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Analysis of Optimal Shape of Cam Mechanism with Roller Rocker

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***Abstract*—Cam mechanisms are crucial for driving different types of drive trains. From simple mechanisms to metal cutting machines, combustion engines, filling machines and others. Because many old machines do exist, and use such mechanism, an algorithm is proposed so that the position function can be obtained from an existing profile. Also a optimization is carried out, so that the kinematics of the new mechanism meets criteria for smooth running conditions. A polynomial function of specific order is proposed, for reverse engineering an existing profile from a filling machine.**

Keywords—cams, design, optimization of profile, position function.

I. INTRODUCTION

The featured cam mechanism transforms the rotary motion of the cam into oscillating movement of a lever. Normally the rocker and cam are pushed into one another via a spring or others types of connections, so the kinematic pair is guaranteed at all time. A variety of approaches can be seen in [1], [2], [3], [4] to obtain the position function and to optimize it in the design phase of many machines.

Most approaches presume a polynomial or simple harmonic function and have the input information as rise, dwell and fall. With this date a series of equations are constructed to form a system, which is deterministic in nature, as also seen in [5].

Filling machines accurately deliver product into containers with cams acting as main mechanism. Normally the movement is related to either accurately delivering piston position or for indexing and timing. In our case Fig. 1 the mechanism is for timing and cutting the exact volume needed to fill a container.

The main purpose of the mechanism is when during the filling, the containers are getting lifted up, to reduce splashing and foaming. The lifting way is fixed by the stoke of the mechanical lifting cam and can't be adjusted. The position of the lifters can be adjusted by the tension rod at the back side of the machine.

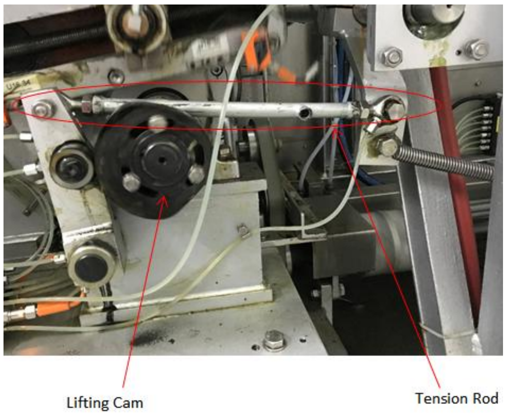

Fig. 1. Cam and rocker mechanism.

Because the machine will be rebuilt a cloud of points is collected with direct measurement, via 3D measuring machine, and supplied for this study. This date is used to investigate the design, and to get a better understanding of how this cam will fit into the new concept for the filling machine. The existing profile is extrapolated via spline function in a CAD product environment Fig. 2. The main goal is to examine the kinematics of the existing mechanism and to propose a more analytical approach to how and why the shape should change.

The overall dimensions are captured and checked with the physical cam from the machine, all changes are strictly for the sake of improvement of kinematics, no changes to stroke or overall dimensions are needed, because of other

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parts that will result in conflict in movement if changes are made.

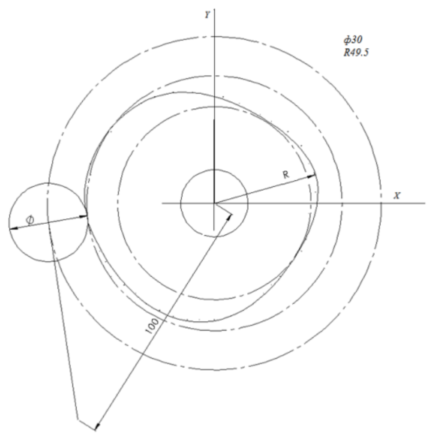

Fig. 2. Dimesnsions and profile of existing cam.

It is possible to get significantly good results in kinematic behaviour using a polynomial function (1), its derivatives to the second order (2) and specifying boundary conditions (3).

$$s = a_O + a_1 \frac{\theta}{\beta} + a_2 \frac{\theta^2}{\beta^2} + a_3 \frac{\theta^3}{\beta^3} + a_4 \frac{\theta^4}{\beta^4} + a_5 \frac{\theta^5}{\beta^5} \tag{1}$$

$$\frac{ds}{d\theta} = a_1 \frac{1}{\beta} + 2a_2 \frac{\theta}{\beta^2} + 3a_3 \frac{\theta^2}{\beta^3} + 4a_4 \frac{\theta^3}{\beta^4} + 5a_5 \frac{\theta^4}{\beta^5}$$

$$\frac{d^2s}{d\theta^2} = 2a_2 \frac{1}{\beta^2} + 6a_3 \frac{\theta}{\beta^3} + 12a_4 \frac{\theta^2}{\beta^4} + 20a_5 \frac{\theta^3}{\beta} \tag{2}$$

$$s(0) = 0,\ s(\beta) = h,\ ds(0)/d\theta = 0,\ ds(\beta)/d\theta = 0$$

$$d^2s(0)/d\theta^2 = 0,\ d^2s(\beta)/d\theta^2 = 0 \tag{3}$$

The cam system in this article is a single degree of freedom system, with known input motion, rotation with constant speed. This mechanism is intended for certain output motion, mainly periodic.

Equation (1) demonstrates the functional relation between the travel distance s of the rocker and the angle with which the cam rotates θ. This relation is known as position function or displacement diagram Fig. 3.

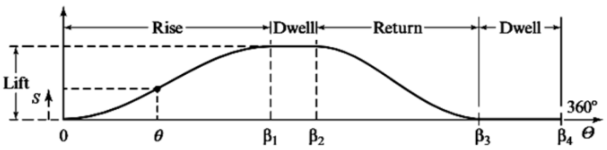

Fig. 3. Position function of cam.

The relation $\frac{\theta}{\beta}$ is a dimensionless relation between the angle of rotation and the angle β, which denotes the cycle of the phase, given in the diagram above.

Each phase is bounded from both sides, and since the rise and return will be governed by the same polynomial equation, the focus will be on the dwell-rise-dwell portion of the graph from here on.

II. Materials and Methods

A. CAD Model

The model is prepared using the polynomial function (4), which is plotted via Excel spread sheet, and the points are imported into a CAD product. The data with initial values is stated in Table 1.

TABLE 1 INITIAL VALUES FOR THE CAM DESIGN

Phases	Design Parameters		
	Degrees for interval	***Start radius (mm)***	***End radius (mm)***
Rise	70°	49.5	63
Dwell	100°	63	63
Return	70°	63	49.5
Dwell	120°	49.5	49.5

The radius values are with zero offset from the central point of the cam to the contact point of the oscillating follower. The follower diameter is 30 mm, and will be taken into account during the synthesis.

The position function (1) becomes (4), after being subjected it to initial conditions (3).

$$s = h[10 \frac{\theta^3}{\beta^3} - 15 \frac{\theta^4}{\beta^4} + 6 \frac{\theta^5}{\beta^5}] \tag{4}$$

This function is referred to as 3-4-5 polynomial in [6], [7], and [8]. The equation gives motion control of acceleration at the terminals. This is additional control to displacement and velocity Fig.4.

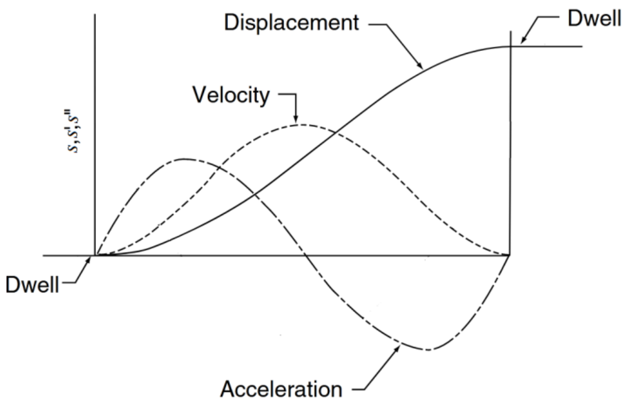

Fig. 4. Position function and derivatives for dwell-rise-dwell curve.

This design improves the kinematic behaviour at the start and end of each cycle phase.

To confirm this, an analysis of the existing cam is made and compared to the mathematically modelled one.

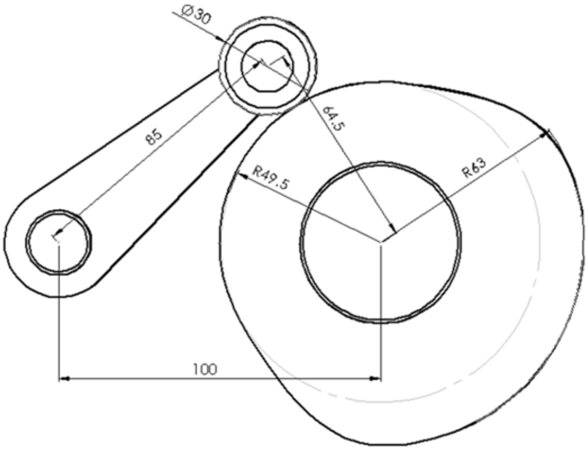

Fig. 5. Setup for initial simulation of cam mechanism.

The initial simulation is done with the setup shown in Fig.5.

The dimensions are fixed, only the cam profile is changed, kinematics analysis of initial and final design is made, based only on cam shape.

The distance travelled by the oscillating follower, between the rise and dwell portion, is given by the radial coordinate $s(\theta)$, the maximum travelled distance is denoted as *h* Fig.6.

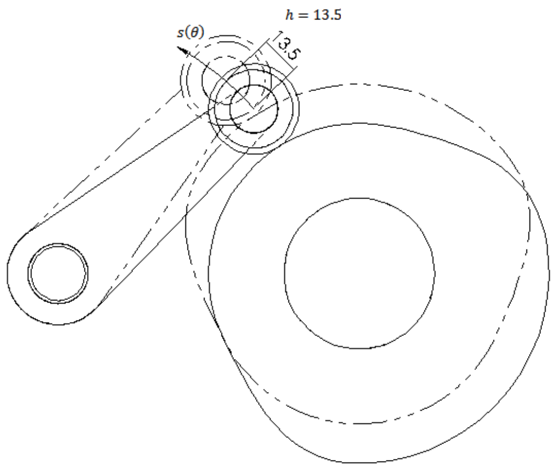

Fig. 6. Alternate view of rise-dwell position of cam mechanism.

The rise-dwell portion essentially describes how the follower moves from its initial to its peak position, for the given phase.

The position function defined (4) as 3-4-5 polynomial, is plotted and its first and second derivative is taken Fig.7.

The graph is transferred to a CAD environment, where each point is mapped. The position of the oscillating follower is traced back for each phase of the cams movement and a new profile is created.

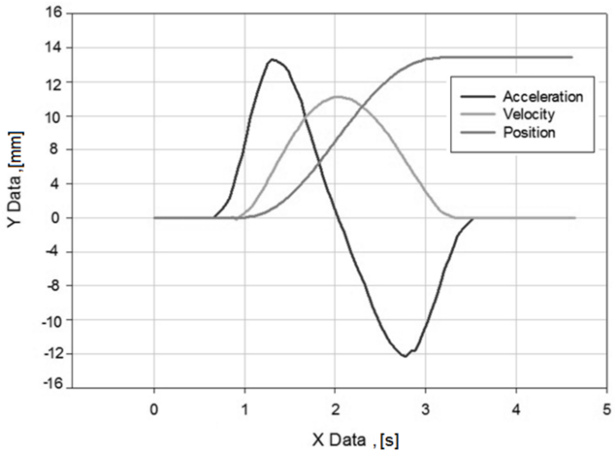

Fig. 7. Plot of position function, first and second derivatives for final cam design.

The plot above is generated with all the initial data gathered following the process of designing, and using the polynomial equations as basis.

The plot was generated with a user-defined code, using Sigma Plot and the internal regression wizard.

Program code is shown below:

```
Initial condition
y0 = F(0)[1] ''Auto {{previous: 0.01868}}
c = F(0)[4] ''Auto {{previous: -15.897}}
d = F(0)[5] ''Auto {{previous: 4.3448}}
e = F(0)[6] ''Auto {{previous: -7.43786}}

Equation
f = y0+c*x^3+d*x^4+e*x^5
fit f to y
''fit f to y with weight reciprocal_y
''fit f to y with weight reciprocal_ysquare
''fit f to y with weight reciprocal_x
''fit f to y with weight reciprocal_xsquare
''fit f to y with weight reciprocal_pred
''fit f to y with weight reciprocal_predsqr
''fit f to y with weight weight_Cauchy
x = col(1) ' {{prevmin: -3.000000}} {{prevmax:
3.000000}} {{intervals: 100}}

Variable call
y = col(2)
reciprocal_y = 1/abs(y)
reciprocal_ysquare = 1/y^2
reciprocal_x = 1/abs(x)
reciprocal_xsquare = 1/x^2
reciprocal_pred = 1/abs(f)
reciprocal_predsqr = 1/f^2
weight_Cauchy = 1/(1+4*(y-f)^2)
'Automatic Initial Parameter Estimate Functions
F(q) = ape(x;y;3;0;1)

Options
```

```
Iteration: 200
Step size: 1
Tolerance: 1e-10
```

B. *Motion simulation*

Using the Solid Works Motion simulation allows to analyse the kinematic behaviours.

Workflow of creating and simulating the model in [9], [10] is presented in steps:

- Assembly preparation – defying contact mates and initial conditions;
- Motion study – motion type and pair contact definition;
- Calculation and analysis – defying contact mates and initial conditions;

The model is shown in Fig.8

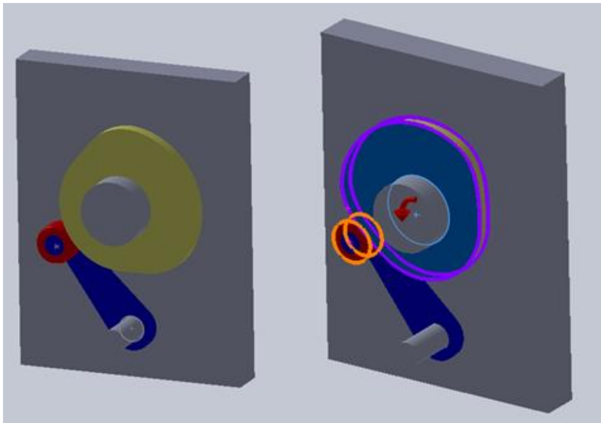

Fig. 8. CAD model of cam mechanism.

III. Results and Discussion

The results – position, velocity and acceleration are shown in Fig. 9 and Fig. 10.

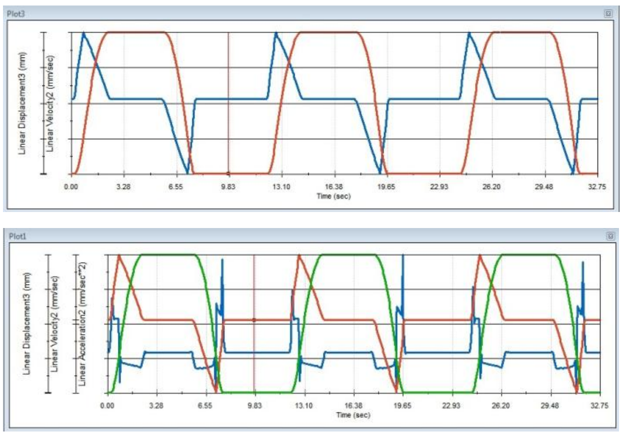

Fig. 9. Plot of the kinematic behaviour of initial cam.

The plot on Fig. 9 represents the initial cam mechanism, before any changes to the shape are made.

The plots are separated below each other for visual ease. First one represents displacement and velocity, second one adds the acceleration of the follower.

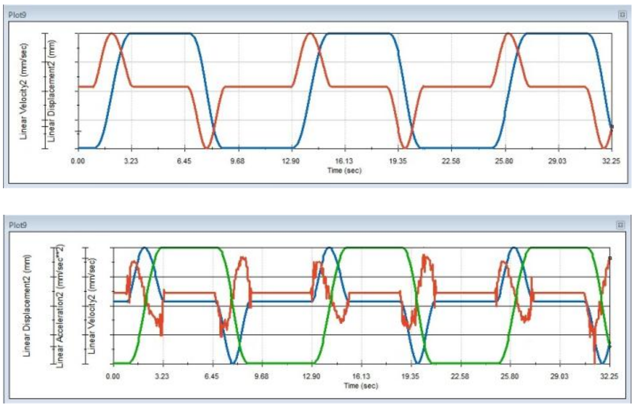

Fig. 10. Plot of the kinematic behaviour of final cam.

The plots shown in Fig.10 represent the modified cam mechanism shape. The design is the final one, based on the 3-4-5 polynomial. Plot of position and velocity are joined and shown first, the plot on the second row adds acceleration of the follower.

Upon examining the two plots, it’s obvious that the one on Fig. 10 satisfies the kinematic conditions that were required at the ends of each phase.

The final design is shown in Fig.11

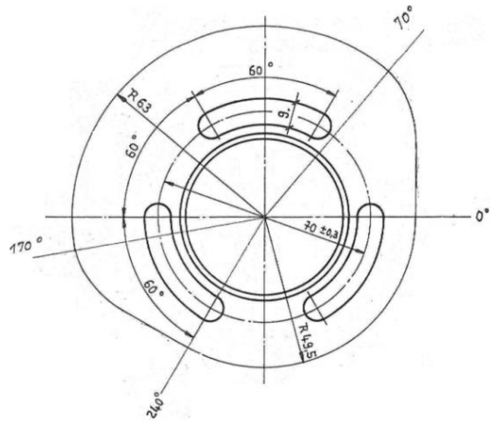

Fig. 11. Final design of cam.

IV. Conclusion

In conclusion the paper presents an approach of improving kinematic behaviour of cams without changing dimensions in confined spaces. Two models were investigated, one is with initial shape and the other is with modified shape, corresponding to a polynomial equation.

A significant change is observed in the plots presented. The goal to achieve piecewise functions, with no sudden changes is attained to the first and second derivatives.

The theoretical contribution of this study is to provide a workflow of how to rebuild, and to improve cam mechanisms kinematics.

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