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A Novel Transport-Vehicle Design for Moving Optic Modules in the National Ignition Facility

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A NOVEL TRANSPORT-VEHICLE DESIGN FOR MOVING OPTIC MODULES IN THE NATIONAL IGNITION FACILITY

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ABSTRACT

The National Ignition Facility, currently under design and construction at Lawrence Livermore National Laboratory, will be the world's largest laser when complete. The NIF will use about 8,000 large optics of 26 different types to focus up to 192 laser beams on a dime-size target. Given the constraints of the NIF operating environment, the tasks associated with optics transport and handling require a novel, versatile transport system. The system will consist of a computer system containing guidance, traffic management and order entry functions, and four or more automated laser-guided vehicles. This transport system will transport optics enclosures that are essentially portable clean rooms and will lift, align, and position them as needed to contact and engage mating points on the laser support structure.

KEYWORDS

automated guided vehicle; line-replaceable unit; transport and handling system; laser guided vehicle

1.0 Introduction

The National Ignition Facility (NIF), currently under design and construction at Lawrence Livermore National Laboratory (LLNL), will be the world's largest laser when complete. The NIF will use about 8,000 large optics of 26 different types to focus up to 192 laser beams on a dime-size target. Among the many coordinated NIF project efforts is the design of a transport system that can initially install and later exchange optic modules, known as line-replaceable units (LRUs). Given the constraints of the NIF operating environment, which is essentially a stadium-sized class 100 clean room full of specialized optics and components squeezed into many layers of a minimally accessible steel framework, the tasks associated with LRU interchange require a novel, versatile transport system.

The NIF Laser Bay Transport System (LBTS) is the key transport and delivery system for moving LRUs between their installed locations in the laser structure and their initial point of assembly and alignment. The LBTS will contain the LRUs either inside a temporary enclosure, which acts as a portable clean room, or mounted on a temporary skid. The LBTS will consist of a computer system containing guidance, traffic management and order entry functions and four or more automated guided vehicles (AGVs). This system will transport the LRU enclosures from the NIF Optics Assembly Building (OAB) and lift, align, and position them, as needed, to contact and engage mating points on the laser support structure in the adjacent Laser and Target Area Building (LTAB) The LBTS will be designed to handle LRU placement and removal from three orientations in the laser structures: from underneath the laser structure is called bottom loading (BL), from beside the laser structure is side loading (SL), and lifted up, over, and then into the structure is top loading (TL).

2.0 Design Constraints and Requirements

The design of this versatile AGV is driven by dimensional constraints. The LBTS vehicle must travel through confined areas and be able to position itself in very tight places. The maximum vehicle footprint (1.8 by 3.6 m) and the total weight (133.5 kN) are constrained by the size of the elevator that the transporter must ride to and from the OAB basement. The vehicle configuration (forklift) is determined by the need to move LRUs into positions next to walls and in corners.

The AGV will need to travel from the LRU source in the OAB to 528 BL, 48 SL, and 4 TL LRU insertion stations in the LTAB. Fine positioning is an essential part of delivery. BL clearance is as tight as 25 mm, top and bottom, yet another operation requires a 2.5-m lift. The LBTS vehicle is designed to maneuver efficiently and with complete repeatability in confined areas within a small window of clearance.

The overall system requires that the LBTS must maintain close communication with NIF operations (LRU dispatch, monitoring position/load status, etc.). In addition, the NIF project funding requires long-term cost-effectiveness through manpower savings, indicating heavy reliance on automation.

3.0 The LBTS Transporter Vehicle Design

RedZone Robotics, Inc. and AGV Products, Inc. have teamed with Lawrence Livermore National Laboratory to design and build this versatile transport system for the NIF Project. Instead of building a system requiring high stiffness and mechanical accuracy, this design incorporates both gross and fine positioning capabilities. This design removes the strict operational constraints inherent in an ultrastiff, low-tolerance alternative. This design has the following key components: transporter and load lift mechanism (gross positioning), load platform and fine positioning system, control and communications system, power system and batteries, and traffic management and laser-assisted guidance system.

3.1 The AGV Mechanical Design

The many design constraints require the load to be cantilevered from one side of the vehicle. Because the vehicle must fit in the elevator, counterweighting cannot be placed at great moment arm lengths from the load. Therefore, the counterweighting must be heavy, resulting in a heavy vehicle. Because the counterweighting should be as low as possible, this puts space constraints on other components that must be placed low, such as the wheel modules and the leveling jacks. Requirements to restrict the tip-over likelihood during a seismic event also have a major impact on the design. The resulting design is a product of the dimensional restrictions placed on the vehicle (see Figure 1).

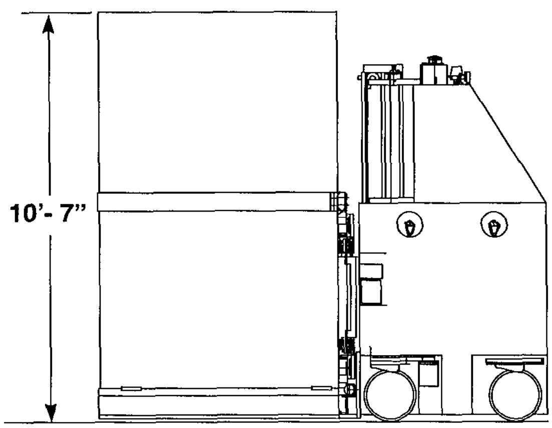

Figure 1. The AGV design satisfies footprint, load-handling, and maneuverability requirements.

This compact vehicle handles required loads at full lift height while satisfying all maneuverability requirements. (One AGV design accommodates all three required loading types—bottom, side, and top). Stabilizer arms are removed to carry the TL canister and SL skid. For BL and SL operations, the LRU canister or skid engages with the laser support structure during the docking operation. The AGV will be able to handle an 8,000-lb. load and accommodate all physical dimension limits imposed by the three types of loading. It will be capable of executing required navigation and positioning tasks autonomously while providing for operator intervention for critical tasks or emergency situations. The transporter is battery powered, with the batteries on a slide-out rack to simplify replacement and servicing. The system automatically returns to a station to recharge during idle periods, and a standby backup battery ensures continued operation.

Four-wheel steering enables sideward travel, allowing easier access to BL docking ports (see Figure 2). Two drive/ steer wheel modules power the AGV; two non-driven wheels rotate between 0° or 90°, fixed directions. The AGV can turn about its midpoint and travel sideways, allowing for a raster access pattern to the BL docking ports. Rotation about the midpoint ensures maximum accessibility to parking. Sideways travel (1) minimizes the number of maneuvers needed to park in corners, (2) minimizes disconnections of critical NIF components attached to the steel support framework, and (3) simplifies the guide path coding and layout.

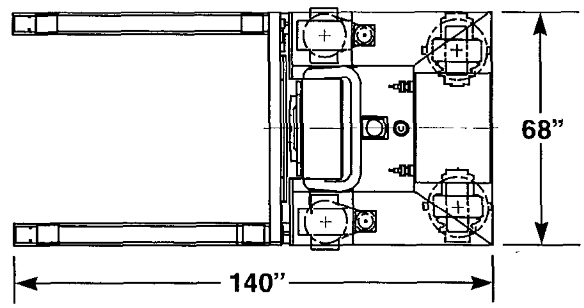

Figure 2 The AGV's four-wheel steering two drive/steer wheels and two nondriven, rotating wheels

The AGV design incorporates four successively finer position and alignment control mechanisms:

1. Guided vehicle feature places vehicle at parking locations within 12 mm and 0.5° about vertical axis.
2. Leveling jacks with active feedback from a level sensor on the load platform align canisters in tip/tilt to 1.3 mr.
3. An actively driven load platform in conjunction with a vision feedback system positions the load at docking height to within 6 mm of final position and 1.3 mr in orientation.
4. A passive capture mechanism guides the BL canister onto the kinematic locators in the laser support structure, and the final position is achieved with less than 0.26-mm error in all axes.

Moreover, the proposed system provides the ability to adapt to wear and deviations in the facility without modification or system refurbishment

Each transporter is equipped with appropriate safety features, and is designed according to relevant safety standards [1] as well as the more stringent European standards. The design also takes into account the clean environments of the LTAB. All components of the system are sealed or covered to prevent contamination. All actuators are sealed electric motors. The ball screws used for the leveling and the load lift carriage will require lubrication, but they are adequately covered to prevent leakage. The polyurethane tires on the transporter will not mark or leave any deposits on the laser bay floor.

3.2 The AGV Communication and Controls System Design

The controls systems are proven technologies and have been used in previous AGV systems. The control system provides a closed-loop control to enable accurate and precise speed control at all speeds. Interactions with emergency stops, bumpers, and other sensors provide for safe and quick stops of the system. A key element of control is AGV Products' standard Traffic Routing AGV Command Executive (TRACE) system. The TRACE computer and the vehicle will communicate through access to LLNL's wireless Local Area Network (LAN).

3.3 The LBTS Guidance System

The AGVs to be supplied for the LBTS incorporate a Laser-Assisted Guidance System (LAGS) for navigating through the facility. The LAGS incorporates a scanning laser and sensing unit mounted on the vehicle, a set of retro-reflective targets placed throughout the facility, a drive wheel encoder, a vehicle-mounted rate gyro, and a steering angle encoder, with all sensor inputs processed through a Kalman filter and tied together via a software-based reference system. The laser/sensing unit consists of a rotary scanning, 6-kHz, pulsed GaAs laser controlled by an Intel 586/133 processor. The maximum range of the laser/sensor is 30 m when using 11-cm-diameter retro-reflective targets. When operating within range of four or more targets, the system will provide positioning repeatability of 13 mm and angular accuracy of 0.12°. The laser/sensor unit measures both the range and angle from reflective targets mapped into the on-board memory, enabling the unit to identify unique locations while navigating.

The system incorporates a rolling-frames method of navigation, where the area in close proximity is framed to determine position. As the vehicle moves, it may enter an adjacent frame where it examines new reflective target data to determine how to navigate. The various operating modes are as follows:

- Mapping Mode. This mode of operation provides a method of mapping all of the target positions throughout the layout in relation to a known reference position.
- Navigation Mode. This is the normal mode of operation where the unit is reporting real-time status of the location of the vehicle.
- Stand-By Mode. This is merely an idle power-saving mode to be used when not in operation.

4.0 Status of Design

The LBTS conceptual design was completed in January, 1998, and detail design is to be completed in May, 1998. Delivery of the prototype AGV is expected in September of this year. Seismic moments analysis for turnover and slide of the AGV have been completed, as has a seismic response simulation [2]. Prototyping of the vision system is being planned for Fall of 1998. Extensive prototyping will be completed using the versatile AGV with each of the transport delivery systems over the next year, and final facility installation is projected for Spring of 2000.

5.0 Conclusion

The demands of required NIF performance and long-term operations are exacting and demanding at best, making the overall engineering and design a monumental task. One of the many complex designs is this transporter system that will initially install and later exchange the thousands of optic LRUs. We and our industrial partners have developed a novel, versatile, automated transport system to perform the wide array of these required tasks accurately and reliably. The vehicle (LBTS or transporter) will be able to handle a 3,630-kg (8,000-lb.) load and will accommodate all of the physical dimension limits. It will be capable of executing routine navigation and positioning tasks autonomously while providing for operator intervention for critical tasks or in emergency situations. This system will also be adapted to shifting requirements as the NIF performance and operation demands change over time.

6.0 Acknowledgments

There are always many individuals to be acknowledged in such a massive undertaking as the design of this complex vehicle. Those individuals include Mike McDaniel, Janice Girven, Ray Iaea, Donn McMahon, Arlen Rowe, Jo Sander, Fred Sass, Bill Spruit, and Steve Yakuma. Our corporate partners, RedZone Robotics, Inc. and AGV Products, Inc. are also key in delivering a quality product on an aggressive schedule. Their teams are greatly appreciated.

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NOTES AND REFERENCES

1. ANSI B56.5 and B56.1.
2. A. Tabiei, D. Tiszauer, "Dynamic Response of NIF Bottom Loading System During a Seismic Event" to be published in Proceedings of the 1998 ASME/JSME Joint Pressure Vessels and Piping Conference, San Diego, CA, July 26-30, 1998

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