ANALYSIS OF DISK CAM MOTION FOR FOLLOWER SHAPE IN HORIZONTAL POSITION

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BORANG PENGESAHAN STATUS TESIS ◆

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MOHD SOBRI BIN HUSAIN

Report submitted in partial fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
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NOVEMBER 2008

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing

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Name of Supervisor : Mr Mohd Ruzaimi bin Mat Rejab
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To my beloved mother and my brother,

Mdm Saudah binti Mustafa

And

Mr Muhammad Izwan bin Husain

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

This thesis is a analyzing of disk cam motion follower shape in horizontal position using roller follower. The objective of this thesis is to analyze disk cam profile using roller follower that neglected the friction as the interruption. This thesis also analyzes the disk cam motion in horizontal follower position. The performance of the disk cam mechanism system is based upon the shape of the cam, type of the follower that will be used, and what the application that the cam is used it, wherever high speed application or low speed application. The method that will be used in analyzing the disk cam mechanism in this thesis is two, using the theoretical manner that is graphical method and the experimental method using the Dewesoft software. The comparison between these two methods will be discussed and the characteristics of this shape of the cam will be analyzed. From this thesis, show that this type of cam only suitable for low speed application because it will endure the high vibration while operating in high sped application. Vibration is some sort of cause of failure to the mechanism that can give disadvantage to the industries nowadays. It also causes the system to go unbalance while operating and draw the system to fail if no action that will take.

ABSTRAK

Tesis ini mengenai analisis kepada bentuk pengikut sesondol jenis cakera dalam posisi mendatar. Objektif tesis ini adalah untuk menganalisis bentuk lengkungan kepada sesondol bentuk cakera mengunakan pengikut beroda yang mengabaikan geseran sebagai gangguan. Tesis ini juga menganalisis gerakan sesondol bentuk cakera dalam keadaan mendatar. Pelaksaan kepada mekanisma sistem sesondol cakera bergantung kepada bentuk sesondol, jenis pengikut yang akan digunakan dan jenis aplikasi yang akan dilaksanakan oleh sesondol, sama ada aplikasi kelajuan tinggi atau aplikasi kelajuan rendah. Cara yang akan digunakan untuk menganalisis sesondol cakera di dalam tesis ini adalah dua, mengunakan cara teori iaitu kaedah grafik dan kaedah ujian mengunakan perisian dewesoft. Perbandingan diantara dua method ini akan diperbincangkan dan karekter kepada bentuk sesondol ini akan dianalisis. Daripada tesis ini, menunjukkan bahawa bentuk sesondol ini hanya sesuai untuk digunakan bagi aplikasi kelajuan rendah kerana ia akan melalui gegaran tinggi apabila mengunakan aplikasi kelajuan tinggi. Gegaran merupakan salah satu penyebab kepada kegagalan yang akan merugikan industri pada masa sekarang. Ia juga akan menyebabkan sistem itu menjadi tidak sekata semasa mengerakkannya dan akan menyebabkan sitem itu gagal jika tiada langkah penyelesaian yang diambil.

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LIST OF SYMBOLS

$\boldsymbol{H}$	Total follower displacement during the rise or fall interval
$\boldsymbol{\beta}$	Rotational angle of cam during the rise or fall interval
$\boldsymbol{\Phi}$	Angle into rise or fall interval that defines the instantaneous follower properties
$\boldsymbol{\omega}$	Speed of the cam (degree / time)
$\Delta \boldsymbol{R}$	Instantaneous follower displacement at cam angle β
s	Displacement of the follower
$\boldsymbol{v}$	Instantaneous follower velocity
$\boldsymbol{a}$	Instantaneous follower acceleration
$\boldsymbol{T}$	Time period of cam for 1 full cycle

LIST OF ABBREVIATIONS

LVDT	Linear Variable Displacement Transducer

CHAPTER 1

INTRODUCTION

1.1 Introduction of cam

Cam is the machine component that either rotates or moves back and forth (reciprocates) to creates a prescribed motion in contacting element known as follower. In fact, cam can be used to obtain unusual or irregular motion that would be difficult to obtain from other linkage.

A common use of a cam and the follower system within a pump, such as oil pump. In such pump, the cam and follower system is used to suck oil through one non-return valve and push it out on other non-return valve. The suck action is achieve within a tight fitting cylinder so oil is suck in and push out as the follower move up or down.

Because of a profile of the cam, the rate of the follower move up and down can be controlled. When the cam turn through one motion cycle, the follower executes a series of events consisting of rises, dwell and return. Rise is the motion of the follower away from the cam center, dwell is motion during which the follower is at rest, and return is the motion of the follower toward the cam center.

Towards the motion of this event, the cam performance can be determined due to horizontal position of the cam and follower system. The time period, T, of the follower move up and down and cam rotation angle, Φ, can be measured and analyzed.

1.2 PROBLEM STATEMENT

Performance of cam mechanism system is based upon cam shape, type of follower used, and what it will use for. These performances depend on the high speed or low speed application. Theoretically, if cam is used in high speed application, it will undergo the high vibration and affect the performance of the cam.

1.3 PROJECT OBJECTIVES

The objectives of the project are two:

- To analyze disk cam profile
- To analyze disk cam motion in horizontal follower position

1.4 PROJECT SCOPES

The scopes of this project are:

- To analyze disk cam profile using roller follower
- To analyze disk cam motion due to kinematics motion
- To analyze the performance of cam system in horizontal follower position

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is to explore and gathered all information's in order to understand clearly about cam mechanism. The information's is come from reference books, journals and thesis. These sections are mainly concern about related knowledge about the cam and it system. In the middle part of the Literature Reviews, detailed explanation regarding types of cam, type of follower, cam nomenclature, and cam motion scheme. This particular area is discussed to give better understanding on what is purpose of this research.

2.2 Cam Definition

Cam mechanism is preferred over a wide variety of machines because the cam is possible to obtain an unlimited variety of motions. The cam has a very important function in the operation of many classes of machines, especially those of the automatic type, such as printing presses, shoe machinery, textile machinery, gear-cutting machines, and screw machines.

The *cam* may be defined as a machine element having a curved outline or a curved groove, which, by its oscillation or rotation motion, gives a predetermined specified motion to another element called the *follower* [Yi Zhang, 2006]. In other word, cam mechanism transforms a rotational or oscillating motion to a translating or linear motion. In fact, cam can be used to obtain unusual or irregular motion that would be difficult to obtain from other linkage.

2.3 Different Type of Cam

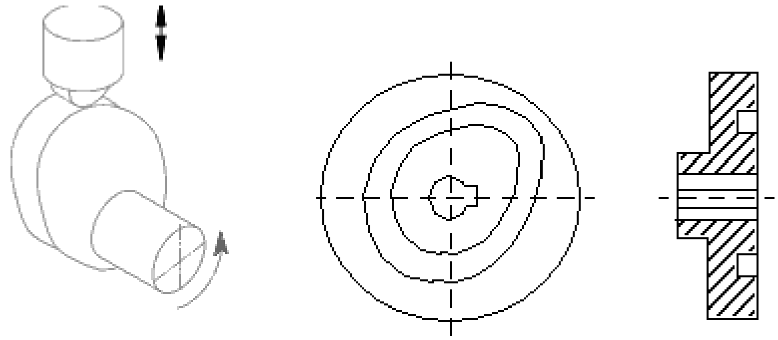
The variety of different types of cam and follower systems that one can choose from is quite broad. It depends on the shape of contacting surface of the cam and the profile of the follower. Cams are made in a variety of forms, including:

- A rotating disk plate with radial required profile
- A reciprocating wedge of a required shape
- A cylindrical barrel cam with a follower groove cut in a diameter
- A cylindrical with required profile cut in the end (end cam)

2.3.1 Cam Shape

1. **Plate cam** or radial cam (Figure 2-1a):

   The follower moves in a plane perpendicular to the axis of rotation of the camshaft. A translating or a swing arm follower must be constrained to maintain contact with the cam profile.



(a) (b)

Figure 2-1: Illustration for plate cam and groove cam

2. **Grooved cam** or closed cam (Figure 2-1b):

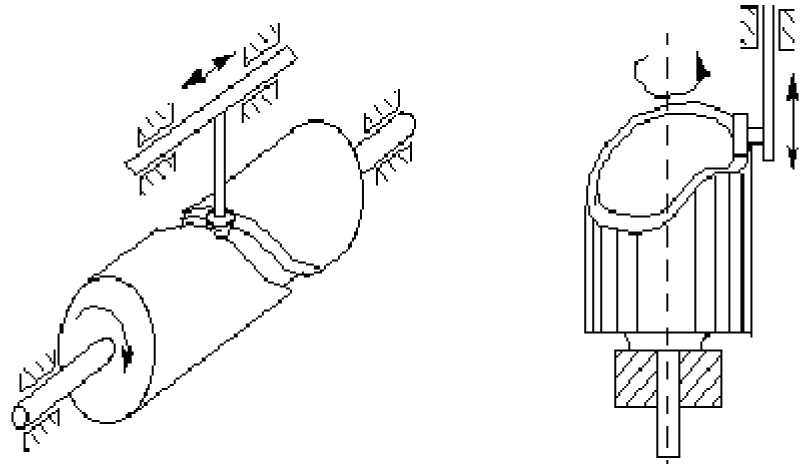
This is a plate cam with the follower riding in a groove in the face of the cam.

3. **Cylindrical cam** or barrel cam (Figure 2-2a):

The roller follower operates in a groove cut on the periphery of a cylinder. The follower may translate or oscillate. If the cylindrical surface is replaced by a conical one, a conical cam results.

4. **End cam** (Figure 2-2b):

This cam has a rotating portion of a cylinder. The follower translates or oscillates, whereas the cam usually rotates. The end cam is rarely used because of the cost and the difficulty in cutting its contour.



(a) (b)

Figure 2-2: Illustration for cylindrical cam and end cam

2.4 Cam Mechanism

The transformation of one of the simple motions, such as rotation, into any other motions is often conveniently accomplished [Roymech, 2006]. Cam is the common mechanism element that drives a mating component. A cam mechanism usually consists of two moving elements, the cam and the follower, mounted on a fixed frame. The cam mechanism can be classified by the modes of input/output motion, configuration and arrangement of the follower, and the shape of the cam [Chen, 1982].

2.4.1 Follower Configuration

1) The knife edge follower (Figure 2-3a):

   This is the simplest type, is not often used due to the rapid rate of wear. When it is adopted, it is usually for reciprocating motion, running in slides and there is considerable side thrust, this being a component of the thrust from the cam.

2) The roller follower (Figure 2-3b):

This eliminates the problem of rapid wear since the sliding effect is largely replaced by a roller action. Some sliding will still take place due to the varying peripheral speed of the cam profile, due to the changing radius of the point of contact. Note also that the radial position of the contact between the cam and the roller, relative to the follower center, will change according to whether a rise or fall motion is taken place: this fact has to be considered when constructing the cam profile. Again, with the roller follower, considerable side thrusts are present, a disadvantage when dealing with reciprocating motions. This side thrust will be increased when using small rollers.

3) The flat face follower (Figure 2-3c):

This has the advantage that the only side thrust present is that due to the friction between the follower and the cam. The problem of wear is not as great as with the knife-edge follower, since the point of contact between the cam and follower will move across the face of the follower according to the change of shape of the cam. A trick to lesson further the effect of wear is to design the follower to be capable of axial rotation and arrange the axis of the follower to lie to one side of the cam. Thus the contact with the cam will tend to cause rotation of the follower. The cam profile, to work with a flatfoot follower, must be convex at all parts, in order to prevent the corners of the follower digging into the cam profile. The minimum cam radius should be as small as possible to minimize sliding velocity and friction.

4. Oblique flat-faced follower

5. Spherical-faced follower (Figure 2-3d)

6. Offset roller follower (Figure 2-3e)

7. Pivoted roller follower (Figure 2-3f)

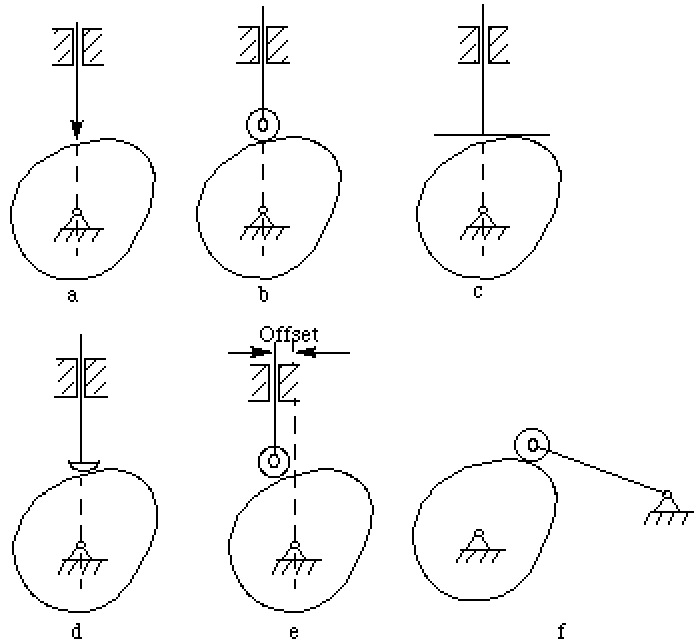


Figure 2-3: Follower configuration for disk cam mechanism

2.5 Cam Nomenclature

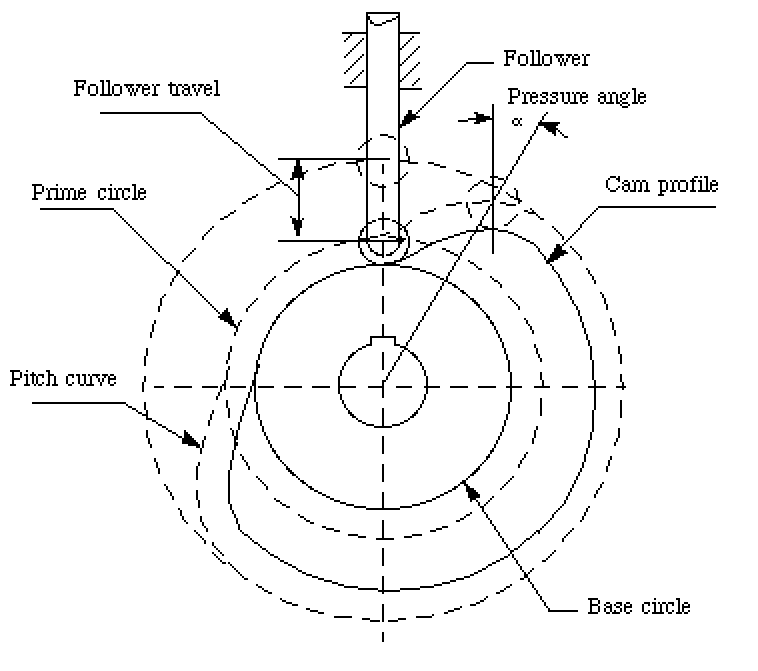


Figure 2-4: Cam Nomenclature

- Trace point: A theoretical point on the follower, corresponding to the point of a fictitious *knife-edge follower*. It is used to generate the *pitch curve*. In the case of a *roller follower*, the trace point is at the center of the roller.
- Pitch curve: The path generated by the trace point at the follower is rotated about a stationary cam.
- Working curve: The working surface of a cam in contact with the follower. For the *knife-edge follower* of the plate cam, the *pitch curve* and the *working curves* coincide. In a *close or grooved cam* there is an *inner profile* and an *outer working curve*.
- Pitch circle: A circle from the cam center through the pitch point. The pitch circle radius is used to calculate a cam of minimum size for a given *pressure angle*.
- Prime circle (reference circle): The smallest circle from the cam center through the pitch curve.
- Base circle: The smallest circle from the cam center through the cam profile curve.
- Stroke or throw: The greatest distance or angle through which the follower moves or rotates.
- Follower displacement: The position of the follower from a specific zero or rest position (usually its the position when the follower contacts with the *base circle* of the cam) in relation to time or the rotary angle of the cam.
- Pressure angle: The angle at any point between the normal to the pitch curve and the instantaneous direction of the follower motion. This angle is important in cam design because it represents the steepness of the cam profile.

2.6 Cam Motion

When the cam turns through one motion cycle, the follower executes a series of events consisting of rises, dwells and returns. Rise is the motion of the follower away from the cam center, dwell is the motion during which the follower is at rest; and return is the motion of the follower toward the cam center [Yi Zhang, 2006].

Notation

H = total follower displacement during the rise or fall interval

β = rotational angle of cam during the rise or fall interval

Φ = angle into rise or fall interval that defines the instantaneous follower Properties

ω = speed of the cam (degree / time)

ΔR = instantaneous follower displacement at cam angle β

v = instantaneous follower velocity

a = instantaneous follower acceleration

2.6.1 Constant Velocity Motion

If the motion of the follower were a straight line, it would have equal displacements in equal units of time, *i.e.*, uniform velocity from the beginning to the end of the stroke, as shown in b. The acceleration, except at the end of the stroke would be zero. The diagrams show abrupt changes of velocity, which result in large forces at the beginning and the end of the stroke. These forces are undesirable, especially when the cam rotates at high velocity. The *constant velocity motion* is therefore only of theoretical interest.

Rise

$$\Delta R = H\Phi/\beta$$

$$v = H\omega/\beta \qquad (1)$$

$$a = 0$$

Fall

$$\Delta R = H(1 - \Phi/\beta)$$

$$v = -H\omega/\beta \qquad (2)$$

$$a = 0$$

2.6.2 Constant Acceleration Motion

The velocity increases at a uniform rate during the first half of the motion and decreases at a uniform rate during the second half of the motion. The acceleration is constant and positive throughout the first half of the motion, as shown in f, and is constant and negative throughout the second half. This type of motion gives the follower the smallest value of maximum acceleration along the path of motion. In high-speed machinery this is particularly important because of the forces that are required to produce the accelerations.

When

$0 \le \varphi \le \frac{\beta}{2}$,

Rise

$$\Delta R = H - 2H(1 - \Phi/\beta)^2$$

$$v = (4H\omega/\beta)(1 - \Phi/\beta) \qquad (3)$$

$$a = -4H(\omega/\beta)^2$$

Fall

$$\Delta R = 2H(1 - \Phi/\beta)^2$$

$$v = -(4H\omega/\beta)(1 - \Phi/\beta) \tag{4}$$

$$a = 4H(\omega/\beta)^2$$

2.6.3 Harmonic Motion

A cam mechanism with the basic curve will impart *simple harmonic motion* to the follower. The velocity diagram indicates smooth action. The acceleration is maximums at the initial position, zero at the mid-position, and negative maximum at the final position.

Rise

$$\Delta R = H/2\,[1 - \cos(\pi\Phi/\beta)]$$

$$v = (\pi H\omega/2\beta)\,[\sin(\pi\Phi/\beta)] \tag{5}$$

$$a = (\pi^2 H\omega^2/2\beta^2)\,[\cos(\pi\Phi/\beta)]$$

Fall

$$\Delta R = H/2\,[1 + \cos(\pi\Phi/\beta)]$$

$$v = -(\pi H\omega/2\beta)\,[\sin(\pi\Phi/\beta)] \tag{6}$$

$$a = -(\pi^2 H\omega^2/2\beta^2)\,[\cos(\pi\Phi/\beta)]$$

2.6.4 Cyclodial Motion

Another motion scheme derived from trigonometric functions. This scheme also exhibits very smooth motion curves and does not have the sudden change in acceleration at the end of the motion, which makes it popular for high- speed application. It has low vibration wear and stress characteristics of all basic curves described. In a physical sense, it is the motion of a point on a disk rolling on a straight line.

Rise

$$\Delta R = H\ [\ (\Phi/\beta) - (1/2\pi) \sin (2\pi\Phi/\beta)\ ]$$

$$v = (H\omega/\beta)\ [1 - \cos (2\pi\Phi/\beta)\ ] \tag{7}$$

$$a = (\pi H\omega^2/\beta^2)\ [\ \sin (2\pi\Phi/\beta)\ ]$$

Fall

$$\Delta R = H\ [\ 1 - (\Phi/\beta) + (1/2\pi) \sin (2\pi\Phi/\beta)\ ]$$

$$v = -\ (H\omega/\beta)\ [1 - \cos (2\pi\Phi/\beta)\ ] \tag{8}$$

$$a = -\ (\pi H\omega^2/\beta^2)\ [\ \sin (2\pi\Phi/\beta)\ ]$$

2.7 Theory of Envelopes

From theory of Envelops, the analytical development of cam profiles, desired positions of the follower are obtained for an inversion of the system (with the cam stationary). The desired cam profile is then obtained by fitting a tangent curve to the successive follower positions [Arunava Biswas, Michael Stevens, Gary L. Kinzel, 2003].

In this theory, it shows that, in designing the cam, another method is to draw the follower position at the profile of the cam. The points lying on the envelope obviously also lies on the curves (figure 2-5). Using partial derivative, the cam profile will be produce using the point from envelopes theory (figure 2-6).

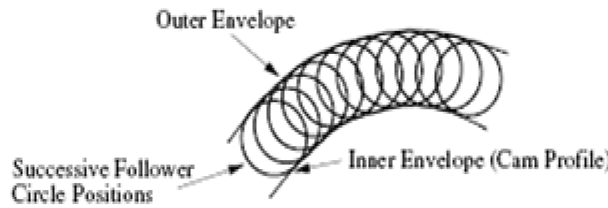


Figure 2-5: Series of circles representing roller follower and cam profiles.

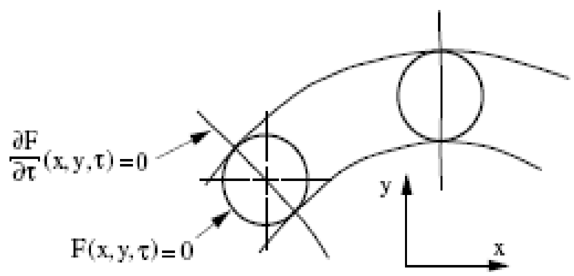


Figure 2-6: Points on the profiles can be obtained from envelope theory.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In analyzing cam motion geometry, first thing that will be considered is designing the cam shape. From the cam shape analysis, the parameter that will be found out is the follower displacement, follower velocity and follower acceleration. The analysis is done by the two difference method, graphical method and experimental method. The data taken by experimental method using the software called Dewesoft software. Later the data is analyzed to compare with the graphical method. The pre-extermination is done by showing the error occurs between these two methods.

3.2 Cam Motion Concept

In designing the cam profile, the most important aspects that will be considered are the shape of the cam. Once the desired motion of a cam and the follower had been defined through a displacement diagram, the shape of the cam can be design and produce. This means that the relative motion between the cam and the follower is a combination of a relative turning motion and a relative translating motion. It can effect the follower velocity and follower acceleration. The kinematics equations and the cam profile are derived based on the geometry of the cam and mechanism of the follower.

3.3 Cam Shape

In this design, ellipse shape has been choosing to be analyzed. This shape is a basic shape that generally use in the industries nowadays. This shape has been choose because of the performance between input data can be differentiate and can be analyze according to the parameter that been considered. The figures below (figure 3-1 and figure 3-2) show the shape and geometry of the ellipse shape cam.

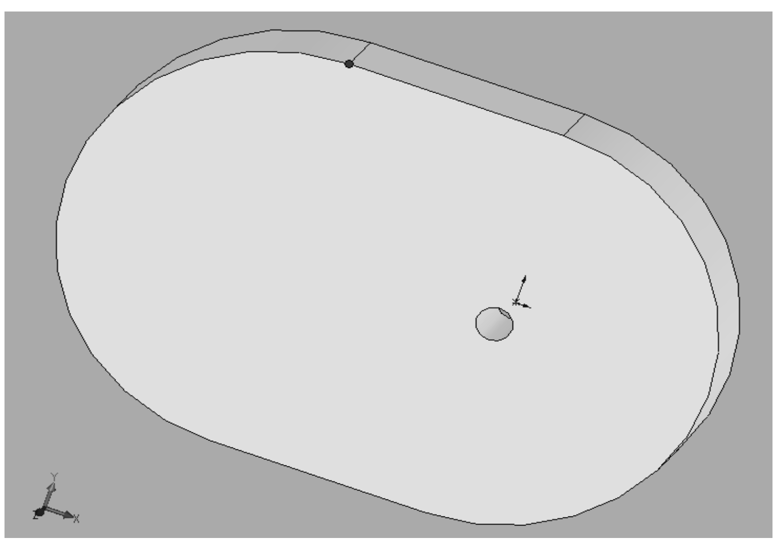


Figure 3-1: Ellipse shape cam

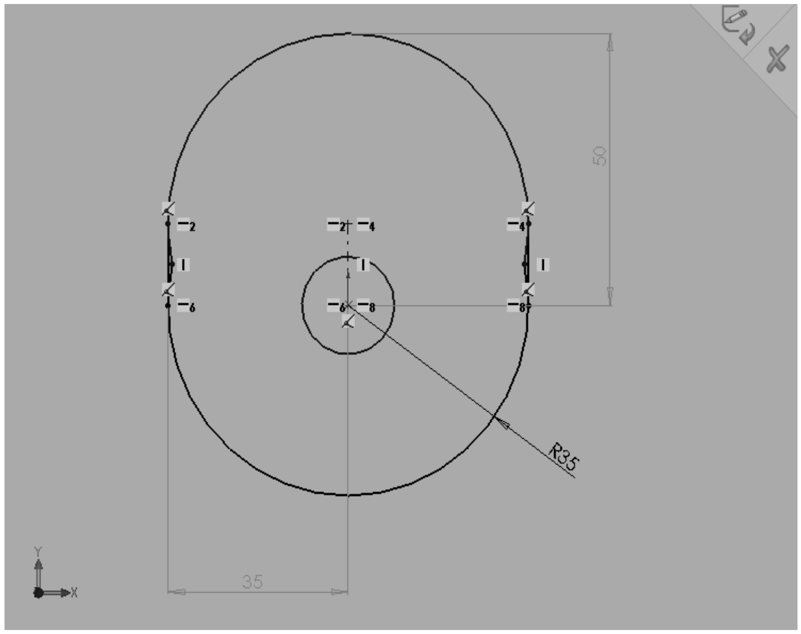


Figure 3-2: Geometry of cam

3.4 List of Equipments for Cam Analysis

3.4.1 Cam Mechanism Analysis System

In analyzing cam motion mechanism, the machine that had been used is cam mechanism analysis system. From this experiment, the parameter that will be gathered is the kinematics motion parameter, displacement (s), velocity (v) and acceleration (a) of the follower. From this data, the performance of the cam and follower system can be analyze and had been compared with the theoretical analysis.

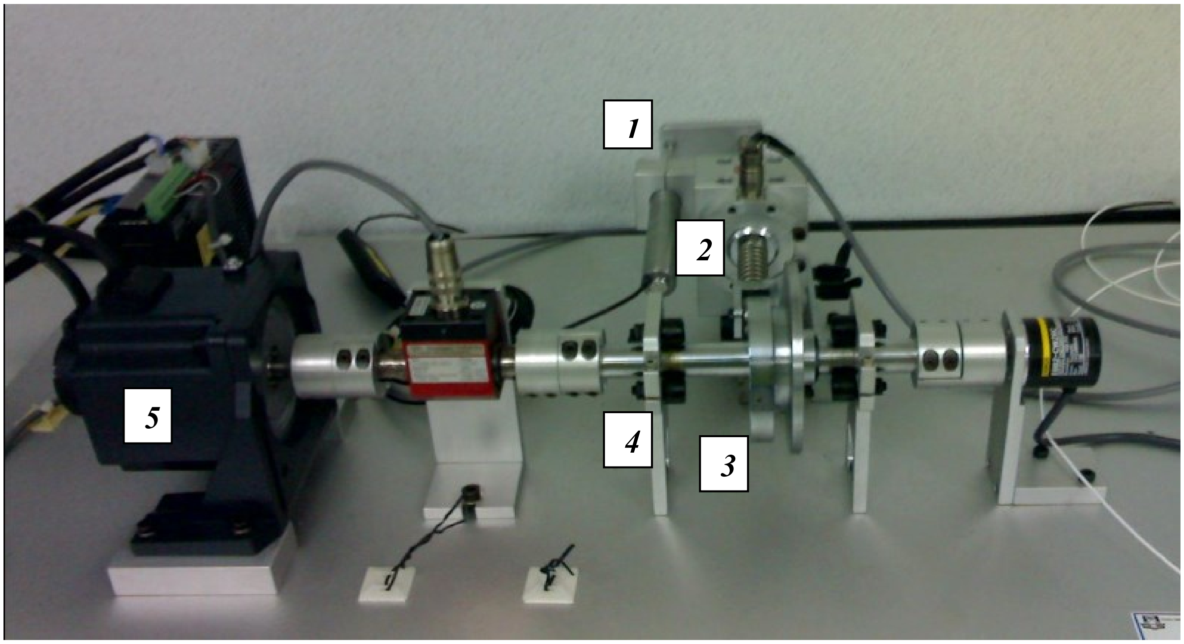


Figure 3-3: Cam mechanism analysis system

1. LVDT (linear variable displacement transducer) used to measure the displacement of the roller follower.
2. Roller follower consists of the follower that has separate part, the roller, which is pinned to the follower stem.
3. Position of the ellipse cam
4. Cam shaft, the component that been used to hold the cam.
5. Motor that will be use to rotate the cam mechanism analysis system.

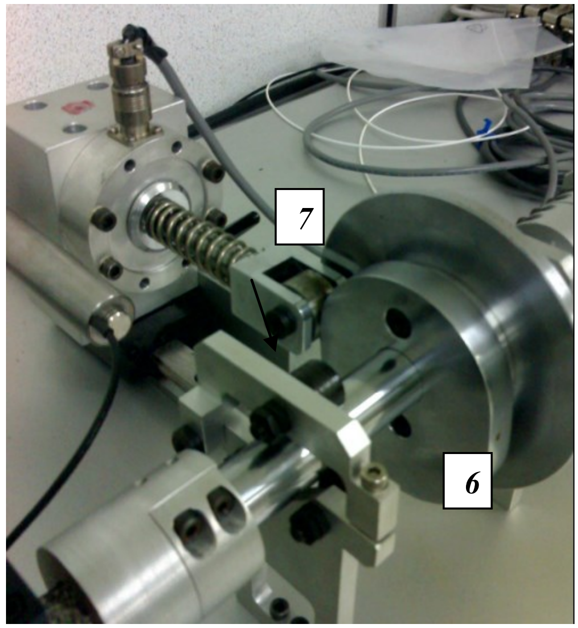


Figure 3-4: Location of cam

6. Position of cam that attach to the follower
7. Roller Follower, the follower that will be use in this analysis.

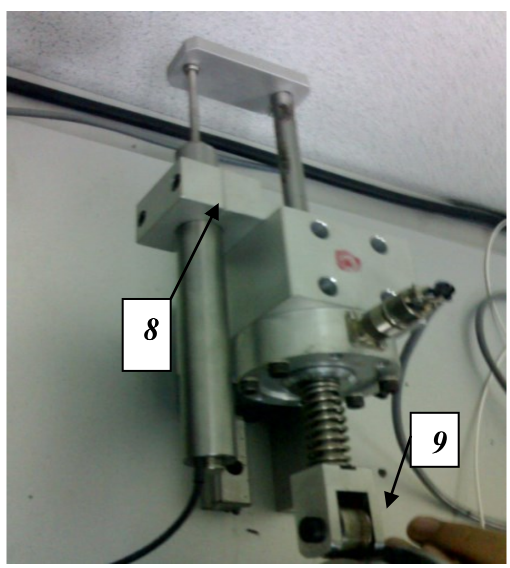


Figure 3-5: Linear Variable Displacement Transducer

8. Position of linear variable displacement transducer (LVDT)
9. Position of the roller follower

The cam mechanism analysis system is a customize system that used the Dewesoft software to run the experiment.

3.4.2 Dewesoft Software

DEWESOFT software is only one part in whole chain of measurements within the overall instrument, which is comprised of sensors, signal conditioning hardware, an Intel computer, A/D boards from various manufacturers and their drivers, and which has been written using commercially available software and compilers from various manufacturers Therefore, the best and time-tested way of proving the accuracy of the calculations made in any data acquisition system is to input known values from a proven reference source, and then verify that the measured results in the software match this known input [DEWESoft Software User Manual corresponds with software version 6.3].

Using the Dewesoft software application, 5 sensors had been used to determine the parameter of the moving cam and follower system. It because, while the cam system is moving, many think can interrupt in order to reduce the performance of cam and follower system. The sensor that been uses are:

1. Incremental Rotary Recorder

Type of measurement:	**RPM (speed)**
Range:	1000 pulses / revolution (P/R)
Type of signal conditioner:	**DAQP-Freq -A**

2. KSM Torque Transducer

Type of measurement:	**Torque**	
Range:	100 Nm	
Calibration:	Torque 0 Nm	Output 0.000 mV/V
	Torque 100 Nm	Output 2.002 mV/V
Type of signal conditioner:	**DAQP-Bridge -B**	

3. FGP Load Cell

Type of measurement:	**Force**
Range:	10 kN
Sensitivity	-177.36 mV
Type of signal conditioner:	**DAQP-Bridge -B**

4. Accelerometer

Type of measurement:	**Vibration**
Range:	+/- 500 g
Sensitivity	10.75 mV/g
Output connection:	ICP
Type of signal conditioner:	**DAQP-Charge –A** or **DAQP-ACC-A**

5. LVDT (Linear Variable Displacement Transducer)

Type of measurement:	**Displacement**
Range:	-
Sensitivity	-
Output connection:	Potentiometer, Half Bridge
Type of signal conditioner:	**DAQP-Bridge –A** or **DAQP-Bridge-B**

Simulation in the Dewesoft Software

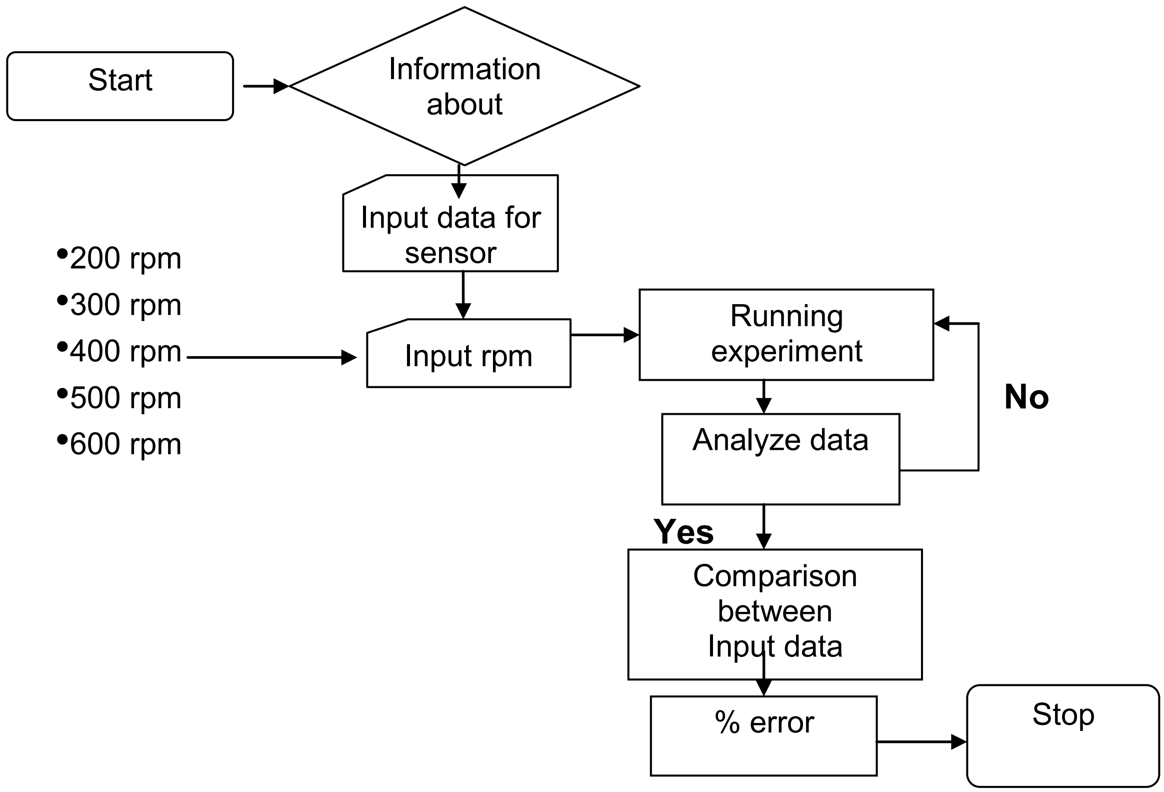


Figure 3-6: Flow chart for Dewesoft Software analysis

The figure 3-6 shows the flow of the analysis using Dewesoft software. For this experiment, the input data is the cam speed that be manipulate from the motor of the machine. From that, the experiment can be run to get the appropriate output.

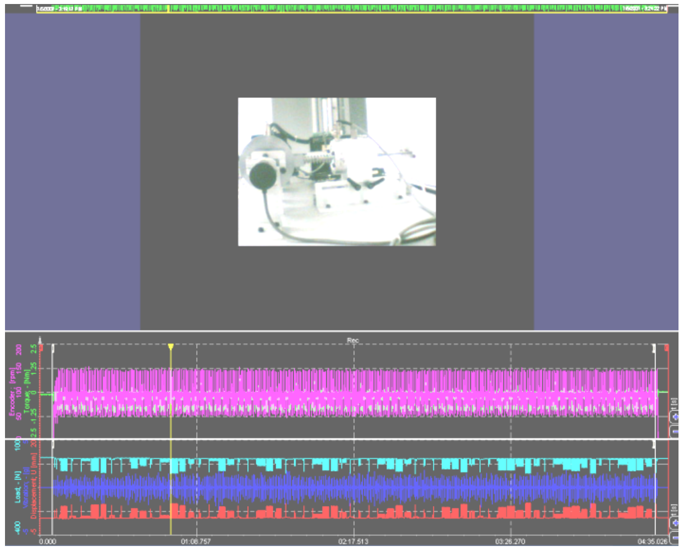


Figure 3-7: Cam analysis in Dewesoft Software

Figure 3-7 show the example of cam analysis using the Dewesoft software. In that analysis, it use camera to show the how the follower move related to the rotation of the cam. Below the graphic of the camera is the output data that generate from the software in term of graph versus time.

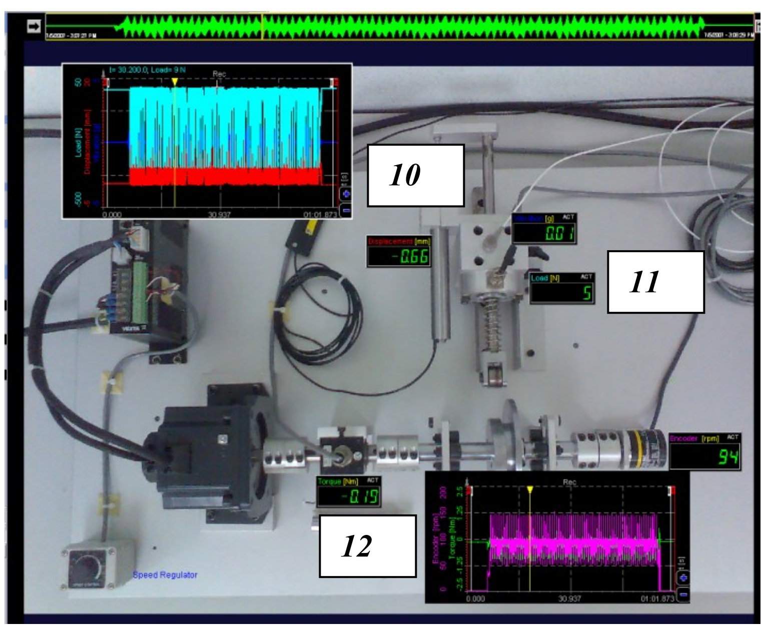


Figure 3-8: Cam analysis in Dewesoft Software (2)

10. Displacement meter reading show the displacement of the follower due to rotation of cam
11. Load meter reading show the load that will be face by a follower
12. Torque meter reading show the torque that influence by the shaft due to the rotation of cam.

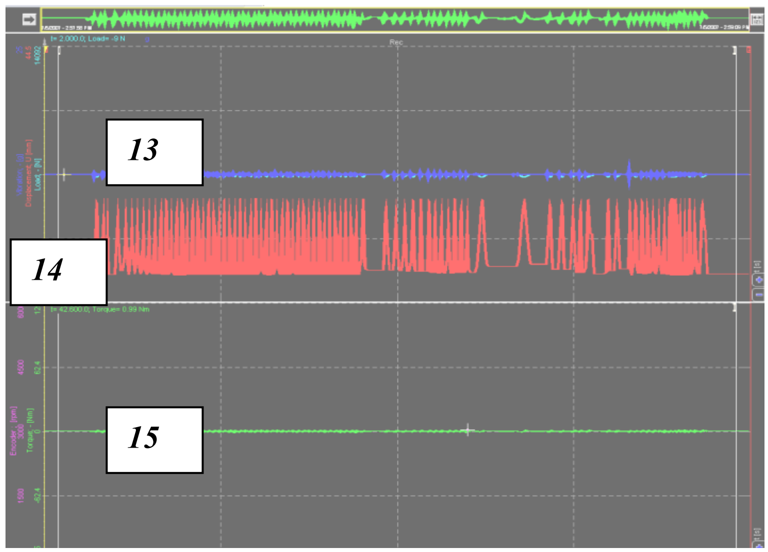


Figure 3-9: Graph generated from the cam analysis in Dewesoft software

13. Velocity graph versus time, show the velocity of the follower for the some time constrains.
14. Displacement graph versus time show the displacement of the follower for some time constrains.
15. Torque graph versus time show the torque of the cam shaft due to rotation of cam.

3.5 Data collection method

From the ellipse shape of cam that had be used, the performance of this type of the cam using kinematics parameter can be differentiate from the experiment in the cam mechanism analysis system using different speed of cam. In this experiment, the speed of cam that will be used is 200 rpm, 300 rpm, 400 rpm, 500 rpm and 600 rpm.

3.6 Cam analysis method

After doing the experiment, the cam performance in experimental method will be compare with the theoretical method to get how different it is. The percentage of error will be calculated to prove the error regarding the experimental method and analytical method.

Percentage of error (%) for displacement, velocity and acceleration according to input data compare to theoretical method will be interpret to recognize if this cam is suitable for low speed or high speed application.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

To implement the analysis of cam mechanism system, two processes were applied: graphical method and experimental method. The graphical method is theoretical method from actual cam while the experimental method is the simulation from the Dewesoft software.

4.2 Graphical method

Regarding the cam profile analysis, first thing is to get the actual cam profile geometry. To get this, the cam will be trace to get the actual profile. From this, the graphical of the cam can be constructing. Figure 4-1 below illustrates the cam profile for graphical method.

From this graphical method of cam (figure 4-1), from 0^o to 90^o of cam rotation angle (β) is rise part, from 90^o to 180^o is fall part and 180^o to 360^o is dwell part. From this graphical method also know that the diameter of the base circle of this cam is 70 mm and total follower displacement (H) of this cam is 15 mm. From this graphical method the displacement diagram, velocity diagram and acceleration diagram can be constructed to view the follower moving via a cam angle rotation (β).

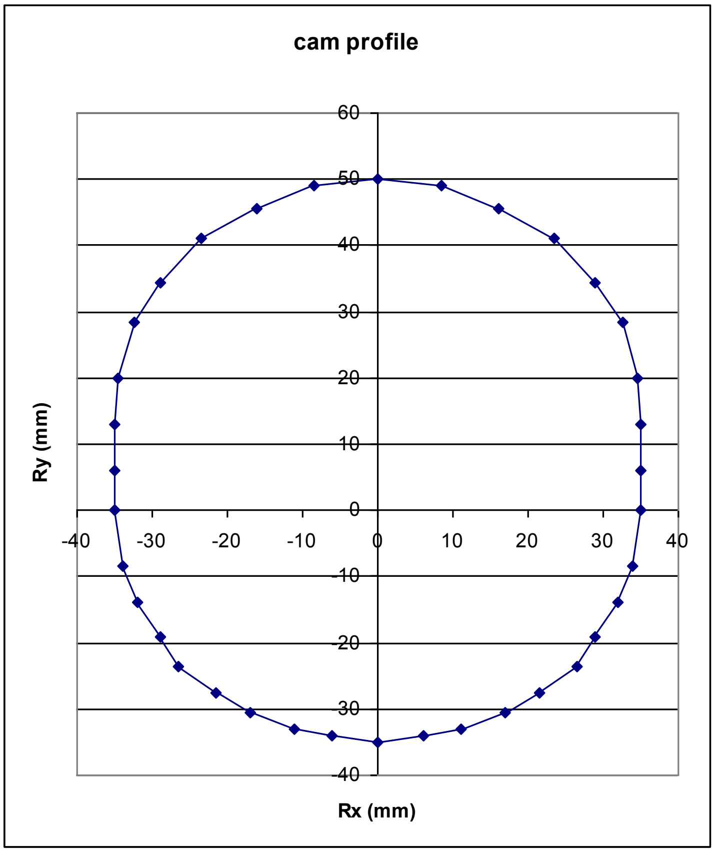
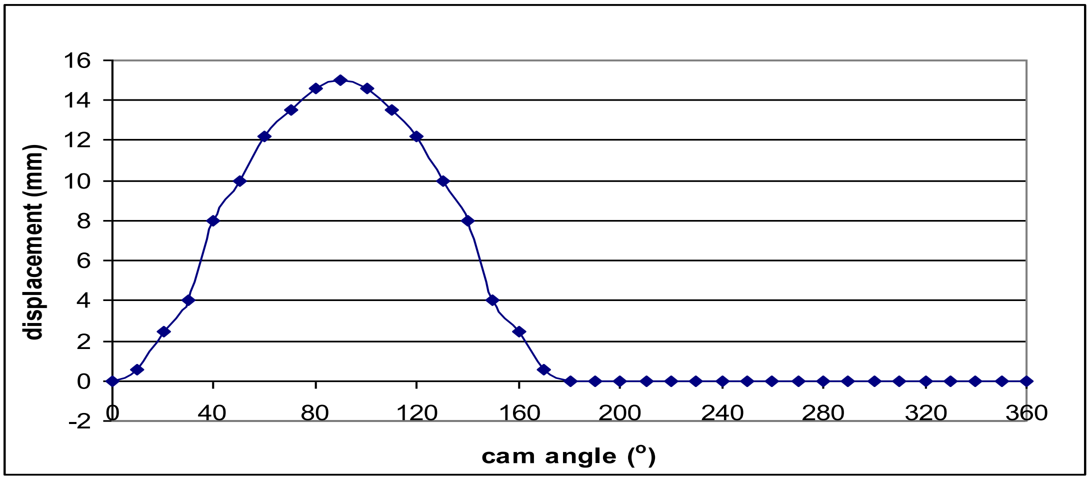
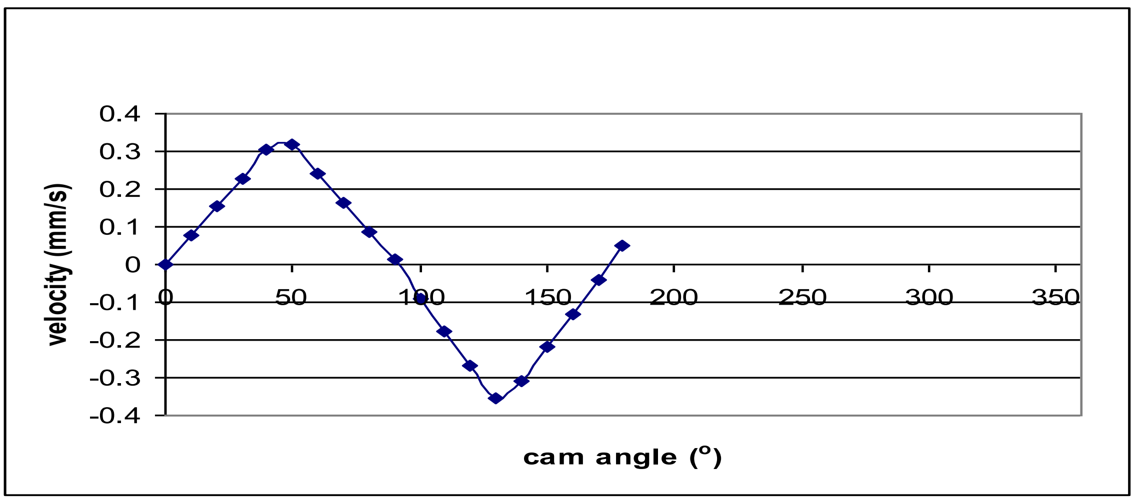


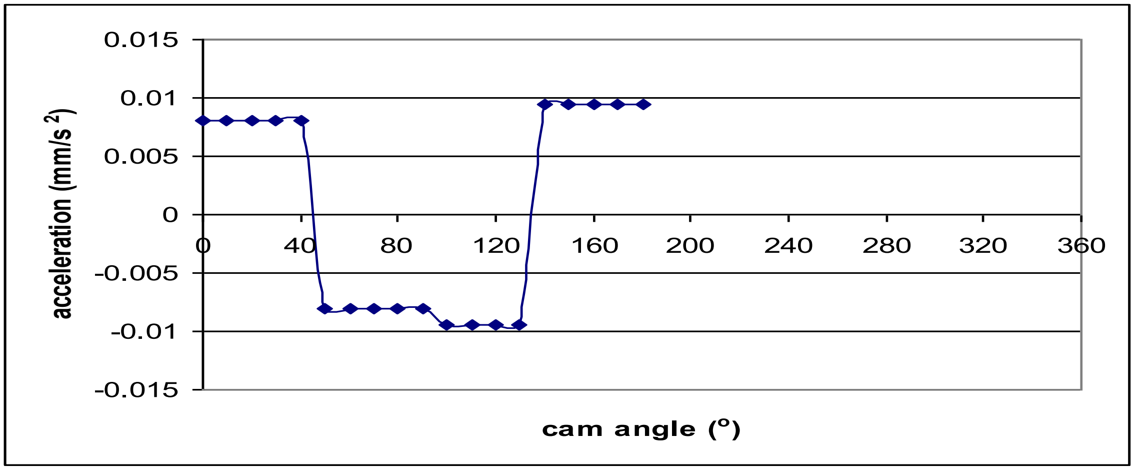
Figure 4-1: Cam profile for graphical method


displacement (mm)
cam angle (°)
16
14
12
10
8
6
4
2
0
-2
0
40
80
120
160
200
240
280
320
360

(a)


velocity (mm/s)
cam angle (°)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
0
50
100
150
200
250
300
350

(b)



(c)

Figure 4-2: Displacement diagram (a), velocity diagram (b) and acceleration diagram (c) diagram for graphical method

Using the constant acceleration motion scheme, because of the shape of displacement curve is parabolic (figure 4-2a), the velocity diagram (figure 4-2b) and acceleration diagram (figure 4-2c) had been determine and had been plotted versus cam angle rotation (β). The increment $\beta = 10^o$ had be choose because of the curve that will be plotted show the smoothest line compare to the larger increment.

From displacement diagram (figure 4-2a), it show that the maximum displacement of follower from graphical method is 15 mm. For velocity diagram (figure4-2b), the maximum velocity of the follower is 0.3164 mm/s and the minimum velocity is -0.3564 mm/s. After having the rise of velocity from 0^o to 50^o, the graph go down constantly until 130^o and go up again till 180^o. And for acceleration diagram (figure 4-2c), the maximum acceleration of the follower is 0.0095 mm/s^2, while the minimum acceleration of the follower is -0.0095 mm/s^2. It shows the perceptible change between maximum and minimum value of acceleration within cam angle 130^o and 140^o.

The constant acceleration motion scheme, also known as parabolic or gravity motion has constant positive and negative acceleration. However, it has and abrupt change of acceleration at the end of the motion and at the transition point between the acceleration and deceleration halves. These abrupt changes result in abrupt changes in inertial forces, which typically cause undesirable vibration. Therefore, this motion in its pure form is uncommon except for low-speed application.

4.3 Experimental result

From the experiment, the output had been get are in form of graph (displacement, torque, force, vibration and speed) versus time (figure 4-3), and the raw data is about the 60 000 data for every single experiment. Figure below show mode output data while doing experiment with input 200 rpm.

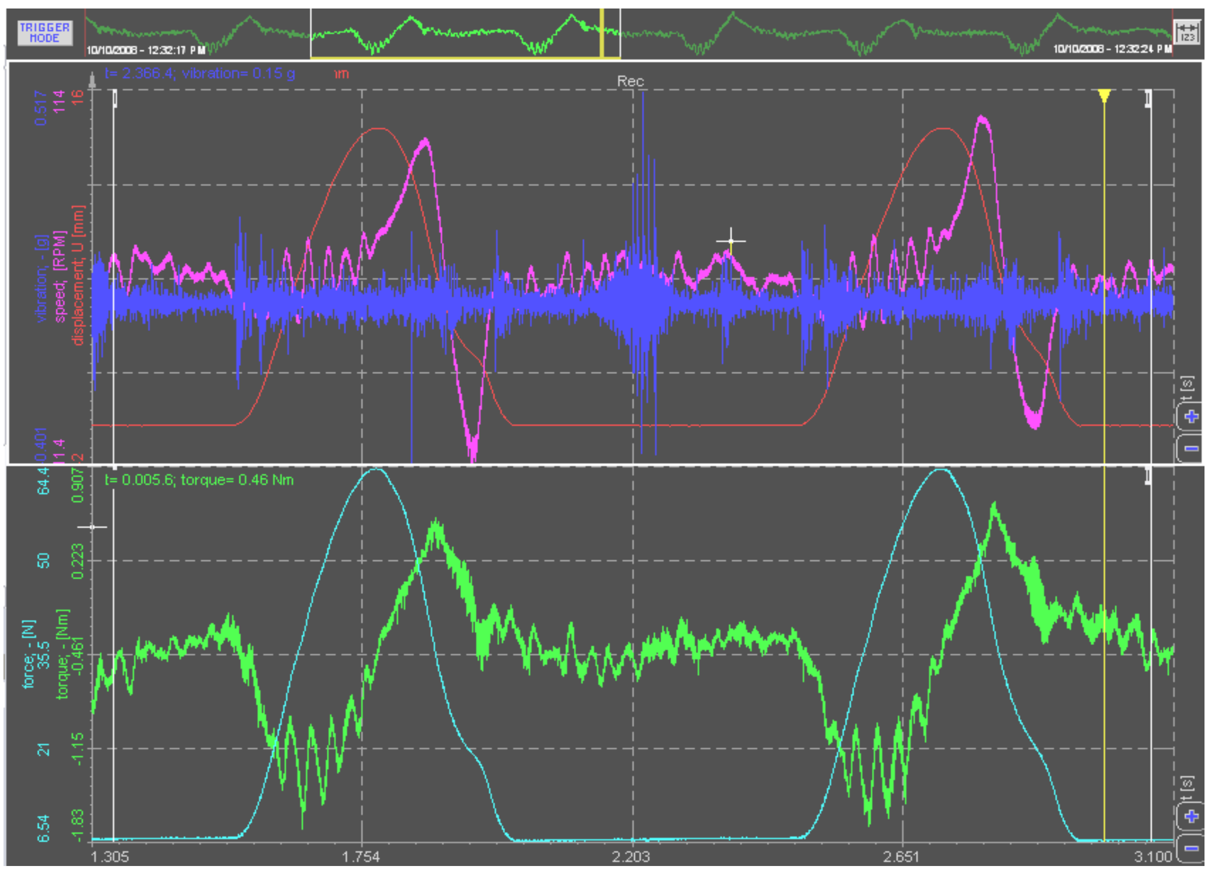
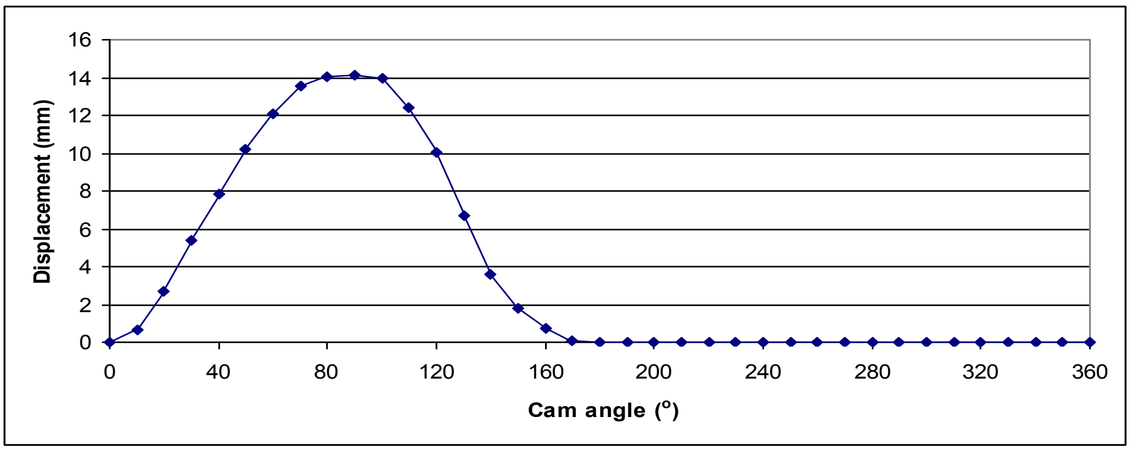


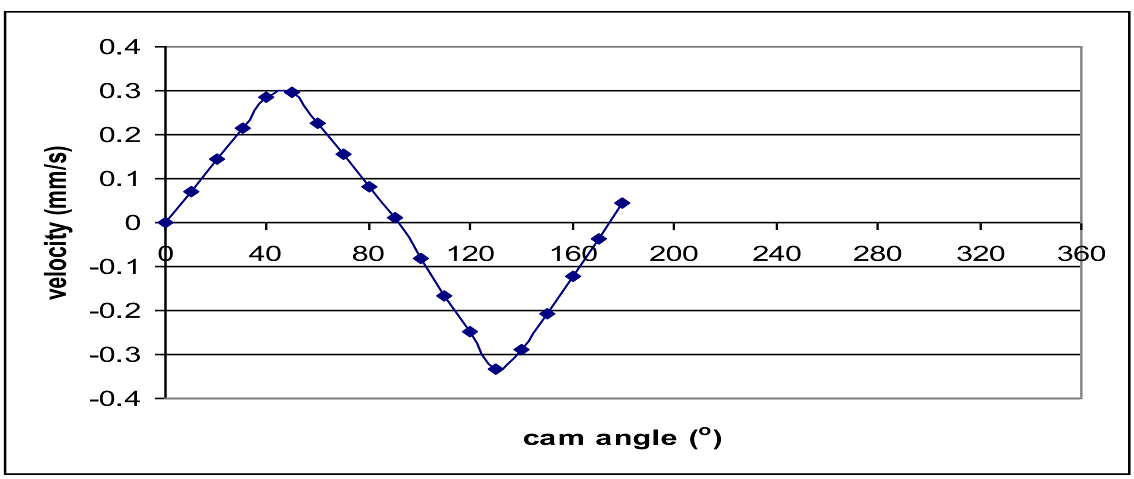
Figure 4-3: Mode of output data for 200 rpm for one motion cycle

From the experiment, the data gather can be interpret due to kinematics analysis, which meaning that, the data can be reconstruct in form of displacement, velocity and acceleration analysis. For that, the data for one cycle of cam rotation (β =360^o) was determined.

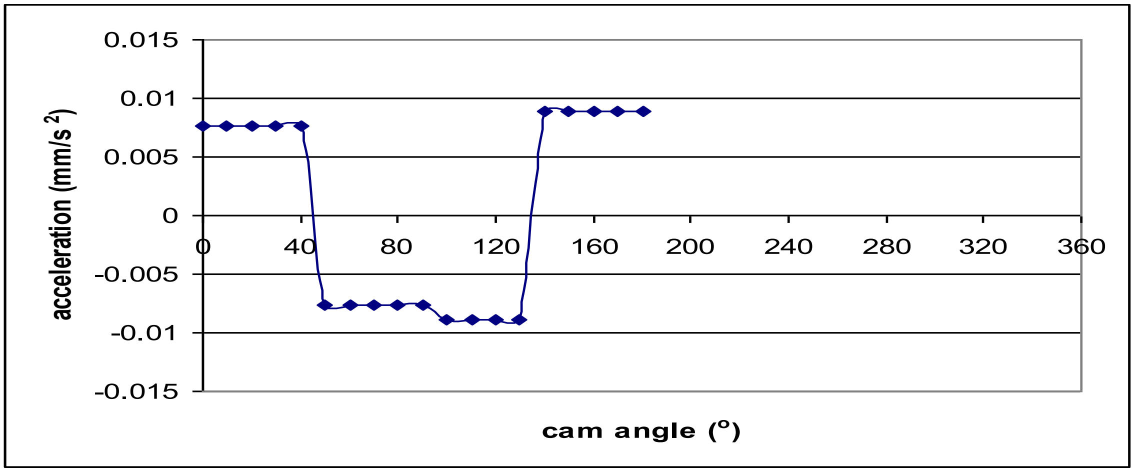
Figure 4-4 shows the displacement diagram (a), velocity diagram (b), and acceleration diagram (c), after the reconstruction of the output data for the experimental method using speed 200 rpm. The data had be reconstructed according to the one motion cycle, that mean one rotation of cam angle (β = 360^o).



(a)



(b)



(c)

Figure 4-4: Displacement diagram (a), velocity diagram (b) and acceleration diagram (c) for 200 rpm

For other input value (300 rpm, 400 rpm, 500 rpm, 600 rpm), they have the same pattern of graph. They have same value and same graph of displacement diagram. From displacement diagram (figure 4-4a), it show that the maximum displacement of follower from experimental method is 14.12 mm. It shows the reducing of value compare to the graphical method. It happens because of the error while doing the scaling to the linear variable displacement transducer (LVDT) before running the experiment.

The differences among the input value are the maximum value of velocity and acceleration that has change constantly with the change of speed of the cam (figure 4-5 and figure 4-6).

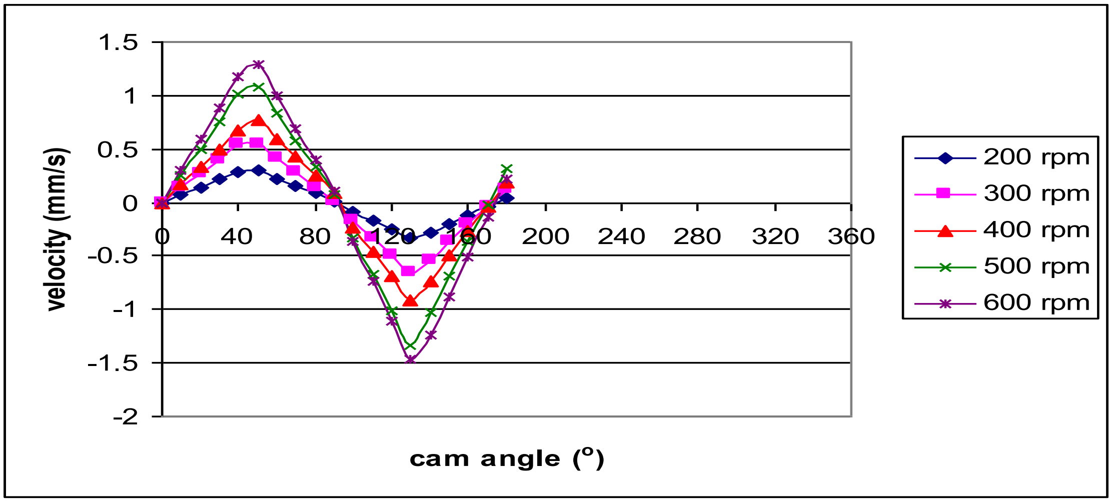


Figure 4-5: The difference in term of velocity after the reconstruction of the output data from experimental method

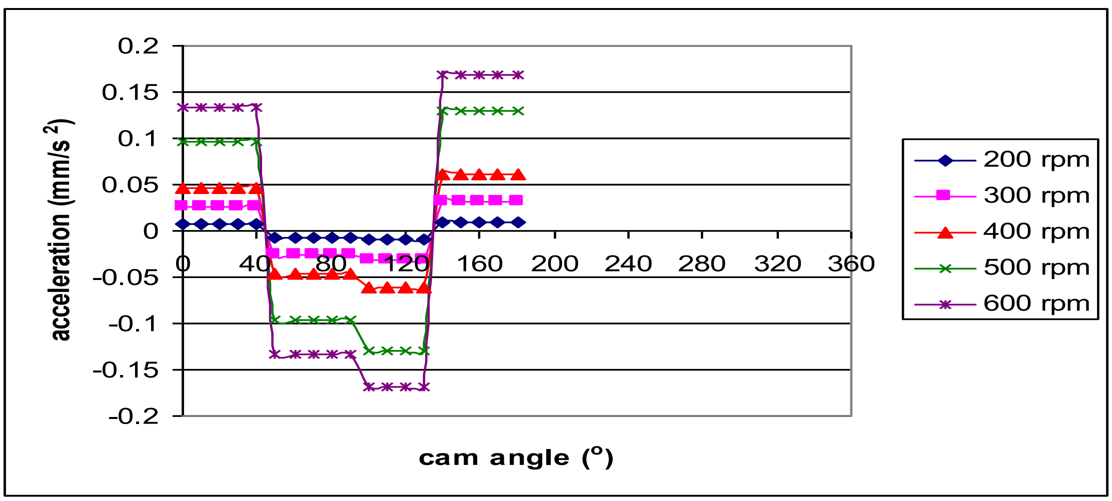


Figure 4-6: The difference in term of acceleration after the reconstruction of the output data from experimental method

For this shape of cam, the maximum value of displacement, velocity and acceleration will be summarizing in the table below (table 4-1) according to the input value (speed).

Table 4-1: Data collection for experimental method

Speed (rpm)	Displacement (mm)	Velocity (mm/s)	Acceleration (mm/s^2)
200	14.12	0.2978	0.0089
300	14.12	0.5514	0.0324
400	14.12	0.7637	0.00618
500	14.12	1.0844	0.1295
600	14.12	1.2836	0.1676

For velocity diagram (figure4-5), the velocity of the follower will rise from 0^o to 50^o before it constantly go down until 130^o. The velocity of the follower will rise again constantly until 180^o. Compare to the acceleration diagram (figure 4-6), the acceleration of the follower maintain from 0^o to 40^o before it rapidly go down to the negative value since 50^o to 120^o. And then the acceleration of the follower will go up rapidly until 180^o.

4.4 Cam profile analysis

From cam profile analysis, it show some different between graphical method and experimental method (figure 4-7). It may occur when reconstruction of cam profile between actual cam compare to experimental calculation. But from analysis, it show the small different between actual cam and experimental method construction cam.

From comparison between graphical method and experimental method, the different of instantaneous follower displacement can be calculated and shows the small value of displacement occur among them. The calculations below prove this situation.

$$d\Delta R = \Delta R\text{graphical} - \Delta R\text{exp} \qquad (9)$$

$$= 15\text{-}14.12$$

$$= 0.88 \text{ mm}$$

$$= d\Delta R < 1 \text{ mm}$$

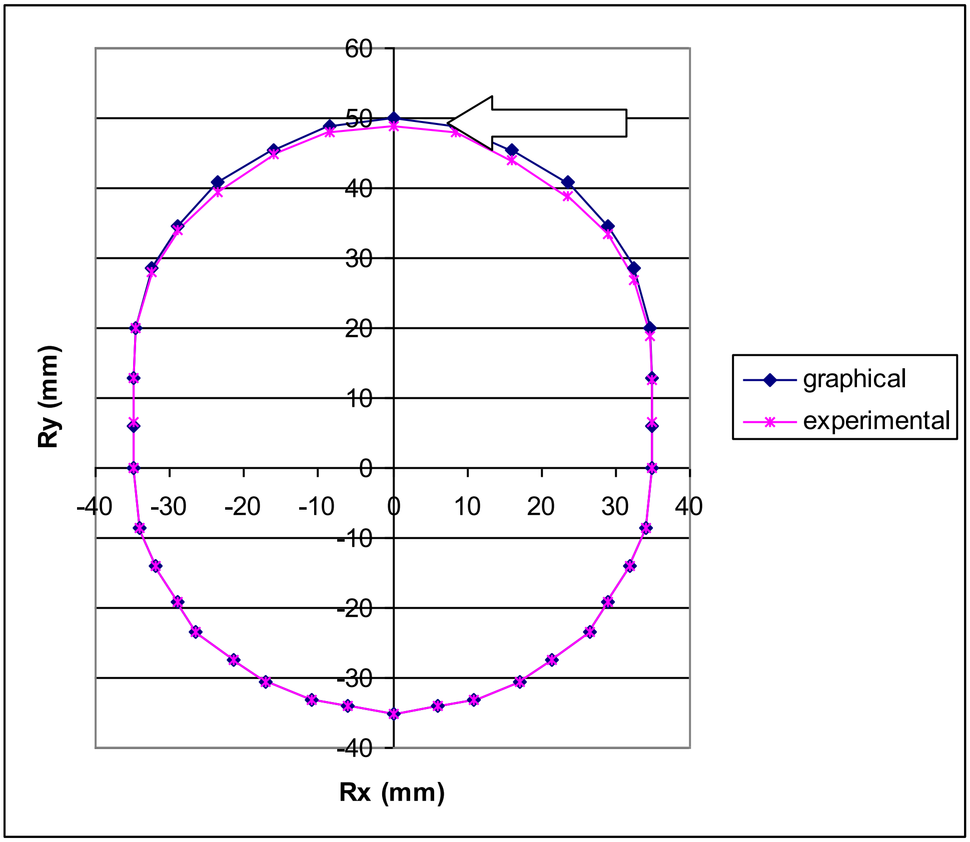


Figure 4-7: Comparison of cam profile between graphical and experimental method

Figure 4-7 shows the difference occurs between graphical method and experimental method in term of cam profile. It shows that the experimental cam profile became smaller than the actual cam or the graphical cam profile. The arrow show where the difference occurs. It has same base circle but have change on the top of the profile.

4.5 Cam motion analysis using kinetics motion analysis

Kinematics analysis is analysis according three type of parameter, displacement (s), velocity (v) and acceleration (a). From this analysis, the error occurs can be determined and comparison between theoretical and experimental can be show and why the error occurs during the experiment.

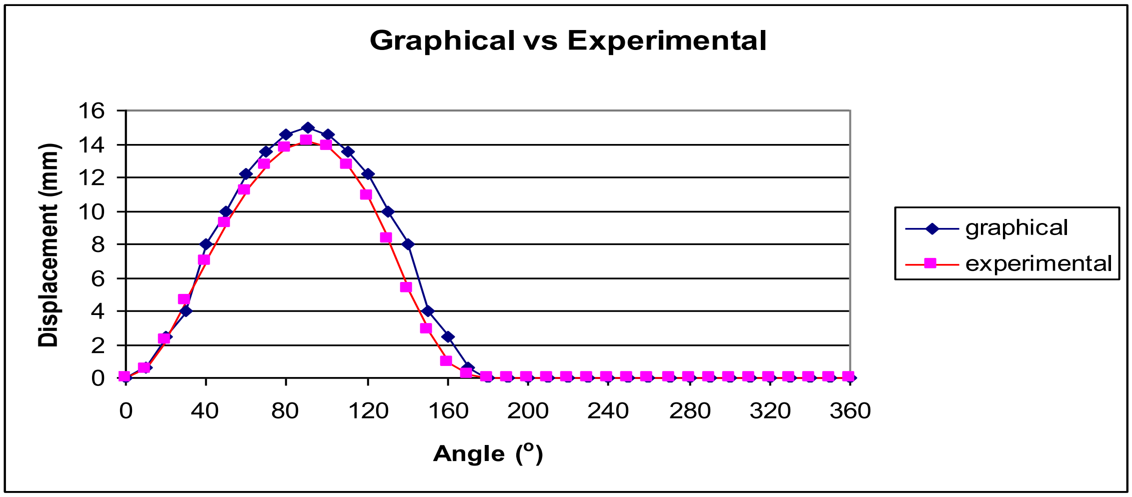


Figure 4-8: Displacement comparison between theoretical and experimental method for 200 rpm

The maximum value get from graphical method is 15 mm and the maximum value get from experimental method is 14.12 mm (figure 4-8). The percentage of error occurs among them can be calculate to show big the error is.

$$\text{Percentage of error} = \frac{(14.12 - 15)}{15} \times 100 \tag{10}$$

$$= -5.867\ \%$$

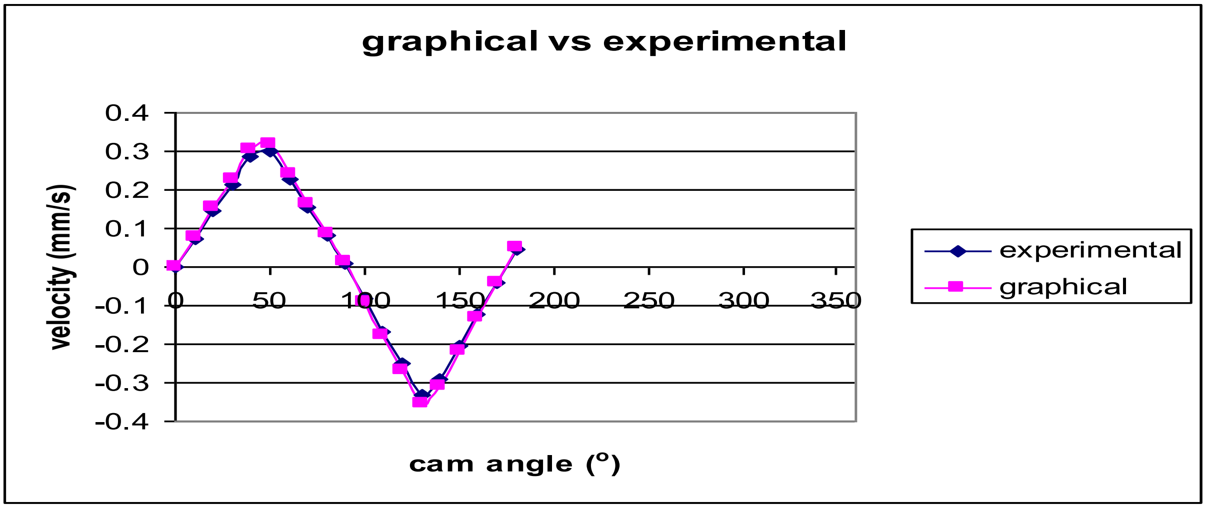


Figure 4-9: Velocity comparison between theoretical and experimental method for 200 rpm

The maximum value get from graphical method is 0.3164 mm/s and the maximum value get from experimental method is 0.2978 mm/s (figure 4-9). The percentage of error occurs among them can be calculate and this value will be compare with other input value.

$$\text{Percentage of error} = \frac{(0.2978 - 0.3164)}{0.3164} \times 100 \qquad (11)$$

$$= -5.88\ \%$$

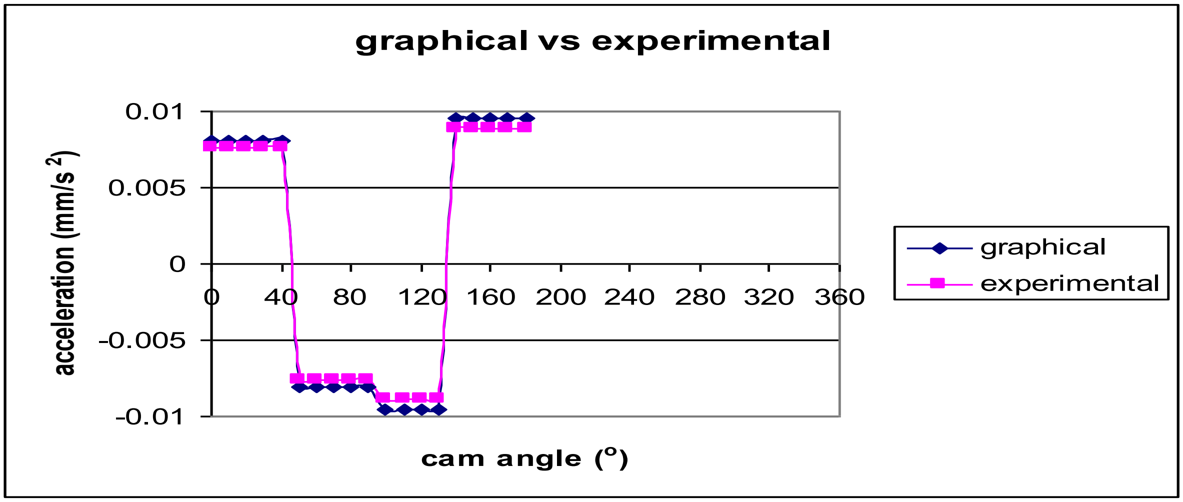


Figure 4-10: Acceleration comparison between theoretical and experimental method for 200 rpm

The maximum value get from graphical method is 0.0095 mm/s^2 and the maximum value get from experimental method is 0.0089 mm/s^2 (figure 4-10).

$$\text{Percentage of error} = \frac{(0.0089 - 0.0095)}{0.0095} \times 100 \qquad (12)$$

$$= -6.32\ \%$$

The detail of the error between graphical and experimental method had been summarize in the table 4-2. Overall, the error occurs during the low speed application is small compare to the error occur during high speed application.

Table 4-2: Error occur during the experiment compare to graphical method

		Displacement (mm)		Velocity (mm/s)		Acceleration (mm/s^2)	
			Error (%)		Error (%)		Error (%)
graphical		15	-	0.3164	-	0.0095	-
Experimental (rpm)	200	14.12	-5.86	0.7999	-5.88	0.0089	-6.32
	300	14.12	-5.86	0.5514	74.27	0.0324	70.68
	400	14.12	-5.86	0.7637	141.37	0.0618	550.53
	500	14.12	-5.86	1.0844	242.73	0.1295	1263.15
	600	14.12	-5.86	1.2836	305.69	0.1676	1664.21

In general, the error comparison between input data had been summarize in the table 4-3 to prove that the error will increase in term of speed increase.

Table 4-3: Percentage of error according to input data

Speed (rpm)	Displacement (**s**)	Velocity (**v**)	Acceleration (**a**)
200	-5.867	-5.88	-6.32
300	-5.867	74.27	70.68
400	-5.867	141.37	550.53
500	-5.867	242.73	1263.15
600	-5.867	305.69	1664.21

4.6 Performance analysis of cam

From the comparison of velocity diagram between input value (figure 4-12), show that when the speed increase, it will also increase the velocity of the cam and the follower system. Yet, the system will undergo the faster moving while operating in high speed.

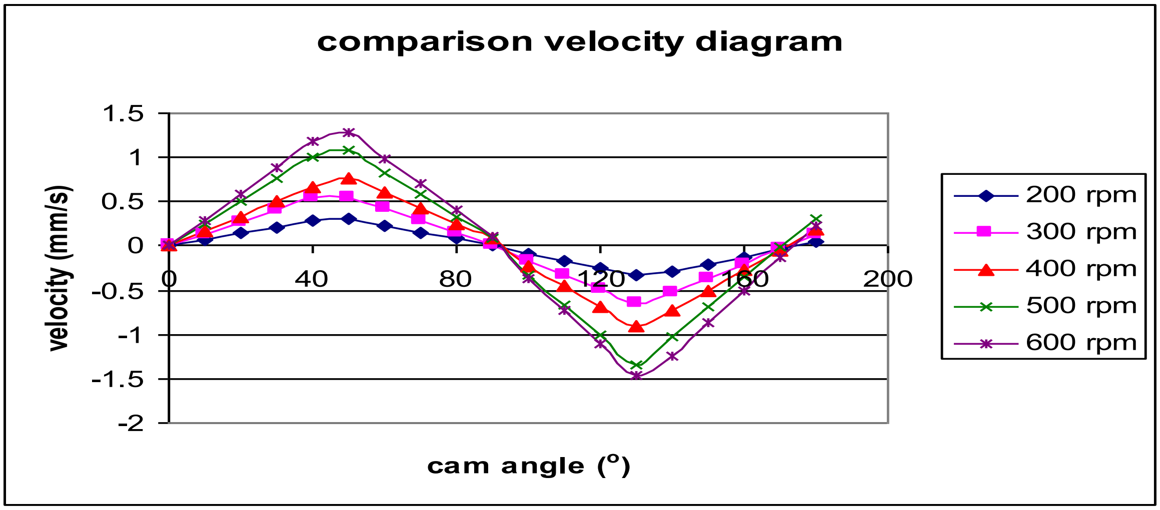


Figure 4-11: Comparison of velocity according to input data

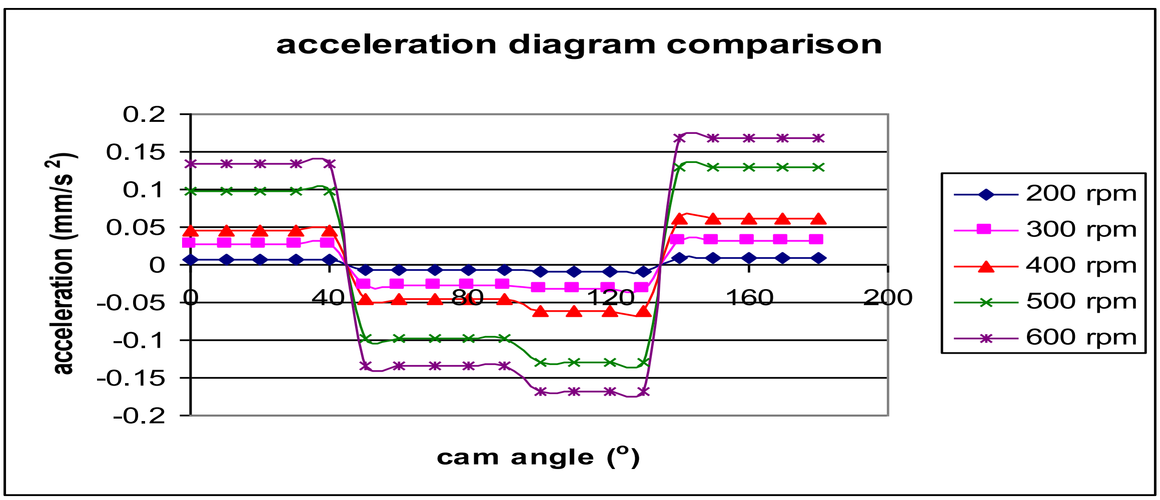


Figure 4-12: Comparison of acceleration according to input data

From the acceleration comparison (figure 4-13), also show that when the system undergoes the high speed application, the acceleration of the cam and the follower system will increase. Also, it can increase the vibration of the system. Increasing in vibration will affect the system due to rapid wear and the system will collapse for the certain time.

In high-speed application of disk cam, it may be desirable to reduce the magnitude of the negative acceleration during the second the part of he rise. It also causes the tendency toward the follower jump, the separation of the follower from the cam surface followed by crashing of the follower back to the surface.

In conclusion, this shape of cam is not suitable to be used in high speed application because it will be the unbalance system when operating in high speed. It will cause the failure of the system to endure the long live application.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

In this chapter, the main target is to make a summary about overall thesis. This includes the expected outcome. The expected outcome basically comes from the previous chapter which is chapter 4. In last chapter, the conclusion is made to emphasizing the results as an addition is going to have some recommendation for further study.

5.2 CONCLUSION

In summary, this project attempts to analysis:

The cam profile of the ellipse shape of cam show that the rise quadrant is from 0^o to 90^o, fall quadrant is from 90^o to 180^o and the last quadrant is a dwell quadrant that is from 180^o to 360^o of the cam mechanism system.

Comparison between graphical method and experimental method of cam mechanism show that the error occurs in many type of parameter using in the analysis. From this analysis, the displacement error between graphical and experimental method is -5.86 %. It shows that whatever error is small or not, it still has an error because of many aspects that interrupt while doing experiment. The velocity error between graphical and experimental method is -5.88 % and the acceleration error between graphical and experimental method is -6.32 %. The error will increase while the speeds of the cam mechanism increase.

The error occurs between low speed application and high speed application show that when this shape of cam used for low speed, it endure low follower velocity and low follower acceleration, that cause little bit of vibration. But when this shape of cam having a high speed application, it endure the large external force, used to be in high velocity and high acceleration of cam, that cause high vibration not only to the cam and follower, but to the whole system. When operating at 200 rpm, it only show the low percentage of error (velocity error = -5.88 % and acceleration error = -6.32 %), but when operating at 600 rpm, it show very high percentage of error (velocity error = 305.69 % and acceleration error = 1664.21 %)

This shape of cam (ellipse shape) only suitable for low speed application, because it show the unbalance system when operating in high speed. It must endure the rapid ware due to high vibrations when operating in high speed application. It also causes the failure to the system for the certain time and can cause the spending more money and time to repair it.

Significant contributions from the research:

- The cam mechanism can be use in many applications in mechanical area that contribute linear and rotating motion.

- In order to endure the rapid ware and another collapse in cam mechanism system, the right selection of shape of cam is the important thing that engineer must analyze and synthesis.

5.3 RECOMMENDATION

There is a lot of future research that can be continued. The potential areas that can be considered are list below.

Optimization of high speed application cam

The cam development is based on type of application. Some cam suitable for low speed application but not suitable for high speed application because of rapid ware and some sort of collapsing. Future research shall move towards the cam that can endure rapid ware in long term application.

Friction on the surface of cam

The cam that use the roller follower were neglect the friction as the consequence of the reducing the cam performance. In the actual application, using other type of follower, friction is the most important thing that gives problem to the cam and follower system.

Force that endure by follower and cam

Cam mechanisms that use the follower in horizontal position cannot attempt to the large load compare to the cam mechanism that use the vertical follower position. The added load also can be a factor of the rapid ware for the cam both in low speed and high speed application.

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