MAS419 - Modeling and Simulation of Mechatronic Systems

Introduction

This project is a part of the course MAS416 Modeling and Simulation at the University of Agder. The course is at Master level and is taken by students in Mechatronics and Renewable Energy. The project consists of the following parts:

- Create a dynamic model of an industrial robot from ABB using Simulink/Simscape. This robot has six degrees of freedom and contains a parallel linkage system. At the robot's wrist, an electric machining spindle is attached.
- The tip of the spindle should follow a certain path, see Fig. 3, during the operation of interest. Make some Matlab code that computes a reference position and a reference velocity for the tip of the robot for the entire operation.
- In Simulink/Simscape make the tip of the spindle follow the prescribed path, see details under "Robot load case". Use the Matlab code in the Simulink/Simscape model to compute the reference position and velocity for the tip of the robot.
- In Simulink/Simscape develop a model with geared servomotors as drivers for each axis. Use the joint angles and joint velocities from the previous step as reference.
- Optimize the design so that the robot costs as little as possible and moves as fast as possible through the prescribed path, see details under "Robot design".

The machine which is shown in Figs. 1 and 2.

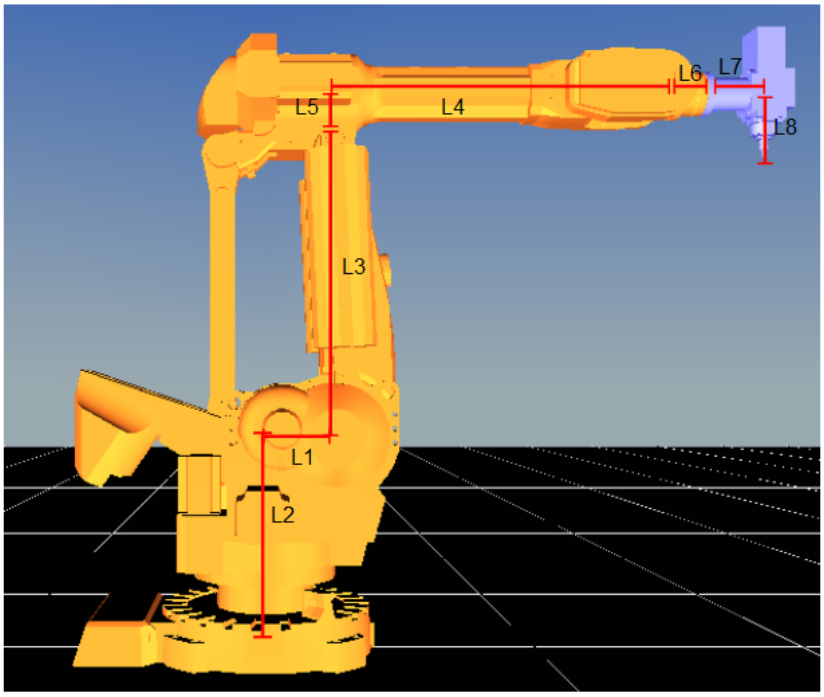


Figure 1 ABB-robot with some of the basic measurements = open loop kinematic parameters, $L_{1..8}$.

Simulink/Simscape modeling
In Simulink/Simscape it is recommended to design the model as a multibody dynamics model and then add components from rotational mechanics, power transmission and signals as needed.

The robot itself contains a single closed chain and when the tool point (point J in Fig. 2) is to be prescribed this must be done by introducing a second (virtual) closed chain.
There are six driven revolute joints, see Tab. 1.

Table 1 Actuated revolute joints.

Point	Axis	Reference body	Driven body
A	Reference z-axis	Frame	BLUE
B	Out-of-the-plane	BLUE	GREEN
B	Out-of-the-plane	BLUE	RED
G	Along GH-line	CYAN	GRAY
H	Out-of-the-plane	GRAY	BLACK
I	Along HI-line	BLACK	LIGHT BLUE

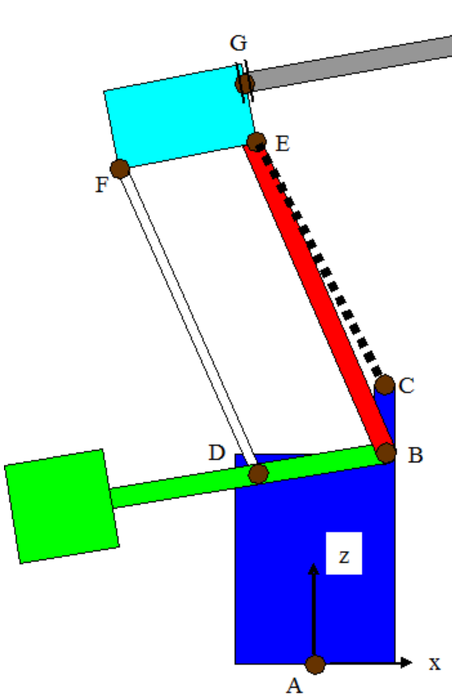


Figure 2 Simplified kinematic model of ABB-robot. The right hand reference coordinate system is shown in point A.

The machine has the following open loop kinematic parameters (all units in mm):

$$L_{1..8} = [240 \quad 800 \quad 1050 \quad 1175 \quad 225 \quad 200 \quad 235 \quad 248]\ mm$$

The links BE and HI are limited in motion.
The rotation of the link BE is limited to $\pm 80°$ relative to vertical and the rotation of the link HI is limited to $\pm 90°$ relative to the centre line from G to H.
Between point C and E a single spring is suspended. The undeformed length and stiffness of the undamped spring are 750 mm and 100 kN/m, respectively.

The kinematic and inertia data (inertia data relative to mass center and local coordinate system) of the different bodies are given in Appendix A. Any other geometry data can be chosen freely but should reflect the approximate dimensions of the robot.

Robot load case

The point J must start from rest in point P1, pass through points P2..P4, and finish in point P5 where it should come to rest. The coordinates of the five points are listed in Tab. 2. During the entire period of operation the tool (Body IJ) should translate, i.e., L7 must remain horizontal (+/- 0.2º) and L8 must remain vertical (+/- 0.2º), and the tool must not rotate around the L8-axis (+/- 0.2º), see Fig. 1.

Table 2 Coordinates of path points relative to reference coordinate system (closed loop).

Point	**x [mm]**	**y [mm]**	**z [mm]**
P1	2000	500	1600
P2	2000	-500	1600
P3	1600	500	900
P4	1600	0	900
P5	2000	500	1600

Point J must start exactly at P1 and it must pass P2..P4 within a distance of 3 mm and come to rest at P5=P1 within a distance of 1 mm.

Robot design

The six actuated revolute joints are all driven by geared servomotors. You can choose any of three different servomotors for each of the six axes. The three different servomotors should all have a mass moment of inertia J = 0.002 kgm^2 and the maximum current is $I_{max} = 16\ A$. The motor torque constant that can be any of the three values:

Motor torque constant, K_m	0.5 Nm/A	1.0 Nm/A	1.5 Nm/A
Motor dimensionless cost	1	1.25	1.5

The motor torque, M_m, must lie within the interval: $-M_{max} \leq M_m \leq M_{max}$, where $M_{max} = K_m \cdot I_{max}$.

The gearboxes are to be modeled as ideal with one of the following four gear ratios:

Gearbox ratio	20	50	100	200
Gearbox dimensionless cost	1	1.25	1.5	2.5

Design the robot (choose servomotors and gearboxes) and prescribe the motion P1-P2-….-P5 so that the total cost of the servomotors and gearboxes are minimized and the total time P1-P2-…-P5 is minimized.

Energy costs

The total energy costs should be minimized for the robot. The energy costs should be divided into two parts, a motoring energy E_{mot}, and a generating energy, E_{gen}. The motoring energy is computed as the integral of the power of all six servomotors whenever they are in motoring mode, i.e., when the torque produced by the motor is in the same direction as the speed. Similarly, the generating energy is computed as the integral of the power of all six servomotors whenever they are in generating mode, i.e., when the torque produced by the motor is in the opposite direction of the speed. NOTE: Typically, the same motor will be in both motoring and generating modus during a load case.

Grading
The project grade accounts for 40% of the grade in MAS419.

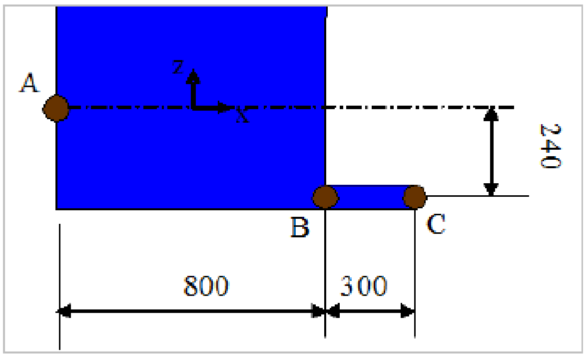
Evaluation
The project is evaluated via the handed-in report, see also the sensor guidance.

Special considerations

Normally, the project must be carried out with either 3 or 4 participants. Alternatively, the project can be carried out individually, i.e., 1 participant. In that case the project is fundamentally the same, however, the task is reduced. The task reduction is agreed upon between student and teacher.

Appendix A

All coordinate systems shown on the different bodies are local coordinate systems positioned in the mass center of the individual bodies.

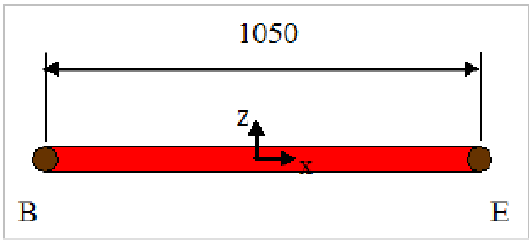


$m = 750\ kg$

$I_x = 50\ kg \cdot m^2$

$I_y = 50\ kg \cdot m^2$

$I_z = 50\ kg \cdot m^2$

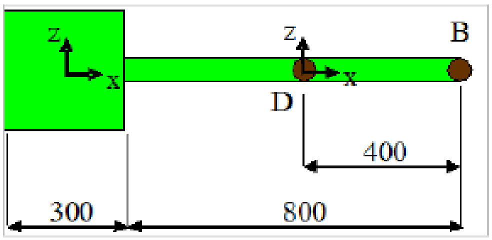


$m = 250\ kg$

$I_x = 1\ kg \cdot m^2$

$I_y = 20\ kg \cdot m^2$

$I_z = 20\ kg \cdot m^2$



$m = 150\ kg$

$I_x = 0.5\ kg \cdot m^2$

$I_y = 8\ kg \cdot m^2$

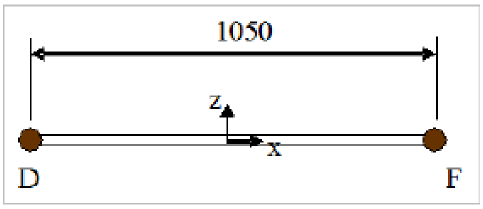
$I_z = 8\ kg \cdot m^2$

$m = 500\ kg$

$I_x = 10\ kg \cdot m^2$

$I_y = 10\ kg \cdot m^2$

$I_z = 10\ kg \cdot m^2$

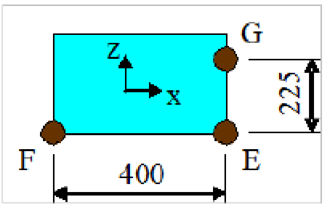


$m = 50\ kg$

$I_x = 0.2\ kg \cdot m^2$

$I_y = 1\ kg \cdot m^2$

$I_z = 1\ kg \cdot m^2$

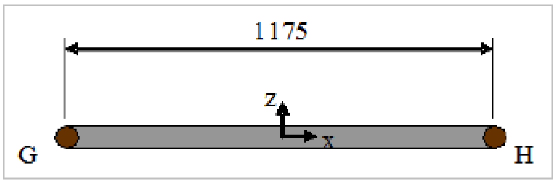


$m = 150\ kg$

$I_x = 2\ kg \cdot m^2$

$I_y = 3\ kg \cdot m^2$

$I_z = 2\ kg \cdot m^2$

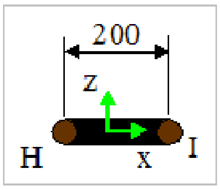


$m = 200\ kg$

$I_x = 1\ kg \cdot m^2$

$I_y = 18\ kg \cdot m^2$

$I_z = 18\ kg \cdot m^2$

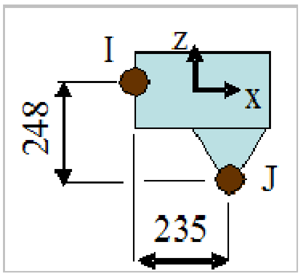


$m = 100\ kg$

$I_x = 0.5\ kg \cdot m^2$

$I_y = 2\ kg \cdot m^2$

$I_z = 2\ kg \cdot m^2$



$m = 50\ kg$

$I_x = 1\ kg \cdot m^2$

$I_y = 1\ kg \cdot m^2$

$I_z = 1\ kg \cdot m^2$