MET 2
MANUFACTURING ENGINEERING TRIPOS PART IIA

Friday 26 April 2024 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) In the context of machining operations, identify the sources of error that influence the process and its outcomes.

[20%]

(b) In statistical process control (SPC), what are *control limits* and why do they change over time?

[20%]

(c) A manufacturing plant produces metal shafts, and the diameter of these shafts is a critical quality attribute that must be closely monitored. The design specification for the shaft diameter is 50 mm ± 0.5 mm. Data was collected from 5 consecutive days of production. Each day 5 shafts were randomly selected and measured for diameter ϕ (mm). This data is shown in Table 1.

Day 1	50.1	49.8	50.2	49.9	50.0
Day 2	50.3	50.1	50.2	50.4	50.3
Day 3	49.9	50.0	49.8	50.1	49.7
Day 4	50.2	50.3	50.5	50.4	50.1
Day 5	49.8	50.0	49.9	49.7	50.1

Table 1.

(i) Construct X-bar and Range charts from the data in Table 1 and comment on your findings. Control chart factors are given in Table 2.

[30%]

(ii) Given that the standard deviation of the process, $\sigma = 0.2246$, calculate the value of the process capability index, C_{pk}. Is the process capable and in control?

[15%]

(iii) Based on your findings, what recommendations would you make to the manufacturing team to improve their process?

[15%]

(cont.

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

Table 2.

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Question 2

(a) Laser Powder Bed Fusion (LPBF) is an additive manufacturing process used for producing metal parts with complex geometries.

(i) Discuss four main challenges in achieving optimum part density and strength in the LPBF process.

[10%]

(ii) Describe the main factors that influence part resolution and surface finish.

[20%]

(b) In the LPBF process *volumetric energy density* (VED) and *melt rate* (MR) are crucial parameters.

(i) Define the terms VED and MR. How do VED and MR influence process optimisation?

[15%]

(ii) A LPBF machine is being tested to identify its optimum process parameters. Seven test cubes have been produced and their densities have been measured. The results are shown in Table 3. Sketch a graph of Density against VED and discuss the reasons why it takes this form.

[25%]

(c) *Laser scanning strategy* is another means of controlling the LPBF process.

(i) Describe the key parameters that can be used to develop an optimised laser scanning strategy.

[20%]

(ii) Cite two advantages *and* two disadvantages of a density optimised laser scanning strategy.

[10%]

(cont.

Laser Scanning speed (mm/s)	Laser Power (W)	Hatch Spacing (mm)	Layer Height (mm)	Density (%)
800	200	0.1	0.05	95.0
700	200	0.1	0.05	96.0
600	200	0.1	0.05	97.5
500	200	0.1	0.05	99.0
400	200	0.1	0.05	99.5
300	200	0.1	0.05	99.0
200	200	0.1	0.05	97.5

Table. 3.

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SECTION B

Answer one question from this section.

Question 3

(a) Demonstrate, using appropriate diagrams, the way that Petri Nets can be used to manage issues of:

(i) Causality of operations;

(ii) operations required to occur concurrently;

(iii) prioritisation of one operation over another.

For each issue provide examples from an industrial automation setting.

[30%]

(b) The Petri Net in Fig. 1 models the material flow for an existing production line. Parts A and B are first machined in separate CNC machines, and finished parts are stored in separate Work in-Progress (WlP) buffer areas. Finally, both parts are transferred for assembly.

The production line has to be modified to incorporate the following factors:

1. Add a material handling robot, which is used to load parts to, and unload parts from, both CNC machines.
2. Limit the space in WlP Buffer 1 (for part As) to five parts.
3. Limit the space in WlP Buffer 2 (for part Bs) to ten parts.
4. Introduce an additional transfer robot able to transfer 1 of part A and 2 of parts B at the same time to the transfer station.

(i) Redraw this Petri Net to incorporate the required changes, ensuring that Part A has priority over Part B in loading, that unloading is always prioritised over loading, and that the operation is deadlock-free. Explain the role of each new place, transition, arc, and weight you have introduced in your diagram. State any assumptions made.

[40%]

(cont.

(ii) Comment on how your model would change if separate loading and unloading robots were introduced and were able to operate simultaneously. If it was subsequently decided that for safety reasons that only one could operate - while the other was required to be idle - what effect would that have? State any assumptions made.

[30%]

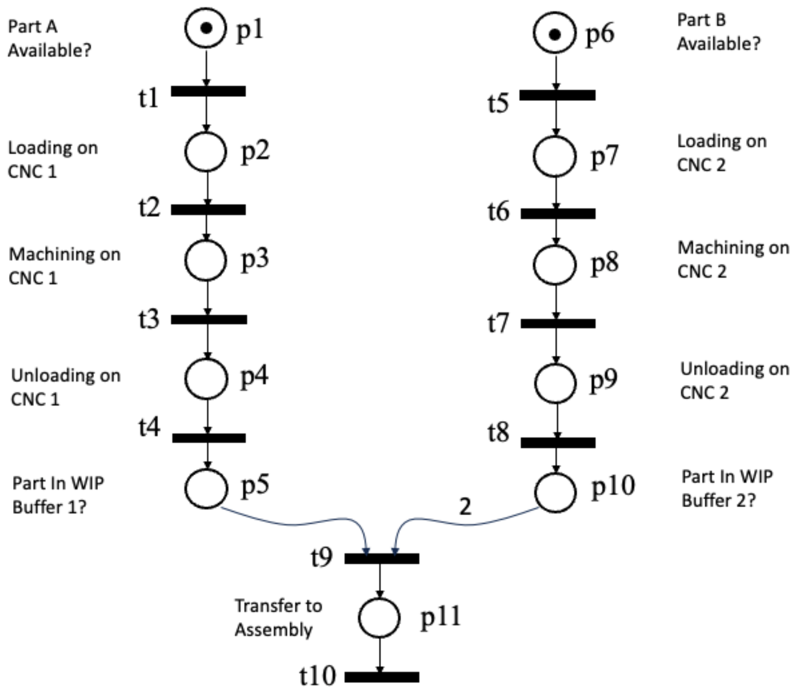

Fig 1

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Question 4

(a) Machine and cell level operations play a key role in the control hierarchy of a factory. Stating any assumptions,

(i) discuss key operations and decisions typically made at each of these levels providing examples,

[10%]

(ii) identify any issues which need to be considered if the operations are to be automated in each case,

[10%]

(iii) identify any further issues which need to be considered if the automated system in each case is to operate continuously in a "stand-alone" mode, with little or no human support.

[10%]

(b) A gearbox manufacturer has machining requirements that typically consists of several turning and drilling operations - the exact number and type depending on the gear box specification. The manufacturer has acquired a suitable machining centre and is in the process of integrating it into the factory. To begin, the machine will be manually loaded and unloaded.

(i) Given the type of product and machining operations, what are the opportunities for automation?

[20%]

(ii) Increased demand means that the machining centre will need to run up to 24 hours per day with little or no human input. What factors would you need to consider in planning this development?

[30%]

(c) It is proposed to connect the machining operation directly to the downstream gear box assembly operation and fully automate the process. An identical second machining centre is purchased to balance the machining and assembly throughputs. Stating any assumptions, comment on additional automation requirements for such a modification, especially if the operation will need to run stand alone for significant periods of time.

[20%]

END OF PAPER