Precise synchronization with EtherCAT: Self-Propelled Modular Transporters, working in tandem

NASA uses Wheelift® heavy transporters

Since January 2014, Wheelift® Self-Propelled Modular Transporters (SPMTs) have successfully addressed the extreme material handling needs of NASA.
U.S. space agency NASA is currently working on the Space Launch System (SLS) rocket program for manned space exploration beyond a low Earth orbit. The SLS will be the most powerful rocket ever built, with a payload of around 130 metric tons (143 tons) in several stages. The initial Block 1 configuration of SLS will stand 322 feet (98 m) tall, higher than the Statue of Liberty, with a launch weight of 5.75 million pounds (2,500 tons). The first unmanned SLS mission – Exploration Mission-1 (EM-1) – is scheduled for the end of 2018 with crewed missions to follow. Today, the rocket components must be transported over long distances in large manufacturing facilities, and NASA uses Wheelift® Self-Propelled Modular Transporters (SPMTs) from Doerfer Companies to move these giant shuttle components. The challenge is to maintain precisely synchronized coordination of multiple SPMTs carrying rocket components with enormous dimensions and heavy weights.

Large NASA production facilities, such as the Michoud Assembly Facility (MAF) in New Orleans, are among the largest manufacturing facilities in the world with over 1,870,000 square feet (173,728 m²) of floor space. A major activity at the MAF is assembly of components for the NASA SLS rocket program. The huge rocket components, which can weigh hundreds of tons, and various tank sections must be moved throughout assembly and manufacturing processes over distances of 1 to 2 miles (up to 3 kilometers). However, handling and moving heavy loads is nothing new to Doerfer’s successful Wheelift transporters. The special challenge for the NASA application is that four SPMTs have to work in tandem, and that special support fixtures are required for the sensitive loads.
This requires Doerfer to gather continuous feedback from the fixture that supports the various tanks to maintain precise alignment of the load.

The four Wheelift SPMTs are each rated for load capacity up to 100 tons, and together move the rocket stage equipment onto a public road, over a levee and onto a barge which takes the SPMTs and rocket components to the next NASA facility. John Pullen, Principal Controls Designer at Doerfer Companies, explains the automation requirements necessary to successfully pull off this weighty balancing act: “It is challenging to maintain coordination of multiple SPMTs balancing a support fixture over difficult ground conditions, such as bumps and other elevation changes in plant floors and pathways. Managing these loads also requires heavy duty servomotors and tires, as well as an advanced automation and control system that can keep up with constantly changing conditions.”

One Embedded PC coordinates the movements of four heavy equipment transporters

The four SPMTs, working in tandem, constantly maintain safe velocity and steering centers. “This required a significant modification of the control architecture,” as Tom Phillips, Wheelift Business Manager, Doerfer Companies, explains: “We need one controller to coordinate the work of four vehicles.” Leveraging TwinCAT 3 automation software from Beckhoff, Doerfer has designated one SPMT that works as the “master” for the vehicle group with the others following as slaves in an object-oriented control architecture. The master PLC performs all the calculations for each of the vehicle groups. “This includes equalizing the torque and steering centers, velocities, load distribution and cylinder height every 10 milliseconds,” Pullen adds. The newest generation of

For automation and control, the newest generation of Wheelift SPMTs are equipped with DIN rail-mounted Beckhoff CX2030 Embedded PCs that feature powerful 1.5 GHz Intel® Core™ i7 dual-core CPUs.

Wheelift SPMTs accomplish this via Beckhoff CX2030 Embedded PCs. For the user interface, CP29xx series multi-touch Control Panels are used.

Increased performance with TwinCAT 3

“When we began integrating the Embedded PCs, we increased our software performance because we added so much processor capability. We also expanded our debugging functionality, implicit checks, and timing of the program organizational units (POUs),” says Ryan Canfield, Controls Engineer, Doerfer Companies. “Core isolation in TwinCAT 3 is another important consideration: we dedicated Core 1 for TwinCAT and assigned Core 0 to handle the Windows OS and InduSoft HMI software. This provided considerable benefits for maximizing processor efficiency and making our control software even more robust and responsive.”

Also key to Doerfer’s programming efforts for the Wheelift are the source code and version control features in TwinCAT 3. “We no longer have to worry about code loss when managing the work of multiple programmers – we can more easily collaborate in teams and merge work from Project A into Project B, for example,” Canfield continues. “We have drastically reduced our manual programming efforts and streamlined our engineering process using source code and version control in TwinCAT 3.”

Part of the challenge with the NASA projects was the requirement for Wheelift vehicle grouping: Doerfer now has vehicle “objects” in the programming that are grouped together. “We program Wheelift code using object-oriented extensions
of IEC 61131-3 in TwinCAT 3,” Pullen explains. “This supports the creation of highly complex features, but also allows our programmers to be abstracted from the process and fine details of the functionality. Essentially, it’s like giving the objects a ‘start’, getting the parameters to function and letting those objects do the rest on their own. This approach is rather elegant and requires minimal engineering effort.”

**EtherCAT as the integrated communication system**
EtherCAT serves both as fieldbus system and drive bus system in the SPMTs. This creates the potential for flexible connectivity between EtherCAT and other bus systems and seamless integration of peripheral devices. For example, EL6751 CANopen Master Terminals are used to establish connectivity for engine diagnostics and inverters for battery systems, and to connect to the radio control interface used for manual SPMT operation by Wheelift operators. Safety functions, such as e-stop, are integrated into the control system via EL6900 TwinSAFE logic terminals. “EtherCAT is also indispensable for fault monitoring,” Pullen explains. “With the built-in diagnostic capabilities of the EtherCAT system, we can immediately point the operator to any specific cable or device in the event of a service or maintenance need.” In addition, Doerfer has implemented the EtherCAT Automation Protocol (EAP) for inter-vehicle communication. “We’re easily getting 10 millisecond communication latencies between the Wheelift vehicles,” Pullen adds. Wheelift vehicles in a group communicate wirelessly via radio equipment, but the operator can easily take control via a handheld interface.

The heavy equipment transporters can have as many as 24 axes per vehicle. The automation system must handle highly advanced positioning algorithms to successfully compensate for the movement of the heavy loads. Motion control for Doerfer’s heavy duty Uniload® wheels on the Wheelift is handled by AX5000 EtherCAT Servo Drives with AM3000 servomotors and high-torque planetary gear units. “With the servo drives, the Wheelift can achieve resolution for servo axes and hydraulic axes down to a thousandth of an inch,” Canfield reports. “In addition, the load distribution algorithms the Doerfer team programmed in TwinCAT 3 distribute the load throughout all of the present cylinders on the Wheelift. This remains true when driving over bumps or if the load is off-center.”

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Doerfer reports that with single and dual channel versions of AX5000 EtherCAT Servo Drives, the Wheelift can achieve resolution for servo axes and hydraulic axes down to a thousandth of an inch.

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From left: Semir Music and Greg Tagtow from the Wheelift engineering team at Doerfer Companies; Colonel James Kelly, NASA; John Pullen, Ryan Canfield and Luke Offner, also of the Wheelift engineering team.