Part I

Bond Graph Theory and Methodology

Part I of this book addresses theoretic foundations and concepts of bond graph modelling. Moreover, it presents methodologies for a bond graph-based solution of various types of problems.

Chapter 1 closely reviews the model development process. After a formal foundation of bond graphs, principles and fundamental concepts of port-based physical systems modelling in terms of bond graphs are pointed out and are discussed in a clarifying way that may help avoid model developers to fall into traps, to overlook assumptions and the context dependency of models, or to mix concepts which may give rise to confusions, e.g. with regard to ideal concepts and physical components. A key issue of Chapter 1 is that it emphasises the distinction between configuration structure, physical structure, and conceptual structure.

Clearly, a model to be developed should meet the accuracy requirements of an application and at the same time should be as simple as possible. However, as today’s engineering systems tend to become larger, more complex, and more integrated, it is not always obvious at the beginning of a modelling process which phenomena are relevant with regard to the application and to decide what to include into a model and what to neglect. As a result, one approach often applied is to start with a complex model and to reduce its complexity subsequently as far as the application permits.

Chapter 2 presents three model reduction techniques based on the consideration of energy flows in a bond graph model. One approach ranks energy stores and dissipators on the basis of a power norm called activity in order to reduce the model complexity by eliminating the least ‘active’ elements.

Chapter 3 introduces a special decomposition of bond graph elements in a part with nominal parameters and one with uncertain parameters. The resulting bond graph model of a bond graph element is called linear fractional transformation (LFT) model. In case of linear models, bond graphs with elements replaced by their LFT model enable the derivation of state space and output equations in LFT form as used for stability analysis and control law synthesis based on $\mu$-analysis.

Moreover, LFT bond graphs can also support robust fault detection and isolation (FDI) of systems with uncertain parameters. The decomposition of bond graph elements leads to a derivation of analytical redundancy relations (ARRs) composed of a nominal part representing their residuals and an uncertain part due to parameter
uncertainties. The latter one can be used for the calculation of adaptive thresholds and for a parameter sensitivity analysis of the residuals.

*Incremental* bond graphs present another approach. Similar to the LFT bond graph approach, they are obtained by replacing elements by their incremental model. The latter one is also a decomposition of a bond graph element into a nominal part and one that accounts for parameter variations. Opposed to LFT bond graphs, bonds of incremental bond graphs carry variations of the conjugated power variables due to parameter variations.

Chapter 4 shows how incremental bond graphs enable a matrix-based determination of parameter sensitivities of transfer functions for direct as well as for inverse linear models. The necessary matrices can be generated from a bond graph and its incremental bond graph by means of existing software. Furthermore, incremental bond graphs also support a parameter sensitivity analysis of ARR residuals.