

## THE INFLUENCE OF CAMS EXTERNAL GROOVE IN CAM-FOLLOWER MECHANISM FUNCTIONING

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ABSTRACT – In the paper, as a first phase, one is presenting a study of the pointing precision influence on the external groove of a cam that is part from a cam-follower mechanism. There is used a simple mechanism that has an analytic solution for the reduced velocities and acceleration. With a calculus program are determined the values of the reduced velocities and reduced accelerations of four precision indications of the cams groove. In the second part of the paper, one is studying the influence of the processing precision for a good functioning of the cam-follower couple. A cam is obtained in AutoCAD based on an AutoLisp function, by using an algorithm called "by cutting". The solid that makes the cam is next used for obtaining the displacement of a flat translation follower after using the algorithm called "by nearby". The presented algorithm is the foundation of an AutoLisp function, that is used to obtain numerical values that are next written in a text file. With these values are obtained, by numerical derivation, the values of the reduced velocities and accelerations in the case of cutting the cam with an angularly step of 1, 2, 5 and 10 degrees. One is concluding that a good precision is obtained in the case of pointing the cams groove with a precision of a tenth of a micron (0.0001 mm) and the cams cutting is made with an angularly step of maximum two degrees.

### INTRODUCTION

Although structurally simple, cam mechanisms require a high precision in mechanical processing. In the auto industry, the cams of heat engines are given under a table of values from degree to degree or by each two degrees. The table values are in mm with four decimals after the comma and represents the displacement of the tool that is processing the cam. After finishing the cam, in the control gamma are not only checked the displacements but also the reduced velocities and accelerations that require a limit of some maximum values. The problem in hand is that the precision with that a displacement is read is enough to obtain a real and correct value of the reduced velocities.

A second issue that the paper is approaching is one of processing the cams with an angularly step of 1°, 2°, 5°, 10° and the influence of these over the obtained groove and over the values of the reduced velocities and accelerations.

### THE POINTING PRECISION OF THE CAMS EXTERNAL GROOVE

In the end of the dimensional synthesis problem, using polar or parametrical coordinates, one can obtain the external groove of the cam in the own reference system. For processing the cam on a traditional tool machine one must indicate the displacement rule of the tool that is processing in parametrical coordinates considering the rotation angle of the cam. In the case of a flat follower, the displacement rule of the processing tool is the same with the one of the

followers displacement. In the case of a cam with a curve follower there must be made another displacement rule for the processing tool.

In [4] one is presenting two modalities for obtaining the displacement rule of the processing tool for a cam with a given groove. The first method is an analytical one that transforms the problem into one of cinematic analysis for determining the displacement rule of a flat follower in a translation movement. As a second method, one gives a CAD method that uses an AutoLisp function for obtaining the cam and the displacement rule of the processing tool.

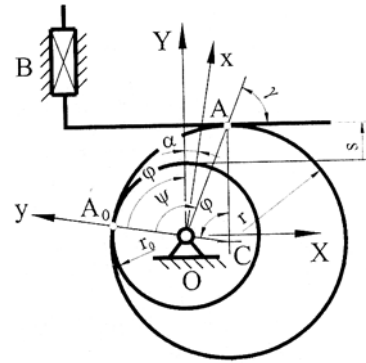


Fig. 1. Circularly cam mechanism.

To study the influence of the pointing precision of the external groove, the reduced velocities and accelerations have analytical calculus formulas. So, for the mechanism with a circularly rotation cam and flat translation follower from figure 1, one knows: the radius of the base circle  $r_0$ , the radius of the cam  $r$  and the eccentricity  $e = r - r_0$ . Next, using the notations from figure 1, one can write:

$$x_1 = r \sin \varphi; y_1 = r \cos \varphi - e; \quad (1)$$

$$\rho = \sqrt{x_1^2 + y_1^2}; \quad (2)$$

$$d_e = e \sin \varphi; \quad (3)$$

$$\alpha = \arcsin \frac{d_e}{\rho}; \quad (4)$$

$$\gamma = \frac{\pi}{2} - \alpha; \quad (5)$$

$$\psi = \varphi + \alpha; \quad (6)$$

$$s = \rho \sin \gamma - r_0. \quad (7)$$

Using the above relations one can make a calculation program that can obtain numerical values for the displacement  $s$  of the flat follower, the reduced velocity  $\frac{ds}{d\varphi}$  and the reduced

acceleration  $\frac{d^2s}{d\varphi^2}$  according to angle  $\varphi$  of the cam that takes values from degree to degree

from  $0^\circ$  to  $360^\circ$ . In figure 2 one is presenting the graph of the follower displacement variation and in figure 3 the overlaid variation graphs of the reduced velocity (discontinued line) and the reduced acceleration (continuous line) in the case where  $r = 30$  mm and  $r_0 = 25$  mm.

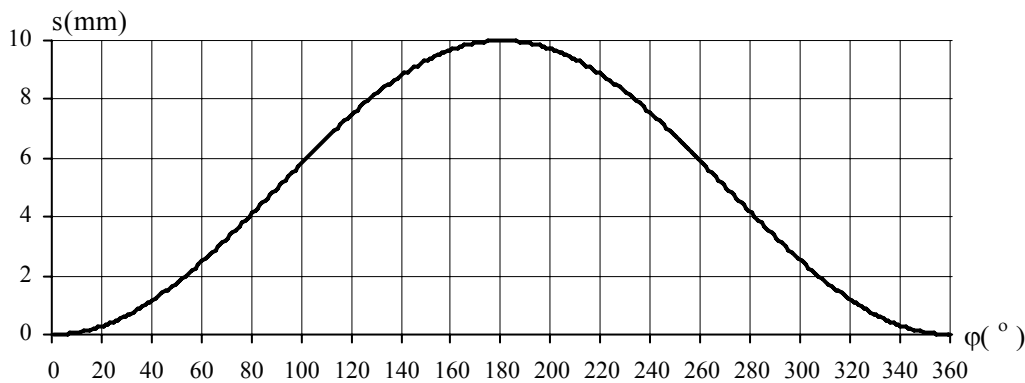


Fig. 2. The variation graph of the valves displacement  $s(\varphi)$ .

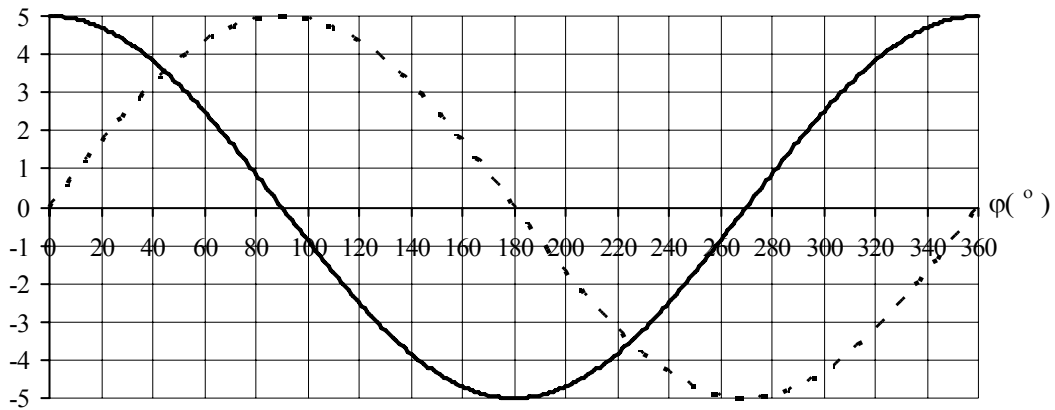


Fig. 3. The variation graphs of the reduced velocities  $\frac{ds}{d\varphi}$  and reduced accelerations  $\frac{d^2s}{d\varphi^2}$ .

With the same calculation program one saves in files the value of the displacement  $s$  with the precision of 0.001, 0.0001, 0.00001 and 0.000001 mm. These values are then read by the same program, after are numerically calculated the first and second degree derivates and finally the obtained values are written in a script file. Using this scrip in AutoCAD one creates the graphs of reduced acceleration for the four precision cases. In figure 4 are presented the four obtained curves.

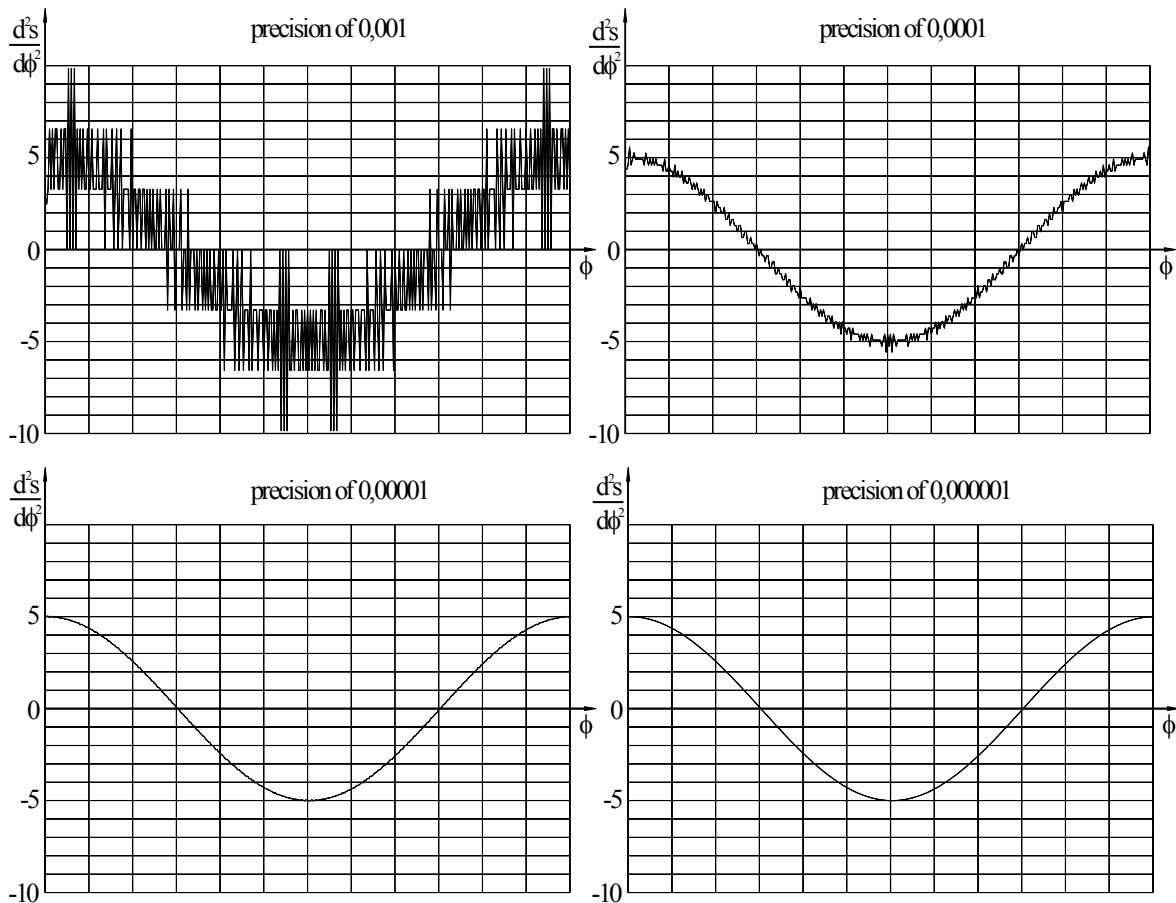


Fig. 4. The variation graphs of reduced velocity depending on the precision.

One observes that in the first couple of cases (with three and four decimals after the comma) the values obtained for reduced accelerations by numerical derivation are not the same with the theoretical ones, the induced errors distorting the curves. In the case of 0.000001 mm precision, the values obtained for the reduced acceleration does not differ from the theoretical ones.

As a first conclusion, the cams groove cannot be given with the precision of 0.001 mm (a micron) because the values obtained at numerical derivation for the reduced acceleration is being hardly distorted by the derivation errors.

A good improvement, but also not enough, it is in the case of indicating the external groove with a precision of a tenth of a micron (0.0001 mm), but necessary being the indication with a hundredth of a micron (0.00001 mm).

## THE PROCESSING PRECISION OF THE CAMS EXTERNAL GROOVE

For one to study the influence of the processing precision of cams, we used the AutoCAD program which can be "transformed" in a processing tool by using the AutoLisp program. On a traditional processing tool the semi-manufactured from which the cam is obtained has a geometrical shape that covers its final shape thorough an added processing. The most utilized method for obtaining cams is the copying method, where by following the external groove of a mother cam, the desired cam is being obtained through a mechanical process where the extra material is removed from the semi-manufactured. So we propose to process the cam "by cutting" it with an angularly step of 1°, 2°, 5° and 10°, after we obtain a solid in a CAD software that is identical with the one obtained on the processing tool.

The problem is one of cams synthesis, the process presuming the positioning of the semi-manufactured that makes the cam, then removing the material in the current position and going to a new position until the 360° angle course is routed.

For obtaining the cam through synthesis by using the process "by cutting" one uses an AutoLisp function as the next algorithm.

- I.** A solid model (semi-manufactured) that approximates is positioned in the 0° position ( $\varphi = 0$ ). „The semi-manufactured” that makes the cam is obtained from a solid using AutoCAD commands, which includes the external groove of the cam. The part is a cylinder (AutoCAD command CYLINDER) with the radius of  $2r_0$  and the thickness of  $h = 20$  mm.
- II.** A solid that makes the follower that later will be eliminated from the cams material is positioned on the surface. Then the solids lower surface will have to coincide with the followers position for this particular position of the cam (relation 7). The solid is a parallelepiped built with the AutoCAD command BOX.
- III.** One excludes from the solid that makes the cam the solid that makes the follower by using the AutoCAD command *SUBTRACT*.
- IV.** The cam is rotated into a new position with an angularly step of 1°, 2°, 5° or 10° and the processes I ÷ III are resumed.

In figure 5 are presented four angularly positions (90°, 180°, 270° and 360°) of the obtained solid, the last position being the one of the final cam.

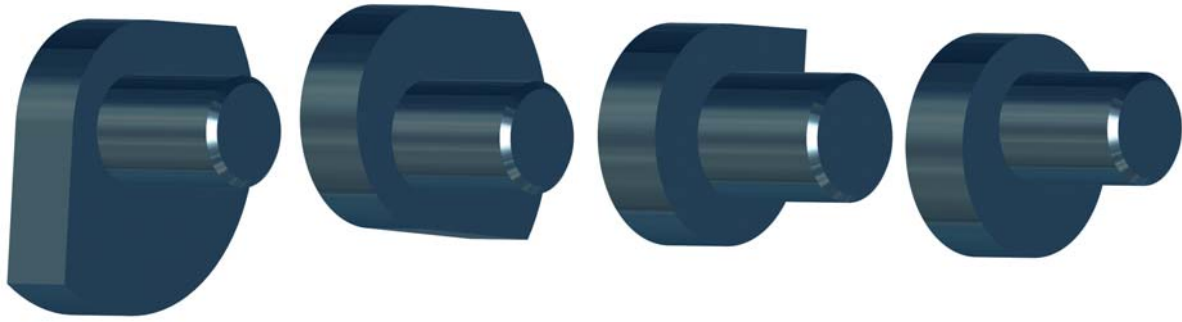


Fig. 5. The cam in intermediary positions in the cutting process.

Next, one will make a cinematic analysis for a mechanism with rotation cam and flat translation follower using AutoCAD and an AutoLisp function. In [5] the method called "by nearby" is similar to the one of measuring the cams groove using the comparator. The algorithms principle is to close the distance between the solid that makes the follower and the cam until the two are in contact. For this operation we will also use an AutoLisp function that applies the next algorithm:

- I.** one builds a parallelepiped that will make the tool by using the AutoCAD command *BOX*,
- II.** then, the solid that makes the cam is positioned,
- III.** after, the two solids approaches until contact is reach and the value obtained is written in a file,
- IV.** finally, the cam is rotated into a new position and the process II ÷ III is resumed.

The AutoLisp function performs:

- assigning the name *cama* to the cam previously obtained by cutting;
- building a parallelepiped with the AutoCAD command *BOX* and assigning it the name of *tachet*;
- into a repetitive cycle *While* in the interval  $[0, 2\pi]$ :
  - one rotates the cam with a constant angularly step by using the AutoCAD command *ROTATE*;
  - then it is notated with *e3* the solid obtained through a Boolean operation of intersecting the cam with the parallelepiped (with the AutoCAD command *INTERSECT*);
  - if there is no *e3* then one uses a second *While* repetitive circle where the parallelepiped is displaced (with the AutoCAD command *MOVE*) with the constant step of *dy* until the parts are in contact (there is *e3*);
  - the obtained value is written in a file and we move next to a new angle.

The linearly step of approaching the follower to the cam has to be of 0.000001 mm in order not to influence the obtaining precision of the reduced acceleration in a numerical derivation process.

The values obtained for the followers displacement are written in a text file from which are later obtained the numerical values of the reduced velocities and accelerations. The obtained cam will have an external groove formed of plane portions with tighter or longer bearings depending on the angularly step. So one obtains a circularly cam approximated through line segments.

The AutoLisp function that performs these operations has content below.

```
(Defun C:Cama ()
  (setq r0 25.0 r 30.0 e (- r r0) h 20 dy 0.000001 pas 1)
  (Command "Osnap" "OFF") (Command "Ortho" "OFF")
  (Command "Zoom" "W" "-100,-100" "100,100")(Command "Viewres" "Y" "20000")
  ;SINTEZA CAMEI
  (Command "Cylinder" "0,0,0" (* 2 r0) h) ;Constructie semifabricat cama
  (Setq cama (entlast))
  (setq i 0 )
  (While (< i 360)
```

```

(setq fi (* i (/ pi 180))
  ro (Sqrt (+ (* e e) (* r r) (* -2 e r (Cos fi))))
  de (* e (Sin fi)) sina (/ de ro) cosa (Sqrt(- 1 (* sina sina)))
  alfa (Atan sina cosa) gama (- (/ pi 2) alfa) csi (+ fi alfa)
  s (- (* ro (Sin gama)) r0) csj (List (* -2 r) (+ s r0) 0)
  cds (List (* 2 r) (+ s r0 h h) 0))
(Command "Box" csj cds h) (Setq tachtet (entlast)) ;Constructie tachtet
Command "Subtract" cama "" tachtet "" (Setq cama (entlast))
(Command "Rotate" cama "" "0,0,0" pas)
(setq i (+ i pas))
)
      ;ANALIZA CINEMATICA
(Setq f(Open "deplasare.txt" "w"))
(Command "Box" csj cds h) (setq tachtet (entlast))
(setq fi 0 y r0 B (list 0 y 0))
(While (< fi 360)
  (Command "_Rotate" cama "" "0,0,0" 1)
  (Command "Intersect" cama tachtet "") (setq e3 (entlast)) (setq a 0)
  (if (null e3)
    (Command "U")
    (setq a 1)
  )
  (While (= a 0)
    (Setq y (- y dy)) (setq P (list 0 y 0)) (Command "Move" tachtet "" B P)
    (Command "Intersect" cama tachtet "")
    (setq e3 (entlast))
    (if (null e3)
      (Command "U")
      (setq a 1)
    )
  )
  (setq B (list 0 y 0))
)
(While (= a 1)
  (Command "U")
  (Setq y (+ y dy)) (setq P (list 0 y 0))
  (Command "Move" tachtet "" B P) (Command "Intersect" cama tachtet "")
  (setq e3 (entlast))
  (if (null e3)
    (setq a 0)
    (setq a 1)
  )
)
  (setq B (list 0 y 0))
)
  (Command "U")
  (setq s(- y r0)) (Write-line (rtos s 2 8) f) (Setq fi (+ fi 1))
)
(Close f)
)

```

Varying the angularly step for obtaining the cam (variable step), one obtains cams cut from degree to degree, from two degrees to two degrees, from five degrees to five degrees and from ten degrees to ten degrees. After the cinematic analysis, one obtains the displacement of the flat translation follower, values being written from degree to degree in the file `deplasare.txt`. These values are then entry values for the calculation program described before in which we numerically determine the values of reduced velocities and accelerations.

It was considered that is significantly to look only at the reduced accelerations depending on cams cutting angularly step. In figure 6 one presents the variation graphic of reduced accelerations when the cam is being cut with an angularly step of  $1^\circ$ .

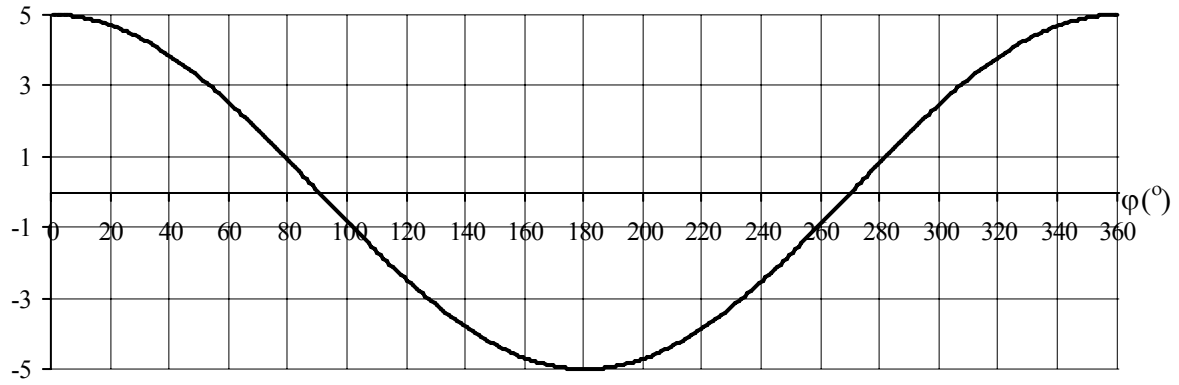


Fig. 6. Variation graph of the reduced acceleration  $\frac{d^2 s}{d\varphi^2}$  for an angularly step of  $1^\circ$  used for cutting the cam.

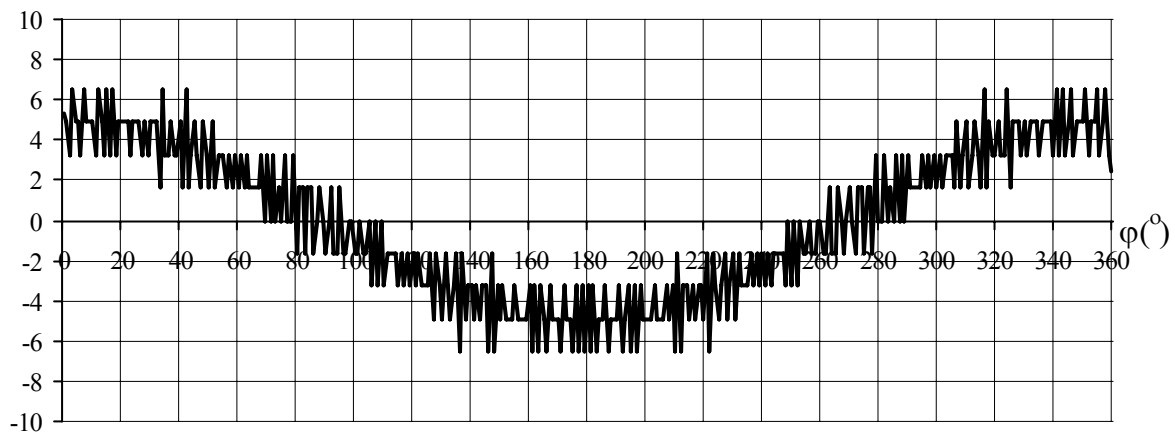


Fig. 7. Variation graph of reduced acceleration  $\frac{d^2 s}{d\varphi^2}$  for an angularly step of  $2^\circ$  used for cutting the cam.

One presents the case where the cam is cut with an angularly step of 2 degrees in figure 7 and with 5 degrees in figure 8. The case of an angularly step of 10 degrees is not presented because the obtained cam is practically polygonal and the reduced acceleration have high values.

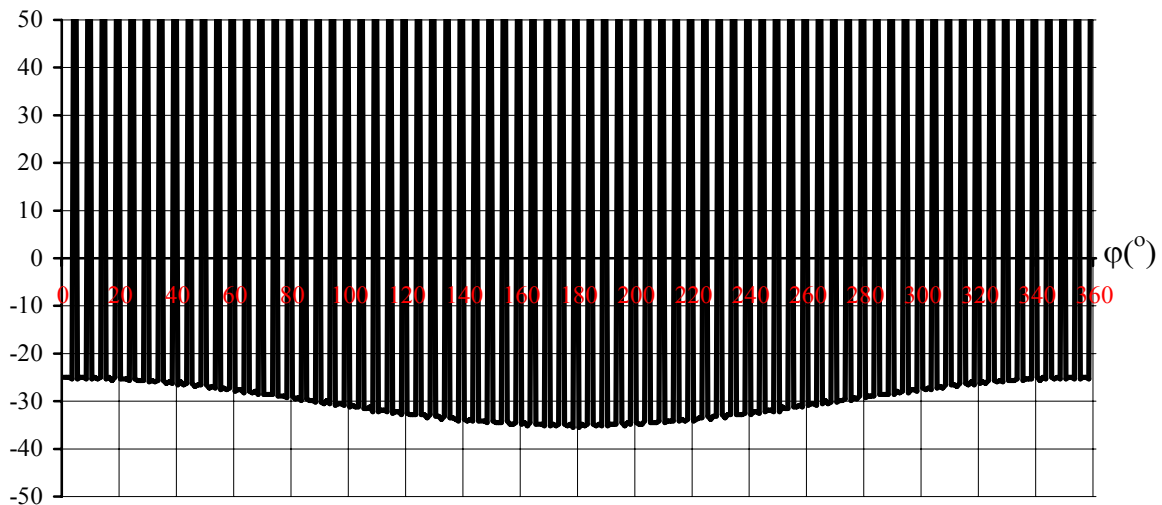


Fig. 8. Variation graph of reduced acceleration  $\frac{d^2 s}{d\varphi^2}$  for an angularly step of  $5^\circ$  used for cutting the cam.

From the variation graphs of the reduced angularly accelerations can be concluded that:

- the best solution is obtained when the cam is cut with an angularly step of 1 degree;
- an acceptable solution is the one of cutting the cam from two to two degrees;
- there aren't obtained any usable cams when the cutting step is beyond two degrees.

## CONCLUSIONS

The paper presents a study regarding the influence of deviations in the construction and operation of cam mechanisms.

A first aspect of the study is the one of precision of the external groove that must be indicated in order to have a real and correct value of reduced accelerations. By pointing the external groove of the cam with a precision of a tenth of a micron the minimum precision is reach. But the recommended precision is still the one of a hundredth of a micron.

A second aspect is one of the influence of angularly step in processing cams over the correctness of the obtained groove. An acceptable solution is obtained for an angularly step of two degrees but a better option being the angularly step of 1 degree.

The presented synthesis method is inspired from practice, where a modality of obtaining the cam is to process a semi-manufactured on a copying machine. The cam obtained by synthesis is a solid and the process is called "by cutting". It has four steps and based on that, an AutoLisp function from which cams are obtained is made.

The principle of positional analysis method in AutoCAD is called "by nearby". It consists in modeling with solids the cam and follower, rotating the cam with an AutoLisp function and closing the distance between the follower and the cam until contact is reach. The AutoLisp function can be used for cinematic analysis of any type of cam-follower mechanism, plane or spatial, having any type of form.

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