EXPERIMENTS IN DYNAMICS OF MACHINERY

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DEPARTMENT OF MECHANICAL ENGINEERING

SUBJECT : DYNAMICS OF MACHINERY

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INDEX

PRACTICAL: 01

AN OVERVIEW OF DYNAMICS OF MACHINERY

THE SUBJECT OF KINEMATICS AND DYNAMICS OF MACHINES

This subject is a continuation of statics and dynamics, which is taken by students in their freshman or sophomore years. In kinematics and dynamics of machines and mechanisms, however, the emphasis shifts from studying general concepts with illustrative examples to developing methods and performing analyses of real designs. This shift in emphasis is important, since it entails dealing with complex objects and utilizing different tools to analyze these objects.

The objective of kinematics is to develop various means of transforming motion to achieve a specific kind needed in applications. For example, an object is to be moved from point A to point B along some path. The first question in solving this problem is usually: What kind of a mechanism (if any) can be used to perform this function? And the second question is: How does one design such a mechanism?

The objective of dynamics is analysis of the behavior of a given machine or mechanism when subjected to dynamic forces. For the above example, when the mechanism is already known, then external forces are applied and its motion is studied. The determination of forces induced in machine components by the motion is part of this analysis.

As a subject, the kinematics and dynamics of machines and mechanisms is disconnected from other subjects (except statics and dynamics) in the Mechanical Engineering curriculum. This absence of links to other subjects may create the false impression that there are no constraints, apart from the kinematic ones, imposed on the design of mechanisms. Look again at the problem of moving an object from A to B. In designing a mechanism, the size, shape, and weight of the object all constitute input into the design process. All of these will affect the size of the mechanism. There are other considerations as well, such as, for example, what the allowable speed of approaching point B should be. The outcome of this inquiry may affect either the configuration or the type of the mechanism. Within the subject of kinematics and dynamics of machines and mechanisms such requirements cannot be justifiably formulated; they can, however, be posed as a learning exercise.

KINEMATICS AND DYNAMICS AS PART OF THE DESIGN PROCESS

The role of kinematics is to ensure the functionality of the mechanism, while the role of dynamics is to verify the acceptability of induced forces in parts. The functionality and induced forces are subject to various constraints (specifications) imposed on the design. Look at the example of a cam operating a valve (Figure 1.1).

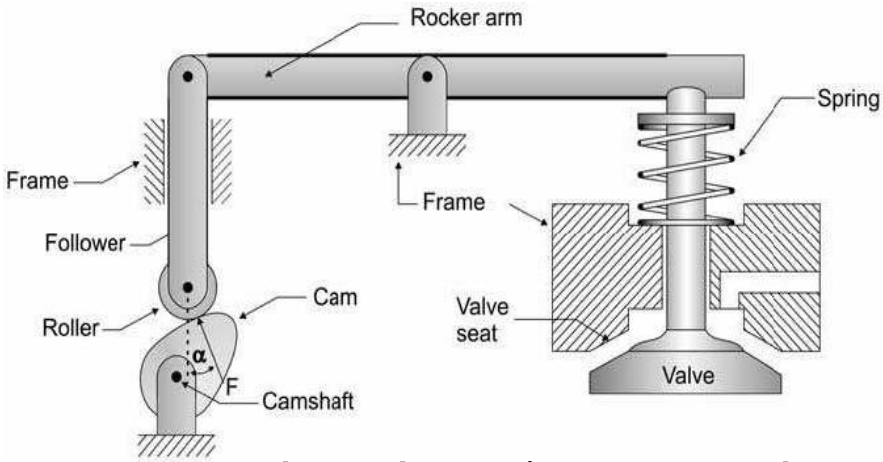


FIGURE 1.1 A schematic diagram of cam operating a valve.

The design process starts with meeting the functional requirements of the product. The basic one in this case is the proper opening, dwelling, and closing of the valve as a function of time. To achieve this objective, a corresponding cam profile producing the needed follower motion should be found. The rocker arm, being a lever, serves as a displacement amplifier/reducer. The timing of opening, dwelling, and closing is controlled by the speed of the camshaft. The function of the spring is to keep the roller always in contact with the cam. To meet this requirement the inertial forces developed during the follower–valve system motion should be known, since the spring force must be larger than these forces at any time. Thus, it follows that the determination of component accelerations needed to find inertial forces is important for the choice of the proper spring stiffness.

Kinematical analysis allows one to satisfy the functional requirements for valve displacements. Dynamic analysis allows one to find forces in the system as a function of time. These forces are needed to continue the design process. The design process continues with meeting the constraints requirements, which in this case are:

- Sizes of all parts;
- Sealing between the valve and its seat;
- Lubrication;
- Selection of materials;
- Manufacturing and maintenance;
- Safety;
- Assembly, etc.

The forces transmitted through the system during cam rotation allow one to determine the proper sizes of components, and thus to find the overall assembly dimension. The spring force affects the reliability of the valve sealing. If any of the requirements cannot be met with the given assembly design, then another set of parameters should be chosen, and the kinematic and dynamic analysis repeated for the new version.

Thus, kinematic and dynamic analysis is an integral part of the machine design process, which means it uses input from this process and produces output for its continuation.

Classical dynamics is by now an old subject, i.e. at least several hundred years old if one takes Newton's Laws as a starting point. As such, classical physics does not always seem as trendy as more modern developments (special / general relativity, quantum mechanics etc.). Nevertheless, classical non-relativistic dynamics is a highly complex and beautiful subject, and is still providing new areas of active research (e.g. chaos theory is a fairly young offshoot). Furthermore, the ideas and formalisms of classical physics underlay all other modern theories of physics. There is a strong sense in which the language of modern physics is deeply rooted in classical physics, particularly in the Lagrangian formalism, which we will learn in this course. Thus, an understanding of classical behavior is a necessary prerequisite for understanding systems which are quantum, relativistic, or both! What I hope we will also see is that classical mechanics is interesting in its own right. After all, we are all surrounded by classical phenomena in everyday

The first law seems obvious nowadays, although perhaps only because we have it drummed into us from an early age. Nevertheless, the idea that objects can continue moving without any applied force would certainly have seemed strange to pre-Newtonian physicists (including the ancient Greeks), perhaps because in everyday life motion is usually damped by air resistance or friction. Thus, the first law is more of a conceptual breakthrough than it might first appear.

The second law is a clear statement of how a particle's trajectory (x(t)) is related to the forces which act on the particle. It gives a differential equation for this trajectory, and tells us that if we know the initial conditions of a particle at some initial time t0 (e.g. its position and velocity), we can calculate the trajectory at all later times. If there are many particles, each acted upon by forces, we have one such equation for each particle. These are the equations of motion of the system.

The third law is perhaps the most confusing and misunderstood, but often helps us to simplify calculations in many-particle systems. We will see this in what follows.

Newton's Laws are relatively easy to apply to simple mechanical systems e.g. one or two particles, with force acting. It can also be useful in many-particle systems, where the equations of motion can be solved numerically if necessary. However, for very complicated systems (e.g. particles subject to nontrivial constraints) Newton's Laws can be difficult to apply. For some systems, e.g. fields rather than particles, it is even more confusing to have to think in terms of forces. Thus, it is useful to have powerful, general methods for describing classical dynamics.

The aim of this course is twofold. Firstly, we review some aspects of Newtonian mechanics which may be unfamiliar (e.g. rotating / accelerating reference frames, many particle systems). Secondly, we develop an alternative formulation of classical dynamics, which avoids us having to think about forces at all, and which is much easier to apply to complex mechanical systems. This is the Lagrangian formalism, and we will see that this approach not only makes problem solving easier, but also reveals hitherto hidden conceptual ideas of great power (e.g. the relationship between conserved quantities and symmetries).

PRACTICAL: 02

BALANCING:- SHEET PROBLEMS

SHEET 1: BALANCING OF ROTATING MASSES

- A shaft is supported between two bearings 2.0 m apart and extended 0.5 m beyond bearing at each end. The shaft carries 3 pulleys one at each end and one at middle of its length. The masses of end pulleys are 50 kg and 25 kg and their c.g. are 20 mm and 15 mm respectively from the shaft axis. The center pulley has a mass of 60 kg and its center of gravity is 20 mm from the shaft axis. If the pulleys are arranged so as to give the balance, determine
    - (1) The relative angular position of the pulley and
    - (2) The dynamic forces produced on the bearings when the shaft rotates at 340 rpm.

Calculations:-

SHEET 2: BALANCING OF RECIPROCATING MASSES

- A six cylinder two stroke in line reciprocating engine has a firing order 1-4-5-2-3-6. The firing takes place with equal angular interval. The mass of reciprocating parts per cylinder is 3 kg. the length of cranks and connecting rods are 50 mm and 200 mm respectively. The cylinders are spaced at 300 mm pitch. If the engine runs at 1000 rpm, determine
    - (1) The unbalanced primary and secondary forces if any and
    - (2) The maximum value of unbalanced primary and secondary couples with reference to central plane of the engine and position of crank no.1 at which these maximum values occur.

PRACTICAL: 03

STATIC AND DYNAMIC BALANCING APPARATUS

AIM :- To check experimentally the normal method of calculating the position of counter balancing weight in rotating mass systems.

DESCRIPTION :

The apparatus basically consists of a steel shaft mounted in ball bearing in a stiff rectangular main frame. A set of six blocks of different weights is provided & may be clamped in any position on the shaft, and also be easily detached from the shaft. The disc caring a circular protractor scale is fitted if the side of the rectangular frame. Shaft carries a disc & rim of this disc is grooved to take a light cold provided with two cylindrical metal containers of exactly the same weight. The scale is fitted to the lower member of the main frame & when used in conjunction with the circular protractor scale, allows the exact longitudinal & angular position of each adjustable block to be determined.

The shaft is driven by a 230 V. single phase 50 cycles electric motor, mounted under the main frame, through a belt. For static balancing of individual weights the main frame is suspended to the support frame by chains & in this position the motor driving belt is removed.

For dynamic balancing of the rotating mass system the main frame is suspended from the support frame by two short links such as that the main frame & the supporting frame are in the same plane.

PROCEDURE :

1. *STATIC BALANCING :*

Remove the drive belt. The value of Wr. for each block is determined by clamping each block in turn on the shaft & with the cord & container system suspended over the protractor disc, the number of steel balls, which are of equal weight, are placed into one of the container to exactly balance the blocks on the shaft. When the block becomes horizontal, the number of balls 'N' will give the value of Wr. for the block.

For finding out 'Wr" during static balancing proceed as follows.

1. Remove the Belt.

2. Screw the combine hook to the pulley with groove (This pulley is different than the belt pulley).

3. Attach the cord ends of the pans to the above combined hook.

4. Attach the block No. 1 to the shaft at any convenient position & in vertical downward direction.

5. Put steel balls in one of the pan till the block starts moving up

(Upto horinzotal position).

6. Number of balls give the 'Wr' value of block 1. Repeat this for 2 to 3 times & find the average no. of balls.

7. Repeat the procedure for other blocks.

2. *DYNAMIC BALANCING :*

It is necessary to leave the machine before the experiment. Using the value of Wr. obtained as above, & if the angular positions & planes of rotation of three of four blocks are known, the student can calculate the position of the other blocks (S) for balancing of the complete system. From the calculations, the student finally clamps all the blocks on the shaft in their appropriate positions. Replace the motor belt, transfer the main frame to its hanging position & then by running the motor, one can verify that those calculations are correct & the blocks are perfectly balanced.

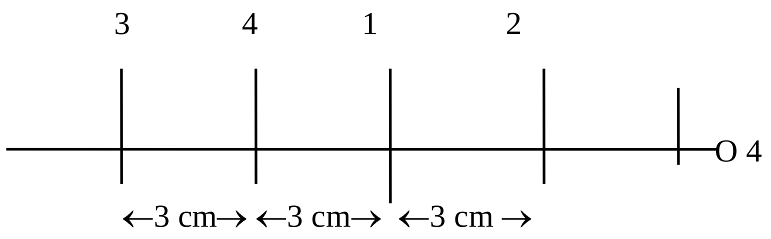
<u>EXPERIMENT No. A</u>

1. DYNAMIC BALANCING OF 4 BLOCKS.

Obtain Dynamic Balance of a set of four blocks with unbalance as shown, by properly positioning them in angular & internal position on the shaft.

Sr. No.	Unbalanced (Wr. Product)
1.	74.
2.	71.
3.	70
4.	76.

Distance between each block is 3 Cm. The arrangement is as shown in fig.



(Planes 4 & 1 are unbalanced planes and 3 & 3 are balancing planes)

First of all assume that reference plane is 3. Then find out the couples for blocks

4, 1 & 2 W.R.T. 3 & then draw couple polygon

Plane	Wr.	Dist From No - 3	Couple
3.	70	0.	0.
4.	76.	3.	228.
1.	74.	6.	444.
2.	71.	9.	639.

Block No. is assumed in horizontal Position.

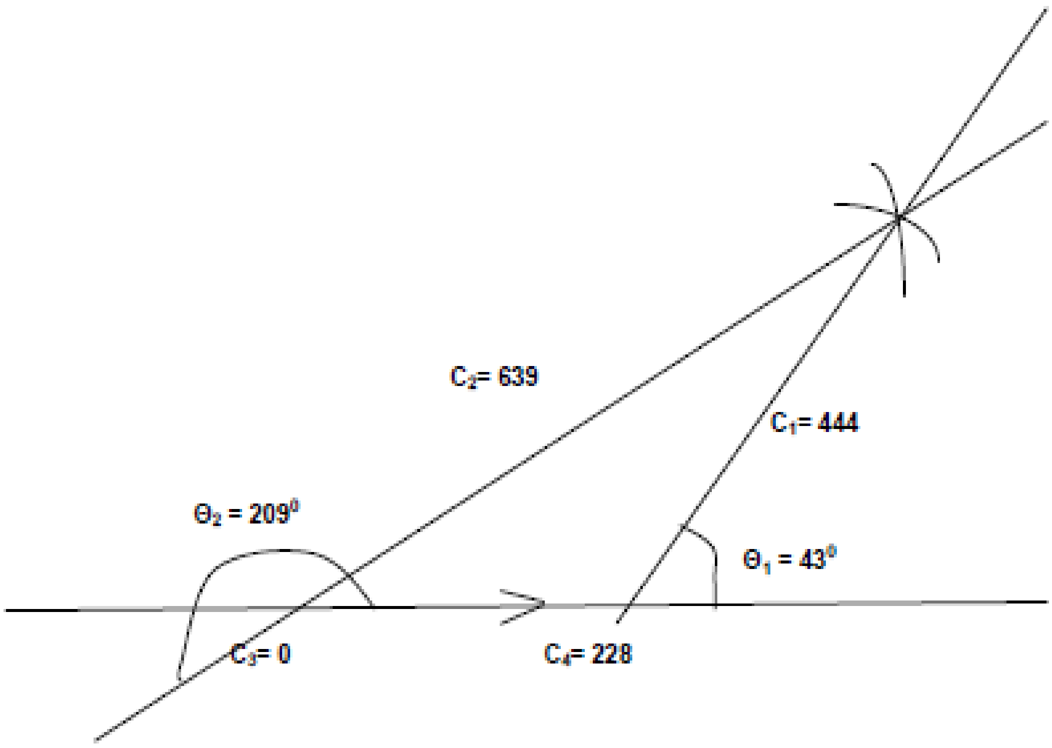
Angular position 1 & 2 No. of blocks is obtained from the couple polygon Wr. to block

Angular position of No. 3 block is obtained from the force polygon & its magnitude is also obtained F3 = 70. Adjust all angular & lateral position properly & find that the shaft rotates without producing any vibrations

Draw couple polygon assumed Block No.4 in Horizontal Position

COUPLE POLYGON

SCALE : 1 CM : 100 COUPLE



Angular Position of Block No.1 : $\Theta_1 = 43^0$

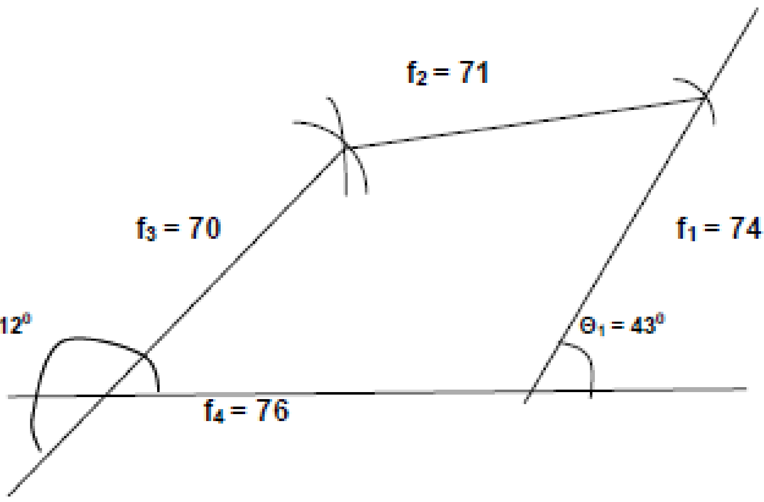
Angular Position of Block No.2 : $\Theta_2 = 209^0$

Angular Position of Block No.4 : $\Theta_4 = 0$

Angular position of No.3 block is obtained from the force polygon

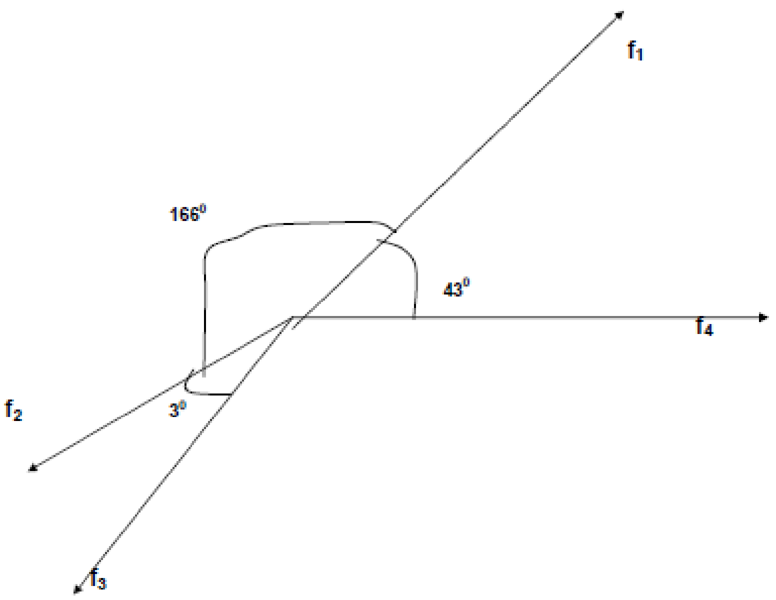
FORCE POLYGON

Scale : 1 cm : 20 force.



Angular Position of Block No.3 : $\Theta_3 = 212^0$

REPRESENTATION OF FORCE



Adjust all angular and lateral position properly and find that the shaft rotates without producing any vibrations.

PRACTICAL: 04

BALANCING OF V ENGINE

PRACTICAL: 05

TO STUDY ABOUT DIFFERENT VIBRATION MEASURING INSTRUMENTS

QUIZ

1. Why the measurement of vibration is necessary?
2. Classify the vibration measuring instrument.
3. Explain the working principal of (i) Vibrometer (ii) Velocity Pick ups (iii) Accelerometer\
4. What are the various types of frequency measuring instrument?
5. What is FFT? Explain with block diagram and FFT analyzer.
6. What do you mean conditioning monitoring of machines? What are the various monitoring conditioning technique?
7. What are the various instrumentation system used for conditioning monitoring?

PRACTICAL: 06

TO DETERMINE THE CRITICAL SPEED OF THE SHAFT (WHIRLING OF SHAFT) WITH DIFFERENT END CONDITION AND TO COMPARE THE VALUE WITH THEORETICAL CALCULATION.

DESCRIPTION OF THE APPARATUS:

This Apparatus is special product of DATACONE EQUIPMENTS developed for the study of whirling phenomenon. The Shaft can be tested for different end connections.

The Apparatus consists of a frame support its driving motor, & fixing & sliding blocks, etc. A special design is provided to clear out the effects of bearings of motor spindle from those of testing shafts. The special design features of this equipment are as follows :

A. KINEMATIC COUPLING (C).

This coupling is specially designed to eliminate the effect of motor spindle bearings on those of the rotating shafts.

B. BALL BEARING FIXING ENDS (M & N):

These ends fix the shafts while it rotates. The shaft can be replaced within a short tome with the help of this unit. The fixing condition of the rotating shaft as per the requirement.

SHAFT SUPPLIED WITH THE EQUIPMENT :

Polished bar steel bar shafts are supplied with the machine, the dimensions begin, as under :

SHAFT NO	Dia. IN (Approx)	LENGTH IN (Approx)
1	3/16” i.e 0.47 cms	44” i.e 112.0 cms
2	1/4” i.e 0.64 cms	44” i.e 112.0 cms
3	5/16” i.e 0.79 cms	44” i.e 112.0 cms

END FIXING ARRANGEMENT:

At motor end as well as tail end different end conditions can be developed by making use of different fixing blocks.

1. Supported end condition : Make use of end block with single self aligning bearing.

2. Fixed end condition : Make use of end block with double bearing.

GUARDS D1 & D2 :

The guard D1 & D2 can be fixed at any position on the supporting bar frame which fits on side supports F. Rotating shafts are to be fitted in blocks in A & B stands.

SPEED CONTROL OF DRIVING MOTOR :

The driving motor is Permanent Magnet, 180 V, DC, 1/6 HP, 5500 RPM, 50 c/s motor, & Speed Control unit is a dimmerstat of 180 V, 2 Amps, 50 c/s.

MEASUREMENT OF SPEED :

To measure the speed of the rotating shaft a simple tachometer may be used (will not be supplied with the equipment) by removing the bearing cover the opposite side of the shaft extension of the motor.

WHIRLING OF ELASTIC SHAFTS :

If L = Length of the shaft in cms.

E = Young's Modules Kg/cm^2 .

I = 2 nd moment of inertia of the shaft cm^4 .

W = Weight of the shaft per unit length Kg/cm.

g = Acceleration due to gravity in cms/sec^2 = 981

Then the frequency of vibration for the various modes given by the equation :

$$f = k \times \sqrt{\frac{E.I.g}{W.L^4}}$$

The various values for K are given below :

End Condition	Value of K	
	1 Mode	2 Mode
Supported, supported	1.57	6.28
Fixed, Supported	2.45	9.80
Fixed, Fixed	3.56	14.24

Shaft Dia	I = CM^4	W = Kg/Cm
3/16 " = 0.47 cm	25.39 x 10 $^{-4}$	0.15 x 10 $^{-2}$
1/4 " = 0.64 cm	79.91 x 10^{-4}	0.28 x 10 $^{-2}$
5/16" = 0.79 cm	194.78 x 10^{-4}	0.424 x 10^{-2}
1/8 " = 0.3175	4.9879 x 10^{-4}	566 x10^{-3} Kg/cm

PRECAUTIONS TO BE OBSERVED IN EXPERIMENTS :

1. If the revolutions of an unloaded shaft are gradually increased it will be found that a certain speed will be reached at which violent instability will occur, the shaft deflecting into a single bow & whirling round like a skipping rope. If this speed is maintained the deflection will become so large that the shaft will be fractured, but if this speed is quickly run through the shaft will become straight again & run true until at another higher speed the same phenomenon will occur, the deflection now however, being in a double bow & so on. Such speeds are called critical speeds of whirling.

2. It is advisable to increase the speed of shaft rapidly & pass through the critical speeds first rather than observing the first critical speed which increases the speed of rotation slowly. In this process there is a possibility the amplitude of vibration will increase suddenly bringing the failure of the shaft. If, however, the shaft speed is taken to maximum first end than slowly reduced, (thus not allowing time build up the amplitude of vibration as response) higher mode will be observed first & the corresponding speed noted & then by reducing the speed further the next mode of lower frequency can be observed without any danger of rise in amplitude as the speed is being decreased & the inertia forces are smaller in compression with the bending spring forces hence possibility of build-up of dangerous amplitude at resonance or near resonance is avoided.

3. Thus it can be seen that it is a destructive test of shafts & it is observed that the elastic behavior of the shaft material changes a little after testing it for a few times & it is advisable therefore, to use fresh shaft samples afterwards.

4. Fix the apparatus firmly on the suitable foundation.

TYPICAL TEST OBSERVATION :

a. Both ends of shaft free (supported) first & second mode of vibration can be observed on shafts with 3/16 " dia & 1/4 " dia.

b. One end of shaft fixed & the other free, first & second mode of vibration can be observed on shaft with 3/16" dia.

c. Both ends of shaft fixed second mode of vibration cannot be observed on any of the shafts as the speeds are very high & hence beyond the range of the apparatus.

d. There is difference between theoretical speed of whirling & actual speed observed, due to following reasons:

1.The end conditions are not so exact as assumed in theory. **2**.Pressure of damping at the end bearings. **3**.Assumptions made in theoretical predications. **4**.Lack of knowledge of exact properties of shaft material. **5**.A Uniformly loaded shaft has, theoretically infinite no. of natural frequencies to transverse vibration for fundamental mode observations of the first mode of whirling is therefore, not so defined & thus difficult, second mode can be very easily observed

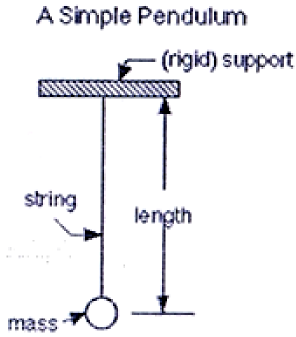
PRACTICAL: 07

TO FIND THE NATURAL FREQUENCY OF DIFFERENT SYSTEM

1. Simple pendulum
2. Spring and mass system
3. U-tube manometer

1. Simple pendulum

Theoretical formulas



$$T = 2\pi\sqrt{\frac{l}{g}}$$

$$f = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$$

$$Wn = 2\pi \times f = \sqrt{\frac{g}{l}}$$

Where l = length of string

m = mass of ball

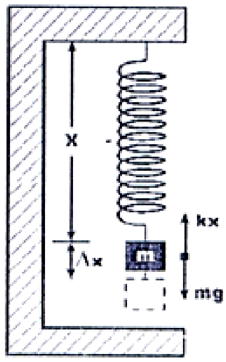
g = gravitational acceleration (9.81 m/s^2)

Observation Table

Sr.No.	Length of String (mm)	Time for 10 oscillation (sec)
1		
2		
3		
4		
5		

2. Spring and mass system

Theoretical Formulas



$$T = 2\pi\sqrt{\frac{m}{k}}$$

$$f = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

$$Wn = 2\pi \times f = \sqrt{\frac{k}{m}}$$

Where k = Spring Stiffness

m = mass of block connected

Observation Table:-

Sr. No.	String stiffness k (g/mm)	Mass attached m (gram)	Time for 10 oscillation (sec)
1			
2			
3			
4			
5			

3. U-Tube Manometer

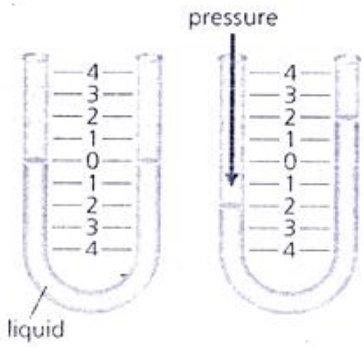
Theoretical formulas

$$T = 2\pi\sqrt{\frac{l}{2g}}$$

Where l = liquid column length

$$f = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{2g}{l}}$$

$$Wn = 2\pi \times f = \sqrt{\frac{2g}{l}}$$



Observation table

Sr.No.	Length of Water column (m)	Time for 10 oscillation (sec)
1		
2		
3		
4		

Result table

Sr.No.	System	Time for 1 oscillation		Frequency (f) Hz	Natural Frequency (Wn) theoretical	Natural Frequency (Wn) experimental
1	Simple Pendulum	1				
		2				
		3				
2	Spring Mass system	1				
		2				
		3				
3	U-Tube Manometer	1				
		2				
		3				

CALCULATION:-

PRACTICAL: 08

UNIVERSAL VIBRATION APPARATUS

TUTORIAL 1

TUTORIAL 2