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Cam Follower System Design for High Speed Machinery Using Analytical & Computational Methodology

Sandeep Sharma
Technical Head, MAeSI
Aerosphere, India
sandeep@aerosphere.in

Lavya Sharma
Research Associate
Aerosphere, India
lavyasharma1704@gmail.com

ABSTRACT
A cam can be defined as a gyratory or sliding member in a mechanical system which is used in transmuting rotary motion into a linear motion. It is basically a part of a rotating wheel and is later connected to a level known as follower which is responsible for transmitting linear motion. There are varieties of Cam follower systems which can be used for particular application. This paper presents a systematic methodology for the development of a typical cam follower system that can be used specifically in high speed machinery where sudden impacts and noise are the driving parameters. The Objective is to develop a suitable cam follower system that can reduce the noise and sudden impact loads while machine operation.

Keywords
Cam; Follower; High Speed Machinery; CATIA V5; Sine set up; Cam Calculations; Displacement Diagram

1. INTRODUCTION
Cams can be classified in two categories: uniform motion cams and accelerated motion cams. The uniform motion cam, as the name says, the rate of speed remains constant during the full stroke. It starts from zero and reaches full speed of the uniform motion abruptly and similarly it reaches zero at the end of stroke abruptly which results in a shock at the beginning and the end of stroke. Therefore, it is very necessary to construct cams for high speed machinery in such a way that it doesn't propagate any kind of shock in the machinery at the starting of the motion or during motion reversal of the follower. For moderate speeds, the uniformly accelerated motion cam is suitable, but it leads to sudden changes in acceleration at the beginning, middle and end of the stroke, which is not preferable for various operations. The optimum solution to such problems is a cycloidal motion curve cam. The main advantage of such cam is that it produces no abrupt changes in acceleration which results in low noise, vibration and wear. Hence, they are most preferred for the high speed machinery.

2. CAM FOLLOWER SYSTEM
The most commonly used cam and follower systems are:

- Radial translating roller follower
- Offset translating roller follower
- Swinging roller follower

When the cam rotates, it imparts linear motion to the roller follower as shown in Fig. 1 & 2 and a swinging motion to the roller follower as shown in Fig. 3. The motion of the follower is purely dependent on the anatomy of cam which will be discussed in the following sections.

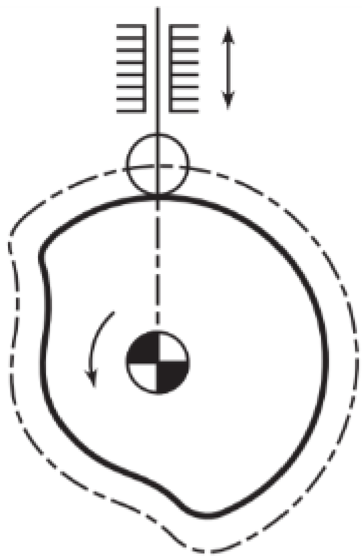

Fig. 1: Radial Translating Roller Follower

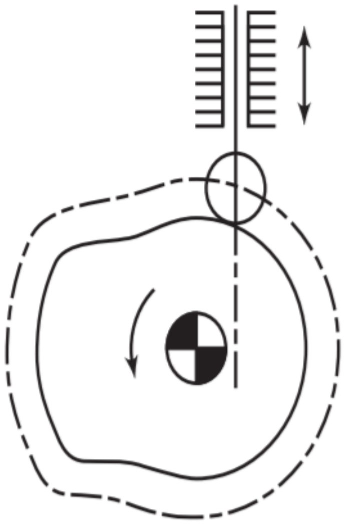

Fig. 2: Offset Translating Roller Follower

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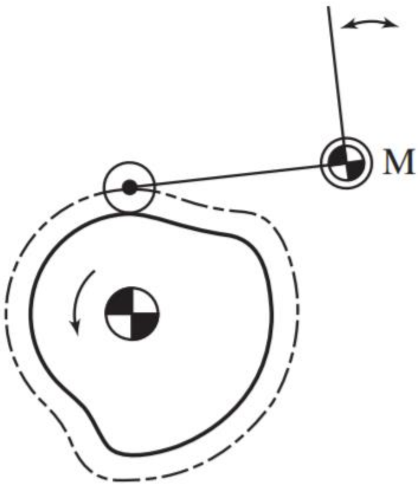


Fig. 3: Swinging roller follower

The above shown system are open-track cams and are smaller in size than closed-track cams and require spring to keep roller in contact with the cam at all times.

Following are the closed-track cams which don't require spring and have a benefit of positive drive during the rise and return cycle:

- Closed-Track Cam (Fig. 4)
- Closed-Track Cam With Two Rollers (Fig. 5)

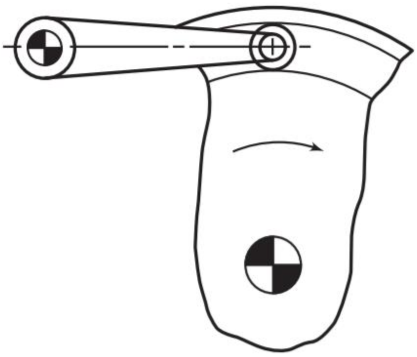


Fig. 4: Closed-Track Cam

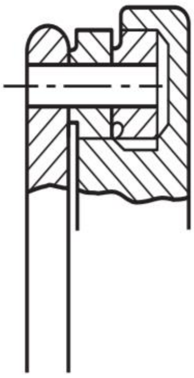


Fig. 5: Closed-Track Cam with Two Rollers

3. DISPLACEMENT DIAGRAM

Displacement diagram is the backbone of cam design. Fig. 6 shows a basic displacement diagram. One cycle signifies 360° rotation of cam. The horizontal values "T1, T2, T3, T4" or sometimes denoted by "b" are expressed in units of time (seconds); or radians or degrees. The vertical value, h, represents the maximum "rise" or stroke of the follower.

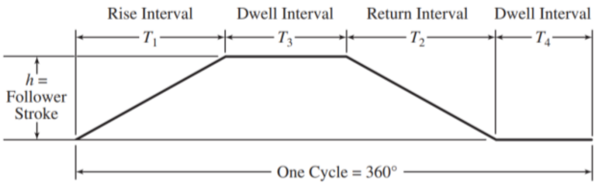


Fig. 6: Basic Displacement Diagram

Following four displacement curves are used in cam design:

1. Constant-Velocity Motion
2. Parabolic Motion
3. Simple Harmonic Motion
4. Cycloidal Motion

For the case of designing cam follower system of high speed machinery cycloidal motion displacement curves will be used which are shown in the Fig. 7 below.

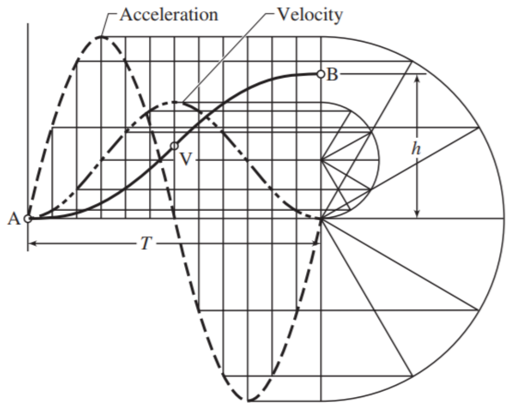


Fig. 7: Cam Displacement, Velocity, and Acceleration Curves for Cycloidal Motion

Following expressions are used for the calculation of displacement, velocity and acceleration at different intervals of stroke.

$$y = h\left[\frac{t}{T} - \frac{1}{2\pi}\sin\left(\frac{360°t}{T}\right)\right] \quad \text{or} \quad y = h\left[\frac{\phi}{\beta} - \frac{1}{2\pi}\sin\left(\frac{360°\phi}{\beta}\right)\right]$$

$$v = \frac{h}{T}\left[1 - \cos\left(\frac{360°t}{T}\right)\right] \quad \text{or} \quad v = \frac{h\omega}{\beta}\left[1 - \cos\left(\frac{360°\phi}{\beta}\right)\right]$$

$$a = \frac{2\pi h}{T^2}\sin\left(\frac{360°t}{T}\right) \quad \text{or} \quad a = \frac{2\pi h\omega^2}{\beta^2}\sin\left(\frac{360°\phi}{\beta}\right)$$

For the accurate designing of the cam follower system, only displacement expression will be used for calculations at all the angles of rise and return intervals of displacement diagram. The above expression of "y" can be rewritten as following:

$$x(z) = \begin{cases} 0 & (z \le 0) \\ -A\sin(2\pi \frac{z}{b}) + \frac{h}{b}z & (0 < z < b) \\ h & (z \ge b) \end{cases}$$

Where
z is the difference in initial and final angle
b is the total angle of rise or dwell
h is the total height of the stroke

4. ANALYTICAL & COMPUTATIONAL METHODOLOGY

As per the machinery requirement, to proceed with the cam follower system design, following parameters are considered as the baseline:

Height (h) = 94 mm

Rise interval = 70 degrees

Return interval = 120 degrees

The detailed displacement diagram is shown in Fig. 8 below.

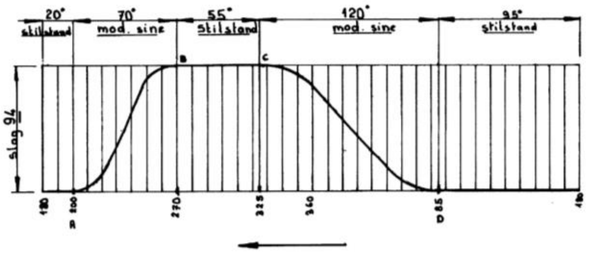
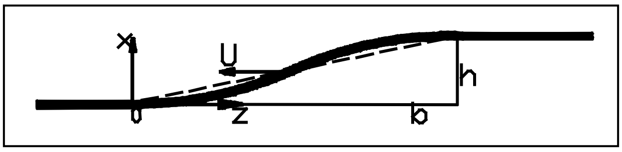


Fig. 8: Displacement Diagram

Following analytical calculations are performed for rise and return interval of the stroke:

Height (h)	94
angle (b)	70
start angle	200



2*PI()* z/b	sin(2*PI()* z/b)	h/2*PI()	h*z/b	Sine value
0	0	14.961	0	0
0.090	0.090		1.343	0.002
0.180	0.179		2.686	0.014
0.269	0.266		4.029	0.049
0.359	0.351		5.371	0.115
0.449	0.434		6.714	0.223
0.539	0.513		8.057	0.384
0.628	0.588		9.400	0.606
0.718	0.658		10.743	0.900
0.808	0.723		12.086	1.272
0.898	0.782		13.429	1.732
0.987	0.835		14.771	2.286
1.077	0.881		16.114	2.940
1.167	0.920		17.457	3.700
1.257	0.951		18.800	4.572
1.346	0.975		20.143	5.557
1.436	0.991		21.486	6.661
1.526	0.999		22.829	7.883
1.616	0.999		24.171	9.226
1.705	0.991		25.514	10.689
1.795	0.975		26.857	12.272
1.885	0.951		28.200	13.972
1.975	0.920		29.543	15.786
2.064	0.881		30.886	17.712
2.154	0.835		32.229	19.743
2.244	0.782		33.571	21.875
2.334	0.723		34.914	24.101
2.424	0.658		36.257	26.414
2.513	0.588		37.600	28.806
2.603	0.513		38.943	31.270
2.693	0.434		40.286	33.795
2.783	0.351		41.629	36.372
2.872	0.266		42.971	38.991
2.962	0.179		44.314	41.643
3.052	0.090		45.657	44.316
3.142	0.000		47.000	47.000
3.231	-0.090		48.343	49.684
3.321	-0.179		49.686	52.357
3.411	-0.266		51.029	55.009
3.501	-0.351		52.371	57.628
3.590	-0.434		53.714	60.205
3.680	-0.513		55.057	62.730
3.770	-0.588		56.400	65.194
3.860	-0.658		57.743	67.586
3.949	-0.723		59.086	69.899
4.039	-0.782		60.429	72.125
4.129	-0.835		61.771	74.257
4.219	-0.881		63.114	76.288
4.308	-0.920		64.457	78.214
4.398	-0.951		65.800	80.028
4.488	-0.975		67.143	81.728
4.578	-0.991		68.486	83.311
4.668	-0.999		69.829	84.774
4.757	-0.999		71.171	86.117
4.847	-0.991		72.514	87.339
4.937	-0.975		73.857	88.443
5.027	-0.951		75.200	89.428
5.116	-0.920		76.543	90.300
5.206	-0.881		77.886	91.060
5.296	-0.835		79.229	91.714
5.386	-0.782		80.571	92.268
5.475	-0.723		81.914	92.728

5.565	-0.658		83.257	93.100
5.655	-0.588		84.600	93.394
5.745	-0.513		85.943	93.616
5.834	-0.434		87.286	93.777
5.924	-0.351		88.629	93.885
6.014	-0.266		89.971	93.951
6.104	-0.179		91.314	93.986
6.193	-0.090		92.657	93.998
6.283185307	-2.4503E-16		94	94

Following anatomy of cam follower system is developed as per the machine requirement.

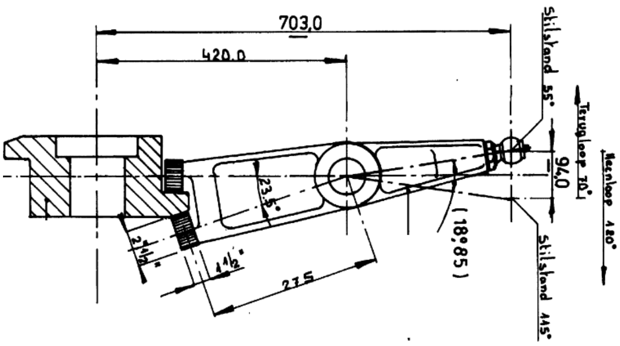


Fig. 9: Cam Follower system motion anatomy

Based on the calculations, CAD model is developed for cam follower system using surface design in CATIA V5.

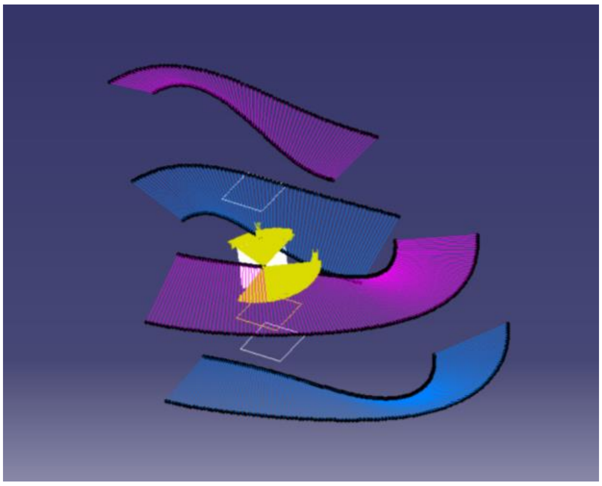


Fig. 10: Plane and respective sketches at different angles of rise and return interval of stroke

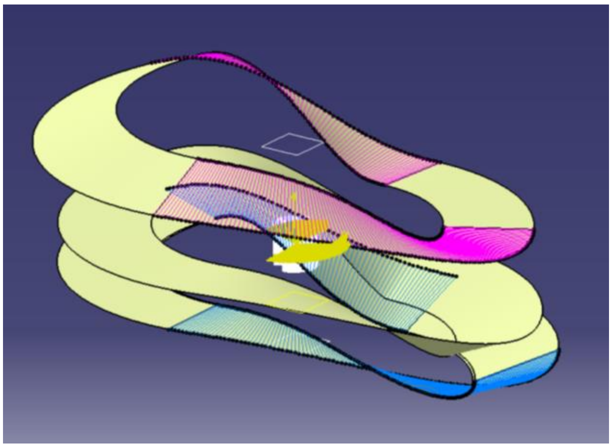


Fig. 11: Loft Surfaces as a result of sketches at different angles of rise and return interval of stroke

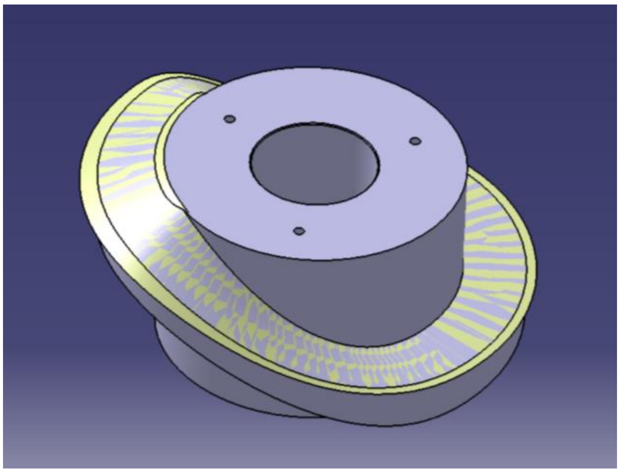


Fig. 12: Cycloidal cam profile as a result of lofted surfaces at different angles of rise and return interval of stroke

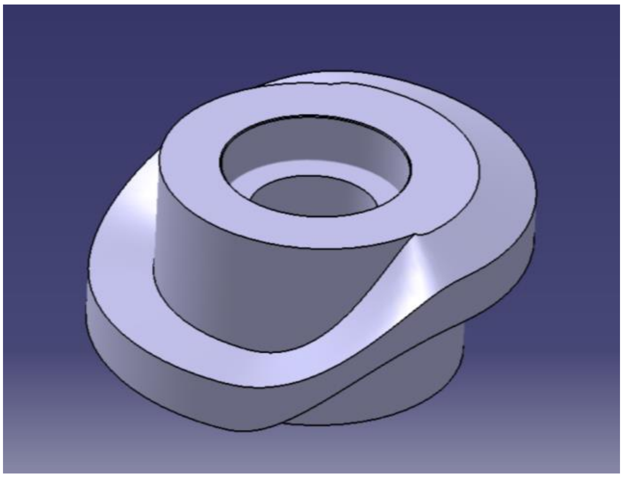


Fig. 13: Final cam model

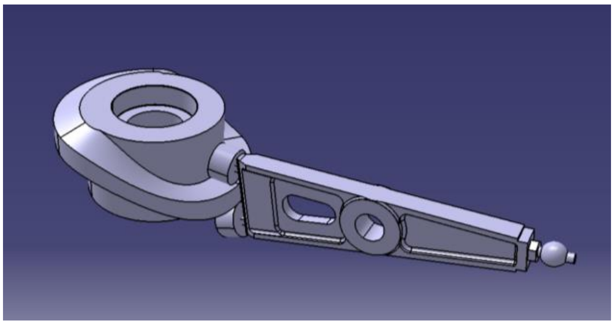


Fig. 13: Cam Follower System as per the high speed machinery requirements

5. FUTURE SCOPE

- Stress analysis can be carried out on the system to identify the weak areas
- Further optimization can be carried out considering the strength to weight ratio

6. REFERENCES

[1] Machinery’s Handbook, Induatrial Press, Edition 30

[2] Roark’s Formulas for Stress and Strain

[3] Dassault Systems, CATIA V5