VIRTUAL DEVELOPMENT ENVIRONMENT FOR FLUID POWER MECHATRONIC SYSTEMS

Torsten Verkoyen
Institute for Fluid Power Drives and Controls
RWTH Aachen University
Aachen
Germany
Torsten.Verkoyen@ifas.rwth-aachen.de

René von Dombrowski
Institute for Fluid Power Drives and Controls
RWTH Aachen University
Aachen
Germany
Rene.von.Dombrowski@ifas.rwth-aachen.de

Univ.-Prof. Dr.-Ing. Hubertus Murrenhoff
Institute for Fluid Power Drives and Controls
RWTH Aachen University
Aachen
Germany
post@ifas.rwth-aachen.de

ABSTRACT

In this paper the results of the German state-funded research project "Fluidtronic", that deals with a virtual development environment for fluid technical mechatronic systems, is presented. Firstly the conventional development process of a fluid technical mechatronic system is introduced. The conventional development process typically takes a long time because design failures are often only identified during the plant commissioning. Secondly the new virtual development environment, which is worked out in the "Fluidtronic" project is presented. It shows how both the system performance can be optimized and also how the commissioning time can be reduced extensively, if the interactions between mechanical, electrical and fluid power parts are tested at an early point of time in the development process. Optimizations in the development process are realized with the help of new and improved simulation models as well as soft- and hardware in the loop simulations.

INTRODUCTION

In German machine and plant engineering, the fluid power industry is an important manufacturing branch, with an international trade share of 33%, and growing [1]. The industry sector of fluid power technology is divided in a small number of major enterprises with a large product range, and a wide field of small and medium sized companies, which provide specialized fluid power components or system specific solutions. In the present cooperative project "Fluidtronic" [2], a hydraulic forging press is selected as an example for a fluid technical mechatronic system. Because of the interactions between mechanical, electrical and fluid power parts of presses, and their huge dimensions, the development and commissioning of a system such as this is complex and takes a long time [3].

CONVENTIONAL DEVELOPMENT PROCESS

The development process of a hydraulic forging press, as an example for a fluid technical mechatronic system, consists of different steps. Fig. 1 shows the conventional development process.

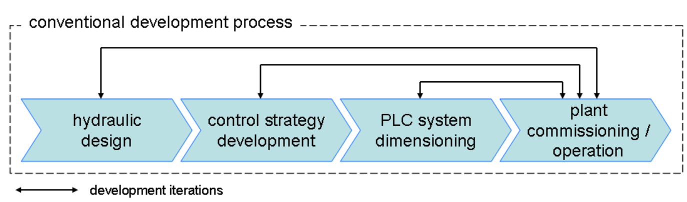

FIGURE 1. CONVENTIONAL DEVELOPMENT PROCESS

The hydraulic design is often characterized through estimated empirical formulas and simple static load cycle assumptions for the dimensioning of the hydraulic system. This leads to a neglect of optimizing potential, and more than that to an insufficient consideration of dynamic effects in the system operation. The occurrence of dynamical effects like vibration or pressure spikes often lead to damage, or even to downtime of a system. Hydraulic components are often over-sized to overcome these uncertainties in the system design. This uncertainty is also then transferred to the involved subcontractors, which have to develop their subsystems on the basic of unspecific operation conditions instead of detailed system constraints.

After the design of the hydraulic system, the control strategy and the PLC (Programmable Logic Controller) system are developed. Since there is no real plant available at this state of the development process, this can only happen in a limited manner. The real testing and parameterization of the control has to be done in connection with the real plant. To avoid any damage to the plant every PLC commissioning step, such as wiring, final parameterization or safety function test, has to be done very carefully.

During the subsequent commissioning of the forging press, inadequate machine performance or failures are often detected and lead to several iterations in the development process. This takes a lot of time and results in additional costs. Because of the large dimensions of a forging press (see Fig. 2) the different parts are directly delivered to the press operator, who notices all unintentional development iterations. This is a big disadvantage in the conventional development process and stresses the manufacturer-operator relationship.

FIGURE 2. FORGING PRESS

VIRTUAL DEVELOPMENT ENVIROMENT

To overcome the deficits of the conventional development process an additional virtual development environment was set up within the state-funded research project “Fluidtronic”. The software based environment guides the Engineer along the different development phases with the help of a continuous development workflow [4]. The focus is thereby transferred to the development process of small and medium-sized companies of the machine and plant industry, and the interactions between the original equipment manufacturers (OEMs) and subcontractors involved. Besides two research institutes, the consortium working on this research project consisted of two press manufacturers as well as several subcontractors from different areas.

The core of the new development environment is built through new mathematical descriptions and models for fluid technical effects, as well as new methods for a virtual plant commissioning. The developed models and methods are implemented into a simulation tool and integrated into the development environment. In the showcase of the research project “Fluidtronic” the system simulation software DSH*plus* 3.6 was used as a basic platform for the integration of the developed models and methods [5].

To guarantee the acceptance in industry, the out-worked development environment can be used in modular or parallel to the conventional development process, as illustrated in Fig. 3.

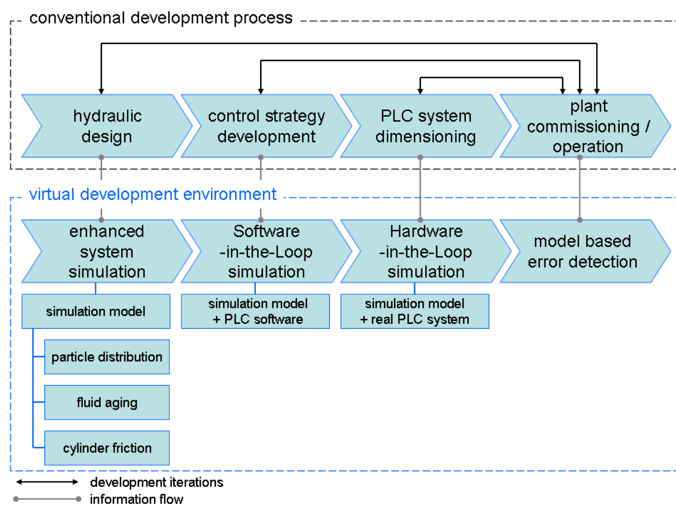

FIGURE 3. VIRTUAL DEVELOPMENT ENVIRONMENT

Fig. 3 shows the conventional development process and the continuous support through the additional development environment. The support begins with the design of the hydraulic system. With the help of an enhanced and applicable simulation software, a virtual model of the system is built up. The simulation model of the system is the initial point for all further virtual development steps, and allows a realistic system testing with virtual instead of real plant.

Enhanced System Simulation

In contrast to the simplified conventional design by estimated formulas, the simulation model allows a detailed analysis of the dynamic system behavior. The effects of different component parameters and modifications in the system structure can easily be tested with the help of the virtual plant model. Because of the lack of possibilities for testing the real system, or even real subsystems, the virtual testing of modifications is important for an optimal system performance of the mechatronic system. Another positive effect of the work with the virtual plant is the better system knowledge transferred to the involved engineers. This, in most cases, leads to innovative ideas and more efficient systems.

Fig. 4 shows a simulation model of a forging press and the curves of the cylinder position and pressure as a result of the dynamic calculation. Because every state variable is very accessible, the simulation models gains a deep insight into the system behavior.

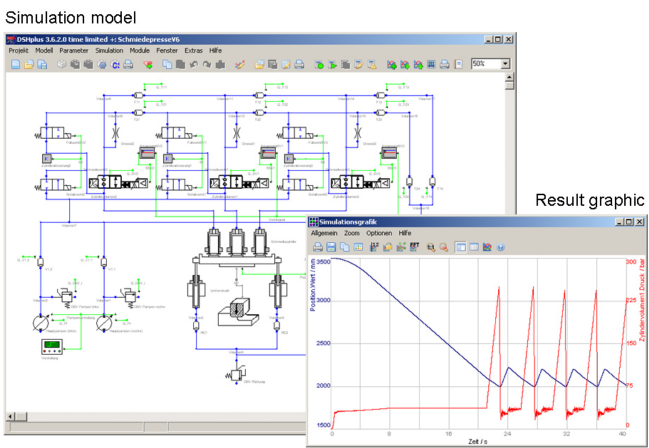

FIGURE 4. VIRTUAL PLANT MODEL

Implemented modules for a "know-how" protection, for example through black box structures or parameter protection, allow a safe exchange of the model with subcontractors or colleagues of different departments. With the help of the virtual plant model the subcontractors are able to develop their systems with regard to realistic operation states, instead of roughly estimated operation constraints.

To allow an efficient simulation of the system, further models for hydraulic effects, such as system contamination and fluid aging, were developed within the research project. One result of this is the possibility to simulate the dynamic distribution of particles within the system [6]. On the one hand this allows the design of an optimal filtration concept for a reliable plant operation, and in addition it also reveals new possibilities for a virtual condition monitoring development. The developing engineer is able to look at the particle size distribution at each point of the system so that he can keep the purity levels low at locations of sensitive components, such as servo valves. He is also able to analyze the amount of absorbed contamination in different filter elements, which leads to a better planning of maintenance intervals and results in a shorter downtime of the plant [7]. Fig. 5 shows simulation results of the particle distribution.

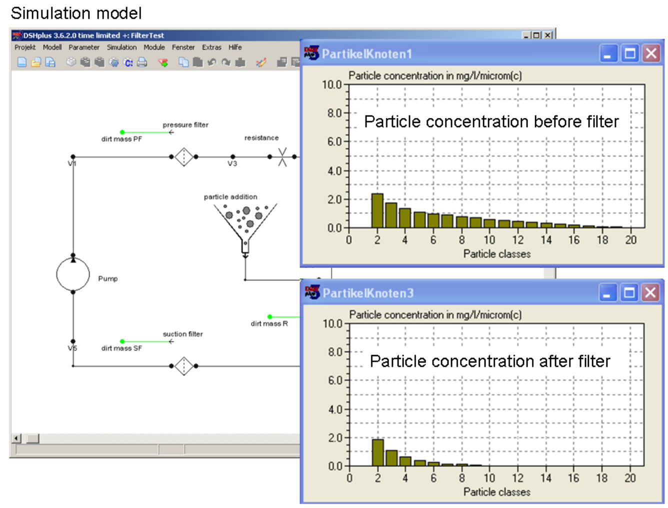

FIGURE 5. SIMULATION OF PARTICLE DISTRIBUTION

Another point for an optimal maintenance is the consideration of the fluid aging within the system simulation. With the help of characteristic values, which describe the fluid aging in dependency of the system circle time, the temperature change at certain components and the amount of fluid in the circle, it is possible to make an association between system structure and fluid lifetime [8].

To raise the accuracy of the simulation a deeper look into the cylinder friction was taken. A correct implementation of the cylinder friction is very necessary because it determines the whole system performance and control parameters. Previous models for the inner friction of hydraulic cylinders describe the friction in dependency of the velocity. Other relevant influences on the friction, like the kind of sealing or the dependency of pressure changes, are neglected. With the help of a special friction test rig, developed within the project "Fluidtronic", a new model for the inner cylinder friction was set-up. Apart from the velocity dependency of the friction, the new model includes the influences of the chamber pressures and the fluid viscosity. The parameterization of the model is user friendly, because construction data like piston and rod diameters and the kind of sealing system has to be parameterized [9].

With the help of the simulation extensions described before, an applicable and strong simulation environment is now available for all partners of the development process. The usage of such a powerful simulation model, at an early state of the development process, makes it possible to develop a system with a high grade of accuracy. This helps to avoid a lot of redesign steps in the subsequent commissioning phase.

Software-in-the-Loop Simulation

After the design of the hydraulic system and the analysis of the system performance, the control strategy has to be developed. The control strategy manages the whole system operation. It includes all process-dependent sequential controls, the safety functions, which have to be activated in case of an operation failure, and the failure detection itself. Furthermore it includes the controller strategies for position and force controlled operations of the plant, as well as diagnostic and monitoring functions.

Today the development of the plant control can be done comfortably with special software tools for the programming of programmable logic controllers (PLC). With the help of the software tools, the sequential control can be defined graphically by operation charts. In addition to the main control program the visualization and the graphical interface for the plant operator can be defined here as well.

In this phase of development there is neither the real PLC-system available nor the plant ready for operation. For this reason the basic PLC-software is developed stand alone, without any feedback of the real system. Initially in the plant commissioning phase the performance of the control strategy can be analyzed and all logical and functional connections can be tested. To avoid any damage of the plant every function has to be tested very carefully, and all parameter adjustments or signal conditionings must be done with great accuracy, which require significant time. Most of today's control strategies, therefore, are more or less conventional programs with a lot of grown structures, and less innovative strategies and control methods.

To shorten the development time and to give more flexibility in the PLC-software development, the system simulation software can be coupled to the PLC-Software within the virtual development environment. With this Software-in-the-Loop (SiL) approach, the PLC-software is not linked to the real plant but to the virtual plant model, which imitates the real plant and generates all signals for the process control. This offers the possibility to develop and test most of the PLC-software in-house instead of at the later operating place. Apart from the time and cost saving effects this procedure gives the opportunity to develop and test new control strategies without the risk of damaging the real plant.

Fig. 6 illustrates the coupling of the plant control program and the virtual plant. Within the project the widely-used tool CoDeSys was used as an example for the PLC-software. To make this coupling possible a SiL-interface was developed. The SiL-interface is responsible for the data-exchange between both programs, and it synchronizes the calculation so that both programs exchange the relevant data at a specific step size.

Within the research project two standard exchange protocols were implemented. The first one uses the standard windows dynamic data exchange (DDE) protocol and the second one the more efficient, but less universal, OLE (Object Linking and Embedding) technology.

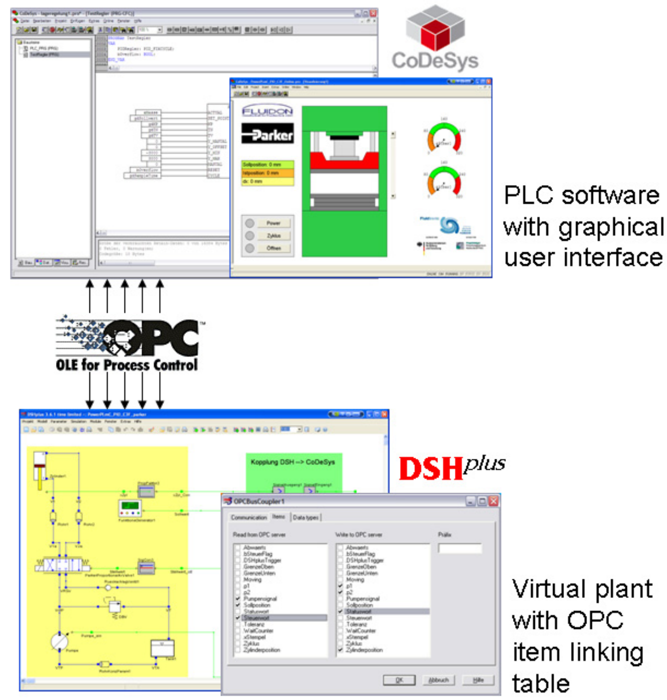

FIGURE 6. SOFTWARE IN THE LOOP SIMULATION

For the purpose of process control the OLE technology was enhanced to the OPC (OLE for Process Control) standard. The function of OPC in short is that there is an OPC-server, which collects data and makes it available for OPC-clients connected to it. The system simulation software and the PLC-software act as OPC-clients, which send and receive the required signal values to and from the OPC-server. The principle function is shown in Fig. 7.

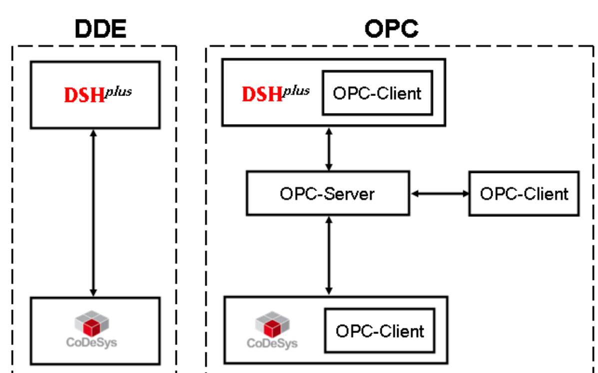

FIGURE 7. DIFFERENT EXCHANGE STANDARDS

In considering data exchange, with the help of the OPC-technology, more than two applications can be linked, unlike when using the DDE protocol. The challenge is that not all programs support the OPC-standard.

The possibility to test the PLC-software early with the help of a virtual plant is a big advantage for the development process, but it even reveals more virtual support features. Firstly, it is possible to use the virtual plant model linked to the graphical user interface as a training tool for the plant operator. The operator can sit in front of the real user interface, but operates the virtual plant. Secondly the virtual model can be linked to the OPC-server of the real plant so that simulated data can be compared to real data from plant operations. This gives the opportunity to reveal differences between the real plant operation values and the ideal values from the simulation model.

Hardware-in-the-Loop Simulation

As a final step before the plant commissioning, the PLC-system has to be conditioned. The hardware like the PLC itself, the I/O-hardware, the A/D- and D/A-converters and the controllers have to be dimensioned in a way, that the PLC-system can fulfill the control time requirements of the desired plant operation performance.

As there is no real plant or other way of testing available at this development phase, the PLC-system is often dimensioned by experience values or rough estimated calculations, which often leads to an over-sizing of the different components. Furthermore the commissioning of the PLC-system takes place at the operation place in interaction with the real plant, which requires a high level of attention.

To optimize the development of the PLC-system the research project aims to allow a virtual PLC development by coupling the PLC-hardware with the virtual plant model. Analogue to the SiL-simulation the virtual model acts like the real system and generates the signals, which the real hardware normally gets from the real plant. This procedure is known as Hardware in the Loop (HiL) simulation. With the help of soft- and hardware-interfaces developed within the project, it is possible to couple different PLC-Hardware, from the single controller to the whole PLC-cabinet, with the virtual plant [10].

Fig. 8 shows the HiL-simulation of real controllers. In this case the PLC-software, including the process-depending sequential controls, is still coupled to the virtual plant via the SiL-interface. Only the real controllers are coupled to the virtual plant in a HiL-simulation. With this development step it is possible to analyze the performance of the real controller hardware. The control deviation of the position- or force-control, for example, is a good incident for analyzing if the controller hardware is fast enough for the desired operation cycles.

For the modular coupling of various PLC-hardware, different interfaces were implemented in the development environment. The interlinking between hardware and virtual plant model, for example, can be established using a serial interface, like RS232/485 or USB, or via a bus-system, e.g. Profibus or Modbus. The support of different interfaces is very helpful to guaranty the acceptance of the HiL-simulation as a practicable development method, because the existing PLC-hardware can be used and no additional hardware has to be bought for compatibility purposes.

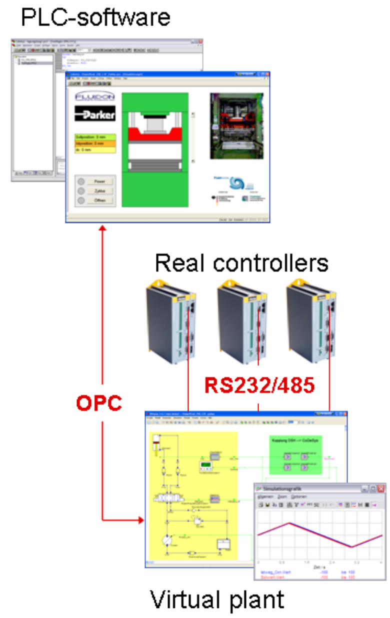

FIGURE 8. HIL-SIMULATION OF CONTROLLERS

The principle coupling of the complete PLC-system to the virtual plant model is shown in Fig. 9.

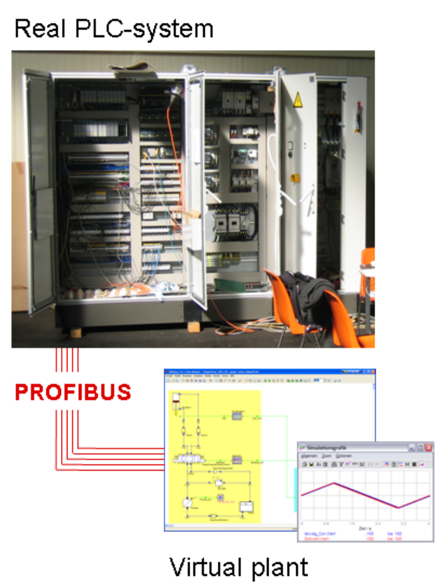

FIGURE 9. HIL-SIMULATION OF THE WHOLE PLC-CABINET

With the help of HiL-testing of the real PLC-system at an early state of the development process it is possible to develop an efficient PLC-system, which just needs smaller adjustments in the subsequent commissioning phase. By the use of a coupled virtual plant all control functions can be tested, the complex wiring within the PLC-cabinet can be checked, and the peripheries can be dimensioned.

CONCLUSION

The virtual development environment presented in this paper is a contribution to an optimal development process for fluid power mechatronic systems. Fig. 10 illustrates the demand of time for the different development phases of the conventional development process, and the development process supported by virtual design methods.

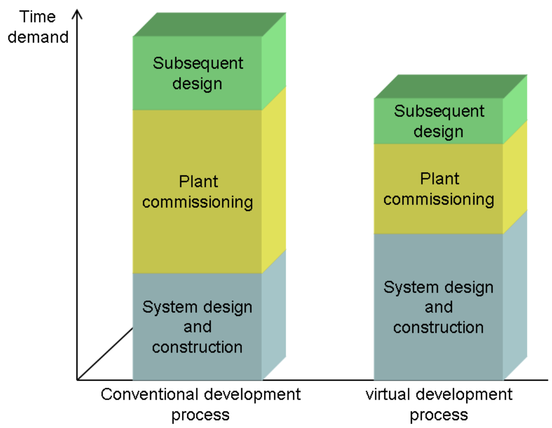

FIGURE 10. TIME DEMAND RELATION

Because of an insufficient and estimated hydraulic design in the early development phase, a lot of time-consuming redesign steps are done in the conventional process. Failures in the hydraulic design can firstly be detected during the plant commissioning or even in the later operation, so that the correction of these failures is a very time- and cost-intensive procedure. Another disadvantage in the conventional development process is the fact, that the interactions between PLC-software, PLC-system and plant are initially tested during the plant commissioning. This requires a lot of time and a very careful management because of the risk of damaging the plant. For this reason defensive control strategies are often used instead of innovative control strategies, for optimal mechatronic systems.

In contrast to the conventional development process a lot more time is spend with the early design in the virtual supported process. This results from the modeling of the plant, and the previous testing of the PLC-system with the help of the virtual plant model. One important fact is, however, that all this design work can be done in-house at the OEMs office whereas the commissioning and necessary rework has to be done at plant operation places worldwide. The bigger effort in the design phase within the virtual development process results in a shorter plant commissioning and less subsequent design, because a lot of insufficiencies in the plant behavior are detected already in the design phase. Furthermore the PLC-software and the PLC-system are pretested in this early design phase, so that a nearly optimal conditioned PLC-system is available in the plant commissioning phase. In an optimal case, the PLC-system, which is developed and tested in-house with the help of a virtual plant, can be connected to the real plant, and just little adjustments are necessary to start the final plant operation.

Besides the advantages in development time and costs, the virtual development process allows the development of optimized systems and the testing of new innovative system structures and control strategies.

To analyze the achievable improvements of the virtual development environment a demonstrator was build within the research project. The demonstrator is shown in Fig. 11. The demonstrator consists of a miniature press and a SiL- / HiL-board and helped to develop and test all presented virtual commissioning methods and interfaces.

FIGURE 11. DEMONSTRATOR

ACKNOWLEDGMENTS

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