

## Lecture 6: Bond Graph Construction Methods

Reading: KMR Chapter 4

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### Introduction

- Temporarily ignore causality and concentrate on model structure.
- Simple bond graphs can be obtained by inspection.
- More complex graphs are better handled by a construction method.
- The construction method results in a non-minimal bond graph. Reduction needed.
- Focus will be on electrical, mechanical, hydraulic and mixed models.

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# Electrical circuits and networks by inspection

- Electrical circuits use  $0, 1, C, I, R, S_e$  and  $S_f$ .
- Electrical networks connect several circuits with  $GY$  and  $TF$ .
- Correspondence btw  $R, C$  and  $I$  and physical components is direct.
- Use  $0$  for common voltage and  $1$  for common current junctions. May not be obvious in some cases.
- Direct half arrows toward  $R, C$  and  $I$  and away from sources.
- Ambiguous power directions are assigned arbitrarily.

Example: KMR Fig. 4-2

# Circuit construction method

- Include a 0-junction for each distinct voltage node.
- Insert a 1 between 0 junctions and attach the corresponding element ( $R$ ,  $C$  or  $I$ )
- Assign power directions. Use thru-power for 0-1-0 sections.
- Delete explicit ground potentials and their bonds. If no explicit ground potentials are present, chose any 0-junction and delete it together with its bonds.
- Simplify “mutilated” 0’s and 1’s that have through powers. If opposite half arrows are present in such a junction, don’t delete it (why?)

Examples: KMR Probs. 4-1 (h), Figs. 4-9, 4-10

# Translational mechanics by inspection

- Similar guidelines as for electrical case.
- Use 0 for common force and 1 for common velocity junctions.
- Velocities must be defined with respect to inertial frame of reference.

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Example: KMR Fig. 4-13

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# Mechanical translation construction method

- Include a 1-junction for each distinct velocity node.
- Insert a 0 between 1 junctions and attach the appropriate force generator ( $C$  and  $R$ ).
- Attach inertias directly to corresponding 1-junctions.
- Delete all zero-velocity 1-junctions together with their bonds.
- Simplify “mutilated” 0’s and 1’s that have through powers. If opposite half arrows are present in such a junction, don’t delete it.

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## Example: KMR Fig. 4-15, 4-17

- Note the loop equivalence simplification technique
- Follow the examples of Figs. 4-16, 4-18 on your own

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# Fixed-axis rotation construction method

- Include a 1-junction for each distinct angular velocity.
- Insert a 0 between 1 junctions and attach the appropriate force generator ( $C$  and  $R$ ). Add sources.
- Attach inertias directly to corresponding 1-junctions. Add linear-rotational velocity constraints “ $(v = wr)$ ”
- Delete all zero-velocity 1-junctions together with their bonds.
- Simplify “mutilated” 0’s and 1’s that have through powers. If opposite half arrows are present in such a junction, don’t delete it.

Example: KMR Fig. 4-22

# Hydraulic circuit construction method

- Include a 0-junction for each distinct pressure.
- Insert a 1 between 0 junctions and attach the appropriate elements.
- Assign power directions.
- Define all pressures with respect to a reference. Delete the reference 0-junction together with its bonds.
- Simplify “mutilated” 0’s and 1’s that have through powers. If opposite half arrows are present in such a junction, don’t delete it.

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Example: KMR Figs. 4-23, 4-24

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# Transducer models

- Transducers are multiports which may have different energy domains at the ports.
- Typical devices: hydraulic pumps and motors, electric motors and generators.
- Coupling is typically introduced with gyrators and transformers.
- Construction of a large system bond graph is done from smaller, pre-packaged blocks.
- Software can treat smaller blocks as new multiports (object-oriented).
- Please read KMR Sections 4.4 and 4.5 carefully. Follow the example of Fig. 4-28.