Manufacturing Qualifying Examination Syllabus

Exam Contents: (will be based on material covered in the following courses)

ME 451, Computer-aided manufacturing Systems
ME452, Numerical Control of Manufacturing Processes
ME 350, Design for Manufacturability

Exam Topics:

1. Processes (Part A)
   - Material removal processes (incl. metal cutting theory)
   - Metal casting processes
   - Metal forming and shaping processes
   - Processing of polymers, composites, and ceramics
   - Assembly, materials handling, robotics, and CIM (incl. DFA)
   - Rapid Prototyping
   - Mechanistic and empirical modeling (incl. Design of Experiments)
   - Process selection (advantages/disadvantages, economics, recommendations, etc.)
   - Manufacturing Cost Analysis (incl, DFM principles)

2. Systems (Part B)
   - Computer-Aided Design
     Geometric Modeling
     Surface and Feature-based Modeling
   - Cellular and Lean Manufacturing Systems
   - Computer Numerical Control (CNC) systems
     Fundamental of CNC
     Programming of CNC machines
     Design and Analysis of CNC loop
   - Robotics
     Classification and structure of robotic systems
     Trajectory planning and programming of industrial robots
QUALIFYING EXAMINATION

FOR

Manufacturing

Department of Mechanical and Industrial Engineering
University of Illinois at Urbana-Champaign

Wednesday, August ___
9:00 AM – 12:00 PM

IMPORTANT EXAMINATION INFORMATION

1. Identify your examination and work with your University Identification Number (UIN, I-Card number in blue beginning with 65) on each page. DO NOT ENTER YOUR NAME ANYWHERE IN THE EXAMINATION.

2. Choose 3 out of the 4 problems.

3. Each problem counts 10 points.

4. Start each problem in a new examination booklet and write on only the right-hand side (front side) of each sheet.

5. Hand in this problem package with your exam booklets.
Part A

Manufacturing

Question 1.

a) Name a process for each of the following descriptions:

i) A final finishing process for producing cylindrical internal surfaces to a surface finish of 0.2 µm, or better.
ii) A process for producing plastic parts at very high production rates
iii) A process for creating holes and notches of various shape in sheet metal
iv) A process for creating bends in sheet metal, suitable for low production volumes.

b) The face milling application, illustrated below, has a 3 mm depth of cut (into the paper), starts at point A, moves to point B at the programmed machining feed rate of 12 mm/sec, and returns to A again at the rapid traverse rate of 80 mm/sec to complete the operation.

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a) What is the machining time \( t_m \) (mins) for the operation.
b) The average material removal rate (mm\(^3\)/min).
c) The maximum material removal rate (mm\(^3\)/min).
d) Find the engagement time, \( t_e \), of a single insert with the workpiece.
e) The specific cutting energy for the material being machined is 3.0 W.s/mm\(^3\), and the efficiency of the machine is 80%. What is the smallest milling machine (power rating) which should be selected to perform the operation.

c) Draw Merchant’s circle for a typical single-point metal cutting process. Label each force and angle, and describe their contribution to achieving good cutting conditions.
Question II.

a) The diagram below shows a simple rolling configuration with 180 mm diameter rolls rotating at 250 rpm. The strip of AISI 1020 carbon steel being rolled is 400 mm wide (note: no spreading occurs during the rolling operation) and starts out at a thickness of 20 mm. Assuming that the maximum possible draft is used, and that the coefficient of friction $\mu$ is approximately 0.3, determine the following:

![Rolling Configuration Diagram]

- i) the final thickness of the rolled strip (mm).
- ii) assuming that the average stress $Y_{\text{avg}}$ is 280 MPa, the roll force (N).
- iii) the required power (W).

b) The shaping process is being used to reduce the height of the casting, shown below, by 6 mm. The cutting speed, return speed, and cross indexing speed are 2 m/sec, 10 m/sec, and 20 mm/sec (yes units are correct...only a small cross index motion!) respectively. The incremental cross indexing feed is 0.5 mm/pass. Three complete operations at equal depth of cut are required to reduce the workpiece to the required dimensions. Assume that the stroke length of the tool is equal to the length of the part plus 10%.
The following parameters should be assumed: handling time \( t_h \) and tool change time \( t_c = 5 \) mins., Taylor's C and \( n = 150 \) and 0.2 respectively (time in mins and velocity in m/mins), sales revenue \( R_n = \$60 \), tool cost \( C_t = \$5.00 \), labor and overhead cost \( C_o = \$30/hr \).

a) Calculate the total number of required passes, \( N_p \).

b) Find the total machining \( t_m \) time (mins).

c) Find the tool engagement time \( t_e \) (mins).

d) Derive a general expression, for one complete surface operation using this Shaping Process, for unit cost in terms of \( t_m, t_c, t_h, C_t, C_o, V, \dot{V}, V_r, f, L, N_p, C \) and \( n \).

e) Evaluate unit cost for the total three complete surface operations: ($)
Part B

Manufacturing

1(a) Give one positive and one negative characteristic of each of the following solid modelling representations:

(i) wire-frame
(ii) B-Rep
(iii) CSG
(iv) octtree

1(b) Outline a procedure to find a B-Spline curve that interpolates a set of N given points. Explain what parameters must be selected, and, if possible, describe a method for selecting these parameters. Explain what system of equations must be solved. Some relevant definitions for the B-Spline representation are given on an attached page following this exam question.

1(c) Given a general 3x3 rotation matrix, $^A R_B$, and a displacement vector, $^A q$, construct a 4x4 homogeneous transformation matrix, $^A T_B$. Explain the notation, and show how this matrix can be used to transform a vector $^B p$ into $^A p$ (i.e. set up an matrix equation that returns $^A p$ given $^B p$). Derive the inverse transformation matrix, $^B T_A$, and show that it can be used to obtain $^B p$ given $^A p$. 
Part B

Manufacturing

2(a) Answer the following:

(i) Explain the concepts of “feature-based” and “parametric” design.
(ii) Explain what a Voronoi diagram is, and how it is relevant for tool-path generation.
(iii) Describe the issues in selecting a build direction for SLA.
(iv) Sketch a SCARA robot configuration, and explain how it is commonly used.
(v) Explain the role of an interpolator in an NC control system.

2(b) Consider the two DOF planar manipulator shown below. There are two revolute joints. The joint variables are $\theta_1$ and $\theta_2$. Write out the forward kinematics for this manipulator. Derive the differential kinematics and the Jacobian matrix (You do not need to follow a formal procedure such as Denavit-Hartenberg). Show that the Jacobian matrix is singular for certain positions of the manipulator, and explain the practical significance of this.

![Two-arm revolute manipulator](image)

2(c) Consider a B-Spline curve, $\mathbf{P}(u)$ of order $k$, with $n+1$ control vertices, $\mathbf{P}_i$, and a uniform non-periodic knot vector, $t$. Show that any such B-Spline curve will interpolate the first vertex of the control polygon, $\mathbf{P}(t_{k-1})=\mathbf{P}_0$. Some relevant definitions for the B-Spline representation are given on an attached page following the exam questions.
Definitions for the B-Spline Curve Representation:

\[ P(u) = \sum_{i=0}^{n} P_i N_{i,k}(u) \quad (t_{k-1} \leq u \leq t_{n+1}) \]

\[ N_{i,k}(u) = \frac{(u-t_i)N_{i,k-1}(u)}{t_{i+k-1} - t_i} + \frac{(t_{i+k} - u)N_{i+1,k-1}(u)}{t_{i+k} - t_{i+1}} \]

\[ N_{i,1}(u) = \begin{cases} 1 & t_i \leq u < t_{i+1} \\ 0 & \text{otherwise} \end{cases} \]

Uniform Non-Periodic Knot Spacing:

\[ t_i = \begin{cases} 0 & 0 \leq i < k \\ i-k+1 & k \leq i \leq n \\ n-k+2 & n < i \leq n+k \end{cases} \]