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Mechatronic Challenges to Develop and Implement New Hydraulic Technologies: Independent-Metering Electrohydraulic Valve Examples

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Abstract: A new generation of hydraulic components with their integrated control capability, provides more precision and flexibility, but brings implementation challenges. To cope with this changing reality, the fluid power industry needs to redefine work processes surrounding mechatronic machine development, including the creation of training programs. Although a new generation of students accustomed with numerical simulation technologies is starting to emerge, their applied knowledge is often very limited. In addition, experienced specialists who possess this expertise are also getting scarce and harder to replace. To facilitate this technological transition, simulation and numerical analysis tools seem promising. However, to truly be effective, these tools must enable a collaborative work environment that will leverage the machine knowledge of everyone involved in the development process. The goal of this paper is to provide hydraulic engineers with an optimized and integrated approach, in-line with the working process evolution. This approach is demonstrated by two case studies of electrohydraulic independent-metering valves systems. The first one is the development of a hydraulic and control simulation environment of a CMA Eaton valve. The second one studies the interactions of a virtual Sun Hydraulic valve system that regulates the actuator movement under different loads, co-simulated with a PLC.

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1. Introduction

CAE tools continuously evolve to meet the needs of OEMs and system integrators in terms of development time, system accuracy and energy efficiency. With the electrification of hydraulic technologies, we are witnessing a gradual but irreversible work reorganization. However, several schools of thought are opposing each other instead of embracing joint improvement opportunities.

Technical universities and schools are training new generations of specialists initiated to numerical simulation methods based on traditional mathematical and physics equations. Industries who are still advocating a theoretical approach are engaging in a tedious process of creating accurate simulation models. Even though a realistic simulation is possible, this process is time consuming and does not significantly reduce test and prototyping phases. Furthermore, the scope of this analysis is limited to a small circle of experts and is rarely reusable downstream of the design phase. On the other hand, companies who have the field expertise and experience in design and hydraulic application often display some internal resistance in accepting as valid conclusions the result of virtual simulation studies.

These two visions are considered as antagonists, but should complete each other in reality. To get there, we need simulation tools that allow macroscopic machine simulation without neglecting the realism of simulation models. These tools quickly improve the understanding of a machine’s key functions and help people focus on the important simulation details. These models must also be adjustable by integrating test or performance data and the know-how.

This paper demonstrates an optimized approach for Hydraulics Engineering that will reduce significantly development time cycle when designing and testing hydraulic circuits by using a fully integrated multi-technology platform and/or co-simulation. The Section 2 illustrates this approach through two examples of electrohydraulic design of independent-metering valves which represent solutions for hydraulic control system and application. The Section 3 concludes with some final remarks on how this approach will help the work process in which Hydraulics specialists will necessary be pressed to become multidisciplinary.

2. Electrohydraulic Trend

Electrification and control of hydraulic technology has the potential to maximize the concept's flexibility for many mobile hydraulic applications. The objective is to modify the valve's operating parameters to adjust the performance depending on an operator's desired operation mode and the machine's operating conditions. Since this concept requires several distinct expertise, the flexibility offered is inversely proportional to the ease of integration of such solutions. This electrohydraulic concept was developed following the approach previously introduced and studied from two different perspectives presented in the following sections. Fig. 1 illustrates how the different inputs that contribute to generate the design tool (multi-technology software & co-simulation).

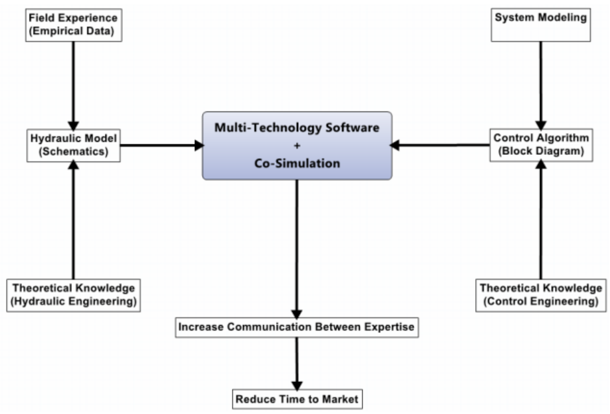

Fig. 1: Multi-Technology Software & Co-Simulation Tool and Approach

2.1. CMA Valves Simulation Environment

A first case study shows the CMA valves – an innovative Eaton sectional valve that integrates the two stage twin spools independent metering valve concept (2). This valve is also equipped with many internal sensors and on board electronics that collect data to monitor its states and compute, via a control algorithm, the command signal to obtain the desired valve performance.

The hydraulic schematic (Fig. 2) was faithfully reproduced to ensure a proper understanding of the model's components. A simulation model of two work sections has been established by including dynamic parameters influencing the valve movement and responsiveness. As for the spools' hydraulic parameters, a flow gain curve based model has been used and theoretical relationships were used to evaluate the spool flow at each LVDT position. Mechanical and hydraulic parameters can be easily adjusted, according to different configurations, by integrating a maximum of empirical data. This allows hybrid simulation, to have a better matching with reality, using both theoretical models and data that were collected from field experience or from other sources of test. The fix displacement pump inlet option has been used to reduce the model dependency from the pump characteristics. Pressure sensors, located at each work port and in the inlet section, and main stages' LVDT measures provide the actual system state to the control loop.

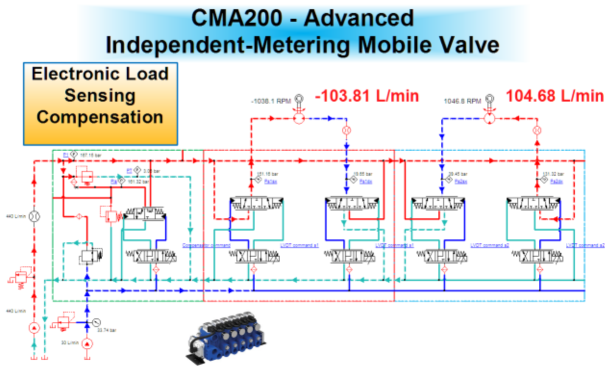

Fig. 2: Eaton CMA Hydraulic Circuit

To simulate this technology of hydraulic valves, hydraulic knowledge alone is not enough: control engineering aspects must be taken into account. Thus, the control algorithm was implemented using a block diagram environment. This environment receives set points, the operator flow demand for each work section, and system's sensor signals from the hydraulic circuit. From there, using a close loop (PID) position controller it calculates the commands that need to be sent to the electrohydraulic pilot stage valves to control, in each section, the main stage spool position according to the selected control strategy. Two control types have been modelled to respond at different operating conditions: flow sharing and cascade mode. Depending on the system status and the selected control response, the control signal is then calculated in real time and activates the pilot stage in each valve section to ensure the desired level of flow and overall hydraulic valve performance. The control valve is thus adapted to match the operator desired behaviour and automatically adjust to the operating conditions without any modification to the valve's physical parameters or configuration. Potentially, an infinite number of scenarios can be implemented reusing the developed model to test the controller's robustness depending on application types.

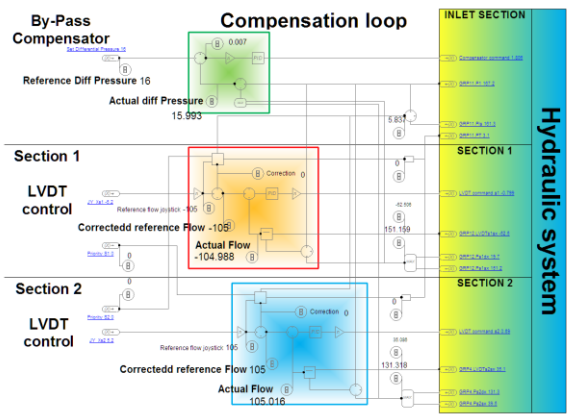

Fig. 3 : Famic CMA Control Algorithm

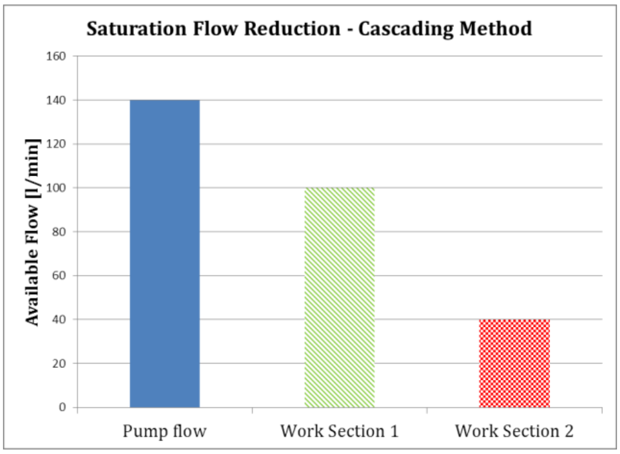

Fig. 4: Cascading Priority Method at Pump Saturation

2.2. Realistic Simulation of a Hydraulic Actuator's Simultaneous Inlet and Outlet Control

The second case study (1) represents the new hydraulic specialist generation. By using an integrated approach, it successfully combined advanced simulation and an engineer field expertise, as well as the SUN Hydraulic test data. The project was to develop and test the validity of a concept for a hydraulic actuator's inlet and outlet control through simulation – a function found in Atlas Copco's concrete spraying robots. More specifically, the aim of this development was to improve the robot's hydraulic cylinder control precision to ensure a smooth displacement by using also independent-metering valves concept. The approach is demonstrated in four steps.

As a first step, the existing inlet and outlet control solution for the hydraulic actuator was recreated in a simulation environment to get the state of the art circuit. As shown on Fig. 5, this circuit is divided in three parts to distinguish the hydraulic power supply, the closed loop control circuit and the disturbance.

The control loop is modeled using SUN Hydraulics Electro-Proportional 3-Way Flow Control Valves (Fig. 5, Components 3-4) and SUN Hydraulics CBCA Mechanically Adjustable Counterbalance Valve (Fig. 5, Components 5-6). These valves were modeled using test data provided by SUN Hydraulics in order to accurately represent the hydraulic system's dynamic behaviour.

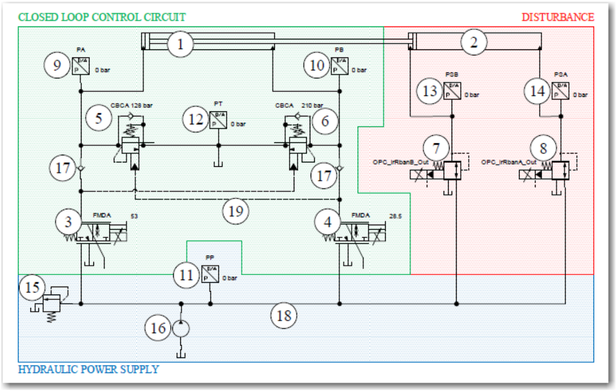

Fig. 5: Hydraulic Test Bench Circuit at State of Art

To represent the disturbance as a contributing force, cylinder 1 and 2 are mechanically interconnected. The resulting face to face double acting cylinder was modeled using a 2D planar mechanism. In order to obtain a realistic simulation, the various component parameters were also adjusted. The behaviour of this test bench system was then validated through simulation.

As a second step, the closed loop control circuit was modified to test the new concept by including the independent-metering valves. As shown on Fig. 6, Components 5-6 were substituted by HydraForce TS12-27 Proportional Pressure Relief Valves.

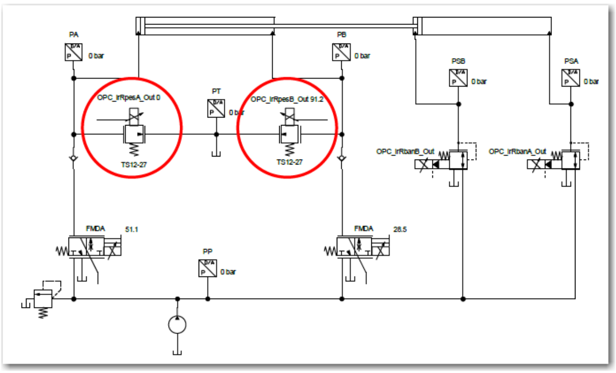

Fig. 6: Modified Hydraulic Circuit with Electro-Proportional Counterbalance Functionality

The TS12-27 valve model was revised using the virtual component test bench shown in Fig. 7. The characteristic curves shown in Fig. 8 derived from the manufacturer technical data sheet were used to reproduce a representative behaviour of this valve type.

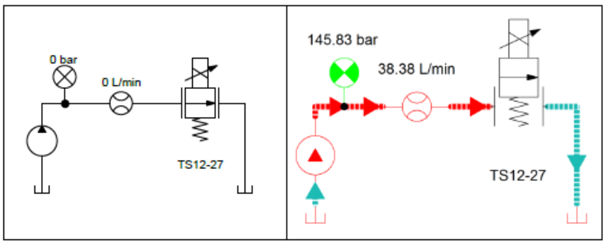

Fig. 7: TS12-27 Virtual Component Test Bench

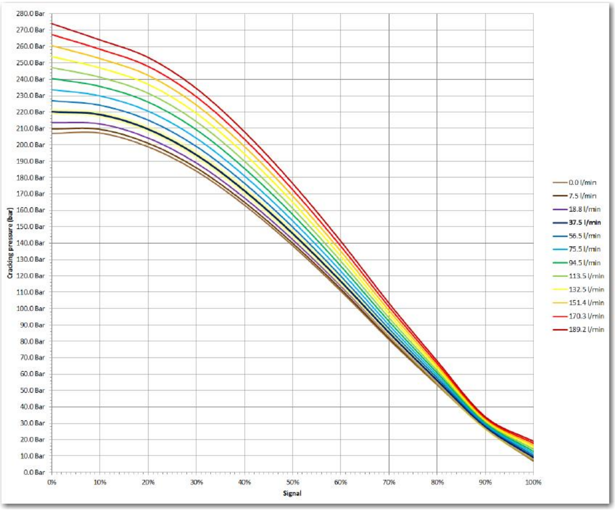

Fig. 8: TS12-27 Characteristic Curves

As a third step, the main control program was developed in PLC and tested via OPC connection with the hydraulic circuits in the simulation environment. This co-simulation environment was setup using the architecture shown on Fig. 9. The hydraulic simulation containing is then able to send/receive signal trough the gateway server to the soft PLC and vice versa.

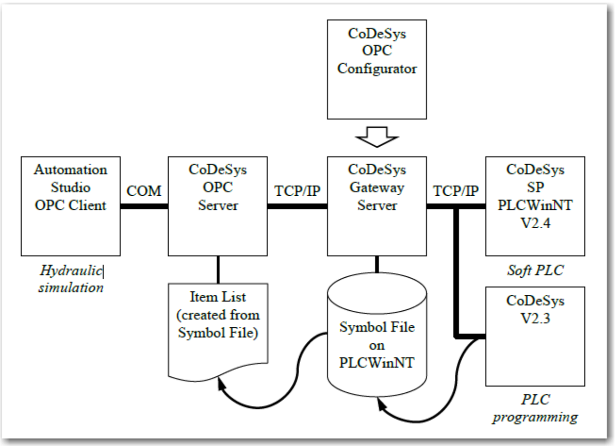

Fig. 9: Architecture of Co-Simulation Environment

Finally, the path accuracy of the test bench circuit with Counter Balance Valve Control and the hydraulic circuit with simultaneous inlet and outlet control were simulated and compared for different initial simulation environment.

5. Conclusion

Overall, these projects study presented here demonstrate the feasibility of this approach to combine different expertise of a work group in one virtual simulation environment and by co-simulation. There are numerous benefits for using this integrated systems methodology. It allows Hydraulic Specialists to test several numerical parameters in order to perform better parameter adjustments for machine controllers. Therefore, their expertise and testing data becomes part of the simulation environment. That enables control specialists to have a better visualization and understanding of the system's operation. It reduces the gap between different expertise involved in the implementation and the integration of complex electro hydraulic control systems.

The Independent-Metering Electro hydraulic Valve technology has a promising future but need to be understood. This type of valve is one example of challenge that OEM will face with more and more mechatronic solutions to implement. This is why the optimized approach presented before can help the work process in which Hydraulics specialists can contribute.

Acknowledgement

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