MANUFACTURING ENGINEERING TRIPOS PART I

Monday 26 April 2010 9 to 10.30

PAPER 2

Module 3P2: PRODUCTION MACHINES AND SYSTEMS (CRIB)

Answer not more than **two** questions, **one** from each of sections **A** and **B**.

Answers to sections **A** and **B** must appear in two separate booklets.

All questions carry the same number of marks.

The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.

There are no attachments.

STATIONERY REQUIREMENTS	SPECIAL REQUIREMENTS
8 page answer booklet x 2	Engineering Data Book
Rough work pad	CUED approved calculator allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

SECTION A

1 (a) Figure 1 shows a cross-section of a cutting tool and shows the typical wear on the flank and the rake face. The width of the flat VB worn on the flank is taken as the measure of wear.

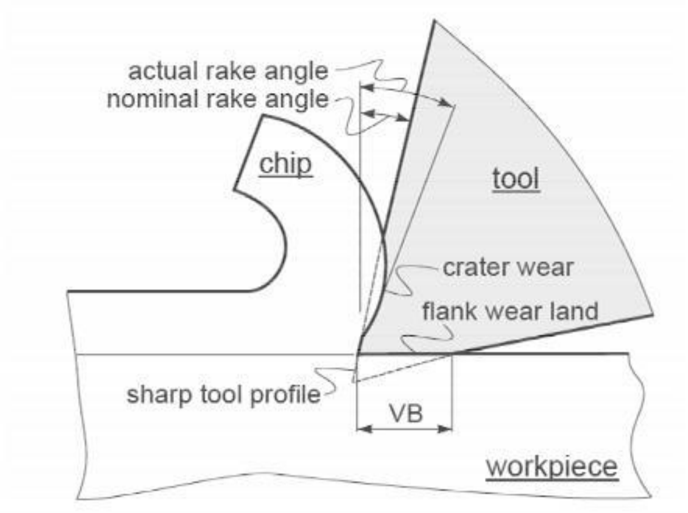


Figure 1

(b) Figure 2 shows the wear/time curve for a tool, in which the mid point on the curve – the half-life – is taken as the design life.

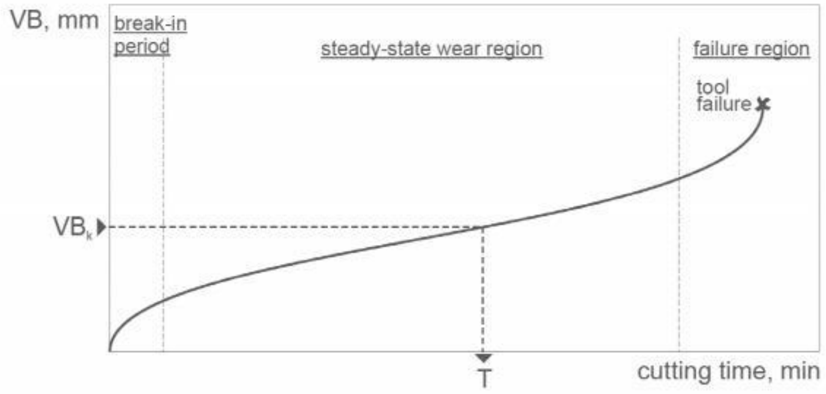


Figure 2

Figure 3 shows the effect of different cutting speeds in the left hand plot, and the right hand plot shows that on a log-log plot the speed/life relationship is a straight line of slope 1/n, so that n becomes a defining characteristic of a particular cutting tool/component material combination.

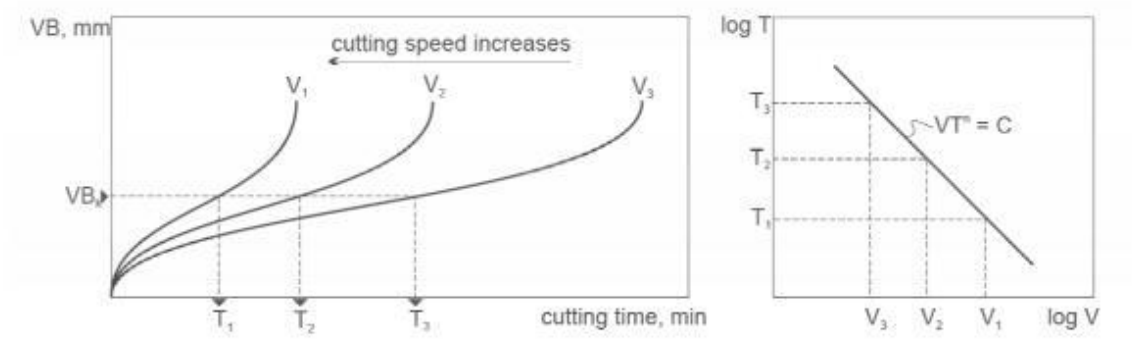


Figure 3

(c) What the effect of the ratio of pearlite to ferrite shows is that there is a great advantage to machining the steel in the annealed condition. This suggests that rapid production will be best achieved by beginning in an annealed condition (by taking the components through an annealing process if necessary) and then after machining taking the components through either a complete hardening process, if the whole body of the material needs to be in a hardened condition, or through a surface hardening process if it is only surface hardness that is needed, e.g. to resist wear.

(d) Figure 4 shows a qualitative plot for the total cost of machining, with the different elements that make up the cost laid out in Figure 5.

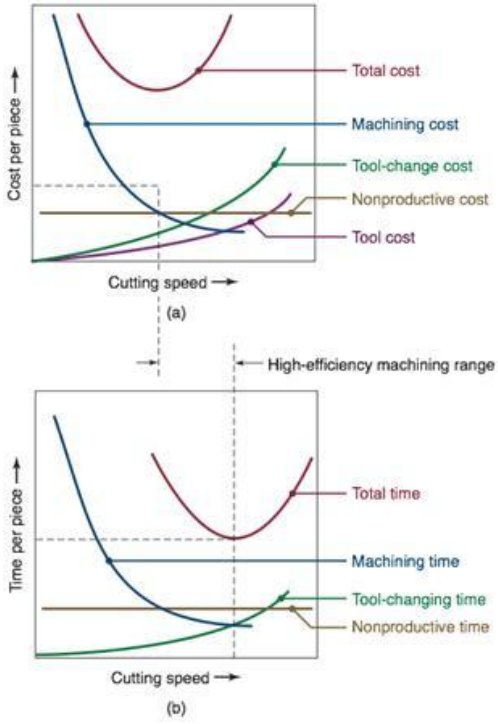
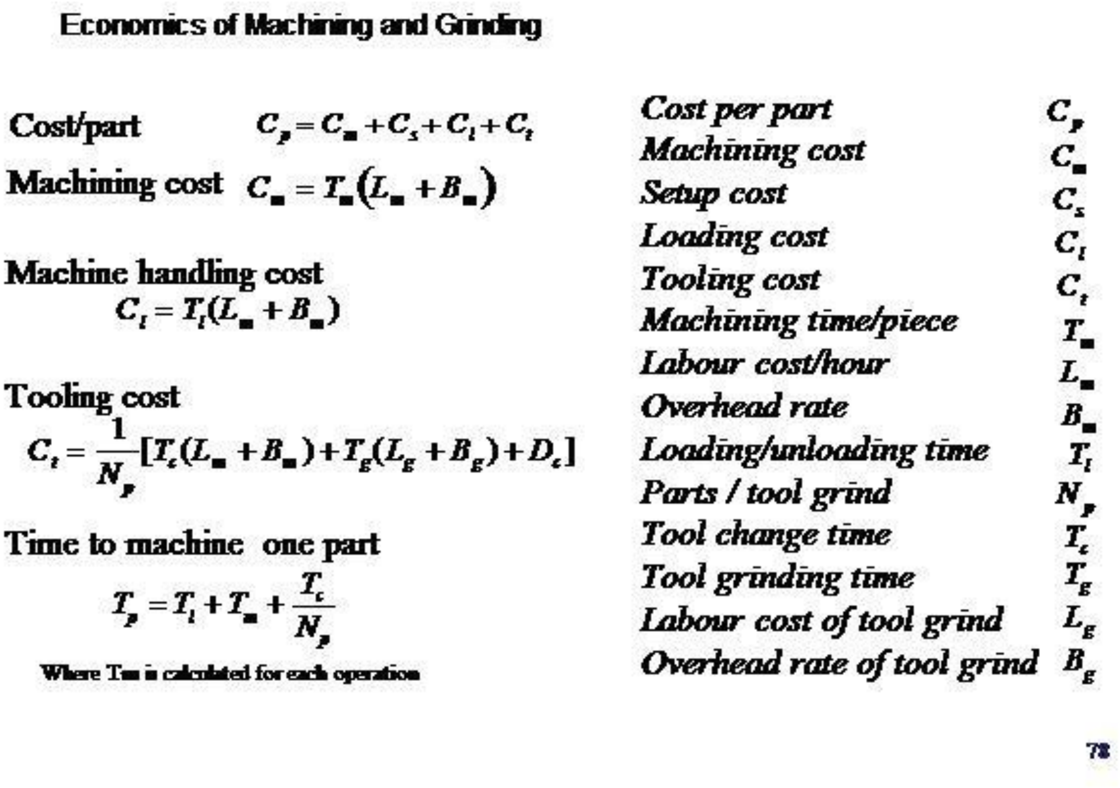


Figure 4



Economics of Machining and Grinding

Cost/part $C_p = C_m + C_s + C_l + C_t$

Machining cost $C_m = T_m\left(L_m + B_m\right)$

Machine handling cost

$$C_l = T_l(L_m + B_m)$$

Tooling cost

$$C_t = \frac{1}{N_p}\left[T_c(L_m + B_m) + T_g(L_g + B_g) + D_c\right]$$

Time to machine one part

$$T_p = T_l + T_m + \frac{T_c}{N_p}$$

Where Tm is calculated for each operation

Cost per part	C_p
Machining cost	C_m
Setup cost	C_s
Loading cost	C_l
Tooling cost	C_t
Machining time/piece	T_m
Labour cost/hour	L_m
Overhead rate	B_m
Loading/unloading time	T_l
Parts / tool grind	N_p
Tool change time	T_c
Tool grinding time	T_g
Labour cost of tool grind	L_g
Overhead rate of tool grind	B_g

Figure 5

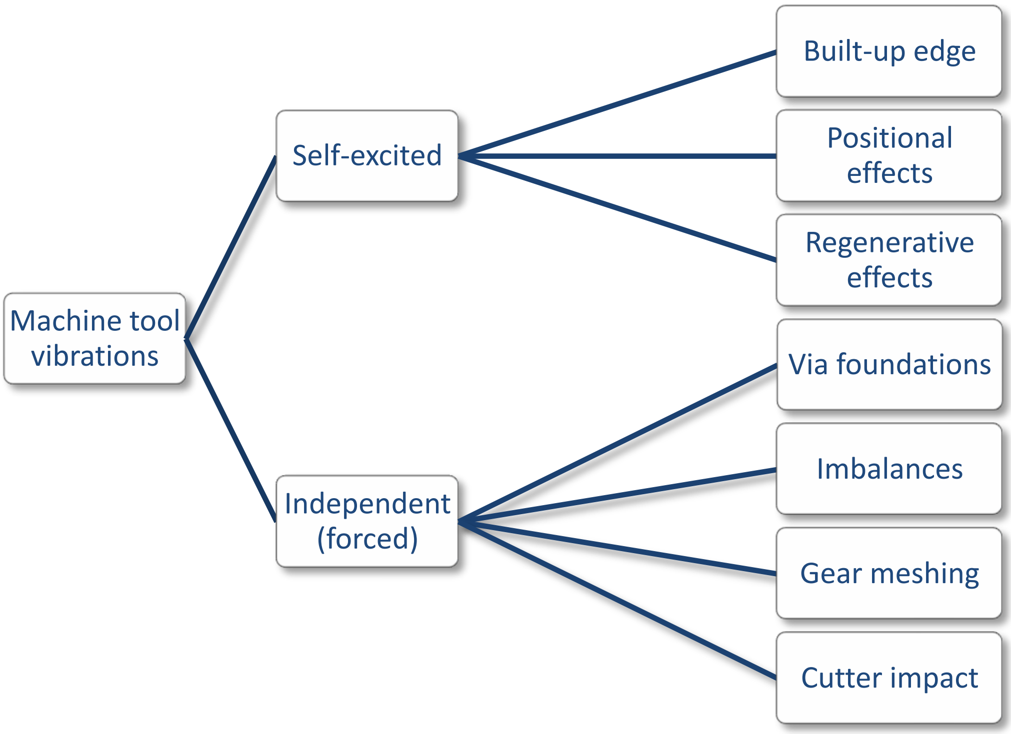
2 (a) Precision: Repeatability, exactness, and/or the ability to obtain the same quantity (of a dimension, say) over and over. Quantified as a function of standard deviation (statistical spread) of the quantity.

Accuracy: Being “on target” with a specification. Quantified by the bias, or difference, between the obtained result and the desired result.

(b) The factors that affect workpiece accuracy stem from the machine tool itself, the tool actions and the workpiece material. Sources of error from the machine design, environmental effects, machine workzone, the cutting tool and the workpiece are detailed in the figure. They can be broken down into static and dynamic effects.
A good discussion would include the following issues:

	Static	**Dynamic**
Workpiece	Datum preparation	Thermal properties
	Stress condition	Stiffness
Tool	Tool material	Wear
	Tool set-up	Feeds and speeds
	BUE	Chatter
Machine	Workzone accuracy	Stiffness
	Precision	thermal stability
	Materials	vibration
Environment	Temperature	Dust
	External vibrations	Humidity
	Lighting	Coolant

(c) Dynamic disturbances are caused due to vibrations caused by external or internal processes. Machine tools are subject to three types of vibrations: free vibrations, self-excited vibrations and forced vibrations. Free vibration occurs in the absence of a long-term, external excitation force. This is not of much importance to us in this context.



Self-excited vibrations (also known as “chatter”) occur because the dynamic cutting process forms a closed-loop system. Disturbances in the system (i.e., vibrations which affect cutting forces) are fed back into the system and over time, under appropriate conditions, may result in instability.

Self-excited vibrations result from variations in chip thickness (recall earlier lectures), depth of cut, and cutting speed, which result in cutting force variations. Force variations can lead to machine vibration, which in turn can cause additional force fluctuations by inducing variations in the uncut chip thickness. The variations of the uncut chip thickness due to vibrations during the previous pass or previous tooth cause additional force fluctuations. When the dynamic cutting force is out of phase with the instantaneous relative motion between the tool and workpiece, this leads to the development of self-excited vibrations.

Forced vibration takes place when a continuous, external periodic excitation produces a response with the same frequency as the forcing function (after the decay of initial transients). Two types of independent excitation exist:

- Harmonic
- Pulsating

When the disturbance is harmonic in nature, the machine tends to vibrate at the forcing frequency. Examples of such disturbances are unbalanced rotating masses, bearing irregularity. However, when the disturbance is pulsating in nature, the machine tends to vibrate at its natural frequency. Examples of such disturbances are cutting forming forces on hammers, interrupted cuts on metal cutting machines, and vibrations from the floor.

How can we identify whether a disturbance is caused by chatter or by external sources? Self-excited vibrations disappear when the cutting stops; forced vibrations will exist and will persist regardless of whether or not the tool is engaged.

The characteristic features of chatter are: (i) the amplitude increases with time, until a stable limiting value is attained; (ii) the frequency of the vibration is equal to a natural frequency or critical frequency of the system; and (iii) the energy supporting the vibration is obtained from a steady internal source.

Machine behaviour in the face of these vibrations can be represented by its *transfer function,* $\boldsymbol{G(s)}$**,** from vibration to deflection:

$$\frac{Y(s)}{U(s)} = G(s) = \frac{\omega_n^2}{s^2 + 2c\omega_n s + \omega_n^2}$$

Recall that natural frequency is defined as $\omega_n = \sqrt{k/m}$

We can infer that the behaviour of the machine tool in the face of vibrations depends on the following three key factors:

- mass distribution, *m*
- stiffness, *k*
- damping, *c*

Hence, the dynamic response of the machine tool can be improved by (i) increasing the stiffness, (ii) high damping factor; and (iii) improved mass distribution.

SECTION B

3 (a) The key points to note regarding the three strategies are:

Corrective maintenance

- "Run-to-failure" or "reactive" maintenance
- If it ain't broke, don't fix it – sounds simple and reasonable
- No money spent on maintenance until the machine stops working
- Disadvantages
  - High spare parts inventory
  - High overtime costs
  - Long machine downtime
  - Low production availability
  - Spare machines required
  - Knock-on effects on other machines and overall loss of production
  - Danger of unsafe failures

Preventive maintenance

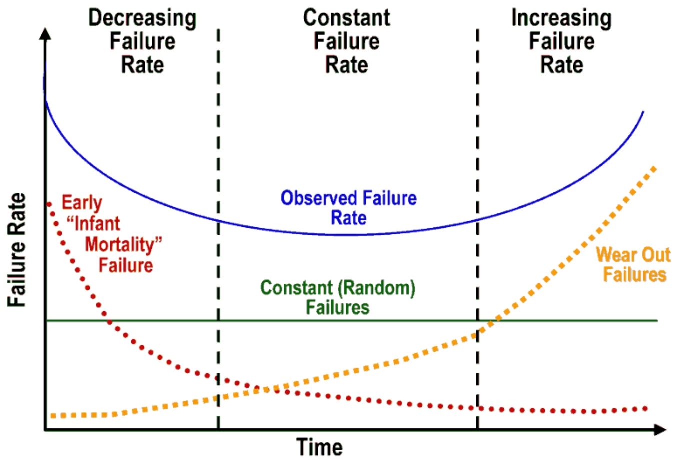
- All maintenance is time-driven or usage driven
- Based on elapsed time/hours of operation/ number of parts produced
- Time between maintenance based on statistical data or manufacturer's recommendations
- Treats all machines as same
- Scheduled maintenance costs are around one-third of corrective maintenance costs

Predictive maintenance

- Regular monitoring of actual mechanical condition of the machine and other indicators of operating condition provide data for maximum interval between repairs
- Costs
  - Design of monitoring system
  - Monitoring equipment (sensors, analysis tools, etc.)
  - Staff training
  - Labour costs for inspection, measurement, analysis, etc.
- Savings
  - Elimination/reduction of unexpected breakdowns
  - Increased time between repairs
  - Reduction of spare part stock
  - Reduction in insurance premium

PS: Good students will explain these strategies with the help of proper examples as to when each should be used.

(b)



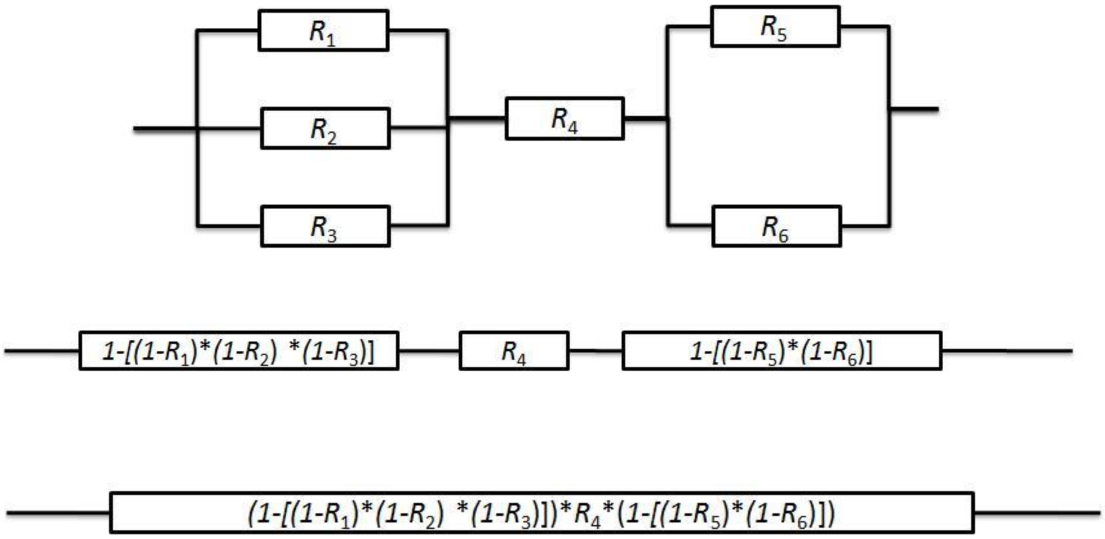
Over many years, and across a wide variety of mechanical and electronic components and systems, people have calculated empirical population failure rates as units age over time and repeatedly obtained a graph such as shown above. Because of the shape of this failure rate curve, it has become widely known as the "Bathtub" curve.

The initial region that begins at time zero when a customer first begins to use the product is characterized by a high but rapidly decreasing failure rate. The high failure rate during this "burn-in" period accounts for parts with slight manufacturing defects not found during manufacture's testing. This region is known as the **Early Failure Period** (also referred to as **Infant Mortality Period**, from the actuarial origins of the first bathtub curve plots). This decreasing failure rate typically lasts several weeks to a few months.

Next, the failure rate levels off and remain roughly constant for (hopefully) the majority of the useful life of the product. This long period of a level failure rate is known as the **Intrinsic Failure Period** (also called the **Stable Failure Period**) and the constant failure rate level is called the **Intrinsic Failure Rate**. Note that most systems spend most of their lifetimes operating in this flat portion of the bathtub curve

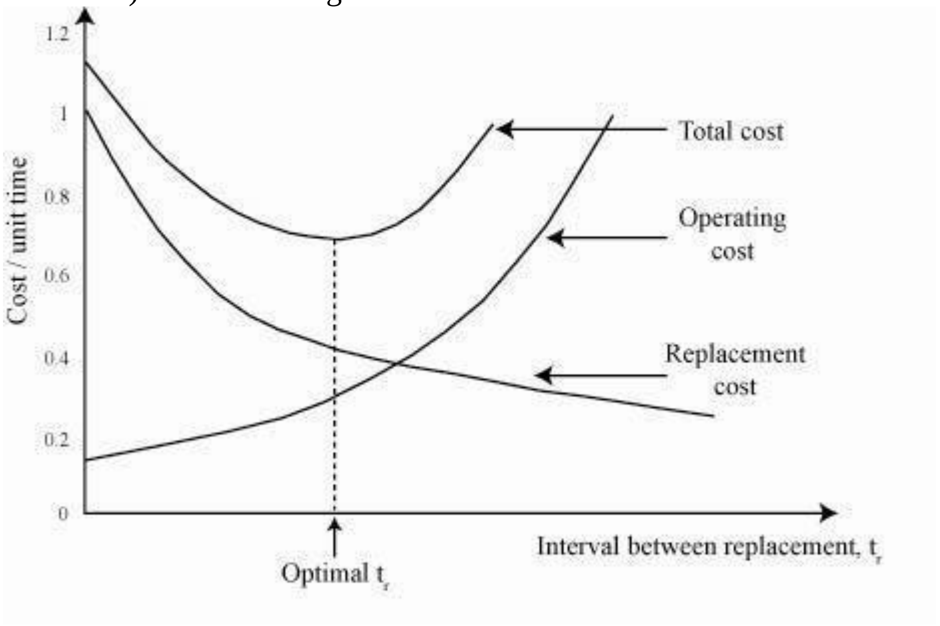
Finally, if units from the population remain in use long enough, the failure rate begins to increase as materials wear out and degradation failures occur at an ever increasing rate. This is the **Wearout Failure Period**.

(c) The system reliability can be found by combining the sub-system reliabilities as follows:



Total system reliability = 0.934.

(d) 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

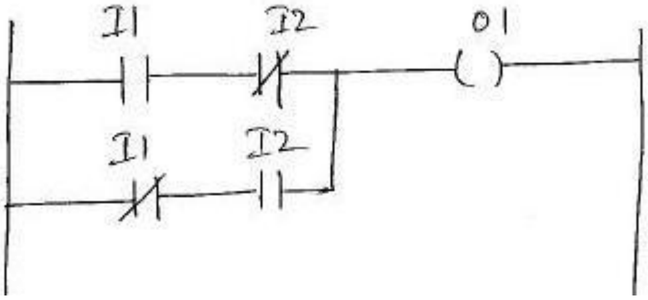
$$\therefore C(t_r) = \frac{1}{t_r}\left[\int_0^{t_r} c(t)dt + C_r\right]$$

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

t_r	1	2	3	4	5
$C(t_r)$	1931.3	1521.6	1479.1	1510.0	1559.5

Hence, it is optimal to replace the pump after every 3 years.

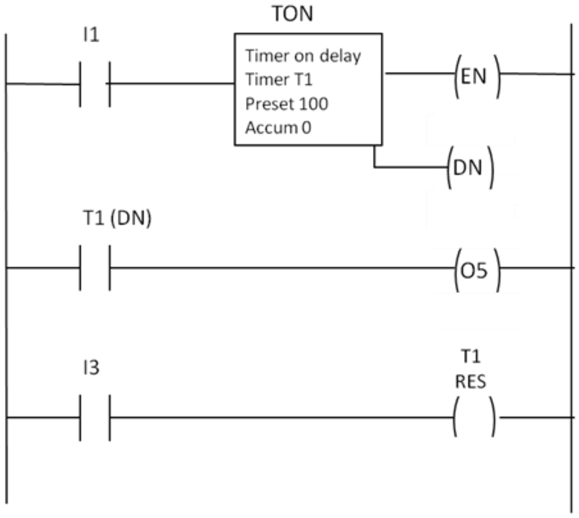
4 (a) The following PLC code will achieve an XOR logic.



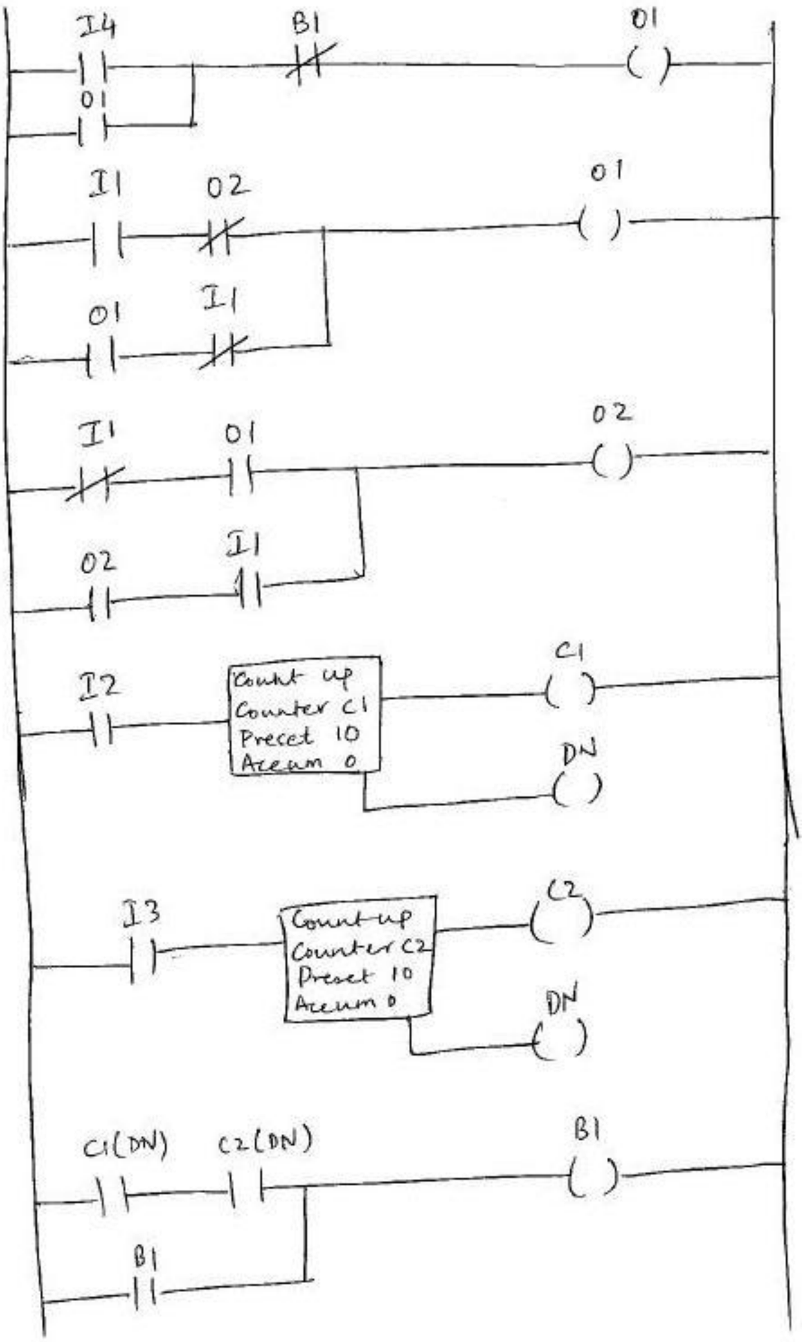
The truth table for the above logic is given by:

I1	I2	O1
0	0	0
0	1	1
1	0	1
0	1	0

(b) Timer-On (respectively Timer-Off) functions are set by the associated rung conditions becoming true (resp. false). They remain set until the accumulated time reaches a preset value. EN indicates that the timer is enabled.



(c) The PLC code that will achieve the required operation is given below:



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