MODELLING AND SIMULATION OF HYDRAULIC LOAD-SENSING SYSTEMS USING OBJECT-ORIENTED PROGRAMMING ENVIRONMENT

Gunnar Grossschmidt
Mait Harf
Tallinn University of Technology
Institute of Cybernetics
Akadeemia tee 21, 12618 Tallinn, Estonia
E-mail gunnarg@edu.ttu.ee, mait@cs.ioc.ee

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Hydraulic load-sensing system, multi-pole model, visual programming, automatic program synthesis.

INTRODUCTION

Modelling and simulation of hydraulic systems has been investigated in Tallinn University of Technology for several decades. General principles of the research have been published in (Grossschmidt 1997; Grossschmidt et al. 2003).

In this paper we consider a way of modelling and simulation of hydraulic load-sensing systems that enables to optimise such systems.

Hydraulic systems, in which working pressure (pressure in pump output) is kept proportional to load, are called hydraulic load-sensing systems. Such systems are mainly used in mechanisms containing numerous drives to run with purpose to save energy. These are quite complicated automatically regulating systems and until now optimal solutions for static, steady-state motion and dynamics for such systems have not been found. In this paper we consider a simulation system that enables to describe and search hydraulic load sensing systems and find better solutions to those problems. A high-level programming environment NUT (developed in the Institute of Cybernetics, Tallinn) is used as a tool for building up and managing the simulation system.

NUT PROGRAMMING ENVIRONMENT

The NUT system is a programming tool, which supports declarative programming in a high-level language, automatic program synthesis and visual programming.

The NUT programming language rests on two paradigms: procedural object-oriented programming and the automatic synthesis of programs from declarative specifications. The NUT language is object-oriented. Concepts in it are specified as classes, and then used either in computations or for specifying new concepts. There is one big difference between the classes in ordinary object-oriented language and in NUT. The latter contain more knowledge than ordinary classes, and can be directly used as specifications for problem solving. The description of NUT classes may contain specifications of their components, methods, initial values and other properties. Due to an equation solver built into the language processor, the system is able to interpret arithmetic equations as multi-way procedures for computing the unknown components of the equation. Each class can have a visual representation as well, so that much computing can be described visually.

Automatic synthesis of programs is a technique for the automatic construction of programs from the knowledge available in specifications of classes. Having a specification of a class, we are, in general, interested in solving the following problem: find an algorithm for computing the values of components y1, ..., yn from the values of components x1, ..., xm. The automatic synthesis of programs, as practised in NUT, is based on proof search in intuitionistic propositional logic.

The NUT graphics facilities include Graphics Editor, a set of graphics functions in the language, and the Scheme Editor. The Scheme Editor is a tool for visual programming that allows the user to define and use classes by means of graphical schemes. In order to draw schemes of problem specifications, we must have, for each class, an icon in the palette and an image, which will represent an object in a scheme. So there must be an icon and an image for every class. This can be done immediately after specifying a class. After specifying all the classes together with their icons and images one can specify and use for computations a number of different schemes using defined classes. There are numerous built-in features of the scheme editor, which support visual programming:

- connection lines between ports which represent equalities binding the ports;
- an interactive zoom-in window can be opened for showing or editing of any object of a scheme (this window is formatted automatically on the basis of the class specification);

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- requests for computing elements of a schema can be given from menus.

MODELLING OF HYDRAULIC SYSTEMS

A number of packages for hydraulic systems simulation have been implemented in the NUT system. Multi-pole models of hydraulic elements have been described as NUT classes together with their icons and images. Besides multi-pole model classes, several supporting classes as "clock" for the time, "source" for the disturbance, "process" for organizing the whole computing process, have been specified. Using visual specifications of described multi-pole models one can graphically compose models of various hydraulic systems.

When solving specific simulation problem, model has to be adjusted by evaluating different parameters of the elements and adding sources to elements of the model that describe disturbances of the necessary shape and values.

During the simulation, several elements of the model need parameters, which values cannot be computed at the moment they are required. For computing values of such parameters a special method has been used. When starting the process, approximate values of such critical parameters have been given as initials. At each step of the simulation process we try to refine these initial approximate parameters using a special iteration procedure. We use the NUT system to synthesize a program for recomputing some parameters and try to recompute them iteratively until precise values of the parameters have been attained.

A special element "disp" can be used in the scheme for graphical displaying of dependencies we are interested in.

The simulation is organized as computing of static, steady-state motion and dynamics of the hydraulic device. In general, model for static and steady-state motion differs from the model for dynamic responses. Nevertheless fragments for static calculations can expand the model for dynamic responses.

MODELLING A HYDRAULIC LOAD-SENSING SYSTEM

The scheme of a hydraulic load-sensing device of Bosch GmbH we investigate is shown in Fig. 1.

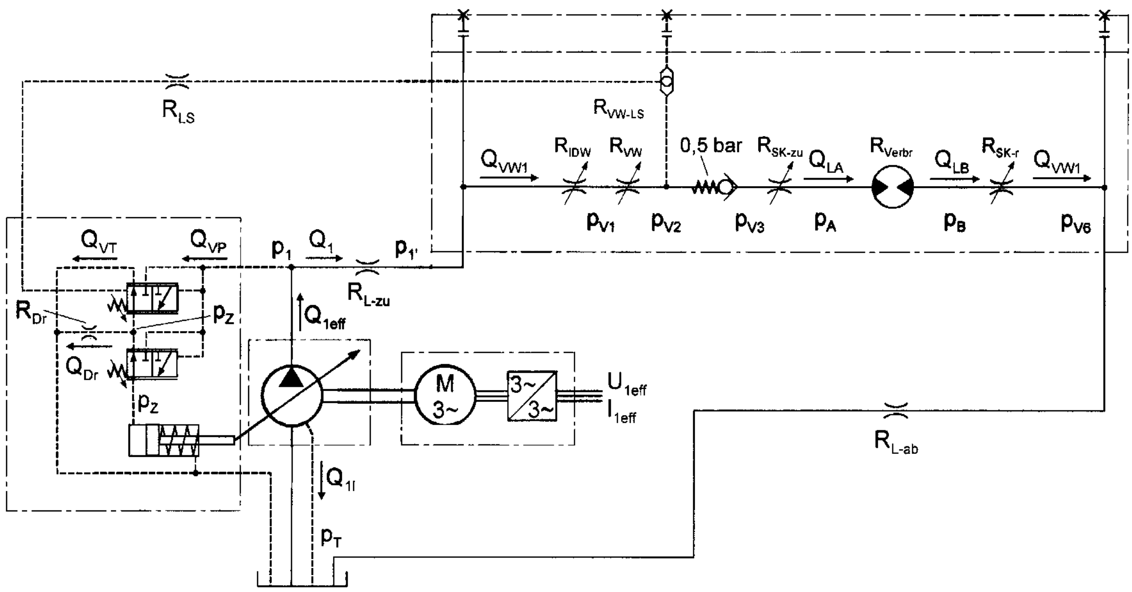


Figure 1.

The variable displacement axial piston pump is driven by an electric motor *M*. Hydraulic-mechanical control of the pump volumetric flow is performed by regulating valves and hydraulic cylinder. The feeding chain of the hydraulic motor *Rverbr* contains tube *Rl-zu*, pressure compensator *Ridw*, measuring valve *Rwv*, check valve, meter-in throttle edge *Rsk-zu*. The output chain of the hydraulic motor contains a meter-out throttle edge *Rsk-r*, and tube *Rl-ab*. The device contains load-sensing pressure feedback with resistance *Rls*.

Mathematical models of the following components of a hydraulic load-sensing system have been developed: hydraulic-mechanical controller components, variable displacement axial piston pump, electric motor, pressure compensator, measuring valve, meter-in throttle edge, hydraulic motor, meter-out throttle edge, tubes, multiple tube connection elements, etc. All the components of the hydraulic load-sensing system have been described as NUT classes.

First, all the models of components had to be composed and tested separately. For this purpose, for each component a computing model was composed, input signals were chosen and finally, action of the component was simulated to make sure everything is correct.

Second, the separately tested components were connected into more complicated computing models and tested in behaviour. At this and following stages, problems of growing difficulty rise. Typical is the appearance of feedback chains, which make dependencies between parameters essentially complicated and more difficult to observe.

Finally, model of the whole load-sensing system was composed

EXAMPLE OF A COMPONENT

Simulation problem description for testing variable displacement axial piston pump PV is shown in Fig.2. The input values of pump pressure (4) and angle velocity of the electric motor (5) are given as constants and a range of values for position angle of the pump swash plate is given as static (1).

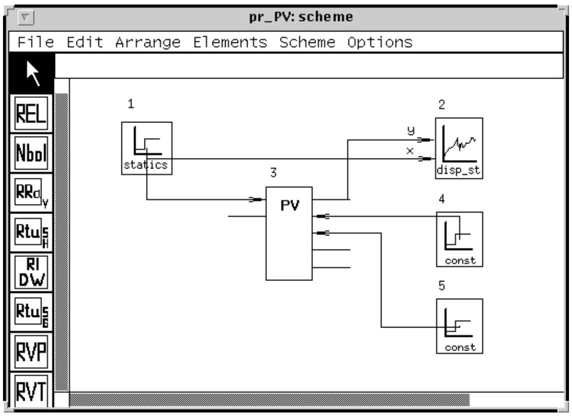


Figure 2.

The volumetric flow in dependence of the position angle of the pump swash plate is calculated, and then visualized by disp (2). The result is shown in Fig. 3.

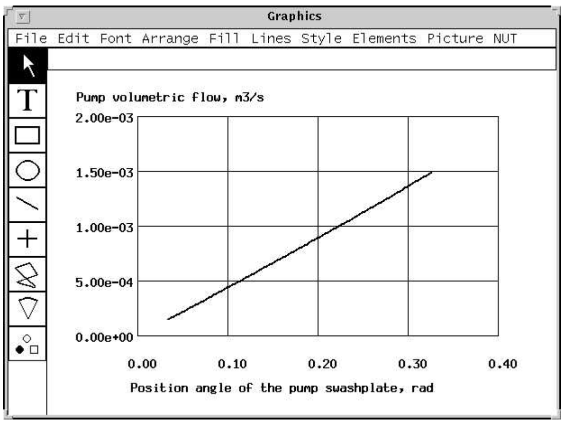
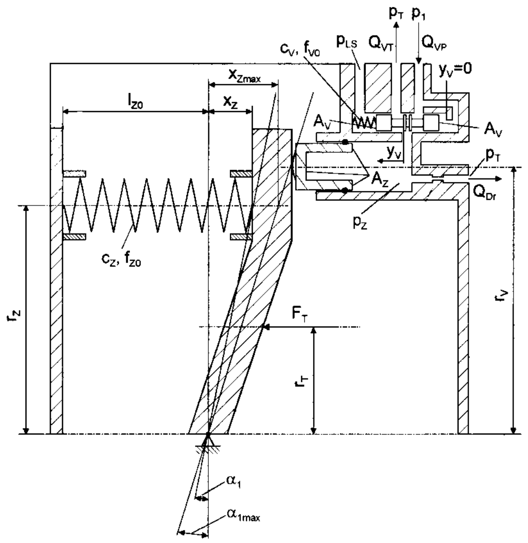


Figure 3.

We need to choose input parameters and parameters of the pump itself to make pump operate in the manner required by other components of the whole system. A great number of different problems with different parameter values have to be solved to test the pump.

EXAMPLE OF A SUBSYSTEM



The scheme of a hydraulic-mechanical controller (Fig. 4.) contains spool valve *Av* with two slots, constant resistor *Qdr*, positioning cylinder *Az*, and swash plate with spring.

Figure 4.

Simulation problem description for testing hydraulic-mechanical controller together with pump and electric motor is shown in Fig. 5.

The scheme contains variable displacement axial piston pump *PV*, electric motor *ME* and pump controlling device which consists of pump control spool valve *VP*, inflow spool valve slot *RVP*, outflow spool valve slot *RVT*, interface element *IEH*, constant resistor *REL* and positioning cylinder *ZV*.

Input values load-sensing pressure (3) and controller output pressure (10) are given as constants and a range of values for pump pressure is given as statics (1).

In Fig. 6 the graph of pump volumetric flow depending on pump pressure is shown. The volumetric flow value is maximal if the difference of pump pressure and load-sensing pressure is less than approximately 15 bars. The volumetric flow value is minimal if the difference of pump pressure and load-sensing pressure is more than approximately 18 bars. In interval 15 to 18 bars the dependence is linear.

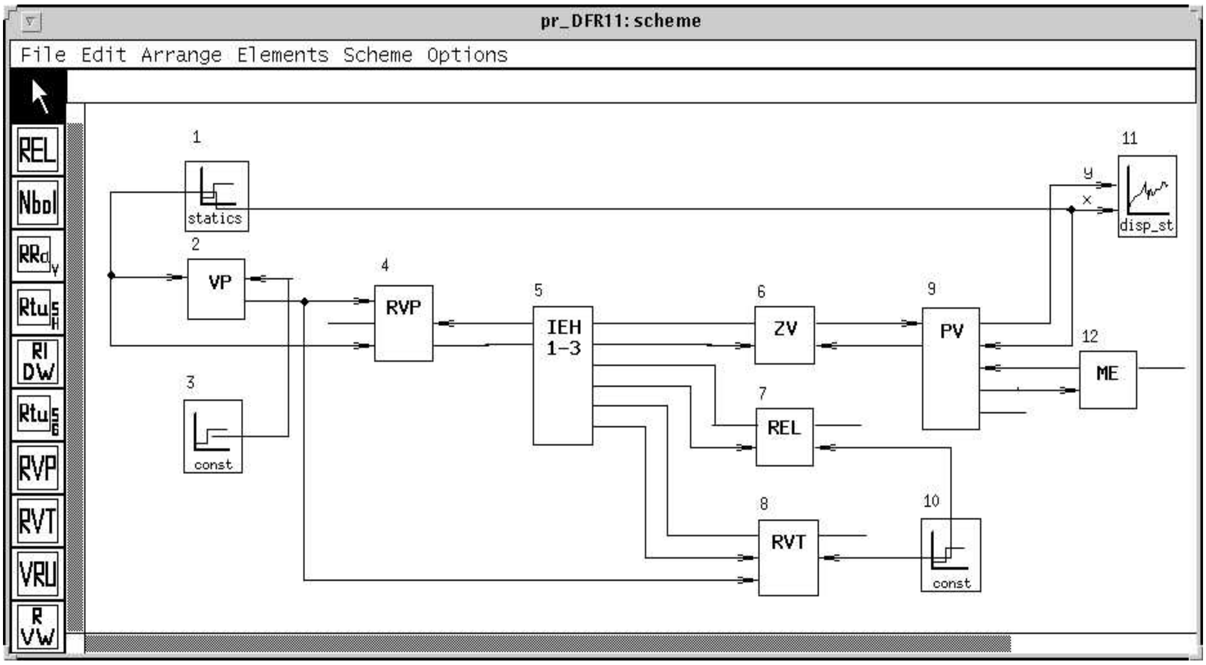


Figure 5.

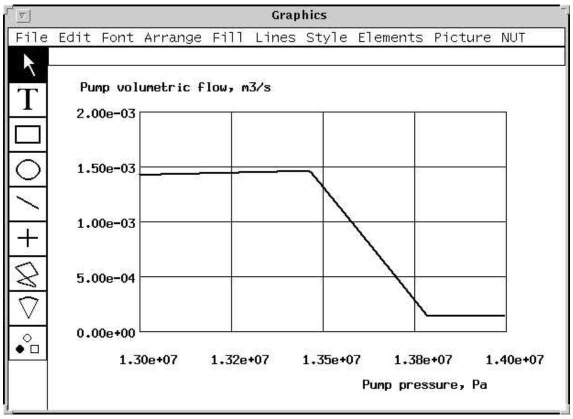


Figure 6.

All the subsystems must be simulated and tested separately. At this stage number of different schemes and problems grows considerably.

MODEL OF THE WHOLE LOAD-SENSING SYSTEM

The simulation problem description of the whole load-sensing hydraulic system steady-state calculations is shown in Fig. 7.

The model contains 19 component models and several constants and static parameter components.

Elements 1-6,8,9,11 are the components of the subsystem, described above. Besides them the scheme contains relief valve (7), pressure compensator with measuring valve (14), meter-in throttle edge (21), hydraulic motor (22), meter-out throttle edge (23), tubes (12, 13, 25), interface elements (10, 16), efficiency coefficients calculator (18), constant inputs (9, 15, 24), range input for displacement of the direction valve (19) and range input for hydraulic motor load moment (24).

In Fig. 8 the dependency graph of the efficiency coefficient of the whole system on the displacement of the direction valve in the case of constant value of hydraulic motor load moment is shown.

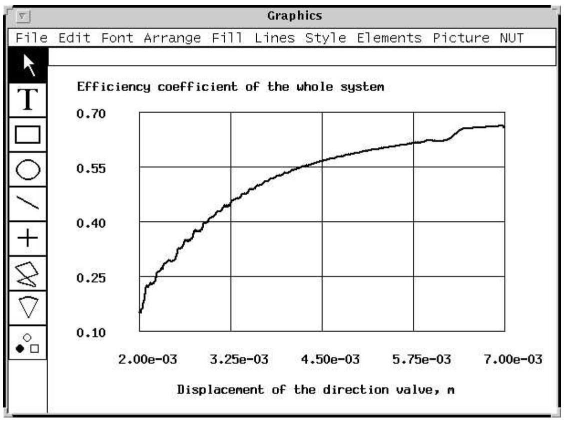


Figure 8.

All the simulations were performed on the SunUltra10 workstation in the UNIX environment.

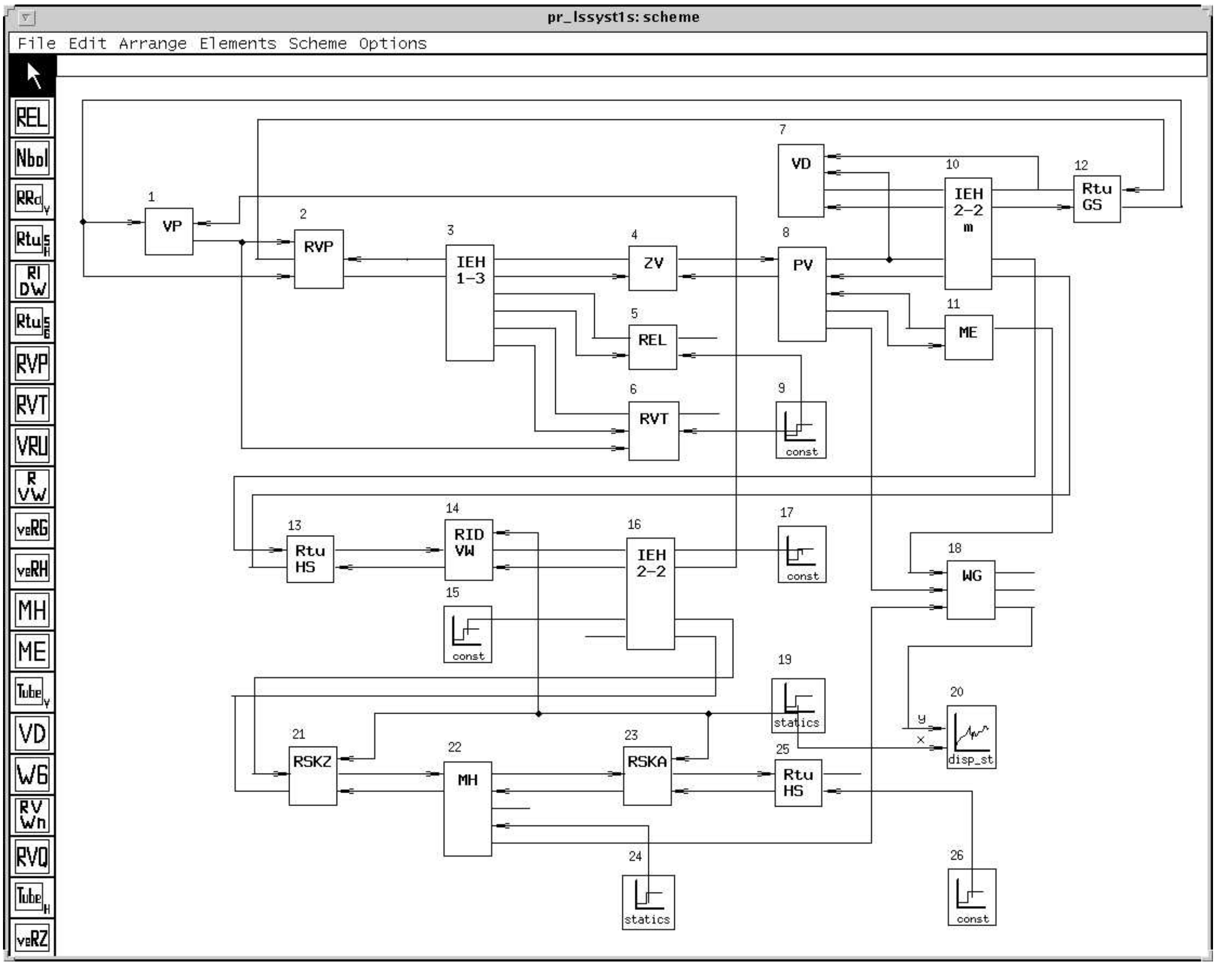


Figure 7.

CONCLUSIONS AND FUTURE WORK

The approach used for simulation of hydraulic devices described above has the following main features:

- mathematical models of the functional elements are as multi-pole models, having various causality and take into account the signal propagation in both direction;
- mathematical model of the whole system carries the full information about connections of input/output variables, which express the considered mathematical causalities and guarantees the completeness of the mathematical model;
- modelling and simulation is built up in object-oriented way using the NUT programming environment, which enables to visualize and automate the simulation process;
- simulation is performed step by step, starting from simulation of components and moving to more complicated subsystems;
- iteration methods have been used in cases of loop dependencies which may appear if models are connected together into more complicated ones.

The hydraulic load-sensing systems require very precise parameter setting, especially for resistances of hydraulic valve spools. Proposed in the paper simulation system enables quite fast and not expensive way to get optimal solutions to these problems.

In the future problems of modelling dynamics of such systems will be considered.

ACKNOWLEDGEMENT

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