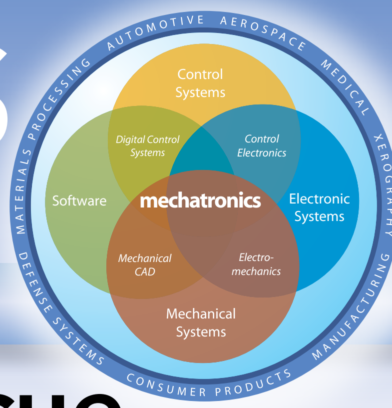
# MECHATRONICS IN DESIGN

FRESH IDEAS ON INTEGRATING MECHANICAL SYSTEMS, ELECTRONICS, CONTROL SYSTEMS AND SOFTWARE IN DESIGN




# Bond Graphs to the Rescue

BY KEVIN CRAIG

What comes to mind when you hear the words "bond graph?" Maybe it's James Bond trying to get out of a jam or get the attention of someone he'd like to bond with.

There are similarities. Bond graphs quantify attractive forces in nature — among atoms or among people. They can also help an engineer deal with daunting multidisciplinary modeling problems by showing how disparate systems interact when connected through bonds — energy bonds.

We all know modern mechatronic systems depend on the interaction of sensors, actuators and computers with the physical system being designed or investigated. We also know that taking these complex multidisciplinary systems from concept to commercialization requires modeling — physical and mathematical modeling. However, no computer software can replace the engineer's judgment and understanding of science and mathematics in developing the hierarchy of models needed in design or investigation to obtain the necessary insights. Computers and the accompanying software are, and always will be, tools for engineers — most helpful tools in the hands of the right person, but nothing more.

In modeling a complex mechatronic system, you must connect subsystems and account for nonlinearities and parasitic effects. The different energy domains must be described in communal terms to enhance understanding and facilitate computer simulation. Physical systems that interact with each other all store, transport or dissipate energy. The bond graph accounts for all energy through energy-exchanging bonds and thus provides the common link among various engineering systems. The only variables needed for each system are the effort and flow variables whose product is power (e.g., force and velocity, voltage and current) and their integrals. So, there is a natural connection with state-space equations based on energy variables. Power, which is the rate of energy transport, is the universal currency of physical systems. The graphical nature of bond graphs separates the system structure from the mathematical equations. Bond graphs are thus ideal for visualizing the essential characteristics of a system.

With bond graphs, you can often design and analyze the structure of a system using only a pencil and paper. What a refreshing idea! The focus can then be placed on the relationships among the components and subsystems. Bond graphs can provide an engineer, early in the design process, with information about benefits and consequences of potential approximations and simplifications. Bond graphs offer qualitative insight to the engineer, in addition to being used for numerical analysis.

Bond graphs also show causality most effectively. For example, you can easily see which power variable, effort or flow, is the input and which is the output. Nature doesn't care about causality, but engineers and the computer programs they use to solve the mathematical equations, do care very much about causality. Some computer programs today transform bond graphs into mathematical equations and then simulate the overall dynamics of a system.

Figure 1; below, top; shows a schematic of a motor driving a load through a gear box with a compliant coupling and Figure 2; below, bottom; is the bond graph of this system. There is not enough space here to discuss all the benefits of bond graphs. To learn more, the best and most up-to-date textbook I have found on the topic is "System Dynamics — Modeling and Simulation of Mechatronic Systems" by Dean Karnopp, Donald Margolis and Ronald Rosenberg. This is the book I would use, if I should decide to teach this subject at the university.

In my next article, I will compare the three modeling techniques I have presented in this column — block diagrams, linear graphs and bond graphs — and compare them through a relevant, practical engineering example.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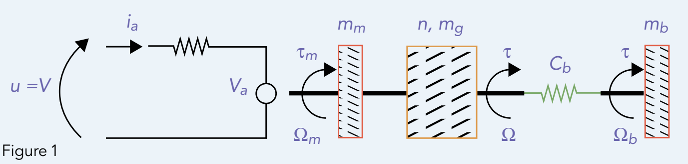


Figure 1

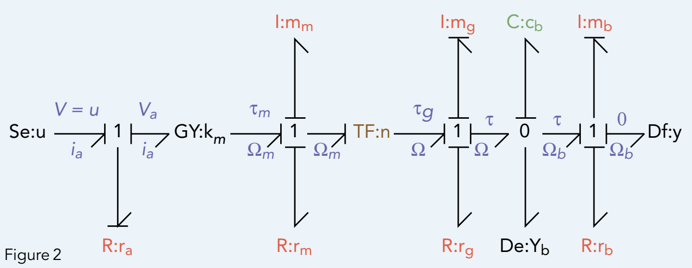


Figure 2

**Figure 1, top, shows a schematic of a motor driving a load through a gear box with a compliant coupling. Figure 2, above, is the bond graph of this system.**

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