the rod 2, is also a follower that, in this case has a plane-parallel motion.

Such mechanisms [1], [2] are used in constructing mechanisms with intermittent biting, differential mechanisms, projection devices, presses, variable mass mechanisms, sorting and feeding mechanisms, cutting and punching mechanisms. For instance, in Fig. 7, we present the kinematic schema of a mechanism for feeding with raw materials.

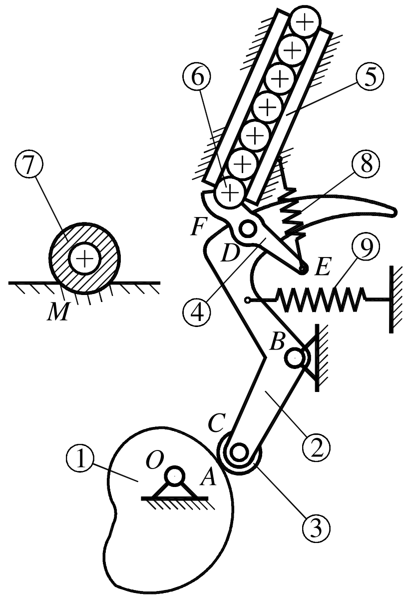

Fig. 7. Kinematic schema of a mechanism for feeding with raw materials.

The motion is transmitted from the cam 1, by the roller oscillating tappet 2. This follower oscillates around the joint B, and at the point D, by a revolute pair, it has the feeding element 4. From the channel 5 the element 4 transports the raw material to the feeding point 7. The spring 8 has the role to maintain the contact between the feeding element and the raw material, why the spring 9 has the role to bring back the tappet in the initial position. At a complete rotation of the cam 1 the tappet 2 rotates putting into motion the feeding element 4 by means of which one transports one by one raw material 6 to the feeding place 7.

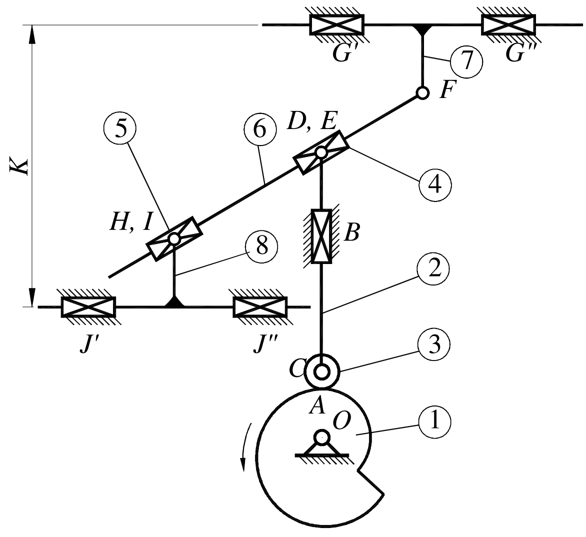

Fig. 8. Kinematic schema of a differential cam mechanism.

From the structural point of view the mechanism is obtained from a mechanism with mobile cam (the elements 1, 2) amplified with the BDE dyad.

In [3] are presented cam mechanism that enter in the composition of some mechanism which describe certain curves, in the composition of the differential mechanism, index mechanisms etc. An example of such mechanism is presented in Fig. 8.

The cam 1 rotates around the fixed axis O and by the contact kinematic pair at the point A realized with the role 3 and the tappet 2 it puts the tappet into a translational motion along the axis OB.

The tappet 2, by the sieve 4 (a double kinematic pair of translation and rotation) transmits the motion to the element 6. Element 6 is linked by the rotational kinematic pair at the point F to the element 7 and by the sieve 5 to the element 8.

The elements 7 and 8 have translational motion, their axes – $J' - J''$ and $G' - G''$ – being parallel one to another and both of them perpendicular to the axis OB of translation of the follower.

Denoting by $F(\varphi_1)$ the law of displacement of the follower 2 (where φ_1 is the rotation angle of the cam 1) and by s_7 and s_8 the displacements of the elements 7 and 8, respectively, then there exists the following relation between the three parameters

$$s_7 = s_8 \times \frac{k - F(\varphi_1)}{F(\varphi_1)},$$

where k is a constructive constant that represents the distance between the two translational axes of the elements 7 and 8.

From the structural point of view the mechanism is obtained from a mechanism with mobile cam (elements 1, 2) amplified with three dyads BDI, $J'HI$ and EFG'.

From those presented above it results that there exists a great variety of cam mechanisms which fulfill the functional roles imposed by the users.

To be out to use some general methods of kinematic and dynamic analysis and of synthesis it is necessary to perform firstly a structural study in order to classify this great number of mechanism in only a few representative types.

Albeit one may concept also cam mechanisms in plan-parallel motion, they are not very used, we will limit only to the mechanisms with one degree of mobility, with cams either in rotational motion, or in translational motion.

From the examples presented above it results that the complex cam mechanisms are obtained either from a simple cam mechanism amplified with structural groups (as the examples in Figs. 2 – 5, 7, 8), or the cam put into motion an element of the mechanism (as in the example in Fig. 6). In this last case the mechanism can not be obtained from a simple cam mechanism amplified with structural groups.

Further on, we will deal only with simple and complex cam mechanisms with rotational cam.

2. FORMING THE SYNTHESIS PROBLEM

In a problem of cam mechanism synthesis, we know: the type of the cam mechanism, the shape and displacement law of the follower. It is required the profile of the cam.

Synthesis methods can be classified in graphical methods and analytical methods.

The analytical methods determine the profile of the cam by using analytical calculation relations, usually the profile of the cam is obtained under the form of value tables (by points). In the case of the distribution mechanisms cams of cars heat engines, the profile of the cam is determined from 2 to 2 degrees, with a precision of 10^{-4} (tenths of a micron).

In [5] are obtained, by synthesis, cams using the theory of envelopes. The used method is an analytical one, the obtained equations being different depending on the configuration of the mechanism.

Usually, the analytical methods determine the shape of the cam with the aid of a function of synthesis. For this one chooses 3 reference systems, one fixed and two mobile that are jointed in rotation with the cam-follower contact point in the general reference system.

So it is obtained a function of 2 parameters whose envelope is the cam. The exterior profile of the cam is obtained through points (the value table).

The graphical methods, abandoned for while due to the low precision, have become current in the presence of CAD software. They locate and determinate the points with the same precision of an analytical method. Even in this case, the simplicity of graphical methods is "shadowed" by the number of constructions made, usually 180 construction sets being made for the synthesis of one cam. That's why macros are used in solving problems, script files generated by a programming language, AutoLisp functions, C/C++ programs etc.

In [6] we present a method for the obtaining of planar or spatial mechanisms based on AutoLisp functions performed in AutoCAD. The cams are modeled with solids and given final shape by Boolean operations. The method is called "cutting" method and the cam is obtained by removing material, like in the case of classical mechanical machining. The material to be removed is of a solid that is forming the follower, which is positioned according to the displacement law of the follower. Finally, after 360 of these positioning operations of the cam and removing material, it is obtained the solid that materializes the cam.

Next we propose to present a graphical synthesis method based on obtaining the characteristic points with AutoLisp functions.

3. THEORETICAL ASPECTS

The envelope of a family of curves

$$f(x, y, \varphi) = 0 \tag{1}$$

is the geometrical locus of the characteristic points A_i (Fig. 9)

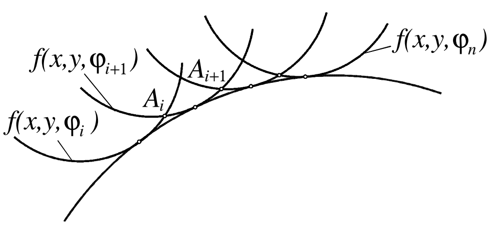

Fig. 9. The envelope of a family of curves.

The characteristic point A_i is the intersection point of two consecutive curves

$$\begin{cases} f(x, y, \varphi_i) = 0, \\ f(x, y, \varphi_{i+1}) = 0, \end{cases} \tag{2}$$

where

$$\varphi_{I+1} = \varphi_i + \Delta\varphi \tag{3}$$

and

$$\Delta\varphi \to 0\,. \tag{4}$$

As in the case of graphical methods, where the cam is the envelope of consecutive positions of the follower, the characteristic points, according to the definition, can be used in solving a synthesis problem of the cam mechanism.

The synthesis problem is reduced to determining the succession of meeting points of two neighboring follower shapes, meaning the characteristic points A_i.

4. WORKING ALGORITHM

We aim to achieve a valid working algorithm for any mobile cam mechanism configuration. We choose 3 coordinate systems (Fig. 10):

– a fixed general reference system XO_1Y,

– a mobile coordinates system $x_1O_1y_1$ rigidly jointed to the cam,

– a mobile coordinates system $x_2O_2y_2$ rigidly jointed to the follower.

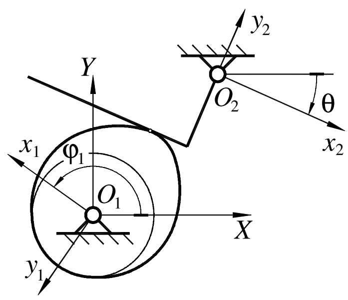

Fig. 10. Coordinate systems.

For the determination of the characteristic point A_i the following steps are performed:

– the follower is rotated around the point O_1 with the angle φ_1 and are determined the coordinates of point O_2 in the position $O_2^{(i)}$,

– by knowing the displacement law of the follower $\theta(\varphi)$ its displacement is calculated for the position $\theta^{(i)} = \theta(\varphi_1)$,

– the follower is rotated around the point $O_2^{(i)}$ with the angle $\varphi_1^{(i)} = \varphi_1 - \theta^{(i)}$,

– the position of the follower is retained, the curve C_i,

– the follower is rotated around the point O_1 with the angle $\varphi_1 + \Delta\varphi$, wherefrom it results the new position of point O_2, denoted by $O_2^{(i+1)}$,

– the displacement of the follower is calculated in this position $\theta^{(i+1)} = \theta(\varphi_1 + \Delta\varphi)$,

– the follower is rotated around the point $O_2^{(i+1)}$ with the angle $\varphi_1^{(i+1)} = \varphi_1 + \Delta\varphi - \theta^{(i+1)}$,

– the position of the follower is retained, the curve C_{i+1},

– the curve C_i is intersected with the curve C_{i+1}, from which it results the coordinates of point A_i.

If values are given to φ in the interval [0...360°] the characteristic points A_i determined at each step i are determining the curve that defines the cam's shape.

We will exemplify in the second part of the paper this algorithm for several cam mechanisms.

5. CONCLUSIONS

The great variety of cam mechanisms used in the industry of machines' construction leads to a great variety of methods for the kinematic analysis and dimensional synthesis. For this reason, in the first part of the work, we classified the mechanisms with mobile cam and presented some examples of simple and complex mechanisms with mobile cam and their fields of use.

The presented synthesis method updates, with the aid of AutoLisp functions, in a CAD medium, a graphical method recognize for its simplicity and clarity. Hence, the main disadvantage, the reduced precision, vanished, the precision in the obtaining of the exterior shape of the cam being now equal to the precision of the most used analytical methods.

The graphic modality to obtain the characteristic points is updated for a CAD medium and thus one obtains an working algorithm, algorithm that leads to the exterior profile of the cam. The algorithm is influenced neither by the type of the mechanism with mobile cam, nor its complexity.

In the second part of this work we will realize applications for simple and complex mechanisms with mobile cam in order to highlight the simplicity and the precision of the method of synthesis based on the obtaining of the characteristic points with the aid of AutoLisp functions.

REFERENCES

[1] Artobolevski, I., *Les mecanismes dans la technique moderne*, Tome 1-5, Ed. MIR, Moskow, 1978.

[2] Artobolevski, I., *Mechanisms in modern Engineering Design*. Vol. 1-5, Ed. MIR, Moskow, 1978.

[3] Scater, N., *Mechanisms and mechanical devices sourcebook,* Fifth Edition, Mc Graw-Hill, 2011.

[4] Patent RO86307, Mechanism for the actuation of the valves at the thermal engines with the adjustment of the valves' lift during the functioning, author Hara Vasile.

[5] Charles, W., Sadler P., *Kinematics and dynamics of machinery*, Second Edition, Harper Collins College Publishers, 1993.

[6] Pandrea, N., Popa, D., Stănescu N-D., *Classical and modern approaches in the theory of mechanisms*. John Wiley & Sons, Chichester, UK, 2017.

[7] Norton, R.L., *Design of Machinery: An Introduction to the Synthesis and Analysis of Mechanisms and Machines*, McGraw-Hill, 2003.

[8] Scater, N., *Mechanisms and Mechanical Devices*, McGraw-Hill, 2011.

SINTEZA MECANISMELOR CU CAMĂ MOBILĂ UTILIZÂND PUNCTELE CARACTERISTICE. PARTEA I: NOŢIUNI TEORETICE ŞI ALGORITM DE CALCUL

Abstract: *Lucrarea este structurată în două părţi. În prima parte, cea de faţă, sunt prezentate mecanismele simple şi mecanismele complexe cu camă mobilă, precum şi domeniile lor de utilizare. Lucrarea evidenţiază avantajele metodelor grafice şi propune utilizarea punctelor caracteristice în rezolvarea problemelor de sinteză de mecanism cu camă mobilă, în prezenţa unui soft CAD. Numărul considerabil de construcţii grafice sunt realizate în AutoCAD cu ajutorul unor funcţii AutoLisp. Se propune un algoritm de lucru şi o funcţie AutoLisp cu care sunt obţinute, în partea a doua a lucrării, în trei aplicaţii, camele unor mecanisme simple şi mecanisme complexe cu camă mobilă.*

Claudia-Mari POPA, Ş. l. dr. ing., Universitatea din Piteşti, Departamentul de Fabricaţie şi Management Industrial, e-mail: claudia_mari_1965@yahoo.com, Office Phone: 0348453155, Home Address: str. Smeurei, nr. 29, bl. PS 38, sc. A, ap. 9, Piteşti, Argeş, România, cod 110046, Home Phone 0751017468.

Dinel POPA, prof. univ. dr. ing. Universitatea din Piteşti, Universitatea din Piteşti, Departamentul de Autovehicule şi Transporturi, e-mail: dinel.popa@upit.ro, dinel_popa@yahoo.com, Office Phone: 0348453155, Home Address: str. Smeurei, nr. 29, bl. PS 38, sc. A, ap. 9, Piteşti, Argeş, România, cod 110046, Home Phone 0751017458.

Nicolae-Doru Stănescu, prof. univ. dr. ing. habil. dr. mat., Universitatea din Piteşti, Departamentul de Fabricaţie şi Management Industrial, e-mail: doru.stanescu@upit.ro, s_doru@yahoo.com, Office Phone: 0348453155, Home Address: Piteşti, str. Matei Basarab, nr. 22, cod 110227, Home Phone 0745050055.

Nicolae PANDREA, prof. univ. emerit dr. ing., membru al Academiei de Ştiinţe Tehnice din România, vicepreşedinte Secţia de Mecanică, Universitatea din Piteşti, Departamentul de Fabricaţie şi Management Industrial, e-mail: nicolae_pandrea37@yahoo.com, Office Phone: 0348453155, Home Address: Bascov, str. Rotăreşti Foraj, nr. 71B, Home Phone 0723395567.