

Exercise 1

This exercise covers the kinematic (week 2) and dynamic (week 3) analyses of planar systems. The theory from the lecture notes is applied to analyse systems analytically and SPACAR is used for numerical analyses. The first system is the sliding bar taken from example 4.3.1 in the lecture notes. This part of the exercise is mainly intended to become familiar with the SPACAR software. You don't need to hand-in your answers of these questions and you can select the exercises that are most useful for your understanding of the theory and software. Next a slide-crank mechanism is considered where the parts explicitly marked as "hand-in exercises" should be handed in to be graded.

Part 0: Getting started with SPACAR (answers not to be handed in)

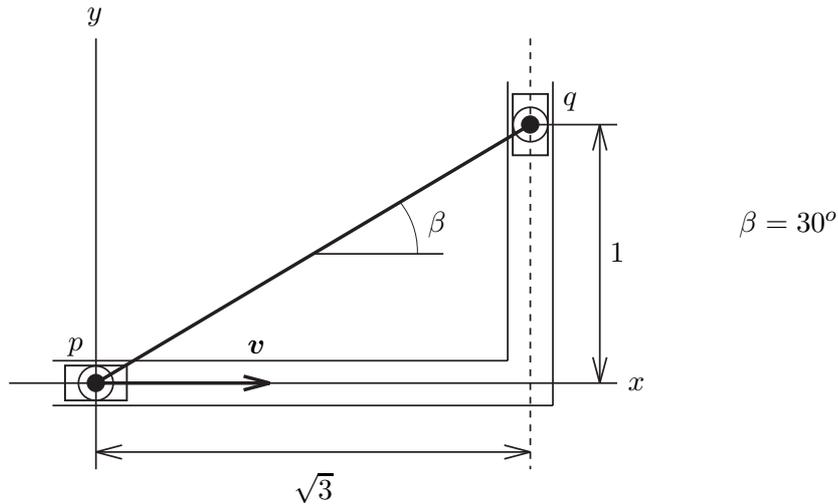


Figure 1: Sliding bar.

Consider the sliding bar of example 4.3.1 in the lecture notes, see figure 1. The sliding bar is a rigid bar pq of length 2 m is suspended from two sliders. The bar is driven by the condition $x^p - vt = 0$, where $v = |\mathbf{v}|$ is the constant horizontal velocity component of point p . Thus $\dot{x}^p = v$ and $\ddot{x}^p = 0$. We want to compute \dot{y}^q and \ddot{y}^q for $0 \leq t \leq 2\sqrt{3}$ s and $v = 1$ m/s. To use SPACAR for a simulation, we need to build a model of the system. This can be done either by writing the SPACAR input `*.dat` file with a text editor or by using the GUI to define the system and write the `*.dat` file. Both possibilities will be outlined below.

1. First we create the kinematic input for SPACAR. This part of the `*.dat` file is described in section 2.2 of the SPACAR manual. Using the GUI it implies that we need to define the element(s) that describe the system. Check the following statements and answer the questions:

For the bar we need only one element. What is the simplest choice?

How many nodal points are connected to this element. Are these translational nodes and/or rotational nodes? What are the initial conditions for the nodal coordinates.

How can we deal with the constraints? Note that a constraint along a straight line parallel to one of the axes can be specified easily by FIX-ing one of the nodal coordinates.

How can we deal with the prescribed motion? In the kinematic part of the input file we only need to specify which coordinates and/or deformations are prescribed DOF's.

- (a) In the GUI you can create the element and specify the initial positions of its end points. Next you can change its appearance by editing the dimensions. You need to edit both nodes to set the correct types of the coordinates: dependent (default), fixed, input DOF or dynamic DOF. For a correct model of this sliding bar the DOF counters in the GUI should indicate that both `Ndof` and `Userdefined DOF` equal 1.

- (b) Alternatively, you can use a text editor to type the kinematic part of the `*.dat` file with the keywords from section 2.2 in the manual. It must be concluded with two lines with the keywords `END` and `HALT` respectively, see manual section 2.1.
2. SPACAR always needs a dynamic section in the input file, manual section 2.3. In this example we need to specify (at least) two properties of our model: A (mathematical) description of the motion of the prescribed DOF's and the duration of the simulation.
- (a) To specify the input motion in the GUI, the node has to be edited in order to Add an `INPUTX` line, see below.
 - (b) If you edit the `*.dat` file, you have to add the `INPUTX` keyword manually. The syntax of this `INPUTX` keyword is described in section 2.3 of the manual. It can be used to specify simple second order functions for the prescribed DOF's.
How can we use this keyword for this exercise? Note that it is often misleading that the `INPUTX` (and `INPUTE`) keywords are used twice: In the kinematic section they only specify *which* coordinates and/or deformations are prescribed DOF's. In the dynamic section they can specify *how* these DOF's evolve in time in the case simple second order functions of the time are applied. For all other functions e.g. user defined inputs with M-scripts can be used, see keyword `USERINP`.

Next, we need to specify the duration of the simulation and the number of time steps.

- (a) In the GUI this can be enabled in the top line of the “Extra input for DAT-file” window: Specify the end time of your simulation (3.46 s) and the number of time steps.
 - (b) Alternatively see the SPACAR manual to add this line manually to your `*.dat` file. Take e.g. 100 time steps. Finally, the dynamic part of the input file is concluded with two lines with twice (!) the keywords `END`, see manual section 2.1.
3. Save your input file.
- (a) Using the GUI, you will save a file with extension `spa`, e.g. `slider.spa`. The accompanying `slider.dat` file is created and shown in your text editor if you press the `DAT` button. Alternatively, the `slider.dat` file is also written and `MATLAB` is started by pressing the `abacus` button.
 - (b) Alternatively, using a text editor, save your input file and make sure it has extension `.dat`.

Check that the `*.dat` is in your current `MATLAB` working directory (either save the file at the correct location or change the working directory).

Run your simulation with the command `spacar(1, 'yourfile')` where `yourfile` is of course the name of your input file (without the extension `.dat`). Does it look OK?

4. Next we want to have a closer look at the results:
- Are the constraints satisfied for the coordinates and deformations? You will have to use the `lmp` and/or `le` matrices to determine the exact location of the coordinates and deformations in the simulation output.
- Do the velocities and/or accelerations look reasonable? In the lecture notes some symbolic expressions are given for the initial configuration. See also section 3.1 of the manual.
- SPACAR always carries out a dynamic analysis. What do you expect for the forces and stresses in this case? Check this expectation with the actual results from the simulation.
5. When you did nothing wrong, you have not seen any error messages yet. It may be illustrative to force errors, so that you can understand what is wrong in cases you did not make an error on purpose. Some deliberate errors are:

- I. Increase the duration of the simulation beyond $t = 2 + \sqrt{3}$ s.
 - II. `FIX` an additional coordinate or release a deformation (keyword `RLSE`). You will see that SPACAR imposes very strict demands on the correct kinematic definition of a mechanism. In SPACAR terms: The number of `NXC` (dependent or calculable nodal coordinates) must be exactly equal to `NEO+NEM` (prescribed plus independent deformations), see e.g. figure 5.3.1 in the lecture notes.
In the GUI you will notice that it is not possible to click the abacus button if this requirement is not satisfied.
6. In the third week of this course the dynamics will be discussed, but we can already give it a try: Adding a mass should give some more interesting dynamic results.
- (a) In the GUI you add a mass to a node by editing the node properties.
 - (b) Alternatively, to edit the `*.dat` file, look in section 2.3 of the manual how you can add e.g. a mass of 1 kg in one of the nodes.
- Is it very “dynamic” to add this mass in node p ? You may try and look at the results if you want. Add the mass in node q and run a simulation. Now look at forces and stress(es). The direction of the force vector in e.g. node p should be along the beam and the length of the force vector should equal the stress in the bar. Can you check these expectations?
7. SPACAR does not implicitly add gravity to a model, so we always have to do that explicitly. Check the `Gravity` in the navigation pane near the left side of the GUI and/or the `GRAVITY` keyword in the manual.

In the rest of this exercise a new system is introduced, see the next page.

Part 1&2: Planar kinematic and dynamic analysis (general introduction)

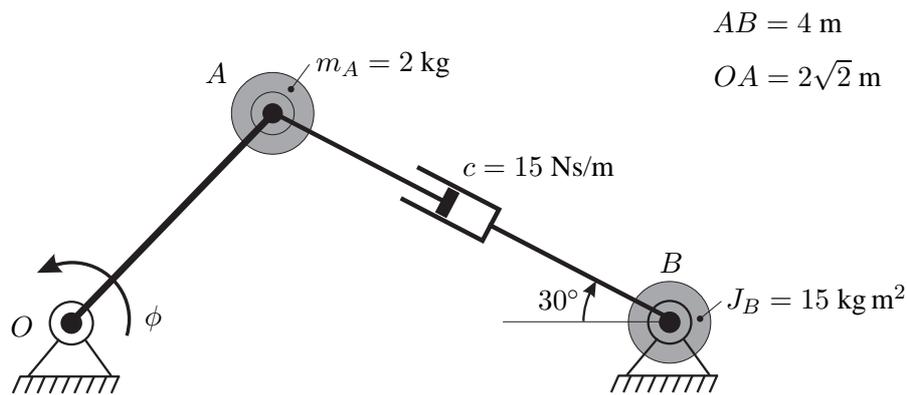


Figure 2: Inverse slider-crank mechanism.

Figure 2 shows a configuration of the inverse slider-crank mechanism. Crank OA rotates counterclockwise with an angular speed $\dot{\phi} = 2\pi \text{ rad/s}$ and acceleration $\ddot{\phi} = 3 \text{ rad/s}^2$. In point A a concentrated mass of 2 kg is mounted and in point B a rotational inertia $J = 15 \text{ kg m}^2$ is attached to slider AB . The viscous damping coefficient equals $c = 15 \text{ Ns/m}$.

In the exercises 1, 2, 3, 5, and 6 analytical mathematical expressions have to be derived that are verified with SPACAR simulations in exercises 4 and 7.

Hint: Crank OA and slider AB can be modelled by means of rigid beam elements.

Part 1: Planar kinematic analysis (hand-in exercises)

1. Determine the first and second geometric transfer functions $\mathbf{D}\mathcal{F}^{(x)}(\phi)$, $\mathbf{D}\mathcal{F}^{(e)}(\phi)$, $\mathbf{D}^2\mathcal{F}^{(x)}(\phi)$, and $\mathbf{D}^2\mathcal{F}^{(e)}(\phi)$ for the given initial configuration (time $t = 0$).
2. Calculate the velocity \dot{e} and acceleration \ddot{e} of the slider.
3. Calculate the angular velocity and acceleration of point B .
4. Compare your results so far with responses computed with SPACAR.

Part 2: Planar dynamic analysis (hand-in exercises)

5. Derive the equations of motion and compute the driving torque on the crank at time $t = 0$.
6. Compute the reaction forces in points O and B at time $t = 0$.
7. Check your results from responses computed with SPACAR.