MSE 480/780 – Mid-Term Exam

Friday, February 24th, 2:45pm, Room 3170

Non-programmable calculators may be used. With the instructor's permission,
specific programmable calculators may be used provided that all memory is
cleared before the exam begins and any communication capabilities are disabled.

Web-enabled devices, smart phones, smart watches, etc. are <u>not</u> permitted

One page (8.5" x 11", both sides) of handwritten notes is permitted

SFU ID cards must be available for inspection and students must sign the
attendance sheet provided

Students must seat themselves according to the seating assignment provided
(exceptions will be handled by the course instructor as needed)

Only one student at a time will be permitted to leave the room to use the washroom
(escorting may also be implemented)

Provide all final answers <u>clearly</u> and <u>unambiguously</u> in your exam booklet.

Total Marks: **40**

This exam has <u>3</u> pages

Problem 1 (20 Marks)

A two-toothed milling cutter is being used in an up-milling operation. Following are the parameters describing the machining operation. It may be assumed that the equivalent chip thickness (h_{eq}) is approximately equal to the feed per tooth (s_t) in each pass.

Depth of cut (a): 3.5mm

Entry angle (Φ_1): 0

Exit angle (Φ_2): $2\pi/3$

Swept angle of cut (Φ_s): $2\pi/3$ (i.e. two thirds-immersion)

Tool Radius (R): 12.5mm

Feed Per Revolution (s): 0.08 mm

Spindle Speed: 700 RPM

Cutting Force Constant (K_1): 1900 N/mm^2

Critical Chip Thickness (h*): 0.01 mm

Cutting force ratio (r_1): 0.25

Cutting force ratio (r_2): 2.2

Chip Flow Angle (Ψ_e): $\pi/4$

<u>Part a (5 marks)</u>

Plot (sketch) the corresponding cutting torque versus time for one complete revolution of the cutter (during steady state cutting), clearly indicating the scale (and/or key values) of torque on your diagram.

Part b (5 marks)

Calculate the <u>maximum</u> values of the following, occuring during one complete revolution of the cutter.

- Cutting Torque, T_c (N*m)
- Tangential Force, F_t (N)
- Thrust Force, F_{th} (N)
- Radial Force, F_r (N)
- Axial Force, F_z (N)

Part c (5 marks)

The operator would like to increase the feed rate for the operation described above (leaving all other parameters unchanged). The machining system's spindle is rated for a continuous power output of 0.4 kW. Assuming that this is the most stringent constraint in the operation described above, what would you recommend as the maximum feed per revolution (mm)?

Part d (5 marks)

Ignore Part d (not covered in Spring 2018)

Problem 2 (20 Marks)

Consider the manipulator shown to the right (no end effector is attached), with Joint #1 omitted from the diagram. Note that the x-axis (x_0) corresponding to the world frame (F_0) points out of the page as shown. The x_0 axis is also perpendicular to (and passes through) the axis created by link zero, and must be used as shown in solving all parts of this problem. In the starting configuration with all joint variables equal to zero (as shown), all links rest within the plane of the page.
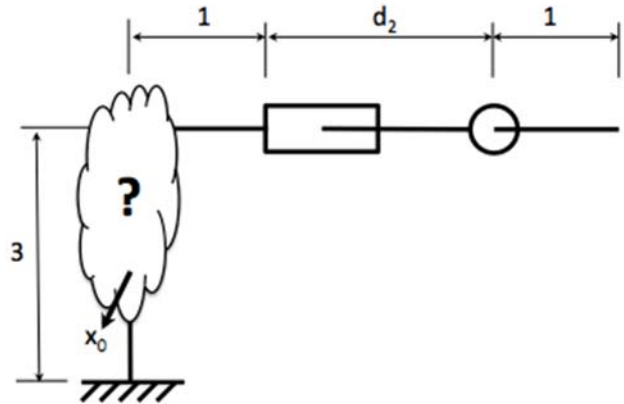
Part a (5 marks)

Assuming that the following homomogeneous transformation (A_{01}) corresponding to the missing Joint has been developed using the Denavit-Hartenberg (DH) convention as applied in this course, sketch the complete manipulator (including Joint #1) in your answer booklet.

$$A_{01} = \begin{bmatrix} \sin\theta_1 & \cos\theta_1 & 0 & 1.5\sin\theta_1 \\ -\cos\theta_1 & \sin\theta_1 & 0 & -1.5\cos\theta_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Part b (10 marks)

Making use of your complete sketch (and A_{01} as given above), assign frames to the manipulator following the DH convention. Clearly list the resulting table of DH parameters (including those for Joint #1) and develop the homogenous transformations A_{12} and A_{23}.

Part c (5 marks)

Assuming now that an end effector (gripper) is attached to the manipulator above as shown to the right (with the approach vector extending to the right and the normal vector directed out of the page), construct the final transformation matrix A_{3t}