OHCS: Hydraulic Circuit Design Assistant

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ABSTRACT

This paper describes an expert system, called OHCS, which actually has been deployed for designing hydraulic circuits. OHCS enables to increase productivity by integrating the four processes of expert reasoning, designing, analysis, and drawing inspection. The application of artificial intelligence to this domain poses a number of challenges, including: how to integrate these four processes, how to realize drawing inspection, and how to couple qualitative reasoning and numerical computing. To overcome this problem, OHCS employs various kinds of AI technologies such as time-state reasoning, qualitative reasoning, hypothetical reasoning, constraints propagation technique, TMS, ATMS, and symbolic algebraic manipulation. In this paper, our approach to dealing these problems is described.

1. Introduction

Uses of oil hydraulic power and control are found in almost every manufacturing plant, construction, agriculture, transportation, mobile, marine, and aerospace. Oil hydraulic power systems are those that transmit and control power through use of a pressurized oil within an enclosed circuit.

The process of designing hydraulic circuits can generally be divided into four stages: circuit design; components selection; static and dynamic analysis of the circuits; and inspection of completed drawings, as shown in figure 1.. These four stages are normally entrusted to experts in respective field. A dynamic analysis is primarily handled by the analysis experts, while the designing and inspection of drawings is entrusted to the designers (the inspection of drawings is entrusted to the senior designers).

One major problem with such an approach to circuit design occurs when drawings are found which do not meet specifications, and much of the design and analysis must be redone. These additional engineering tasks cause a great loss of time and decrease productivity levels by the hydraulic engineer. Since there is so much expertise involved in each of these engineering tasks, the traditional approach taken in developing hydraulic systems is extremely tedious and inefficient.

In analyzing the concentration of expert knowledge required for each task, we have developed an Expert System for Hydraulic Circuit Design (OHCS: Oil Hydraulic Circuit Simulator), which is an assistant for design and manufacturing engineers who are responsible for efficient design and performance of oil hydraulic power systems.

Our goal was to increase productivity by integrating the four processes of expert reasoning, designing, analysis, and drawing inspection into a single system.

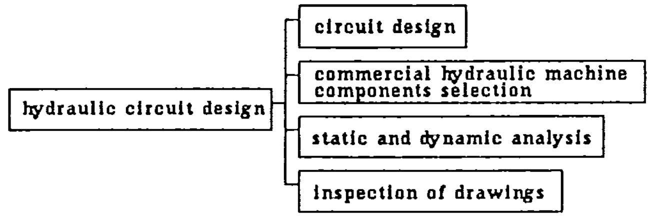

Figure 1. Hydraulic circuit design tasks

2. OHCS Architecture and Its Functions

OHCS runs on a Symbolics Lisp Machine within the ART* environment. OHCS consists of Lisp program, 700 rules, and 2000 schemata. The coding ratio is 7 parts of Lisp and Flavors to 3 parts of ART. And the system needs 80MBytes under runtime for general use.

Figure 2. illustrates the architectural organization of the system, which consists of six major components. The OHCS system performs the following five primary functions.

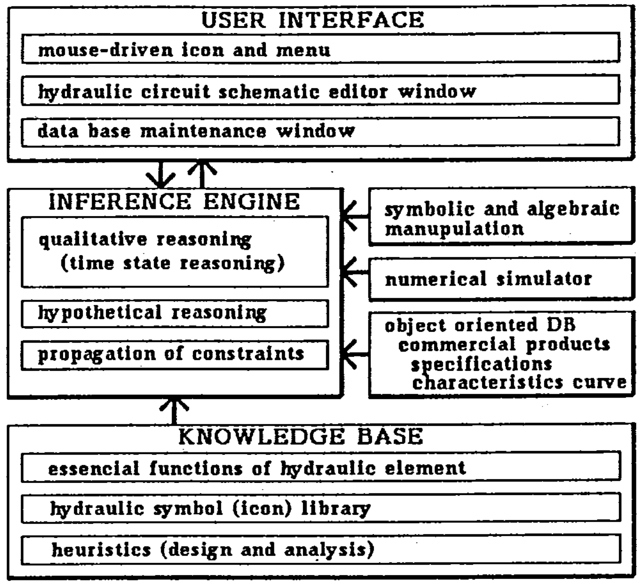

Figure 2. The architectural organization of the system

2.1 Supports the Generation of Circuit Diagrams

The system is able to apply the expertise of the designers to generate circuit designs as well as CAD drawings that meet specifications. The graphic symbol representing hydraulic machine components are shown at the right side of the user interface (as shown in figure 3.) and can be mouse-selected. Since there are 150 graphic symbols representing components of hydraulic machine to choose from, the selection of the various types of components is facilitated by a layered menu array. Graphic symbols are those which give symbolic representation of the

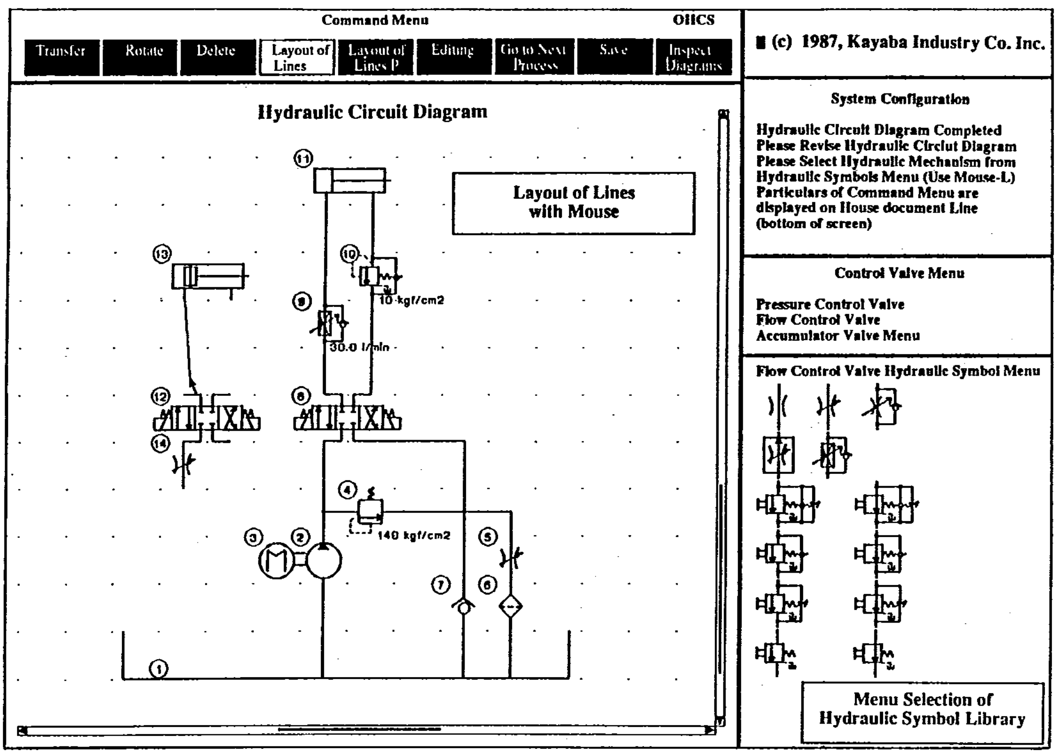

Figure 3. Hydraulic circuit design drawing

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component and all of its features pertinent to the circuit diagram. The composition of the circuit diagram, which takes place in the center of the screen, is directly connected to the knowledge base and its image is recognized as knowledge (we call intelligent feature-based CAD). Therefore, a "picture" on the screen that indicates, for instance, that "machine A and machine B are connected", will also be kept in the knowledge base as a "condition" in which "machine A and machine B are connected". The graphic images seen on the screen are not merely pictures in ordinary sense.

2.2 Components Selection

The designer proceeds to select commercial hydraulic machine components after the generation of circuit diagrams. OHCS provides an objet-oriented data-base, which contains the specifications and characteristics curve of 1500 commercial components.

OHCS automatically generates the used parts table, which is shown at the right side of figure 4. This table is also the selection menu of commercial hydraulic machine components, which retrieves components from object-oriented data-base that may be characterized as flexible indexing and retrieving.

2.3 Diagram Inspection Based on Experience

Since the system's knowledge base consists of diagram inspeciton expertise, the operation of diagram inspection proceeds as if such specialists were actually on hand to supervise the operation. In addition, the diagram inspection results such as comments, and the calculation of parameters are displayed in the upper part of the screen, as shown in figure 4., acting as a guide for the designer.

Traditionally, the senior designer checks to see that the functions of each circuit correspond to the specifications. This operation is approximately 80 percent qualitative, and deeply dependent on the special knowledge of the expert.

2.4 Automatic Generation of Analytic Models

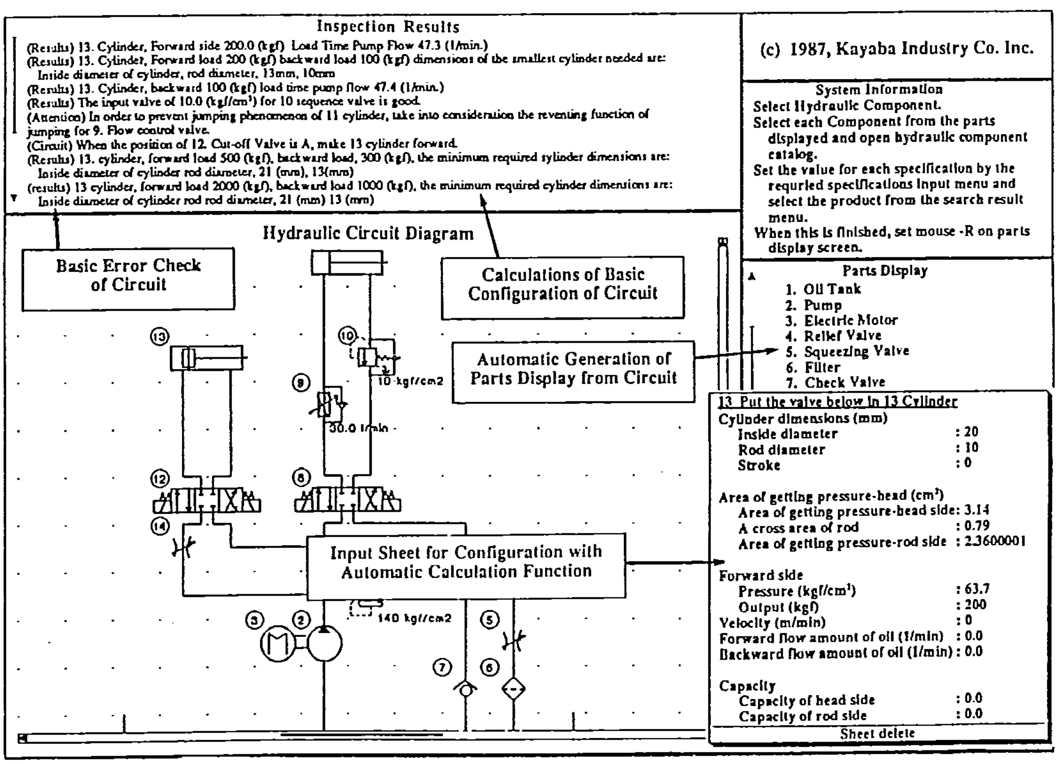

Figure 4. Diagram inspection

In addition to the drawing made of the hydraulic circuit diagram itself, simulation of static and dynamic analysis must be carried out. The models used in these simulations is automatically constructed in accordance with the expertise of the analysts, who express the state of hydraulic machine components in the from of ordinary differential equations. OHCS simulates the analytical expert's qualitative experience in mathematical modeling.

2.5 Quantitative Simulation

Numerical simulation of the hydraulic circuit is carried out after the automatic generation of the analytic model, which is described in terms of sets of ordinary differential equations. In the past, the simulation process was an operation completely separate from the process of circuit diagram construction. In OHCS, however, it is linked to the designing process, producing real-time simulation results, as shown in figure 5..

Furthermore, the simulation process is characterized as the process to be repeatedly executed as modifying parameters of components until designers are satistied with results. OHCS makes easy to perform this process, and is able to decrease the amount of time.

3. Representation and Qualitative Reasoning about Circuit

3.1 Knowledge Representation

OHCS utilizes three forms of knowledge representations:

(1) Declarative knowledge base of primitives and composite components, relation for circuit construction, interface to data base, analysis model parameters for components, icon graphic symbols, and others; time

(2) Production Rules in the form of IF-THEN rules of many types: control of time-state reasoning and hypothetical reasoning, empirical associations of predictable problems and measures, processing of mouse driven graphic interface, generating ordinary differential equations, and others;

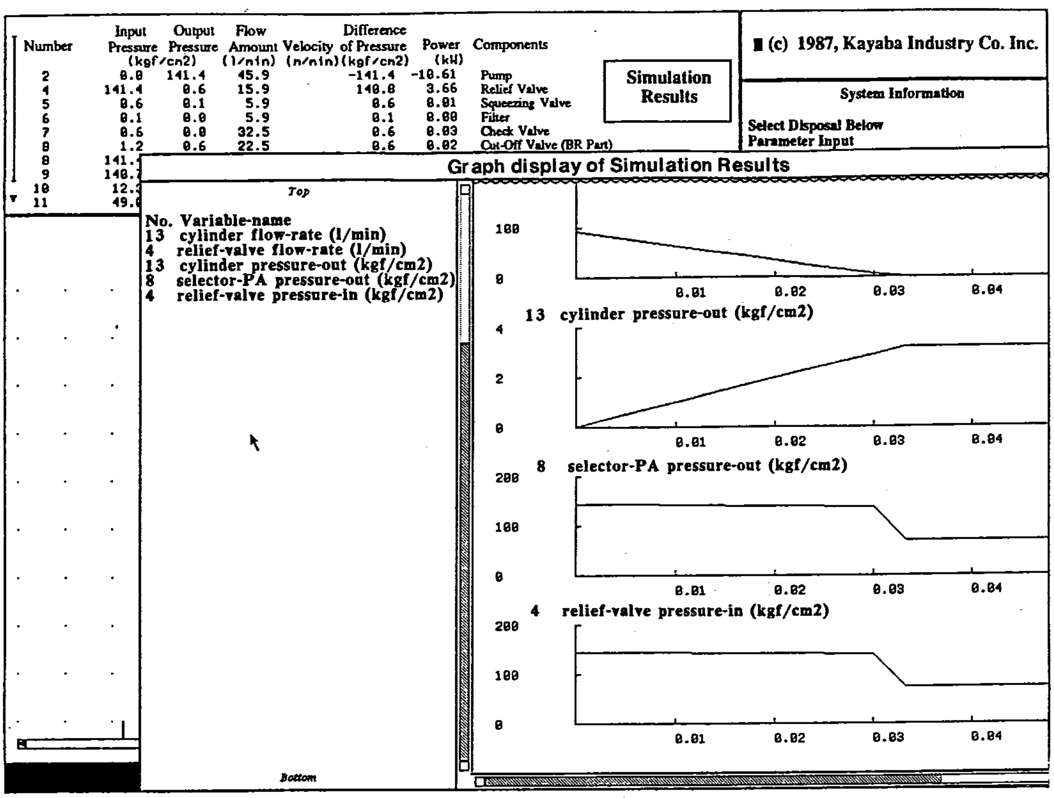

Figure 5. Simulation results

(3) Algorithmic knowledge expressed as functions: symbolic and algebraic manipulation to simplify and substitute equations, and other calculations.

OHCS contains complete representations for hydraulic circuits, called the Circuit Representation Language. This language admits a relatively simple representation using well known ideas about schemata (frames) and inheritance. Figure 6. illustrates an example of circuit knowledge. The graphic images seen on the screen in which "pump and relief valve are connected" are expanded to the internal knowledge through relations, as shown in figure 6., which is a part of knowledge representation of figure 3..

3.2 Qualitative Reasoning

OHCS identifies qualitatively the circuit topology from the circuit diagram by searching the flow path, and by using heuristics for the following three purposes such as recognition of the circuit, basic diagram inspections, and giving important informations for generating equations by constraint propagation methods.

Identification of the circuit topology is executed after constructing piping relations, which are "port-in" and "port-out" relations shown in figure 6.. When hydraulic machine components are added or changed by the designers, constraints with piping that exert an effect throught the circuit system are changed at the same time, since OHCS maintains the logical consistency.

After that, OHCS infers the flow path by means of the concept of node and link. Nodes represent each device terminals (inlet and outlet ports of components). Links represent each components, which are conduits that oil fluid flows from node to node [Gentner, 1983]. OHCS uses both qualitative application of a time-state reasoning, which is characterized as a non-monotonic reasoning, and heuristics for solving the flow path problem.

We call the flow path representation of the circuit diagram as the circuit topology shown in Figure 7., which is a part of the circuit topology of figure 3..

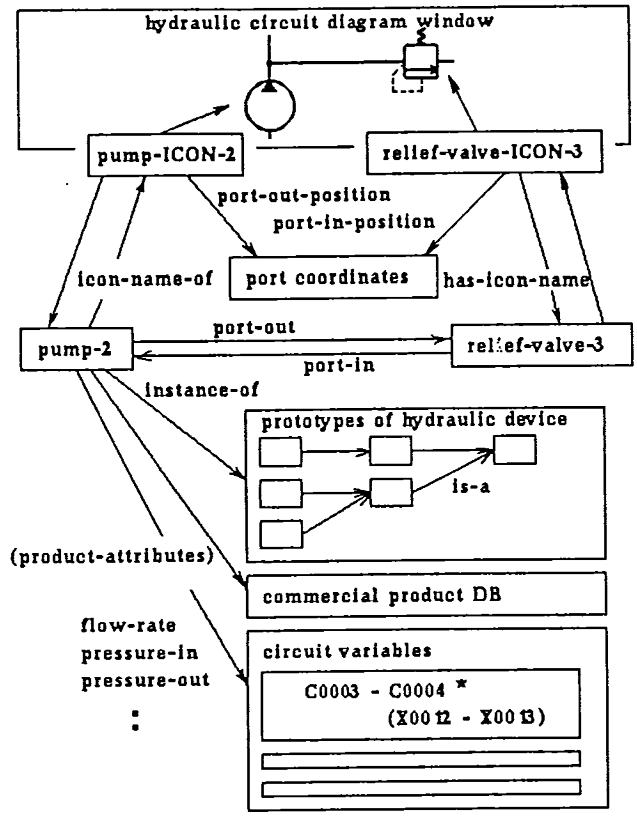

Figure 6. An example of circuit knowledge

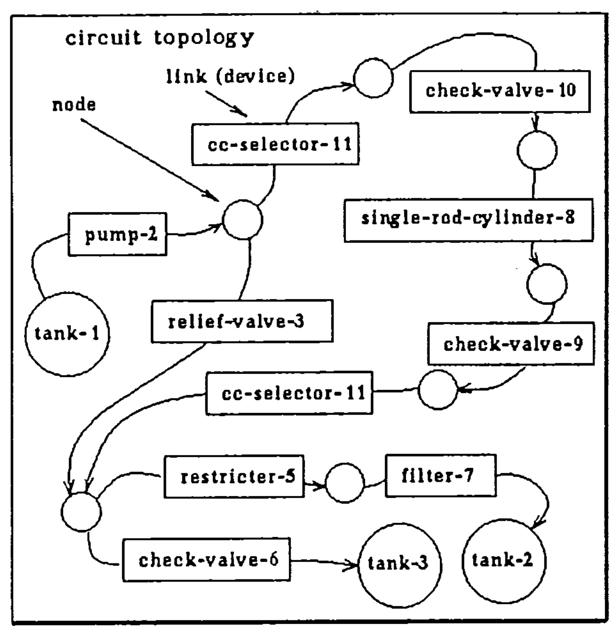

Figure 7. An example of circuit topology

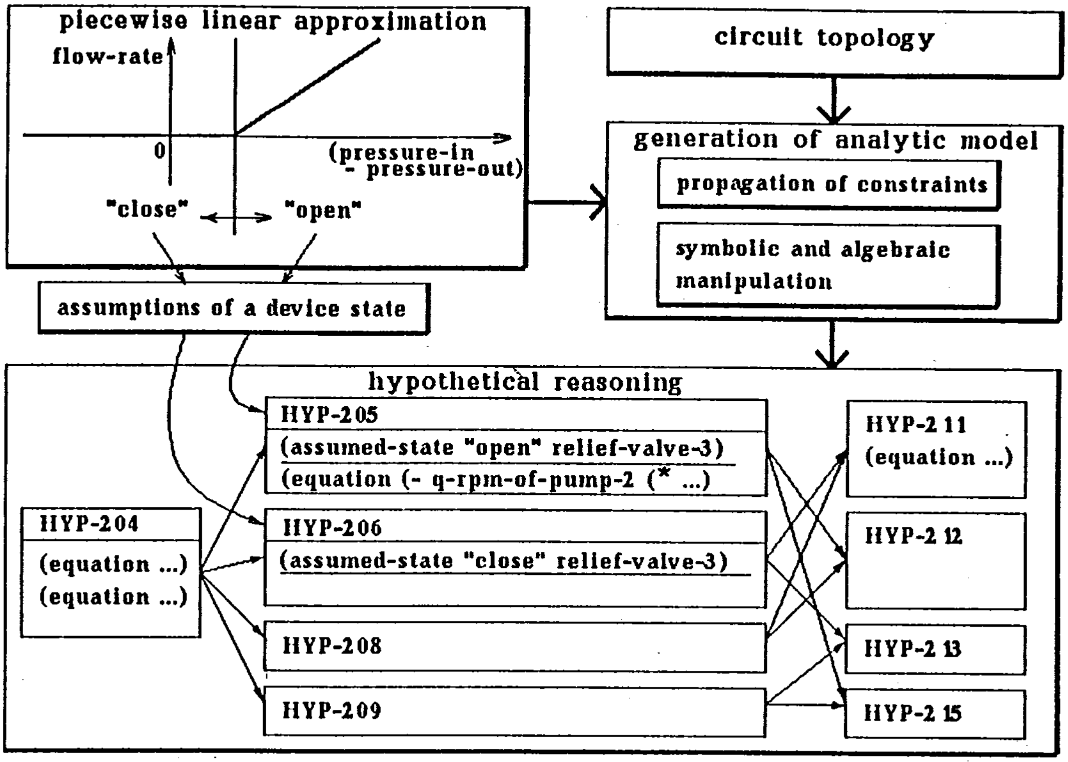

Figure 8. Generation of analytic model with hypothetical reasoning

4. Coupling Qualitative Reasoning and Numerical Computing

OHCS provides the capability of piecewise linear approximations of ordinary differential equations for the circuit, because ordinary circuits can be expressed as nonlinear systems.

In general, piecewise linear approximations has exponential complexity in the number of nonlinear components in the circuit [Sacks, 1987]. Therefore OHCS provides the search-limiting combinatorial methods, which leads to efficient analysis of the circuit with piecewise linear models.

The search-limiting combinatorial method supplied by OHCS is as follows. OHCS generates piecewise linear equations as conflictive hypotheses based on deductive logic that can be viewed as a single analysis space for each hypothesis shown in Figure 8..

While OHCS constructs sets of equations, it substitutes, and simplifies equations by symbolic and algebraic manipulation to which propagation of constraints applies [Stallman, Sussman, 1977], as shown in Figure 9.. Instantaneously each hypothesis is examined by both designer's practical experience and circuit topology-based heuristics. In the course of generating hypotheses one after another and pruning them, OHCS maintains the logical consistency among the hypothetical worlds.

Consequently, the parameterized circuit equations, which are contained in consistent several analysis spaces, can be obtained. Those equations are examined by the analytical expert's heuristics again, then these are computed to get

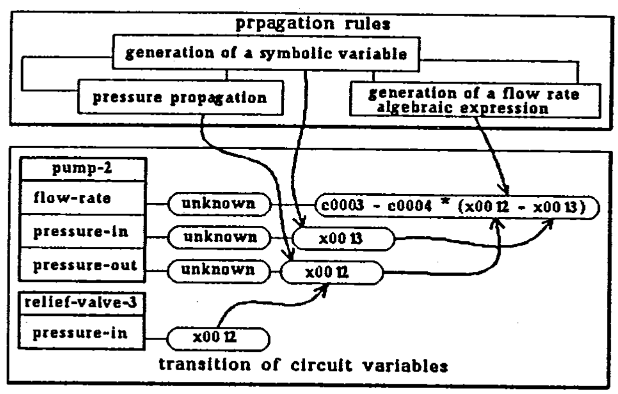

Figure 9. Propagation of constraints

the circuit state variables such as input-pressure, output-pressure, flow rate, and generation of heat.

The analysis space is able to be viewed as three layer structure, which consists of qualitative reasoning level, hypothetical reasoning level, and meta level, as shown in Figure 10.. Multiple contexts are expanded as network in each level. A context is a primitive in the analysis space. The meta level contains common informations through the analysis space. Informations in the lower level are visible to the higher level, and the reverse cannot do so. Accordingly, the analytic model generator generates automatically equations as making reference to the information of the circuit topology.

5. Knowledge Acquisition

The first step in developing OHCS was the information-gathering process from both documentation and human experts. Much of the existing design documentation turned out to be defective in practice, since this type of expertise is not easily documented. As a result, only 20 percent of the documented information could be used to good effect in OHCS. The documentation did, however, play an important role in triggering the extraction of knowledge when the interviews with experts were conducted.

6. Results

The system actually has been deployed since 1988. OHCS expert system was put into operation a year and a half after the beginning of the knowledge acquisition process, and needed 5 people for development. OHCS's payoff for our organization are as follows:

1. OHCS has reduced the amount of work at the designer level by 50 %. If the work pertaining to analysis and diagram inspection is also taken into consideration, an even greater time saving has been effected.

2. Maintaining the quality of circuit diagram drawings at a specified level is possible since the expertise involved in designning, analysis and diagram inspection has been regulated.

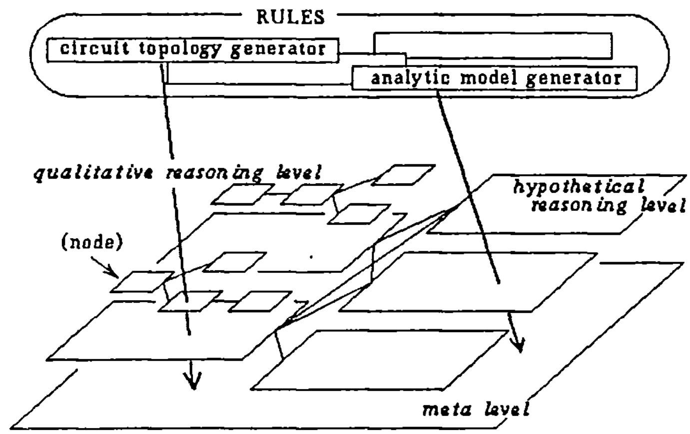

Figure 10. Multi layered analysis space

3. The technology transfer process completed during the development of OHCS has resulted in a further enrichment of analytic knowledge for the researchers who have been working on dynamic analysis.

In the general flow of designing operations the first step is the receipt of circuit specifications from the client. Then a table of quality requirements is drawn up and the actual designing is carried out. The area covered by OHCS is this type of designing. The next step is the layout design and the preparation of a quality assurance sheet. It was at first that OHCS would fulfill a part of the general flow of designing operations. In future we will build other expert systems that fulfill the remainder of the entire designing operations.

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