HVAC PROCESS DESIGN IMPROVEMENT BY METHODICAL PROCESS DESIGN

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ABSTRACT

The frame work of methodical design as developed at the University of technology Twente is used to specify dynamic system design/configuration concepts and alternatives for HVAC-installations (Heating Ventilation And Air Conditioning). A method of implementing different design representation is integrated into a modelling paradigm. This paradigm describes the design process in terms of several major phases, levels of abstraction and connected levels of modelling centred on layered design representations. Design can be considered a problem solving activity where a design problem and its solutions co-evolve. Functional reasoning is central to designing, but current models of mechanical device functionality are not sufficiently refined to support the new generation of computer design aids. Bond Graph techniques are applied to a new design methodology entitled Methodical Process Design.

DESIGN, AN INTRODUCTION

In design the resources consist of knowledge, materials and machining processes, while the constraints include many laws of nature as well as time and financial limitations. Hence the following definition of design can be given. To design is to formulate a product model, taking into account

1) the objectives to be achieved
2) the available resources
3) the prevailing boundaries.

The result of this activity, the product model is frequently called “a design” i.e. a complete description of the object to be manufactured. Through the different levels of abstraction, the product model is gradually described in an increasingly more detailed manner. The different levels of abstraction should be considered as a representation of a particular view on the total information available for a design. The development of an integrated product model paradigm must be considered as a prerequisite for an intelligent CAD system.

This integrated product model must:

- be able to distinct related information
- support distinctions related to the different levels of abstractions (views) by being structured into corresponding sub-models.
- ensure the satisfaction of consistency and completeness constraints linking different levels of abstraction in methodical design.

In the future, information that is useful in designing, will be available in quantity and quality here to fore not possible. One of the major decisions to be taken, is the choice of a design paradigm. A paradigm refers to a principle, or a set of principles, which is based on a theory or a methodology. It will provide the general knowledge needed for the design process. As design paradigm is chosen the Methodical design method from Van den Kroonenberg (1). It is based on system theory and also on the ideas of the German school: Koller (2), Roth (3), Beitz (4), Pahl (5) and Hubka (6). The use of a methodical design process method is a necessary guideline for the designer and makes it possible to structure the design process in such a way that it becomes possible to integrate it into a computer system.

CONCEPTUAL MODEL

The methodical design process can be described on the conceptual level as a chain of activities which starts with an abstract problem and which results in a concrete solution. Four main phases are distinguished: problem definition phase, working principle phase, decision phase and shape giving phase. An important feature in methodical design is the distinction of levels of complexity based on abstraction hierarchy. In methodical design a number of levels of design complexity are distinguished: 'system', 'installation', 'multiple machine', 'machine', 'component', 'part' and 'material'. It should be stressed that this distinction in seven levels in methodical design will normally work out alright.

In specific cases however it may be necessary to introduce one or more extra levels of abstractions in order to describe the complexity of an object properly e.g. module, assembly and for sub-component.

The emphasis at the higher levels of complexity is in the problem definition phase, while at the lower levels of complexity the emphasis is on detail design. This is a description of methodical design at the conceptual level.

A basic four-step pattern (also called basic cycle) can be recognized within each phase and sub-phase of the methodical design process; generate, synthesize, select and shape.

In system theory the same activities are proposed for decision processes as can be found for the design process.

Generally speaking the activities of the first step of design are mainly of a diverging nature. After an analysis of the task the target is to generate a large number of elements that may be used to perform that task. A number of techniques can be used to stimulate generating ideas. In a second step the activities are primarily of a systemizing nature. After analyzing the elements obtained in the previous step the target is to synthesize these elements into solutions that are in principle suitable to preform the task. Combining the elements can be done in many ways such as structuring, arranging and varying.

The alternative solutions obtained all meet the basic requirements of the task. In a third step the activities are of a converging nature. The solutions obtained are analyzed in order to decide on the most suitable solution that will perform the task. The most suitable solution will be worked out into more detail and with this solution the design activities continue in a next phase and the four-step pattern is used once again. In this four-step pattern each step consists of a characteristic operation, see fig. 1. The focus of this paper is on the working principle phase.

FUNCTIONAL DECOMPOSITION

In order to survey solutions, engineers classify solutions based on various features. This classification provides means for decomposing complex design tasks into manageable size problems. An important decomposition is based on building component functions. The functional decomposition is carried out hierarchically so that the structure is partitioned into sets of functional subsystems. The decompositions carried out until we arrive at simple building components whose design is a relatively easy task.

The design problem as defined here is how to obtain a physical description of a technical system given a high-level (abstract) specification. Theoretically, one can envision a continuous decrease in abstraction ranging from one extreme to the other. In other words: the design is gradually taking shape. In practice, however, design will never be of a completely top-down nature. In order to determine what the next refinement action will be, a designer has to have knowledge of what the possibilities roughly are. Knowledge about the functions possible realised given specific physical properties of the realisation material is propagated upwards. In the framework presented here, this bottom-up knowledge is represented as sets of generic components (that are known to have several possible physical realisations an representations) at different levels of abstractions.

Hierarchical abstraction means the decomposition of information into levels of increasing detail, where each level is used to define the entities in the level above. In this sense each level forms the abstract primitives of the level above. These terms in the upper level, form condensed expressions of a given relational and/or operational combination of primitives from the level below. In any given level of detail the representation is based on a partly repetition of a structural pattern. In this pattern there are places, for each combinatorial product which can be made of the variables defined, Zeiler (8).

The sets of generic components are located at distinct levels of abstraction, ranging from the system level to the physical level. The contents of the layers is based on the technical vocabularies in use, therefore we will speak of technology based layers of levels. Each layer represents an abstraction of the levels below.

For a more extensive description of the models that formed the basis for the notion of technology-based layers, Alberts, Wognum an Mars (7). It is important to realise that the actual contents of the layers as well as the number of layers will be domain-specific. Generic components represent behaviours represent behaviours that are known to be physically realisable. They are generic in the sense that each component stands for a range of alternative realisations. This also implies that the generic components still have to be given their actual shape. Relevant technical or physical limitations manifest themselves in the values of a specific set of parameters belonging to the generic components.

These parameters are used to get a rough impression of the consequences of certain design choices at the current level of abstraction for the final result.

The design process can be described in terms of transformations of the design description within or between the technology-based layers.

The behaviourial description of the required system at a certain level is decomposed according to the behaviours of the available generic components, different configurations may arise. In order to estimate what the restrictions imposed by generic components imply for the overall system, the resulting configuration has to be parameterised in terms of the form characteristics of the individual components. Throughout this process, the performance requirements serve as constraints on the possibilities for configuring generic components into larger structures and for assessing the physical characteristics.

METHODICAL DESIGN

PHASE	ABSTRACTION	CHARACTERISTIC OPERATIONS
Problem	Need	1) describe needs goals etc.
		2) compose problem descriptions
		3) select problem description
		4) task
	Design problem	1) list demands, check points, wishes
		2) structure and quantity list of requirements
		3) determine programme of requirements
		4) specification
Working	Functional	1) determine functions to be fulfilled
		2) combine functions to function block diagrams
		3) select best function block diagram
		4) function structure
	Physical	1) list various physical processes
		2) arrange according to importance
		3) select most feasible working principles
		4) principle solution
Detail	Module	1) generate combinations of working principles
		2) arrange compatible combination
		3) select most promising combination
		4) structure
	Prototype	1) sketch lay-out of the selected combination
		2) vary lay-out by mixing, moving, fusing etc.
		3) select preliminary lay-out optimum structure
		4) preliminary lay-out
Realisation	Engineering	1) generate different forms
		2) vary forms
		3) select best form
		4) definitive lay-out
	Material	1) list possible materials
		2) make calculations with different materials
		3) select material
		4) product documents
	Solution	

fig. 1, Pattern of Design

FUNCTIONAL COMPONENTS

Device Components play a central role in the conceptual borderlines between different classes of engineering knowledge. Most current models of function are based on a systems model as written about in methodical design methods Pahl (5), Beitz (4), Koller (2) and Roth (3). Although there are differences in their individual approaches, all methodical design authors use a system transformational definition of "function". A more formal use of the same model is in the bond graph technique. This was developed by Karnopp and Rosenberg (11) as a tool to support the design and analysis of dynamic systems.

In this method function is represented by a transfer function as in all formal systems methods. Finally as computer systems are developed to support more of the design process methods to formally model function and behaviour become more important. Basically research on function in the artificial intelligence world takes two approaches; functional representation and qualitative physics.

A major activity in engineering is to design and develop generic physical components with more or less ideal functions. The overall design task given a specific problem can be reduced to a configuration task, if necessary supplemented with some local tuning. This means that such generic components should play an important role in automated modelling. An engineering drawing fig. 2 is typically used for configuration of a system out of device components. On the other hand, the drawing is also interpreted as a representation of more or less ideal functions or processes: an initial abstraction step is implied. Do the connecting lines in the figure stand for pipes with a certain length, mass, unique number etc., do they represent a class of pipes with a certain shape or do they denote ideal, frictionless connections? It depends on the modeller how an engineering drawing is going to be interpreted.

Hence, the engineering drawing as such is not an unambiguous representation. Therefore the initial abstraction levels defined in terms of functional components, which are subsystems expressing two aspects o the observed system:

1. The interface between a subsystem and its environment. As far as its energetic-dynamic behaviour is concerned, a component is completely defined by the set energy ports through which it exchanges energy with the environment. Energy ports can occur in degenerate form, only passing through simple signals. The interface could be referred as the energetic extension of a subsystem.
2. A label to indicate a class of engineering functions. Since devices with common functions are usually based on similar physical processes, they provide additional organization for the underlying bond graph level. In automated modelling the labels provide an initial selection mechanism for process submodels.

One way to represent this initial abstraction of the observed system can be the word bond graph Karnopp, provided that it is used in a rather specific way. The nodes of the word bond graph map to functional components, whereas the edges represent power or signal flow between ports. Thus, the interconnections in the component model shown in fig. 3 have a well defined meaning: they refer to specific measurement points for pressure and fluid flow.

PHYSICAL PROCESSES

The first level of the model describes the actual physical processes that implement model behaviour or rather classes of model behaviour. A proper way to describe these processes in the bond graph figure. For the fluid flow system an example is given in fig. 4. The basic difference between the component view and the process view is the fact that the latter represents abstract processes or mechanisms rather than devices. Bond graph nodes stand for generic physical mechanisms, such as power sources (Se, Sf, Sw), dissipation (R), energy storage mechanisms (C.I) energy conversion (TF, GY), and energy distribution mechanisms based on conservation principles (0.1). Edges (called bonds, hence the name) stand for energy exchange paths (implying a complementary pair of shared physical quantities between mechanisms, called effort and flow). As a whole, a bond graph can be viewed as representing the topology of the physical mechanisms active in the system. Within a functional component each bond graph is a flat structure: the hierarchical structure of a bond graph model is organized at the component level.

At this level, a number of model properties can serve as meta-assumptions. By employing the bond graph as a descriptive language on already assumes a macro-physical approach. Moreover, it is assumed that the system can be viewed as a network of internally homogeneous lumps, although these lumps can be very small. The bond graph itself can be characterized by the following properties:

- Causal characteristics such as: consistency, locations and types of feedback paths, presence of static coupling (in particular rigid links in mechanical systems), dynamic system order.
- Being closed or open with respect to energy.
- Existence of a steady state.
- Complexity.

The basic difference between the component view and the process view is the fact that the bond graph represents abstract processes or mechanisms rather than devices. In evolutionary modelling a physical domain is assigned to every bond. Within a functional component each bond graph is a flat structure; the hierarchical structure of a bond graph model is organized at the component level.

Of course, for presentation purpose bond graphs may be condensed, but this type of condensation is not necessarily linked to the component structure of the model and it is not specific for a component.

ENGINEERING MODEL LIBRARIES

The Methodical Process Design approach depends on the availability of a collection of submodels, and it provides the organizational frame work required for structuring and maintaining such a collection. Model libraries can be used to share and reuse knowledge that is not part of an abstract theory (such as physics) but still generic across different applications.

A model library is structured along two dimensions. First, there is a part of hierarchy that is defined by the decomposition of functional components. Every functional component knows about one or more decompositions to its immediate sub-components and about the super-components it can be a part of. Second, models are ordered in a taxonomy based on invariant properties. More detailed models (that is, models based on more detailed assumptions) can inherit general properties form less detailed ones.

This framework is used in practice as a basis for organizing the library to be developed in the OLMECO project. The model part in this figure shows the actual contents of a composed model for a given situation. A complete model - i.e. a model for a particular device within a certain task environment - is composed by selecting a library component from each level, while keeping the references to possible alternatives.

The information that can be retrieved from the library in terms of the two levels is;

- Component level. This level describes the hierarchical decomposition of the model in terms of functional components is domain dependent. For each component the energetic interface and a component label is defined. The ports in this interface are specified with regard to their domain and type (energetic, input signal or output signal). The interconnections between components is defined by undirected energy bonds or directed signals.
- Process level. This level describes the bond graph - no more and no less. Its external ports refer to the ports of the associated component model. At the bond graph level power directions and domains are known for all bonds. Causal directions however are not represented as a part of the model, because they do not add information: they are inherent to the bond graph. Note that the original, unsimplified bond graph contains all information available at this level and must be stored as such. A condensed bond graph can always be expanded unambiguously into a full bond graph.

CONCLUSION

Methodical design is proposed as a theoretical basis for automate design of physical-systems. Design is viewed as a problem solving activity in which functional reasoning is central. In order to allow a stepwise approach in which each design decision has well-defined implications, two different on to logical levels have been distinguished for designing energetic-process;

- Functional components
- Physical Processes

These levels provide a structured framework for model libraries, which in addition could contain separate entries for structural and behaviourial observation data for validation purposes. Bond Graphs can be used as a formal modelling technique based on a methodical design systems model. The benefits of evolutionary methodical Bond Graph Design for process design improvement strongly depend on the availability of generic models stored in structured libraries. We believe that model libraries based on the approach presented here will significantly advance the state of automated process design.

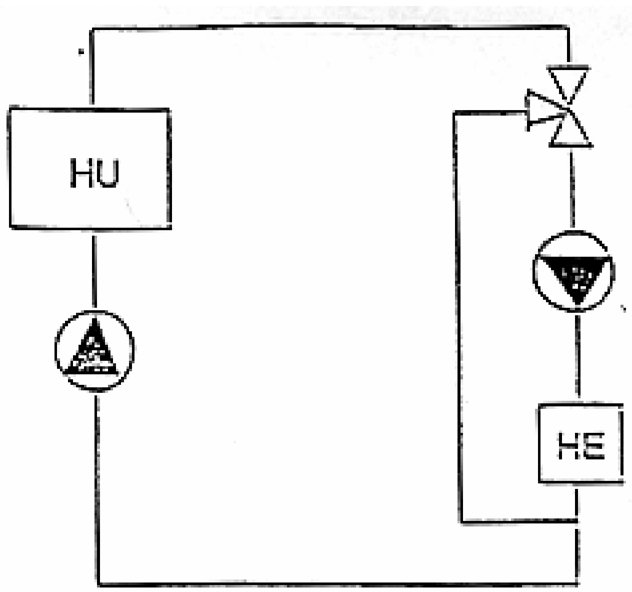

Fig. 2 Engineering drawing of simple fluid flow system, with two pumps, heating unit (HU), heat exchanging element (HE), three way valve and connecting pipes.

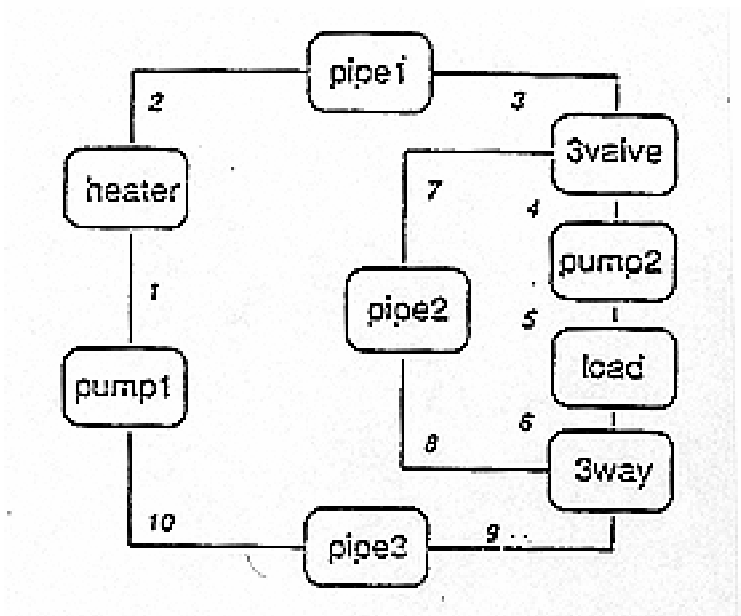

Fig. 3 Functional component model of the fluid flow system.

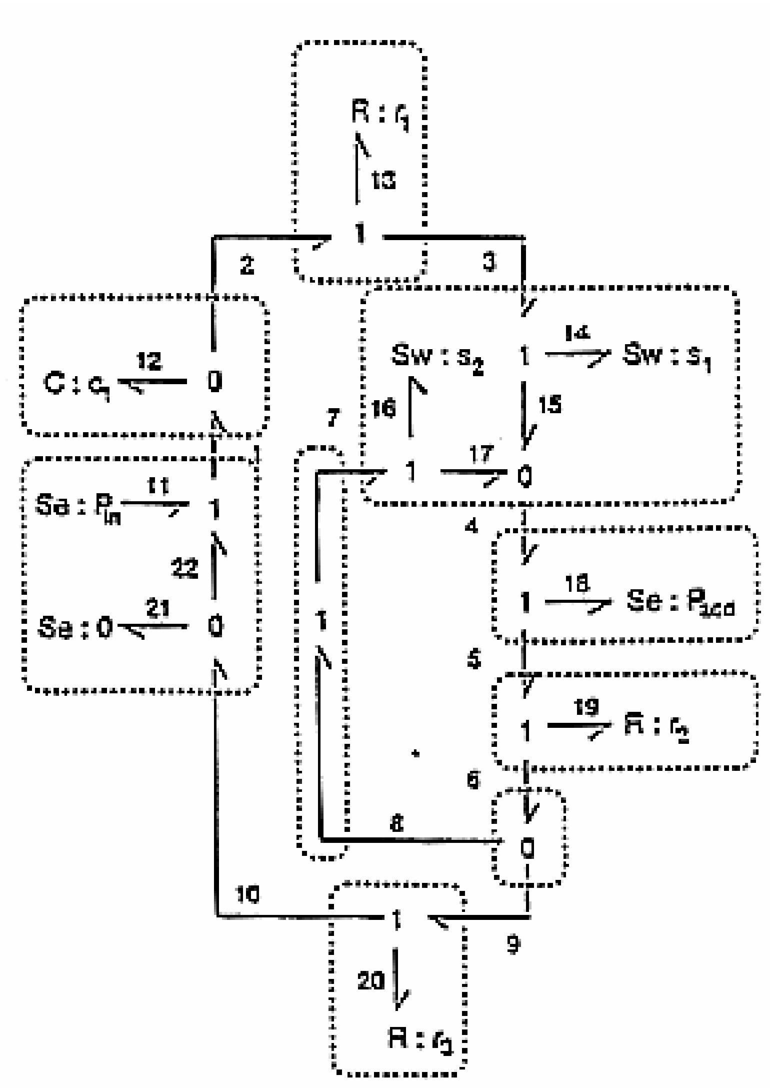

Fig. 4 Process level description of the fluid flow system. All bonds are in the hydraulic domain, with total pressure as effort and flow rate as flow.

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