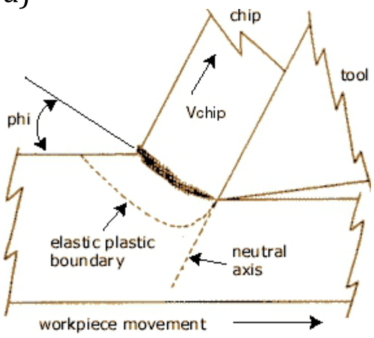
2013 Manufacturing Engineering Tripos Part IIA
Paper 2: Operation and Control of Production Machines and Systems
Examiner: Prof Duncan McFarlane

Question 1

a)

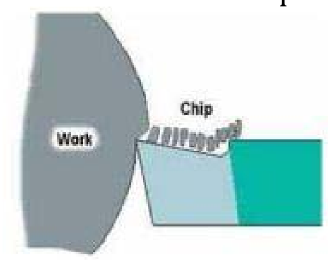


The material immediately in front of the tool is bent upward and is compressed in a narrow zone of shear which is shaded on the drawing above. For most analyses, this shear area can be simplified to a plane. As the tool moves forward, the material ahead of the tool passes through this shear plane. If the material is ductile, fracture will not occur and the chip will be in the form of a continuous ribbon. If the material is brittle, the chip will periodically fracture and separate chips will be formed. It is within the shear zone that gross deformation of the material takes place which allows the chips to be removed. As on the stress-strain diagram of a metal, the elastic deformation is followed by plastic deformation. The material ultimately must yield in shear

b)

The Four main categories of chips are:

- Discontinuous Chips



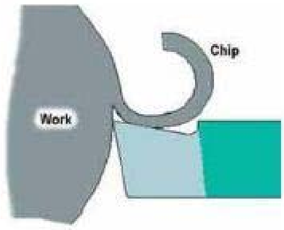
Discontinuous chips are formed by a series of ruptures occurring approximately perpendicularly to the tool face. Each chip element passing off along the tool face in the form of small segmented may adhere loosely to each other. Since the chips break up into small segments the friction between the tool and the chips reduces' resulting in better surface finish. These chips are convenient to collect, handle and dispose off. Discontinuous chips tend to be formed when one or more or the following conditions exist:

1. Brittle material , such as cast iron and bronze.
2. large chip thickness

3. low cutting speed
4. small rake angle

Discontinuous chips are also produced when cutting more ductile material with the use of a cutting fluid.

- Continuous or Ribbon Type Chips



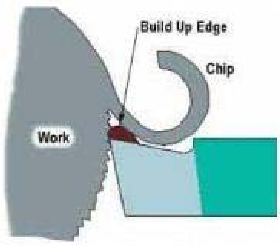
Continuous chips are formed by the continuous plastic deformation of metal without fracture in front of the cutting edge of the tool, with a smooth flow of the chip up the tool face. Mild steel, Al, and Cu are typical materials for obtaining continuous chips. The chips obtained have same thickness throughout. This type of chip is the most desirable. Since it is stable cutting, resulting in generally good surface finish. On the other hand these chips are difficult to handle and dispose off.

Continuous chips tend to be formed when the following condition exist:

1. ductile material
2. high cutting speed
3. small chip thickness
4. large rake angle
5. minimum friction of chip on tool face by :

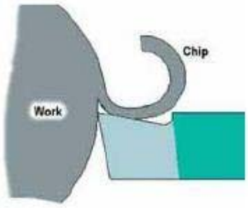
· polished tool face
· use of efficient cutting lubricants.
· Use of tool material with low-coefficient of friction.

- Continuous Chip Built-up-Edge (BUE)



This type of chip is very similar to the continuous chip. With the difference that it has a built up edge adjacent to tool face. It is obtained by machining of ductile material, in the conditions of high local temperature and extreme pressure in the shear zone, and high friction at the tool chip interface. These conditions cause the work material to adhere or weld to the cutting edge of the tool. Successive layers of work material are then added to the built up edge. When this edge becomes larger and unstable , it breaks up and part of it is carried up the face of the tool along with the chip while the remaining is left over the surface being machined, which contributes to the roughness of the surface. The built up edge changes its size during the cutting operation which affects the principal cutting parameters.

- Serrated Chips



These chips are semi continuous in the sense that they possess a saw-tooth appearance that is produced by a cyclical chip formation of alternating high shear strain followed by low shear strain. This chip is most closely associated with certain difficult-to-machine metals such as titanium alloys, nickel-base super alloys, and austenitic stainless steels when they are machined at higher cutting speeds. However, the phenomenon is also found with more common work metals (e.g., steels), when they are cut at high speeds.

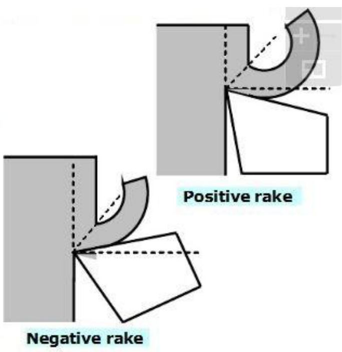
c)
There are two distinct tool geometries, positive and negative rake angles.

Positive is suitable for machining soft, ductile materials (like aluminum) and negative is for cutting hard materials, where the cutting forces are high (Hard material, high speed and feed). They offer the following characteristics

- Makes the tool more sharp and pointed. This reduces the strength of the tool, as the small included angle in the tip may cause it to chip away.
- Reduce cutting forces and power requirements.
- Helps in the formation of continuous chips in ductile materials.
- Can help avoid the formation of a built-up edge.

Negative rake angles are often used with high strength cutters such as carbide inserts, they offer the following process characteristics

- Make the tool more blunt, increasing the strength of the cutting edge.
- Increase the cutting forces.
- Can increase friction, resulting in higher temperatures.
- Can improve surface finish.



d) Assuming Taylors tool life equation is $VT^n = C$

$V_1T_1^n = V_2T_2^n = V_3T_3^n = C$

Here, V_1 = 60 m/min; T_1 = 80 min.
V_2 = 120 m/min; T_2 = 20 min.
V_3 = (to be determined); T_3 = 40 min.

$$V_1T_1^n = V_2T_2^n = C$$

$$\left(\frac{T_1}{T_2}\right)^n = \left(\frac{V_2}{V_1}\right)$$

$$\left(\frac{80\min}{20\min}\right)^n = \left(\frac{120m/\min}{60m/\min}\right)$$

from which n = 0.5

again $V_3T_3^n = V_1T_1^n$

i.e

$$\left(\frac{V_3}{V_1}\right) = \left(\frac{T_1}{T_3}\right)^n$$

or

$$V_3 = \left(\frac{80}{40}\right)^{0.5} \times 60 = 84.84\,m/\min$$

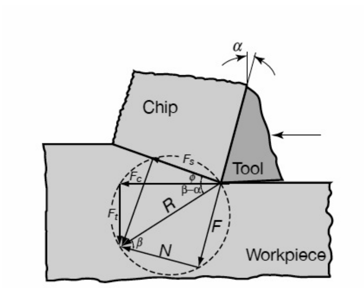
Question 2

]

a)

A force circle diagram is given below, which shows the principal forces acting on the tool in orthogonal cutting. The cutting force, F_c, acts in the direction of the cutting speed, *V*, and supplies the energy required for cutting. The thrust force, F_t, acts in the direction normal to the cutting velocity, that is, perpendicular to the workpiece. These two forces produce the resultant force, R. The resultant force can be resolved into two components on the tool face: a friction force, F, along the tool-chip interface and a normal force, N, perpendicular to the interface. F_s is the shear force which causes shear deformation to occur in the shear plane. The rake angle is α, the shear angle is ϕ, and the friction angle is β.

Good students then went on to discuss the nature of each of these forces and how different cutting conditions [speed, feed rate, material, tool geometry] can affect the forces

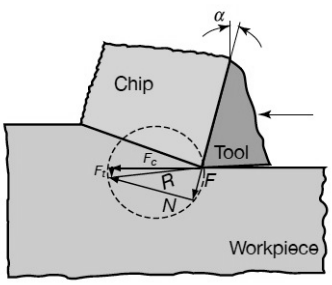


b)

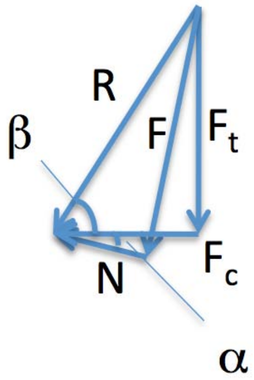
It is important to note that the use of a cutting fluid will reduce the friction force, F, at the tool-chip interface (as well as helping to reduce temperature etc)

This, in turn, will change the force diagram, hence the magnitude of the thrust force, F_t. Consider the sketch given below. It 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. Good students provided a formula for the relationship between Ft and friction coefficient.

The largest effect is on the thrust force, but there is also a noticeable effect on the cutting force.



c) Forces acting on the tool face can be developed from the following figure



Where
$$F = F_c \sin\alpha + F_t \cos\alpha$$
$$N = F_c \cos\alpha - F_t \sin\alpha$$

F/N = u (friction coefficient)

$$\mu = \frac{F}{N} = \frac{F_t + F_c \tan\alpha}{F_c - F_t \tan\alpha}$$

The friction angle β, is $\tan^{-1} \mu$

d)

from part c)

$$\tan\beta = \frac{F}{N} = \frac{F_t + F_c \tan\alpha}{F_c - F_t \tan\alpha}$$

For the initial case.

$$\tan\beta = \frac{740 + (1330)\tan - 5^0}{1330 - 740\tan - 5^0} = 0.447$$

therefore, β =24.1^0

With the application of a cutting fluid we have

$$\tan\beta = \frac{710 + (1200)\tan - 5^0}{1200 - 710\tan - 5^0} = 0.479$$

therefore, β=25.6^0

Thus, the cutting fluid has caused a change in β of 25.6-24.1 = 1.5^0

Question 3

Q3, Solution

(a)

Automated manufacturing gernerally involves:

- one or more machines
- producing families of parts with similar characteristics.
- integration of both work-piece and tool handling is typical

The role of the PLC in this environment is to:

- Coordinate the functions of different automated machines/devices
- Distribute operational commands to machines/devices
- Receive status/task complete reports from machines/devices
- Controls the sequence of production
- Manages logic decisions in production

(b)

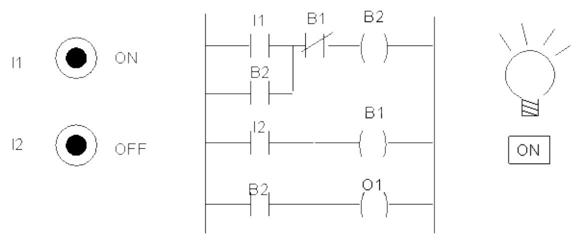
(i) The PLC scanning sequence: the series of three scan cycles run to operate the PLC

STEP 1: INPUT SCAN
- map external inputs to input image table

STEP 2: PROGRAM SCAN
- evaluate each ladder in sequence based on existing input image tables
- write the new outputs to the output image table

STEP 3: OUTPUT SCAN
- send output image table to output channels

(ii) An unlatching function: many inputs are momentary and to generate a permanent output it is possible to use the internal state of the PLC to generate a latch variable which permanently turns that state [and a connected output] on. An additional unlactching function ensures that the state is turned off when no longer needed:

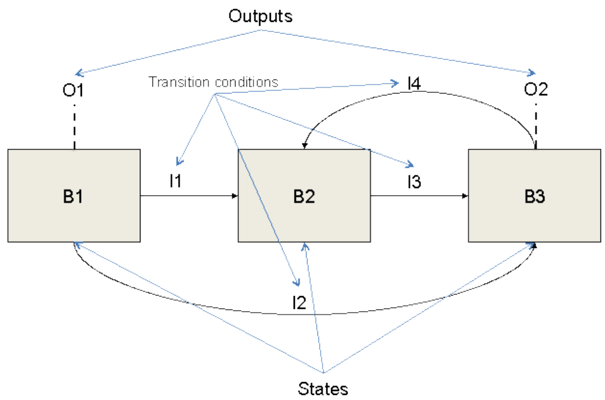


(iii) Timers and counters.

- Upward and downward counters are used to monitor the accumulation of events (e.g. parts passing a particular point). Once the accumulated counter reaches the preset value the rung (DN) becomes “true” or “on” and can be used as an alarm or as part of a resetting sequence. CD indicates that the counter is counting.

- 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.

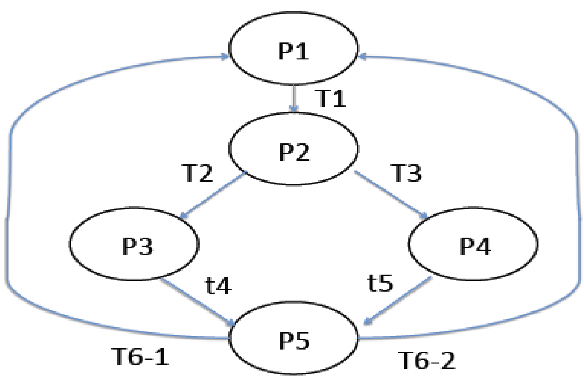
(iv) State machine diagrams: a means of demonstrating the connection between different independent states of a system. Additionally links to external inputs and outputs can be added. A simple state machine is given below.



c)
(i)

Rung	Description
1	Latch set when system has been powered on and is ready or that if already on, an item has left the detection system. Unlatched when there is a product in detector. P1: system ready/awaiting new product
2	Latch set to indicate product at detector unit. Unlatched by completion of successful or unsuccessful detection. P2: product at testing station
3	Latch set to indicate product has come from detector and unsuccessful test [defect] detected. P3: Product defective at quality test
4	Latch set to indicate product has come from detector and successful test detected. P4: Product passed quality test
5	Latch set to indicate product is now on either pass or expel conveyor and unlatched by departure signal from either conveyor P5: Part on Pass/Expel conveyor

(ii) A state machine along the lines of the following diagram is expected. There will be numerous variants possible, and the outcome will also depend on the interpretation of states in part (i). Good students also added logical NOT conditions to the transitions and associated states with with outputs and arcs with inputs to the PLC system.



Question 4

a)

(i) Initial marking: an initial marking of a petri net, M_0, is the assignment of tokens to specific places in the petri net indicating the starting point of the operation modelled by the petri net.

(ii) Enabling and firing: a transition is enabled is the required number of input tokens are available at the places at the transition input [as designated by the weights on the input arcs joining places to the transition

(iii) Concurrency: refers to a situation where two events must occur simultaneously and often a single transition is used to enable and hence mark the places associated with both events.

Good answers will also provide diagrams of examples to illustrate their response.

b)

(i) The detailed operations of the petri net are described below:

1. When the power is on, the pallet moves to station A automatically.
2. The pallet is idle at station A and waits for a new part.
3. Once the product detector locates a product on the pallet, the electrical motor is activated, which moves the pallet forwards to either station B or station C.
4. If a Part 1 is detected, then the pallet stops at station B. If a Part 2 is detected, then the pallet stops at station C.
5. When the part is removed from the pallet at station B or C, the pallet moves backwards to station A.
6. Return to step (ii) and repeat steps (ii) to (vi).

Good answers also assess the role of each of the sensors in the control logic and the different operating states of the conveyor motor.

(ii) The additions needed might include:

- Sensing: sensors to detect the presence and location of either or both parts on the pallet. A manual input or timer to indicate that the pallet loading is completed
- Logic: additional logic to deal with the possibility of a second part being added to the pallet. Logic to include a second unloading operation once the first is concluded.
- Actuation: ammendments to the actuation system to be able to deal with the part being in multiple locations on the pallet.

Good students also indicated how the petri net might be redrawn under these changed circumstances to enable a third logical strand involving both parts.