ANALYSIS OF DISK CAM MOTION FOR FOLLOWER SHAPE IN VERTICAL POSITION

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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 Bachelor of Mechanical Engineering.

Signature : …………………………………………..
Name of Supervisor : MR. MOHD RUZAIMI BIN MAT REJAB
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Date : 10 November 2008

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To my beloved mother and father,

Mrs. Rohani binti Mamat
Mr. Abd Rahman bin Abdullah

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Praise to Allah S.W.T, the Most Merciful and the Most Compassionate. Peace upon him Muhammad S.A.W, the messenger of Allah.

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ABSTRACT

Cam is a mechanical component that translates movement from circular to reciprocating by using mating component, called the follower. The cam performance can be analyzed in vertical position to find time of one cycle, $\boldsymbol{T}$, and the displacement of cam follower $\Delta \boldsymbol{R}$ at the rotational angle, $\boldsymbol{\Phi}$. Every cam profile have it own performance and different from each other. This thesis is carried out to analyze the disk cam profile for the heart shape cam and tested in vertical position to find out it kinematics motion. In order to do the analysis, graphical method and experimental data are used to compare the error from the actual cam. The results from the analysis show that this cam is most suitable for low speed application because it show small error at low speed input.

ABSTRAK

Sesondal merupakan komponen mekanikal yang menukarkan pergerakan daripada pusingan kepada pergerakan timbal balik dengan mengunakan pasangan komponen yang dikenali sebagai penurut. Prestasi sesondol boleh dianalisis dalam kedudukan tegak untuk mencari satu selang masa,***T,*** dan jarak pergerakan penurut sesondol ∆***R*** pada setiap darjah pusingan , ***Φ.*** Setiap tampang muka sesondol mempunyai prestasi tersendiri dan adalah berbeza untuk setiap sesondol. Tesis ini dibuat adalah untuk menganalisis tampang muka sesondol yang berbentuk jantung dan diuji pada kedudukan menegak untuk mencari pergerakan kinematik. Untuk membuat analisis ini,kaedah grafikal dan data yang diperoleh dari experiment telah digunakan untuk membuat perbandingan kesalahan yang berlaku dengan sesondol yang sebenar. Hasil analysis menunjukkan bahawa sesondol ini lebih sesuai digunakan pada kelajuan yang rendah kerana ia menunjukkan kesalahan yang paling kecil ketika beroperasi pada kelajuan rendah.

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Cam is a mechanical component that translates movement from circular to reciprocating by using mating component, called the follower. A cam can be defined as a device that having a curved outline or a curved groove that usually called as cam profile. Cams can be conveniently classified into two main groups,

1. Cams that impart motion to the follower in a plane in line with the axis of rotation of the cam (as does a cylindrical cam).
2. Cams that impart motion to the follower in a plane at 90 degrees to the axis of rotation, as with face or edge cams and most cams fall into this category. (Kenneth Nolan,1998)

There are three types of cam followers, and each the type of follower influences the profile of the cam. The three types are the knife-edge, the roller follower and the flat-face follower.

The cam mechanism is the most versatile one which is suitable for various applications. It can be designed to produce almost unlimited types of motion in the follower. It is used to transform a rotary motion into a translating or oscillating motion.

Cam is widely used in variety of automatic machines and instruments. Typical examples of their usage include textile machineries, printing presses, food processing machines, internal combustion engines and other automatic machines, control system and devices.

For instance, in internal combustion (IC) engine, the valvetrain mechanism takes place as operated device to control the exchange of inlet and exhaust gases in the internal-combustion engine. The valvetrain assembly includes the poppet type valve (inlet or exhaust), the spring which closes it, the force transmission components (cam follower, pushrod, rocker arm) and the cam driving assembly, which transmits the operating force from the engine power output shaft to the camshaft in which the cam is mounted.

In real world application, cam is offering a high repeatability, low cost and minimal maintenance for long term maintenance. The mechanism is also a simple rotary motion that can be utilized to produce linear motion.

Today, common cam manufacturing method can be categorized such as, manual or numerical control (NC), analog duplication of hand dressed master cam, computer numerical control (CNC) with linear, circular, spherical or Bezier curve interpolation, electrodischarge machining (EMD) and others method such as flame cutting, die casting, die forging, stamping and powder metallurgy.

1.2 PROBLEM STATEMENT

When cam rotates, it shows a series of motion such as rises, dwell and fall. Rises is the follower motion away from cam center while dwell is the follower at rest and fall is follower motion toward the cam center. The cam performance can be analyzed in vertical position to find time of one cycle, $\boldsymbol{T}$, and the displacement of cam follower $\Delta \boldsymbol{R}$ at the rotational angle, $\boldsymbol{\Phi}$. Every cam profile have it own performance and different from each other.

1.3 PROJECT OBJECTIVES

The objective of this project is;

1. To analyze disk cam profile
2. To analyze the disk cam motion in vertical position.

1.4 PROJECT SCOPE

This research is carried out to verify the disk cam motion by following the according scopes:

1. To find the disk cam profile and its performance.
2. To run the experiment for the disk cam in vertical position.
3. To analyze the data and find it’s the kinematics motion.

CHAPTER 2

LITERITURE REVIEW

2.1 INTRODUCTION

Cams are widely used in many types of machines because they make it possible to obtain an unlimited variety of motions. Many different types of cam profiles are designed and manufactured depending on a machine's requirements (P.W. Jensen, 1987). Cam is a part of a rotating wheel or shaft that strikes a lever at one or more points on its circular path.The cam is in most cases merely a flat piece of metal that has had an unusual shape or profile machined onto it.

This cam is attached to a shaft which enables it to be turned by applying a turning action to the shaft. As the cam rotates, the profile or shape of the cam will cause the follower to move in a particular way. The movement of the follower in vertical or in horizontal position is then transmitted to another mechanism or another part of the mechanism.

2.2 TYPES OF DISK CAM

2.2.1 Pear Shaped Cam

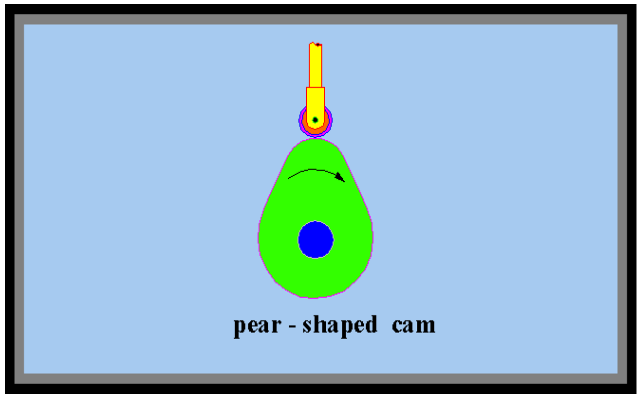


Figure 2.1: Pear shaped cam

The pear shaped cams are often used for controlling valves. For example, they are used on motor car camshafts to operate the engine valves. A follower controlled by a pear-shaped cam remains motionless for about half a revolution of the cam (V.Ryan, 2006). During the time that the follower is stationary, the cam is in a dwell period. During the other half revolution of the cam, the follower rises and then falls. As the pear-shaped cam is symmetrical, the rise motion is the same as the fall motion.

2.2.2 Heart Shaped Cam

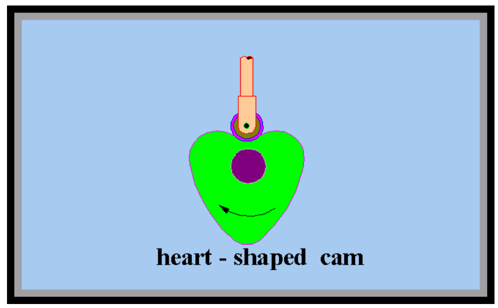


Figure 2.2: Heart-shaped cam

Figure 2.2 shows the heart shape cam. This cam causes the follower to move with a uniform velocity. The follower moves up and down in a vertical direction. Its movement is very smooth. Heart-shaped cams are essential when the follower motion needs to be uniform or steady. For example, in the mechanism that winds thread evenly on the bobbin of a sewing machine and in winding wire evenly on the former of a solenoid.

2.2.3 Circular Shaped Cam

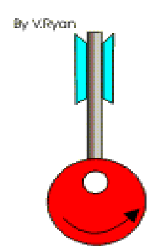


Figure 2.3: Circular-shaped cam

Figure 2.3 sometimes called eccentric cams. The cam profile is a circle and the center of rotation of the cam is often from the geometric center of the circle. The circular cam produces a smooth form of motion called a simple harmonic motion. These cams are often used to produce motion in pumps and also used to operate steam engine valves (V.Ryan, 2006). As the cam is symmetrical, the rise and fall motions are the same.

2.3 FOLLOWER SHAPE

The follower shape can be categorized in four categories, which is;

2.3.1 The knife edge follower.

A knife edge follower in Figure 2.4 is formed to a point and drags the edges of cam. This is the simplest type, is not often used due to the rapid rate of wear.

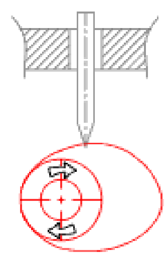


Figure 2.4: Knife Edge Follower.

2.3.2 The Roller Follower.

A roller follower consists of follower that has a separate part, a roller that is pinned to the follower stem as shown in Figure 2.5. This is most commonly used follower because the friction and contact stress are lower than knife edge follower. However, it can possibly jam during steep cam displacement.

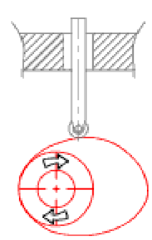


Figure 2.5: Roller Follower

2.3.3 The Flat-faced Follower

Figure 2.6 show a flat-faced follower that consists of a follower that is formed with large, flat surface to contact the cam. This type of follower can be used with steep cam motion and do not jam. Usually, this cam is used when quick motions are required.

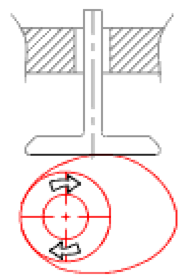


Figure 2.6: Flat-Faced Follower

2.3.4 Spherical faced follower

A spherical faced follower consist of a follower formed with a radius face that contact the cam and this follower can be used with steep cam motion without jamming. However, the frictional force of this follower greater than roller follower.

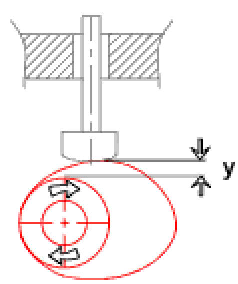


Figure 2.7: Spherical Faced Follower

2.4 CAM MATERIAL

Cam are usually made from a strong and hard materials because to avoid wear. Basically, the four kinds of wear in cam follower mechanism are: adhesive wear, abrasive wear, corrosive wear, and surface fatigue wear (Harold A. Rothbart, 2005) .The most commonly used cam material are cast iron and steel. (Robert L.Norton, 2002)

2.4.1 Cast iron

Cast iron constituted a whole family of material. Their main advantages are relatively low cost and ease of fabrication. Some are weak in tension compared to steel but like most cast material, have good compressive strength .their densities are slightly lower than steel at about 6920kg/m3.Most cast iron are not exhibit a linear stress-strain below the elastic limit and do not obey Hooke's Law.

2.4.2 Gray cast iron

This iron is most commonly used to form of cast design. Its graphite flakes gives its gray appearance and name. The ASTM grades gray cast iron into seven classes based on the minimum tensile strength in kpsi. Class 20 has a minimum tensile strength of 20 kpsi(138MPa).The class number 20,25,30,35,40,50 and60 then represent the tensile strengths in kpsi. This alloy is easy to pour, easy to machine and offer good acoustical damping.

2.4.3 Hot Rolled Steel

This hot rolled steel is produced by forcing hot billets of steel through set of roller or dies that progressively changes their shape into I-beam, channel section, angle iron, etc. The surface finish of this material is rough due to oxidation at the elevated temperatures. The mechanical properties are also relatively low because the material ends up in annealed or normalized state, unless deliberately heat-treated later.

2.4.4 Cold-rolled Steel

This steel is produce from a billet, the shape of cold rolled steel are brought to final form and size by rolling between hardened steel roller or drawing through dies at room temperatures. The result is a material with good surface finish and accurate dimension compared to hot rolled material. Its strength and hardness are increase at the expense of significant built in strain which can later be release during machining, welding or heat treatment.

2.4.5 Forged Steel

Large cams or complex shapes such as IC engine camshaft are often form by hot forging a steel billet to an approximate shape for later machining. If sufficient quantity is required to offset the cost of forging dies significant saving of machining time can be realized over starting each cam with billet. Also, the strength of forged part especially against fatigue loading can be superior to that of cam made from billet.

2.5 CAM MOTION EVENT

In cam mechanism, it usually has two part of moving elements, the cam and the follower that mounted on a fixed frame. Cam devices are versatile, and almost any arbitrarily-specified motion can be obtained. In some instances, they offer the simplest and most compact way to transform motions, 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 with Susan Finger and Stephannie Behrens, 2006)

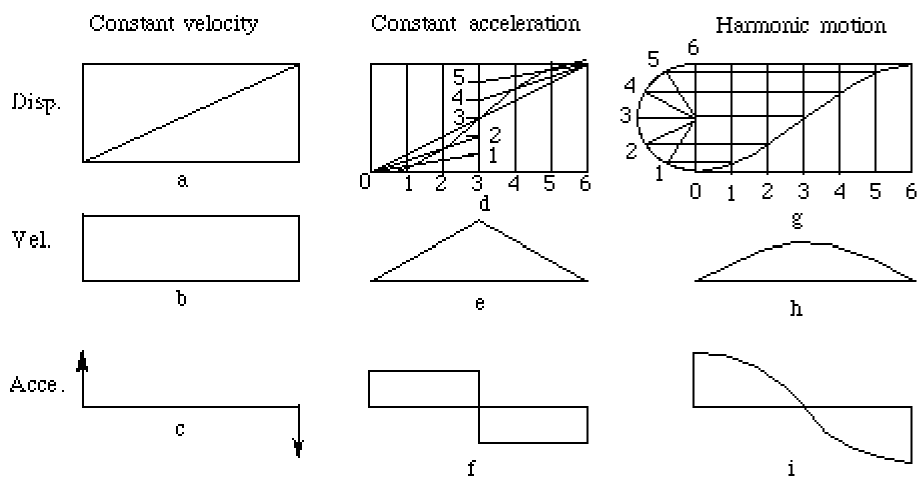


Figure 2.8: Motion events (courtesy by Yi Zhang with Susan Finger and Stephannie Behrens)

Notation

Φ: The rotary angle of the cam, measured from the beginning of the motion event;

β: The range of the rotary angle corresponding to the motion event;

h : The stoke of the motion event of the follower;

S : Displacement of the follower;

V : Velocity of the follower;

A : Acceleration of the follower.

2.5.1 Constant Velocity Motion

If the motion of the follower were a straight line, Figure 2.8 a,b,c, 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, as shown in c. 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.

$$S(\varphi) = h\frac{\varphi}{\beta}$$

$$V(\varphi) = \frac{h}{\beta} \quad \textbf{(1)}$$

$$A(\varphi) = 0$$

2.5.2 Constant Acceleration Motion

Constant acceleration motion is shown in Figure 2.8 d, e, and f. As shown in e, 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

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

$$S(\varphi) = 2h\frac{\varphi^2}{\beta^2}$$

$$V(\varphi) = \frac{4h}{\beta^2}\varphi \tag{2}$$

$$A(\varphi) = \frac{4h}{\beta^2}$$

When

$\frac{\beta}{2} \leq \varphi \leq \beta$,

$$S(\varphi) = h - \frac{2h}{\beta^2}(\beta - \varphi)^2$$

$$V(\varphi) = \frac{4h}{\beta}\left(1 - \frac{\varphi}{\beta}\right) \tag{3}$$

$$A(\varphi) = \frac{4h}{\beta^2}$$

2.5.3 Harmonic Motion

A cam mechanism with the basic curve as shown in Figure 2.8 g,h,i, will impart simple harmonic motion to the follower. The velocity diagram at h indicates smooth action. The acceleration, as shown at i, is maximum at the initial position, zero at the mid-position, and negative maximum at the final position.

$$V(\varphi) = \frac{h\pi}{2\beta}\sin\frac{\pi\varphi}{\beta}$$

$$S(\varphi) = \frac{h}{2}\left(1 - \cos\frac{\pi\varphi}{\beta}\right) \tag{4}$$

$$A(\varphi) = \frac{h\pi^2}{2\beta^2}\cos\frac{\pi\varphi}{\beta}$$

2.6 CAM DESIGN

Nowadays, method for design disk cam became more complex and sophisticated. Recent methods focus on the design of dynamically compensated cams with the purpose of minimizing residual vibrations in high speed cam-follower systems (B. Demeulenaere and J. De Shutter, July 2001). There are three groups of methods distinguish by SriniMsan and Jeffrey Ge :

(i) The traditional polydyne method and more robust modifications of it
(ii) Numerical methods such as linear programming and quadratic optimization and Lagrange multiplier techniques and
(iii) Methods based on optimal control theory.

2.6.1 Fundamental Law of Cam Design.

Any cam designed for operation at other than very low speeds must be designed with the following constraint:
The cam followers must be continuous through the first and second derivatives of displacement (i.e. velocity and acceleration) across the entire interval.(Robert L.Norton)

Therefore, in the simplest cams, the motion program cannot be defined by a single mathematical expression but must be defined by several separate functions. Each of it defines the follower behavior over one segment or piece of the cam.

2.6.2 Design of Disk cam with roller follower

The basic principle of designing a cam profile with the inversion method is still used. However, the curve is not directly generated by inversion. This procedure has two steps:

1. Imagine the center of the roller as a knife edge. This concept is important in cam profile design and is called the trace point of follower. Calculate the pitch curve *aa*, that is, the trace of the pitch point in the inverted mechanism.
2. The cam profile *bb* is a product of the enveloping motion of a series of rollers.

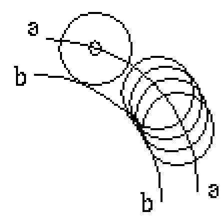


Figure 2.9: The trace point of the follower on a disk cam

Design equations:

The problem of calculating the coordinates of the cam profile is the problem of calculating the tangent points of a sequence of rollers in the inverted mechanism. At the moment shown Figure 2.10, the tangent point is *P* on the cam profile.

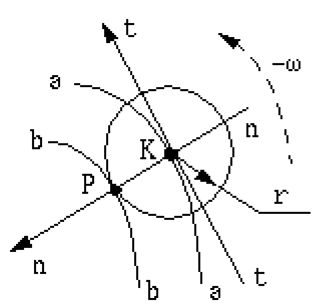


Figure 2.10 : The tangent point, P, of a roller to the disk cam

Where;

r_o =The radius of the base circle;

e = the offset of the follower from the rotary center of the cam. Notice: it could be negative.

s =the displacement of the follower which is a function of the rotary angle of the camΦ.

IW= A parameter whose absolute value is 1. It represents the turning direction of the cam. When the cam turns clockwise: *IW=+1*, otherwise: *IW=-1*.

r = the radius of the roller.

IM = a parameter whose absolute value is 1, indicating which envelope curve will be adopted.

RM = inner or outer envelope curve. When it is an inner envelope curve: *RM=+1*, otherwise: *RM=-1*.

The calculation of the coordinates of the point *P* has two steps:

1. Calculate the slope of the tangent *tt* of point *K* on pitch curve, *aa*.
2. Calculate the slope of the normal *nn* of the curve *aa* at point *K*.

Since we have already have the coordinates of point *K:* (*x, y*), we can express the coordinates of point *P* as

$$\begin{cases} x_p = x - IW \cdot RM \cdot r \cdot \dfrac{dy/d\varphi}{\sqrt{(dx/d\varphi)^2 + (dy/d\varphi)^2}} \\ y_p = y + IW \cdot RM \cdot r \cdot \dfrac{dx/d\varphi}{\sqrt{(dx/d\varphi)^2 + (dy/d\varphi)^2}} \end{cases} \qquad (5)$$

- When the rotary direction of the cam is clockwise: *IW = +1*, otherwise: *IW = -1*.
- when the envelope curve (cam profile) lies inside the pitch curve: *RM = +1*, otherwise: *RM = -1*.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION.

Here, in this chapter, the way on how of this project will be carried out will be discussed. Compare to the chapter 2, this chapter will be focus on how this project will be held to find the disk cam profile and its performance. Figure 3.1 show about the flow of the experiment.

3.2 FLOW CHART FOR METHODOLOGY

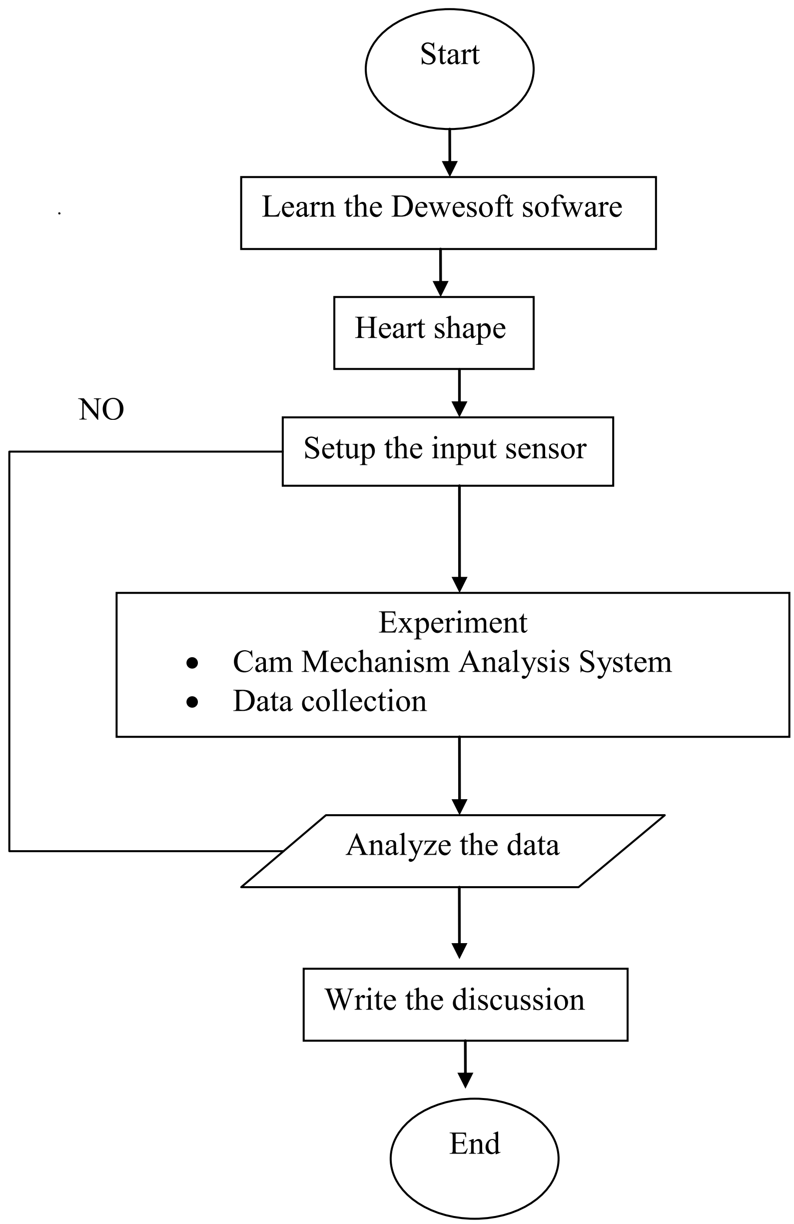


Figure3.1: Flow Chart of the Experiment

3.3 DESIGN OF DISK CAM.

In designing the cam profile, there are few thing need to be consider such as the type of the cam profile and the type follower that suitable with the cam. When the suitable cam motion is desired, the displacement diagram can be constructing based on the motion of cam. From the diagram, the equation of motion can be determined and can be used to compare with the experimental result.

For this analysis, the heart shape cam has been choose and tested with vertical cam mechanism analysis system. Figure below show the heart shape cam that designed in SolidWork Software.

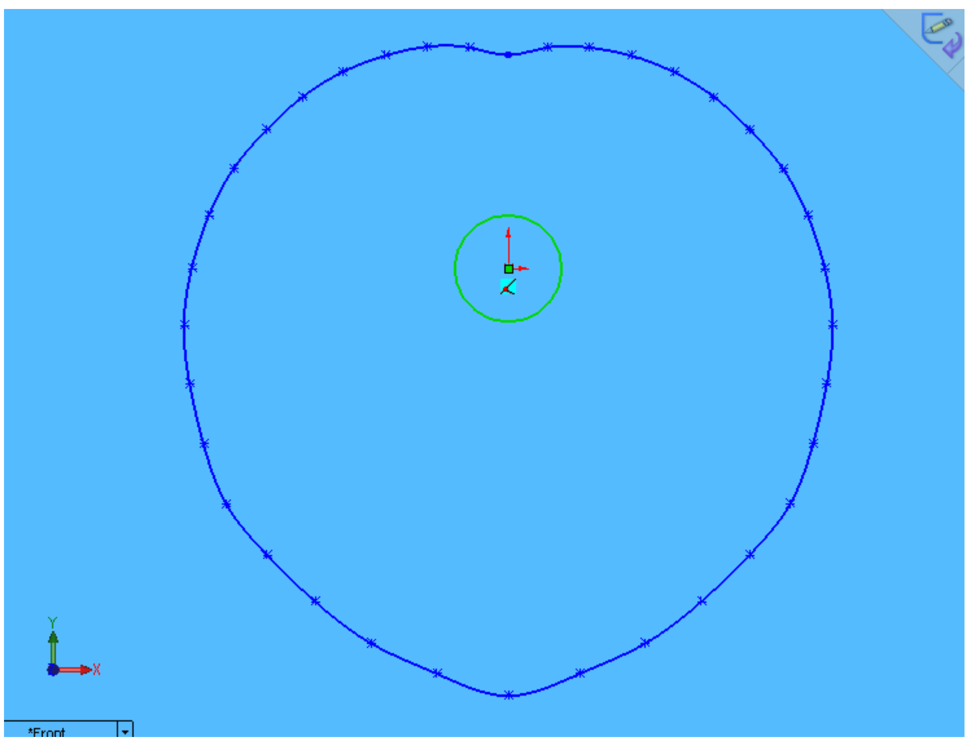


Figure 3.2: Sketching of Heart Cam

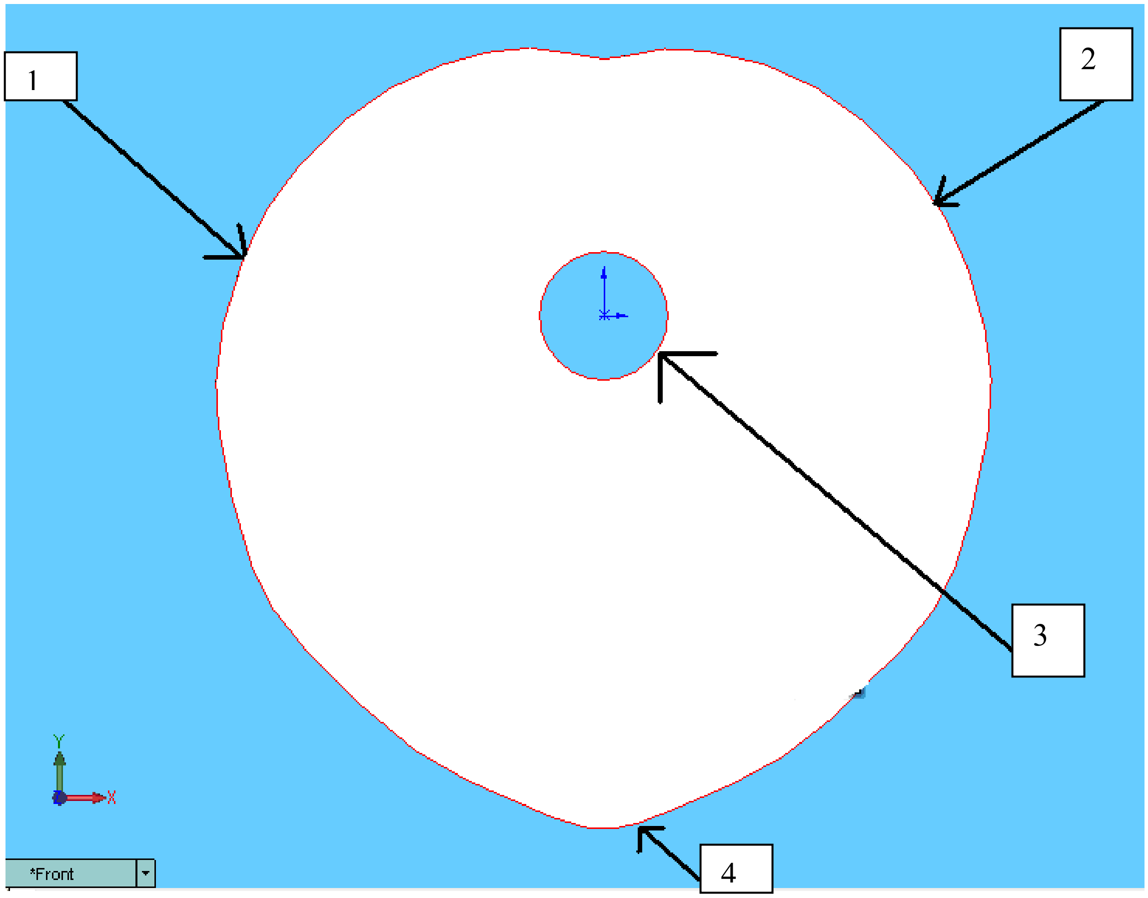


Figure 3.3: Heart Shape Cam

Where:

1. The rise part of the cam from 0º to 180º when cam rotates anti clockwise
2. The part where the fall occur from190º to 360º.
3. The slot where the cam is fix with the shaft.
4. The highest displacement of the cam.

3.4 ANALYSIS PARAMETER

This experiment used Cam Mechanism Analysis System as the machine to run the disk cam in vertical position and DEWESOFT Software are used as software to collect the data and analysis of disk cam profile. The results are shown in a graph type such as displacement graph, torque graph and vibration graph.

3.4.1 Dewesoft Software

The Dewesoft Software is software that used to perform a series of standard procedure test, however the system are flexible where so any kind of additional test can be defined to meet the requirement that needed.

The system run a standard software package which allow user to customized input setup, acquisition, analysis, exporting and print out data. The input data is usually a sensor that connected to the A/D board. There are a few type of sensor that been used to measured the disk cam analysis and below are the specifications for each sensor.

1. **Type of Sensor** **Accelerometer**
   Type of Measurement Vibration
   Range +/-500g
   Sensitivity 10.75mV/g
   Output connection ICP

2. **Type of Sensor** **Draw Wire Displacement Transducers**
   Type of Measurement Displacement
   Range 1000mm
   Output connection Potentiometer, Half Bridge

3. **Type of Sensor** **Velocity Transducer**
   Type of Measurement Air Velocity
   Range 0 to 10 m/s
   Output connection 0 to 10 Vdc

4. **Type of Sensor** — **Incremental Rotary Encoder**

Type of Measurement	RPM(speed)
Range	1000 pulses/revolution
Output connection	0 to 10 Vdc

5. **Type of Sensor** — **FGP Load cell**

Type of Measurement	Force
Range	10kN
Sensitivity	-177.36mV

3.4.2 Cam Mechanism Analysis System

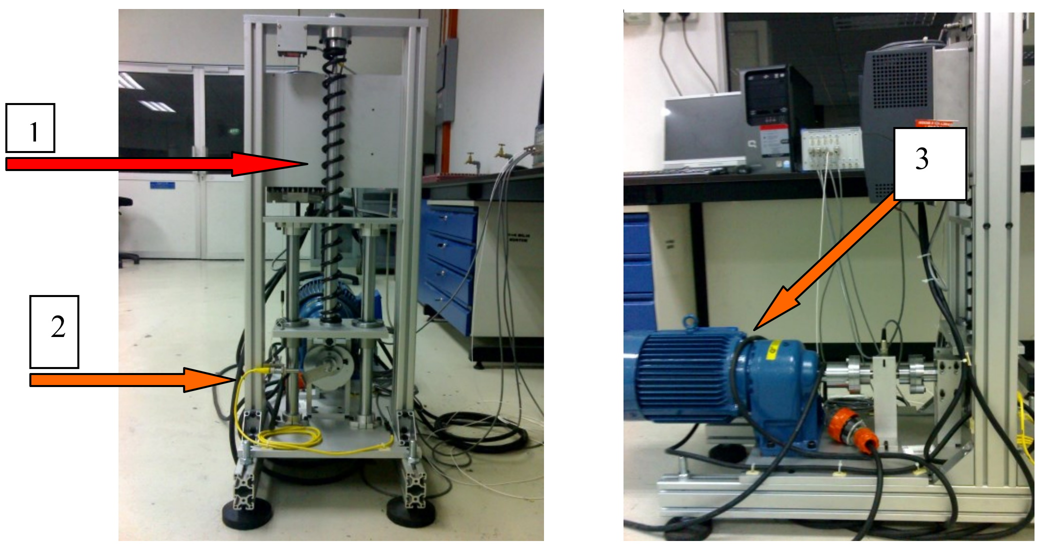


Figure 3.4: Front and side view of Cam Mechanism Analysis System

Where:

1. Cam follower location
2. Position of Air velocity transducer sensor.
3. Motor that rotates the shaft.

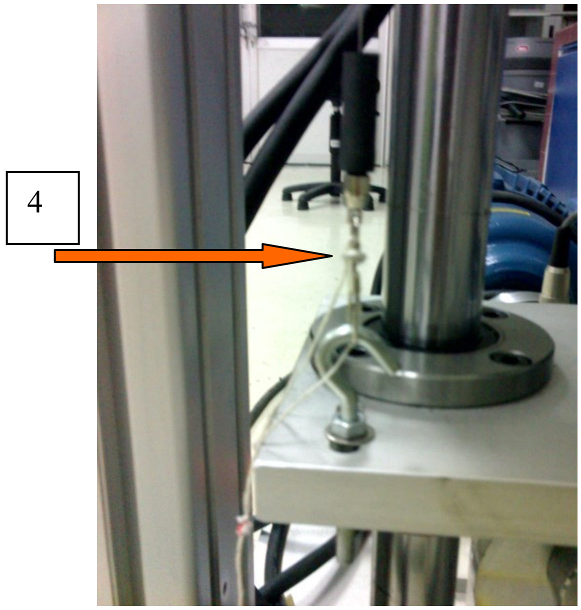


Figure 3.5: Displacement Gauge

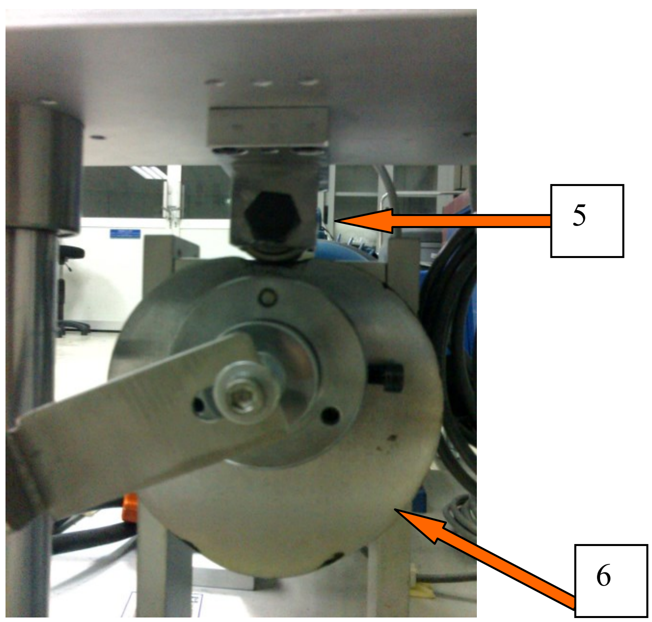
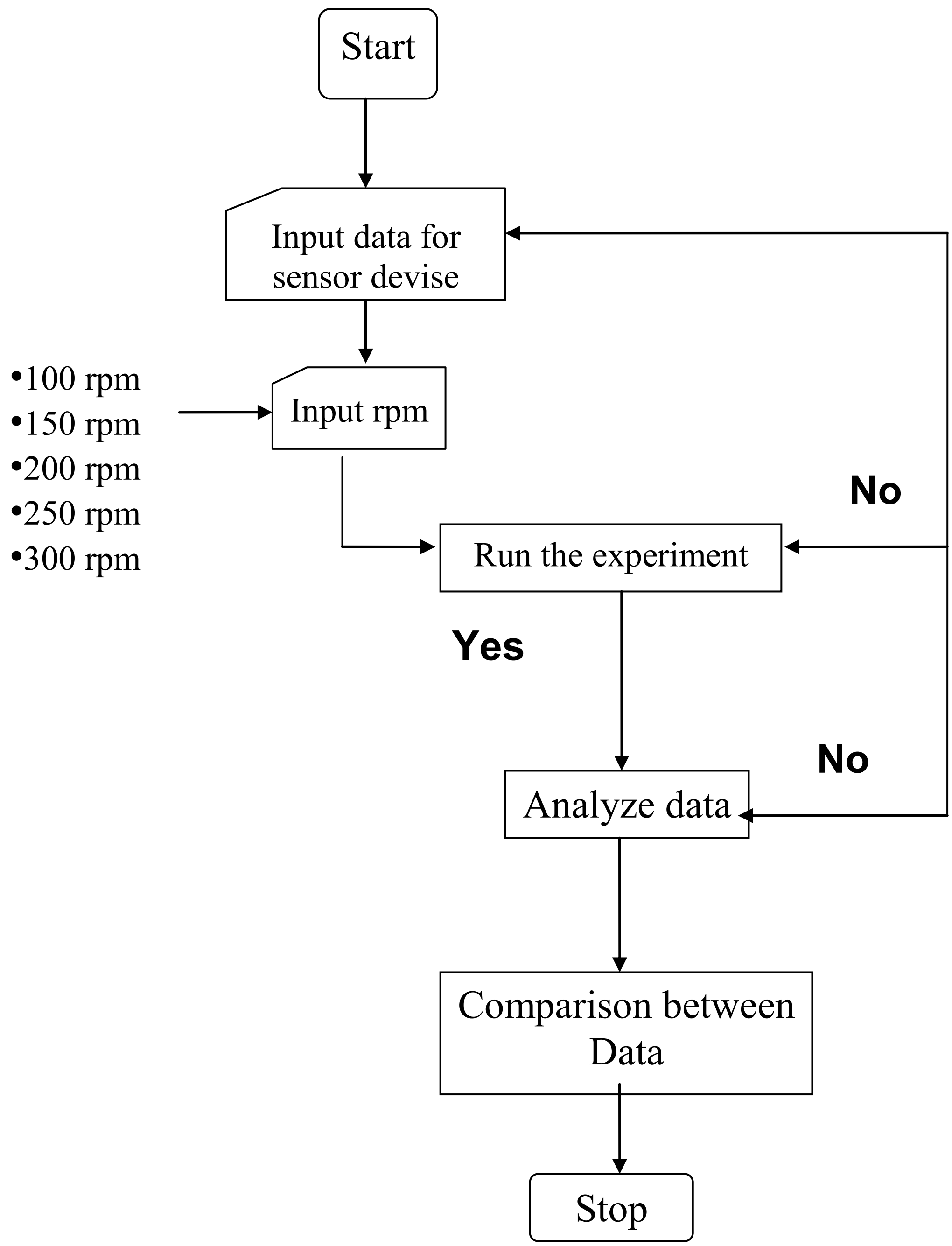


Figure 3.6: Cam location

Where :

4. Draw Wire Displacement Tranducer location.
5. Roller Follower Position,
6. Cam position.

3.5 METHODOLOGY OF DEWESOFT SOFTWARE



3.6 DATA COLLECTION

Result from the heart shape cam that used to do the analysis are collected and put in the table. The different speed has been used to find the kinematic motion of each RPM at 180º.

3.6.1 Cam analysis method

After doing the experiment, the cam performance in experimental method will be compare with the analytical calculation to get how different it is. The percentage of error will be calculated to prove the error regarding the experimental method and analytical method. Each of the data from the different input experiment is compared with analytical calculation and list in the table below.

Percentage of error (%) for displacement, velocity and acceleration according to input data are comparing with analytical method to see whether this cam is suitable for low speed or for high speed application.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTIONS

In this chapter, the result and analysis that gathered from the experiment and from the actual cam is discuss. Basically, the analysis of disk cam can be done by two ways, by using analytical method and by using graphical method. In this thesis, graphical method is more preferable to design the disk cam profile.

4.2 RESULT FROM GRAPHICAL METHOD

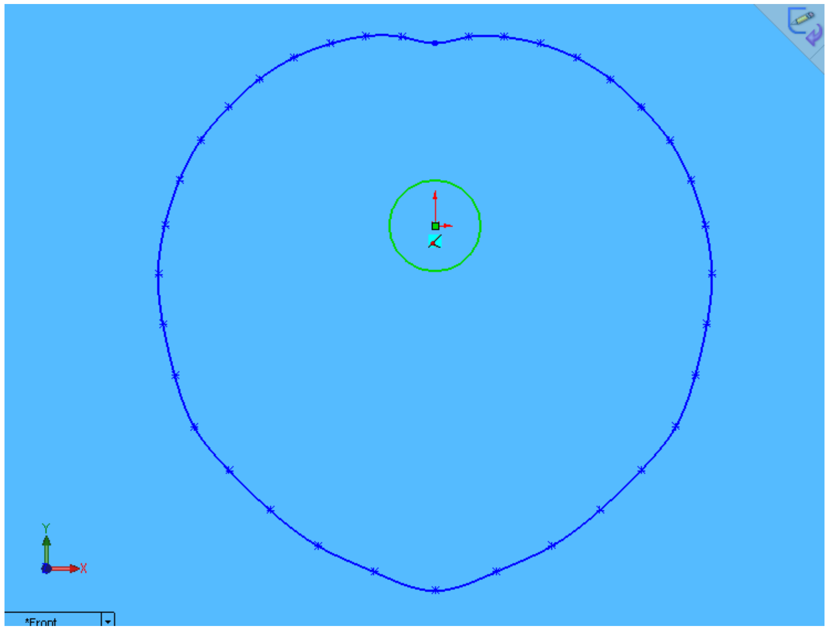


Figure 4.1: The Actual Cam Profile.

This Figure 4.1 is the SolidWork drawing of an actual heart cam shape that been used in the analysis. The actual cam is trace to get the actual cam profile, from the actual cam profile, the displacement diagram is created. When this cam turn through one motion cycle, the follower only execute two series of motion consist of rise and fall motion event. The first 0º to 180º of cam rotation angle (***β***) is a rise part then the second sequence from 190º to 360º is a fall part. Noticed that the base circle radius ***Rb*** is 40mm and total follower displacement ***(H)*** is 40mm.

The velocity and acceleration diagram are constructed by using the constant acceleration motion equation. The graph are plotted versus the cam angle rotation (***β***), the incremental angle ***Φ=10º*** is choose because it show smoothness line when the graph is plotted. The equations of constant acceleration motion are show below;

4.2.1 Constant Acceleration Motion

For 0< *Φ<0.5 β*

Rise

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

$v = 4H\omega\Phi/\beta^2$

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

Fall

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

$v = -4H\omega\Phi/\beta^2$

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

For 0.5 β<Φ<β

Rise

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

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

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

Fall

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

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

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

Where:

Δ*R*=Instantaneous follower displacement at time t or cam angle ***β***

V= Instantaneous follower velocity

A= Instantaneous follower acceleration

H=Total follower displacement during the rise or fall interval

B=Rotation angle of cam during the rise or fall interval

Φ=Angle into rises or fall interval

ω= Speed of the cam

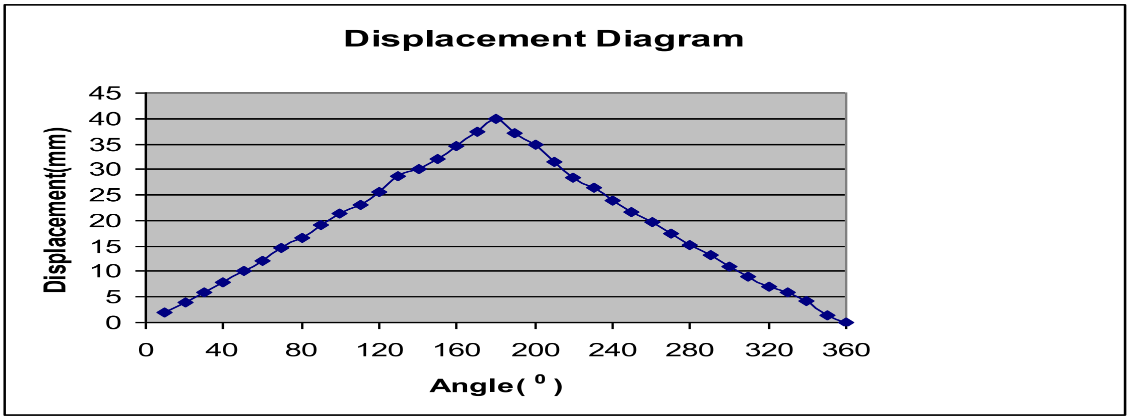


Figure 4.2: Displacement graph for actual cam

From this figure 4.2, the maximum displacement is 40mm at 180 º. This graph show that the displacement diagram only has two sequence of motion, from 0º to 180º it rises with constant accelerations and then fall from 190º to 360º with constant deceleration.

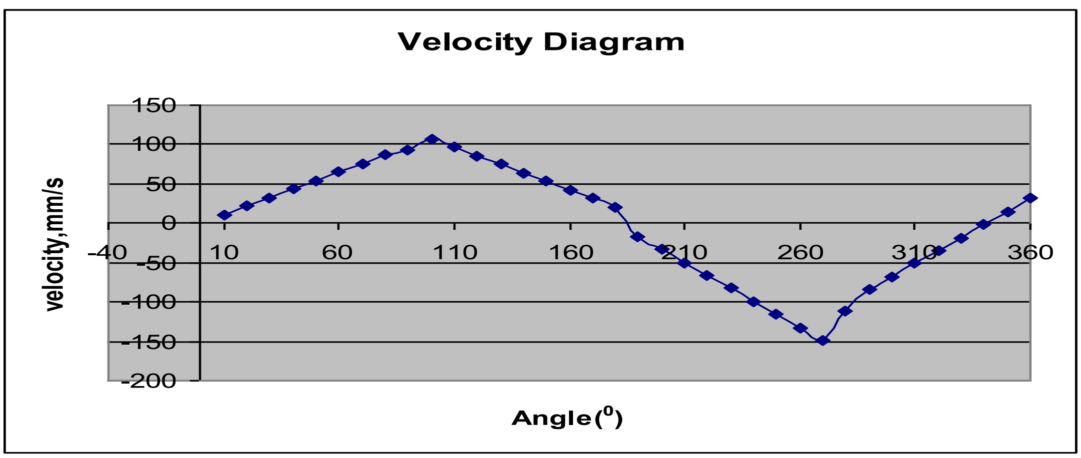


Figure 4.3: Velocity graph for actual cam

The velocity at 180º is 20.60mm/s, from 0º to 90º the velocity is increase and then fall from 100º to 180º. 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.

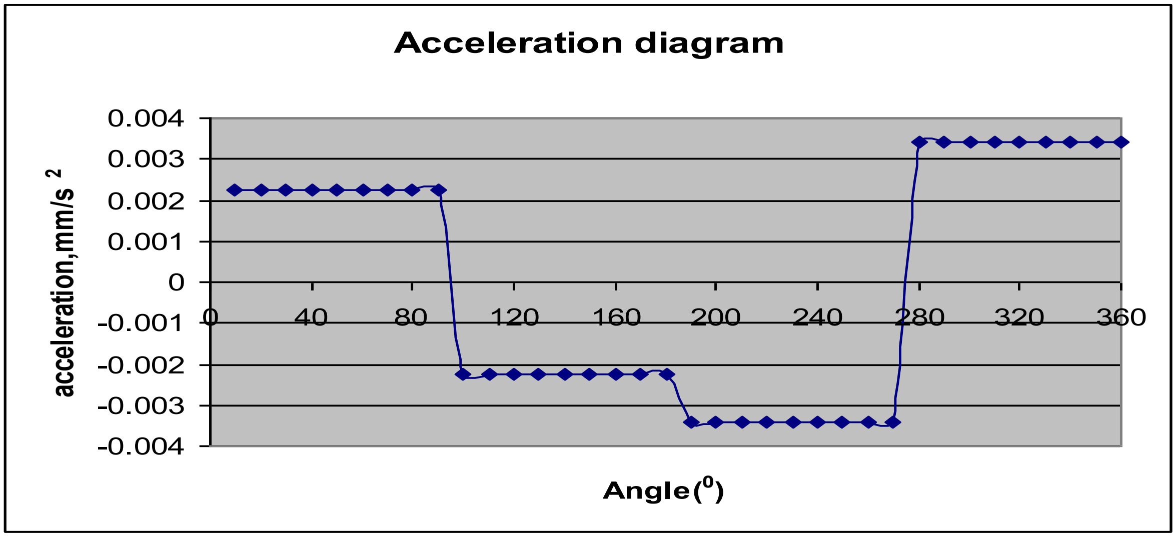


Figure 4.4: Acceleration graph for actual cam

This type of motion gives the smallest value of maximum acceleration along the path of motion, where at 180º the acceleration is -0.00223. From this figure 4.4, the motion has constant positive and negative acceleration value of acceleration. However, it has an abrupt changes change of acceleration at the end of the motion and at the transition point between the acceleration and deceleration halves

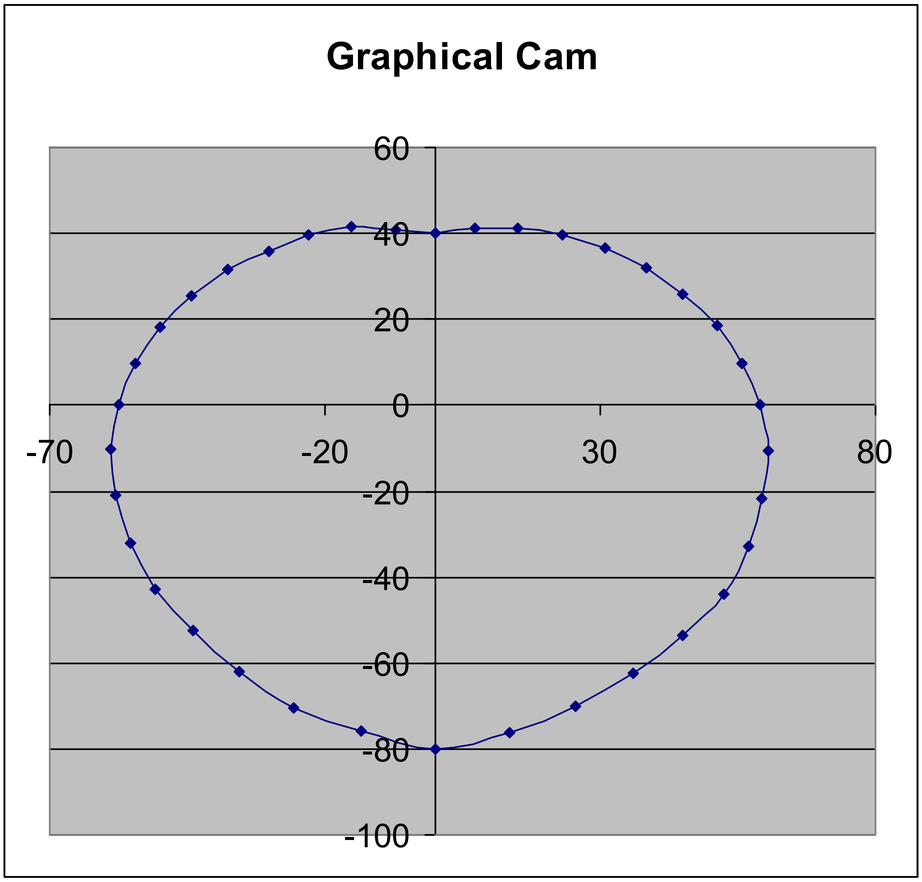


Figure 4.5: The Actual Cam Construct by Using an Equation

This is the actual cam that has been reconstruct again by using an equation $Rx=(Rb+\Delta \boldsymbol{R})\sin\boldsymbol{\Phi}$ and $Ry=(Rb+\Delta \boldsymbol{R})\cos\boldsymbol{\Phi}$**,** where all the needed value gathered from the displacement diagram above.

The following notation is used:

Rx= x coordinate of cam surface profile

Ry=y coordinate of cam surface profile

Rb= Radius base circle

Φ=cam notation angle measured against the direction of cam rotation from the home position

ΔR=Follower displacement at cam angle Φ

4.3 RESULT FROM EXPERIMENTAL.

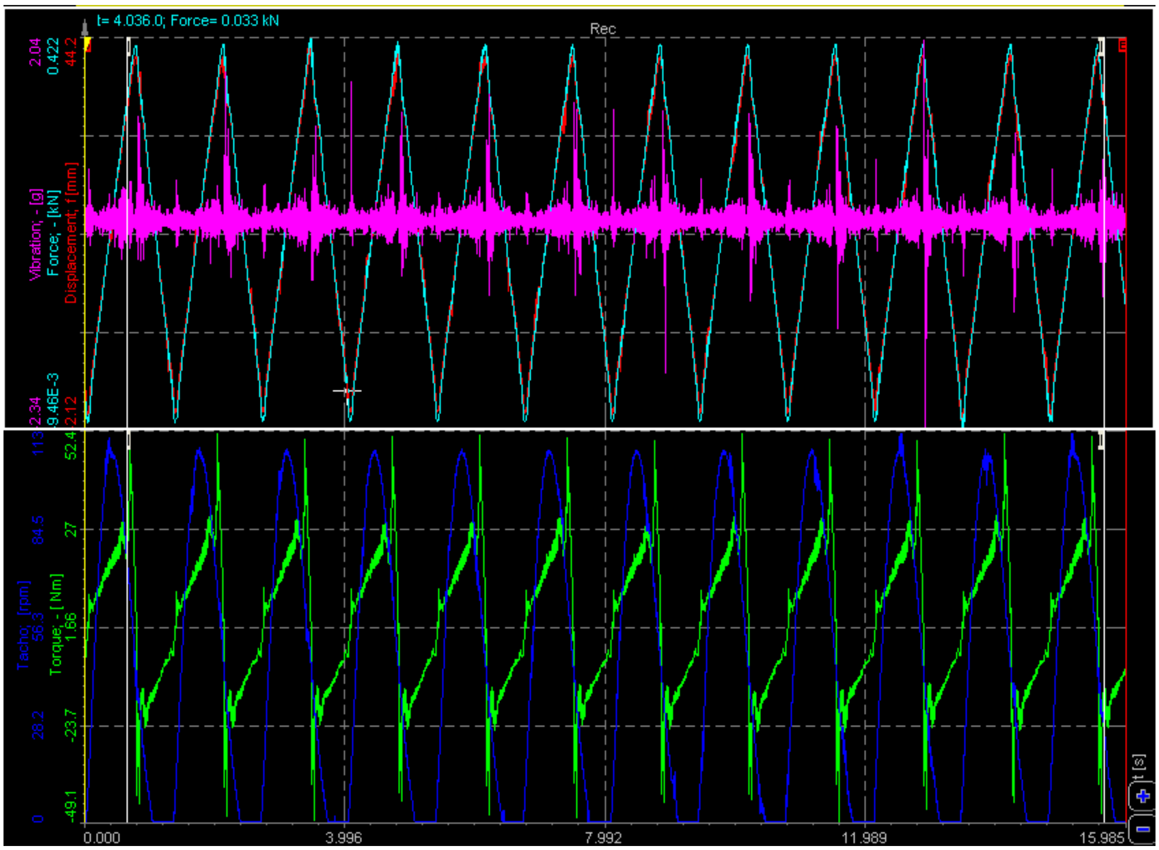


Figure 4.6: Experimental result for 100rpm

This is result from the Dewesoft software for input 100rpm. This result shows data for Displacement, Torque, Vibration, Speed and Force versus time. From the data, the displacement diagram are reconstruct again by using cam rotation angle ($\boldsymbol{\beta}$ =360). Then the velocity and acceleration diagram are construct based on the displacement diagram and using the constant acceleration motion.

4.3.1 Analysis from the experimental result.

For the analysis, one cycle of complete displacement diagram are chose for each input, 100Rpm, 150Rpm, 200Rpm, 250 Rpm and 300Rpm. Then, from the calculations that are made by using constant acceleration motion, the graph kinematics' motion for velocity and acceleration is constructed.

4.3.1.1 100RPM

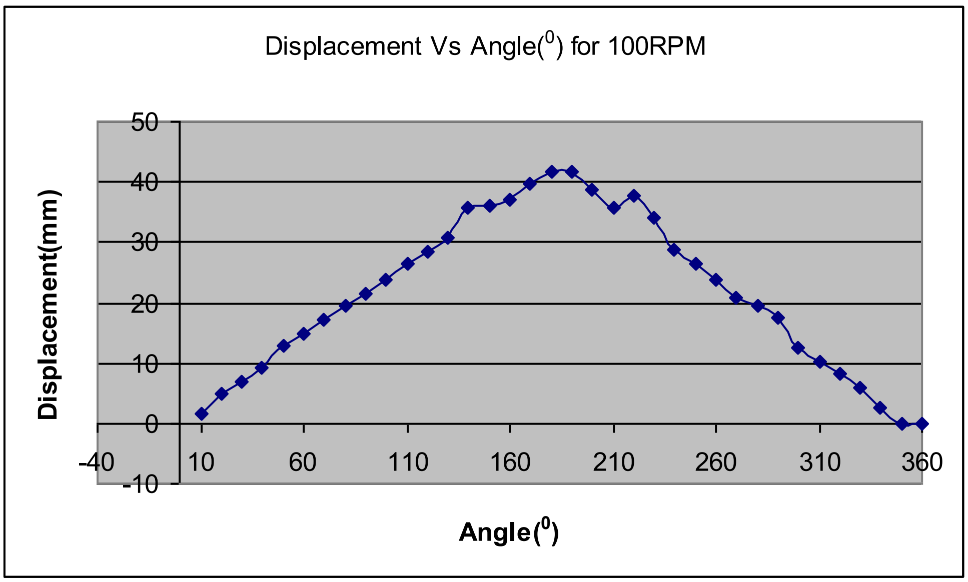


Figure 4.7: Displacement Diagram for 100Rpm

The cam turn through one cycle of 360º, in calculation the incremental Φ=10º is use to plot the graph. The maximum value at 180° is 41.86mm. The displacement increase proportionally with the angle from 0°to 180° except at angle 140°,this is because error had occur when reading the experimental graph. For the fall sequence, it also shows the constant decreasing of displacement from 190° to 360°.

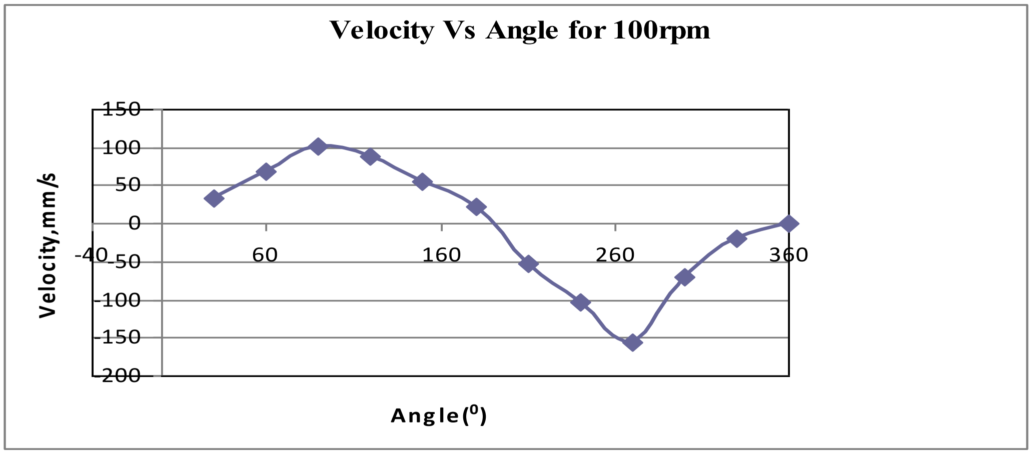


Figure 4.8: Velocity Diagram for 100Rpm

From the calculation for velocity diagram, the value at 180º is 21.46mm/s².From this graph, it shows that the velocity is increase and decreases for each half of motion cycle because it only has rise and fall sequence in displacement diagram.

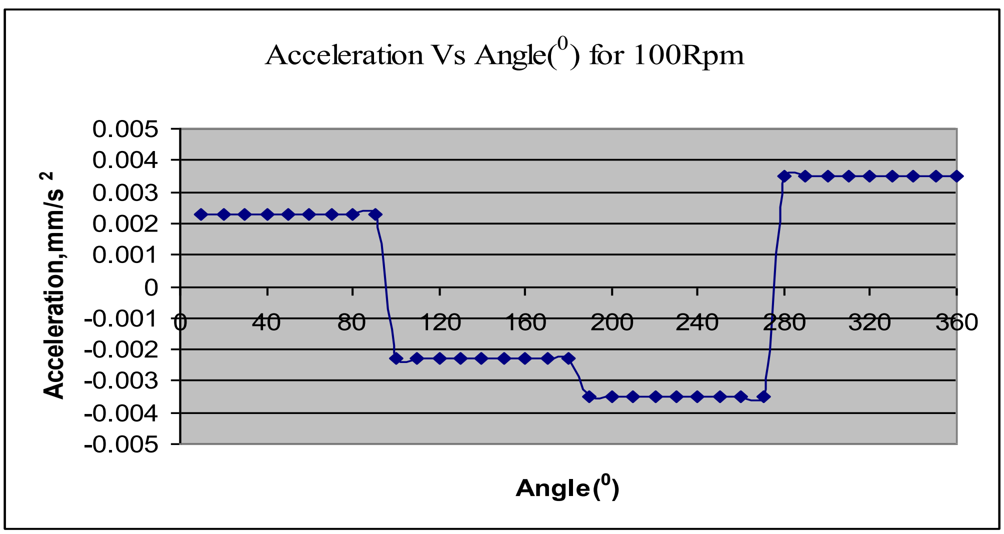


Figure 4.9: Acceleration diagram for 100Rpm

The value at 180º for the acceleration diagram is -0.0023. These values show negative sign because the deceleration had occurred from 90º to 180º. From the Figure 4.9, the acceleration is constant at 0 ºtill 90 º, then it decelerate constantly at -0.0023 till point 180 º. From point 190 º, it decelerates again to -0.0035 then it drastically accelerate to 0.0035.

4.4 DATA COLLECTION

For other input value 150 rpm, 200 rpm, 250 rpm and 300 rpm as shown in the Figure 4.10, Figure 4.11, Figure 4.12, graph of displacement, velocity and acceleration that have been constructing, shows that the result almost has the same pattern but what make it differ from each other is it has different value of displacement, velocity and acceleration at 180°. This because the different motor inputs are set up which mean the rotational of the motor became higher and cause the time in the displacement diagram became shorter. The angle at 180 º is selected because want to see what is the percentage of error occur at the highest rise of the cam for the displacement, velocity and acceleration compare to the actual cam

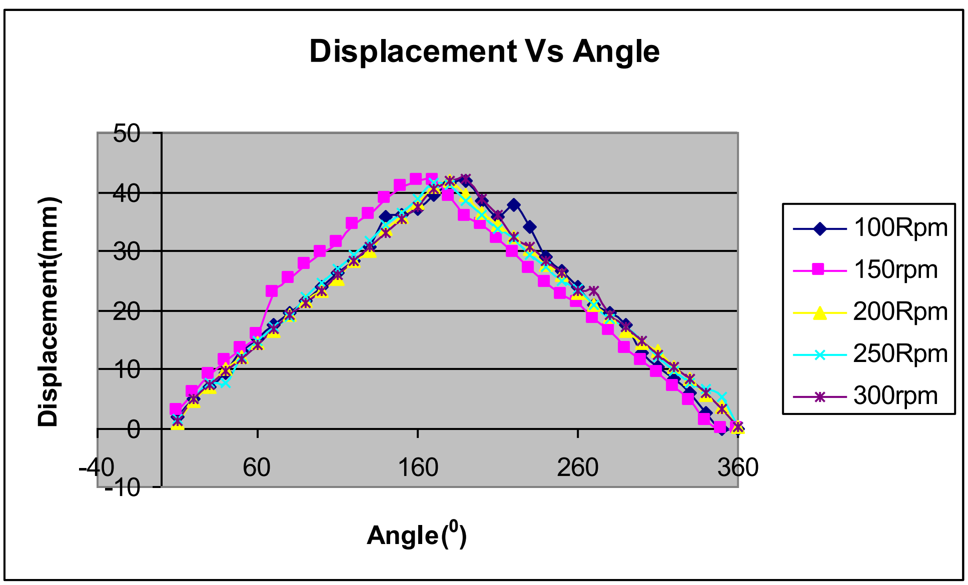


Figure 4.10: The difference of displacement for each input.

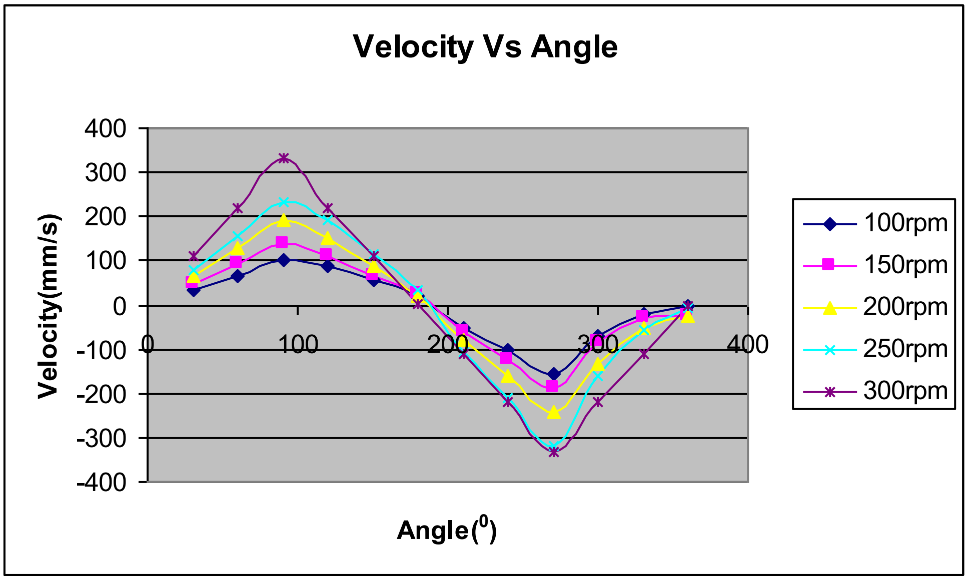


Figure 4.11: The difference of velocity for each input

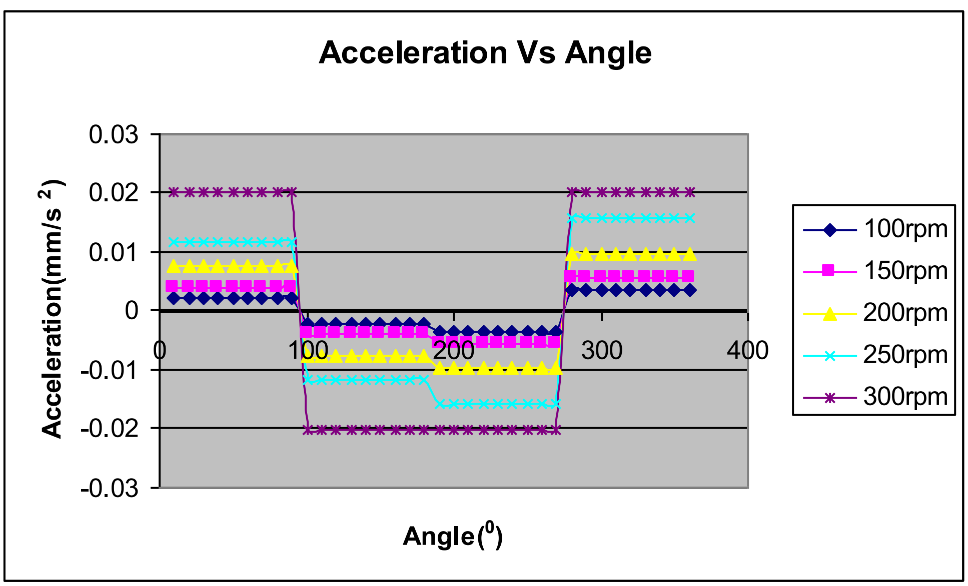


Figure 4.12: The difference of acceleration for each input .

For this shape of cam, the maximum value of displacement, velocity and acceleration is summarized in the Table 4.1 according to the input value (speed). From the table 4.1, the displacement, velocity and acceleration for each input are increase proportionally by the increase of the speed.

Table 4.1: Result from the experiment.

RPM	Displacement(mm)	Velocity(mm/s)	Acceleration(mm/s2)
100	41.6	21.465	-0.0023
150	41.93	26.77	-0.004
200	41.86	21.68	-0.00767
250	41.37	35.92	-0.0116
300	41.936	0.40506	-0.0203

.

4.5 ANALYSIS OF ERROR

This analysis is carried out to determine the percentage of error for actual and experimental cam. The error maybe occurs when the graph of experimental is reconstructing. From cam profile analysis in Figure 4.16, it show some different between graphical method and experimental method. 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.

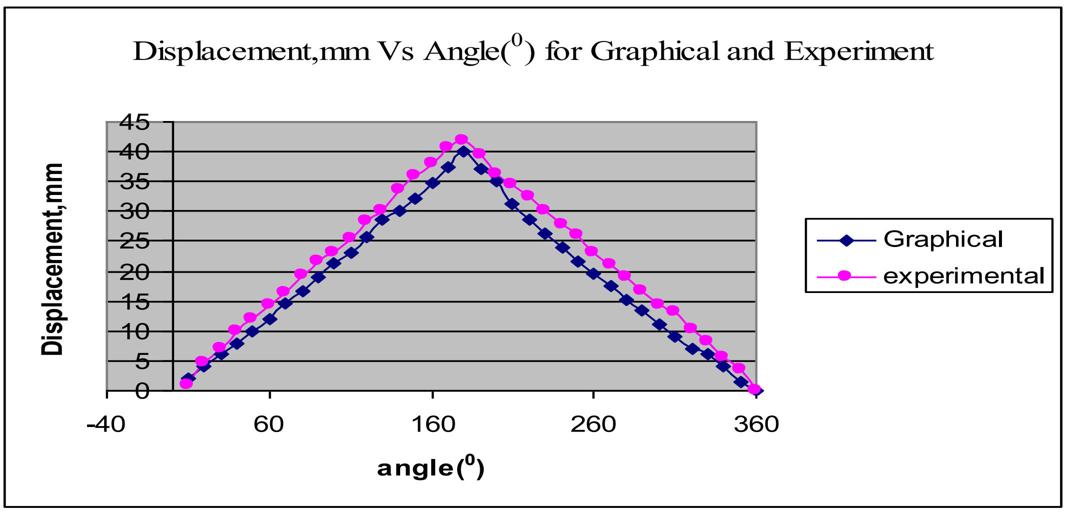


Figure 4.13: Displacement between graphical and experimental at 100rpm

<u>For 100 rpm:</u>

Value at 180°

Experimental:40 mm Graphical:41.6 mm

% error

$$= \frac{(41.6 - 40) \times 100}{40}$$

= 4%

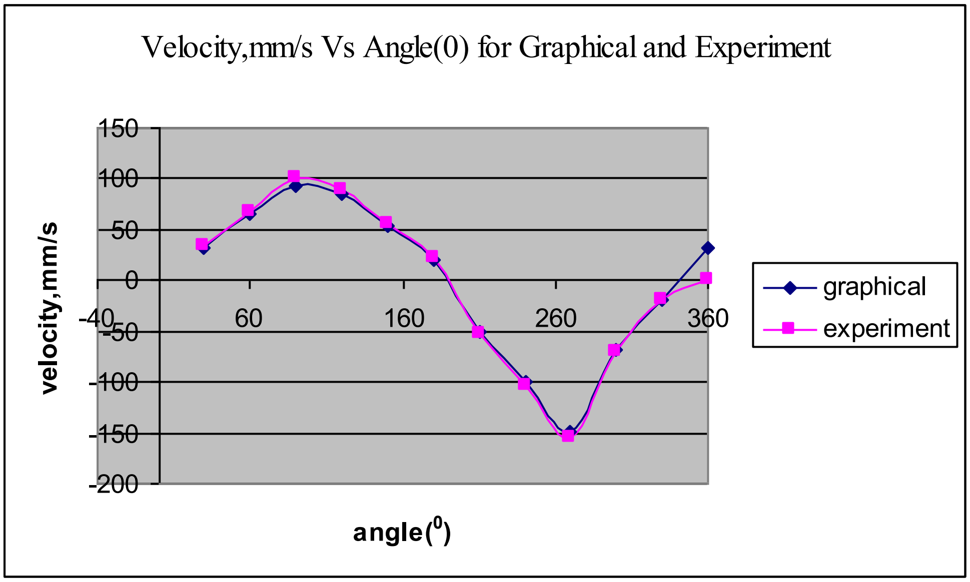


Figure 4.14: Comparison velocity between graphical and experimental at100rpm

Value at 180°

Experimental:21.456 mm Graphical:20.56 mm

% error

$$= \frac{(21.456 - 20.56)}{20.56} \times 100$$

= 4.4%

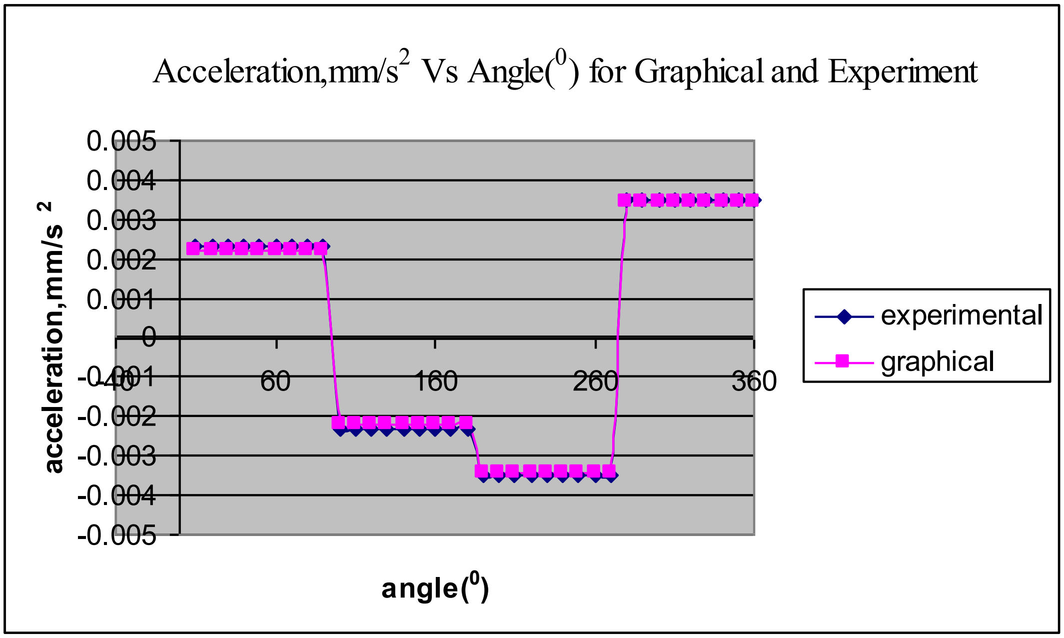


Figure 4.15: Comparison acceleration between graphical and experimental at100rpm

Value at 180°

Experimental: -0.0023 mm   Graphical: -0.00223 mm

% error

$$= \frac{(-0.0023 - -0.00223)}{-0.00223} \times 100$$

= 3.14%

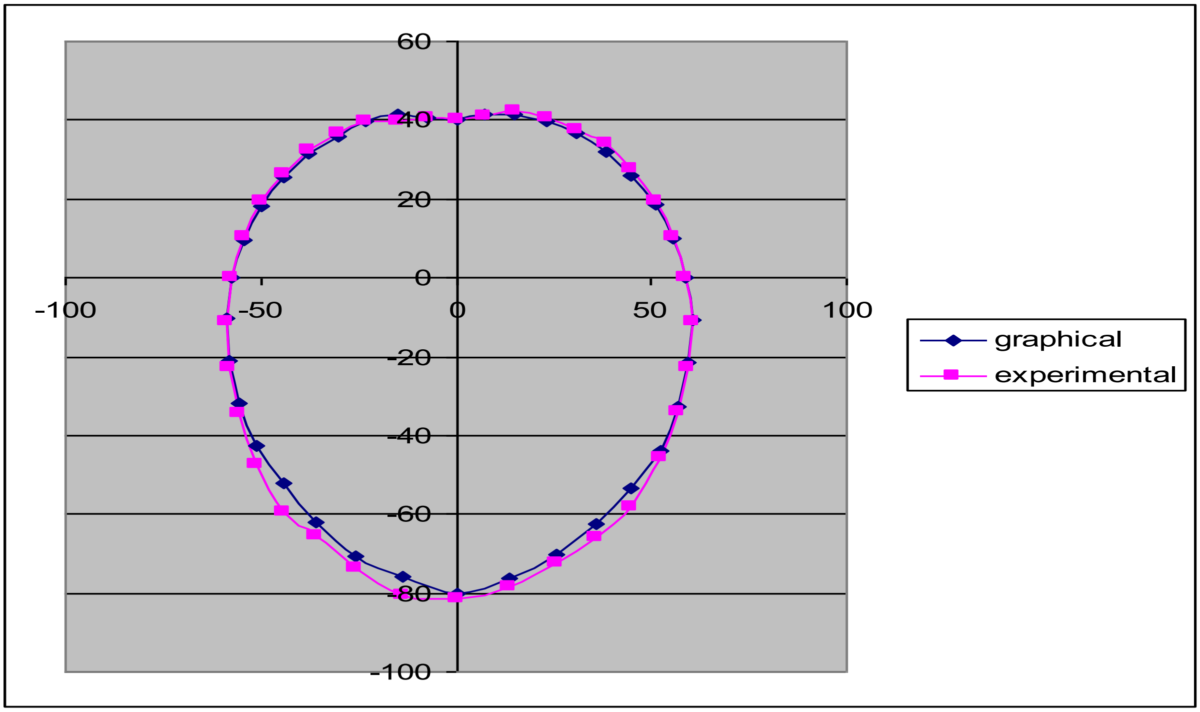


Figure 4.16: Comparison between graphical and experimental cam

From the actual cam profile, the comparison between actual and experimental cam are made to see the differences at 180º for 100rpm. So from the comparison, instantaneous follower displacement between graphical and experimental can be seen and calculate. Where:

$d\Delta \boldsymbol{R} = \Delta \boldsymbol{R}\text{graphical} - \Delta \boldsymbol{R}\text{exp}$

$= 81.6\text{mm} - 80\text{mm}$

$= 1.6 \text{ mm}$

The detail of the error between graphical and experimental method had been summarize in the table 4.2 below. From the table, the smallest error occurs at low speed input compare to the error occur at high speed input. These percentages of error are highest especially for the velocity and acceleration start from 150rpm until 300rpm.

Table 4.2: Percentage Of Error For Each Input Compare With Graphical Cam.

		Displacement (mm)		**Velocity (mm/s)**		**Acceleration (mm/s^2)**	
			Error (%)		Error (%)		Error (%)
Graphical		40	-	20.56	-	-0.00223	-
Experimental	100	41.6	4	21.465	4.4	-0.0023	3.139
(rpm)	150	41.93	4.825	26.77	30.20	-0.004	79.37
	200	41.86	4.65	21.68	5.45	-0.00767	99.23
	250	41.37	3.425	35.92	77.78	-0.0116	404.34
	300	41.963	4.9	0.405	98	-0.0203	782.6

All the errors of kinematic motion for each input are summarize together in the Table 4.3 below. From the table, the percentage of error are increase proportional to the increase of the rpm. The error for velocity and acceleration are very high after 100rpm, which mean that this cam is not suitable for high speed application because it cause the undesirable vibration at initial forces that influence the efficiency of the cam..

Table 4.3: Percentage of error for each RPM

Speed (rpm)	**Displacement (s)**	**Velocity (v)**	**Acceleration (a)**
100	4	4.4	3.139
150	4.285	30.20	79.37
200	4.65	5.45	99.23
250	3.423	77.78	404.34
300	4.9	98	782.6

4.6 DISCUSSION

From the actual cam profile and the experimental, the displacement diagram shows error occurs at each rpm. The error is about 4% to 5% compare to the actual displacement, this small error occurs because when the cam rotate at high speed it cause the follower to jump and cause the error in the experimental graph.

The cam only has rise and fall movement, usually tendency to create a jerk at follower displacement. This jerk cause the vibration to the cam machine and at high speed, the vibration will affect the experimental result. The velocity of the cam mechanism increases the magnitude of the torque acting on the shaft increases and torsional vibrations occur on the camshaft

The velocity analysis for experimental compare to the graphical show that there is increment in percentage of error, from 100rpm till 300rpm the error is up to 99 percent. The error occur because of the data for modeling device for is not insert

This motion scheme have constant positive and negative acceleration, there are highly percentage of error for this motion. The highest error is at 300rpm where the error is about 782.6 percent compare with 100rpm the error only 3.139 percent. This motion has an abrupt change of acceleration at the end of motion and at the transition point, which typically cause the undesirable vibration for the cam.

Commonly, there are a few type of error when do the analysis. Firstly, when read the experiment graph from the Dewesoft software, the cursor did not read at the exactly point that needed. Then, while doing the analytical calculation, the decimal places always be rounded up till one or 2 decimal places and this will cause the point is not exactly like the actual profile. The vibrations that occur could also influence the sensor sensitivity, this can cause the sensor to read the false reading.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

From the analysis, the cam profile show only two sequence of motion that is rise and fall. The rise sequence is from 0º to 180 º and for the fall sequences it from 190 º till 360 º. From the experimental result and the actual graphical, there an error occur for each data collected.

The analysis of error shows that for the input 100RPM, the percentage of error occur at180º for displacement(s), velocity(v) and acceleration(a) diagram are small compare with input 300RPM. Where for 100rpm the error is s=4%, v=4.4% and a=3.139%, for 300rpm the percentage of error is s=4.9%, v=98%, a=782.6%.

The higher error occurs at high input speed especially for velocity and acceleration because it has an abrupt change of acceleration at the end of the motion and at the transition point between acceleration and deceleration halves. These abrupt change cause the undesirable vibration when the cam running at high speed level, therefore this cam is most suitable for low speed applications.

5.2 RECOMMENDATION

In order to achieve the good result during the experiment, the precaution step should be follow and all the input setup for sensor should be in the range of sensitivity.

In future research, the diameter of roller follower should be study and change to find the suitable diameter of roller follower for the heart cam. This study will help in order to decrease the percentage of error and to reduce the undesirable vibrations that happen when the cam is rotating at high speed.

The design of the heart cam also should be study in order to see if the roller follower always contact with the cam at all location. If the cam and roller follower is not contact at certain angle, the cam will not push the roller follower to the desired position and can cause error during the analysis.

The other potential area that should be improved is the optimization of the cam speed. There are lot types of cam and each cam has the maximum cam speed that they can endure. So the analysis should be carried out to know the maximum speed of cam can endure and whether the cam it suitable for high or low speed application.

REFERENCES

- Ahmad Razlan Yusoff and Rosdi Daud (2006). Reverse Engineering Approach in developing of a Cam profile for Internal Combustion Engine Proc. Of National Seminar on Science Technology and Social Sciences (STSS 2006) pp. 535-540, Kuantan, 17-18 May 2006.
- Arthur G. Erdman, George N. Sandor, Mechanism Design: Analysis and Synthesis, Prentice Hall, Volume 1, New Jersey, 1984
- Arunava Biswas, Michael Stevens, Gary L. Kinzel, *A comparison of approximate methods for the analytical determination of profiles for disk cams with roller followers*, 2003.
- Borg J, Bonello P and Ciantar C (1997). A Computer Based Tool for the Design and Manufacture of Automatic Lathe Cams. Computers in Industry. 34 11-26
- Bouzakis, K.D., Mitsi, S. and Tsiafis,J. (1997). Computer-Aided Optimum Design and NC Milling of Planar Cam Mechanisms. International Journal Machine Tools Manufacturing. 37 (8) 1131-1142.
- Chen, F. Y., *Mechanics and Design of Cam Mechanisms*, Pergamon Press, New York, 1982.
- David H. Myszka, *Machines & Mechanisms*, Pearson Prentice Hall, Third Edition, New Jersey, 2005
- http://en.wikipedia.org/w/index.php?title=Displacement_diagram
- http://en.wikipedia.org/wiki/cam
- http://www.scs.cmu.edu/%7Erapidproto/home.html
- Jensen, P. W. (1987) Cam Design and Manufacture 2nd ed Marcel Dekker Inc.
- Lee R,S. & She C H (1998). Tool path Generation and Error Control Method for Multi Axis NC machining of Spatial Cam. International Journal Machine Tools Manufacturing. 38 (4) 277-290.

- Lin, P.D. and Tsai, I.J. (1996) The machining and On Line Measurement of Spatial Cams on Four Axis Machine Tools. International Journal Machine Tools Manufacturing. 36 (1) 89-101.
- Q. Yu and H.P. Lee, *optimum design of cam mechanisms with oscillating flat-face followers*, 1995.
- Rothbart, H.A.(2005) Cam Design Handbook. McGraw-Hill Handbooks, New York
- Wei, W J, Lai, H.T. and Chen, C.K.(2000). Machine Tool Setting for the Manufacturing of Spherical Cams. Journal of Materials Processing Technology. 100 147-155.
- Yi Zhang, Susan Finger, Stephannie Behrens, *Rapid Design through Virtual and Physical Prototyping*, Carnegie Mellon University, 2006.

APPENDIX A1

Gantt Chart/ Project Schedule For Final Year Project I

No	Tasks	WEEK															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	**Discussion with Supervisor**																
	briefing about the title	■															
	Set up time for every weeks meeting	■															
2	**Finding an Information about disk cam**																
	Internet		■	■	■	■	■	■	■	■	■	■	■	■			
	books		■	■	■	■											
	journal		■	■	■	■	■	■	■								
3	**Derive an equation**																
	used manual calculation			■	■	■	■	■									
	using mathcad			■	■	■	■	■									
	attending FYI briefing					■											
4	**Writing Chapter 1**																
	Writing the objective, scope of project								■	■							
5	**Writing literiture review**																
	Overview of the project									■	■	■					
	Writing literature review										■	■					
6	**Methodology**																
	How to carry out the project											■	■	■			
	Simplified methodology												■	■			
7	**Writing Conclusion**																
	Writing FYP I conclusion													■	■	■	
8	**Compiling the Report**																
	Introduction													■	■	■	
	Literature Review													■	■	■	
	Methodology													■	■	■	
	Conclusion + References													■	■	■	
9	**Presentation**																
	make slide presentation													■	■		
	present to supervisor														■	■	
	present to panel															■	■

APPENDIX A2

Gantt Chart/ Project Schedule For Final Year Project II

No	Tasks	WEEK														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	**Grapical design of cam**															
	grapical calculation	■	■	■	■											
	Illustrate into 2D and 3D			■	■											
2	**Test the disk cam in vertical position**															
	setup the apparatus					■	■	■								
	run the experiment						■	■	■	■						
3	**Analyze the data**															
	analyze the data								■	■	■					
4	**Organise the Data**															
	compare the performance									■	■	■	■			
5	**Finish the Thesis**															
	write result										■	■	■	■	■	
	writing the conclusion											■	■	■	■	■
	combine all chapter											■	■	■	■	■
6	**Prepare for the final presentation**															
	make a slide presentation											■	■	■		

APPENDIX B1

Spreadsheet for Actual Cam

grapical cam

	A	B	C	D
1	deg	rx	ry	
2	0	0	40	
3	10	7.3	41.362	
4	20	15.048	41.3464	
5	30	23	39.837	
6	40	30.854	36.77	
7	50	38.302	32.14	
8	60	45.033	26	
9	70	51.213	18.64	
10	80	55.84	9.8485	
11	90	59	0	
12	100	60.467	-10.6619	
13	110	59.338	-21.6156	
14	120	56.81	-32.8	
15	130	52.55	-44.095	
16	140	44.995	-53.623	
17	150	36	-62.354	
18	160	25.54	-70.157	
19	170	13.44	-76.224	
20	180	0	-80	
21	190	-13.371	-75.83	
22	200	-25.65	-70.477	
23	210	-35.7	-61.834	
24	220	-43.903	-52.32	
25	230	-50.87	-42.68	
26	240	-55.425	-32	
27	250	-57.88	-21.068	
28	260	-58.79	-10.366	
29	270	-57.4	0	
30	280	-54.46	9.603	
31	290	-50.08	18.23	
32	300	-44.17	25.5	

Sheet1 Sheet2

APPENDIX B2

Spreadsheet for Experimental Cam

grapical cam

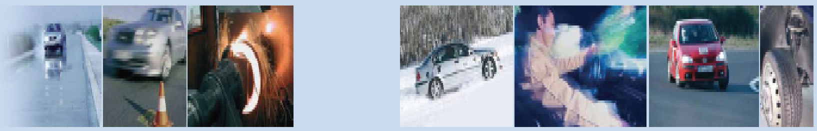
	A	B	C	D
46	deg	RX	RY	
47	0	0	40	
48	10	7.241	41.06	
49	20	15.39	42.286	
50	30	23.6	40.703	
51	40	31.325	37.689	
52	50	40.523	34.003	
53	60	47.63	27.5	
54	70	53.844	19.597	
55	80	54.498	10.3147	
56	90	61.6	0	
57	100	62.83	-11.078	
58	110	62.3	-22.68	
59	120	59.236	-34.2	
60	130	54.236	-45.509	
61	140	48.723	-58.066	
62	150	38.05	-65.904	
63	160	26.335	-72.356	
64	170	13.822	-78.39	
65	180	0	-81.6	
66	190	-14.187	-80.458	
67	200	-26.88	-73.86	
68	210	-37.9	-65.644	
69	220	-50.073	-59.67	
70	230	-56.68	-47.566	
71	240	-59.669	-34.45	
72	250	-62.58	-22.78	
73	260	-62.929	-11.096	
74	270	-60.7	0	
75	280	-58.49	10.347	
76	290	-53.94	19.63	
77	300	-45.64	26.35	

Sheet1 / Sheet2

APPENDIX C1

Datasheet for DEWE -101

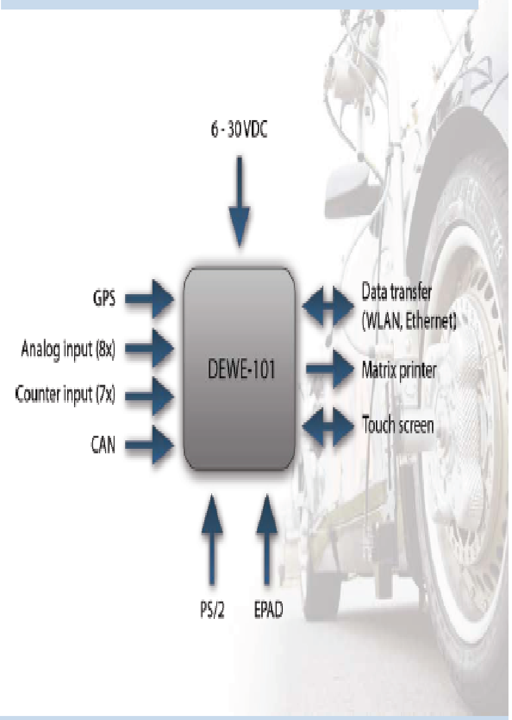
worldwide
DEWETRON
www.dewetron.com



DEWETRON TECHNICAL SPECIFICATIONS

	DEWE-101-VGPS	DEWE-101-V
GPS		
Refresh rate	100 Hz	N/A
Differential	WAAS, EGNOS	N/A
Speed accurancy	0.1 km/h	N/A
ANALOG INPUT		
Number of channels	8 (simultaneously sampled)	
Input configuration	Differential	
Resolution	24-bit	
Type of ADC	Sigma-Delta	
Sampling rate	20 ks/s	
AMPLIFIER CHARACTERISTICS		
Input ranges	±10mV, ±0.1V, ±1V, ±10V	
Input impedance	„1GΩ‖33pF (differential) 10MΩ‖33pF (common mode)"	
CMRR	>55dB	
Sensor supply voltage	+- 5 V precise 50mA, 12 V@ 100 mA	
Voltage mode coupling	DC	
Overvoltage protection	100 V	
DYNAMIC CHARACTERISTICS		
Signal to noise @ fs<100Hz	< -100 dB	
Crosstalk	< -100 dB	
COUNTER DIGITAL INPUTS		
Number of channels	7	
Counter modes	event counting encoder input period, pulsewidth, duty cycle frequency measurement	
Resolution	32-bit	
Time base	50MHz	
Signal levels	TTL/CMOS	
Input voltage protection	30V	
CAN INPUTS		
Number of channels	2	
Specification	CAN 2.0B	
Physical layer	High speed	

	DEWE-101-VGPS	DEWE-101-V
ENVIRONMENTAL		
Operating temperature	0 ÷ 50°C	
Storage temperature	-20 ÷ 70°C	
Relative humidity	10 ÷ 90%	
POWER REQUIREMENTS		
Supply voltage	6-36VDC	
Supply overvoltage protection	80V	
Negative input voltage protection	-30V	
PHYSICAL		
Dimensions	210mm X 140mm X 80mm	
Weight	<2.5 kg	



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