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# Magnetically Coupled Transport

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## Abstract

Throughout the DOE complex, materials are routinely transported within glovebox processing lines. Cylindrical product cans, crucibles, sample containers, tools, and waste products are all examples of items that are moved between equipment stations during glovebox operations. Traditional transport methods have included manual handling using tongs, chain and belt conveyors, carts with pull wires, and overhead hoists on monorails. These methods rely on hands-on operations and/or utilize high maintenance equipment located inside the gloveboxes, which can lead to high radiation exposure to personnel and can generate large amounts of radioactive waste. One innovative approach incorporates linear induction motors (LIMs) so that high maintenance items are located outside the gloveboxes, but LIMs produce heat, do not move smoothly over a wide range of velocities, and are not locked in position at zero velocity.

Savannah River Technology Center (SRTC) engineers have developed and demonstrated a concept for a magnetically coupled transport system to transfer material within process lines and from line to line. This automated system significantly reduces hands-on operations. Linear actuators and lead screws provide smooth horizontal and vertical movement. Rare earth magnetic coupling technology allows the majority of the equipment to be located outside the glovebox, simplifying maintenance and minimizing radioactive waste.

## 1. Introduction

Glovebox lines in many existing and currently planned DOE radionuclide handling facilities are typically arranged with processing lines on one floor level. The lines are generally of moderate length (<60 feet) (<18 meters), with multiple lines positioned parallel with each other and alternating maintenance and operating corridors between the lines. Interconnection of these parallel lines is usually done with a common overhead tunnel and vertical shafts through which materials are moved from line to line. Figure 1 illustrates a generic layout.

The goal of this work was to conceptualize and demonstrate a universally adaptable method for transporting materials within process lines and from line to line, while minimizing both hands-on operations and equipment inside the process containment. There are three independent subsystems used in this concept - a glovebox process line magnetically coupled cart, an elevator for vertical translation, and an inverted overhead magnetically coupled transfer carriage. Two of the subsystems were designed, fabricated, and assembled at

Savannah River Site (SRS) Building 305-A as part of a technology demonstration for radioactive material handling. A 22-foot (6.7 m) long horizontal cart tunnel and 8-foot (2.4 m) vertical elevator shaft provide a test bed for magnetically propelled cart and elevator testing. The tunnel and elevator shaft are both 36-inch (0.9 m) square cross sections, assembled with Plexiglas walls and roofs to enhance viewing of the equipment.



See Figure 2 for an overall view of the demonstration setup. The third system, the overhead transfer carriage, can be added to this existing setup.

The three subsystems operate independently, but must be compatible with each other so that payloads can be transferred between them. No grippers are used, which means that payloads must have a standard "footprint" to interface with lifting and carrying fixtures. Utilizing the orthogonal relationships between glovebox lines, elevator shafts, and overhead tunnels, a 24-inch (0.6 m) cubic box with lifting edges on all four sides was built as a standard payload. The box has two sets of edge lifts, an upper set for use by the overhead transfer carriage and a lower set for use by the elevator. The payload footprint could also be incorporated into a simple base plate for carrying cans, etc.

## 2. Magnetic Couplings

In an effort to minimize the equipment located within the process lines and tunnels, we used magnetic coupling as an alternative to direct coupled drive systems. Rare earth permanent magnets outside the containment wall couple to either magnets or magnetic iron on the inside, providing a "shaftless" drive with no wall penetrations. This technique is realistic since gloveboxes and transfer tunnels are constructed of nonmagnetic stainless steel plate. Since the external magnets must be rotated or translated linearly to produce motive force, permanent magnets were chosen over electromagnets to avoid cabling problems (i.e. no slip rings or cable festooning required). The magnets can be sized for various load requirements.



The glovebox cart system uses a linear array of magnets mounted on the magnet platen located underneath the glovebox floor (see Figure 3). The magnets couple to strips of magnetic iron on the underside of the cart inside the glovebox. Ten rows of magnets are arranged on the platen, and each 4½-inch (114 mm) long row contains nine half-inch (13 mm) cubes of grade 35 Neodymium-Iron-Boron magnets. The rows are spaced 1½ inches (38 mm) apart, center-to-center. Ten 6-inch (152 mm) by 1-inch (25 mm) by 1/16-inch (1.6 mm) thick magnetic iron strips are mounted on the cart underside to couple to each magnet row. Both the magnet platen and the iron platen maintain a constant 1/16-inch (1.6 mm) standoff from the glovebox floor. Standoff distance is maintained using wheels on the platens. With the 1/8-inch (3.2 mm) thick stainless steel floor, the total magnet to iron gap is ¼ inch (6.4 mm). This configuration yields 3.2-lbs. (14 N) thrust per magnet strip for a total of 32 pounds (142 N) horizontal force for the ten strip setup. The magnet platen is also spring loaded to ensure contact with floor underside even when no cart is present. This compliant technique eliminates any floor flatness requirements over long runs. The magnet platen under the floor is transported the length of the glovebox line using a commercial linear actuator driven by a stepping motor.

The elevator system uses a rotary magnetic coupling to allow the stepping motor/gearbox to be located outside the elevator shaft. A self-locking lead screw inside the elevator shaft drives the elevator lifting tines vertically the length of the shaft. The rotary coupling is a pair of 4-inch (102 mm) diameter stainless steel discs; each disc contains sets of alternating pole rare earth magnets arranged radially around the outer perimeter with magnetic poles oriented toward the coupling faces. Magnetic shielding is also included on one face of each coupling so that the magnetic field is minimized near the coupling edges and back face but maximized on the front face. This provides good magnetic coupling when used in "face to face" arrangement, but presents no problems when used around ferrous metals such as motor cases and gearbox housings. The coupling is capable of transmitting 2.6 ft-

lbs. (3.5 N·m) torque with ¼-inch (6.4 mm) face to face gap. Figure 4 shows the coupling from inside the elevator shaft.



Both the cart magnet platen and the elevator rotary coupling can be cogged if the load or torque limitation is exceeded. During motion a slight angular lag between the two mating couplings is normal for both the cart and elevator. This lag disappears when motion is halted, and is inconsequential since only final positioning is of importance.

### 3. Distributed Control

Both the cart and elevator mechanical drives are driven by DC stepper motors operated in an open loop fashion using commercial indexer/drives. Each independent drive allows concurrent cart and elevator moves. All stop points are programmable, with all positions being referenced from a known "home" position. Position or velocity control may be used with these controllers, but for this application standard trapezoidal velocity move profiles were employed using position control. Each of the motor controllers is interfaced via "daisy chained" RS232 communication link to a desktop computer and coordinated motion of the two subsystems is controlled using LabVIEW software. The LabVIEW application-specific user interface gives the operator the ability to perform the following functions:

- "Home" each system (search for zero position sensor)
- Execute preprogrammed moves actuated via soft buttons
- Download and retrieve sequences resident within each motor controller
- Manually move each system and change velocities for each system
- Graphically show cart and elevator positions on manual move screen
- Emergency stop all movements



This control architecture gives the ability to expand the control system to include the overhead tunnel subsystem without substantial redesign since an additional motor controller can be added to the communication chain and the LabVIEW application can be changed to accommodate this additional controller. For a specific application with multiple glovebox lines and elevators interconnected via an overhead tunnel, "traffic controller" application software must be written to coordinate motion between all the system resources (carts, elevators, etc.) based on operator material movement requests.

### 4. Drive System

The cart magnet platen is mechanically driven using a commercial linear actuator that runs the length of the horizontal tunnel. This actuator is a timing belt/sprocket assembly coupled to an inline 5:1 planetary gear reducer and stepping motor. External positioning using a stepper motor drive gives the ability to control cart (or elevator) velocity and position without using additional sensors at each stop point. The sprocket and gear head reduction coupled with the indexer motor resolution (i.e. indexer step counts per motor revolution) yields an electronic resolution of 21,980 step counts per inch (25 mm) of cart movement. Mechanical resolution is of course much less than this. The positional repeatability of the cart has been measured to be better than 0.10 inches (2.5 mm).

The elevator is a forklift type design with the identical stepper motor coupled directly to a 3:1 right angle planetary gear reducer. The gear reducer is coupled through the two piece rotary magnetic coupling to a self-locking 1-inch (25 mm) diameter 72-inch (1.83 m) long lead screw that has a ¼-inch (6.4 mm) lead. The effective vertical travel of the elevator is 66 inches (1.68 m). The electronic resolution of the elevator system is 300,000 step counts per inch (25 mm) of vertical travel.

## 5. Sensors

External sensors are used for each system to limit end-of-travel and to define the "home" position for each system. For the cart magnet drive, inductive proximity sensors are used. The two end-of-travel proximity sensors sense a metal actuator disc installed on the plastic timing belt. The home proximity sensor senses a metal actuator disc mounted on the magnet platen. All sensors and actuators are outside the tunnel below the floor with all other drive components.



The elevator uses Hall effect switches flush mounted on the outside of the elevator shaft for the end-of-travel and home sensing. All three sensors are mounted such that one single magnet can actuate all three sensors. This 1/2-inch (13 mm) diameter by 1/2-inch (13 mm) long rare earth magnet is mounted on the moving elevator lifting tine assembly. The magnet is housed in a compliant mount so that it tracks the elevator shaft wall with a fixed standoff distance of 1/32 inch (0.8 mm) (see Figure 5). Total gap from magnet to switch is approximately 5/32 inch (4 mm), but tests have shown that this gap could be as much as 3/8 inch (9.5 mm) and still reliably actuate the Hall effect switches.

## 6. Cart and Parts Basket

The cart is a rectangular plate with four v-wheels that run atop parallel angle steel tracks on the glovebox tunnel floor. A payload frame is bolted to the top of the cart. This frame is sized to contain the payload (in this case a rectangular parts basket) during transit. The floating iron platen under the cart rides on top of the floor with a fixed standoff distance maintained by rolling wheels. The iron strips are on the bottom of this platen, as shown in Figure 6. The v-wheels are engaged with angle steel track sections that are bolted to the tunnel floor. In an installed application, it would be preferable to have v-wheels on one side of the cart with flat wheels on the other side, so that no track-to-track alignment is necessary.



The parts basket is a 24-inch (0.6 m) cube Plexiglas box with 1-inch (25 mm) angle steel lifting edges on all four sides. There are two sets of lifting edges - an upper set for use by the overhead tunnel subsystem and a lower set for use by the elevator lifting tines. The parts basket weighs 72.5 lbs. (33 kg) and is intended for demonstration purposes only.

## 7. Elevator

The elevator lifting unit consists of a pair of parallel angle steel lifting tines (see Figure 7) that engage the payload lower set of lift edges. Each lift tine has two tapered dowels that engage holes on the parts box lift edges. This provides for positive payload location without using an actuated gripper. The lift tines are mechanically connected to a backplate that also has the lead screw supernut mounted on it. The backplate is guided by v-wheels and matching track on one side of the elevator and by flat rollers on the other side. Four v-wheels (two upper and two lower) are arranged so that the track is captured between wheels. An identical arrangement is done for the flat rollers.



## 8. Conclusion

The methodology developed for this task has proven to be a versatile and accurate method of moving materials within a glovebox line. Most of the complex components have been removed from within the containment for both the elevator and horizontal tunnel systems. The simple orthogonal payload handoff scheme using no actuators is reliable and easy to implement. A wide range of velocities with smooth motion is achieved using stepper motors and moving permanent magnets.

This application had reasonable payloads (approximately 125 pounds) (57 kg) so that permanent magnets were feasible. If higher payloads are anticipated, electromagnets may be considered. The moving magnet concept may not be feasible for long lengths, such as the not-yet-designed overhead tunnel subsystem, since translational mechanisms of this length (200 feet) (61 m) are impractical using commercial linear actuators. Linear synchronous motors (LSMs), now commercially available, have high potential as another alternative. LSM technology is adaptable to long travel lengths, and can be easily integrated with the cart/elevator/overhead system handoff technique. Some commercial LSMs also provide continuous position feedback, which is necessary for good closed loop servo control. LSMs coupled with AC vector drives could provide good control over a reasonable speed and payload range. However, SRTC has not tested any of these systems. Future work may include setting up a small LSM test bed in order to determine system capabilities (controllability, robustness, etc.).

Techniques for loading and unloading payloads from the transfer cart need to be developed and demonstrated. A concept such as a slide table can be used to laterally move the payload into a working glovebox that is arranged at right angles to the cart tunnel. Also, a method for moving the cart through an airlock needs to be developed and demonstrated. Negotiating through an airlock presents a unique technical challenge since the track and possibly the propulsion system (LSM or moving magnet) will have to be discontinuous.

The Plutonium Immobilization Program at SRS has utilized a similar cart/elevator/overhead payload handoff technique in preliminary facility layouts. This facility may require variations of the basic layout such as intersecting overhead transfer tunnels. Additional work needs to be done to ensure that these types of transfers are feasible.

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## **References**

G. Dyches, K. Peterson, S. Breshears, J. Wong, "Magnetically Coupled Transport System," WSRC-TR-98-00328, September 21, 1998.