

Virtual commissioning of a hydraulic press application using a non real-time capable simulation environment

**Nils Menager, Rüdiger Kampfmann, Thomas Ehehalt, Michael Liedhegener
Bosch Rexroth**

Einführung

Die steigende Forderung nach effizienteren und leistungsfähigeren Maschinen sorgt für eine zunehmende Komplexität bei der Entwicklung. Um auf lange Sicht die Wettbewerbsfähigkeit zu erhalten, ist es gleichzeitig notwendig, die Time-to-Market und somit die Entwicklungszeiten weiter zu reduzieren. Ein Ansatz, um mit dieser Herausforderung umzugehen, ist die Verwendung modellbasierter Entwicklungsmethoden. Dies bedeutet, dass der gesamte Entwicklungsprozess, von der Anforderungsdefinition bis in die Phase des Betriebs, durch Modelle begleitet und unterstützt wird. Hierbei ist insbesondere die Virtuelle Inbetriebnahme ein wichtiger Anwendungsfall. Für die Durchführung der Virtuellen Inbetriebnahme wird üblicherweise die reale Anlagensteuerung mittels Hardware-in-the-Loop mit dem Anlagenmodell gekoppelt, um auf diese Art und Weise die Steuerungsapplikation zu testen. Hierfür muss normalerweise sowohl die Modellausführung als auch die Datenübertragung in Echtzeit erfolgen. Dies erfordert Aufwände im Bereich der Modellvereinfachung und zum Aufbau der Kommunikation. In diesem Beitrag wird daher eine Kopplungsstrategie vorgestellt, die diese Echtzeitanforderungen nicht benötigt. Anschließend werden die Vorteile dieser Kopplungsart unter Verwendung von SimulationX und einer Rexroth Industriesteuerung an einem Hauptantrieb einer hydraulisch angetriebenen Presse demonstriert.

Introduction

The increasing demand for more efficient and more powerful machines leads to a growing complexity during the development process. In order to maintain

competitiveness it is at the same time necessary to reduce the time-to-market and hence the development time. One approach to deal with this challenge is to utilize model-based development methods. This means that the entire development process, from the definition of the requirements to the operational phase, is supported by models. One important use case of model-based engineering is the virtual commissioning, which allows an early testing and optimization of the controller application. In order to perform such a virtual commissioning, the Programmable Logic Controller (PLC) is coupled with a simulation model of the machine using a Hardware-in-the-Loop setup. For this purpose, usually, the model execution and the data transmission have to take place in real time. Normally, this requires large efforts for model simplification and setup of the real-time communication. Hence, within this paper a coupling strategy is presented which avoids these real-time requirements while maintaining a consistent and deterministic simulation. The advantages of this approach are demonstrated on a main drive of hydraulic press system using SimulationX and a Rexroth PLC.

Main Part

Since an essential aspect during the machine development is the investigation of the dynamic behavior, physically motivated models, like those considered in SimulationX, are of particular interest. An essential property of model-based development is the integrated usage of models. This means that already existing models from previous phases of the development are reused in following steps. By doing this the previously mentioned efficiency increase can be obtained within the development process. This procedure is also applied for the virtual commissioning. Hardware-in-the-Loop (HiL) simulation is used to link the real control hardware and the corresponding control algorithms with the virtual representation of the machine, which was already created in previous development steps. This means that the real control application is already included during the machine design phase. Hence, the overall machine quality can be significantly improved, since hardware and software components are ideally adjusted to each other. On the one hand, virtual commissioning allows to start the testing of the control application much earlier, i.e. before the real machine has been manufactured and assembled, and on the other hand safety-critical conditions can be tested without causing harm to people, machines or the environment. This results in significant reductions of development times and rises the overall machine safety.

When performing a HiL simulation, some technological aspects have to be considered. Since the control application on the PLC is executed in real-time while the simulation of the controlled system is often only possible slower than real-time, the synchronization between control hardware and simulation is a major challenge. Generally, there are two options to deal with this problem: Executing the simulation in real-time or slowing down the speed of the PLC to the speed of the simulation. In practice, the first approach is mainly used, i.e. the simulation model is executed on a dedicated real-time hardware and the data is transferred between the PLC and the simulation via a real-time bus. However, this procedure has a serious disadvantage. In order to be able to investigate the dynamic behavior of the machine as accurately as possible, a detailed model of the plant is required. Due to the typically contained events and algebraic loops, these models generally cannot be executed without simplification on the real-time hardware. On the one hand, this results in a significant increase in effort, and on the other hand, these model adaptations contradict to the concept of integrated engineering. Furthermore, a simplification of the system model reduces the quality of the virtual commissioning. Following the idea of integrated engineering the direct usage of the already existing complex simulation model is desirable.

In this contribution a solution that enables virtual commissioning using the simulation environment SimulationX is presented. The synchronization is achieved through the aforementioned adaptation of the execution of the control application to the simulation speed. Hence, no special real-time hardware is required in order to conduct the simulation. At the beginning of the simulation, the controller is automatically decoupled from the real-time execution by a distinct firmware feature and set to a mode that allows external triggering of the controller. The simulation environment has the role of the master during the execution and ensures the transmission of the data and the triggering of the individual calculation steps at the right time. The procedure of such a synchronized HiL simulation is shown in Figure 1. The required firmware functions are available inside the IndraControl XM industrial controller from Bosch Rexroth by default. Thus, no modifications are necessary within the control application.

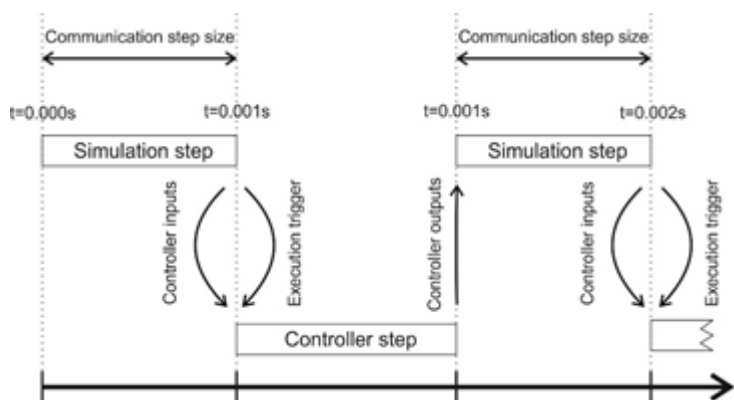


Figure 1. Coupling and synchronization procedure

For an easy integration of the control hardware into the simulation environment the Modelica library `mlpi4Modelica` developed from Bosch Rexroth is available for free. This library contains components, which encapsulate all functions which are necessary in order to establish the connection between the controller and the simulation environment as well as functions for the data exchange and for maintaining synchronization. This method of non-real-time-capable virtual commissioning provides the possibility to couple any complex simulation model with a control hardware, while maintaining a consistent and deterministic HiL simulation. This not only improves the quality of virtual commissioning, but also eliminates the effort, which is required to adapt the model for the execution on dedicated real-time hardware. Instead, the HiL simulation can be performed within the same environment which is used for offline simulation. The capabilities of this solution are demonstrated below using a real hydraulic eccentric press application.

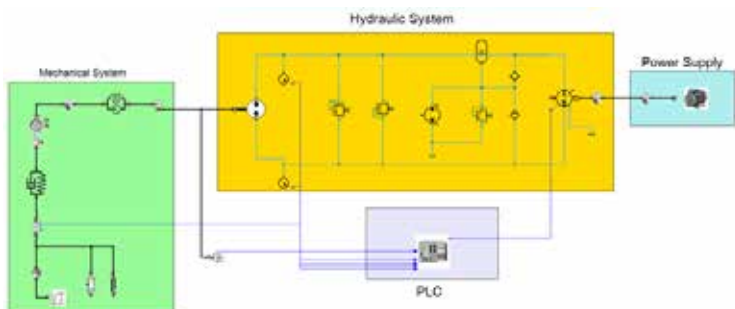


Figure 2. Block diagram of the hydraulic press model

Figure 2 shows the block diagram of the press model. The model is divided into four subsystems: Mechanics, hydraulics, interface to the PLC and the electric power supply of the hydraulic pump. In the mechanical subsystem, the eccentric kinematics, the moved masses and the forces caused by the forming process are considered. The hydraulic subsystem refers to a closed hydraulic circuit. A radial piston motor connected to the eccentric kinematics is driven by a hydraulic axial piston pump with adjustable displacement and respective ports connected to each other. The pump is driven by an asynchronous motor with constant speed. The position of the radial piston motor and thus the position of the press is controlled via the swivel angle of the axial piston pump. In addition, the booster unit and overpressure protection are required in the hydraulic subsystem. The subsystem PLC contains the interface to the real control system. The functionality of this block is explained in more detail below.

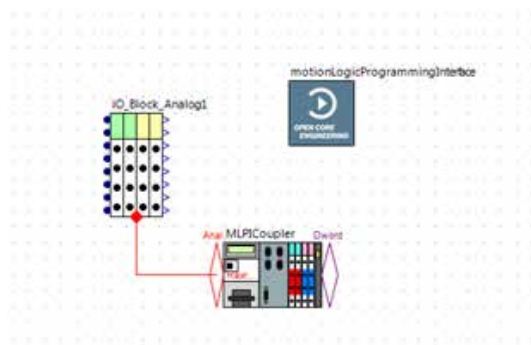


Figure 3. Mlpi4Modelica components

For the build-up of the hardware-in-the-loop simulation, three model components are required. These are shown in Figure 3: a general interface component, the MLPI Coupler component, and at least one I/O block component. In the general interface component, basic information for establishing a connection to the controller, e.g. the IP address of the controller, have to be set. Application-specific data such as the used cycle time are parametrized in the MLPI Coupler component. This cycle time is used as an exchange step size between simulation and control. The assignment of the simulation variables to the corresponding control parameters is contained in the I/O blocks. For each input or output of the I/O block, the name of the control variable to which it is linked can be specified in the parameter window. This is shown in Figure 4 for the application considered in this contribution.

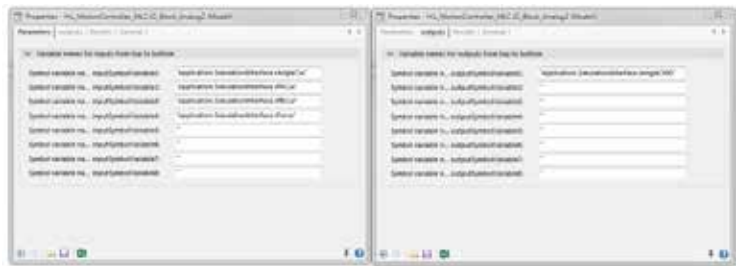


Figure 4. Parametrization of I/O block

In the considered example for virtual commissioning, the control algorithms are computed on the real control hardware. The response of the system is calculated on a non real-time standard PC within the simulation environment SimulationX. The ready-to-use components of the *mlpi4Modelica* library enable the extension of the offline simulation by the PLC application in a simple way. The virtual commissioning allows to investigate the impact of changes within the control application in order to obtain the best possible parameterization of the controller. At the same time, all states of the machine can be observed simultaneously within the simulation model, especially values that are very difficult to measure and are normally not considered in practice. In addition it is possible to analyze critical controller parameterizations without having to risk damage to man and machine.

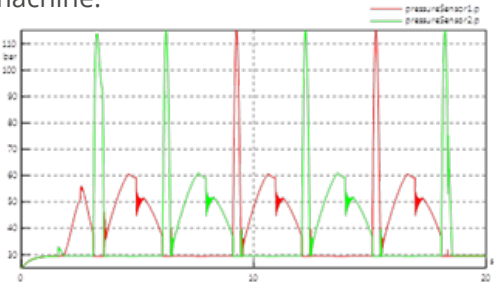


Figure 5. Pressure values of the hydraulic motor

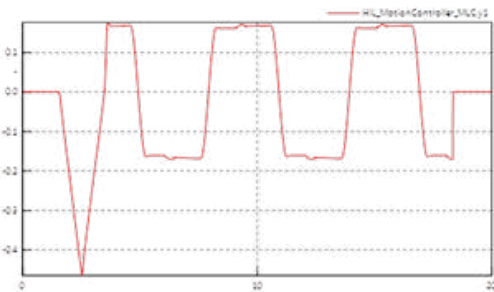


Figure 6. Commanded swiveling angle

Figure 6 shows the control value calculated by the PLC, the swivel angle of the pump unit. Figure 5 shows the pressures that are used as input of the control algorithm on the PLC in order to calculate active damping. The control application, which has been extensively tested and parameterized with the help of the simulation model, is a very good starting point for the commissioning of the real plant. Since even a complex model is always a simplified representation of reality, some parameters still have to be adjusted slightly during the final commissioning. But the basic sequence of the application has already been tested and validated. Hence, the time required for the final commissioning can be significantly reduced. This has a direct positive impact on the time-to-market.

Summary

Model-based development methods are an approach to handle the increasing complexity of nowadays developed machines with competitive development times. An essential building block for the realization of time savings in the development process is the virtual commissioning. In this contribution an approach was presented that enables virtual commissioning in a simple way using a non real-time capable simulation environment. The approach presented has some advantages over the virtual commissioning under real-time conditions, which has been the most used variant up to now. A complex simulation model of the plant is usually already available from previous steps of the development process, in particular from the validation of the machine design by the use of simulation. In the transition from dynamic validation to virtual commissioning of the machine this model can be reused without adaptations in the sense of integrated engineering. Only the coupling components to the PLC described above have to be added to the model. Therefore, the time-consuming model simplifications and porting to dedicated real-time hardware are obsolete. At the same time, the quality of the virtual commissioning is increased by using the complex, more realistic model of the machine.