Multi-Disciplinary Design: Capturing and Managing All Design Disciplines Holistically

CIMdata Commentary

Key takeaways:

- *Product development in the advanced machine industry needs more than mechanical CAD data management to control product data.*
- *Modern machines are assembled from a variety of manufactured and purchased parts and are controlled by electronics and software as well as actuators and motors driven by electricity, pneumatics, and hydraulics.*
- *An integrated environment that supports the creation and management of all domains on a common platform enables developers to share data and status quickly improving communication and reducing mistakes.*
- *Siemens provides deep support for all machinery related domains including mechanical, electrical, and software via its integrated platform-based product suite*

Complex machines have been common for centuries, well before the industrial revolution. Museums are full of amazing machines that all used some sort of mechanical power source and control system. Over the decades, machine developers have evolved power and control systems from waterwheels, linkages, simple cams, and other mechanical devices to include a number of other disciplines. In most cases today the energy to run a machine is provided by electrical power, but within machines hydraulics and pneumatics are often used for power or force transmission and an abundance of software driven electronic systems are used in combinations to control very complex and variable processes.[1]

Hydraulics and pneumatics are functionally similar, but each has its own optimal use cases. Both are used to control mechanical systems and are relatively simple, especially when compared with electrification. With hydraulics, a fluid, commonly water or a petroleum-based liquid is the working fluid. Significant power can be transmitted, and the system is very stiff and precise. A typical application is to control construction equipment such as bulldozers and excavators or in areas of machines where a lot of force needs to be applied.

Pneumatics and vacuum use air or other gas as the working fluid. Pneumatics is used for lighter duty applications and has other positive characteristics when compared to hydraulics. Air is easily available, and compressed air is transportable and not flammable. Vacuum is used throughout equipment design in places where engaging and manipulating parts requires less precision, faster response, and less risk of end product damage. Food processing equipment often uses pneumatics and vacuum to avoid the risk of product contamination. Each has its own design issues and they use different schematic diagrams. Maintenance is lower for air-based solutions, and it is easy to control the pressure, speed, and force of a pneumatic system.

For machinery applications most hydraulic, pneumatic, and vacuum systems are configured from commercial off the shelf (COTS) components. System requirements drive functional and logic designs which get implemented using COTS components. Schematic diagramming software is used create the logical design and the physical design is created with a CAD application. Best in class design solutions enable selection of components that meet specifications from a library and properly positioning them within a 3D product model. Tubing

[1] Research for this commentary was partially supported by Siemens Digital Industries Software.

or piping are then routed to connect the appropriate components. Connection lists are output as tabular data for manufacturing.

Electric motors and other control devices are at the heart of virtually all modern machines and becoming more popular due to their efficiency and sustainability. Motors are used to provide power to perform whatever work needs to be done but can also be used to configure and adjust aspects of the machine including amount of force or power applied as well as settings and positioning. Electronic controllers manage motors teamed with actuators and sensors that provide feedback to ensure the machine works properly. Sophisticated machines use microprocessors and computer software to manage more complex equipment that may contain many controllers and sensors. Multiple pieces of equipment are often managed by local services or edge computers via manufacturing execution software, and in the most modern equipment interconnection happens in the cloud enabling remote and even global operations.

Software is used in several different contexts. Embedded software runs on machine controllers in real-time directly interfacing and controlling physical operation. Desktop or edge computers oversee machine modules and production lines, providing local reporting and analysis as well as feeding data to the factory or enterprise level via sensors and internet of things (IoT).

Hybrid Systems

Almost all modern machinery, such as HVAC solutions, food processing, robots, machine tools, printing, material handling, injection molding, etc., is mechanical and electrical/electronic based, usually controlled by software. But, some machine requirements are still best satisfied with hydraulic or pneumatic subsystems. Within these hybrid systems the pump or compressor and control circuits are managed by embedded software and monitored by electronic sensors. The hybrid nature of machines adds both capabilities and complexities. Trying to assess the operation of highly-complex hybrid systems is a challenge that requires the ability to perform multi-discipline analyses that include mechanisms, hydraulics, pneumatics, electronic controls, and software—all working together as a system. This system-level, multi-disciplinary analysis adds most value when it can be done virtually as the machine is designed, so that it can influence and improve the design, rather than when done as an after construction verification step.

Machine Design Issues

Ask any engineer about the problems he faces getting his work done, and the complaints will usually revolve around tools, data, and processes. Probe a bit further and difficulties in collaboration get mentioned. Interfaces or boundaries are where most problems occur—they happen across functional domains such as mechanical, electronics, and software and across organizational domains such as engineering, validation and test, manufacturing, installation, and service. In the case of data interoperability, issues arise due to the various types of software used in each domain. At the process level, the handoffs of data from one domain or department to the next cause additional issues. Transferring the right data to the right people and tools at the right time is complex when a project team is larger than a handful of people.

These issues are made much more difficult because modern machines are complex, flexible, and leverage a variety of technology domains to meet their requirements. In summary, the main issues are:

- Managing data from multiple disciplines and sharing it across disciplines (including protracted change management processes)

- Variety of design tools used across disciplines and lack of common data formats and inconsistent data translation
- Multi-disciplinary, multi-domain simulation and analysis
- Variety of tools used by suppliers (especially in sub tiers)
- Lack of common data visualization
- Complexity of commercial parts discovery and use
- Electrification and software design
- Integration of control systems
- IoT sensor support
- Support for machine learning

Machine Design Business Processes

To maximize profitability many machine building companies, use a modular design strategy. At its most basic level modular design involves ensuring interface or connection points between modules are consistent so modules that increase capability or capacity can be easily added. Within the mechanical or physical domain connection points need to match. The input and output of one module needs to meet the requirements of the modules with which it connects. On the electrical side wiring harnesses need to connect, and the electronic signals and power conductors need to align. Software is where it starts to get very complex. Ensuring that embedded controllers can be managed as a single unit across modules without customizing each installation's software is critical to smooth operation. Hydraulics, pneumatics, and vacuum devices have similar issues to electrical and electronics.

The most advanced machine builders use a systems level design methodology to support their modular design strategy. This approach allows them to develop product architectures based on functionality customers need while keeping the mechanical, electronic and software elements organized so data reuse is maximized and cost effective, supportable machines can be produced.

Machine companies primarily use three business models, build-to-stock (BTS), engineer-to-order (ETO), and configure-to-order (CTO) and often blend these. In a BTS business, the strategy is optimized for volume production and machines are designed to meet well defined requirements with predictable sales volumes. In an ETO process, significant elements of the machine are customized or designed from scratch to meet specific customer requirements. In a CTO process, common modules and parts are assembled to meet a customer's requirements. These three business models are often thought of as a continuum, wherein elements of each can be combined to produce a wide range of products. For instance, core product modules may be produced in volume using a BTS strategy, then, these core modules and standard components can be configured to support more complex applications using a CTO strategy. Then, for customers with unique requirements the machine builder configures as much of the product as possible with these core BTS and CTO modules and custom engineers only what is special. Few machine companies are pure BTS, CTO, or ETO. Adding some configurability to a BTS product is an easy way to grow sales, while fully engineering from scratch is usually too expensive. BTS is usually the lowest cost and most predictable approach, ETO the highest cost (but with the highest potential margins) and least predictable approach, and CTO is in the middle.

A good example of a mixed mode machine is an HVAC system. The system is configured using standard duct and control components, but custom sheet metal may be used to support nonstandard building design features. Product configurators can be used in both CTO and ETO processes. Using a configurator, an application engineer or even a customer can input requirements that support a desired process. This is evaluated by an algorithm that understands how modules and parts may be configured to achieve a particular result. This automation approach can dramatically reduce the design and planning time required to produce a machine once its architecture is defined. When reusing existing parts in a configurator, it is easier to forecast cost and profitability as the cost data from previous equipment can be incorporated into the configuration enabling better business decisions for both the machine builder and the customer.

Two areas of innovation within machine engineering companies are IoT and machine learning (ML). IoT uses sensors to report on machine environment and performance. The data from IoT is usually reported to enhance operation of the machine, but in the most advanced implementations machine builders are using IoT to provide condition-based and predictive maintenance services. They are also using IoT data to improve product designs. ML, an application of artificial intelligence, has received a lot of attention and is being applied to many problems. Equipment operation optimization is perhaps the most developed use of ML. As sensors drop in cost, they are used more and more and output more and more data. Processing that data is a bottleneck and CIMdata is seeing more case studies on how machine learning is helping transform raw IoT data into actionable information.

Siemens Solution

Siemens Advanced Machine Engineering (AME) is a subset of the Xcelerator portfolio focused on supporting machinery companies by packaging all the appropriate portfolio technologies to support the three capabilities all machine builders need—multi-disciplinary design, configuration management, and virtual commissioning.

Mechatronics Concept Designer enables systems to be designed by using a library of reusable data to build up a machine concept including joints, motion characteristics, sensors, actuators, collision behavior, and other kinematic and dynamic properties for each component. The model built with this data is executable, that is it simulates the machine’s behavior, including executing controller code in real time. The Siemens portfolio also has authoring tools to support the entire product lifecycle including NX for MCAD and domain-specific modeling including hydraulic, pneumatic, sheet metal, and wiring harness. Simcenter supports multidomain and multiphysics simulation including computational fluid dynamics and structural analysis for design and validation. Capital for ECAD, and Polaron for software development, and Teamcenter to tie the authoring tools and their data together with development processes into a comprehensive digital thread and provide the foundation of the actionable digital twin. Furthermore, virtual testing is supported, so machine functions can be validated virtually in a fraction of the time it would take on a physical product, enabling more thorough V&V.

Teamcenter provides the data and process management backbone to manage the digital thread and digital twin through design, manufacturing and production and ensure all configurations across the lifecycle are managed and fully traceable. It supports all the domains used in design and can be extended to support manufacturing and rest of the lifecycle

Conclusion

Most machine builders require capabilities from multiple domains to define their products: mechanical, electrical, electronics, software, hydraulics, and pneumatics. The best companies start with a product architecture to develop modular designs that support as much reuse as possible to optimize business performance. Domain specialists need authoring tools that support their domains to get their job done effectively, but they also need a tool to design and manage machine architecture and provide configuration control to ensure customer expectations are met and the machine can be delivered on time, on budget, and with appropriate quality. While these requirements are straightforward, putting together a sustainable multidomain design environment is a difficult problem. The Siemens Xcelerator portfolio and the Advance Machine Engineering solution provide one stop shopping to get the capabilities necessary to design, develop, and operate a machine building business. Getting these tools from a single source helps ensure they can be used together with strong interoperability. CIMdata believes the AME solution can give machine builders a competitive advantage and should be on their evaluation list.

For more information please see Siemens Digital Industries Software at:
siemens.com/plm/advancedmachinery

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