Pearson BTEC Level 4 Higher Nationals in Engineering (RQF)

Unit 30: Operations and Plant Management

Unit Workbook 2

in a series of 4 for this unit

Learning Outcome 2

Power Transmissions Systems

Contents

GUIDANCE

This document is prepared to break the unit material down into bite size chunks. You will see the learning outcomes above treated in their own sections. Therein you will encounter the following structures;

Purpose Explains *why* you need to study the current section of material. Quite often learners are put off by material which does not initially seem to be relevant to a topic or profession. Once you understand the importance of new learning or theory you will embrace the concepts more readily.

Theory Conveys new material to you in a straightforward fashion. To support the treatments in this section you are strongly advised to follow the given hyperlinks, which may be useful documents or applications on the web.

Example The examples/worked examples are presented in a knowledge-building order. Make sure you follow them all through. If you are feeling confident then you might like to treat an example as a question, in which case cover it up and have a go yourself. Many of the examples given resemble assignment questions which will come your way, so follow them through diligently.

Question Questions should not be avoided if you are determined to learn. Please do take the time to tackle each of the given questions, in the order in which they are presented. The order is important, as further knowledge and confidence is built upon previous knowledge and confidence. As an Online Learner it is important that the answers to questions are immediately available to you. Contact your Unit Tutor if you need help.

Challenge You can really cement your new knowledge by undertaking the challenges. A challenge could be to download software and perform an exercise. An alternative challenge might involve a practical activity or other form of research.

Video Videos on the web can be very useful supplements to your distance learning efforts. Wherever an online video(s) will help you then it will be hyperlinked at the appropriate point.

3. Friction Clutches

Purpose

Understand flat single and multi-plate clutches; conical clutches; coefficient of friction; spring force requirements; maximum power transmitted by constant wear and constant pressure theories; validity of theories

Theory Revision

Consider the friction clutch shown in Figure 2.

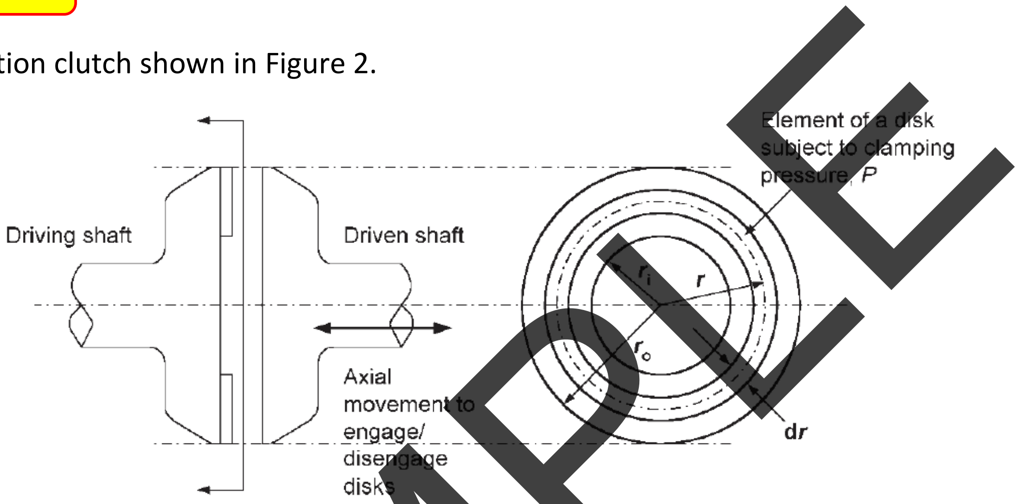

Figure 2 A basic friction clutch

The total number of discs required (N) on a multiple-plate clutch is given by Eq.9:

$$N = \frac{T}{\pi r_i p_{max} \mu (r_o^2 - r_i^2)} \qquad \text{(Eq.9)}$$

where:

- N number of clutch discs required (rounded up to nearest integer)
- T transmitted torque
- p_{max} maximum allowable pressure for the friction surface
- μ coefficient of friction between rubbing surfaces
- r_o external radius of friction plate
- r_i internal radius of friction plate

The axial clamping force (W) is given by Eq.10:

$$W = \frac{2T}{\mu N (r_o - r_i)} \qquad \text{(Eq.10)}$$

4. Gear Trains

Purpose

Understand compound and epicycle gear trains; velocity ratios; torque, speed and power relationships; efficiency; fixing torques

4.1 Simple Gear Trains

A simple gear train is used to transmit rotary motion and can change both the magnitude and the line of action of a force, hence is a simple machine. The gear train shown in Figure 3 consists of spur gears and has an effort applied to one gear, called the driver, and a load applied to the other gear, called the follower.

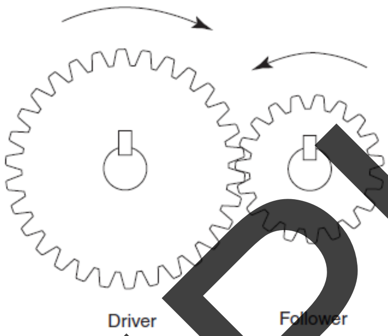

Figure 3 Simple Spur Gears

In such a system, the teeth on the wheels are so spaced that they exactly fill the circumference with a whole number of identical teeth, and the teeth on the driver and follower mesh without interference. Under these conditions, the number of teeth on the driver and follower (N_1 and N_2, respectively) are in direct proportion to the radii of these wheels, (see Eq.11).

$$\frac{N_1}{N_2} = \frac{r_1}{r_2} \qquad \text{(Eq.11)}$$

When the same direction of rotation is required on both the driver and the follower an idler wheel is used as shown in Figure 4.

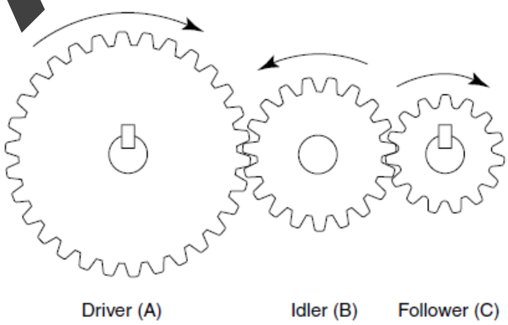

Figure 4 Simple Gear Train with Idler Wheel

Worked Example 4

Consider the compound gear train given in Figure 6

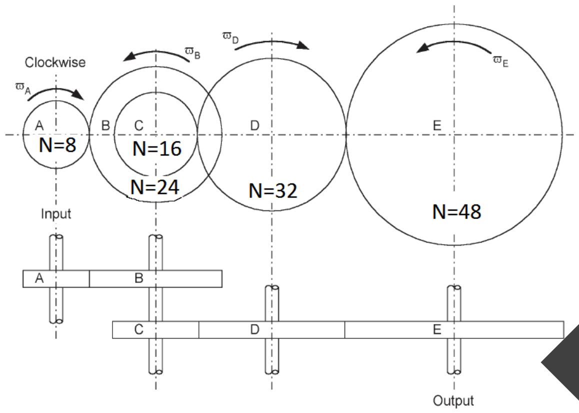

Figure 6 An example compound gear train (Worked Example 4)

The system consists of five gears, two of which, gears B and C, are on the same shaft. If gear A drives the system at 300 rpm (clockwise) and the number of teeth (N) on each gear are as shown, determine;

a) The angular velocity of output gear E.
b) The system gear ratio.

ANSWERS

a) The angular velocity of output gear E is given by:

$$\omega_E = \frac{N_A N_C}{N_B N_E}\omega_A = \frac{(8)(16)}{(24)(48)}(300) = \mathbf{33.\dot{3}\ rpm}$$

b) The gear ratio (G) is given by:

$$G = \frac{\omega_A}{\omega_E} = \frac{300}{33.\dot{3}} = \mathbf{9}$$

Worked Example 5

A gear box has an input speed of 1500 rpm clockwise and an output speed of 300 rpm anti-clockwise. The input power is 20 kW and the efficiency is 70%. Determine the following:

c) The gear ratio
d) The input torque.
e) The output power.
f) The output torque.
g) The holding torque.

ANSWERS

a) The sequence of operations needed to find the output shaft rpm are most easily described by using Table 1

Table 1: Output shaft rpm calculations

Steps Needed	Sun	Link	Ring
Rotate all parts by 'a' revolutions	**+a**	**+a**	**+a**
Hold the link steady and turn the Sun by '+b' revolutions	**+b**	**0**	$-b\left(\frac{t_{\text{sun}}}{t_{\text{planet}}} \cdot \frac{t_{\text{planet}}}{t_{ring}}\right)$ $= -b\left(\frac{t_{\text{sun}}}{t_{ring}}\right)$ $= -b\left(\frac{60}{100}\right)$ $= \mathbf{-0.6\,b}$
Add	a + b	a	$a - 0.6\,b$
Real	1000	rpm for the link is calculated below.	0 (fixed)

Video 2

The URL below explains the steps to create the calculations used in Table 1

https://www.youtube.com/watch?v=XaBLGdNxQYY

Calculating the link rpm:

From the sun column:

$$a + b = 1000 \qquad [1]$$

From the ring column:

$$a - 0.6\,b = 0$$

Rearranging Eq.13 gives:

$$b = \frac{a}{0.6} \qquad [2]$$

Substitute [2] into [1]:

$$a + b = 1000$$

$$\therefore \quad a + \frac{a}{0.6} = 1000$$

5.2 Simple Screw-Jacks

A Screw-jack is a device used for lifting heavy weights or loads with the help of a small effort applied at its handle. The followings are two types of screw-jack:

- Simple screw-jack, and
- Differential screw-jack.

This workbook will only consider the simple screw jack. Figure shows the simple screw jack, which consist of a nut, a screw the square threads and a handle fitted to the head of the screw. The nut also forms the body of the jack. The load to be lifted is placed on the head of the screw. At the end of the handle, fitted to the screw head, an effort P is applied in the horizontal direction to lift the load W. The screw-jack works on the same principle on which an inclined plane works.

The following parameters are defined:

W is the weight placed on screw head,

P is the effort applied at the end of the handle

L is the length of handle,

p is the pitch of the screw,

d is the mean diameter of the screw,

α is the angle of the screw or helix angle,

ϕ = Angle of friction,

μ is the coefficient of friction between screw and nut (which is also $\tan\Phi$)

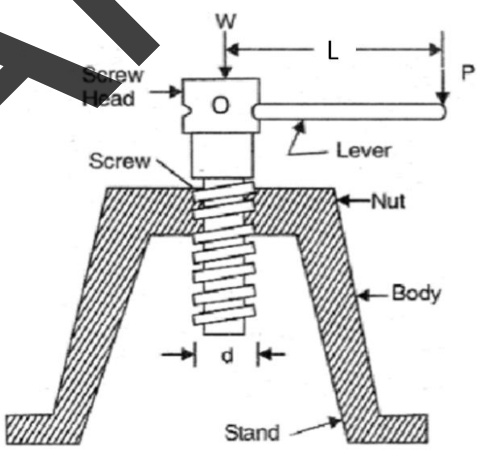

Figure 9 Simple Screw-Jack

When the handle is rotated through one complete turn, the screw is also rotated through one turn. Then the load is lifted by a height p (pitch of screw).

Resolving forces normal to the plane and substituting for R, we get;

$$P' = W\,\frac{\sin(\varphi - \alpha)}{\cos(\varphi - \alpha)} = W\ \tan(\varphi - \alpha) \qquad \text{(Eq.20)}$$

If $\alpha > \alpha$ then:

$$P' = W\ \tan(\alpha - \varphi) \qquad \text{(Eq. 20)}$$

But P' is the effort applied at the mean radius of the screw-jack. In reality, the effort is applied at the handle of the jack. Let the effort applied at the handle be P. Equating the moments of P and P' about the axis of the jack we get:

$$P \times L = P' \times \frac{d}{2}$$

Giving:

$$P = \frac{d}{2L} \times P = \frac{Wd}{2L} \times W\ \tan(\varphi - \alpha) \qquad \text{(Eq. 21)}$$

Expression for P in terms of the coefficient of friction and the pitch of the screw.

From Equation (Eq. 21);

$$P = \frac{Wd}{2L} \times W\tan(\varphi - \alpha) = \frac{Wd}{2L} \times \frac{\tan\varphi\ - \tan\alpha}{1 - \tan\varphi\ \times \tan\alpha}$$

Giving:

$$P = \frac{Wd}{2L} \times \frac{(\mu\pi d - p)}{(\pi d + \mu p)} \qquad \text{(Eq. 22)}$$

Worked Example 7

a) Find the effort required to apply at the end of a handle, fitted to the screw head of a screw-jack to lift a load of 1500 N. The length of the handle is 70 cm. The mean diameter and the pitch of the screw-jack are 6 cm and 0.9 cm respectively. The coefficient of friction is given as 0.095.
b) If instead of raising the load of 1500 N, the same load is lowered, determine the effort required to apply at the end of the handle.

Given:

$$\mathrm{W} = 1500\mathrm{N}$$

$$\mathrm{L} = 70\ \mathrm{cm} = 0.7\mathrm{m}$$

$$\mu = 0.095$$

$$\mathrm{d} = 6\mathrm{cm} = 0.06\mathrm{m}$$

$$\mathrm{p} = 0.9\mathrm{cm} = 0.009\mathrm{m}$$

a) Effort (P) required at the end of the handle for raising the load (W), using Eq.20:

$$P = \frac{Wd}{2L} \times \frac{(p + \mu \pi d)}{(\pi d - \mu p)} = \frac{1500 \times 0.06}{2 \times 0.7} \times \left(\frac{(0.009) + (0.095 \times \pi \times 0.06)}{(\pi \times 0.06) - (0.095 \times 0.009)} \right) = \mathbf{8.64\ N}$$

b) The effort (P) required at the end of the handle for lowering the load (W) using Eq.22:

$$P = \frac{Wd}{2L} \times \frac{(\mu \pi d - p)}{(\pi d + \mu p)} = \frac{1500 \times 0.06}{2 \times 0.7} \times \left(\frac{(0.095 \times \pi \times 0.06) - 0.009}{(\pi \times 0.06) + (0.095 \times 0.009)} \right) = \mathbf{3.02N}$$

The only problem with this arrangement is that if the input rotates at a constant rate the output does not and speeds up and slows down during each revolution. It can be shown that if the angular velocity in is ω_1 and out is ω_2 the relationship is;

$$\frac{\omega 1}{\omega 2} = \frac{\cos \phi}{1 - \sin^2 \phi \cos^2 \theta} \qquad \text{(Eq.23)}$$

Where ø is the angle between the two axes and θ is the angle rotated by the input. This problem can be resolved if two joints are used as shown in Figure 9.

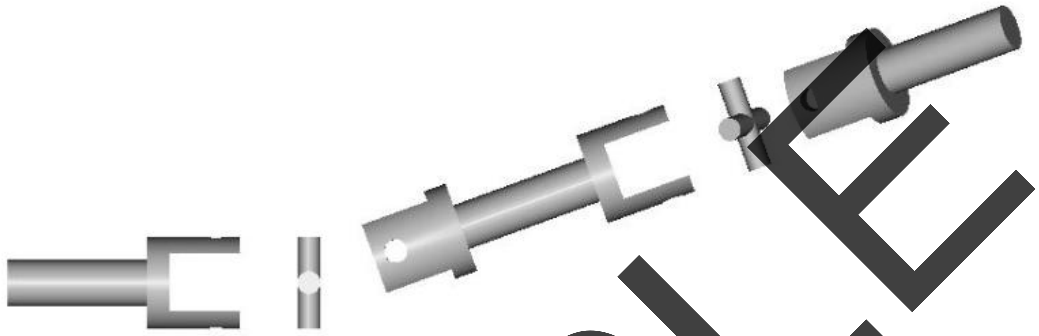

Figure 9 Constant Velocity Joint

This is called a constant velocity joint.

Worked Example 8

Find the greatest and smallest values of the velocity ratio of two shafts jointed with a universal coupling when the axes are at $45°$ to each other.

From Eq.23:

$$\frac{\omega 1}{\omega 2} = \frac{\cos \phi}{1 - \sin^2 \phi \cos^2 \theta}$$

So,

$$\frac{\omega_1}{\omega_2} = \frac{\cos(45)}{1 - \sin^2(45)\cos^2(\theta)} = \frac{\frac{\sqrt{2}}{2}}{1 - 0.5(\cos^2\theta)}$$

When $\cos(\theta) = 1$: $\quad \frac{\omega 1}{\omega 2} = \frac{2}{\sqrt{2}} \quad$ (Maximum)

When $\cos(\theta) = 0$: $\quad \frac{\omega 1}{\omega 2} = \frac{1}{\sqrt{2}} \quad$ (Minimum)