MET 2
MANUFACTURING ENGINEERING TRIPOS PART IIA

Friday 28th April 2023 9:00 to 10:40

Paper 2

MODULE 3P2: OPERATION AND CONTROL OF PRODUCTION MACHINES AND SYSTEMS

Answer two questions, one from each of sections ***A*** *and* ***B.***
Answers to sections ***A*** *and* ***B*** *must appear in 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.*
Write your candidate number <u>*not*</u> *your name on the cover sheet of each booklet.*

STATIONERY REQUIREMENTS
8 page answer booklet x 2
Rough work pad

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering data books

10 minutes reading time is allowed for this paper at the start of the exam.
You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.
You may not remove any stationery from the Examination Room.

SECTION A

Answer one question from this section.

Question 1

(a) Merchant developed a model to predict cutting forces in orthogonal cutting operations (refer to Fig. 1). What are the benefits of applying Merchant's cutting model? What assumptions did Merchant make in developing his model?

[10%]

(b) Sketch Merchant's force circle diagram that incorporates each of the principal force vectors when considering an orthogonal cutting operation. Comment on the feasible ranges of the key parameters in your diagram.

[20%]

(c) Using Merchant's model, derive the following relationship between the energy dissipated in the shear plane W_s and the energy dissipated in overcoming friction at the tool-chip interface W_f.

$$\frac{W_f}{W_s} = \frac{\sin\beta\, V_c}{\cos\big(\emptyset + (\beta - \alpha)\big)\, V_s}$$

Where α is the rake angle of the tool, β is the friction angle, ϕ is the shear plane angle, V_c is the chip velocity, and V_s is the shear velocity.

[30%]

(d) An orthogonal cutting operation is being carried out in which the undeformed chip thickness t_o = 0.13 mm, deformed chip thickness t_c = 0.2 mm, rake angle α = 10°, and cut width w = 3mm. It was observed that the cutting force F_c = 125 N, and thrust force F_t = 25 N.

(i) Calculate the percentage of the total energy dissipated in overcoming friction at the tool-chip interface. Comment on your answer.

[20%]

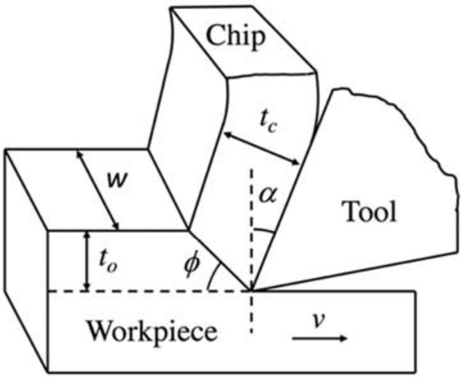
CONT)

(ii) Calculate the *shear stress* and the *shear strain* on the shear plane.

Comment on your answers.

[20%]

Merchant's Cutting Model



t_0	undeformed chip thickness
t_c	deformed chip thickness
α	rake angle
ϕ	shear angle
v	cutting speed
w	chip width

Forces in orthogonal cutting

R	Resultant force
F_t	Thrust force
F_c	Cutting force
F	Friction force
N	Normal force
F_s	Shear force
N_s	Normal force to shear plane
β	Friction angle

Forces on the shear plane

$$F_s = F_c \cos\phi - F_t \sin\phi$$

$$N_s = F_t \cos\phi + F_c \sin\phi$$

Forces on the tool-chip interface

$$F = F_c \sin\alpha + F_t \cos\alpha$$

$$N = F_c \cos\alpha - F_t \sin\alpha$$

Merchant's shear angle relationship

$$\phi = 45 + \frac{\alpha}{2} - \frac{\beta}{2}$$

Fig 1.

TURN OVER

Question 2

(a) (i) Define the term Statistical Process Control (SPC) and describe how it is employed in manufacturing environments.

[5%]

(ii) Define *Chance* and *Assignable* causes of quality variation.

[5%]

(b) In SPC, control charts are used to gather information about the performance of a manufacturing process. *Attribute* and *Variable* control charts are commonly used. Describe their specific features and highlight one example application for each approach.

[30%]

(c) A company manufactures a metal component and employs SPC to assess defect levels. The sampling plan for the product calls for 10 samples of 100 parts each to be taken at intervals and tested. The data acquired is shown in Table 1. Stating any assumptions, determine whether the process is in control. Outline the actions you might take as a result of your findings.

[30%]

Sample Number	Number of defective parts
1	9
2	7
3	13
4	4
5	12
6	14
7	8
8	16
9	6
10	11

Table 1

CONT)

(d) The company wishes to acquire a new machine and performs a series of trials to determine the machine's capabilities in turning high-precision spindles with a low surface roughness. Five surface roughness measurements were taken on each of ten spindle samples. The acquired data is shown in Table 2 and Table 3 provides Control Chart Factor data. Sketch $\bar{X}$ and R charts for this data. What do the charts tell you about the capability of the machine? What other information would you need to make an informed purchase decision?

[30%]

Sample	**Mean Surface Roughness Rz (μm)** $\bar{X}$	**Range (μm)** **R**
1	4.98	0.08
2	5.00	0.12
3	4.97	0.08
4	4.96	0.14
5	4.99	0.13
6	5.01	0.10
7	5.02	0.14
8	5.05	0.11
9	5.08	0.15
10	5.03	0.10

Table 2

Sample Size n	Mean Factor A_2	Upper Range D_4	Lower Range D_3
2	1.880	3.268	0
3	1.023	2.574	0
4	0.729	2.282	0
5	0.577	2.115	0
6	0.483	2.004	0
7	0.419	1.924	0.076
8	0.373	1.864	0.136
9	0.337	1.816	0.184
10	0.308	1.777	0.223
12	0.266	1.716	0.284

Table 3

TURN OVER

SECTION B

Answer one question from this section.

Question 3

(a) Machine tools play a central role in many manufacturing operations, and are required to operate in a fully automated, unattended manner on a regular basis. Discuss the different issues that need to be considered in preparing a machine tool to operate in this manner and the support approaches typically used to manage each issue.

[20%]

(b) The management of vibrations is critical for effective machine tool performance. Discuss three approaches taken in the design of a machine tool to ensure the vibrations that occur during its operation are minimised, suggesting the limitations of each approach.

[15%]

(c) An upgraded position control system for a machine tool is being considered, where the original proportional controller, denoted K_1, is being replaced by a new proportional, derivative controller K_2. A simplified, *G*, of the cutting tool dynamics (from cutting force to end effector position) and models of the two controllers and are given below:

$$G = \frac{1}{1 + 2c\frac{s}{w_N} + \frac{s^2}{{w_N}^2}}$$

$$K_1 = k_P$$

$$K_2 = k_P + sk_D$$

where $c = 0.2,\ w_N = 500\,rad\ s^{-1}, k_P = 0.44\,, k_D = 1.6 \times 10^{-2}$.

CONT)

(i) Draw a clearly labelled feedback diagram for the closed loop system involving the machine tool model, G, and the original controller K_1 showing the reference signal, r, position output, y, and a vibration disturbance, d, at the input to the machine tool. Determine the transfer functions from r to y and from d to y.

[15%]

(ii) If the most damaging vibration disturbances experienced by the machine tool were at 450 rad s^{-1}, determine the level of improvement (in terms of vibration amplitude reduction) achieved when the new controller K_2 replaces K_1.

[35%]

(iii) What additional precautions could be taken to ensure the control system minimises these vibrations and manages the level of control force used?

[15%]

TURN OVER

Question 4

(a) Explain what is meant by the following terms used in relation to Petri Net models.

(i) The marking of a Petri Net.

(ii) The enabling and firing of a transition.

(iii) The weight on an arc.

(iv) An inhibitor arc.

[20%]

(b) A simplified Petri Net model of the operations on a drilling station is illustrated in Fig 2.

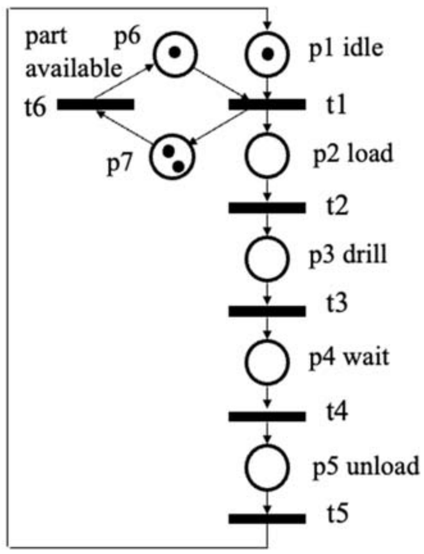


Fig. 2

(i) What is the initial marking of this system and what is the marking of the model after transition t_1 has fired?

[5%]

(ii) Place p6 indicates whether a part is available for drilling. What is the role of p7?

[5%]

CONT)

(iii) The drilling operation modelled in Fig. 2 is to be integrated into a simple automated production cell illustrated in Fig. 3. A single robot moves parts from an incoming parts station to the drilling station and also removes completed parts to an outgoing parts station which can hold up to three completed parts at a time. Stating any assumptions you make, extend the Petri Net given in Fig 2. to integrate the robot and the outgoing parts station.

[30%]

(iv) Referring to your extended Petri Net, explain how your proposed approach can ensure the system is able to operate in a safe and deadlock free manner.

[20%]

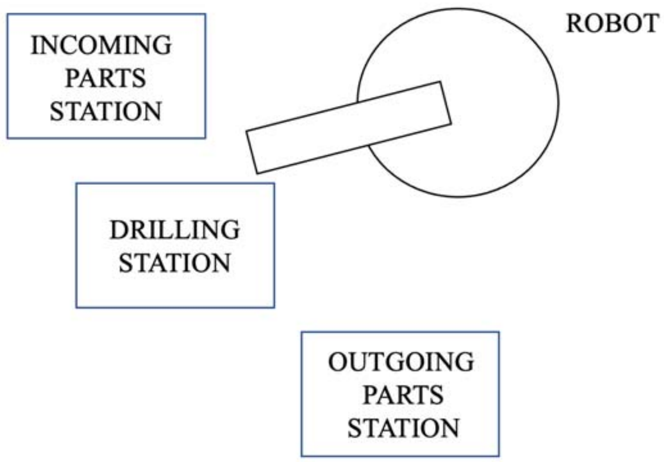


Fig. 3

(c) It is proposed that an inspection station be introduced into the cell described in part b) such that one in every three drilled parts is inspected for drilling quality prior to moving to the outgoing parts station. Describe how this inspection process could be modelled using a Petri Net.

[20%]

END OF PAPER

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