Using the Advantages of SIMPACK‘s Linear System Interface to MATLAB®
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Introduction

- Linear methods are commonly used in the field of vehicle dynamics
- History leads back to the famous formula found by Klingel in 1883
- SIMPACK offers a number of methods like
  - Eigen values and –vectors
  - Linear System Analyses
  - Critical Parameter Investigation
- However, in some special cases additional methods would be very helpful or simply the presentation of the results should be improved
- In these cases the Linear System Interface is very helpful, e.g. the export of Linear System Matrices to MATLAB
Linear Systems in MATLAB

- **LTI-Objects**
  - **SISO**
    - „Single Input Single Output“ System
    - Most commonly described by its Transfer Function (TF) or even Frequency Response Function (FRF)
  - **MIMO**
    - „Multiple Input Multiple Output“ System
    - Either described by a set of Transfer Functions or a so-called State-Space-Description (SS)
    - FRF may converted to SS and vice versa (tf2ss, ss2tf)

\[
G(s) = \frac{\sum b_{nn} * s^{nn}}{\sum a_{nd} * s^{nd}}
\]

\[
\begin{align*}
\frac{dx}{dy} &= Ax + Bu \\
y &= Cx + Du
\end{align*}
\]
Export a Model

Preparation:
Define a input $u(t)$ instead of a time excitation!

Consider using the ParVariation to export the model

All names of states, inputs and outputs are available in MATLAB!
Example 1 – Drive Chain Oscillation

- **Aim**
  - Establish countermeasures to torsional vibration of wheelset
    - This kind of vibration may occur if the traction control fails, e.g. an operating point behind the maximum of adhesion is stabilized
    - This kind of vibration covers a high risk for damaging the wheel nave or the wheelset axle itself
    - The speed sensor is the favorite base to implement a supervision

- **Task**
  - Calculate the mechanical admittance or mobility
Example 1 – Drive Chain Oscillation

- **Process**
  - Add the necessary outputs to the model
    - Angular velocity of the rotor
    - Angular velocities of the wheels (E.g. in order to prepare tests with the laser-vibrometer)
    - Torque at the wheel set axle
    - Force in torque reaction rod
  - Check for equilibrium state
  - Export/import the model
Example 1 – Drive Chain Oscillation

- **Observability**
  - Definition:
    - The system $sys$ is (fully) observable, if its observability matrix
      \[
      O = \begin{bmatrix}
        C \\
        CA \\
        CA^2 \\
        \vdots \\
        CA^{n-1}
      \end{bmatrix}
      \]
      has full rank
  - MATLAB command
    - `rank(observf(sys.a,sys.b,sys.c))`
  - Consider also to check for detectability

- **Controlability**
  - Definition:
    - The system $sys$ is (fully) controllable, if its controllability matrix
      \[
      R = \begin{bmatrix} B & AB & A^2B & \ldots & A^{n-1}B \end{bmatrix}
      \]
      has full rank
  - MATLAB command
    - `rank(ctrbf(sys.a,sys.b,sys.c))`
  - Consider also to check for stabilizability
Example 1 – Drive Chain Oscillation

- **LTI-Viewer**
  - Fast and detailed overview of general system behavior
  - One, two or more systems may be handled at once!
  - Invoke the LTI-Viewer interactively or e.g. by the MATLAB-command

```matlab
ltiview('bodemag', drive_stick(:,1:3), drive_slip(:,1:3),
        logspace(-1,2,1000)*2*pi);
```
Example 1 – Drive Chain Oscillation

In SIMPACK the necessary figures must be read from the file `<model>.eva` and further processed by hand.

After exporting the SIMPACK model “drive” to MATLAB use the following commands:

- \[ [V, D] = \text{eig}(\text{drive.a}) \]
- \[ f = \frac{\text{imag}(\text{diag}(D))}{2\pi} \]
- \[ y = \text{drive.c} \times V \]
- Calculate and normalize the absolute values

This process is more stable and may be integrated in the quality management.

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<td>-2.0979E+01</td>
<td>2.2014E+02</td>
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<td>Im</td>
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<td>-6.5083E+00</td>
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<td>f0 [Hz]</td>
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In MATLAB:

- \[ [V, D] = \text{eig}(\text{drive.a}) \]
- \[ f = \frac{\text{imag}(\text{diag}(D))}{2\pi} \]
- \[ y = \text{drive.c} \times V \]
- Calculate and normalize the absolute values

This process is more stable and may be integrated in the quality management.

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Example 1 – Drive Chain Oscillation

- Investigation may be continued e.g. by closing the loop with any control or other subsystem, e.g. the electrical part of the motor
  - The asynchronous motor is non-linear, i.e. we have to linearize the model for each operating point separately
  - MATLAB commands:
    ```matlab
    asm_drive_ff = feedback(drive(1,1),asm_ff,1,1,+1);
    pzmap(asm_drive_ff, pzopts)
    sgrid([0.05:.05:.25],[0:2.5:10]*2*pi)
    ```
Example 1 – Drive Chain Oscillation

- **Result:**
  - The unit of motor & drive may oscillate for certain frequencies depending on
    - Control of the converter & motor
    - Design of the motor
    - Saturated adhesion
    - Low rotor temperature
Example 2 – Implementing an Observer

- **Aim**
  - Identify track disturbances during standard service, e.g. without specialised measuring car
  - Sensors already defined
  - Standard vehicle dynamics model available (Thanks to my colleague C. Bussmann!)

- **Task**
  - Use an observer, e.g. a so-called Kalman Filter in order to estimate the states of the bogie and finally the track disturbances
Example 2 – Implementing an Observer
Example 2 – Implementing an Observer

- Basics of Kalman Filtering
Example 2 – Implementing an Observer

- **Process**
  - Simplify the SIMPACK model in order to reduce the number of DOF
  - Select the appropriate WRC model
    - “elastic” -> D-matrix is empty
    - “constraint” -> D-matrix may be not empty
  - Define the necessary inputs and outputs
  - Export the state-space model to MATLAB
  - Create the observer using the Control System Toolbox using the covariance matrices of disturbances QN, RN, NN
    - \([\text{KEST}, \text{L}, \text{P}] = \text{kalman}(\text{bogie}, \text{QN}, \text{RN}, \text{NN}, \text{sensors}, \text{known\_inputs})\)
  - Implement the observer to SIMPACK, e.g. using the control element FE 142: AD-Filter: A,B,C,D > File
  - Validate the observer
    - Versus the non-linear simulation by SIMPACK
    - Versus the measurements at the test stand
Example 2 – Implementing an Observer

**FLEXX Track**
Cross Level Estimation using advanced Kalman Filter

![Diagram of FLEXX Track system](image)

- Track Data
  - Measured
  - Karhausen - Dillingen

- FLEXX Track Bogie

- Kalman Estimator
  - zeros(s)
  - poles(s)

- Scope

- Cross Level
  - Virtual Reality
  - Estimation

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Summary & Outlook

- **Summary**
  - SIMPACK’s Linear System Interface to MATLAB
    - Increases the capability to
    - Analyze complex systems like railway vehicles by advanced linear methods
    - Synthesize advanced (e.g. model-based) control systems
    - Allows to share the workload between specialists

- **Outlook**
  - Investigation/prediction of Structure born Noise in the range (10 ... 1000) Hz