

Modeling and simulation of fluid power systems using 20-sim

By Ir. Christian Kleijn
 Controllab Products B.V.

Hengelosestraat 705, 7521 PA, Enschede, The Netherlands

Introduction

20-sim is a modeling and simulation program that allows you to enter models graphically, similar to drawing an engineering scheme. With these models you can simulate the behavior of dynamic systems, such as electric, mechanical or hydraulic systems, including computer control loops.

20-sim has been developed at the Control Laboratory of the University of Twente. It is the successor of the famous TUTSIM package which was developed at the same group in the 70's. In the 80's the Camas project was started to create a successor of TUTSIM. The first version of Camas became available for Unix computers in 1992. For the Open University a PC-version was developed in 1993. In June of 1995 the company Controllab Products B.V. was founded to commercialize the software. At that moment the name was changed from Camas into the brand name 20-sim. Since then the package has been sold worldwide to many companies and universities around the world.

20-sim is an excellent tool for model based design. With 20-sim you can create models to predict the behavior of future systems. 20-sim will help you to improve the system with respect to speed, vibrations, robustness etc. In this way you can increase performance, reduce design errors and reduce design time. 20-sim supports modeling with mathematical equations, block diagrams and physical components. This makes the package suited for the modeling and simulation of computer controlled systems.

Modeling

When you start the program, a library of components and the Editor will appear. You can start modeling by dragging and dropping components from the library to the Editor. By creating connections between the components a model is built-up.

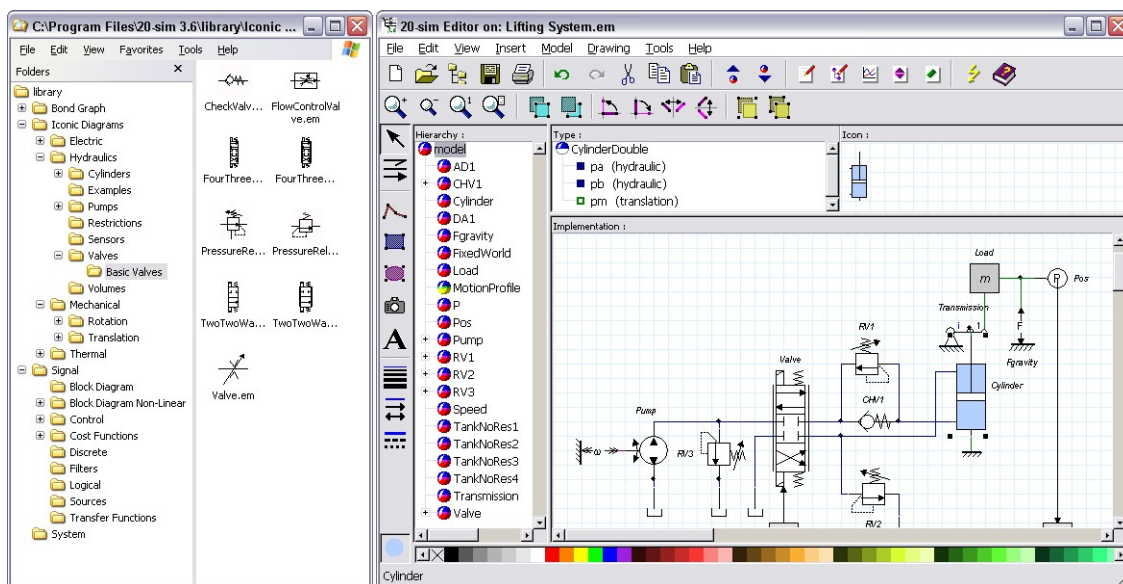


Figure 1: Model Library (left) and Model Editor (right).

The 20-sim library contains domain-oriented components, block diagram elements and bond graph elements. All libraries are part of the standard program. For the building of hydraulic circuits therefore no additional fees have to be paid. The 20-sim library is fully open; this means that every component can be inspected to see the underlying sub components and equations. Library component can be changed at will and stored in user libraries.

The library contains the following models:

Electric

1. Voltage and current sources.
2. Inductors, resistors and capacitors.
3. Diodes, op-amps and rectifiers.
4. Motors and piezo actuators.

Mechanical

1. Inertia's, springs and dampers.
2. Bearings, backlash and clutch models.
3. Belts, spindles, gears and differentials.
4. AC / DC motors.

Hydraulic

1. Orifices and laminar resistances.
2. Cylinders, accumulators and tanks.
3. Pumps, motors and valves.
4. Flow, power and pressure sensors.

Thermal

1. Heat capacity and heat flow.
2. Convection and radiation elements.
3. Heat generators.

Block Diagrams

1. Linear and non-linear blocks.
2. Sources & sinks.
3. Discrete-time blocks
4. Filters and controllers.
5. Transfer functions.

Bond Graph

1. Storage elements.
2. Transformers and dissipators.
3. Sources & sinks.

The Editor contains four windows. The left window shows the model hierarchy with all components and sub components. You can inspect a model at any level by clicking in the model hierarchy. The large window at the right shows the complete model or a subsection of the model. Depending on the kind of model (graphical or equations) specific tool bars are shown. The smaller windows at the top shows the component interface and the representation. Both windows can be double clicked to change the interface (inputs, outputs and ports) and the representation (picture) of a component.

With a click of a button a complete model can be compiled to create simulation code. In the compiling-phase, 20-sim will check if the model is correct and optimize the equations. During optimization a built-in symbolic solver is used to remove derivatives, algebraic loops and other potential problems. The resulting code is loaded in the Simulator.

Simulation

The Simulator is used to run simulations and analyze models. After compiling a model the resulting simulation code is loaded in the Simulator automatically. With the commands of the Properties menu, you can define the settings of a simulation. The finish time of the simulation and the variables that should be plotted are the minimal settings that have to be entered before a simulation run can be started. This makes the Simulator very user friendly for new users of the program. Experienced users will appreciate the ability to change many simulation settings:

1. Parameter values, initial states
2. Start-time, finish time, step size, absolute and relative error
3. Integration methods
4. Number of plots, appearance of plots

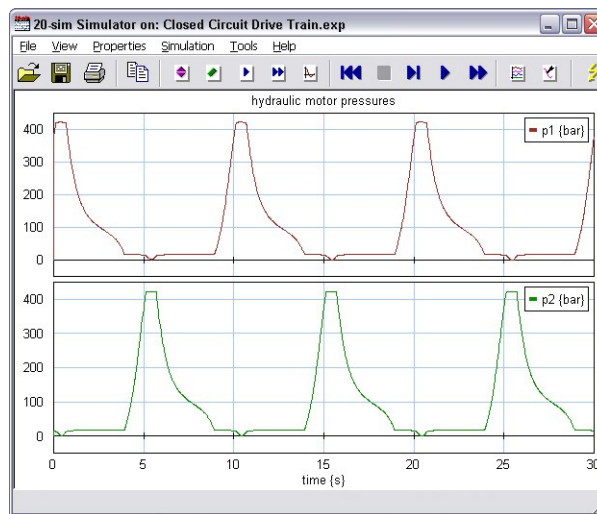


Figure 2: The Simulator.

Next to simulation plots, results can also be shown as animations in 20-sim. A special editor is available in which you can connect any model variable to the position, orientation, size and color of 3D objects. Standard 3D objects are available like cubes and spheres but you can also import objects from CAD packages. This allows you to create thermal animations, 3D moving mechanisms and much more.

Analysis

The 20-sim package has a number of toolboxes which can be used to enter models. The time domain toolbox and the frequency domain toolbox can be used to analyze models.

Time Domain Toolbox

The Time Domain Toolbox allows you to use six powerful model analysis methods with a few mouse clicks. Parameter sweeps, Optimization and Curve Fitting will help to improve model performance. Sensitivity Analysis, Monte Carlo Analysis and Variation Analysis, will help you to check the robustness of models.

Frequency Domain Toolbox

The 20-sim Frequency Domain Toolbox consists of the Linear System Editor, FFT analysis tools and model linearization functionality. The Linear System Editor is a specialized tool for the design and display of linear systems. The editor supports continuous-time and discrete-time SISO systems. Any 20-sim model can be linearized and shown in the linear system editor. You can select bode plots, pole zero plots and nyquist plots to analyze the frequency behavior of the model. Next to direct linearization, Fast Fourier Transforms can be used to show the frequency behavior of a model. Because the transform is applied to a time domain simulation data, it can be applied to measurement data as well. This allows you to compare the model with the measurements in the frequency domain.

Hydraulics Library

The 20-sim Hydraulics library contains components to model the dynamic behavior of hydraulic circuits. Because of the ability of 20-sim to perform symbolic manipulation during processing, components can be connected arbitrarily. Some of the components that are available are:

1. Accumulators
2. Cylinders
3. Pumps
4. Motors
5. Orifices
6. Sources
7. Sensors
8. Valves

Every library component has one or more hydraulic connectors, which are called ports in 20-sim. Ports always include two variables: pressure [Pa] and volume flow [m³/s]. Ports can be connected to other ports like signal outputs to signal inputs in block diagrams.

Hydraulic components can easily be coupled to other library models. The pumps and motors have a rotation port that can be coupled to models of the Rotation library. The cylinder models have a translation port that can be coupled to models of the Translation library. Some models have a signal input that can be coupled to models of the Signal library. This allows you to create a hydraulic circuit which is coupled to a mechanism consisting of translation components regulated by a computer control loop consisting of discrete time block diagram elements in one large 20-sim model.

Example

An example of a system containing a hydraulic circuit, mechanical components and a computer controlled loop is the lifting system of figure 3. A hydraulic cylinder is connected to a pivoted beam that carries a load of 140 kg. The cylinder is driven by a hydraulic circuit that is controlled by a sampled data controller.

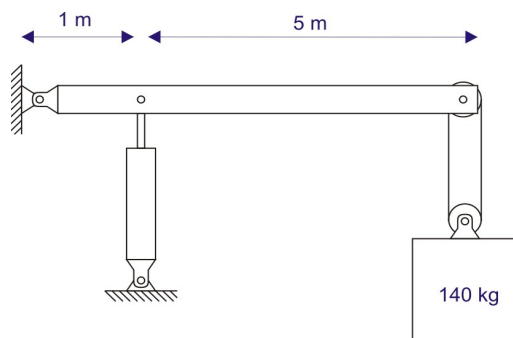


Figure 3: Lifting system.

A model of the system is shown in figure 4. A fixed displacement pump is connected to an open-centre four-three way proportional valve. The pressure relief valve *RV3* is added to keep the supply at a pressure of 138 bar. The valve is connected to the bottom chamber of the cylinder through the counter balance valve *RV1*. The counterbalance valve is needed to hold the load against gravity. The counterbalance valve is accompanied by the check valve *CHV1* to allow a quick loading of the bottom cylinder chamber. The top chamber of the cylinder is also connected to the valve. The pressure relief valve *RV2* is inserted to reduce the acceleration of the load at downward movements.

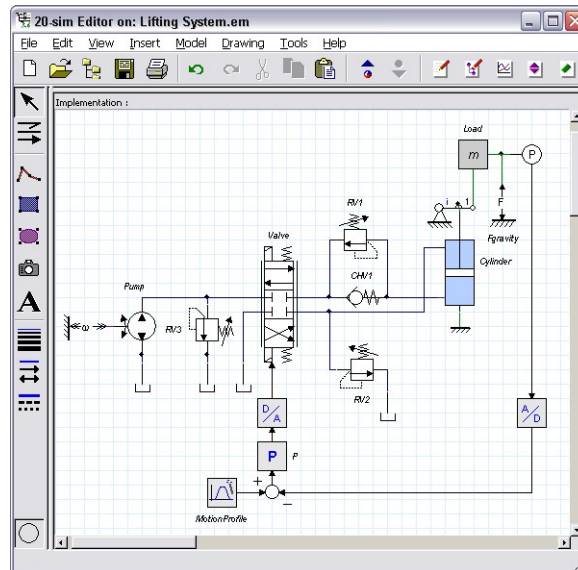


Figure 4: Model of the lifting system.

The cylinder has a translation port which is connected to a lever. The lever is connected to a mass with gravity force. A position sensor measures the position of the load. The position is sampled in an analog to digital converter and compared with a desired motion profile. The error between the motion profile and the actual load position is sent to the proportional controller P. The output of the controller is led to a digital to analog converter and coupled to the valve.

The simulation results are shown in figure 5 and 6. Figure 5 shows the discrete time set point and the continuous time positions of the load and the cylinder. A sample frequency of 10 Hz has been used for the sampled data loop.

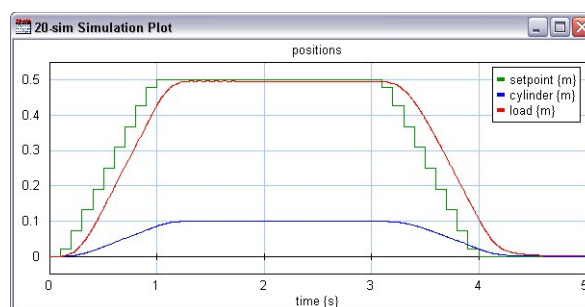


Figure 5: Simulated positions of the lifting system.

In figure 5 there are barely visible vibrations of the load (1 mm amplitude) when the set point has been reached at 1.3 seconds. In the plot of figure 6 these vibrations are more clear in the form of pressure variations.

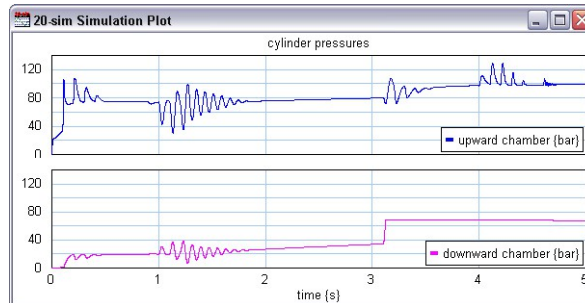


Figure 6: Simulated cylinder pressures.

These vibrations could lead to fatigue of the system components and should be avoided. In the model some adjustments should be tried and checked by simulations. In this example it turns out that a change of pressures of the relief valves *RV2* and *RV3* will not reduce the vibrations. The vibrations are caused by the low sample frequency and can only be reduced by a reduction of the proportional gain or an increase of the sample frequency. A reduction of the proportional gain will give a slower response of the system. An increasing of the sample frequency to 20 Hz will give a similar response with a vibration reduction of more than 300%.

Summary

20-sim is an easy to use modeling and simulation tool. The program is provided with a large number of libraries which are part of all part of the standard program. This makes the program a very affordable tool to create models of hydraulic drive trains which in general contain various physical domains and computer control. A powerful symbolic engine allows an easy compilation of models and optimal simulation code. 20-sim has a built-in simulator, which allows the simulation and analysis of models through various toolboxes. More information on the package can be found at the website www.20sim.com.