Hybrid 320 Ton Off Highway Haul Truck: Quarterly Technical Status Report 1, DOE/AL68080-TSR01

This is the first quarterly status report for the Hybrid Off Highway Vehicle (OHV) project, DOE Award DE-FC04-2002AL68080. It presents the project status at the end of December 2002, and covers activities in the first project quarter, October-December 2002 as well as work done under advance authorization from DOE in the period June-September 2002.

Project Management Events

Key members of the Hybrid OHV project team - Dr Lembit Salasoo, GE Global Research, project leader; Mr Robert D. King, GE Global Research, principal investigator; Mr Alan R. Hamilton, GE Transportation Systems OHV Engineering Manager; Mr Henry T. Young, GE Transportation Systems OHV Lead Systems Engineer – attended the Project Kickoff meeting with DOE staff on December 18, 2002 at the DOE's Forrestal Building, Washington DC. A detailed overview of the Hybrid OHV project was presented, including a discussion of GE Transportation Systems OHV business viewpont.

Progress on Task 1: "Conduct Configuration and system studies to determine system requirements"

In July 2002, a joint GE Global Research (GEGR) – GE Transportation Systems (GETS) team visited the Komatsu Proving Ground, located in Green Valley, Arizona to familiarize the team with the proving ground and the 320-ton 930E mining haul truck Off Highway Vehicle (OHV). The proving ground, leased by project team partner Komatsu, is a former copper mine that is no longer active, with 2 pits which had haul roads spiraling to the bottom of each pit, as well as office space and workshops (see Fig. 1 aerial photo). At present, one operating mine road is maintained, which descends part-way into a mine pit. With excellent cooperation by the proving ground staff, the team was able to inspect the mine road by driving a 930E OHV over the route and electronically recording data on OHV performance (including speed, power, torque) on several runs in both uphill and downhill directions, loaded and unloaded. Since the proving ground is not an operating mine, it was possible for each of the visiting team members to drive the OHV with close supervision by the Komatsu operator. An OHV was inspected (Fig. 2) and candidate locations for installation of the hybrid system were identified. A potential total of approx. 560 cu. ft. was identified. An appropriate combination of these locations will be selected together with Komatsu in the detailed system integration design.

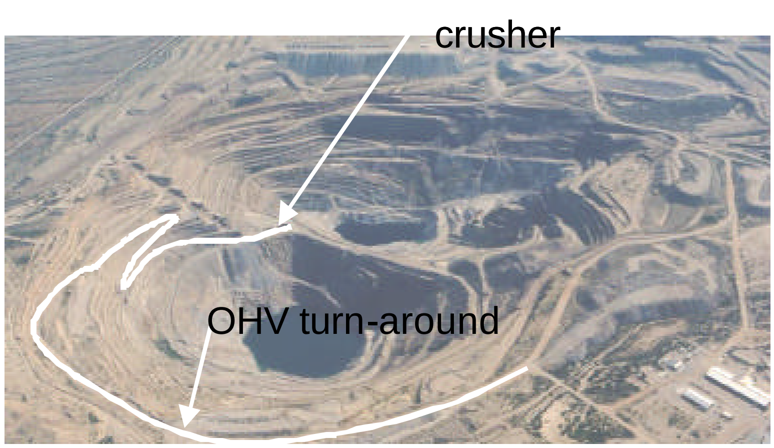

Fig. 1: aerial photo of OHV proving ground.

Fig. 2: GE team with 930E OHV mine haul truck.

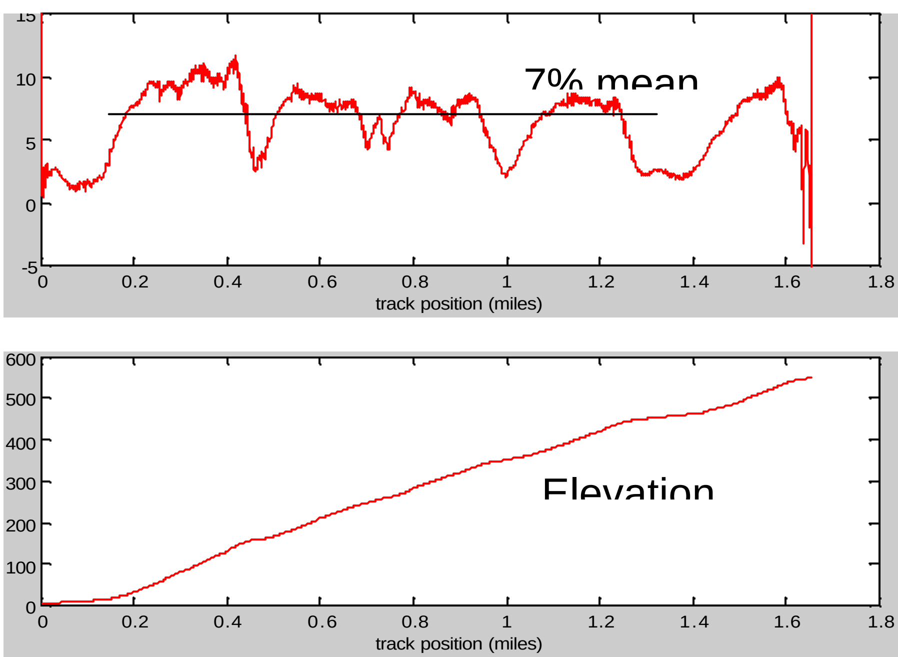

Fig. 3: Mine road grade and elevation profiles.

The datalogs and mine topographical data were analyzed to derive the mine road grade and elevation profiles (Fig. 3). The mission to be used for hybrid OHV demonstration was selected from the total mine road, to run 6500 ft between the lowest point, where a stone crushing plant is located, and a junction with another mine road which has a convenient stopping and turnaround location. The demonstration mission has approx. 7% average grade.

Existing mission analysis (MA) models were upgraded to analyze hybrid OHV performance. These models handle the OHV equations of motion, and power flow between diesel engine prime mover, auxiliary loads, traction system (both motoring and retarding) and the hybrid energy storage. Given the mission profile (grade vs. distance), OHV parameters (weight, subsystem efficiencies and capabilities), driving commands (such as speed limit vs. distance) and hybrid system parameters (energy storage capability and energy management strategy), the MA model simulates the dynamic performance of the vehicle (speed, position, power flows and accumulated energies vs time). The output is post-processed to yield parameters such as diesel prime mover input, mission time, and hybrid system stored energy. The MA model was validated against the datalogs obtained at the mine visit.

To guide sizing of the OHV hybrid system, a benefits assessment study for an uphill haul cycle (OHV uphill loaded and downhill unloaded runs) was done. The MA model was used to analyze the downhill (hybrid system charging from the retarding power) and uphill (hybrid system discharging to augment traction power) runs. The downhill speed limit was varied: faster speeds reduce total cycle time but lead to higher available retard power for shorter periods. The energy storage kW charge and discharge limit was varied. The hybrid OHV charges up energy storage on downhill run, and on uphill run combines diesel 2700GHP power with stored energy to get higher traction power, which speeds uphill run and lowers cycle time. For each combination of parameters, the MA analysis provides the total cycle time and kWh energy provided by the diesel prime mover.

For the mine operator, key performance parameters are productivity (ton-miles hauled per hour) and fuel efficiency (ton-miles hauled per gallon). In this benefits assessment study, prime mover energy efficiency (ton-miles hauled per kWh) is used as a proxy for fuel efficiency. The results of the study were analyzed to show variation of relative efficiency and productivity vs a baseline cycle with 24 mph average downhill speed and 17 min. cycle time. A plot of efficiency contours and productivity contours to be used as design curves was shown at the kickoff meeting. As an example, a hybrid system with 800kW charging and discharging power capability, that is operated over the Proving Ground mission with 18mph average downhill speed, will display baseline productivity and 15% energy efficiency.

A draft requirements specification document was written to capture the Hybrid OHV requirements.

Progress in Task 2: "Develop System Specifications"

A detailed survey of available energy storage technologies has been carried out, and their capabilities in terms of performance (energy and power densities), environmental capability, technical maturity, and battery management requirements have been evaluated. Candidate vendors have been identified. This information will be used, together with the Benefits Study carried out in task 1, to define the energy storage system ESS concept and to determine ESS technology mix and sizing.

Progress in Task 3: "Design and Fabricate Energy Storage Components"

The Nickel Cadmium energy storage battery system, that will be applied to the Hybrid OHV program as part of GE's cost share, was subject to a performance test, in order to establish its baseline performance. The performance test consisted of a controlled battery discharge, with diagnostic high-current pulses superimposed to probe battery internal resistance. Fig. 4 shows the recorded voltages for one battery box plotted against the discharged ampere-hours. The blue data points were used to fit the red and green discharge curves for two different current levels. The batteries performed according to manufacturer's specification, giving us confidence that they will perform in the Hybrid OHV demonstration.

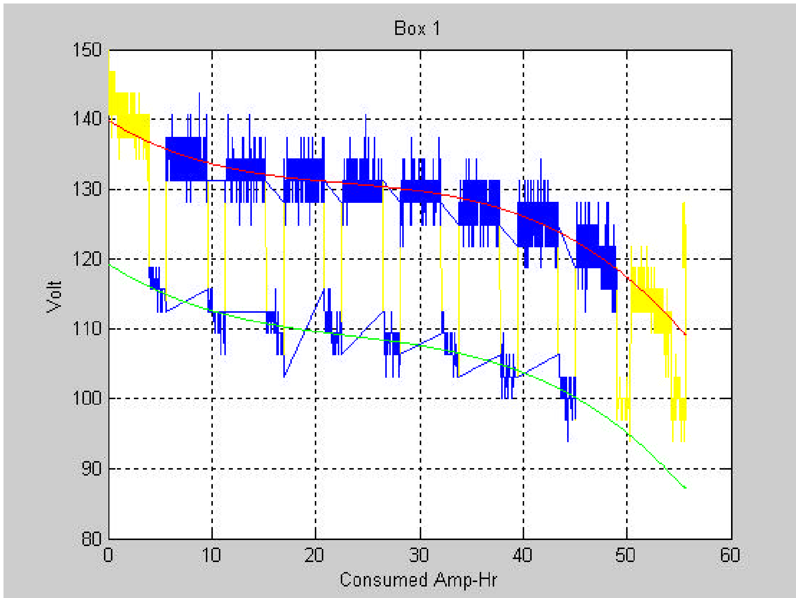

Fig. 4: Example nickel-cadmium battery box performance test results.

In summary, the hybrid OHV system study is well in hand, laying the groundwork for detailed design of the Energy Storage and Energy Management subsystems.