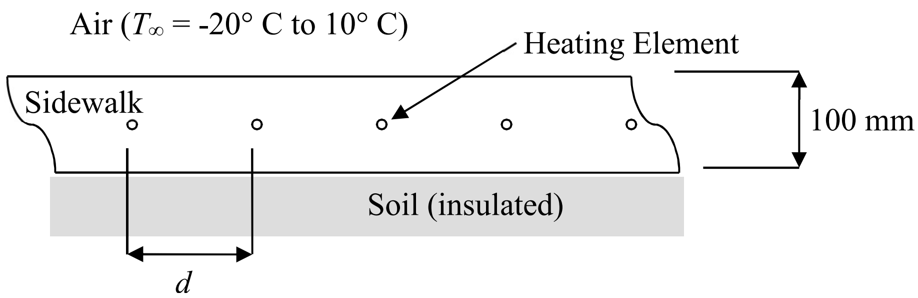
ME 5400 – Numerical Methods for Mechanical Engineers - Fall 2019
Final Project -1

It has been suggested to heat a sidewalk with electric heating elements in order to melt ice and snow. The 100-mm thick concrete sidewalk is to have heating elements embedded at half the thickness, spaced *d* apart.



Your task is to minimize both the cost of the sidewalk and the required temperature of the heating elements while providing a uniform temperature to the top surface of the sidewalk.

The cost of the sidewalk is proportional to the number of heating elements and the temperature *T* at which they operate. Calculate the cost of the sidewalk per linear meter as

$$C = \frac{\$5}{d} + \$0.01(T - 200°C)^2$$

where *d* is in meters and *T* is in °C. The required temperature of the heating elements is such that the top surface of the sidewalk is never less than 5°C, and the spacing *d* between the heating elements must be so that the temperature of the upper surface does not vary more than 3° C. The spacing *d* cannot be less than 25 mm.

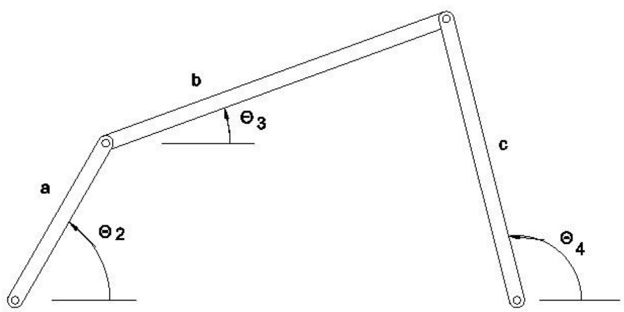
For the sidewalk, the thermal conductivity is 0.30 W/mK
For the air, the convective heat transfer coefficient is 52 W/m^{2}K

Submit a report (due via email before 7 pm on December 12, 2019) that provides – in narrative - the details of your finite-difference model, the steps that you followed to make sure that it was producing correct results, all of the calculations you performed in order to arrive at your solution to the problem, and a complete description of your solution. Illustrate your report with appropriate graphs and figures. Provide an Excel file with calculations that support your conclusions.

ME 5400 – Numerical Methods for Mechanical Engineers
Final Project -2

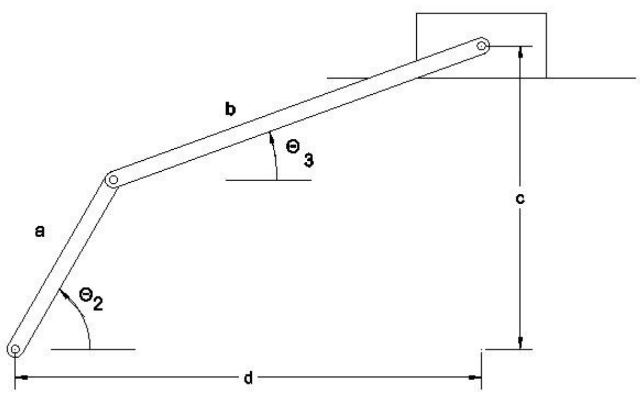
Numerically solve for and graph the quantities indicated for the planar mechanisms shown:

Four-bar Linkage
n_2 = 500 rpm, find θ_3, θ_4, ω_3, ω_4, α_3 and α_4 all as functions of θ_2



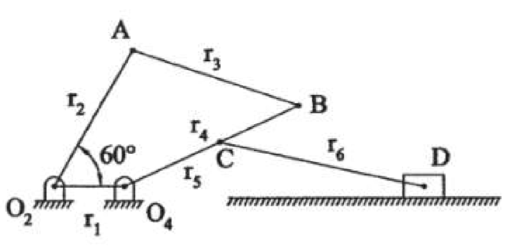
a = 30 mm
b = 60 mm
c = 40 mm
ground link = 100 mm

Offset Four-bar Slider Crank
n_2 = 500 rpm, find d, θ_3, $\dot{d}$, ω_3, $\ddot{d}$ and α_3 all as functions of θ_2



a = 30 mm
b = 60 mm
c = 20 mm

6-bar Quick Return Mechanism
ω_2 = 10 rad/s, find position, velocity and acceleration of block D as functions of O_2



r_1 = 100 mm
r_2 = 225 mm
r_3 = 300 mm
r_4 = 275 mm
r_5 = 100 mm
r_6 = 300 mm

Submit a report (due via email before 7 pm on December 12, 2019) that provides – in narrative - the details of your formulations and solution methods to the two problems above. Illustrate your report with appropriate graphs and figures. Provide an Excel file with your numerical work, including all input data and instructions for both mechanisms above.

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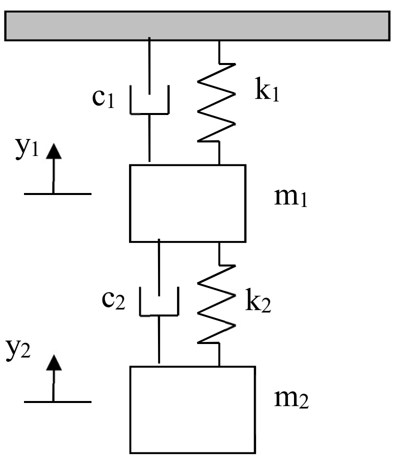
Final Project -3

Develop a general Excel application to solve up to six simultaneous ordinary differential equations using an adaptive 4th-order Runge-Kutta approach and use it in a numerical demonstration of model analysis.

The *undamped* natural frequencies ω of the 2-DOF system below are given by the following:

$$m_1 m_2 \omega^4 - [m_1 k_2 + m_2(k_1 + k_2)]\omega^2 + k_1 k_2 = 0$$



Model the undamped system with parameters

m_1 = 83 kg
m_2 = 21 kg
k_1 = 22 kN/m
k_2 = 25 kN/m

and apply an impulsive force of the form

$F(t) = F_o \sin(\pi t / T) \quad ; \quad 0 \le t \le T$

to mass 2 when the system is at rest, where T is the time of the impulse (typically 2-5 ms). After time T the system will be vibrating freely. During the free vibration, record the response of the system, that is, the accelerations, velocities and positions of the two masses, for an appropriate amount of time. Performing an FFT on these signals (for example, the acceleration of mass 2) should directly reveal the natural frequencies of the system, which you can verify with the equation above.

Repeat the analysis above with $c_1 = c_2 = 5$ N-s/m. Comment on the differences.

Repeat the problem with an additional mass $m_3 = 10$ kg below m_2, suspended via a spring with a rate of $k_3 = 20$ kN/m and damper with $c_3 = 7$ N-s/m. Comment on the differences.

Submit a report (due via email before 7 pm on December 12, 2019) that provides – in narrative - the details of your general purpose application, the detailed model of these problems, the solutions of the system responses, the FFT of the responses and your analyses of the entire solution process. Illustrate your report with appropriate graphs and figures. Provide the Excel files of your application, with all input data and analysis.