
30 74 55 51 021
OP20
0215
ABB

Robot design

Virtual prototyping and commissioning are enhancing robot manipulators and automation systems development

RAMON CASANELLES, XIAOLONG FENG, THOMAS REISINGER, DIEGO VILACOBA, DANIEL WÄPPLING, PETER WEBER –
Industrial product and application design continues to be an art where teams of engineers bring together their knowledge, experience and creativity to create something new. What has changed is how the created solutions or approaches are evaluated and assessed to make sure they lead to a better product. Instead of the simple trial and error efforts of the past, ABB uses sophisticated virtual prototyping and virtual commissioning methods to develop robot manipulators and automation systems that meet increasing performance requirements. Virtual prototyping facilitates the product design phase, and also improves the detailed engineering and function testing of a system. With regards to application testing, virtual commissioning is used to verify the functionality of an automation system before real commissioning starts. ABB's RobotStudio successfully reduces commissioning time by providing a virtual commissioning tool that enables realistic system simulations.

Title picture
Robots such as this ABB IRB 7600FX in the VOLVO Olofström press-shop in Sweden rely on simulation to meet increasingly demanding and complex requirements.

Robot manipulators face increasingly demanding and complex requirements, as do the automation systems using them. Machine builders and system integrators are now expected to deliver and commission systems with higher up-times in a shorter time period, with improvements in quality, performance and cost.

But ABB is able to meet this challenge, and the reason is twofold. ABB engineers take a mechatronic approach – considering mechanical, electrical, and software engineering simultaneously. And they use the latest simulation technology available, including dynamic simulations, 3-D CAD, finite element analysis, probabilistic design and optimization.

Virtual design – product development

An industrial robot is a mechatronic system with a mechanical structure, normally referred to as a robot manipulator, and a controller. A robot manipulator consists of structural links, speed-reducing gearboxes, servo motors, and brakes. Depending on the program for the specific application, the industrial robot performs its motion trajectory and fulfills the task in an automation system. The robot controller consists of a main controller for trajectory planning and servo drives controlling the electrical motors.

> Virtual prototyping is used to accurately assess the design of the robot manipulators by taking multiple parameters into account at the same time.

Designing an industrial robot manipulator is a complex engineering process. The major steps in this iterative process are:

- Kinematics design: deciding the number of joints, arm lengths and configuration
- Rigid-body dynamics design: designing the structure as well as accompanying motors, brakes, and gears (including motion control configuration parameters) that fulfill cycle-time and lifetime requirements
- Thermal design: assessing motor winding and motor shaft temperature based on thermal design criteria
- Stiffness design: assessing robot control performance based on eigenfrequency analysis or path accuracy analysis

Virtual prototyping is used to accurately assess the design of the robot manipulator by taking multiple parameters into account at the same time. These simulations are used to determine all the exact specifications for the robot design, such as weight, robot speed and acceleration, and robot accuracy.

For example, in optimizing the cycle-time of a press-tending robot loading and unloading dies in a press shop the challenge is to determine the correct specifications for gearboxes and select the drive-train control parameters that will minimize cycle-time and gearbox torque. With virtual prototyping, engineers take a

1 High-performance Twin Robot Xbar – TRX for press automation

Through virtual commissioning system tests can be conducted seamlessly and efficiently.

multi-objective optimization approach to analyze the best trade-off relationship between robot cycle-time performance and gearbox torque. Virtual prototyping allows the engineers to run thousands of tests to determine the best trade-off relationship for maximum performance with minimum torque.

Through these techniques ABB developed a twin robot solution that is used in innovative press automation applications, referred to as Twin Robot Xbar – TRX[1] → 1. The trade-off relationship between the press-tending performance and the total rated torque of the gearboxes was obtained with multi-objective optimization → 2. This relationship gives quantitative insight into the impact of robot performance on drive-train design and cost. For example, examination of two extreme design points at the Pareto front discloses that an increase in press-tending performance of 5 percent is achieved by increasing the drive-train cost by 7 percent.

A virtual controller emulates exactly the behavior of a real controller but runs on a standard PC.

System engineering

Once a successful industrial robot design is achieved, the next step is to successfully place the robot in an automation system. Together with devices like programmable logic controllers (PLCs), servo motors and drives, and the required mechanical equipment and software, the robot becomes part of a discrete automation system.

Virtual prototyping [1], [2] also significantly improves the detailed engineering and function testing of a system. Before the detailed work on the automation system can start, a conceptual design is created. The mechanical, electrical and software engineering groups then join the process. A three-dimensional layout created by the mechanical engineers becomes a virtual prototype for the robot engineers. By using RobotStudio, ABB's offline programming and simulation tool for robot applications, engineers can position virtual robots in the model, teach robot targets and paths, and check the robot's reachability. Programming and debugging of the robot applications can be done in the same environment and immediately applied to the virtual prototype by using virtual robot controllers, thus enabling short development and verification cycles. If remodeling is needed, as for example identified by reachability analysis, the required modifications can easily be communicated back to the mechanical engineers.

Using virtual prototypes in the detailed engineering phase does not have to be limited to robot applications. The simulations can be expanded to a much wider range of applications, as for example in developing complex PLC or motion applications, with significant advantages in development and testing.

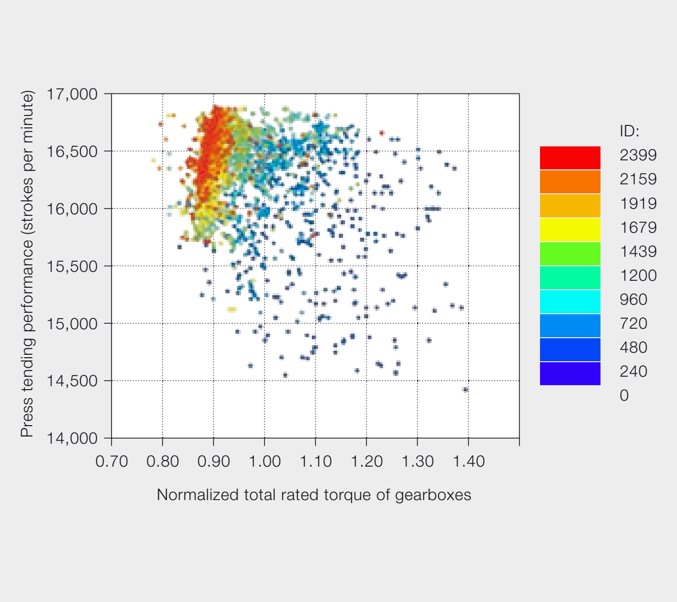
Virtual commissioning

Virtual commissioning is a simulation method for verifying the functionality of an automation system before real commissioning starts. The process involves replicating the behavior of hardware within a software environment, enabling a seamless transition from the virtual to the physical environment.

Footnote

1 TRX robot consists of two (4-axis) manipulators interconnected with a crossbar.

2 Internal design of Twin Robot Xbar – TRX robots created with multi-objective drive-train optimization



3 View of a virtual press shop created with ABB's RobotStudio

4 View on the virtual press shop model

During testing and implementation, virtual commissioning methods, like hardware-in-the-loop (H-I-L) and software-in-the-loop (S-I-L), are used for the integration and system tests up to the final acceptance test.

> The process enables a seamless transition from the virtual to the physical environment.

Depending on which phase is being tested the applied virtual commissioning architecture adapts to the appropriate engineering stage of the process. In early test phases an S-I-L approach is used while in later test phases an H-I-L approach is better suited. S-I-L implies using virtual controllers. H-I-L means the real controllers executing the automation application to be verified are included in the test environment. A virtual controller emulates exactly the behavior of a real controller but runs on a standard PC.

Today H-I-L is the prevailing test scenario, which connects a dedicated PLC via fieldbus to a PC running a simulation model of the system. This architecture permits real-time execution of the control applications. Today's complexity of systems usually requires multiple interconnected controllers of different types to perform the automation tasks. Hence, simulating larger parts or a complete system requires a hardware infrastructure that is only available in later project phases.

To facilitate efficient testing in the early project phases – ideally concurrently to the application development – it is important to have an easy means of loading and sending the programs to the virtual test environment running on the same PC where the applications are developed. Detecting problems as early as possible, and being able to fix them with moderate effort, becomes increasingly important, especially since the software component of an automation system has dramatically enlarged over time and is increasing further.

To simulate the physical/target system or machine a virtual model of the system is needed; sensors and actuators need to be modeled. ABB's RobotStudio has smart components which mimic the behavior of real sensors and actuators and provide a process signal interface to connect them with real or virtual controllers thus enabling a comprehensive simulation of a system. Smart components can be used to flexibly integrate the functionality of various automation components in the virtual commissioning environment.

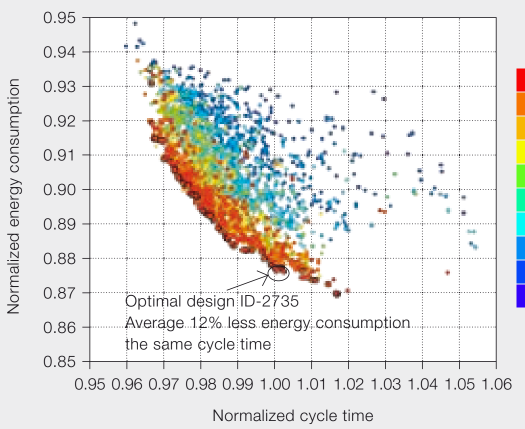
Tandem press lines

Press automation in an automotive press shop demonstrates the value of virtual commissioning technology. The size and power of presses that constitute a press line make doing real system tests on the test floor impossible. However, through virtual commissioning system tests can be conducted seamlessly and efficiently.

A tandem press line creates shaped plates that will later be welded together to constitute a car body. It consists of several aligned presses allowing the blanks passing through to get converted in shaped plates. The first press (draw press) performs the shaping and the others cut the inner and outer contours.

Due to the high cost of a tandem press line in the complete automation system, getting the maximum productivity is crucial to optimize the return on investment of such equipment. To achieve the best output rate the automation of transferring the plates between the different presses requires an optimum coordination between robots and presses.

To build the simulation model all elements/devices that constitute the system are introduced into ABB's RobotStudio → 3. The devices are simulated by smart components, including all logics, kinematics and dynamics properties that will make the model behave exactly as it would on a real site. Typical devices to be simulated are:



The Pareto front method for multi-objective optimization is used in this analysis. In the Pareto front optimization, two separate objective functions (cycle-time and energy consumption) are minimized during optimization. A set of Pareto optimal solutions, which explore the trade-off relationship between the two conflicting objectives, is obtained. The optimization algorithm MOGA-II [4] implements non-gradient methods especially suitable for this type of problem and is used for the energy-efficient design.

The optimization itself is an iterative process. The design variables, in this case the drive-train control parameters, are modified and ABB robot motion simulation software is run using the new set of variables to compute the energy consumption. Simulation results are used for computing both objective function and constraints values. This optimization loop is terminated when the limit for the maximum number of function evaluations defined for the MOGA optimization is reached.

Otherwise, the optimizer analyzes the objective function and constraint values and proposes a new trial set of design variable values. The optimization loop continues until the convergence criterion is met.

The illustration above demonstrates the solution space and the Pareto Frontier of such a multi-objective optimization showing the trade-off relationship of the cycle time performance and the energy consumption. The selected design from the optimal Pareto Frontier shows about a 10 percent improvement of the energy consumption without scarification of the performance of the industrial robot under optimization.

Energy-efficient design is a requirement rapidly gaining importance and one that can be evaluated using virtual prototyping. The objective is to select the drive-train control parameters, eg, allowable torques, and speed, that will minimize energy consumption at the same time that the cycle-time is minimized [3]. The problem is formulated into a multi-objective optimization problem with the drive-train control parameters as design variables and the following two conflicting objectives:
– Minimize energy consumption
– Minimize cycle-time

– Presses with dimensions, control, I/O signals, motion curves
– Robots and other automation devices
– Other mechanical components like destacking tables, blank washer, conveyors and safety elements

These components can be taken from libraries, if they are already in, or added from other sources or even created according to customer specifications.

Once virtually configured, the environment is ready for realistic system simulations. Different scenarios, corresponding to real production cases, can be simulated. → 4 shows a detailed view of the virtual press shop model with the programmed robot motion path highlighted. The optimization of the line performance might require reprogramming of robots, press motion and logics, or adaptations of parameters previously generated. Knowing the performance prior to the real installation is extremely valuable considering the costly risk of not obtaining the expected performance in the real system.

The use of the virtual simulations is not limited to design and commissioning → 5: The introduction of new production processes can be prepared much more easily and diagnosis of eventual faults or potential production improvements can be analyzed prior to their implementation in the real system.

The virtual prototypes developed during the product design process and automation system engineering can also be utilized to support predictive maintenance, identify what components to exchange, and in some cases to optimize robot programs with respect to wear, cycle-time or energy consumption.

Additionally, the virtual prototypes can be run in parallel to the actual automation system in order to test optimized equipment or programs virtually before they are deployed on the real system.

Diego Vilacoba
Ramon Casanelles
ABB Discrete Automation and Motion, Robotics
Barcelona, Spain
diego.vilacoba@es.abb.com
ramon.casanelles@es.abb.com

Xiaolong Feng
Daniel Wäppling
ABB Corporate Research, Mechatronics
Västerås, Sweden
xiaolong.feng@se.abb.com
daniel.x.wappling@se.abb.com

Peter Weber
Thomas Reisinger
ABB Corporate Research, Mechatronics
Ladenburg, Germany
peter.weber@ch.abb.com
thomas.reisinger@de.abb.com

References
[1] V. Miegel, C. Winterhalter, "Comprehensive Use of Simulation Techniques to Support New Innovative Robot Applications." International Symposium on Robotics/Robotik, Munich, Germany, 2006.
[2] P.R. Moorea, *et al.*, "Virtual Engineering: An Integrated Approach to Agile Manufacturing Machinery Design and Control." Mechatronics, Vol. 13, No. 10, pp. 1105–1121(17), December 2003.
[3] X. Feng, *et al.*, "Energy Efficient Design of Industrial Robots Using Multi-Objective Optimization." 43rd International Symposium on Robotics (ISR2012), Taipei, Taiwan, 2012.
[4] A. Konak, *et al.*, "Multi-Objective Optimization Using Genetic Algorithms: A Tutorial." Reliability Engineering and System Safety, Vol. 91, pp. 992–1007, 2006.