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DEPARTMENT OF MECHANICAL ENGINEERING

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MACHINE THEORY
ANALYSIS AND DESIGN OF CAMS

Course 2010/11

INTRODUCTION

The objective of the laboratory is to study cam profiles. In the first part of the practice, a mechanism that simulates the process of making screws out of a hexagonal bar, is examined. The second part focuses on a computer aided application called *SCLevas*.

OBJECTIVES

The objectives of the practice are:

- Check the operation of the miniature version of a real mechanism.
- Study of a cam and its follower movement according to the displacement diagram and lay out theoretical and actual cam profile.
- Dynamic study of the cams by obtaining the jerk angle of a cam presented in the miniature model.
- To get familiar with the most common types of planar rotary cams by using a software *SCLevas.*
- Study the influence of changing some of the parameters (base radius, roll radius, eccentricity, etc.) with the software.

After the theoretical studies a practical work will be carried out with cams, i.e with machine elements that contain *higher order pairs*.

EQUIPMENT AND REQUIRED MATERIALS

For the successful and correct realization, the following equipment is needed:

- Scaled model of a working machine.
- Tools for calculating and drawing.
- PC with the program called *SCLevas*.

DESCRIPTION OF THE MECHANISM

The miniature version of an industrial machine mechanism is shown on Figure 1. The machine is used to produce screws out of a hexagonal bar. The scaled mechanism is simplified, meaning it has no workpiece feeding mechanism. Also, the workpiece-machine tool relative rotational motion for threading is disabled.

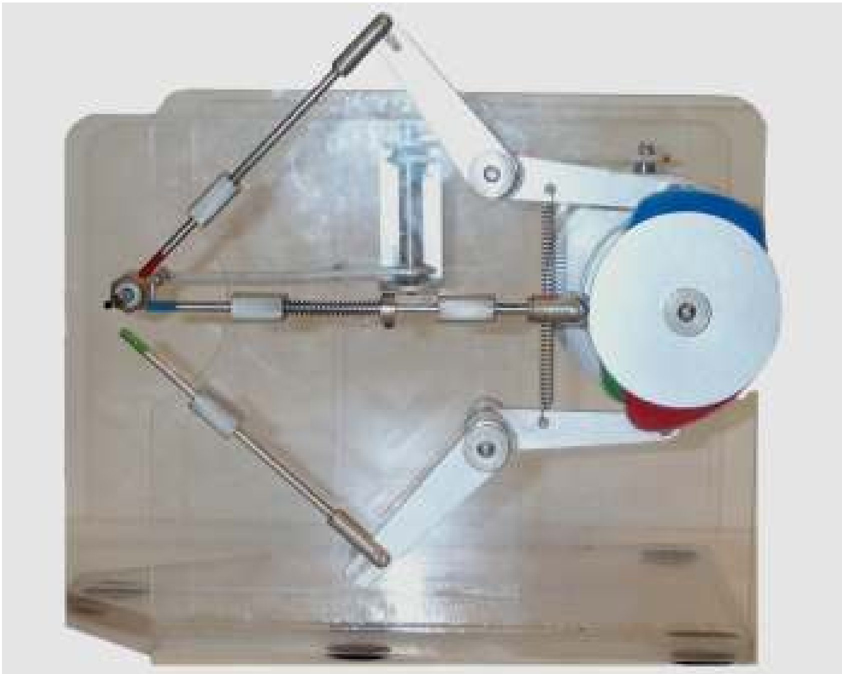

Figure 1. Scaled representation of a screw manufacturing machine

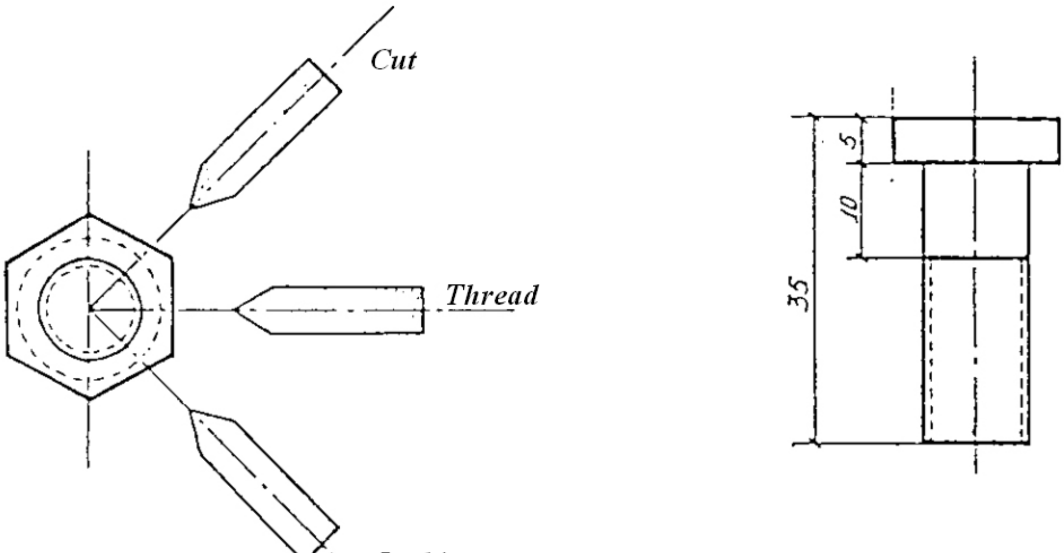

Figure 2. Cutting, threading and lathing tools on the left and the screw dimensions on the right

A driving camshaft is controlling the movement of four cams (3 planar cams and one cylindrical cam) simultaneously. The required operations are lathing (in two phases), threading and cutting (Figure 2).

The intervention of each tool (cutting, lathing, threading) is predetermined by a correspondingly colored cam. Each cam has a previously determined sequence and a profile to comply with its working function.

The position and timing of processes like lathing, threading and cutting are given by planar cams, while the movement of the rod bar is determined by a cylindrical cam.

The different phases of screw manufacturing process are guided by the movement of the cam-follower system which requires careful sequencing (Figure 3).

Stages during the full cycle of the production:

- 0 – 1 Approach of the lathing tool
- 1 – 5 The first phase of lathing
- 5 – 5½ Separation of the lathing tool
- 5½ - 6 Placement of the hexagonal rod
- 6 – 6½ Approach of the lathing tool
- 6½ - 10½ Second phase of lathing
- 10½ - 11 Separation of the lathing tool
- 11 – 11½ Approach of the threading tool and positioning the cylinder
- 11½ - 15½ Threading
- 15½ - 16 Separation of the threading tool
- 16 – 16½ Approach of the threading tool and positioning the workpiece
- 16½ - 20½ Cutting
- 20½ - 21½ Separation of the cutting tool
- 21½ - 22½ Placing the screw
- 22½ - 24 Advancing of the bulk material

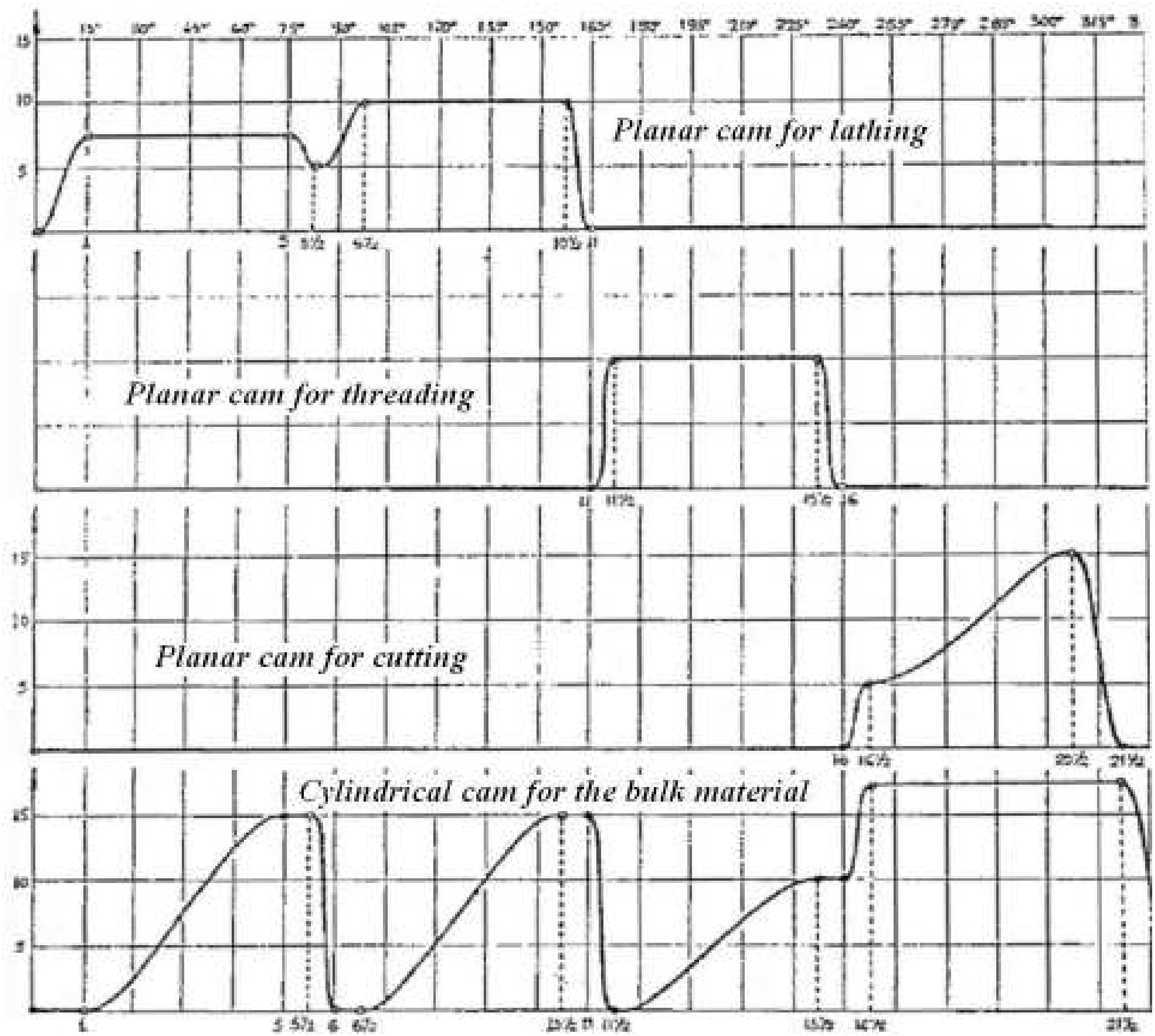

Figure 3. Displacement curves of the four cams.

OPERATING METHOD

For the successful completion of the laboratory, the following points should be fulfilled:

1. Check the different stages of the screw fabrication process and verify the importance of timing of:
    - Feeding the machine with the bulk material (cylindrical cam)
    - Lathing in two phases (green cam)
    - Threading (blue cam)
    - Cutting (red cam)
2. Draw the displacement diagram of the cam for the lathing tool (green), starting with the more representative points (just before the follower starts to move).

3. From the displacement diagram, determine the cam profile (theoretical and actual).
4. Calculate the maximum angle of pressure for the threading cam (blue), using the formula specified in the theory part about the dynamics of the cams.

DEVELOPMENT AND ANALYSIS OF RESULTS

To know the solution to the abovementioned points, it is necessary to do the following:

1. To measure any values from the mechanism, rotate the camshaft. On the shaft there are rigidly mounted all the cams and a needle pointer to read the angular values of the rotation. These values are used to draw the displacement diagram.
2. To draw the displacement diagram, separate the full circle into sectors of 15º. Each 15º (read it from the angular scale) measure the outreach of the tool to calculate the angle of rotation of the rotational follower. To calculate the approximate values of α_p, use the law of cosinus. The triangle consists of the tool supporter, the rotational axis of the follower and a moving joint between them. It is easy to express all the measured points in one table presented on the next page, where:
   - **L_0 (mm):** Initial length of the tool. (when the follower rests on the base circle of the green cam)
   - **L_i (mm):** Measured values of the distance from the tool support to the tip.
   - **R (mm):** Distance from the rotational axis of the cam follower to the joint of a tool. It is considered to be constant all the time.

Nº	ϕ (º)	L_0 (mm)	L_i (mm)	$\alpha_p(rad) = (L_i - L_0) / R$	α_p (º)
1					
2					
3					
4					
5					
6					
7					
8					
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11					
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THE CAM PROFILE

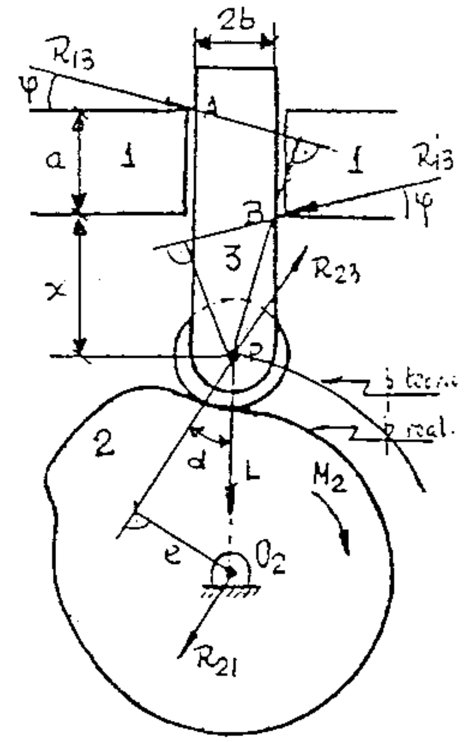

Figure 4. Condition of jamming.

1. The cam profile is determined graphically as follows:
   - Draw a base circle of the cam with a radius of $\mathbf{O_pO_l}$ (distance from the rotation center of the cam to the contact point with the roller of the follower).
   - Draw a circle representing the roller; locate it on a point on the base circle of the cam.
   - Draw a circle with the theoretical cam radius (same rotational center, but adding the roller radius).
   - Divide the circle to 24 equal sectors.
   - Draw the follower **L** from $\mathbf{O_p}$ to the base circle.
   - With the center in $\mathbf{O_p}$ and radius **L**, draw an arc and place the calculated angles on it.
   - Carry the circles centered in $\mathbf{O_l}$ from the previously marked angles to their corresponding sectors. This way the points indicate the theoretical profile of the cam.
   - Constrain the roller to follow the theoretical profile (in the marked points).
   - Obtain the real profile by subtracting the roll radius from the previously attained theoretical profile.
2. Normal and simplified formula for calculating the self-locking angle of the blue cam-follower (Figure 4):

$$\tan \alpha_{\lim} = \frac{a}{\mu \cdot (2 \cdot x + a - 2 \cdot \mu \cdot b)}$$

$$\tan \alpha_{\lim} = \frac{1}{\mu \cdot (1 + 2 \cdot x / a)}$$

EXAMPLE

Determine the theoretical and actual profile of the cam with the rolling follower. Take 12 equally displaced points on the circle. Take the height readings as follows:

- from 0º until 120º, each 15º;
- from 120º until 180º, the rod remains at rest;
- from 180º until 270º, each 15º;
- from 270º until 360º, each 30º, until reaching again the starting point;

Data:

- Distance between the center of rotation of the cam and the follower: 80 mm.
- Length of the follower: 60 mm.
- Radius of the circumference of the theoretical base profile: 34 mm
- Radius of the roller: 3 mm.

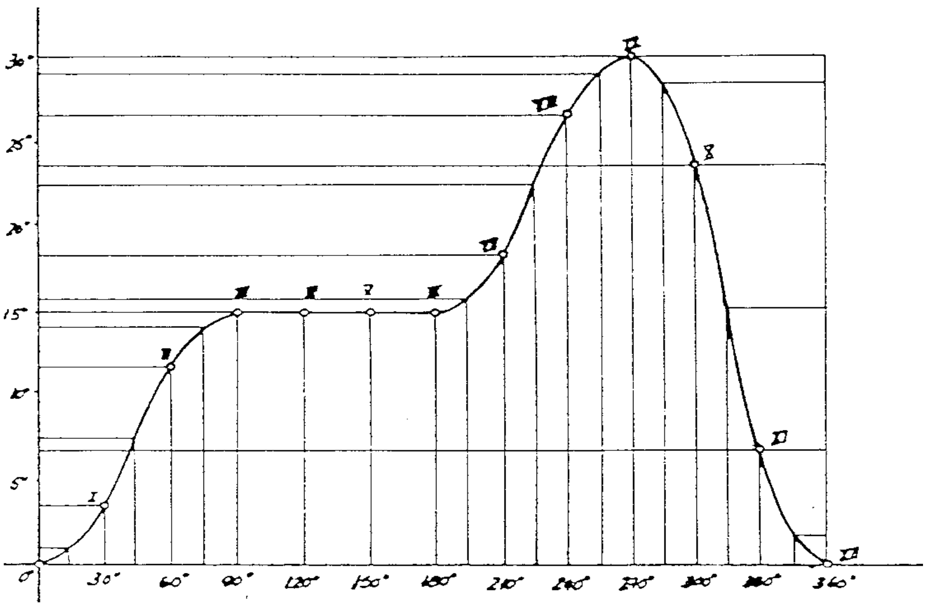

Figure 5. Displacement diagram

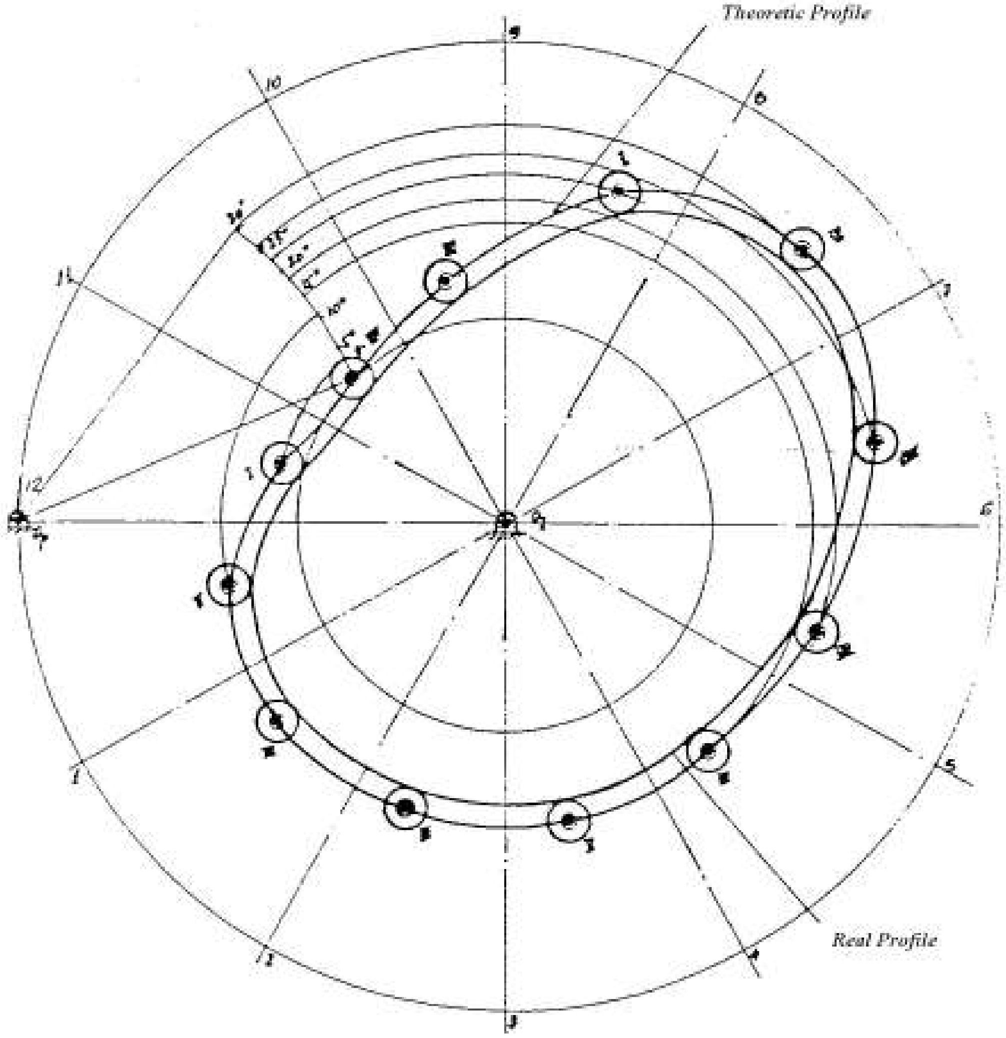

Figure 6. Theoretical and actual profile of the cam.

ANALYSIS AND SYNTHESIS OF CAMS BY COMPUTER

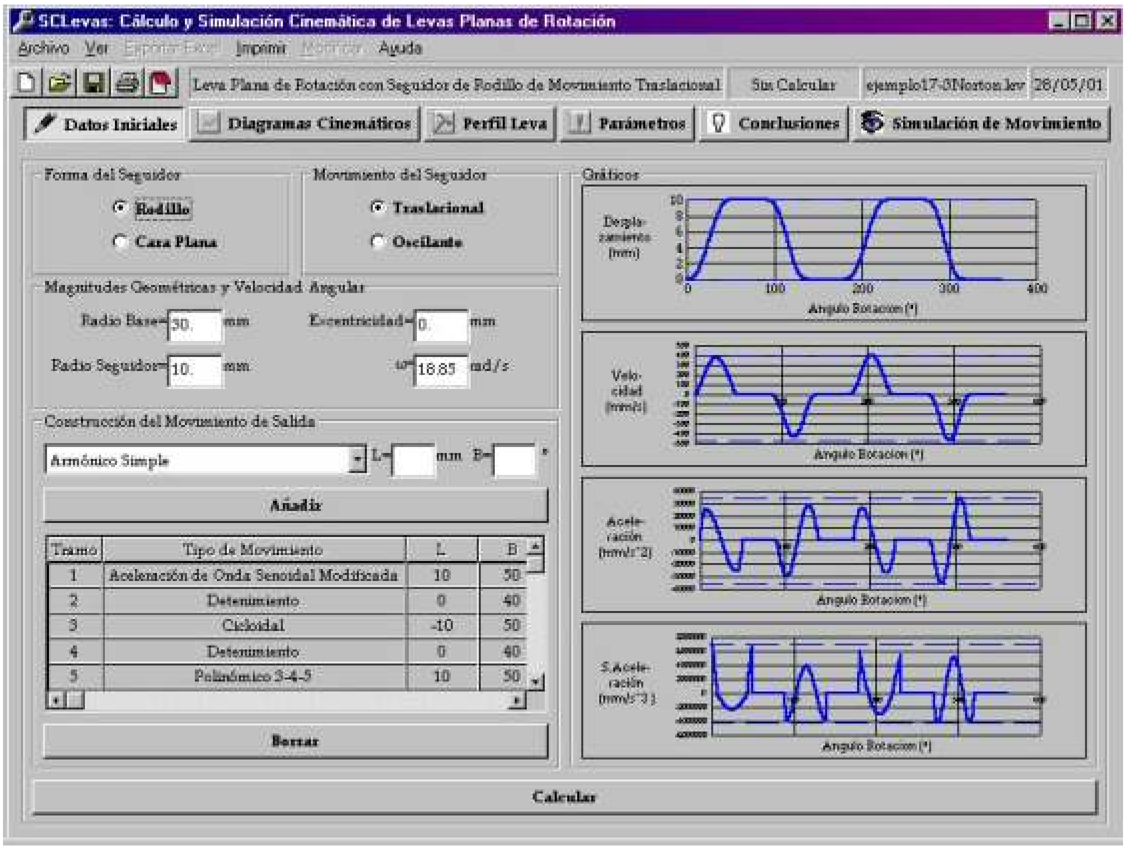

Figure 7. Application *SCLevas*.

With software *SCLeva*s (Figure 7) it is possible to construct a plane cam with the roller follower with or without eccentricity. The displacement diagram is divided into three sections:

1. The rise of the follower of 10 mm during a 90º rotation of the cam.
2. The follower remains level during the next 90º rotation of the cam.
3. The descent of the follower during the remainder of the full rotation of the cam.

For doing this, you should follow these steps:

1. Start the application SCLevas: Start - Programs - SCLevas.
2. Choose translational roller follower (default).
3. Base radius (*Radio Base*) is 50 mm, the radius of the roller (*Radio Seguidor*) is 5 mm and the angular velocity is 100 rad/s.
4. Try the following configurations for the first and the third section of the cam (considering that both sections have the same type of profile):
    - Simple harmonic motion (*Armónico simple*).
    - Cycloidal motion (*Cicloidal*)
    - 3-4-5 polynomial motion (*Polinómico 3-4-5*)

- 4-5-6-7 polynomial motion (*Polinómico 4-5-6-7*)
- Movement with modified sine wave acceleration (*Aceleración de Onda Senoidal Modificada*).
- Movement with modified trapezoidal acceleration wave (*Aceleración de Onda Trapecial Modificada*).

To change the profile type you should choose the appropriate profile and click Add (*Añadir*). To delete the profiles entered and to try another configuration, you must use the Delete (*Borrar*) button.

Indicate which of these 6 profiles meet the fundamental law of continuity.

5. Choose the cycloidal profile for the first and for the third sections to change the cam total lift from 10 to 30 mm and lower the radius of a base circle from 50 mm to 30 mm.

   To apply the changes use the Modify (*Modificar*) menu.

6. Calculate the new cam profile with the button "Calculate" (*Calcular*) and check whether the angle of pressure is too high or not.
7. Using the expression mentioned in a previous section:

   $$\tan \alpha_{\text{lim}} = \frac{a}{\mu \cdot (2 \cdot x + a - 2 \cdot \mu \cdot b)},$$

   calculate the limit of the angle not to produce jamming (Figure 4). You must consider these values: a = 5 mm, 2b = 4 mm, $x_{mín}$ = 20 mm and μ = 0.2.

8. Indicate in how many ways you could reduce the pressure angle to achieve an angle below 30º.
9. Choose any of them, or combination of several, and reduce the pressure angle up to 20º.

QUESTIONS

About the miniature model of the cams

1. Check the model carefully about the various stages of screw manufacturing process from a hexagonal bar (these were fully explained in the section concerning the objectives of the practice) and summarize it in:
    - Lathing in two phases (green cam)
    - Threading (blue cam)
    - Cutting (red cam)
    - Feeding the machine with the bulk material (cylindrical cam)
2. Draw the displacement diagram of the lathing tool (the green cam).
3. Determine the theoretical and actual profile of the lathing cam.
4. Calculate the pressure angle for the threading tool cam (the blue one), using the information from Figure 4 and taking into account that the friction coefficient is estimated as $\mu = 0.4$.

About the application *SCLevas*

5. Which of the profiles referred to in step 4 of Analysis and Synthesis of Cams by Computer meet the fundamental law of continuity?
6. What is the maximum pressure angle after carrying out step 6 of the Analysis and Synthesis of Cams by Computer?
7. What is the maximum pressure angle allowed considering the conditions in step number 7?
8. How many ways can be reduced the pressure angle, as requested in step number 8?
9. Indicate in how many ways you could reduce the pressure angle to levels below 20 º.
10. With the help of CSLevas, construct:
    - Mechanism just like the example on pages 7 and 8.
    - System of cam-follower with the data from the table on page 6.

    Specify which profile has the most appropriate curves for proper operation if the cam has an angular velocity of 25 rad/s.