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.

# 1 Dynamics of Rotating Systems

## 1.1 Machines

A machine is a device that can change the magnitude or line of action, or both magnitude and line of action of a force. A simple machine usually amplifies an input force, called the effort, to give a larger output force, called the load. Some typical examples of simple machines include pulley systems, screw jacks, gear systems and lever systems.

The **force ratio** ($\mathrm{F_r}$) or **mechanical advantage** is defined as the ratio of load to effort, shown in Eq.1. Since both load and effort are measured in newtons, $\mathrm{F_r}$ is a dimension-less quantity.

$$\mathrm{F_r} = \mathrm{load/effort} \qquad \text{(Eq.1)}$$

The **movement ratio** or **velocity ratio** is defined as the ratio of the distance moved by the effort to the distance moved by the load, demonstrated by Eq.2. Since the numerator and denominator are both measured in metres, movement ratio is also a dimension-less quantity.

$$M_r = d_{\mathrm{effort}}/d_{\mathrm{load}} \qquad \text{(Eq.2)}$$

The **efficiency,** η, of a simple machine is defined as the ratio of the force ratio to the movement ratio. It is usually expressed as a percentage, shown in Eq.3:

$$\eta = (F_r/M_r) \times 100 \qquad \text{(Eq.3)}$$

**Worked Example 1**

A simple machine raises a load of 160 kg through a distance of 1.6 m. The effort applied to the machine is 200 N and moves through a distance of 16 m. Taking g as $9.8\mathrm{ms}^{-2}$, determine the force ratio, movement ratio and efficiency of the machine.

From Eq.1:

$$\mathrm{F_r} = \mathrm{load/effort} = (160 \times 9.8)/200 = 7.84$$

From Eq.2:

$$\mathrm{M_r} = \mathrm{d_{effort}/d_{load}} = 16/1.6 = 10$$

From Eq.3:

$$\eta = (\mathrm{F_r/M_r}) \times 100 = (7.84/10) \times 100 = 78.4\%$$

# 2. Belt Drive Dynamics

**Purpose**

Understand flat and v-section belts; limiting coefficient friction; limiting slack and tight side tensions; initial tension requirements; maximum power transmitted

**Theory Revision**

Consider the basic belt drive arrangement in Figure 1.

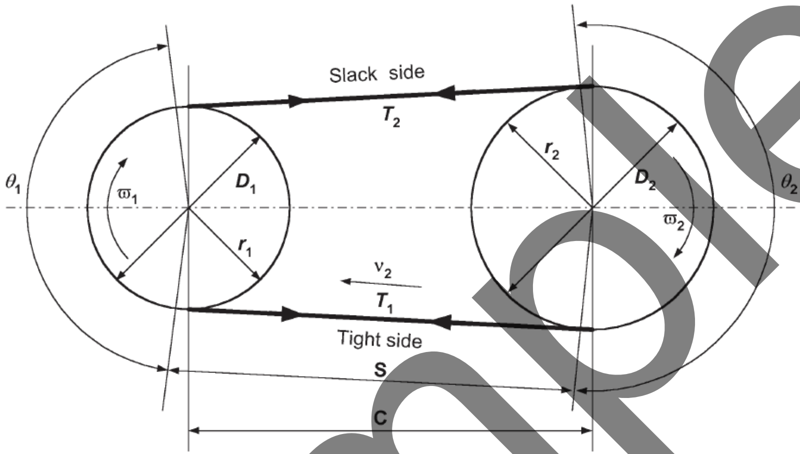


*Figure 1 A basic belt drive arrangement*



The belt drive arrangement in Figure 1 has the driving side on the left and the driven side on the right. This causes the bottom of the belt to be the tight side and the top to be the slack side. Some parameters of note in this arrangement…

| | |
|---|---|
| $\mathbf{D_1, D_2}$ | Respective diameters of the pulleys |
| $\mathbf{r_1, r_2}$ | Respective radii of the pulleys |
| $\boldsymbol{\omega_1, \omega_2}$ | Angular velocity of each pulley (in radians per second) |
| $\boldsymbol{\theta_1, \theta_2}$ | Lap angle (angle subtended to centre of pulley by contact length of belt with pulley surface) |
| $\mathbf{T_1, T_2}$ | Belt tensions on tight side and slack side, respectively |
| $\mathbf{S}$ | Belt length which does not touch the pulleys |
| $\boldsymbol{C}$ | Distance between pulley centres |
| $\mathbf{v_2}$ | Linear belt velocity |

Many formulae may be derived for such a pulley system, but the most important ones are:

**Belt lap angles for pulleys**

$$\vartheta_1 = 180^o - 2\,sin^{-1}\left\{\frac{D_2 - D_1}{2C}\right\} \qquad \text{(Eq.4)}$$

$$\vartheta_2 = 180^o + 2\,sin^{-1}\left\{\frac{D_2 - D_1}{2C}\right\} \qquad \text{(Eq.5)}$$

**Power transmitted by the system**

$$P = T_1\left(1 - e^{-\mu\theta}\right)v \qquad \text{(Eq.6)}$$

where: -

$v = r\omega$

μ is the coefficient of friction between the belt and the pulley

**Belt pitch length**

$$L = 2C + 1.57(D_2 - D_1) + \frac{(D_2 - D_1)^2}{4C} \qquad \text{(Eq.7)}$$

**Span length**

$$S = \sqrt{C^2 - \left[\frac{D_2 - D_1}{2}\right]^2} \qquad \text{(Eq.8)}$$

**Worked Example 2**

A flat belt drive system consists of two parallel pulleys of diameter 300 and 500 mm, which have a distance between centres of 600 mm. Given that the maximum belt tension is not to exceed 1.5 kN, the coefficient of friction between the belt and pulley is 0.3 and the larger pulley rotates at 40 rad/sec. Find;

a) the belt lap angles for the pulleys
b) the power transmitted by the system
c) the belt pitch length L
d) the pulley system span length between centres

**ANSWERS**

a) The belt lap angles for the pulleys are given by equations Eq.4 and Eq.5:

$$\vartheta_1 = 180^o - 2\,sin^{-1}\left\{\frac{D_2 - D_1}{2C}\right\} = 180^o - 2\,sin^{-1}\left\{\frac{0.5 - 0.3}{2(0.6)}\right\} = \mathbf{160.8^o}$$

$$\vartheta_2 = 180^o + 2\,sin^{-1}\left\{\frac{D_2 - D_1}{2C}\right\} = 180^o + 2\,sin^{-1}\left\{\frac{0.5 - 0.3}{2(0.6)}\right\} = \mathbf{199.2^o}$$

b) The power transmitted by the system is given by equation Eq.6:

$$P = T_1\left(1 - e^{-\mu\theta}\right)v$$

where: -

$$v = r\omega = (0.25)(40) = 10\ m.s^{-1}$$

The angle $\theta_1$ is expressed in degrees in part (a) but we must convert this to radians to be compatible with equation Eq.6:

$$160.8^o \equiv \left(160.8 \times \frac{\pi}{180}\right) = 2.81\text{rad}$$

$$\therefore \quad P = T_1\left(1 - e^{-\mu\theta}\right)v = 1500\left(1 - e^{-(0.3)(2.81)}\right)(10) = \mathbf{8.54\ kW}$$

c) The belt pitch length is given by equation Eq.7:

$$L = 2C + 1.57(D_2 - D_1) + \frac{(D_2 - D_1)^2}{4C} = 2(0.6) + 1.57(0.5 - 0.3) + \frac{(0.5 - 0.3)^2}{4(0.6)} = \mathbf{1.53\ m}$$

d) Pulley system span length is given by equation Eq.8:

$$S = \sqrt{C^2 - \left[\frac{D_2 - D_1}{2}\right]^2} = \sqrt{0.6^2 - \left[\frac{0.5 - 0.3}{2}\right]^2} = \mathbf{0.59\ m}$$

***Additional worked examples are available in the eBooks section on Moodle.***

# 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.

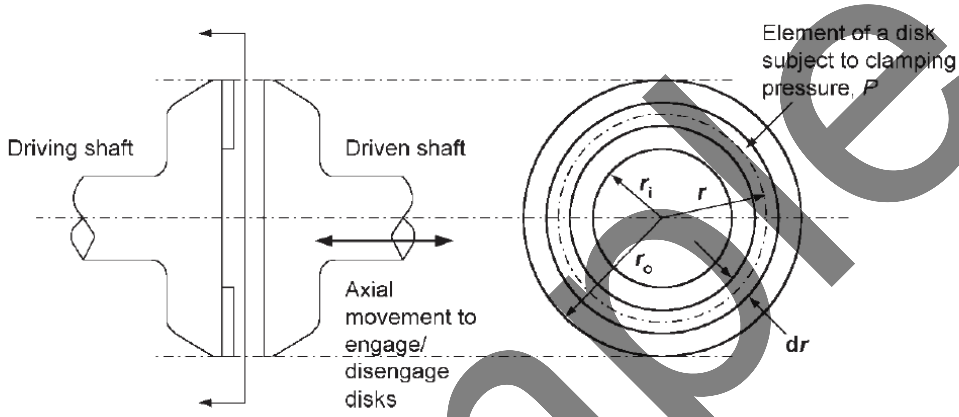


*Figure 2 A basic friction clutch*



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 |
| $\mu$ | 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:

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