How to take advantage of a Machine Knowledge Management Software to enlarge the simulation tool spectrum from the dynamics performances of individual components up to a complete mechatronic systems analysis & monitoring.

Richard Gagne*, Vincent Rémillard, Denis Lenoble, Sang-Jin Lee

Key Words: Virtual Machine, Machine Knowledge Management Software, Simulation Tool, Working Process, Mechatronic, Electrohydraulic, Dynamics, Hydraulic, Manufacturers Catalogue, System Analysis, Hydrostatic Transmission.

Abstract: It is well known that the current economic and market trends are pushing Original Equipment Manufacturers (OEMs) and system integrators to design high-performance systems with tighter development time requirements. Naturally these developers are resorting to simulations to avoid the time and cost of early prototyping. Without losing security and environmental sights, they also wish to reuse their simulation models for different needs and purposes. Automation Studio™ software establishes a new "language" of virtual machines and components that manufacturers of hydraulic, electrohydraulic and control component need to market and promote their products.

This paper presents an innovative approach to aid the design and analysis from simulation of dynamic component behaviours to complete mechatronic systems and machines. The proposed methodology allows the decision maker to select the appropriate simulation setting in order to meet the needs of multiple simulation scopes for every step in the project's lifecycle. This approach used to be called Machine Knowledge Management Software.

R. Gagne (Speaker), V. Rémillard, D. Lenoble:
Famic Technologies inc. E-mail : rgagne@famictech.com,
Tel : +1 514-748-8050
Sang-Jin Lee : Inroot Co., Ltd, Tel : 82-31-399-5711

1. Introduction

In order to cope with many needs in a mechatronic system's lifecycle, OEM must acquire many decision support tools in order to complete prototyping and the subsequent steps of the lifecycle. Certain software tools such as simulation software offer advanced and sharp analysis capacities. However, most simulation tools specialize in a specific modeling niche and require user competence in particular software and technical fields. Thus, we forsake some diversity in simulation capacity. Consequently, users lose sight of an overall view of the system they wish to simulate and are forced to make compromises in their working process. For example, users are obliged to use more than one software tool to simulate an entire system, which complicates the product development cycle and renders this step useless for other purposes. In this paper, we will present a few examples of Automation Studio™ projects that were used as a Machine Knowledge Management Software allowing more flexibility, versatility, and simulation reusability. This is mainly due to:

- the hybrid simulation models as outlined in Rémillard & al. [1],
- the Downstream design approach as referred to by Rémillard & al. [2],
- the different functionalities easing design and analysis, as illustrated by Lenoble & al. [3].

In the second section of this article, we will explore a few software parameters that allow for expansion of the simulation spectrum. Certain simulation parameters such as the simulation pace, the system's environment and simulation options are noted as the main factors affecting the spectrum. These factors will be defined during the application of the work methodology proposed in this paper.

We will present a broader working process in the third section. Initially, we will explain how the simulation's scope and the specific information needs are extracted from the model and shared. This allows us to make informed choices for selecting a suitable simulation model. This methodology brings users and companies to limit compromises and to gain maximum benefits inherent to power system simulation.

In the fourth section, we will show how catalogue components assist in the selection of the right level of detail for the simulation model according to the functions or behaviors needed by the project. It will also show how it is possible to adapt these models and the sub-models that constitute them to fit the project's requirements.

The fifth and final section is where we will present a few examples created with Automation Studio™ that show how the proposed working process brings us to use a Machine Knowledge Management Software efficiently. We will also present two methodology applications where the simulation needs are opposite. The first case study will be the dynamic analysis of an excavator's main control valve; the second will be a demonstration of a Failure Mode, Effects and Criticality Analysis (FMECA) tool that monitors a protection system through a BOP valve in the offshore drilling industry.

2. Simulation Tool Spectrum

Once the simulation's scope and the needs are defined, we must choose the proper simulation tools, while configuring these tools precisely to achieve the original objectives. These objectives must be achieved by minimizing deployment costs without compromising the reusability of project simulation by requiring specialized labor to do the technical work.

One of the factors allowing spectrum expansion is the simulation pace that can be set with different time steps: 0.1 ms, 0.5 ms and 10 ms. By setting a smaller time step, we obtain a more refined behavior representation. For each time step value mentioned above, we associate a type of simulation scope to understand a simulation spectrum as can be implemented in software like Automation Studio ™ (Fig. 1).

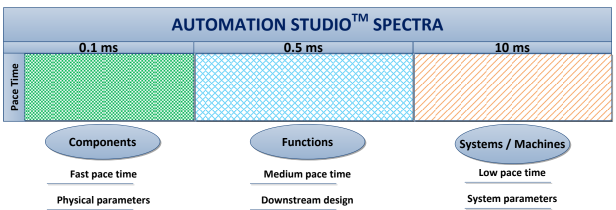

Fig. 1 Simulation Tool Spectrum

If we refer ourselves to the time steps values previously mentioned, a time step that is set at 0.1 ms or less, allows us to simulate a sufficient level of detail at the scale of a system's component. For example, a directional servo valve's behavior can be simulated with a faster simulation pace. The component's physical parameters can be used and a frequency analysis considered.

The second time step, (0.5 ms), allows us to increase the speed of the calculations in order to simulate a more extensive function for a system without losing a certain level of detail for the transient behavior. The simulation of a hydraulic main control valve with its flow demand, electronic control and multi-body mechanism, can be a case study where we increase the time step without rendering the simulation impracticable. Thus, the second time step can allow us to simulate models that do not need to represent phenomenon with a very high level of precision. This will result in an overall gain of computation time enabling us to simulate a slightly broader spectrum. For example, it is possible to have a pairing if the component models, such as dynamic models, are coupled with kinematic models.

The last time step, (10 ms), allows a simulation scope of a more global system where the level of detail of individual components is neglected in order to make way for the system's logic and the overall performance requirements. For example, an entire mechatronic system can be difficult or impossible to simulate with many dynamic complex models of subcomponents. Simulation performance can sometimes hide sough-after information or prevent us from calculating them. By setting a time step at 10 ms or more, a system's simulation be can done from a software point of view by keeping the simulation time equivalent to real time and analyzing performance requirements or training operators.

3. Working Process

The proposed working process, demonstrated with Automation Studio™, can be divided in 4 levels (Fig. 2): The Simulation Scope (1), the simulation needs (2), the usage of the Manufacturer Catalogues' components that ease the implementation of the simulation (3) and the dedicated software features for better analyse and visualise system's behaviors (4).

1- Choose Scope		
Components	Function	Machine
Servo Valves	Hydraulic function	BOP, Crane
Main Control Valves	Hydrostatic Drive	Excavator
2- Needs		
Analysing	Training	Trouble Shooting
Dynamic	Sale and Promote	Monitoring
Functional Analysis		System Logic
3- Catalogue Components		
Dynamic Model	Simplified Model	Manufacturer
Kinematic Model	Discreet Model	Pump Builder
4- Software Options		
Simulation Pace Time	Steady State Analysis	3D Model
Plotter	Trouble Shooting	Oscilloscope
Dynamic Measuring Instruments	Energy Analysis	

Fig. 2 Automation Studio™ Working Process

SCOPE - Establishing the simulation scope is crucial when designing a virtual model. Once the simulation scope is established, it becomes more straightforward to understand the different hierarchical levels needed to paint a complete and useful picture of the system being studied. The first level listed in Fig. 2 shows different scopes that can be focused on. The scope can be 3 types: the machine, the function or the component.

Component – Sometime the need to use simulation is at the component level. For example, a design issue requires a more refined model and simulation of a component becomes essential to help understand, to exchange detailed information between colleagues and to aid decision making. In these situations, the simulation scope is at the level of components such as servo valves, directional valves or main control valves (MCV).

Function - Recently, the market demand for simulating functions has grown considerably. This scope level has the benefit of offering quick and affordable solutions for OEMs, system integrators, and component manufacturers. As manufacturers are portraying themselves more and more as solution providers, they are offering more and more functional solutions: power steering, braking, power units, hydrostatic drive, etc.

Machine – Combined with a wider simulation spectrum, we approach the objectives shared by all OEMs to integrate more simulation in their working process by creating virtual models of their complete mechatronic system. This scope aims mobile equipment such as excavators as well as industrial and offshore systems (for example: drilling infrastructure with its blowout preventer (BOP) security system). As shown further in this section, according to the scope, the simulation of a machine can be reused for various corporate activities like training, engineering and maintenance. It can also be beneficial to reuse it for the analysis of global performances criteria based on different scenario and duty cycles.

PROJECT NEEDS – Establishing the project needs and the use of the simulation. At this stage, simulation needs can be for some activities prior to product development and prototyping such as the analysis of a component or function dynamics or to validate the functional and logical behavior only. And also, it can be in the post development phases, to train new employees or prepare diagnostic and failures materials. Finally, the simulation project can also provide marketing and promotional interactive documents.

CATALOGUE COMPONENTS – To catalyse the methodology and make it more accessible to all potential users, different model types need to be available, easily usable, and easily customisable by users who want to create a complete circuit simulation by connecting all the individual components together.

As explained in Rémillard & al. [1], Hybrid is the answer for that enhanced process: “It is this inner organization, combined with the ability to nest blocks within each-other that give the approach its significance. Whenever information about the system is lacking, simplified models can be used within a block. When more precision is required, the same block can be remodeled with more advanced dynamics without having to readapt other blocks.”

Components from Automation Studio™ manufacturers’ catalogues can have more than one type of simulation models. For example, it includes different models of pumps. There are detailed models which can be used to animate, simulate and individually control the inner components with high precision calculations. This model is dedicated either to train people on the component or function scope or to analyse the internal dynamic performances of the pump. However, if the project requires simulating a complete system, it may be more appropriate to use a model where the sub-component details are not considered without neglecting the overall behavior a complex pump. Combined with the right simulation pace, the calculation will be optimised to ensure a real-time simulation. Similarly, the valves also have different models. One type is kinematic for a machine scope simulation, and another one is fully dynamics, to be used for frequency analysis or other more refined simulation analysis.

SOFTWARE OPTIONS – Select the right tools that increase the machine knowledge access and speed up the decision making process, the learning curves and moreover, the communication. The last step of the working process depends greatly on the analysing and the measuring tool that the software offers. The software features are listed in the figure 2. The selection of those features and corresponding tools for the project will be dictated by the needs established at the step 2.

4. Manufacturers Catalogs Components

Previously, we have explained the simulation tool spectrum and the proposed working process for component or system simulation. Thus, the purpose of this section is to demonstrate the different models that could be used in order to get the best fit with the project's scope. The simplified model idea and the reason for its use will be demonstrated. An example of the detailed models will be demonstrated afterwards.

The Fig. 3 shows how the components are listed in a catalogue and how the user can easily explore and select the right manufacturer component. For example, in Automation Studio™, since the catalogue components are ready to simulate, the catalogue will increase the production of the simulation project.

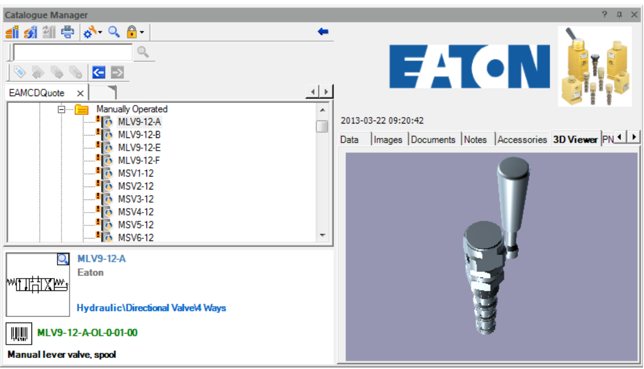

Fig. 3 Catalogue Product Selection Example

Components using a simplified model

As a first example, Fig. 4 illustrates a circuit that tests and analyses the valve's output flow control. This model can be kinematic model, because the operation's representation through simulation is simple. It does not require a model with all of the physical parameters, since its behavior is based on empirical data and kinematic parameters such as the spool's speed, its course and its command value.

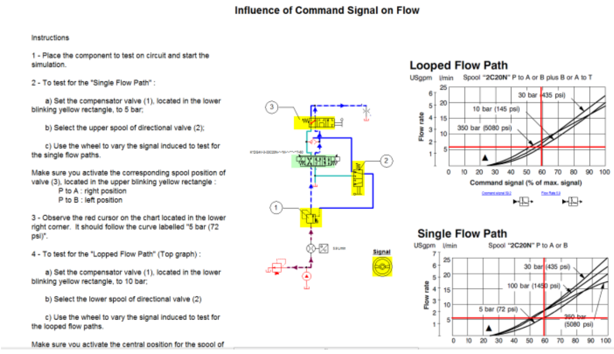

Fig. 4 Manufacturer Component Example 1

In the second example, an axial piston pump used in closed circuits is divided in many sections such as the rotating group, the cylinder block with the swash plate, the regulation and protection valves with the auxiliary components, the pump's control block and the feeding block. By using the simplified model that combine those sections, the pump's functional schematic model allow us to simplify calculations, and to accelerate the simulation while obtaining a good flow rate and a proper pressure control. Figure 5 illustrate the case of a pump in a closed circuit that allows the simulation of a hydraulic system and the flow control analysis.

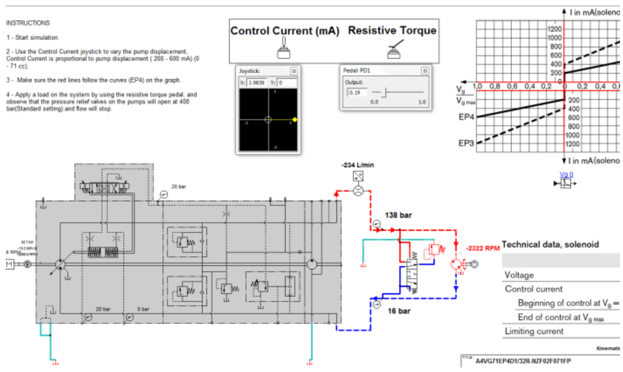

Fig. 5: Pump Builder (A4VG) from catalogue

This simulation model allows us to focus more on the global input and output parameters than the internal components' behavior. That will allow the users to read the data faster and to ease the analysis of the circuit. The circuit's information will be then simplified as demonstrated in the following figure.

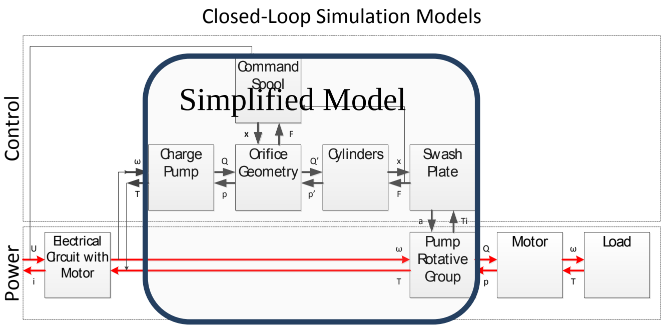

Fig. 6 Block Model Closed Loop Pump

Only the speed ω and torque τ will be calculated at the input shaft while the flow Q and the pressure P will be calculated at the pump's connection ports. This saves time for the simulation of internal components as such as charge pump, command spool, swash plate, cylinders, etc.

The same kind of model can be applied for an open loop pump as shown in the fig. 7. The inner valves, the swash plate with the cylinder block and the pump's rotating group will also be embedded in a single mathematical model of the function of the pump's torque, speed, flow and pressure.

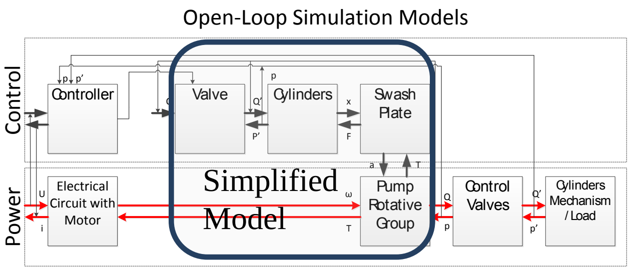

Fig. 7 Block Model Open Loop Pump

<u>Components using a detailed model</u> –

For a proportional valve, the dynamic model allow the analysis of high frequency transient behavior, in addition to other behaviors of the valve such as its flow rate control, the pressure drops, the pressure control , the flow forces and the electromechanical behaviors of commands like hysteresis

For example, the following figure presents an electro-proportional flow control valves where we analysed the influence of the input signal on the regulated flow.

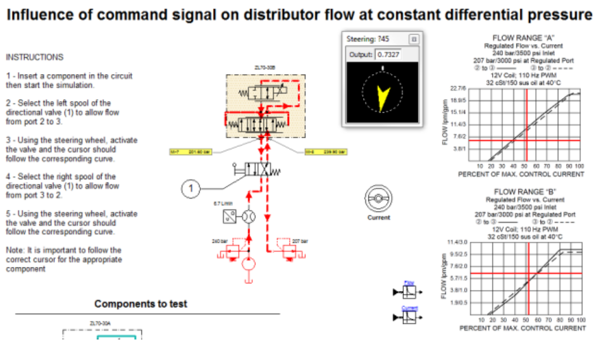

Fig. 8 Manufacturer Component Example 2

The model for this valve include two proportional valves; one for the electronic flow control and the another one for the internal compensator spool which provides compensated flow. In order to bring a better understanding of the dynamic valve model used in this example, the fundamental equations of components that modulate hydraulic behavior are explored here.

To start the analysis, we start by establishing a relationship that dictates the motion of the moving part of a proportional valve. It can be represented by a second order differential equation with position x and its time derivative. With parameters mass m, damping coefficient c and spring stiffness k, the relationship is defined by

$$F = m\ddot{x} + c\dot{x} + kx \qquad (4.1)$$

Also, flow Q and differential pressure Δp are a function of the position of the valve. There are two general models to define theoretical pressure drops. The one to select depends on the geometry of the flow path.

If we describe the flow path with an orifice model, we use the following equation:

$$Q = C_d A_o(x)\sqrt{\frac{2\Delta p}{\rho}} \qquad (4.2)$$

Where C_d is the discharge coefficient, ρ is the specific mass of the fluid and $A_o(x)$ is the area aperture function with respect to position x.

If the flow path is a pressure line model, such as the Darcy-Weisbach [4] relationship, we can use:

$$\Delta p = f\frac{L}{d_i(x)}\frac{\rho(v_f)^2}{2} \qquad (4.3)$$

Where f is the flow loss coefficient, that can be established using a Moody chart or other methods [4], L is the length of the line, ρ is the specific mass of the fluid, v_f is the fluid velocity and $d_i(x)$ is the diameter as a function of position x.

Data Mapping – Equations 4.2 and 4.3 can be presented using curves such as illustrated in Fig 9. We see the aperture $A_o(x)$ as a function of valve's stroke, where the appropriate geometrical model can be selected as needed.

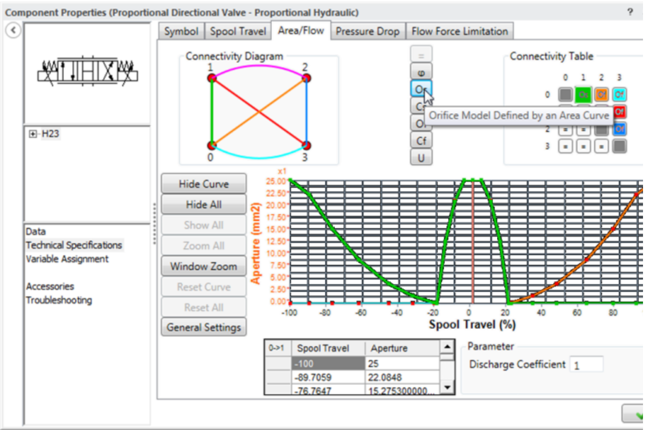

Fig. 9 Orifice Model using Curves

However, once again, the real geometry of a valve cannot be usually represented entirely or precisely by using any one of these theoretical models.

Data mapping makes it possible to define a hybrid model of the valve's flow characteristics directly with the appropriate flow gain curve, such as in Fig 10.

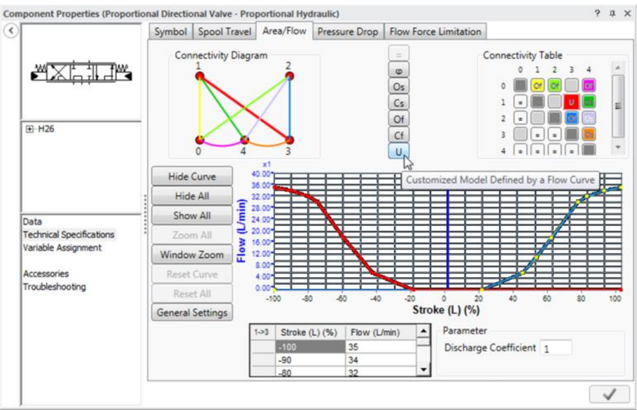

Fig. 10: Flow Model Curves (Eaton CML60)

Moreover, data mapping includes considerations of more complex phenomena such as hysteresis and flow force effects by defining two extra curves. The curve in Fig. 11 adjusts the displacement characteristics and the one in Fig. 12 adjusts the flow relationship by emulating the closing/opening behaviors of the valve as a function of the flow force due to increasing Δp.

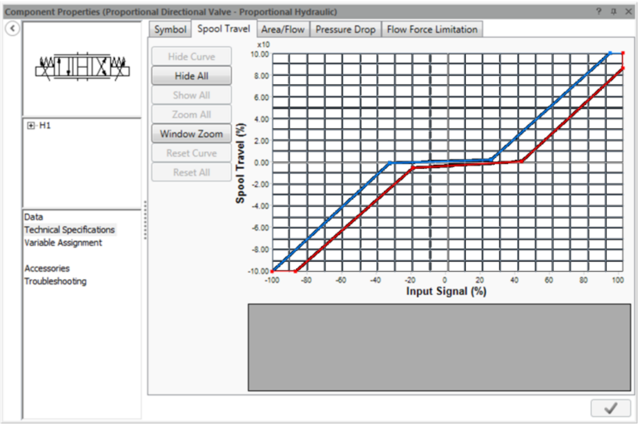

Fig. 11 : Hysteresis Curves

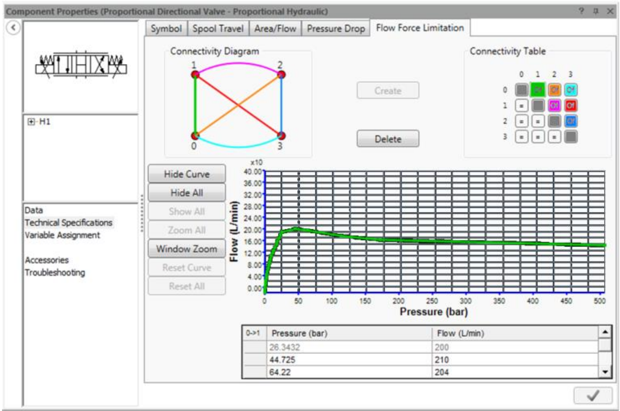

Fig. 12: Flow Force Curves

As stated before, the detailed component model could be also applied to the variable displacement pumps. But, the model will be logically called an exploded model of the pump.

To demonstrate this model with an application example, we take a real pump such as the Linde Series 02 Pump with CA control. This pump has two main displacement regulation modes, and it is specifically these characteristics that are practical and relevant. The simulated pump model is shown in Fig. 13

On one hand, the rotation of the thermal engine (1) drives the charging pump (2), which creates pressure at the orifice (3). If the rotation speed is high enough, this pressure will actuate valve (4). By actuating one of the solenoid-operated valves (5), the pressure will be transferred to the corresponding side of the servo-cylinder (6), which will change the main pump's displacement (7). This first mode allows the main pump's displacement to adapt to the engine's rotation speed.

On the other hand, the changing load creates a working pressure sensed by the opposite side of the servo-cylinder (6), reducing the main pump's displacement. The unit change of the displacement with respect to the variation of working pressure is conditioned by the power regulating valve (8). Consequently, the power can be maintained at a specific level, which is the second mode of regulation.

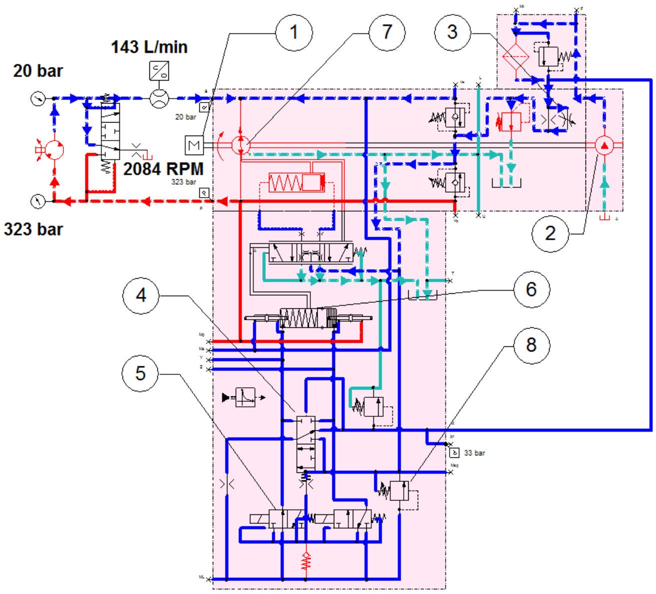

Fig. 13: Discreet model Pump CA Control Simulation Model

Simulating these detailed characteristics allows the designer to analyze the integration of this pump with the thermal engine. Based on the power consumption and generation characteristics of the engine in use, which is also modeled using the hybrid approach (Rémillard & al. [1]), the simulation will allow the designer to identify what adjustments are necessary to maintain the pump at the optimal point where the engine's power throughput is maximized and where stability is not compromised by being too close to the engine's stalling point.

5. Examples using Automation Studio™

Example 1:

Let us refer to the proposed methodology in section 3 and apply it to a circuit design project for an excavator by using a monoblock main control valve as the main component. This example illustrates the simulation of a specific hydraulic function with certain needs for the understanding of the system's operation and a more intensive analysis of performances to attain.

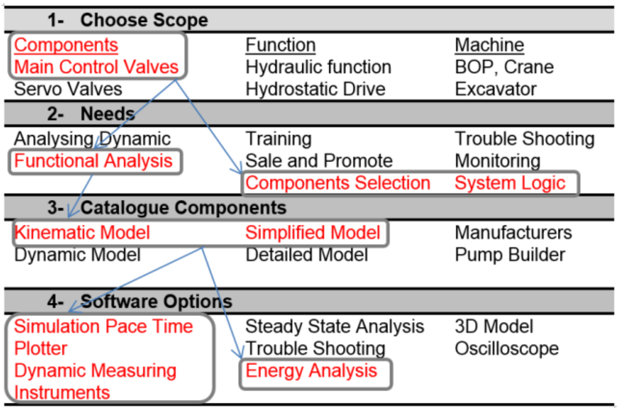

Fig. 14 Working process for the MCV example

- Scope :

Before elaborating a real prototype, the hydraulic design has to start with a simulation model for the excavator's main functions, which are those that are controlled by the monoblock main control valve destined for propulsion and load manipulation functions. Thus, the scope is oriented towards the function level.

- Needs :

At the preliminary design phase, there are many needs that appear. First of all, we need to compare different system architectures and manufacturer's components available in the market. Early on in the system's design, we have to think about testing different ideas. Therefore, there is a need to quickly obtain a functional simulation showing the different characteristics of the systems that we wish to compare.

- Component Catalogue and Software options:

By using manufacturers' components available in the Automation Studio™ libraries, we can create three circuits presenting different control strategies: a positive control circuit, a negative control circuit and flow sharing circuit.

In a few hours, the three circuits are constructed with associated pumps and discussions can be done between different experts in order to see which strategy can be used for the new machine.

At this stage, we can consider different strategies with simplified simulation models such as:

- Function operation logic;
- Nominal pressure and flow rates;

The choice can be limited to a particular strategy. However, it is also possible to further comparisons by refining the simulation models. In fact, it is possible to customize proportional valves characteristics with Downstream design in order to obtain a comparison based on quantitative considerations. Figure 15 illustrates the results of a valve's customization with a negative control block in action.

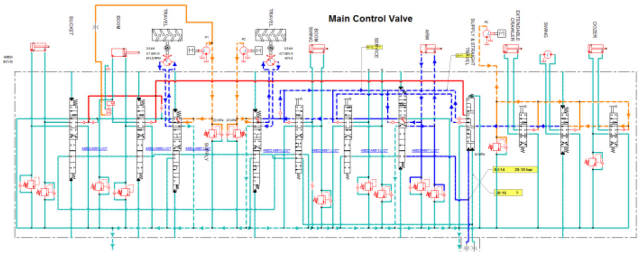

Fig. 15 Main Control Valve

By including the pumps and the mechanism to the analysis, different tests can be done to optimize the global performances of the studied functions among others. For example:

- Function time response
- Maximum speed and force
- Duty cycle analysis
- Energy efficiency
- Fuel consumption

Once the analysis is completed, the prototype's construction can officially start. Since simulation has been done early in the design process, the prototyping process has been considerably reduced. Another benefit is the fact that we can reuse the simulation model in order to produce technical documentation and fulfill other need such as the training of technicians and operators that will intervene on the machine in different ways once it is marketed.

However, most of the time, only a high-level global model of the machine is simulated and it does not take into accounts all the related technologies that impact its behavior.

Example 2:

For the second application case study, we will present an entire system machine simulation integration of a subsea drilling system and its blowout preventer valve (BOP) in order to present how the proposed working process could be also applied to take differently advantage of system simulation.

1- Choose Scope		
Components Main Control Valves Servo Valves	Function Hydraulic function Hydrostatic Drive	Machine BOP, Crane Excavator
2- Needs		
Analysing Dynamic Functional Analysis	Training Sale and Promote Components Selection	Trouble Shooting Monitoring System Logic
3- Catalogue Components		
Kinematic Model Dynamic Model	Simplified Model Detailed Model	Manufacturers Pump Builder
4- Software Options		
Simulation Pace Time Plotter Dynamic Measuring Instruments	Steady State Analysis Trouble Shooting Energy Analysis	3D Model Oscilloscope

Fig. 16 Working process for the BOP system

- Scope:

Compared to the previous case (the MCV valve), the scope of this project will be focusing on the system's global behavior; the machine level scope of that case is the complete BOP system and its control parts.

- Needs:

Since the critical operational mode and environment responsibility are strongly dominant in the lifecycle of the machine for offshore drilling contractors, the needs are to quickly understand the possible failure mode that can occur and how critical its effects can be on the rest of the system and surrounding environment. This project has to monitor also the current state of the real system in order to communicate the failure without delay.

Moreover, to be able to troubleshoot the rig and understand what could be a Failure Mode, Effects and Criticality Analysis (FMECA) tool, the project also aims to train the operators and the maintenance team.

- Component Catalogue and Software options:

Since the project has to represent the main technologies and functions such as the sea level and subsea hydraulic control circuits, the electrical circuits, the control panel and a human machine interface, the simplified model of components will be sufficient for the expected machine knowledge output. This component catalogue type matches the manufacturer specifications with embedded known possible failures that can be hyperlinked to the appropriate failure analysis scenario.

Figures 16, 17 and 18 illustrate the mechatronic system simulation, where all the related technologies are simulated: electrical engineering, hydraulics, mechanics and control panel.

To simplify the monitoring task, the functional reliability block diagrams (RBD) are used to represent each main function of the system simulated in real time with the machine allowing create failure scenarios. This latter point offers the possibility to do interactive tests, giving access to all possible operating conditions.

Furthermore, the plotter and other software options like measuring and troubleshooting instruments, make easy the understanding of the computed data (Fig . 20) and enhanced the interaction of the user with the simulation project.

This case study demonstrates that this simulation type applied with using the appropriate methodology offers many benefits such as:

- Standardization the methodology for Troubleshooting
- Training Tools creation that increase stakeholders knowledge
- Decrease of Time Delay in Decision making and Intervention
- Application on Any System
- Straight Forward Communication

All these benefits will be in line with the first step of the simulation process; avoiding environmental issue and killing down time which will result in saving money.

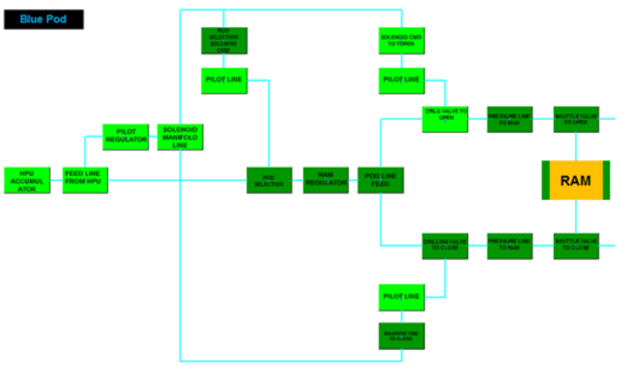

Fig. 17 Functional Reliability Block Diagrams (RBD)

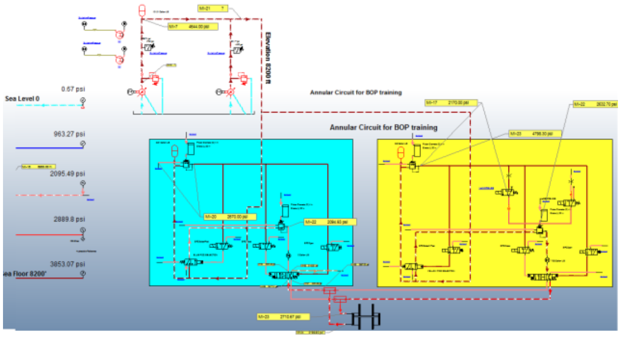

Fig. 18 Hydraulic Circuit for the RAM Function

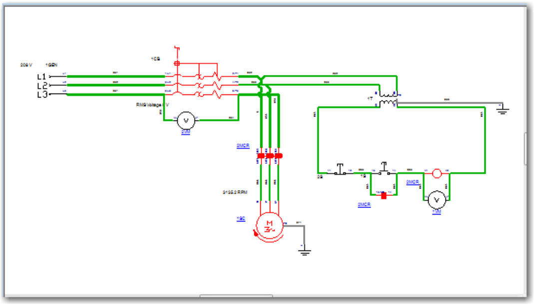

Fig. 19 BOP, Electrical Motor Starter Circuit

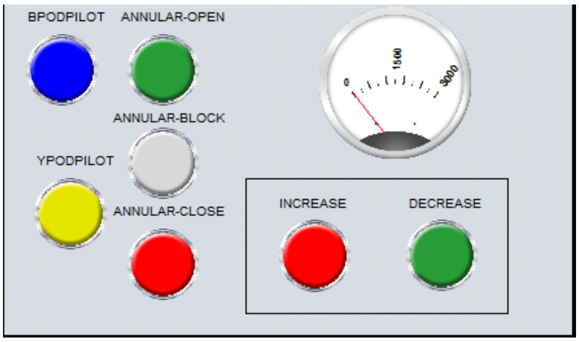

Fig. 20 Control Panel of the operator

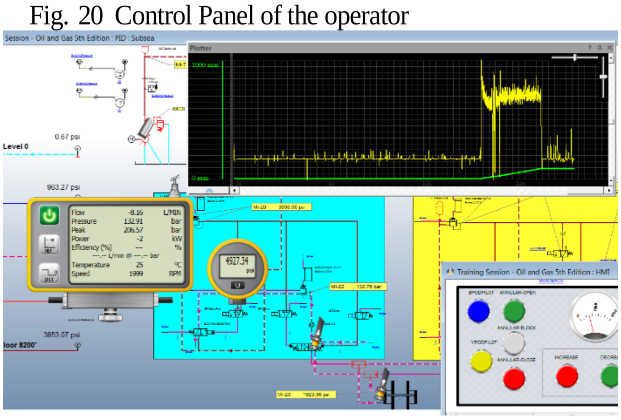

Fig. 21 Troubleshooting Mode, BOP System Simulation

6. Conclusions

We have presented in this article how to take advantage of a Machine Knowledge Management Software which could be applied to different scopes and fill full different needs of the product life cycle.

We have demonstrated with Automation Studio™ examples that proposed working process is versatile and could serve from component analysis to system analysis. The reusability of the same simulation project is another benefit among the other discussed here.

The challenge on using design tools for OEMs or Manufacturers is usually to structure and integrate those in their business activities. If they are using this suggested working process with a clear understanding and a good adaptation to their day to day practices, the return on investment will be highly tangible.

References

[1] Vincent Rémillard & al., Innovative Hybrid Modeling Approach to Enhance Green Design based on Fully Integrated Mechatronic System Simulation, IFPE 2014

[2] Vincent Rémillard & al., New Software Generation for Greener Energy Efficient Mechatronic System Design & Analysis, KSFC 2013

[3] Denis Lenoble & al., Longwall Mining Simulation, IFK, 2014

[4] Frank M. White, “Fluid Mechanics”, McGraw-Hill, 2011.

[저자 소개]

Richard Gagné

(리차드 가네)

Master Degree in Automated Production Engineering, Specialized in Simulation

Ecole de Technologie Superieure, University of Quebec, Montreal, QC, Canada

- He has 18 years of experience as a professional engineer and a trainer in academic and industrial environment. He has joined the Product team of Automation Studio - Famic Technologies Inc. in 2005.