



Figure 1 The displays and slimmed-down controls in the cab of GE Transportation's new Evolution Series locomotive replace traditional levers and gauges.

CENTURY-OLD DIESEL-ELECTRIC TECHNOLOGY ENDURES.

Locomotives pull into the digital age

THOUGH LOCOMOTIVE-DIESEL-ELECTRIC TECHNOLOGY has been around for the better part of a century, nothing sits on the immediate horizon that will displace it for hauling freight and passenger trains in North America. From the perspectives of cost, power, control, efficiency, and reliability, a durable concept exists of a diesel engine's driving a large alternator to power traction motors on each axle.

But that concept doesn't mean that GE (GE Transportation) or the EMD (Electro-Motive Division) unit of GM (General Motors), the two biggest US locomotive builders, have been standing still, especially when it comes to electronics. On Jan 12, GM, which has owned EMD since 1930, said it planned to sell the unit to Greenbriar Equity Group LLC and Berkshire Partners.

Until the digital age a dozen years ago reached locomotives, diesel-electric technology evolved slowly. After all, locomotives at their core going back to steam power are mechanical beasts of burden and remarkably grimy ones at that. Today, they measure 76 ft long,

weigh more than 200 tons, and cost more than \$2 million. Most of all, they are highly specialized, so chances of people ever sitting in one much less operating one are akin to lottery odds. Their builders produce fewer of them than automakers do trucks, for example. In 2004, GE and EMD built 826 and 500 to 600 units, respectively.

During the past decade, computerization and networking has swept the locomotive and infrastructure supporting it. The cab looks more like an aircraft-controller workstation than the traditional hodgepodge of metal levers, knobs, and gauges (Figure 1). What's more, new locomotives wirelessly link to diagnostic and support centers. On the power side, ac traction motors, which are more reliable and less complex than their dc counterparts, now constitute about half of all sales at both GE and EMD. For decades, dc traction motors dominated.

Such innovations come at an opportune time, because rail transportation is entering a period of growth, according to Tony Hatch, an independent railroad analyst. "The railroad industry is moving

At a glance..... 56

Q&A with

Norman Bridge..... 58

from a cost-cutting phase to a growth phase. Coal and container [traffic] are only going to get bigger. That means good things for locomotives,” he says, adding that demand is also strong offshore in countries such as China and Australia.

At their most basic level, locomotives pull, push, start, and stop. The extreme environments in which they operate complicate the job. Moving a 110-car, 10,000-ton grain train—about 2000 tons heavier than a US Navy destroyer—up, over, and down mountains where the air is thin, across scorching deserts, and around sharp curves is challenging enough. But the real enemies of smooth operation are temperature extremes and moisture.

“For the past five years, the biggest emphasis has been on reliability and performance. That’s true with mechanical, combustion, cooling, and the electronics. The challenge is improving reliability to reduce road failures and removals and still getting more freight through the same corridor faster,” says Wolfgang Daum, manager of controls and software for GE Transportation Systems. “The challenge is how to best deliver power to the rail.”

Six years in development, GE’s latest locomotive, the 4400-hp Evolution Series (Figure 2), just completed 4.5 million miles of field testing. The investment in Evolution totaled \$200 million and has yielded 25 patents and 13 patents pending, according to GE’s Web site. The brains of the locomotive are 20 Pentium-class microprocessors that monitor and control the various subsystems, such as the diesel engine, or “prime mover”; traction motors; main alternator; and auxiliary systems, such as the radiator fans, compressors, traction-motor blowers, and battery chargers. They measure and check 2500 to 5000 parameters with data latency varying from tens of microseconds to tens of seconds, depending on the system, says Daum.

For example, one com-

AT A GLANCE

- ▶ Digital electronics have swept the locomotive cabinet.
- ▶ Component testing is brutal and varied for the myriad harsh environments a locomotive encounters.
- ▶ Hybrid engine technology is on the short-term horizon, but more powerful and fuel-efficient diesel engines have already arrived.
- ▶ Computerized diagnostics monitor 3000 to 5000 locomotive parameters and wirelessly transmit the data to technicians.

puter oversees such functions as traction control to maximize wheel adhesion on the rails. The contact surface between rail and wheel isn’t much bigger than a dime. “The steel-to-steel interface is crucial. The 1000-hp inverter in each axle regulates torque and slip. If you get it wrong at 4400-hp, you burn through the rail in a hurry,” explains Daum. Individual axle control minimizes slippage. A typical lo-

The clean lines and the sheer size of GE Transportation’s 4400-hp Evolution Series locomotive are impressive.



Figure 2

comotive has six axles, so if one slips, the horsepower transfers to another that is still getting traction.

The onboard network between the computers borrows heavily from CANs (controller-area-networks) in automobiles. Besides CANBus, other networking and computer interfaces include RS-232, RS-488, Ethernet, and redundant ArcNet. Multiple units in the same train communicate wirelessly, and all networks use error-correcting techniques. The computers run the QNX real-time Unix variant, and the applications to run the various power subsystems are in written in Matlab, Matrixx, and C++, says Daum.

A single jumbo covered hopper car now carries 111 tons of grain. Such a load would damage the lighter rail commonly found on short-line railroads. The demanding power requirements of these newer units and their ability to operate almost anywhere in the world mean that the electrical and digital components undergo brutal testing. At GE, engineers place the board electronics in a chamber in which temperature ranges from -90 to $+180^{\circ}\text{C}$ within 50 sec. Daum declines to disclose the actual temperature speci-

fications of the boards. “We do a lot of testing for margin,” he says. “You need to know how you perform for outside normal operation. You can have temperatures of -50°C in the Canadian Rockies to $+50^{\circ}\text{C}$ in Death Valley and up to $+90^{\circ}\text{C}$ in a tunnel where gases and heat collect. We test for much more than those extremes,” he adds. “I’m happy when you can melt the solder and it still works.”

GE also uses compressed air hammers to simulate as much as 60g of random banging and vibration on the electronics. In the locomotive, specially built cages house the cards. These cages handle thermal shock, vibration, and extreme temperatures, but GE generally doesn’t use shock mounts, says Daum. Electromechanical devices, such as contactors, must withstand the same abuse. Most of the cooling for these compo-

designfeature *Digital-age locomotives*

nents comes from large fans.

Overload testing also includes stressing the diesel engine above its design limit by operating it at 120% of its normal capacity to see what “lets loose” first. This practice helps achieve the lowest possible FLY (failure/locomotive-year) rate.

Key to Evolution is room to grow. For instance, the same diesel engine becomes more powerful but continues to meet increasingly stringent EPA (Environmental Protection Agency) emission standards. Tier 2 standards this year go into effect to reduce the release of nitrogen oxides and particulate matter, and the industry expects the EPA to later impose even tighter regulations. The Evolution diesel has 12 cylinders and still generates more horsepower than its 16-cylinder forebear.

One forthcoming feature in the Evolution will be ability of the traction motors to capture energy when the train is traveling downhill or coasting to a stop. The traction motors convert the energy to electricity and store it in a battery pack, promising a 10 to 15% savings in fuel consumption. This so-called hybrid technology extends a function known as



Figure 3

Looking pumped up, EMD's SD-70ACe 4300-hp locomotive with ac traction motors shows off its vents and radiators.

dynamic braking, which for the past 30 years has deployed the traction motors as a braking system to slow the locomotive, particularly on steep grades. The hybrid principle might sound simple, but one of the major design challenges was developing batteries that could on a daily basis withstand the sudden surges of electricity. “That’s millions of dollar of opportunity,” says Daum.

Engineers seeking ways to conserve fuel need not base those methods on sophisticated technology such as the hybrid. EMD, for instance, has developed AutoStart technology, which determines

when an idle locomotive should start or shut down. AutoStart senses engine temperature, battery voltage, and current and air reservoir pressure and acts upon the readings. In cold weather, locomotives typically run continuously to prevent systems from freezing and becoming damaged. A locomotive runs 50% or more of its lifetime, which can be 40 years or more. EMD estimates that halving the average annual idle time of 3600 hours could result in a potential fuel savings of 5400 to 7200 gallons per locomotive each year. When a locomotive is about to start with no one in the cab, an alarm sounds

Q&A WITH NORMAN BRIDGE

Norman Bridge is the director of control and electrical systems design at GM's Electro-Motive Division and has more than 20 years of experience designing hardware and software for embedded vehicle-control systems. He has bachelor's and master's degrees in electrical engineering from Illinois Institute of Technology and a master's degree in engineering management from Northwestern University. Bridge explains what he thinks electrical engineers need to know in the locomotive field.

EDN: What should electrical engineers be thinking about with respect to locomotive electronics?

Bridge: Locomotive design requires a broad range of electrical engineering skills: Power-systems design, control-systems design, software engineering, and networking and communica-

tions are all core technology skills for locomotive design. Engineers must have an understanding of how to design for rugged environments. [Locomotives encounter] a lot of vibration, dirt, high temperatures, and humidity. We try to stay away from conditioning in terms of filters and shock-mounting as much as possible because that means maintenance problems for the railroads.

EDN: What are the most important developments in locomotive electronics in the past five years?

Bridge: For Electro-Motive, the most important locomotive electronics developments [include] the development of FIRE (functionally integrated railroad electronics), our operator display and cab computer; development of IntelliTrain, the wireless locomotive; and the application of IGBT (insulated-gate-bipolar-

transistor) traction inverters, which have reduced the cost of ac traction locomotives while improving reliability.

EDN: Can you give some examples of the future innovations in locomotive electronics? What are the hot technologies?

Bridge: We are just beginning to scratch the surface with wireless technology and how it can improve railroad operations and improve fuel economy. Electro-Motive is participating in an FRA (Federal Railway Administration)-sponsored project to develop a system to remotely monitor and control train cars using FIRE and IntelliTrain technology. This type of system could improve both safety and operating efficiency.

EDN: How does a customer choose between a locomotive with ac motors and one with dc traction motors?

Bridge: Typically, railroads use ac traction locomotives for

heavy-haul operations, such as coal, that require very high adhesion levels and are very demanding on the traction motors. DC locomotives are typically used in lighter duty service.

EDN: What are the key design challenges and trade-offs for both technologies?

Bridge: AC locomotives require sophisticated power electronics and software to control the operation of the ac motors. DC locomotives have simpler control electronics but require bigger and more complex motors.

EDN: What does the future of innovation look like with respect to ac and dc power generation?

Bridge: Reliability, adhesion, and cost are the keys. Improving the efficiency and reliability of the drive and auxiliary systems through the use of larger power devices and more sophisticated controls [is also important].

so that unsuspecting bystanders don't become frightened.

The two biggest innovations at EMD are the unit's onboard FIRE (functionally integrated railroad electronics) computers and the IntelliTrain system for remote monitoring and diagnostics. The FIRE system, which EMD also based on Pentium-class microprocessors and the CAN architecture, comprises three hardened PC104-bus computers running embedded Windows XP and one to three operator displays, which consolidate a dozen standard gauges, indicators, and controls. "We looked at the locomotive as a networked device. Our engineers must have a good understanding of networking," explains Norman Bridge, director of control and electrical systems design at EMD. "We also leveraged COTS (commercial-off-the-shelf) hardware. We're system integrators asking how can you take these building blocks and integrate them together. The software, for example, is object-oriented and based on Windows XP, so it's much easier to add new functionality" (see sidebar "Q&A with Norman Bridge").

WINDOWS XP ON A LOCOMOTIVE?

Bridge claims that, although Windows XP has a problematic reputation on desktops, EMD has enjoyed a different experience. "We have not had a single failure," he says. "Most of the problems with Windows for desktop PC applications has to do with the limitless combination of software applications and hardware combinations that it must support. The locomotive application is a dedicated hardware platform. The user doesn't change it by plugging in a new video adapter, for example, and incorrectly loading the driver."

The IntelliTrain system, which just moved into commercial production, diagnoses faults and reports them to an EMD technical-support center, which channels the information in any of four directions. The center stores about 5 sec of data for each fault and performs pseudo-real-time checks on about 10% of the 3000 parameters that FIRE monitors. As with GE, latency varies on EMD locomotives, but the system samples some signals at 1-msec intervals.



THE FIRE SYSTEM ... COMPRISES THREE HARDENED PC104-BUS COMPUTERS RUNNING EMBEDDED WINDOWS XP AND ONE TO THREE OPERATOR DISPLAYS, WHICH CONSOLIDATE A DOZEN STANDARD GAUGES, INDICATORS, AND CONTROLS.

The customer can view the data on a secure Web site, or the system can send electronic alerts to pagers, cell phones, or e-mail addresses. Alternatively, the customer's information systems can directly integrate the data, or a technician can diagnose the problem and send work orders to the customer.

The onboard LAN collects data indicating, for instance, the locomotive's speed, location, fuel level and consumption, usage by fleet or region, and kilowatt-hours, and the health of all the major subsystems. Then, cellular or satellite technology uploads the data to the support center. Such highly automated support is available only to newer units, such as EMD's SD70ACe and SD70M-2 and retrofits (Figure 3). Service for most locomotives still requires a visit from a mechanic. "Via the electronics and sensors, we're able to validate the health of the locomotive and the accuracy of a repair. [The challenge] is coming up with algorithms that interpret the various signals coming off the locomotive," says Curt Swenson, EMD director of market development and communications. "The difference is being able to diagnose a problem while the locomotive is still in service. It's not uncommon to lose days of availability when a unit has to go to a shop for diagnosis." Early detection and correction can also help avoid more costly repairs or worse, a catastrophe. GE offers PinPoint and Expert-on-Alert, similarly automated service and support products.

Like many nascent platforms in the digital world, only imag-

ination—and cash—limit the ability to add functions. EMD plans to later implement wireless technology between multiple locomotives operating in the same train. And technicians will eventually be able to remotely start or shut down locomotives.

On the power side, thanks to the migration from gate-turnoff thyristors to IGBTs (insulated-gate bipolar transistors) in the traction inverters, EMD has reduced the number of add-in cards from 50 to two in ac locomotives. One dedicated controller oversees three axles, which makes up a truck, or "bogie." "They are easier to control and allowed us to shrink the cabinet [that housed them]," says EMD's Bridge. "We still have a large cabinet, but the control functions have been greatly simplified. Reliability is very much related to the number of electronic components you have in a locomotive." A single blower and passively cooled computers reduce cabinet heat.

GE has made a similar migration to IGBTs, which it claims has resulted in having 5000 fewer components in the locomotive and 1 million miles between traction motor overhauls. Like GE, EMD performs extensive testing and deploys error and electrical-noise safeguards, such as shielding, balanced signal lines, and adherence to wiring-separation standards. "We also employ input debounce and filtering," Bridge says.

Critical systems, such as the electronics, undergo HALT (highly accelerated life testing). Over the years, engineers have developed standards for designing components to withstand dirt and dust, shock and vibration, thermal shock, heat, and humidity. These systems typically have forced-air cooling, thus whenever possible avoiding the need for replacement filters and shock mounting, explains Bridge.

As for overarching trends in electronics design, GE's Daum would like to see the power electronics catch up with continual advances made in DSPs. The challenge for engineers is to harness the quantum leaps DSP technology makes when the power technology advances at much slower pace. □

TALK TO US

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