Version WON/4

MET2
MANUFACTURING ENGINEERING TRIPOS PART IIA

Thursday 25 April 2019 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 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.*

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS
8 page answer booklet x 2
Rough work pad
Linear graph paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book

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.

SECTION A

Answer **one** question from this section.

1 (a) Merchant's orthogonal cutting model is widely used to understand the basics of force and power of the cutting process. Information on this model is shown in Fig.1.

(i) Why is it necessary to understand the forces and power involved in cutting operations?

(ii) What assumptions did Merchant make in the development of his model?

(iii) How can the main forces at work during an orthogonal cutting operation be determined? Sketch a free body diagram showing their relationships. [30%]

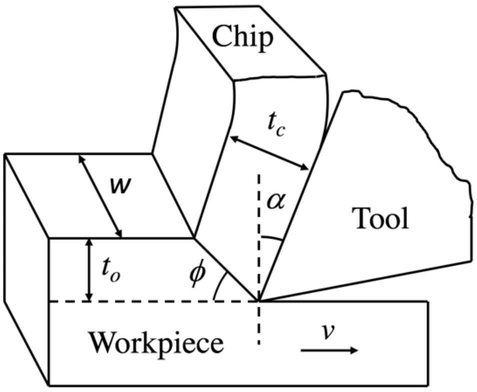
(b) (i) The shear stress τ is the apparent shear strength of the material that has to be overcome to form a chip along the shear plane. Show that [10%]

$$\tau = \frac{(F_c \cos \emptyset - F_t \sin \emptyset) \sin \emptyset}{w t_0}$$

(ii) A material undergoes an orthogonal cutting operation using a tool with a rake angle α = +10°. During this operation the cutting force F_c and thrust force F_t were found to be 400 N and 150 N respectively. If the rake angle is adjusted to +15° with all other cutting conditions unchanged, determine the magnitudes of the new cutting force and thrust force. State your assumptions and comment on your results. [40%]

(c) Explain why the thrust force F_t is not always positive. Describe the conditions under which $F_t = 0$. [20%]

Merchant's Cutting Model



t_o	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

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

Fig.1

(TURN OVER

2 (a) Compare the attributes of *additive manufacturing* and *machining* when manufacturing metal components. Your answer should include consideration of the following attributes: part size; part complexity; accuracy; surface finish; and lead-time. [20%]

(b) The preparation of CAD data is an important first step in any additive manufacturing process. The STL file format is commonly used when converting CAD data into a form used by all additive manufacturing systems.

(i) Describe the essential features of the STL file format and state the *three* essential rules it must follow. [10%]

(ii) Show how the format can influence the resolution of an additively manufactured part. [10%]

(c) A selective laser melting machine is being applied in the production of solid cylinders. The required diameter of each cylinder is 10 mm ± 0.3 mm. In proving trials, the machine manufacturer produced a number of cylinders, and the following data were obtained: $\bar{\bar{X}}$ = 10.06; UCL = 10.14; LCL = 9.99; with a standard deviation of 0.05. For the Range data, $\bar{R}$ = 0.12 and UCL = 0.26. The machine was said to be operating in control and within specification. The customer wishes to validate the manufacturer's data by performing their own trials. Fig.2 shows the plan view of the build chamber following the production of 25 cylinders each produced at different locations on the bed, positions 1 to 25. The optical axis of the system is centred at position 13. The diameter of each cylinder is measured 5 times and its location on the bed is noted. This data represents one subgroup. The measurement data of the 25 subgroups is collated in order to create a pair of Statistical Process Control charts. This data is presented in Table 1.

(i) Sketch and annotate an X-bar chart and R chart for the data in Table 1. What do these charts tell you about the performance of the machine? [20%]

 (cont.

(ii) Compare the C_p and C_{pk} values for the manufacturer's data and those obtained from the data in Table 1. Comment on your results. [20%]

(iii) What are the likely assignable causes of variations observed? What improvements could you make to the machine operations? [20%]

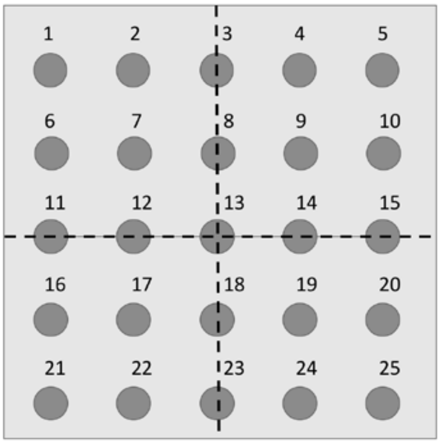


Fig. 2

Subgroup	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Average	10.60	10.50	10.40	10.50	10.60	10.50	10.15	9.90	10.15	10.50
Range	0.35	0.25	0.25	0.25	0.35	0.25	0.15	0.10	0.15	0.25
Subgroup	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Average	10.50	10.10	10.00	10.10	10.50	10.50	10.15	9.90	10.15	10.50
Range	0.25	0.10	0.10	0.10	0.25	0.25	0.15	0.10	0.15	0.25
Subgroup	**21**	**22**	**23**	**24**	**25**					
Average	10.60	10.50	10.40	10.50	10.60					
Range	0.35	0.25	0.25	0.25	0.35					

Table 1

SECTION B

Answer **one** question from this section.

3 (a) Fig. 3 outlines the typical decision hierarchy for a manufacturing plant:

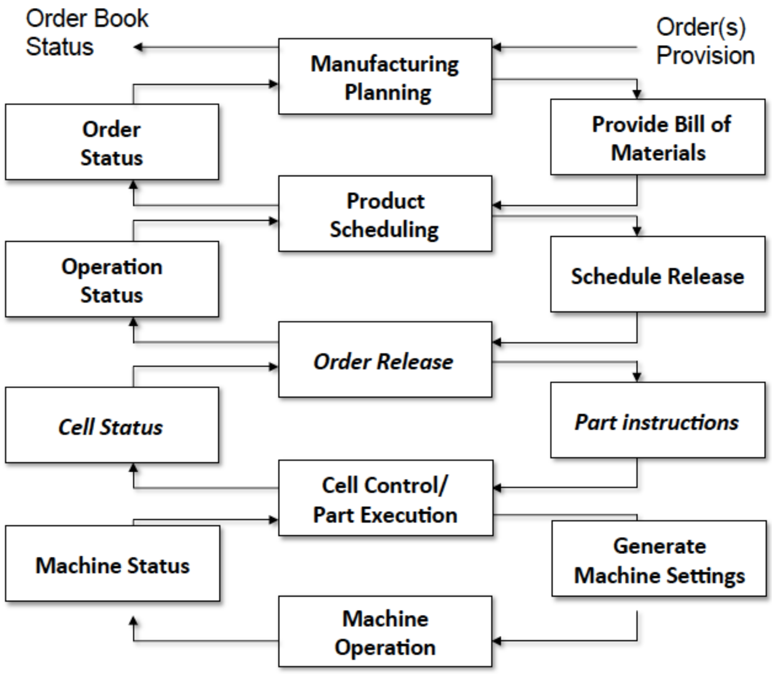


Fig.3

(i) For each of the decision loops in Fig.3, comment on the different information processing requirements, and explain why a hierarchical approach is generally taken for the integration of manufacturing information. [20%]

(ii) For each of the decision loops in Fig.3, outline the computing and communications systems typically used and the main characteristics of each. [20%]

(iii) Comment on how new developments in industrial automation might influence your responses in (i) and (ii). [20%]

(b) A new manufacturing cell is planned within an existing factory. It will comprise machining, assembly operations, a robot for materials handling, and a part storage facility. A machining centre and robots for assembly and materials handling are each supplied with their own controllers. The cell needs to be automated and integrated with the existing factory operations. Stating any assumptions that you make, what additional features would be required to fully automate this cell? Your discussion should include reference to the automation of:

(i) the physical systems;

(ii) the information and control processes;

(ii) the interfaces between the physical and information environments. [40%]

4 (a) Discuss the advantages of using each of the following control strategies for position feedback control in a machining process:

(i) Proportional (P) control;
(ii) Proportional Integral (PI) control;
(iii) Proportional Integral Derivative (PID) control

Indicate under which circumstances a Proportional Derivative (PD) controller might be appropriate. [25%]

(b) The position control system for a milling machine tool adjusts spindle force to ensure the machine tool follows a correct position trajectory.

A transfer function representing the (simplified) relationship between spindle force and tool tip position is given by:

$$G(s) = \frac{{\omega_n}^2}{s^2 + 2\zeta\omega_n s + {\omega_n}^2}$$

where $\omega_n = 1\ rad/sec, \zeta = 0.15$, and s denotes the Laplace variable.

A controller of the following form is used to provide feedback position control

$$K(s) = K_p + K_D s,$$

where $K_p = 8$, $K_D = 2$.

(i) Determine the resulting damping from the closed loop system and compare it to the original (open-loop) damping. Comment on the difference. [30%]

(ii) What would be the effect of increasing the parameter K_D? [15%]

(c) How might you use adaptive control in the context of the machining control system introduced in (b)? Justify your approach. [30%]

END OF PAPER

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