MODAPTO [101091996]: Modular Manufacturing and Distributed Control via Interoperable Digital Twins

9.2.1. Introduction to Virtual Commissioning

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Virtual Commissioning fundamentally revolutionizes the traditional approach to manufacturing system validation by enabling comprehensive testing and optimization in digital environments before physical implementation. But how exactly does virtual commissioning work, and what is a digital twin? Virtual commissioning of a machine's dynamics combines three important pieces: a digital model (sometimes referred to as a digital twin), the controller code that governs the motion and responds to sensor feedback, and a development environment that allows the two to run together.

This digital-first approach has become increasingly critical as manufacturing systems grow in complexity and the cost of physical commissioning errors continues to escalate.

The evolution from traditional commissioning to virtual commissioning addresses fundamental challenges in manufacturing system development. While commissioning is a crucial part of the process, it typically occurs rather late in development. And while it accounts for only 25% of development time, it's during this phase that most of the delays occur (Hoffmann et al. 2010). It's predicted that up to 70% of delays are a consequence of errors in the control software (Reinhart and Wünsch, 2007).

By shifting validation activities earlier in the development process, virtual commissioning enables engineers to identify and resolve issues when corrections are less costly and time-consuming.

The implementation of virtual commissioning within the MODAPTO framework utilizes the RF::SUITE toolset, with particular emphasis on RF::ViPer for behaviour simulation and RF::YAMS for dynamic 3D visualization. RF::ViPer serves as the peripheral simulation component, specifically designed for simulating peripheral elements in virtual production systems. This tool enables the development of individual program modules that can be combined in libraries, facilitating the reuse of standard elements across multiple projects. The modular approach aligns perfectly with MODAPTO's vision of flexible, reconfigurable manufacturing systems.

The integration of sustainability analytics into virtual commissioning represents a significant advancement beyond traditional functional validation. By incorporating Functional Mock-up Units (FMUs) that model energy consumption and carbon emissions, the virtual commissioning process now provides insights into environmental impact alongside operational performance. The Functional Mock-Up Interface (FMI) is a tool-independent open standard for exchanging and co-simulating simulation models created in different simulation tools. Such models can describe the dynamic behavior of a component (e.g. an electrical machine) or a system (e.g. a battery-electric vehicle) consisting of many components and subsystems – and they can be used for virtualized design and testing.

The mathematical modeling approach for sustainability analytics considers multiple factors that influence environmental impact. Energy consumption models account for both steady-state operation and dynamic transitions, including acceleration, deceleration, and idle periods. Carbon emission calculations incorporate not only direct energy consumption but also consider the carbon intensity of the energy source, enabling accurate assessment of the environmental footprint. These models are designed to be parameterizable, allowing engineers to evaluate different scenarios and operating conditions.

The recording and analysis capabilities of the enhanced virtual commissioning system provide unprecedented visibility into system behaviour. Using RF::RECv2, the system can capture approximately 17,000 signals within just 20 milliseconds, creating a detailed record of all process flows. This comprehensive data capture enables thorough analysis of both functional performance and sustainability metrics. RF::SCOUT then processes this data, providing visualization tools, process analysis capabilities, and the ability to calculate derived values using user-defined formulas.

The practical implementation of sustainability analytics in virtual commissioning follows a structured workflow. First, engineers create or modify existing behaviour simulation models to include sustainability considerations. This involves integrating FMUs that calculate energy consumption and emissions based on the simulated operations. Next, virtual commissioning scenarios are executed, with the system recording all relevant operational and environmental data. Finally, the analysis phase uses specialized tools to process the recorded data, identify optimization opportunities, and validate that the system meets both functional and sustainability requirements.

The benefits of this integrated approach extend beyond immediate design validation. Virtual commissioning not only helps manufacturers meet the factory acceptance testing (FAT) date outlined in the project plan, but also ensures that they pass the FAT, and in some cases, even enables Virtual FAT. Often determined by plant shutdown schedules or product launches, missing the FAT deadline leads to costly delays and extensive blame-shifting. It’s a situation all project stakeholders strive to avoid, frequently necessitating extended working hours and performance trade-offs.

By incorporating sustainability analytics from the earliest design stages, manufacturers can ensure that environmental considerations are embedded in the system’s fundamental design rather than added as an afterthought.

References

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