Environmental Restoration and Waste Management Program

TESTING OF THE WEST VALLEY VITRIFICATION FACILITY TRANSFER CART CONTROL SYSTEM*

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ABSTRACT

Oak Ridge National Laboratory (ORNL) has designed and tested the control system for the West Valley Demonstration Project Vitrification Facility transfer cart. The transfer cart will transfer canisters of vitrified high-level waste remotely within the Vitrification Facility. The control system operates the cart under battery power by wireless control. The equipment includes cart-mounted control electronics, battery charger, control pendants, engineer's console, and facility antennas. Testing was performed in several phases of development: (1) prototype equipment was built and tested during design, (2) board-level testing was then performed at ORNL during fabrication, and (3) system-level testing was then performed by ORNL at the fabrication subcontractor's facility for the completed cart system. These tests verified (1) the performance of the cart relative to design requirements and (2) operation of various built-in cart features. The final phase of testing is planned to be conducted during installation at the West Valley Vitrification Facility.

BACKGROUND AND INTRODUCTION

The West Valley Demonstration Project is sponsored by the U.S. Department of Energy (DOE) at the former Nuclear Fuel Services reprocessing plant site at West Valley, New York. West Valley Nuclear Services, Inc. (WVNS), is managing the project. The primary objective of the project is to solidify high-level waste stored in underground tanks into a form suitable for transportation and disposal.

DOE has selected vitrification as the method of solidification and borosilicate glass as the waste form. The vitrified waste is poured into stainless steel disposal canisters and cooled. The canisters are sealed, decontaminated, and transferred to the former Chemical Process Cell (CPC) within the facility for interim storage. The transfer cart will transfer the empty canisters into the Vitrification Cell (VC) and the filled canisters from the VC to interim storage in the CPC. Other future uses of the transfer cart have also been identified.

The design of the transfer cart control system was completed by ORNL in 1992 and has been reported previously.[1] After completion of the detailed design, WVNS contracted for the fabrication of the transfer cart and control system from competitive bids. ORNL worked with WVNS and the fabrication contractor, providing consultation during fabrication and participating in testing.

SYSTEM DESCRIPTION

The transfer cart control system provides battery power and wireless control for the cart to operate in a facility where existing rails, doors, or radiation levels do not permit conductors for power and controls. The control system drives the cart's four motors through independent motor drives, providing the capability to transfer 10 t of payload normally, and up to a maximum of 25 t on the cart. The control system hardware is comprised of two major parts: the facility system and the cart system (see Fig.1). Major equipment items of

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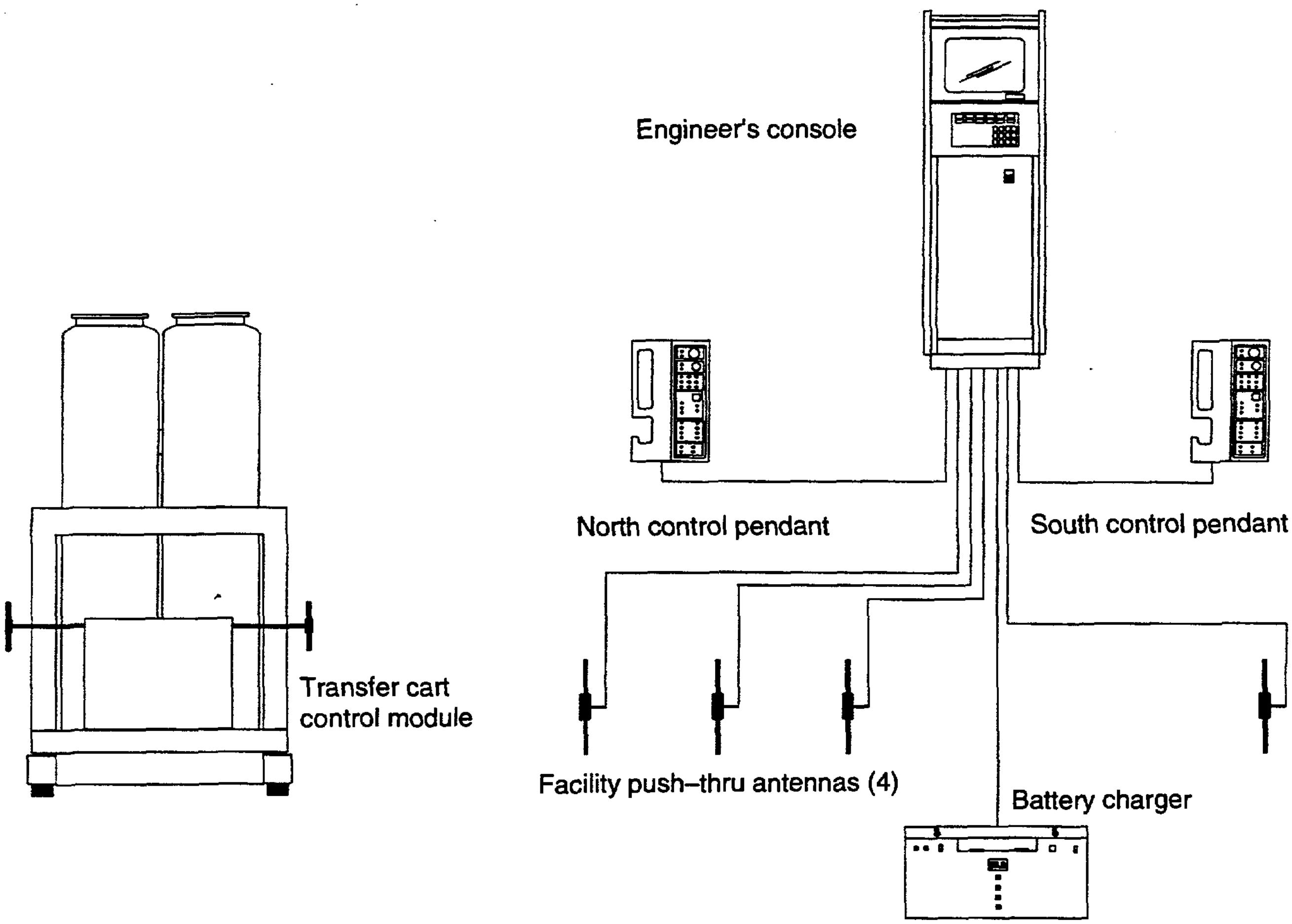

Fig. 1. Overview of transfer cart control system.

the facility system include the north and south control pendants, the engineer's console, and the battery charger. The major equipment item of the cart system is the cart control module. These items are briefly described in the following sections.

Control Pendants

The cart is operated by one of two hand-held control pendants (see Fig. 2). The functionality of both are the same. The control pendants consist of switches, light-emitting diodes (LEDs), and an audible alarm. The switches and LEDs are divided among functional blocks on the front face of the pendant and are used for operator command inputs and for visual status indication respectively. An oversized emergency stop button is provided for stopping the cart and battery charger from either pendant.

The cart control system operates in two basic modes: (1) battery charging and (2) cart operation. In the battery charging mode, the cart is disabled completely. In the cart operation mode, the battery cannot be charged unless it is located at the charging shoes.

Engineer's Console

The engineer's console houses the Programmable Logic Controller (PLC), the engineer's console computer, communications equipment, and ancillary equipment. The PLC is the heart of the control system through which all control activities are coordinated. It interfaces to both control pendants, the communications controller, and the engineer's console computer. The PLC also interfaces to the cart orientation switch, the facility doors, and the battery charger interface. Special ladder-logic software runs on the PLC.

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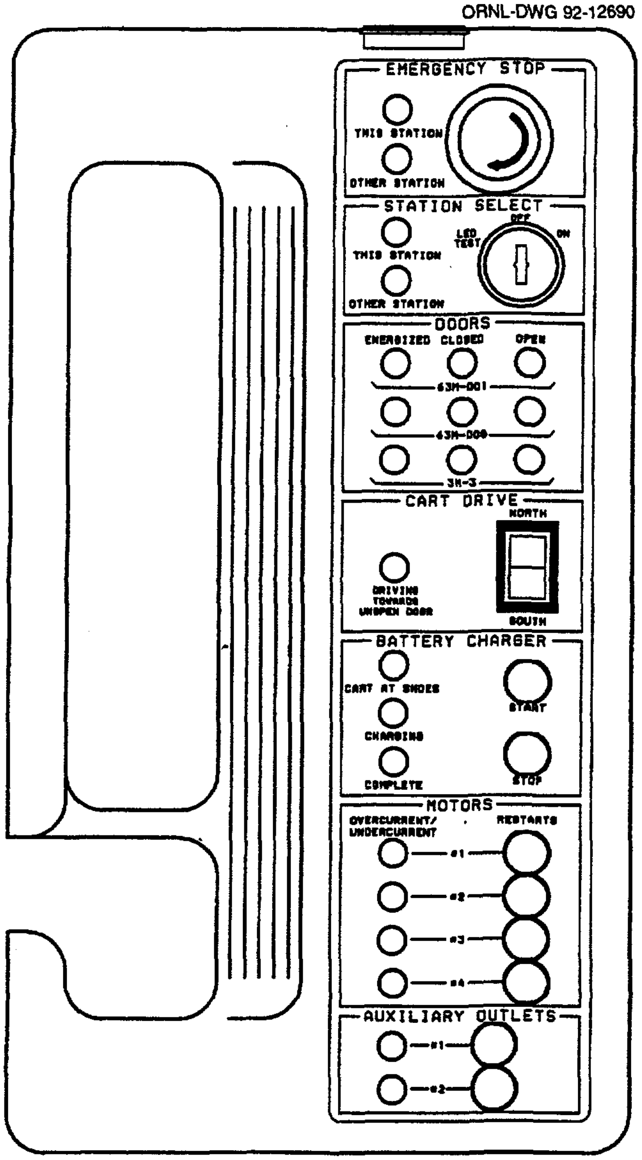

Fig. 2. Operator's control pendant.

The engineer's console computer is the engineer's "window" into the control system. Through the computer, an engineer can monitor cart activity and data and the operational status of the control pendants, doors, and battery charger. In addition, the computer can modify and download ladder logic in the PLC. The engineer's console computer can trend any of its inputs and provide alarm outputs based on the input value. It is also capable of performing mathematical and logical operations on the cart data.

Battery Charger

The battery charger features a microprocessor for interfacing to the control system. A custom polarity interface circuit is also located between the battery charger and the batteries. The primary purpose of this circuit is to reverse charging polarity when the cart has been reversed on the tracks. The battery charger is connected to the cart through a set of spring-loaded charge shoes. The charge shoes are located on the floor between the cart track rails and interface with charging plates mounted on the bottom of the cart control module enclosure.

Cart Control Module

The cart control module contains all of the on-cart controls and electrical equipment to perform all of the cart control functions within a single assembly. The control module is designed as a remotely replaceable module. All of the electrical connections between the control module and the transfer cart are contained in a single remote electrical connector which couples when the control module is installed.

The control module provides two separately sealed internal compartments. The upper space is for the batteries, and the lower space is for electronics, which require shielding from the radiation. The electronics consist of cart control electronics and communication system electronics. The cart control electronics are a combination of commercially available and custom electronics for the cart controller and its interfaces. The communications system provides a wireless, bidirectional, digital data link between the facility and the transfer cart and is designed to overcome multipath rf reflections caused by metal lining on the facility walls and floors. The system uses two cart antennas and wide-band frequency modulation, which allows a portion of the spectrum to be lost to multipath while retaining much of the signal energy.

On the bottom of the module two legs extend down for mounting the battery charging plates, and between the legs is the remote electrical connector. Two additional electrical connectors are located on the sides of the control module near the top to provide auxiliary power outlets. The two dipole antennas are mounted on the sides of the module near the top and extend past the edge of the cart for line-of-sight communications with the facility antennas.

Facility Antennas

The facility antennas are dipole antennas which fold to fit through existing cell penetrations. Stainless steel corrugated hose pushes the antenna through the cell penetration to deploy it in-cell. Once inserted into the cell the antenna unfolds vertically for signal transmission with the cart.

TESTING

Testing was performed in several stages over the design and fabrication phases. Design verification testing of prototype equipment was performed during detail design, board-level testing of completed components was performed at ORNL during fabrication, and system-level testing was performed at the fabricator's facility for the completed cart system. These activities are described in the following sections.

Prototype Testing

During the design phase of the project each major functional block of the facility and cart electronics system was prototyped as needed to verify the design. This allowed problems to be recognized early in the design phase and to be corrected prior to the fabrication of the system. Software for the cart control system was developed using a PLC, engineer's console, and a battery charger (procured during the design phase) in conjunction with the custom electronics hardware. End-to-end system tests were conducted on a limited basis using the prototype hardware prior to releasing the design for subcontract fabrication.

Board-Level Testing at ORNL

Prior to final assembly of the cart electronics system, each of the custom electronics assemblies was sent to ORNL by the fabrication subcontractor for testing. Printed circuit assemblies were tested to verify proper function and then integrated into as complete a cart control system as possible for bench testing. During this phase of testing, a number of minor design errors, some software bugs, and numerous errors in board fabrication were located and corrected. Testing culminated in the operation of a single motor using the rf control link. Operation of various interlocks, control and telemetry functions was verified in as realistic a manner as possible. The hardware was then returned to the fabrication subcontractor for final assembly.

System-Level Testing at Fabricator

The transfer cart was tested on-site at the fabricator's facility. Testing of three sets of cart system electronics, two cart control modules, and the full facility system was completed over a period of 1 week. The testing was carried out on a mock-up section of track (roughly 30 ft long) located in a high-bay building. The track section was long enough to allow operation of a single cart either by itself or with a trailer in tow. The trailer consisted of a complete cart frame less the motor drives and electronics control enclosure. The track was constructed of steel rails and included alignment anomalies in both the horizontal and vertical directions to verify cart capabilities with various loading conditions over rough track areas. A written test procedure was developed to guide system testing and to ensure that all cart features were tested and verified.

Initial Systems Tests

Initial system verification was followed by testing the cart and facility electronics. Work on the facility and cart electronics was conducted simultaneously. A number of minor problems encountered during this phase are discussed in the Results section.

The initial facility testing involved installing support software and some hardware on the engineer's console. In addition, the wiring of the PLC interconnections and the engineer's console was verified. After wiring checks were completed, the engineer's console was checked visually, and all of the system computer dip switch and jumper settings were verified prior to operational tests. Each of the facility subsystems were powered up one at a time. Voltage measurements and observation of status displays were used to verify that each system block was functioning.

Cart operation was verified in a staged fashion. After completing a visual inspection of the cart wiring, power was applied to the cart electronics enclosure from a current-limited power supply with all plug-in cards removed. Operation of all switch mode power regulators was verified without loading. Next, the cart STD bus computer and the cart interface module were installed. The cart design provides local control of the cart through a terminal attached to the STD bus computer. A lap-top computer running terminal emulation software was used during this phase of testing. Each cart subsystem was then brought on-line and its operation verified. The local testing of the cart culminated in actual operation on the test track using the local control mode with the cart wheels elevated off the track by wood blocks. The rotation direction of each motor/drive assembly was verified.

Operations Testing

After operation of the facility and cart electronics was verified, complete cart system testing began. Using local monitor routines at both the cart and facility STD bus computer systems, operation of the rf data system was verified. Once the facility/cart system was fully operational, complete system tests were conducted.

System tests were designed to verify proper operation of all facility and cart subsystems and capabilities. Two phases of testing were carried out. First, all facility and cart subsystems were tested. Second, the cart was operated under various load conditions on the test track.

Subsystems Testing

Once facility-to-cart rf communications were established, a number of subsystems tests were run. These tests involved both control and safety features built into the cart electronics. Motor control functions (driving, braking, and disabled) were tested along with verification of various motor control protection features. Data acquired by the cart for monitoring various cart functions were analyzed to ensure that all systems were operating as expected. Voltage and current measurements were recorded to establish "normal" readout values.

Capabilities Testing

Capabilities testing involved operating the cart under various load conditions with one, two, and three motors disabled and over several track hazards. The cart was operated both with and without loads. Loads were applied in 5-t increments, up to 25 t. The majority of tests were run for a 10-t load (the normal operating load for the cart). Load tests were run to verify cart capabilities, to check motor current draw for various load conditions, to look at cart tracking (wheel slippage or lockup), and to measure the cart stopping distance. Tests were also run with a 10-t cart load using only one motor drive and with the unloaded cart towing a trailer loaded with 25 t.

RESULTS

Facility System

Facility system testing progressed smoothly with only minor wiring errors in relay controls being located. The software used by ORNL was the same used during the design and development phase of the project. Manufacturer's changes in two of the hardware items, the engineer's console PLC interface card, and the battery charger were found incompatible with the facility system software.

For the PLC system, testing at the fabricator's facility was completed using the PLC interface card procured during the design phase. The PLC manufacturer's new interface card operation was later verified at ORNL using a new version of PLC control software on the engineer's console.

Testing of the battery charger revealed that the charger control scheme was changed by the manufacturer. In addition, the mode of charger operation was not functional. Consultation with the manufacturer confirmed a bug in the charger internal firmware. A set of corrected EPROMs for the charger was subsequently sent to ORNL, and the charger control software function was later verified at ORNL.

Cart System

Problems encountered in cart system testing involved mainly fabrication errors requiring minor circuit modifications. The motor overcurrent trip circuitry, designed to protect the motor drive circuits, was unnecessary since the motor locked-rotor currents never exceeded 8 A (the current trips were designed to operate at roughly 15 A). The current for a locked-rotor condition was limited by voltage drops in both the wiring and the motor drive transistors.

The motor undercurrent condition warning (designed to detect wheel slippage or motor failure) failed to operate since no load motor currents were nearly identical to the motor currents with a 5-t load.

Two of the three rf subsystems tested failed to properly switch antennas during cart testing. These two systems were prone to cart stalling due to loss of communication to the facility. This indicates that the diversity (two-antenna system) in the rf link is necessary for reliable cart operation. The failure in the antenna switching was later traced to direct rf coupling at the rf printed circuit board assemblies. A shield housing has been designed and tested for the cart rf receiver board and will be verified during final system installation at West Valley.

SystemOperation

The cart functioned as expected. Tables I and II list the cart motor currents and performance parameters measured during testing. Load tests revealed that for loads greater than 10 t, the cart must be operated on very level track with minimal alignment problems. Obstacles blocked cart motion for these larger loads, in general, due to wheel stalling. At a load of 25 t the cart could not clear a 1/10-in. vertical track misalignment due to stalling of the drive motors. Increasing the cart speed allowed clearance of the 1/10-in. vertical misalignment with up to a 5-t load.

The cart test track, made of 2- by 3-in. steel bar, was installed with 1/4-in.-thick plates located at approximately 3-ft intervals along the track for support. This wide spacing of supports allowed the track to become permanently bowed during operation of the cart with a 25-t load. This bowing affected cart operation for loads of greater than 10 t. The actual track, installed at West Valley, is well supported to prevent such bowing.

The unloaded cart was able to tow the utility trailer loaded with 25 t, but obstacles caused wheel slippage. Minor obstacles may be cleared by loading the driven cart for better traction, but this was not tested. Increasing the cart speed by roughly 100% helped clear track obstacles for the 10-t load.

Table I. Typical motor voltage, current, and power for various load conditions.

Condition	No load	5-t load	10-t load	15-t load	20-t load	25-t load	25 t on cart
Motor voltage (A)	2	2	2.6	2.6	3.8	4.1	4
Motor current (V)	7.1	7.1	6.1	8.6	6.1	5.7	5.5
Power per motor (W)	14.2	14.2	15.9	22.4	23.2	23.4	22.0

Table II. Typical cart performance characteristics.

Stopping distance (10-t load)	Less than 2.5 in.
Cart track speed (10-t load)	15 ft/min (0.25 in./s)
Cart power consumption at idle	48 W
Cart power consumption with 10-t load	111 W
Cart power consumption with 25-t load	141 W
Cart power consumption in stalled condition	244 W
Maximum test load using only one motor	10 t [motor operating conditions of 6 A, 5.5 V (33 W)]
Load needed to stall cart at track end stop	10 t

The effect of doubling the speed is a four-fold increase of inertia. Rather than increasing the cart operating speed, a higher inertia coupling, available from the gear box manufacturer, will be installed to improve the ability to clear track obstacles.

Cart traction was good with only the heavily loaded trailer causing wheel slippage at an obstacle. Operation of the cart in a stalled condition did not harm the control electronics.

CONCLUSION

The West Valley transfer cart tests were successful. The transfer cart carried rated loads without wheel slippage or stalling (on unobstructed track). Track obstructions caused wheel stalling for a loaded cart (5 t or greater) or wheel slippage for an unloaded cart towing a loaded trailer. No damage occurs to the cart in either the stalled or slipping obstructed condition. Testing indicates that it is important to minimize the number of track anomalies to improve the reliability of the cart for loads greater than 5 t. The rf system appeared to be robust with no noticeable stalls occurring due to loss of the rf link.

Final installation and testing for the cart system is planned for early 1995 at the West Valley facility.

REFERENCE

E. C. BRADLEY and F. R. RUPPEL, "Overview of the West Valley Vitrification Facility Transfer Cart Control System," *Proceedings of the Fifth Topical Meeting on Robotics and Remote Systems,* American Nuclear Society, Knoxville, TN (1993), pp. 561-568.