Department of Mechanical and Mechatronics Engineering

Academic Year (2017-2018)

Theory of Machines

Laboratory

Third Year Class

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University of Salahaddin-Hawler **Theory of Machines Laboratory**

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Experiment Number: - 1

Experiment Name: - Scotch Yoke Mechanism

Purpose of the Experiment

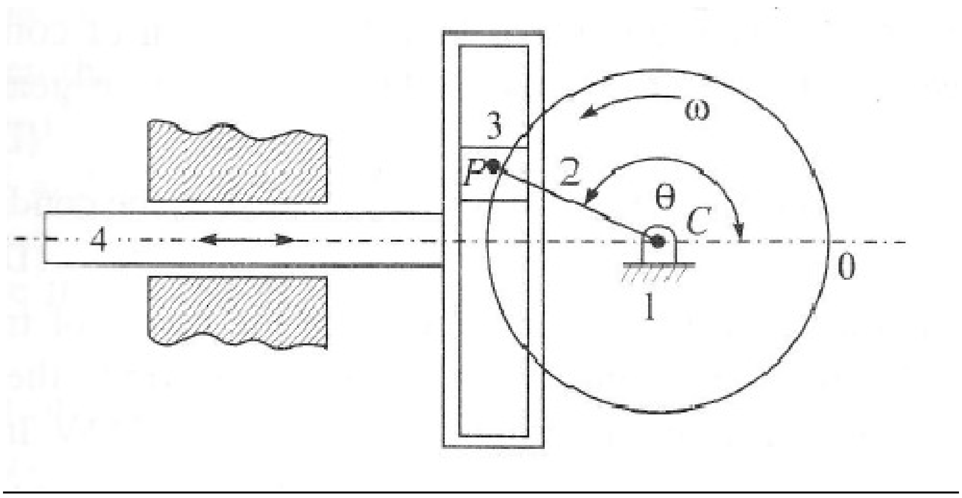
1. To demonstrate the actions of a simple crank driven scotch yoke mechanism.
2. To determine graphically the relationship between the linear displacements of the scotch yoke and the angular displacements of the crank.
3. Calculate the velocity and the acceleration.

Introduction

* When one of the links of a kinematic chain is fixed, the chain is known as **mechanism**.
* Periodic motion is any motion that repeats itself at equal intervals of time. The simplest form of periodic motion is **harmonic motion** represented by circular functions like (sine or cosine). All harmonic motion is periodic.

Pure simple harmonic motion is produced by the Scotch yoke mechanism when it is driven by an acceleration crank.

A **Scotch yoke mechanism** consists of **two revolute** and **two sliding pairs** that can be used to transform uniform rotary motion (rotation of **crank 2**) into linear motion (harmonic translatory motion of **yoke 4**).
Figure below shows a ***Scotch yoke mechanism***. Measuring the angles of rotation θ of the **crank 2** with respect to radius **r (Cp),** and the displacement of the yoke with respect to centre fixed point **C**.



The following equations are used to calculate the displacement, velocity and acceleration of the Scotch Yoke mechanism: -

For displacement;

$x = r\,(1 - \cos\theta)$ - - - - - - - (1)

For Velocity:

$\upsilon = r\,\omega\,\sin\theta$ - - - - - - - - (2)

where r =25 mm and take ω= 100 rad/sec

For acceleration;

$A = r\,\omega^2\cos\theta$ - - - - - - - - (3)

Results of calculations can be tabulated in the following table;

Angle (θ) (degree	Displacement (x) Practical (mm)	Displacement (x) Theoretical (mm)	Velocity (υ) (mm / sec)	Acceleration (f) (mm / sec^2)
0				
30				
60				
90				
120				
150				
180				
210				
240				
270				
300				
330				
360				

From the results tabulated in the above table, draw 3 graphs showing the relationship between the angle of rotation θ on the X-axis and (1. Displacement (theoretical and practical), 2. Velocity, 3. Acceleration) on the Y-axis.

Discussion:

1. Discuss the 3 graphs obtained from the results?
2. Is there any difference between the calculated results and experimental results for displacement? if Yes mention the reason?
3. List the application of the Scotch yoke mechanism?

<u>Experiment Number</u>: - 2

<u>Experiment Name</u>: - Single Slider-Crank Mechanism

<u>Objects of the Experiment</u>: -

1. To perform a complete kinematic analysis of the single slider crank mechanism by analytical method.
2. To calculate the displacement, velocity and acceleration of the piston.
3. To compare between piston displacements theoretically and practically.

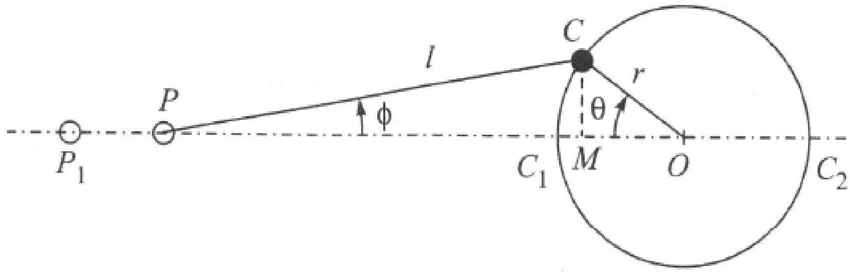
<u>Theory</u>: -

This mechanism consists of one sliding pair and three turning pairs. It is also considered as the modification of basic four bar chain. It is used to convert reciprocating motion into rotary motion and vice versa. It is widely employed in internal combustion engines as well as in pumps and compressors.

In the design of mechanical system, a designer must have thorough understanding of ***kinematics of mechanism***. Kinematics is the study of *displacement, rotation, speed, velocity* and *acceleration* of each link at various positions during the operating cycle. Using this information, a designer can compute forces and thereby dimensions of all links.

The ***kinematic analysis of the mechanism*** can be performed either by ***graphical method*** or by ***analytical method***. Kinematics analysis of single slider crank mechanism helps to answer many questions regarding to the motions of various links of the mechanisms like connecting rod and piston.

Figure below shows schematic sketch of single slider crank mechanism.



Let: -

r = crank radius

ω = angular velocity of the crank

l = length of the connecting rod

n = (l / r) = ratio of connecting rod length to crank radius

θ = angle of inclination of the crank to the inner dead center

ϕ = angle of inclination of the connecting rod to the line of stroke

x = pp_1= displacement of the piston from the commencement of its stroke

Vp = velocity of the piston

Ap = acceleration of the piston

From the above geometry, the following equations can be derived: -

$$x = r\left[(1-\cos\theta) + \frac{\sin^2\theta}{2\,n}\right] ------ (1)$$

$$Vp = r\,\omega\left[\sin\theta + \frac{\sin 2\theta}{2\,n}\right] ------ (2)$$

$$Ap = r\,\omega^2\left[\cos\theta + \frac{\cos 2\theta}{2\,n}\right] ------ (3)$$

<u>Procedure</u>: -

1. From the basic principles and by using the figure above, derive the 3 equations mentioned above which are necessary to calculate the displacement, velocity and the acceleration of the piston.

2. Construct the table shown below, and then record the displacement of the piston (practically) for 10 magnitudes of θ in degrees. After that, determine the displacement, velocity and the acceleration of the piston (theoretically) for the same angles used.

3. Plot the required relationships.

θ (degree)	x practical (mm)	x theoretical (mm)	Vp (mm/sec)	Ap (mm/sec^2)

Experiment Number: - 3

Experiment Name: - Belt or Rope Friction

Objects of the Experiment: -

1. To determine the ratio of belt tensions of each side of the pulley for 180° angle of contact.
2. To calculate the coefficients of friction between the belt and the pulley for different angles of contact.

Introduction: -

A belt or rope drive is frequently used whenever power has to be transmitted from one shaft to another, which are at a considerable distance apart. Pulleys are mounted on the shaft and a continuous belt or rope is passed over them. The transmission of power from one shaft to another is through ***friction*** between belt and pulleys. Belts are usually made from ***leather***, ***rubber*** or ***fabric***. Also there are many types of belts use for power transmission, such as ***flat belt***, ***V belt*** and ***rope*** (circular belt).

Theory: -

One of the most important belt drives is an ***open belt drive*** which consists of 2 pulleys as shown in figure below. The pulley which is keyed to the rotating shaft is known as ***driver pulley***, whereas the pulley which is keyed to the shaft to be rotated is known as ***driven pulley***. The driver pulley A in figure is rotating in clockwise direction in which the belt on the lower section is stretched more than the belt on the top section. Thus, the belt on the lower section is called ***tight side*** and that on the top section is termed as ***slack side***.

The ratio of tensions in belt may be written as follows: -

1. For ***flat belt***:

$$\ln\left(\frac{T_1}{T_2}\right) = \mu \, . \, \theta$$

2. For ***V- belt*** or ***Rope***:

$$\ln\left(\frac{T_1}{T_2}\right) = \frac{\mu \, . \theta}{\sin \alpha}$$

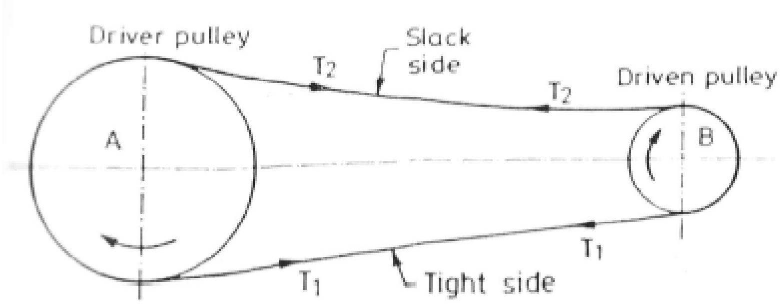
where: T_1 = tension on tight side of the belt.

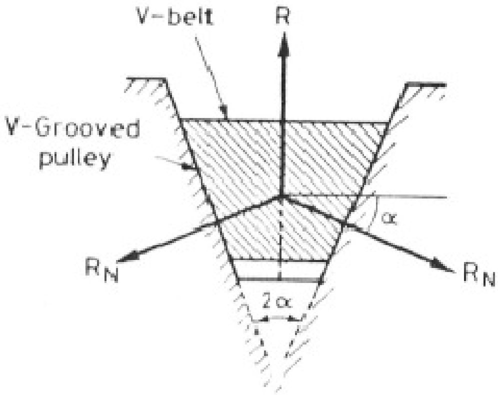
T_2 = tension on slack side of the belt.

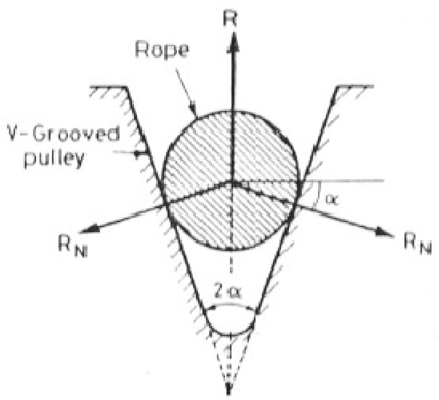
θ = angle of contact of belt with the pulley.

μ = coefficient of friction between the belt and the pulley.

2α = angle of groove.







Procedure: -

1. Construct the table below to determine the belt tensions of each side of the pulley for 180º angle of contact, then calculate the average coefficient of friction.

T_1 (N)								
T_2 (N)								
μ								

2. Repeat the above procedure for different angles of contact.

3. Plot the values of T_1 against T_2 on a graph to verify linear proportionality. The gradient of the best fit straight line gives the ratio of T_1 / T_2 from which a value for μ can be derived since $\alpha = 20^o$ and $\theta = \pi$.

Experiment Number: - 4

Experiment Name: - Relationship between Angular and Linear Speeds

Objects of the Experiment: -

1. To calculate the linear speeds of different diameters of the stepped shaft.
2. To find the relationship between angular rotation and peripheral movement of the stepped shaft and to compare it with theory.

Theory: -

Linear Speed (υ) may be defined as the rate of change of linear displacement (S) of a body with respect to time (t) . Since the speed is irrespective of its direction therefore, it is a scalar quantity. Mathematically, linear speed equals: -

$$\upsilon = \frac{S}{t} \qquad ------ \quad (1)$$

Angular Speed (ω) may be defined as the rate of change of angular displacement (θ) of a body with respect to time (t), when the direction of the angular displacement is constant. It is also a scalar quantity. Mathematically, angular speed equals: -

$$\omega = \frac{\theta}{t} \qquad ------ \quad (2)$$

Also if a body is rotating at the rate of (***N***)revolutions per minute, the its angular speed equals: -

$$\omega = \frac{2\,\pi\,N}{60} \qquad ------ \quad (3)$$

The relationship between the linear and angular speeds is

$$\upsilon = \omega . r \qquad ------ \quad (4)$$

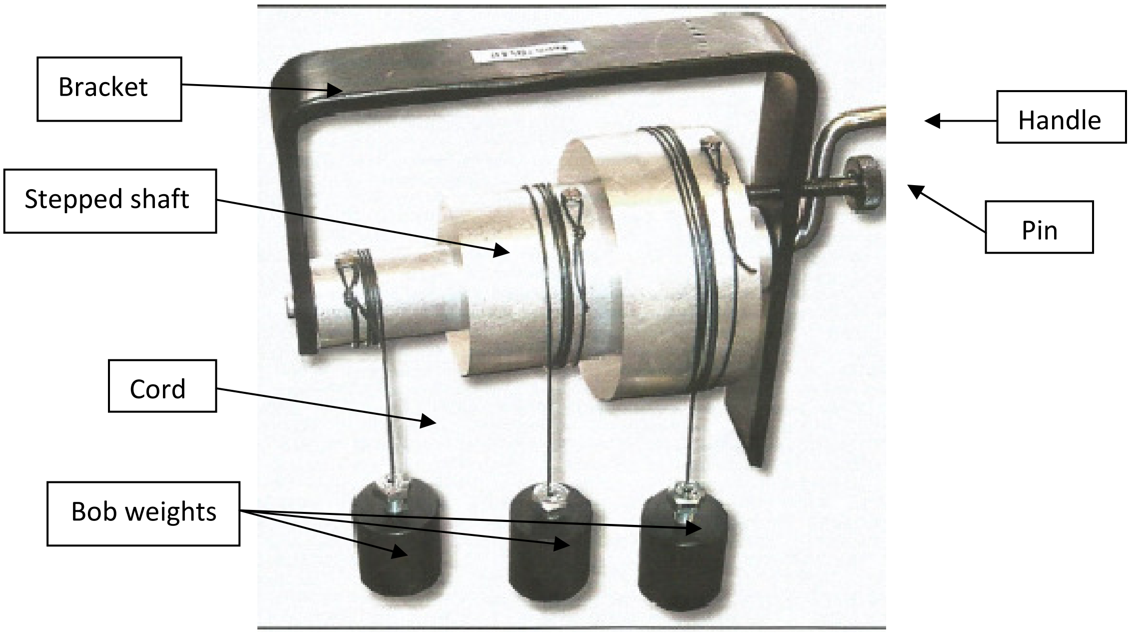
where r is the radius of the rotating element.

Apparatus Description: -

A stepped Aluminum shaft with 3 diameters of (D1 = 70 mm, D2 = 48 mm and D3 = 25 mm) is carried out in bracket which can be screwed in a

wall. Three adjustable bobs with cords are supplied enabling the starting heights of each bob to be made equal or unequal.
The shaft is rotating by a handle which can be locked by a retaining pin. The angular movement of the shaft and the corresponding linear movement of the weights can be compared.

Figure below shows the angular and linear speeds apparatus.



Experimental Procedure: -

1. Measure the length of the three cords for the three diameters of the stepped shaft by using a measure tape.
2. Hang same suitable weights (for example, 1kg) on each cord.
3. Release the pin from its position and let the bob weights go down freely.
4. Use the stopwatch to record the time for each diameter. Then, calculate the linear speed for each of them. This step needs to be repeated more than once until adequate accuracy is reached.
5. Increase the weights for all three cords and then repeat steps **3** and **4**.
6. The results obtained can be tabulated as follows: -

D1 = 70 mm , **D2 = 48 mm** and **D3 = 25 mm**

Weight kg	**Distance** (mm)	**Time (sec)**	**Linear Speed** (mm/sec)	**Angular speed** (rad/sec)	**Rotational speed** ***N*** (rpm)
1	L1 =				
1	L2=				
1	L3=				
1.5	L1=				
1.5	L2=				
1.5	L3=				

2					

<u>Results and Discussion</u>

1.Plot the required graphs which show the relationship between angular and linear speeds.

2. Discuss the obtained graphs and explain the effect of increasing weight on linear and angular speeds.

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Experiment Number: - 5

Experiment Name: - Gear Trains

Objects of the Experiment: -

1. To determine the velocity ratio of different gear trains.

Introduction: -

The ***gear*** is defined as *a toothed element which is used for transmitting rotary motion from one shaft to another.* Gears are means of changing the rotational speed of a machinery shaft. They can also change the direction of the axis of motion and can change rotary motion into linear motion. If the distance between the two shafts is very small, then gears are used to transmit motion from one shaft to another. In gear drive there is no slip or creep which reduces velocity ratio, therefore it is considered as a positive and smooth drive which transmits almost exact velocity ratio.

A *combination of two or more gears*, which are *arranged in such a way that power is transmitted from a driving shaft to a driven shaft*, is known as ***gear* train**. The gear train may consist of *spur*, *bevel* or *spiral* gears. Gear trains can be classified as; (i) simple gear train, (ii) compound gear train, (iii) reverted gear train and (iv) epicyclic gear train.

Theory: -

Figure (1) shows a **reverted gear train** in which driver and driven shafts are having their axes collinear. The gear 1 is mounted on the driver shaft whereas gear 4 is mounted on driven shaft. The gears 2 and 3 are on the intermediate shaft and this is a compound wheel. From the geometry of figure 1, it is seen that: -

$$r1 + r2 = r3 + r4 \quad ----- (1)$$

where r_1 = Radius of gear 1.

and r_2, r_3 and r_4 = Radii of gears 2,3 and 4 respectively.

If the module of all the gears is assumed to be the same, then number of teeth on each wheel will be proportional to its radius. Hence equation (1) can be written as: -

$$T1 + T2 = T3 + T4 \quad ----- (2)$$

where T_1 = No. of teeth on gear 1.

T_2 , T_3 and T_4 = No. of teeth on gear 2, 3 and 4 respectively.

The velocity ratio is given by;

$$\frac{N4}{N1} = \frac{T1 \times T3}{T2 \times T4} \quad \text{- - - - - (3)}$$

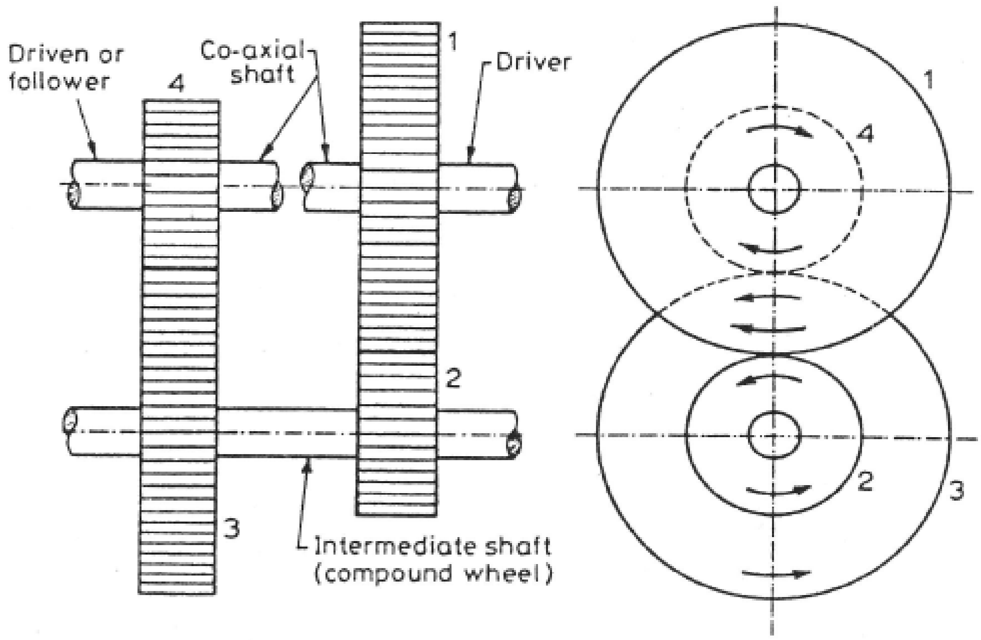


Fig. 10.11

In an ordinary type of gear train, the gears turn about fixed axes, but in an epicyclic gear train, at least on axis moves. An epicyclic gear train shown in **figure (2)**, where the planet (P) meshes with an internally toothed or Annular wheel (A) in addition to meshing with the sun (S).

In practice there may be two, three or more planets arranged round the sun at equiangular intervals to reduce the loads on teeth and to balance the radial force. The velocity ratio is defined as the ratio of the speeds of the last and first wheels or shafts.

Procedure: -

(I) For a reverted gear train apparatus: -

Read the number printed on each gear of the apparatus and then write it down. After that calculate the velocity ratio considering the apparatus as simple gear train first. Then find the velocity ratio of the reverted gear apparatus.

(11) For two speed epicyclic gear train apparatus: -

In order to calculate the first velocity ratio of the apparatus, fix the left annular wheel (A) by inserting the pin inside the hole on the circumference of the left annular wheel then,

1. Dial the input scale (shaft) until the pointer comes to zero degree, then record the angle on the output scale (shaft).

2. Rotate the input scale one complete revolution (from 0º to 360º) anti-clockwise and record the angle on the output scale.

3. Find the difference between the two consecutive readings recorded from the output scale.

4. Repeat steps 2 and 3 (5 to 6 times) *increasing the number of turns in each time* to make sure that the correct ratio is obtained.

5. Calculate the velocity ratio of the apparatus for this condition by using the following equation: -

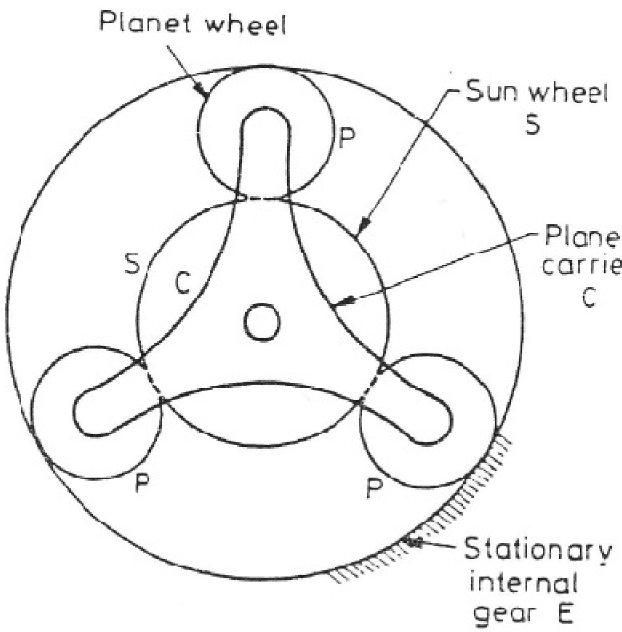
$$velocity\ ratio = \frac{output\ number\ of\ rotation}{input\ number\ of\ rotation}$$

6. Now release the left annular wheel and fix the right annular wheel by inserting the pin inside the circumferential hole.

7. In order to determine the velocity ratio of the apparatus in this condition, repeat steps 1, 2, 3, 4 and 5.

Discussion

Discuss the advantages and disadvantages (if any) of using epicyclic gear train compared to other types of gear trains, also mention some examples of the use of such train.


Planet wheel
Sun wheel
S
P
Planet
carrier
C
S
C
P
P
Stationary
internal
gear E
Fig. 10.25