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SIMULATION OF CAR CAM PROCESSING

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Abstract: *The paper presents the method of obtaining, in AutoCAD, the solids that materialize cams. Starting from an imposed displacement law, the external profile of the cam is determined by an analytical method and by a CAD method, the results obtained being compared. The processing of the outer profile of a cam depends on the type of processing and the profile of the tool. AutoLisp functions are used to model the cams and the machining tools. The algorithms underlying the AutoLisp functions are not influenced by the diversity of the motion laws of the follower or the tools that process the cams. In the course of the paper, the solids that materialize the cams are presented.*

Key words: *cam - follower systems, displacement laws, profile cam, modeling cams, AutoLisp functions.*

1. INTRODUCTION

In the construction of the distribution mechanisms of thermal engines, a variety of cam-follower mechanisms are encountered.

The restrictions imposed on thermal engines in terms of noxious emissions have led car manufacturers to optimize the combustion processes in the cylinders. Cam-follower mechanisms play an important role in this process.

The processes for obtaining the cams differ most of the time from manufacturer to manufacturer [1], the desire to obtain camshafts as cheap as possible, in some manufacturing processes the cams are obtained by sintering from metal powders or hardened steels [2-3].

The cams are then mounted on tubular axles by tightening. The classic method consists in casting the camshafts and then independently machining the spindles and cams.

In all cases, the outer profile of the cam is rectified, [4-5] by copying, in order to obtain a reduced roughness: 0.4...0.08 μm .

The displacement law of the follower does not coincide with the displacement law of the tool that processes the cam semi-finished product, unless the tool has the profile of the follower. That's why, after designing the cam mechanism, the tool displacement law is determined, depending on the type of

processing. This can be done by a CAD method [5-7].

In the paper, two cams are obtained by synthesis, by the analytical method and by the CAD method, and the results are compared.

Next, for this cam, the displacement law of the tool for processing the outer profile is determined.

2. OBTAINING THE EXTERNAL PROFILE OF THE CAM BY ANALYTICAL METHODS

In the case of designing a mechanism with a cam, the following are determined, in order: the type of the mechanism, the cam profile, the radius of the base circle, the displacement law of the follower and, by synthesis, the outer profile of the cam is obtained.

The displacement law of the follower is established from kinematic, dynamic and technological considerations.

In the case of the cams used in the distribution mechanisms, the laws of motion are different from engine to engine. Obtaining the displacement laws is done on the angular intervals for: the lifting phase, the stationary phase at maximum height, the descending phase and the stationary phase on the base circle of the cam. For each phase, a displacement law is established, or several displacement laws,

connected to each other by a polynomial law. This polynomial law makes that there is a continuity of displacement, of reduced speed and of reduced acceleration.

For the following example, we consider the cam mechanism in figure 1 in which the cam 1 has a rotational movement, and the curved follower 2 has a translational movement.

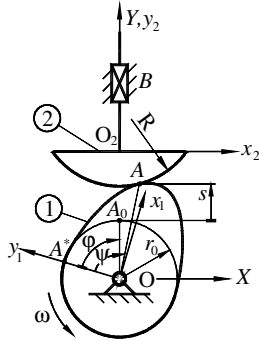


Fig.1. Mechanism with rotation cam and curved translation follower.

In figure 1 was noted with: r_0 - the radius of the base circle, s - the displacement of the follower, ψ the angle of the cam, $\rho = OA$ - polar radius of the cam, φ - rotation angle of the cam, R - the follower radius, A^* - the point of detachment of the outer profile of the cam from the base circle, A_0 - the point of contact of the follower with the base circle, A - the current point of contact between the cam and the follower, OXY - the fixed reference system, Ox_1y_1 - the solidary mobile reference system when rotating with the cam, $O_2x_2y_2$ - solidary reference system for translation with the follower.

By noting the intervals: $[0, \varphi_1)$ for the lifting phase, $[\varphi_1, \varphi_2)$ for stationary at maximum height, $[\varphi_2, \varphi_3)$ for the descent phase, $[\varphi_3, 2\pi]$ for stationary on the base circle.

To exemplify the method, but also, for ease of calculations, we choose a polynomial law $s(\varphi)$ for all phases, of the general form given in [8]:

$$s = \begin{cases} hP(\Phi) & \text{If } \varphi[0, \varphi_1) \\ h & \text{If } \varphi[\varphi_1, \varphi_2) \\ h[1 - P(\Phi)] & \text{If } \varphi[\varphi_2, \varphi_3) \\ 0 & \text{If } \varphi[\varphi_3, 2\pi] \end{cases} \quad (1)$$

where:

$$P(\Phi) = \frac{1}{2} \begin{bmatrix} (n+1)(n+2)\Phi^n - \\ -2n(n+2)\Phi^{n+1} + n(n+1)\Phi^{n+2} \end{bmatrix} \quad (2)$$

and

$$\Phi = \frac{\varphi - \varphi_{i-1}}{\varphi_i - \varphi_{i-1}}, \quad i = 1, 3. \quad (3)$$

It was noted with n the degree of the polynomial. For $n=3$ is obtained the displacement law of the follower:

$$s = \begin{cases} s_{12} & \text{If } \varphi[0, \varphi_1) \\ h & \text{If } \varphi[\varphi_1, \varphi_2) \\ s_{23} & \text{If } \varphi[\varphi_2, \varphi_3) \\ 0 & \text{If } \varphi[\varphi_3, 2\pi] \end{cases} \quad (4)$$

where:

$$s_{12} = h \left[10 \left(\frac{\varphi}{\varphi_1} \right)^3 - 15 \left(\frac{\varphi}{\varphi_1} \right)^4 + 6 \left(\frac{\varphi}{\varphi_1} \right)^5 \right], \quad (5)$$

$$s_{23} = h \left[1 - 10 \left(\frac{\varphi - \varphi_2}{\varphi_2 - \varphi_3} \right)^3 + 15 \left(\frac{\varphi - \varphi_2}{\varphi_2 - \varphi_3} \right)^4 - 6 \left(\frac{\varphi - \varphi_2}{\varphi_2 - \varphi_3} \right)^5 \right]. \quad (6)$$

By deriving relations (4) in relation to φ a reduced velocity is obtained.

In a numerical application the following values are considered: $h = 8$ mm, $\varphi_1 = 88^\circ$, $\varphi_2 = 92^\circ$, $\varphi_3 = 180^\circ$, $r_0 = 15$ mm, $R = 100$ mm.

With a computing program in MatLab, values are given to angle φ , from degree to degree, in the interval $[0, 2\pi]$ radians.

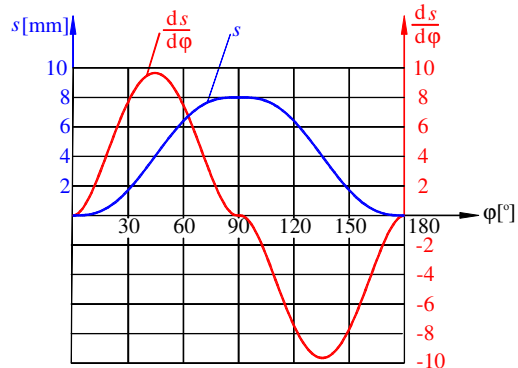


Fig. 2. The displacement graph $s(\varphi)$ and of the reduced

velocity $\frac{ds}{d\varphi}$ of the follower.

The computing program creates two script files with values, on the basis of which are obtained in AutoCAD the graphs from figure 2.

In order to obtain the cam profile, a synthesis problem of a mechanism with a rotation cam and curved translation follower is solved. The parametric equations of the follower are considered:

$$x_2 = R \sin \lambda, \quad y_2 = r_0 + R(1 - \cos \lambda), \quad (7)$$

where λ is a real parameter.

Considering the cam as a winding of the successive positions of the follower, a general synthesis equation was established in [8]

$$\frac{dx_2}{d\lambda} \left(x_2(\lambda) - \frac{ds}{d\varphi} \right) + \frac{dy_2}{d\lambda} (y_2(\lambda) + s(\varphi)) = 0$$

from which, in this case, is obtained:

$$\lambda = \arctan \frac{\frac{ds}{d\varphi}}{r_0 + R + s}. \quad (8)$$

In the coordinate system OXY (Fig. 1.), the parametrical equations of the cam are ([8]):

$$\begin{aligned} x_1 &= -R \sin(\varphi - \lambda) + (r_0 + R + s) \sin \varphi; \\ y_1 &= -R \cos(\varphi - \lambda) + (r_0 + R + s) \cos \varphi. \end{aligned} \quad (9)$$

The previous computing program (made in MatLab) is completed with relations (8) and (9).

The coordinates x_1, y_1 of the cam are written in a script on the basis of which AutoCAD will obtain the groove from figure 3.

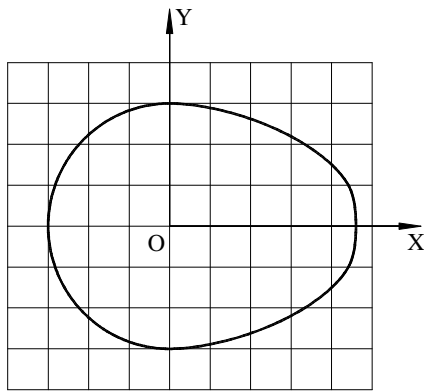


Fig. 3. The synthesis cam obtained by the analytical method.

3. OBTAINING THE EXTERNAL PROFILE OF THE CAM BY THE CAD METHOD

To obtain cams by copying on a traditional machine tool, one starts from an approximate geometric shape that covers the machining allowance.

By copying, the cams are obtained by following the profile of a mother cam and, through a mechanical machining operation, the machining allowance is removed. In [8], a way to obtain the solids that materialize the cams in AutoCAD is presented in 4 steps, with an AutoLisp function that performs:

- p1 - the construction of the solid materializing the cam: a cylinder with the center at the point $O(0,0)$, and radius $r_c = r_0 + h = 23 \text{ mm}$ and thickness $g = 15 \text{ mm}$,
- p2 - in a repetitive cycle values are given from degree to degree to the angle φ , in the interval $0 \dots 360^\circ$:
 - p21 - it is calculated the displacement $s = s(\varphi)$ given by the relation (2),
 - p22 - the solid that materializes the follower is built: a cylinder with the center in $O_c(x_c, y_c)$, where $x_c = 0$, $y_c = r_0 + R + s$, of radius $R = 100 \text{ mm}$ and thickness $g = 15 \text{ mm}$,
- p3 - it is eliminated from the solid that materializes the cam, the solid that materializes the follower,
- p4 - the cam is rotated to a new position and steps p21, p22 and p3 are repeated until the entire interval $0 \dots 360^\circ$ is covered.

The solid obtained after 360 Boolean operations is shown in figure 4. In figure 5 was superimposed on the solid, the 2D profile of the cam obtained by the analytical method. No differences are observed between the profiles.

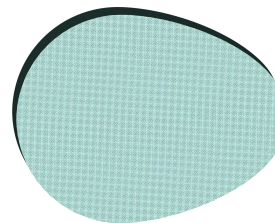


Fig. 4. The CAD cam.

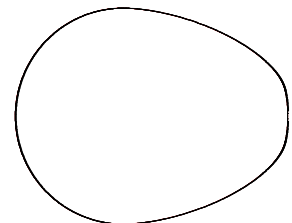


Fig. 5. The CAD profile and the analytical profile.

For better accuracy, the 2D curve obtained by the analytical synthesis in figure 3 is extruded with a height equal to $g = 15 \text{ mm}$. In this way, a solid is obtained whose geometric properties are determined with the MassProp command.

Only the volume is retained (mm^3): The volumes: 13320.7168.

The cam obtained by CAD methods will be processed the same way and the following volume is obtained: 13321.9312.

The difference between the two values is 1.2144, which represents 0.009% of the value. Practically the two solids are identical.

4. THE DISPLACEMENT LAW OF TOOLS FOR MACHINING CAMS

If the cam processing tool does not have the follower profile, relation (3) cannot be used to move the tool.

For this, we will have to solve a problem of kinematic analysis of the mechanism with rotation cam and translation follower. The follower has the shape of the tool or the shape of the path described by the tool during the machining operation.

Having the cam in parametric coordinates $x_1(\lambda)$, $y_1(\lambda)$ and considering the case where the processing tool has a horizontal movement, the problem is reduced to the kinematic analysis of a mechanism with a rotation cam and a flat translation follower (Fig. 6.).

The angle ψ from figure 6 is given by the relation:

$$\psi = \arctan \frac{y_1'(\lambda)}{x_1'(\lambda)} = \arctan \frac{-R \cos(\varphi - \lambda) \left(1 - \frac{d\lambda}{d\varphi}\right) + (r_0 + R + s) \cos \varphi + \frac{ds}{d\varphi} \sin \varphi}{R \sin(\varphi - \lambda) \left(1 - \frac{d\lambda}{d\varphi}\right) + (r_0 + R + s) \sin \varphi + \frac{ds}{d\varphi} \cos \varphi}, \quad (10)$$

where:

$$\frac{d\lambda}{d\varphi} = \frac{\frac{d^2 s}{d\varphi^2} (r_0 + R + s) - \left(\frac{ds}{d\varphi}\right)^2}{\left(r_0 + R + s - \frac{ds}{d\varphi}\right)^2}. \quad (11)$$

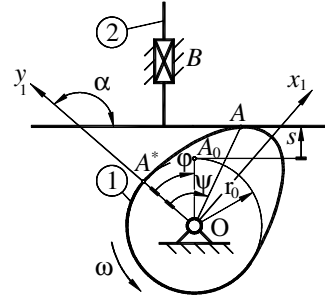


Fig. 6. Mechanism with rotation cam and flat translation follower.

The displacement s_s of the tool is:

$$s_s = x_1 \sin \psi + y_1 \cos \psi - r_0. \quad (12)$$

To obtain numerical results, the previous computing program is completed. For the angle ψ given by the relation (10) to have integer values in the range $0 \dots 360^\circ$, from degree to degree, proceed as follows:

- in a repetitive cycle, values are being given to the angle φ , small step values (tenths or hundredths of a degree),
- it is determined λ with the relation (8),
- it is determined ψ with the relation (10) and by interpolation a whole value is obtained; the following values are retained: $\psi = 0^\circ$, $\psi = 1^\circ$, ..., $\psi = 360^\circ$,
- it is determined the displacement s_s of the tool with the relation (12); the value $s(\psi)$ is retained.

An AutoLisp function with the following algorithm is used to obtain the tool displacement using the CAD method:

- p1 - the construction of a parallelepiped materializing the tool; it has the length $3r_0 = 45 \text{ mm}$, width $g/4 = 3,75 \text{ mm}$ and height $g = 15 \text{ mm}$,
- p2 - in a repetitive cycle, values are given from degree to degree to the angle φ , in the interval $0 \dots 360^\circ$:
 - p21 - the cam is rotated with 1° ,
 - p22 - the solid that materializes the follower moves with a constant step until the intersection; if there is an intersection, it returns to the previous position and in a second repetitive cycle in which the step is halved, the process of approaching the

intersection is resumed; it is returned to the previous position and the step is compared with the maximum value of the imposed precision; the repetitive cycle is exited when the value is obtained with the imposed precision,

- p23 - the displacement value obtained for the displacement of the tool is written in a file,
- p4 - the cam is rotated to a new position and the steps p22 and p23 are resumed until the entire interval is completed 0... 360°.

To obtain a satisfactory result, the values of s_s will have to be determined with a precision of 0.0001 mm.

In table 1 the values obtained for the tool displacement are presented.

For reasons of space, only the values from 5 to 5 degrees have been listed.

Also, the value of the displacement s was listed.

The values obtained for the displacement s_s of the tool by the CAD method were compared with the values obtained from the computing program.

The results are practically identical, the differences being insignificant.

Table 1

The value of the displacement s and s_s

φ [°]	$s(\varphi)$ [mm]	s_s [mm]	φ [°]	$s(\varphi)$ [mm]	s_s [mm]	φ [°]	$s(\varphi)$ [mm]	s_s [mm]
0	0	0						
5	0.01301652	0.0148	65	6.99735477	7.1255	125	5.70507626	5.9835
10	0.09521389	0.1078	70	7.4496055	7.5169	130	4.91756942	5.2604
15	0.29269835	0.3414	75	7.75746129	7.7839	135	4.08426257	4.467
20	0.62933427	0.744	80	7.92931386	7.9358	140	3.24672761	3.6344
25	1.10996759	1.3109	85	7.99321809	7.994	145	2.4468588	2.8012
30	1.72364927	2.0109	90	8	8	150	1.72364927	2.0109
35	2.4468588	2.8012	95	7.99321809	7.994	155	1.10996759	1.3109
40	3.24672761	3.6344	100	7.92931386	7.9358	160	0.62933427	0.744
45	4.08426257	4.467	105	7.75746129	7.7839	165	0.29269835	0.3414
50	4.91756942	5.2604	110	7.4496055	7.5169	170	0.09521389	0.1078
55	5.70507626	5.9835	115	6.99735477	7.1255	175	0.01301652	0.0148
60	6.40875699	6.6108	120	6.40875699	6.6108	180	0	0.0001

5. CONCLUSIONS

The paper presents two ways of obtaining the displacement of the tools that process the cam: an analytical method and a method of obtaining the solids that materialize the cam in a CAD software.

Thermal engine cams were chosen as an example, primarily due to the high precision of obtaining the external profile, but also due to the diversity of types of cam follower mechanisms.

Analytical methods are specific to each type of cam follower mechanism and are often laborious.

In the paper, the cams are also obtained with solids in AutoCAD, with the help of an AutoLisp function.

The algorithm of the function following the steps of a classical mechanical processing.

For a mechanism with a rotation cam and a curved translation follower, a comparison of the

cams obtained analytically and with solids in AutoCAD was made.

The 2D profile obtained with a computing program in MatLab, was transformed into a solid in AutoCAD. The difference in volume between the two solids was insignificant.

The obtained solid can be transferred to a numerical control machine tool, a 3D printer, etc.

In the second part of the work, the processing law of the tool that processes the cam was determined.

The problem, from a theoretical point of view, consists in solving a problem of kinematic analysis of a mechanism with a cam-follower, the follower having the shape of the tool.

Through the analytical method, the calculations are laborious, the results being influenced by the precision of interpolation of the values needed to obtain the cam angle.

The CAD method algorithm for obtaining the displacement of the machining tool is not influenced by the cam profile or the tool profile. As in the previous case, based on a common application, the obtained results were compared. There were no differences.

In conclusion, through the two CAD methods of obtaining the solids that materialize cams and obtaining the movement of their processing tool, it is possible to accurately simulate the processing of cams, regardless of the type of cam mechanism, the type of follower or the tool that processes the cam.

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SIMULAREA PRELUCRĂRII CAMELOR AUTO

Lucrarea prezintă metoda de obținere, în AutoCAD, a solidelor care materializează came. Plecând de la o lege de deplasare impusă, profilul exterior al camei se determină printr-o metodă analitică și printr-o metodă CAD, rezultatele obținute fiind comparate. Prelucrarea profilului exterior al unei came depinde de tipul de prelucrare și de profilul sculei. Funcții AutoLisp sunt folosite pentru modelarea camelor și a sculelor de prelucrare. Algoritmii care stau la baza funcțiilor AutoLisp nu sunt influențați de diversitatea legilor de mișcare ale tchetului sau de sculele care prelucrează camele. Pe parcursul lucrării sunt prezentate solidele care materializează camele.

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