2012 MANUFACTURING ENGINEERING TRIPOS PART II A

P2: PRODUCTION MACHINES AND SYSTEMS

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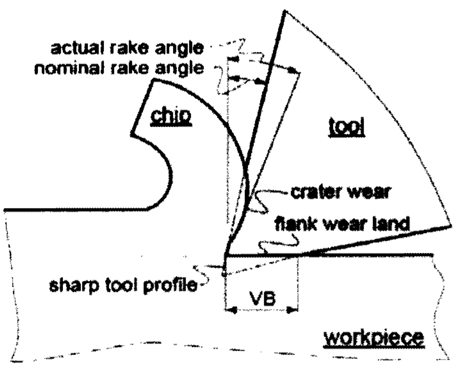
SECTION A

1 a) Gradual wear occurs at three principal locations on a cutting tool. Accordingly, the types of tool wear can be distinguished,

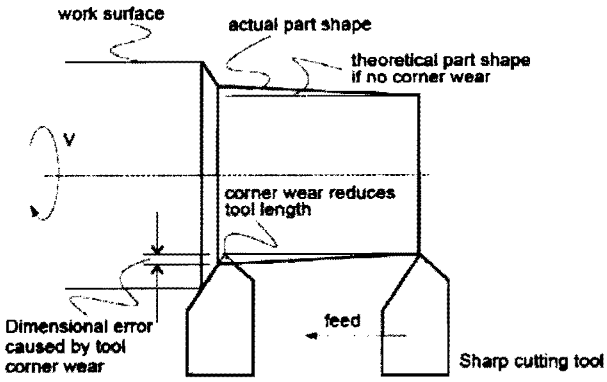
- Flank wear
- Crater wear
- Corner wear

Where **Crater wear**: consists of a concave section on the tool face formed by the action of the chip sliding on the surface. Crater wear affects the mechanics of the process increasing the actual rake angle of the cutting tool and consequently, making cutting easier. At the same time, the crater wear weakens the tool wedge and increases the possibility for tool breakage. In general, crater wear is of a relatively small concern.

Flank wear: occurs on the tool flank as a result of friction between the machined surface of the workpiece and the tool flank. Flank wear appears in the form of so-called wear land and is measured by the width of this wear land, VB, Flank wear affects to the great extent, the mechanics of cutting. Cutting forces increase significantly with flank wear. If the amount of flank wear exceeds a critical value, VB >0.5 ~ 0.6mm, the excessive cutting force may cause tool failure.

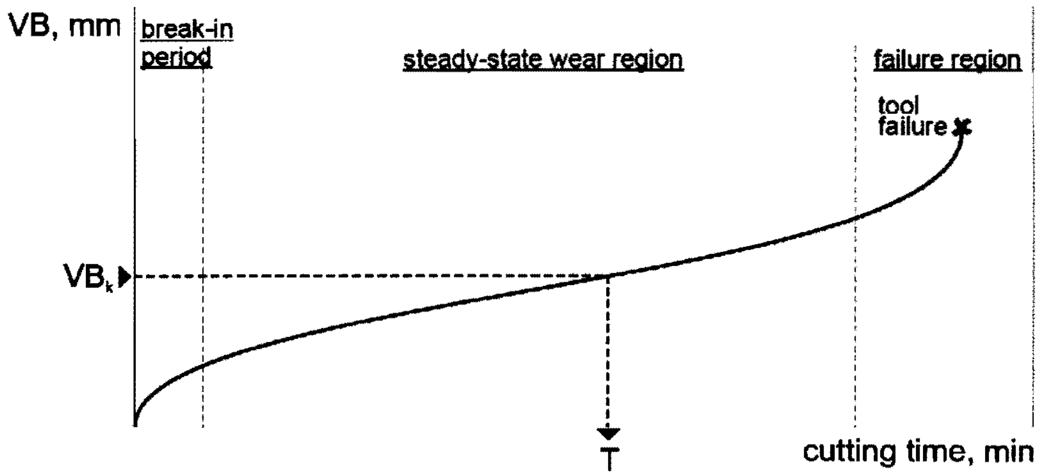


Corner wear: occurs on the tool corner. Can be considered as a part of the wear land and respectively flank wear since there is no distinguished boundary between the corner wear and flank wear land. We consider corner wear as a separate wear type because of its importance for the precision of machining. Corner wear actually shortens the cutting tool thus increasing gradually the dimension of the machined surface and introduces a significant dimensional error in machining, which can reach values of the order 0.03-0.05 mm.

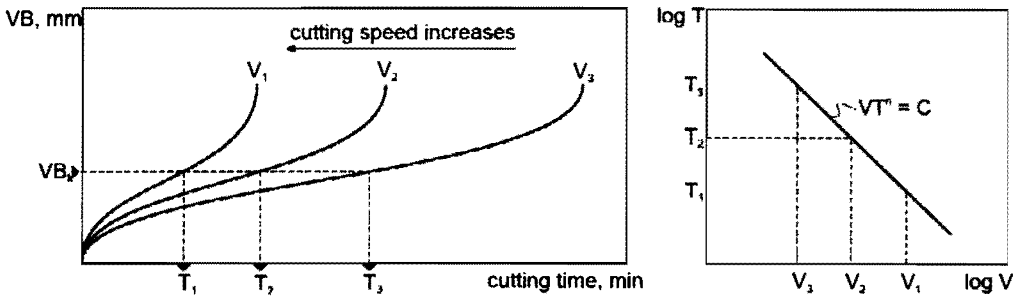


b) Tool wear is a time dependent process. As cutting proceeds, the amount of tool wear increases gradually. But tool wear must not be allowed to go beyond a certain limit in order to avoid tool failure. The most important wear type from the process point of view is the flank wear, therefore the parameter which has to be controlled is the width of flank wear land, VB. This parameter must not exceed an initially set safe limit, which is about 0.4 mm for carbide cutting tools. The safe limit is referred to as allowable wear land (wear criterion), VBk The cutting time required for the cutting tool to develop a flank wear land of width VBk is called tool life, T, a fundamental parameter in machining.

A plot of VB against time is called the 'wear curve' and is a characteristic response of a cutting tool when used to cut a particular material.



The slope of the wear curve, shown below (that is the intensity of tool wear) depends on the same parameters which affect the cutting temperature as the wear of cutting tool materials is a process extremely temperature dependent.



The figure shows how to define the tool life T for a given wear criterion VBk

Parameters, which affect the rate of tool wear are
- cutting conditions (cutting speed V, feed f, depth of cut d)
- cutting tool geometry (tool orthogonal rake angle)
- properties of the work material

From these parameters, cutting speed is the most important one. As cutting speed is increased, wear rate increases, so the same wear criterion is reached in less time, i.e., tool life decreases with cutting speed:

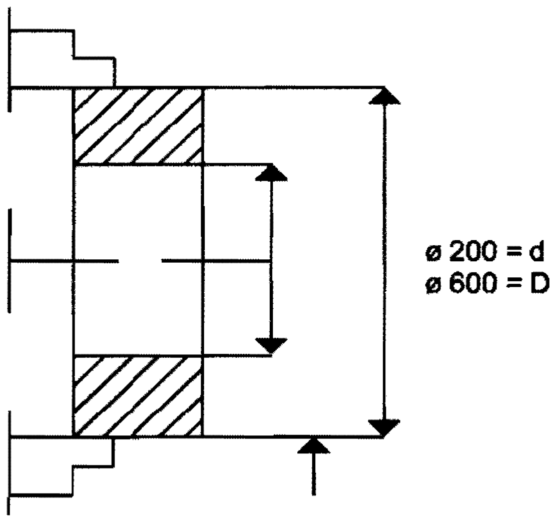
c)

According to the question, the cutting speed V_c = constant, then from Taylor's expression
$V.T^n = C$ and for $T = 60$ (min), $n = 0.3$, we have $C = 170.77$.

Therefore in the present case

$V.50^{0.3} = 170.77$

$V = 52.86$ (m/min)



From the figure, the width of the machined face, S, is

$$S = \frac{D-d}{2} = \frac{\phi 600 - \phi 200}{2} = 200mm$$

At a feed rate, $t = 0.25$ (mm/rev) we will need:

$n_1 = S / t$ revolutions of the spindle to machine the face of the ring

$n_1 = 200 / 0.25 = 800$ (rev)

The total path length of a spiral path is approximated by

$$L = \pi(\frac{D+d}{2})n_1$$

(note students may wish to use an alternative approximation for the spiral path, such as integration of concentric circles etc, this may affect the numerical value of their answer which should be taken into account by the examiner)

$L = 1005.3$ (m)

The time T_1 required for a single workpiece to be machined by the tool is :

$$T_1 = \frac{S_1}{V} = \frac{1005.3}{52.81} = 19.03 \min$$

The number of components that can be machined is therefore

$$N = \frac{T}{T_1} = \frac{50}{19.03} = 2.62$$ components

Examiners Comments: Most candidates gave good answers in describing the different types of tool wear. Responses to the second part of the question were variable, with only a few candidates providing reasonably good answers. Weaker candidates did not sufficiently discuss the effect of cutting speed on wear, and also failed to provide good explanations using proper diagrams. Surprisingly, the numerical part of the question was found to be particularly hard by most candidates – most of them could not correctly calculate the length of the path to be machined, and hence obtained wrong answer to the problem.

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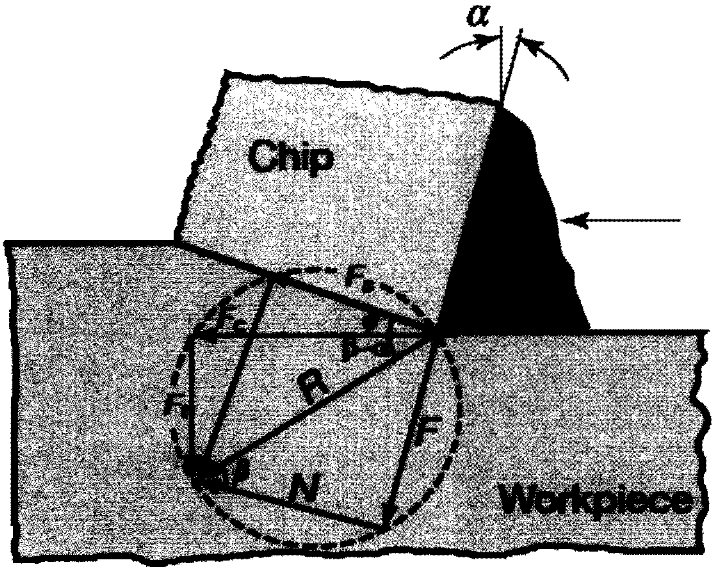
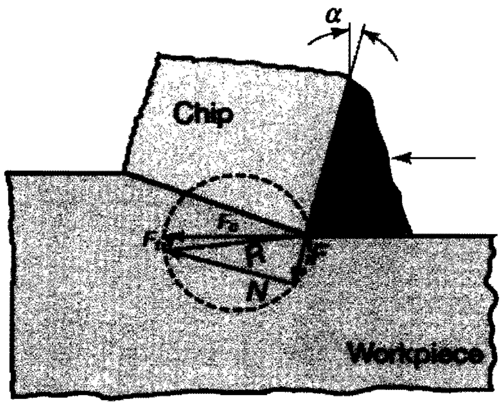
a)



i) Increasing the depth of cut means more material being removed per unit time.Thus, all other parameters remaining constant, the cutting force has to increase linearly because the energy requirement increases linearly. As the rake angle decreases, the shear angle decreases and hence the shear strain increases. Therefore, the energy per unit volume of material removed increases, thus the cutting force has to increase.

ii) The use of a cutting fluid will reduce the friction force, F, at the tool-chip interface. This, in turn, will change the force diagram, hence the magnitude of the thrust force, Ft. Consider the sketch given below. The previous sketch shows cutting without an effective cutting fluid, so that the friction force, F is large compared to the normal force, N. The sketch below shows the effect if the friction force is a smaller fraction of the normal force because of the cutting fluid. As can be seen, the cutting force is reduced when using the fluid. The largest effect is on the thrust force, but there is also a noticeable effect on the cutting force, which becomes larger as the rake angle increases.



b) From the force diagram it is clear that

$$R = \sqrt{(F_c^2 + F_t^2)} = 780N$$

$$F_F = R.\sin\beta = 780.\sin(39.2) = 493N$$

$$F_N = R.\cos\beta = 780.\cos(39.2) = 604N$$

The coefficient of friction is then given by F_F/F_N so

$$\mu = 493/604 = 0.816$$

c) The total power spent can be calculated as

$P = F_c \,.\, V$

Where the F_c is the cutting force and V the cutting speed, which can be calculated by

$V = \Pi.D.N$, where D is the diameter of the workpiece and N the number of revolutions per unit time

The total power is then

$P = F_c.\ \Pi.\ D.\ N$

$$P = 1900\pi\left(27mm.\frac{1m}{1000mm}\right)\left(1400rev/\min.\frac{1.\min}{60s}\right)$$

P = 3760 W = 3.76 kW

The gross power requirement is the power that should be input to the machine tool, which is

$$P_g = \frac{P_c}{e}$$

where e is the efficiency of the machine tool, hence

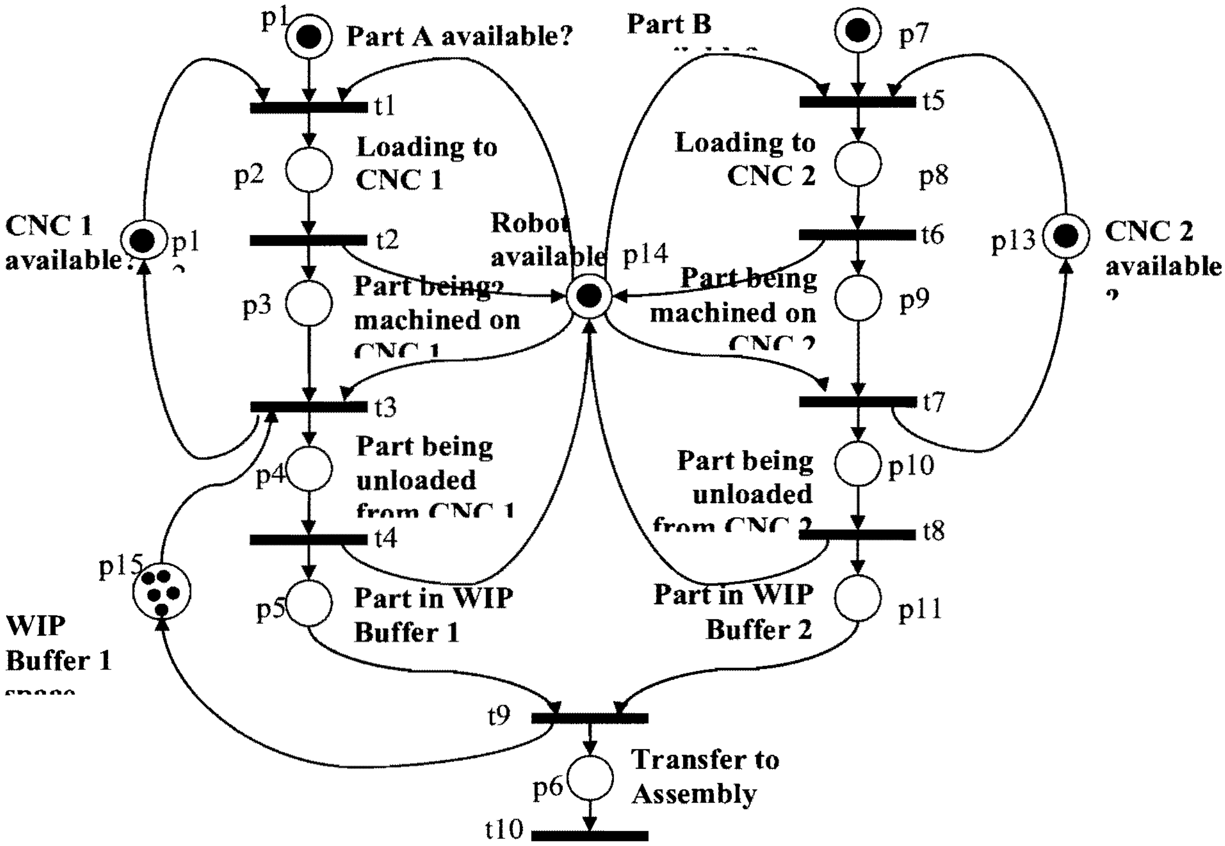
$$P_g = \frac{3.76kW}{0.90} = 4.1\,kW$$

Examiners comments: Most of the candidates performed excellently in parts (b) and (c). The differentiator was part (a), which was descriptive. The weaker candidates did not provide well-marked force diagrams and did not touch on energy requirements to explain why cutting force increases with depth of cut and decreasing rake angle.

SECTION B

3

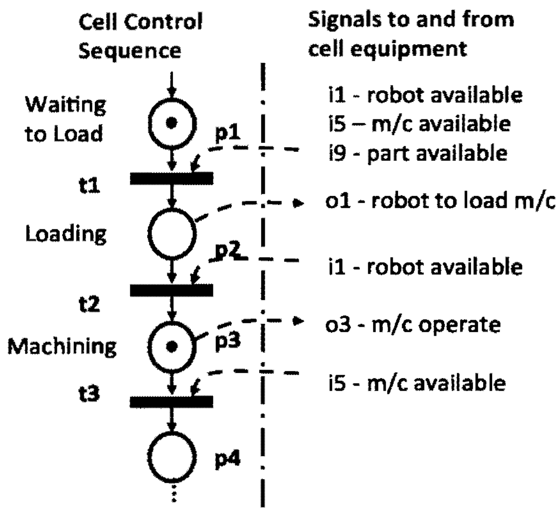
(a) The extended Petri Net is as shown in figure below:



In the Petri Net shown above, places p12 and p13 represents the availability of the two CNC machines, and p14 represents the availability of the robot. Place p15 represents the spaces in the buffer. The sum of the tokens in p5, p4 and p15 will always be 10.

(b)

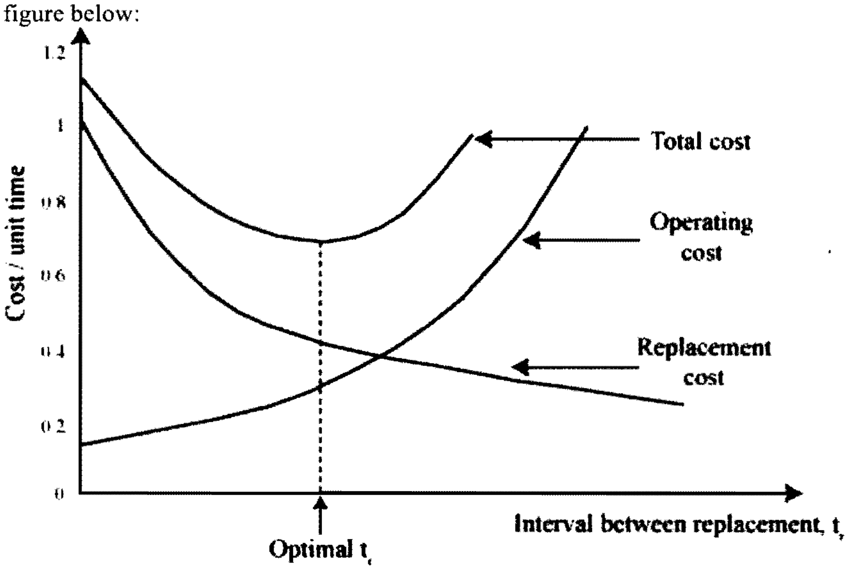
Interfacing between petri nets and physical systems is achieved by linking the transitions with Inputs and places with outputs.



(c)

(i)

The objective here is to minimize the total cost of operation per period (years in this case) as shown in figure below:



c (t) is the operating cost per unit time at time t after replacement.
C_r is the total cost of a replacement.
The replacement policy is to perform replacements at intervals of length t_r.

$C(t_r)$ = total cost in interval $(0,t_r)$/length of interval

Total cost in interval = operating cost + replacement cost

$$\therefore C(t_r) = \frac{1}{t_r}\left[\int_0^{t_r} c(t)\,dt + C_r\right]$$

Evaluation of the above model for different values of t_r is given below:

t_r	1	2	3	4	5
$C(t_r)$	3312.5	2561.6	2428.4	2423.7	2455.7

Hence, it is optimal to replace the pump after every 4 years.

(ii)

When the time taken for replacement cannot be neglected, the total cycle time should include the replacement time. Say, if the replacement time is T_r, then the total cost in interval is given by

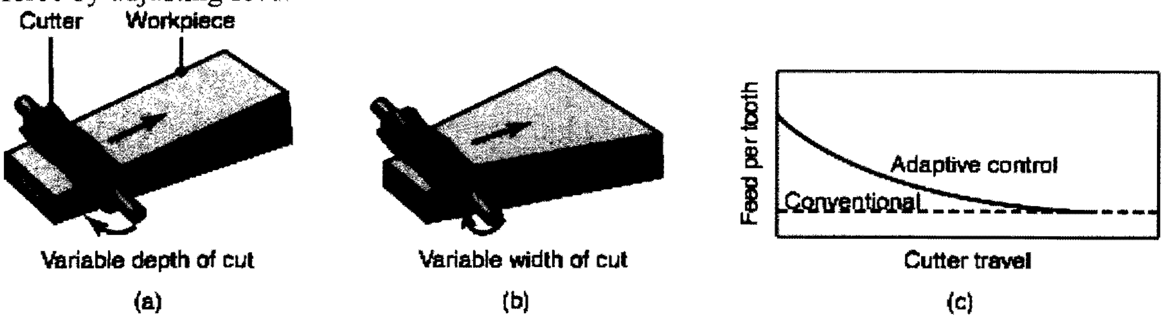
$$C(t_r) = \frac{\int_0^{t_r} c(t)dt + C_r}{t_r + T_r}$$

Examiners Comments: Most of the candidates showed good understanding of Petri Nets, with the weaker candidates not considering deadlock-free operation. A good majority of the candidates also failed to understand the implication of including replacement time in part (c).

(a) For expensive machines and / or components additional control requirements are sometimes employed. Adaptive Control (AC) for machining is defined as the on-line adjustment of process parameters for the purpose of optimising production rate, optimising quality, or minimising the cost of materials and components.
The basic functions of most adaptive systems are:

1. Determination of unknown parameters (measured or inferred)
2. Based on these parameters make an alteration to the control strategy
3. Via the control strategy appropriately adjust existing or additional processing parameters.

A key issue for adaptive control is that of adjusting to variations in the workpiece. The diagram below illustrates differences between adaptive control and conventional (constant) control where the adaptive control is attempting to maintain constant contact force by adjusting feed.



Typical AC objectives in turning involve maintaining constant power or contact force during process variations such as variations in the dimensions of the unmachined component or material hardness. Also, *Auto Cut Segmentation* - which involves the setting of an automated cutting program based on final dimensions and idealised feed-rate, cutting depth and power - employs adaptive control to adjust cutting depth and feed as required.
There are two key types of adaptive control techniques:

(a) Adaptive Control Constrained (ACC): These are systems that place a constraint on a process variable (e.g., force, torque, temperature). Here, if the thrust force and the cutting force (hence the torque) increase excessively, the system modifies the cutting speed or the feed in order to lower the cutting force to an acceptable level. Without adaptive control (or direct intervention of the operator), high cutting forces may cause tool failure or may cause the workpiece to deflect excessively – resulting in workpiece dimensional accuracy and/or surface finish deterioration.

(b) Adaptive Control Optimised (ACO): These are systems which optimize an operation. Optimisation may involve maximizing the material-removal rate between tool changes or improving the surface finish of the part.

For adaptive control to be effective in manufacturing operations, quantitative relationships must be established and coded in the computer software as mathematical models. If, for instance, the tool-wear rate in a machining operation is excessive, the computer controller must be able to calculate how much of a change in speed or feed is necessary in order to reduce the tool-wear rate to an acceptable level.

(b)

(i) Using the mechanics data book it is possible to read directly that for a 75 rad/sec (12Hz) disturbance, this system (with damping factor 0.3 and natural frequency 100 rad/sec) will have a gain of 1.6x0.1 = 0.16mm/kN. Hence for a 0.077kN vibration, the amplitude of the resulting deflection is 0.077x0.13 = 0.01mm.

(ii) For a closed loop system, the impact of vibration on deflection is given by:

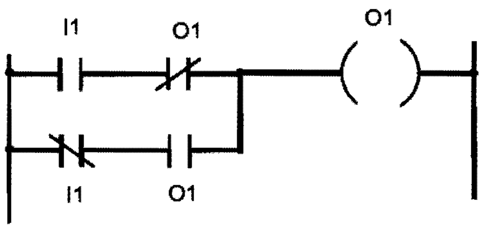
$$\frac{G(j\omega)}{1+kG(j\omega)} = \frac{0.1\omega_n^2}{-\omega^2 + 2c\omega_n\omega j + \omega_n^2(1+0.1k)}$$

The open loop steady state gain is 0.1, and at steady state, $\omega = 0$, the closed loop gain reduces to

$$\frac{G(j0)}{1+kG(j0)} = \frac{0.1\omega_n^2}{\omega_n^2(1+0.1k)} = \frac{0.1}{(1+0.1k)}$$

hence, setting k=10 will reduce the open loop gain at steady state by 50%.

(c) One of the ways in which a flip-flop logic can be implemented is as follows:



The logic is explained as follows:

I1: Momentary push button

O1: Output to conveyor

When the conveyor is not working and if the momentary push button is pressed, I1 gets enabled, and the first rung in the ladder gets activated thereby turning output O1 on. Once the output is on, the second rung acts as a latch to keep it on even when the momentary push button is not pressed. The second time the button is pressed, both rungs of the ladder are not activated (since the conditions are not satisfied), thereby turning output O1 off.

Examiners Comments: The descriptive part of the question was poorly handled by most of the candidates, with many of them discussing the differences between open-loop and closed-loop control rather than adaptive control. Part (b), which should have been quite straightforward to answer was not done correctly by most. Part (c), which involved developing a LLC for a flip-flop circuit was challenging, and most candidates could not provide a reasonably good logic.