Drive & Control
profile

Technical Article

Don't guess: Accelerate hydraulic systems prototyping and validation using numerical simulation

The hydraulic circuit Bosch Rexroth helped create for Woodings' new Hydraulic Distributor for iron blast furnaces delivers a level of burden distribution control previously unheard of in the steel industry.

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Power on, fingers crossed, and hope for the best—The practice of guessing and "let's see how this configuration works" have no place in modern design. Competitive pressures, time and cost limitations force fluid power engineering operations to abandon "good old" trial-and-error methods and replace them with more efficient simulation-based fast prototyping.

Simulation in fluid power

A typical hydraulic circuit consists of a large number of interacting components: transmission lines, pumps, accumulators, motors, cylinders, flow and pressure control valves along with other related equipment. Each of these elements is characterized by individual static and dynamic properties, defined by

Simulation "do's and don'ts"

- Keep the model as simple as possible, as complex as necessary
- Simplifying the simulation can reduce the risk of input data errors and can shorten overall simulation times.
- Test your model. Divide the model into small subsystems and test each one separately as you go.
- Do not underestimate the influence of hydraulic lines on system dynamics. Consider the distance between the power unit, control manifolds and actuators and the dynamic characteristics of those elements
- Check pressures in the system; watch for high pressure spikes, pressure drops and possible cavitation
- Verify component catalog data and review the operational conditions and compare them to the nominal published data
- Calculate static process values such as forces, flows and static pressures prior to simulation.
- Know the basic mathematics behind the component models and understand the settings of the numerical solver and the influence on the simulation results.

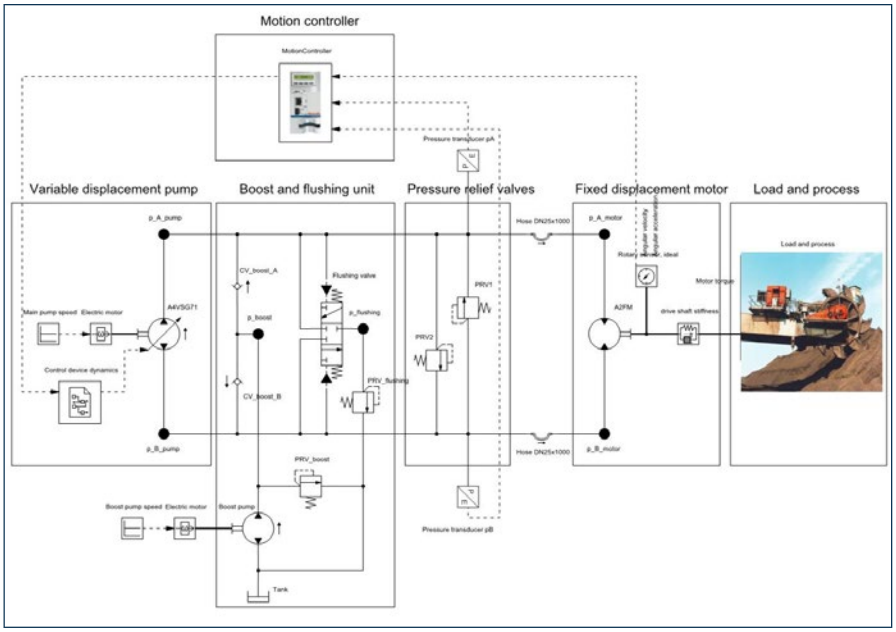

Figure 1 Example of a simulation model of a hydrostatic drive, using Bosch Rexroth's Simster program. The simulation includes detailed models of a servo pump, boost and flushing unit, hydraulic hoses, motor, mechanical load and closed loop motion control. Simulation allows investigation of various system states such as changes in pressure or angular position of the motor.

mechanical design, actuation method, mechanical response, fluid properties and other factors.

It is relatively simple to predict the response of a single component, such as a proportional valve or pump swash plate, especially when the manufacturer provides sufficient data in the product data sheet. However, in many cases, it may be difficult to predict the dynamic response of the overall system along with interactions between dynamic subsystems. The challenge arises from the inherent nonlinear behavior of fluid power systems, resulting from the distinctive physical properties of oil compressibility and the square-root resistor law governing flow across a valves' spool throttling orifices.

In the past, predicting the performance of a hydraulic drive was limited to static calculations and highly simplified linearized dynamic models, based on differential calculus. The last two decades have brought tremendous progress in numerical computation and simulation technologies. Today powerful simulation tools are available to design engineers, making advanced analysis of hydraulic systems' behavior and performance readily accessible.

Key reasons for utilizing simulation

Due to high system complexity, performing a computer simulation can be a handy tool when working on a new system concept or troubleshooting an existing problem. Using a virtual model in an appropriate simulation program offers a completely new insight to the system's properties, allowing validation and optimization of the design.

System modeling and simulation is often performed for any number of reasons. Some of the common ones are:

- Feasibility study and reality check for new designs.
- Verification and optimization of the component selection and system concepts.
- Prediction and analysis of system dynamic behavior, including hydraulics, mechanics, process (metal forming, injection molding, etc.) and closed-loop control algorithms (motion control, force control, etc.).
- Analysis of machine productivity (achievable cycle rates), dynamic performance of the closed loop control, accuracy, energy efficiency.
- Safety analysis under worse-case scenarios.

Simulation is one of the easiest ways to evaluate dynamic and nonlinear characteristics of electrohydraulic drives, and is an efficient and inexpensive way to validate new ideas and concepts without the need for testing physical prototypes. This helps to reduce the risk of expensive field redesign and retrofitting of systems that do not meet required performance and/or stability criteria. The end result is advanced simulation-aided prototyping drastically shortens application development time.

How to approach simulation of a hydraulic system?

Depending on the goal of the simulation, an engineer can select from a number of commercially available simulation tools dedicated to hydraulic systems. Each program offers different component libraries, levels of detail and flexibility in the model's parameterization. Bosch Rexroth has developed a range of tools for in-house use: MOSIHS, Simster and HYVOS, which are tailored to the requirements of application support and development.

Before starting a simulation, the objectives of simulation study need to be precisely specified. What are the main goals of the simulation? What questions need to be answered by simulation? One example is investigation of the response of a closed loop control under specified load scenarios. Other examples would be to compare energy consumption of two different system variants, or presenting the functionality of a new hydraulic schematic.

Problems can arise when application engineers specify simulation requirements too broadly; simply including the requirement "the system should be simulated" is too broad and general. Clear objectives help focus the simulation effort on efficient problem solving.

Remember: A simulation being as meaningful and accurate as the data that was provided. Experience shows that one of the most difficult problems in the overall simulation process is obtaining meaningful information about the mechanical loads (reaction forces due to forming process, gravitational and friction forces, etc).

One critical fact concerns the mechanical inertia of the load to be actuated by hydraulic drive. The mechanical loads and inertias are critical when simulating dynamics and the closed loop control, since they determine the response of the system and performance of the closed loop controls. For example: If you are simulating positioning accuracy of a cylinder drive, the simulation will make little sense if the opposing process and frictional forces are unknown.

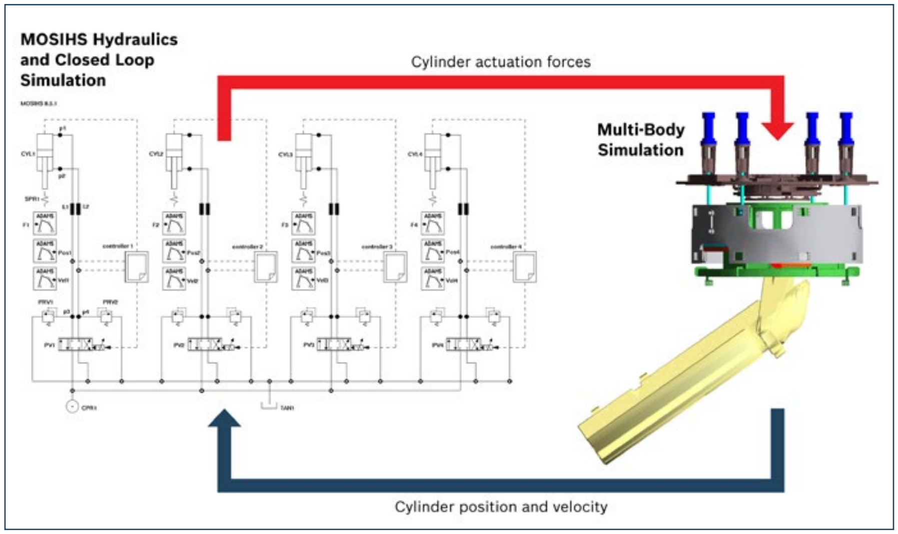

Figure 2 Co-Simulation of blast furnace distributor includes model of electro-hydraulic drive system, closed loop control algorithm and MBS model of the chute assembly

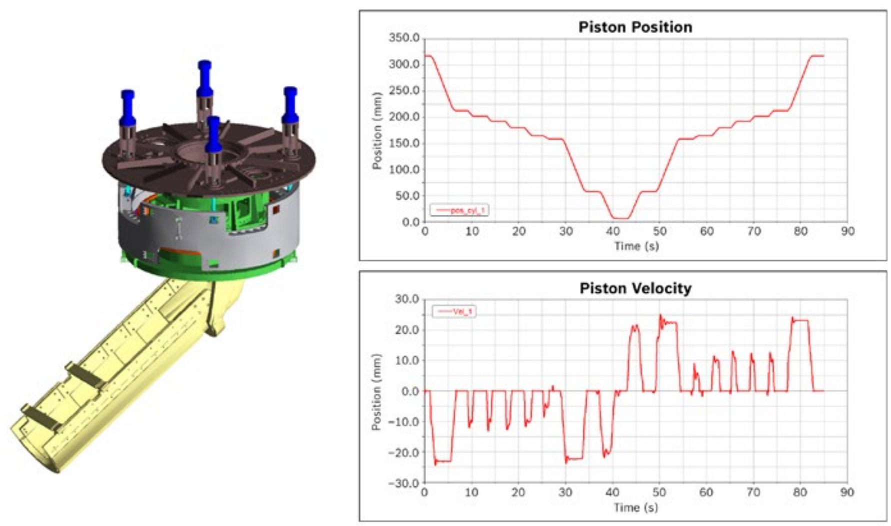

Figure 3 Chute assembly (left) and simulation results (right) depicting the piston position and piston velocity during 90 second distributor duty cycle.

Most model parameters can be obtained from the design documentation, CAD drawings (mechanical inertias), or if simulating an existing application, "system identification" based on measured values (pressure, position, velocity, etc.). If you rely on guesswork, with an engineer performing the simulation relying on experience and engineering "know how", the simulation may not generate accurate results. The simulation input data should always be critically reviewed a system designer and the application engineer.

Co-simulation of complex mechanical and hydraulic systems

In simple simulations, actuated mechanical systems can be modeled as "lumped" elements which are simple single elements that represent a more complex set of elements. Often simple spring-mass-dampers are used in a hydraulic simulation to predict a system's overall dynamic performance. This only works when a known mechanical resonance is dominant and well defined. More complex mechanical systems, such as multi degree-of-freedom manipulators, toggle drives, moving platforms and other systems have multiple resonant modes within the mechanical system and are best modeled using multi-body dynamic simulation software (MBS).

MBS models of complex mechanical systems can take into account the mechanical inertias and flexibilities of the various modeled elements. The MBS model can provide the torque or force inputs, from elements such as hydraulic cylinders to drive the mechanical system, and see the resulting reaction. Combining a simulation of an electro-hydraulic system and an MBS model allows analysis of the overall motion system performance, including interactions between the dynamics of a hydraulic drive, the closed loop control and resonances of the actuated mechanical structure.

Woodings: Simulation case study

An example of such an MBS-Hydraulics co-simulation is a study by Bosch Rexroth of a blast furnace hydraulic distributor, designed and built by Woodings Industrial, Mars, PA. A hydraulic distributor, as seen in Figures 2 and 3, provides two functions: rotation and tilting a chute to deposit layers of iron ore and coke into a blast furnace.

The precision of the deposition of the materials is critical in controlling the melting process. The blast furnace can operate with increased efficiency based on the precision of the layers of the deposited materials charged into the furnace. The hydraulic and control systems have to react quickly to load changes and other disturbances in order to maintain high position accuracy of the chute. Additionally a tight position tolerance between four differential cylinders must be maintained.

A major challenge was a low natural frequency of hydraulic cylinder drive due to high mechanical inertia of the chute and long hydraulic lines between control valves and cylinders. The hydraulic system acts like a mass-damper-spring with a relatively low stiffness and damping, making accurate motion control difficult.

To verify the targeted accuracy and repeatability of the Rexroth hydraulic drive system could be met, a complex multi-domain simulation was performed. The distributor chute hydraulic circuit and controls designed by Rexroth were simulated using MOSIHS, a proprietary simulation program for hydraulic and mechanical systems and controls. All relevant 3D-CAD models of the Woodings sourced components, such as the chute and the rotating distributor head mechanical systems were imported into a commercially available MBS program which is coupled to the MOSIHS simulation tool.

The co-simulation helped to optimize the hydraulic circuit design and component selection and the closed loop controls. The simulation resulted in the need for a specialized control algorithm, using load feedback information, to effectively damp the system oscillations and provide optimal performance. The simulation also allowed the design engineers to analyze and develop a better understanding of how the load forces act on the chute could affect end-point accuracy.

Conclusion

The ability to accurately simulate hydraulic drives can increase the success of many complex applications. Validating design concepts, investigating worst case conditions and modes of operation can reduce operational and financial risks. Being able to verify performance criteria during the proposal and design stages can result in higher performing and more competitive designs.

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