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guest editorial

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THE purpose of the collection of bond graph papers which appears in this issue of the Journal is to demonstrate some recent developments in bond graph modeling techniques for dynamic systems. Although a variety of researchers and designers have used bond graphs to study many types of dynamic systems, the very diversity of the systems studied and the technical fields involved have made it hard for any single individual to keep aware of all the developments in bond graph methods. With this collection, we hope to provide access to a representative group of research papers which indicate the broad scope of the efforts which have contributed to the growth of bond graph theory and an expansion of the areas of applicability of bond graph methods.

We have in mind two classes of readers of the papers in this collection. First of all are those readers who have at least a working knowledge of bond graphs. This collection can serve to make such persons aware of the directions which recent research in bond graph techniques have taken. The second group consists of those with an interest in system dynamics but little or no knowledge about bond graphs. For this group we suggest that a superficial reading of the papers in this collection will suffice to gain some appreciation of the power of bond graphs to aid in modeling, analyzing, and simulating a variety of dynamic systems. Should the reader decide that bond graphs could prove useful in his own work, there are now several references which present the details of bond graphs in a form suitable for self study. In the bibliography at the end of this editorial, a list of references has been presented for the convenience of such a reader. Reference [1][3] is a monograph on bond graph methods. Reference [2] is a general text on systems and control containing a chapter on bond graphs. References [3], [4], and [5] represent preliminary editions of a coordinated textbook, problem set, and computer program guide which present the fundamentals of system modeling, analysis, and computer simulation based on bond graph methods. With these references, a system analyst can gain a detailed understanding of bond graphs and thus can put himself in a position to read the papers in this collection with deeper insight.

In 1968, in the preface to reference [1], we attempted to provide a complete bibliography of bond graph papers. At the time, much of the work in bond graphs was not very visible. Often, bond graph studies appeared only in thesis documents or research notes and many authors simply left any reference to bond graphs out of final publications to avoid the necessity of explaining what bond graphs were. The remainder of the bibliography appended in the following is our attempt to collect bond graph papers from 1968 to 1972. Although the words "bond graph" appear with a gratifying increase in frequency, it still is true that some papers devoted primarily to bond graph modeling do not mention bond graphs in the title. For this reason, we are almost certain to have missed some papers which should be listed and we sincerely apologize to the authors of such papers.

Now for a few words about the papers in the present collection. The first paper by Rosenberg and Karnopp represents an attempt to show standard bond graph notation in a very compact form. The second paper by Martens and Bell provides an excellent insight into the style of system modeling which is facilitated by the use of bond graphs. The third paper by Garg, Wormley, and Richardson represents a case study of a fairly complex fluid vehicle suspension system. The fourth paper by Paynter provides a bond graph modeling approach to the study of the dynamics of controllable turbomachines.

The next three papers, by Rosenberg, Brown, and Karnopp, extend the methods for creating bond graph models in fluid and solid mechanics. These papers show how bond graphs treat the type of nonlinear systems in mechanics which are beyond the scope of many competing schemes of system representation.

The paper by Auslander, Lobdell, and Chong demonstrates a bond graph approach to the modeling of a complex biomedical problem. The following paper by Auslander, Oster, Perelson, and Clifford shows how bond graph methods can be extended beyond their traditional domains of applicability to include chemical reactions and the types of irreversible thermodynamic interactions of interest in biophysics and other fields. The final paper by Oster and Auslander illustrates that new and useful bond graph elements remain to be discovered.

The papers in this package were chosen to illustrate the wide variety of systems which can be usefully studied using bond graphs. A related paper by Brown which deals with bond graph theory rather than with applications follows the collection in this issue of the Journal.

Finally, we cannot resist quoting from C. S. Pierce, the American philosopher who so inspired H. M. Paynter, the inventor of bond graphs, with his theory of relations. Perhaps with this collection, the feelings of the early bond graphers expressed in somewhat extreme form by Pierce will be laid to rest.

> "...young critical common-sensists of intellectual force who burn for a task in which they can worthily sacrifice their lives without encouragement, reward, recognition or a hearing (and I trust such men still live) can find in this field their heart's desire."

Collected Papers of Charles Sanders Pierce, C. Hartshorne, and P. Weiss, eds., Harvard University Press, Cambridge, Mass., Vol. 5, para. 513, 1931-1935.

References

1 Karnopp, D. C., and Rosenberg, R. C., *Analysis and Simulation of Multiport Systems—The Bond Graph Approach to Physical System Dynamics*, The M.I.T. Press, Cambridge, Mass., 1968.

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[3]Numbers in brackets designate References at the end of this Editorial.

2 Takahashi, Y., Rabins, J. J., and Auslander, D. M., *Control*, Addison-Wesley, Reading, Mass., 1970, Chapter 6.

3 Karnopp, D. C., and Rosenberg, R. C., *System Dynamics: A Unified Approach*, Michigan State University Division of Engineering Research, East Lansing, Mich., Oct. 1971.

4 Karnopp, D. C., and Rosenberg, R. C., *Collected Problems in Bond Graph Methods for System Dynamics*, Michigan State University Division of Engineering Research, East Lansing, Mich., Sept. 1971.

5 Rosenberg, R. C., *ENPORT User's Guide*, Michigan State University Division of Engineering Research, East Lansing, Mich., June 1972.

6 Auslander, D. M., "Distributed System Simulation With Bilateral Delay-Line Models," *Journal of Basic Engineering*, TRANS. ASME, Series D, Vol. 90, No. 2, June 1968, pp. 195-200.

7 Paynter, H. M., "Bond Graphs and Diakoptics," *The Matrix and Tensor Quarterly*, Vol. 19, No. 3, Mar. 1969, pp. 104-107.

8 Karnopp, D. C., "Power-Conserving Transformations: Physical Interpretations and Applications Using Bond Graphs," *Journal of the Franklin Institute*, Vol. 288, No. 3, Sept. 1969, pp. 175-201.

9 Nishioka, Roy, *Bond Graph Modeling of the Experimental Tsunami Observation System*, Thesis in Electrical Engineering, University of Hawaii, Apr. 1970.

10 Karnopp, D., "On Bond Graph Theory and 'The Penetrating but Olympian Tensorial Methods of Kron,'" *The Matrix and Tensor Quarterly*, Vol. 20, No. 4, June 1970, pp. 120-124.

11 Karnopp, D. C., "Application of Bond Graph Techniques to Vehicle Dynamics," ASME Paper 70-DE-16, 1970.

12 Karnopp, D. C., and Rosenberg, R. C., "Application of Bond Graph Techniques to the Study of Vehicle Drive Line Dynamics," *Journal of Basic Engineering*, TRANS. ASME, Series D, Vol. 92, No. 2, June 1970, pp. 355-362.

13 Karnopp, D. C., "Resolution of a Paradox Involving Mechanical Gyrators and Transformers," *Journal of the Franklin Institute*, Vol. 291, No. 3, Mar. 1971, pp. 211-217.

14 Rosenberg, R. C., "State-Space Formulation for Bond Graph Models of Multiport Systems," JOURNAL OF DYNAMIC SYSTEMS, MEASUREMENT, AND CONTROL, TRANS. ASME, Series G, Vol. 93, No. 1, Mar. 1971, pp. 35-40.

15 Allen, R. R., and Karnopp, D. C., "Bond Graph Simulation of High-Speed, Rough-Terrain Vehicle Suspensions," *Proceedings 1971 Summer Computer Simulation Conference*, Board of Simulation Conferences, 5975 Broadway, Denver, Colo., pp. 540-549.

16 Radcliffe, C. J., and Karnopp, D. C., "Simulation of Nonlinear Air Cushion Vehicle Dynamics Using Bond Graph Techniques," *Proceedings of the 1971 Summer Computer Simulation Conference*, Board of Simulation Conferences, 5975 Broadway, Denver, Colo. pp. 550-558.

17 Oster, G., and Auslander, D. M., "Topological Representations of Thermodynamic Systems: I. Basic Concepts," *Journal of the Franklin Institute*, Vol. 292, No. 1, July 1971, pp. 1-17, "II. Some Elemental Subunits for Irreversible Thermodynamics," Ibid, Vol. 292, No. 2, Aug. 1971, pp. 77-92.

18 Thoma, J. U., "Bond Graphs for Thermal Energy Transport and Entropy Flow," *Journal of the Franklin Institute*, Vol. 292, No. 2, Aug. 1971, pp. 109-120.

19 Tsai, N.-T., "Analysis of Nonlinear Transient Motion of Cables Using Bond Graph Method," ASME Paper No. 71-Vibr-21, 1971.

21 Karnopp, D. C., "Bond Graph Methods in Structural Dynamics," SAE Paper 71081, Sept. 1971.

22 Brown, F. T., "Direct Application of the Loop Rule to Bond Graphs," JOURNAL OF DYNAMIC SYSTEMS, MEASUREMENT, AND CONTROL, TRANS. ASME, Series G, Vol. 94, No. 3, pp. 253–261.

13 Oster, G., Perelson, A., and Katchalsky, A., "Network Thermodynamics," *Nature*, Vol. 234, Dec. 17, 1971, pp. 393-399.

24 Rosenberg, R. C., "Simulation of Large-Scale Linear Multiports," submitted to *Automatica*.

25 Oster, G. F., Perelson, A. S., and Katchalsky, A., "Network Thermodynamics: The Analysis of Biological Systems," Donner Laboratory and Lawrence Berkeley Laboratory Preprint, LBL-588, Feb. 1972, 245 pp.

26 Thoma, J. U., "Bond Graphs for Flow Control Valves and Other Hydrostatic Components," *Hydraulic and Pneumatic Power*, London, Apr. 1972, (Also in German in *Oethydraulik & Pneumatik*, No. 5, May 1972, and in Italian in *Oleodinamica & Pneumatica*, No. 4, Apr. 1972.)