Engineered Machined Products (EMP) has developed a new electrical cooling system that is currently in field testing with TriMet, a regional transit authority in Portland, Ore. The system, which has been incorporated to this 2003 New Flyer D40LF 40 ft., low-floor conventional transit bus that was one of 25 of the same spec purchased by the agency in 2003, is designed to bring some of the energy saving advantages of hybrid technology to bus retrofit applications.

EXPLORING THE POTENTIAL OF A "MINI-HYBRID" TRANSIT BUS

Electrification of cooling system seen to provide significant improvements in fuel economy

BY MIKE BREZONICK

It is generally accepted that one of the most promising applications for hybrid powertrain technology is transit buses. Both the nature of the vehicle's duty cycle and the fact that the buses are generally operated from a single central location make the use of hybrids a natural.

But it's also true that hybrids remain to this point a very small percentage of the overall transit bus fleet and because of the longevity and durability of existing diesel buses, as well as the higher cost of hybrids, it's likely to remain that way for some time.

However, an interesting field test program of what's been termed a "mini-hybrid" system seems to point to a system that could bring many of the advantages of a hybrid to the diesel retrofit market. The system, which consists of a high output, belt-driven 24 Vdc alternator combined with an electrically driven thermal management package, is in the midst of an extensive test program with TriMet, a Portland, Ore., municipal transit authority. In more than 2000 hours of operation, it helped deliver a 10.5% improvement in fuel economy, while re-

Some information for this article is from the SAE paper "A 'Mini-Hybrid' Transit Bus with Electrified Cooling System," by Robert Page, Ralph Bedogne and Todd Steinmetz of EMP Inc. and Anton A. "Tony" Bryant of Trimet.

Modifications to the TriMet bus included a new high-output al-ternator and EMP's Diesel Grade electric cooling fans and electric coolant pump. Along with the ability to control the fans to precisely match the cooling load required, the electric motors in the fan are reversible, allowing for a daily cleaning cycle.

ducing maintenance costs and enhancing serviceability.

TriMet serves 575 sq.mi. of the urban portions of a three-county metropolitan area. Its transit network includes 91 bus lines and a 64-station light rail service. More than 63.1 million bus trips were made on TriMet transit buses during fiscal year 2006.

The agency has several parallel hybrid buses in service. One of the most appealing aspects of the hybrid system is the electrification of a range of components, including compressors, fans and pumps, which has been shown to reduce fuel consumption and allows for more "intelligent" control of their operations. In an effort to bring some of those capabilities to its existing fleet of diesel vehicles, TriMet Director Tony Bryant met with Engineered Machined Products (EMP). Headquartered in Escanaba, Mich., EMP has been one of the pioneers in the advancement of electrically driven components, primarily in diesel engine cooling systems. The company has developed a product range of Diesel Grade components (see June 2006, *Diesel Progress*) engineered to provide an enhanced degree of performance and controllability to engine thermal management.

In the mini-hybrid system developed by TriMet and EMP, a new cooling system strategy was developed for an existing fleet vehicle. The bus selected for the test was a 2003 New Flyer D40LF 40 ft. low floor conventional transit bus that was one of 25 of the same spec purchased by the agency in 2003. It had been operated in regular urban service since 2004.

The bus is powered by an 8.9 L Cummins ISL engine rated 280 hp at 2100 rpm that drives a Voith D864.3 three-speed automatic transmission with three-stage hydraulic retarder. With a GVWR of 39,600 lb., the vehicle has a passenger capacity of 40 seated and 43 standing.

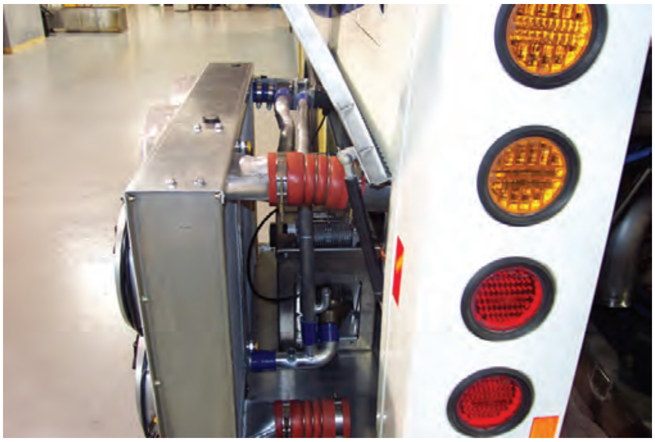
The vehicle was modified at EMP's Escanaba facility. The entire cooling system — including the radiator, charge-air cooler, hydraulic oil cooler, hydraulically driven fan, hydraulic pump, hydraulic oil reservoir and the associated plumbing — was removed, along with the engine alternator. The oil-cooled alternator was replaced with a new high-output, air-cooled, field-wound alternator unit that can deliver up to 400 amps of 28 Vdc current.

The brazed aluminum radiator and charge-air cooler were custom-built to match the performance of the fans, while meeting the requirements of the transit industry. All of the components, save the alternator, were mounted on a slide-mounted tray to facilitate service and maintenance access.

The cooling system has three independently controlled circuits: engine, transmission oil and charge-air. Feedback control systems incorporate strategically placed thermistors as inputs to maintain the fluid temperature of each circuit at the desired setpoint.

Key components of the system include the Diesel Grade electric cooling fans and electric coolant pump that replaced the belt-driven water pump. The motors used in the electric fans allow them to be operated in the reverse rotational direction. Exploiting this capability, software algorithms were added to the system controller to allow the fans to be reversed by actuation of a switch in the engine compartment. Service personnel can use this feature to reverse the air flow of the fans to blow out debris that has accumulated in the grill or fins of the radiator. Adding this 30-second task to the daily service routine may reduce the need for pressure washing of the radiator, saving time and reducing the chance of component damage that can occur during cleaning.

The coolant pump draws fluid from the exit of the heat exchanger or bypass tube, directing it toward the transmission oil cooler control valve that regulates the amount of coolant flowing through the heat exchanger



All of the new cooling system components were mounted on a sliding tray to facilitate service and maintenance access.

to maintain oil temperature. Coolant returning from the engine enters the electronic thermostat, which replaces the engine's mechanical thermostat. The electronic thermostat directs the coolant flow to the radiator or diverts it to the pump via the bypass, depending on the temperature of the coolant. During cold-starts and cold weather operation, these two valves allow heat from the engine to be used to warm the oil in the transmission, thereby making use of energy that might otherwise be lost through the radiator.

To reduce the amount of time necessary to prepare the system for roll out, a quick-drain fitting was installed in the radiator and all hoses were fitted with quick-disconnect couplings. The brazed aluminum radiator and charge-air cooler were custom-built to match the performance of the fans, while meeting the requirements of the transit industry.

The electric water pump and each of the electric fans contain brushless dc motors while the electronic thermostat and the transmission oil cooler control valve each contain stepper motors for their actuation. Each of these electrified components is driven by an electronic control unit that receives its actuation commands from a thermal management controller via a J1939 CAN communication link. The thermal management controller measures thermal system parameters and obtains engine and transmission parameters from the vehicle's J1939 datalink.

The duty cycle of transit buses is unique from most other heavy-duty vehicles in that they spend a high percentage of their time at idle and near idle conditions, rarely experiencing high engine loads or high vehicle speeds. In operation, the national average speed of transit buses is only 12.8 mph. Cooling system loads are relatively low under these conditions, so these vehicles will see a fuel consumption benefit from a reduction in cooling system-related drive power loads at idle and light load conditions.

The fuel economy benefits can be attributed to several sources. These include higher alternator efficiency, the performance optimization capability of the electrically driven pumps and fans, reduced cooling system flow restriction and reduced frictional losses when oil is maintained at optimal temperatures.

The efficiency of the alternator in generating electrical power also has a direct impact on the amount of crankshaft power required to produce that power. The biggest contributors to the power savings are the cooling fans and pump, compared to the mechanically or hydraulically driven devices they replaced. At maximum operating speed, the electrically driven components have been found to consume almost 27 hp less crankshaft power than do the mechanical water pump and hydraulic cooling fan.

In conventional buses, the electrical power demanded by the HVAC system, lights, video surveillance system, audio, etc., exceeds the ability of the alternator to supply power at idle conditions. Deficits are made up by drawing power reserves from the battery pack. The increased current demand on the alternator, which includes battery charging, must be matched by increased power from the engine to drive the alternator, thereby increasing the fuel consumption.

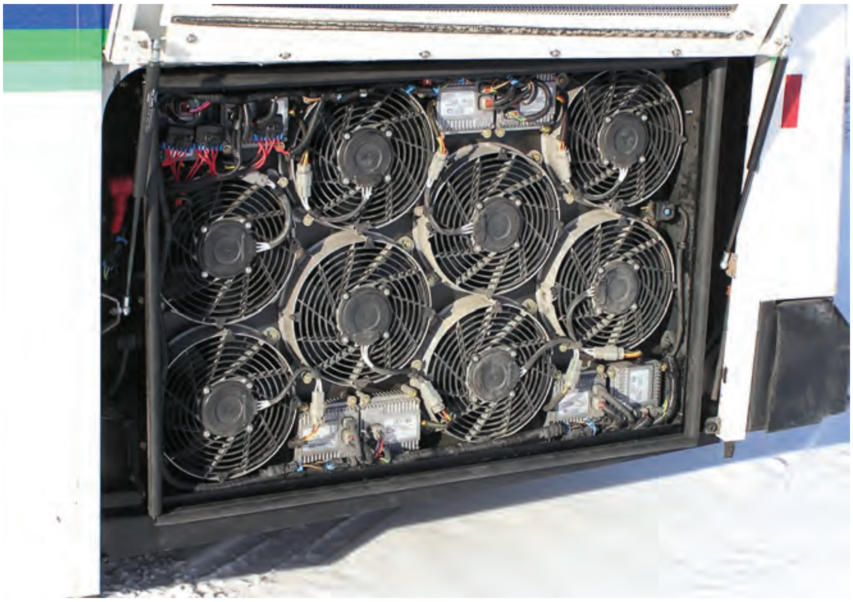
Additionally, typical lead-acid batteries can withstand only a finite number of charge-discharge cycles before they must be replaced. The high loads placed on the charging system also increase the rate of wear on the alternators and belt drive systems. Many transit agencies replace batteries every six to 12 months and alternators are rebuilt or replaced about once a year.

The high-output alternator used in the mini-hybrid demonstration vehicle can supply up to 400 amps of electrical power, which is more than sufficient to provide power to all systems even in the unlikely event that all are operating at their maximum power condition.

The bus was operated on several different bus routes in San Diego, Calif., to evaluate its performance during typical stop-and-go operation. Selected routes included urban areas where high traffic and low speeds were common and suburban routes where vehicle speeds were higher and stops further apart. The bus was instrumented to monitor key fluid temperatures, including coolant, oil, and engine intake air. The charging system was also instrumented to monitor voltage and current draw during operation.

In addition, key parameters of the cooling system were monitored through its system controller, including motor speed, controller voltage, controller power consumption and thermistor values. All data was recorded on a laptop computer for later analysis.

After the city driving portion, the bus was transported to Arizona for further evaluation. Just over the Arizona border from Laughlin, Nev., is a



EMP's retrotfit cooling system is also now in pilot testing with several other transit fleets. Shown here is a bank of Diesel Grade fans being adapted to a bus operated by the Capital Area Transit Authority of Lansing, Mich.

section of Arizona Highway 68 known to testing personnel in the automotive industry as the Davis Dam Grade. Exhibiting a nearly steady 6% grade for a distance of over 10 miles, it is commonly used for evaluating vehicular cooling systems.

After several runs up and down the hill to verify the data acquisition system, the bus was subjected to severe stop-and-go driving up and down the grade. Intended to tax the system beyond what would normally be seen during actual operation, this driving schedule placed a heavy load on the engine and charge-air cooling system upon acceleration and on the transmission oil cooling system upon brake application.

In both of those applications, the performance of the thermal management system was found to exceed the conventional system it replaced.

TriMet maintains accurate records on all buses in their fleet in order to track vehicle usage, fuel costs, maintenance costs and other information used to manage the fleet. After returning to revenue service, the fuel consumption for the bus for the first month of operation was compared to that recorded during the same period in 2004. While specific details on the routes, drivers, downtime, etc., are not known, the mini-hybrid bus demonstrated a 2.3% increase in fuel economy.

In a nonscientific comparison of other buses in the 2700 series fleet, fuel economy was found to be approximately 10.5% better than the average for the fleet during the time period of March 15 to Aug. 22, 2006. It is anticipated that the bus will exhibit an average of 5 to 7% fuel economy improvement on an annual basis.

The vehicle is being operated in its normal rotation in the TriMet fleet for the next six months, during which time its performance will continue to be monitored. As additional data is collected, the variability caused by driver, weather, route and other differences will diminish, allowing for more confidence in the comparison with other buses in the fleet.

EMP said this simple cooling retrofit system is now in pilot testing with four additional municipal transit organizations that are committed to pilot programs. Full production by EMP is expected in the fall, the company said. **dp**

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