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Conceptual Study on Flexible Guidance, Navigation and Docking Systems for ITER RH Transport Casks

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1 Introduction

This report presents a conceptual study on flexible guidance and navigation solutions for the remote transport system to be used in the International Thermonuclear Experimental Reactor (ITER). The transport vehicles under study will operate between the Vacuum-Vessel (VV) and the Hot-Cell Building (HCB), and must be capable of safely moving 20–80 tons of radioactive materials. Details about the buildings and transport operations were taken from documents [IGDR, TCS, DDC, DDD 6.2, DDD].

Most of the study concerns *flexible* guidance and navigation systems, as opposed to "hard guidance" solutions — such as rails. In general, flexible guided solutions have the advantages over hard guide solutions of simpler path modification and "arbitrary" path quitting and resuming points (e.g., when an abnormal situation occurs over a path segment). Therefore, flexible guided vehicles have the potential to show higher robustness — even though their reliability tends to decrease — due to a larger range of rescue options. The study analyses the advantages, disadvantages and requirements of flexible guidance, navigation and docking solutions, when applied to this particular problem.

We define a 100% *reliable* system as one that does not fail or have errors. A *robust* system is able to recover from failures or errors which occur during task execution. Due to the strict safety requirements, the ITER RH transport vehicles must definitely show high reliability, but robustness is a stronger requirement, i.e., a less reliable solution may be chosen, should it achieve a higher degree of robustness.

The topics used in the evaluation of the flexible concepts studied in this document are traction and kinematic structure, logistics, communications, docking, guidance and navigation strategies, and power supply requisites. Major issues are safety during movement, avoidance of active sensors in the building, reliability, robustness, automatic error recovery and teleoperated rescue capabilities.

An effort was made to support most conclusions with results of a wide search on available industrial solutions.

1.1 Objectives

A major task that the transport system is required to undertake is the secure transfer of active in-vessel components (e.g., divertor modules and blanket modules) between the VV and the HCB. Other tasks imply the transportation of tools and maintenance materials. The path to be followed includes line segments and curves of different radius, and requires interfacing with the VV docking ports, a lift, and the HCB docking ports.

In order to prevent irradiation, the transfer containers are sealed but not shielded. This option makes the cask lighter but prevents human access during transfer operations. Maximum transfer cask dimensions are 8m × 3.5m × 4m. Loaded casks may weight from 20 to 80 tons. Inside the sealed transfer containers are the component handling systems responsible for the operations of loading and unloading components. Containers should be decoupled from the transportation casks.

Safety during motion is a major issue to the vehicles. In case of failure, the vehicle must stop immediately in order to avoid damages to the vehicle itself, to the other vehicles, to the container and components inside it and to the buildings. During normal operation, neither humans nor unexpected objects will be around. However, to anticipate possible failures of the navigation system, obstacle detection sensors and procedures must be implemented to increase reliability. Robustness to any kind of failures requires the existence of rescue solutions. Even though partial autonomous control is not excluded, the transfer casks are mainly teleoperated. The operator must be able to intervene at any time and at different resolution levels when required. He/she should have an available set of rescue options.

1.2 Flexible Guidance and Navigation Solutions

This report focuses on flexible guidance and navigation concepts, i.e., systems that do not rely on rails or other "hard guidance" solutions. A list of advantages and disadvantages of flexible guidance systems as compared to "hard guidance" systems follows.

Advantages

- Possibility to leave the path if necessary and if enough space is available;
- No major structural floor modifications are required to modify the path;
- No rails occupying the floor:
- No derail problems. This means that rescue operations are simpler (increased robustness);
- Higher manoeuvrability: vehicles may turn in limited space without turntables.

Disadvantages

- More complex control strategies for navigation and docking;
- Lower reliability: the vehicle may lose its path more easily;
- Accurate sensors and signal processing techniques are necessary to measure the localization of the vehicle;
- More complex safety procedures.

Two different types of transport solutions based on flexible guidance and navigation concepts are studied in this report:

- Automatic Guided Vehicles (AGVs): under this solution, vehicles follow a physical path marked on the floor;
- Mobile Robots: under this solution, vehicles have the capability to use all the free space to move, following a virtual path, defined by the control software or by the operator;

A comparison between these two concepts is made below.

AGVs

Advantages

- Simpler control: only position control along a track is required;
- Higher safety: if the vehicle does not leave the track, there is no risk of collision with the walls;
- Higher reliability: localization errors do not affect trajectories;
- Simpler docking procedure: if the vehicle is accurately on the track, position along the track is the only variable to control.

Disadvantages

- Lower flexibility: if there is an obstacle on the path, the vehicle cannot overcome it unless another track, if available, is chosen;
- Lower automatic error recovery capabilities (lower robustness): once the vehicle runs out of the track, it can no longer sense it so it cannot recover its way by itself and must stop.

Mobile Robots

Advantages

- Higher flexibility: the vehicle is not linked to any track, so it is capable of moving in any free space. Therefore, obstacles can be avoided if there is enough space;
- Higher robustness: rescue operations are simpler, due to an increased number of options.

Disadvantages

- More complex control: three variables (position and orientation) must be controlled.
- Accurate navigation sensors are needed to measure the position and orientation of the vehicle in order to generate collision free trajectories.
- Lower reliability: navigation errors strongly affect the trajectory execution process.

When referring to AGVs and Mobile Robots, we are not referring to different types of *vehicles* or casks, but rather to different types of guidance and navigation *concepts*, even though we may sometimes use the word *vehicle* or *cask* along the text to compare the two types of solution. Actually, a third concept — Mixed Vehicles — will be often used along the text, referring to vehicles with the capability to switch between AGV-like and Mobile Robot-like guidance and navigation strategies.

Mixed Vehicles should be capable of normally following a physical path, and of momentarily leaving that path, switching to a virtual path following mode (e.g., to overcome moving or stopped vehicles, to avoid any other obstacle on the path). Mixed Vehicles are also capable of normally following a virtual path, until they reach some point where they should switch to physical path following mode (e.g., near a docking station, to simplify docking procedures).

Mixed vehicles pick the advantages of AGVs and Mobile Robots regarding reliability, robustness and docking procedures, with increased flexibility. Nevertheless, the complexity of the guidance and navigation systems increases, due to the need to coordinate a larger number of sensors and to switch between modes.

1.3 Organization

Vehicles may have different structures regarding traction and steering. Different structures mean different types of movements, different mechanical strategies and different spanned areas when turning. Three kinematic structures and traction solutions are discussed in Section 2. A computer simulation is presented to help the visualization of the areas spanned by the different types of vehicle kinematic configurations when turning.

In Section 3, the major guidance and navigation solutions suitable to this application are introduced and compared.

The scheduling of cask transfer between the Tokamak and the HC buildings, under flexible guidance concepts, is studied in Section 4. Its propose is to enhance the potential advantages of flexible guidance systems through the results of simulations, which present several different scenarios regarding number of casks moving simultaneously, bidirectional *vs* unidirectional motion in the gallery, and possibility of cask crossovers. The results extend the study on logistics presented in [RRHLS].

Communications with the vehicle(s) are a crucial part of the guidance and navigation systems namely, due to the teleoperation requirements. Different communication systems suited for this application are described in Section 5.

Active docking operations, especially the determination of the position and orientation (localization) errors between the cask and the VV docking port (located in different buildings) by a triangulation-based system, are studied in Section 6. The localization errors are quantified based on the resolution of a typical commercial rotating laser system associated to three retroreflectors.

The transport system is composed of several vehicles operating in parallel. The control of a fleet of automatic vehicles may be either centralized or distributed. In this particular problem, centralized control is advisable since human intervention should be possible for all operations. This way it will be possible to have a global view of the situation. Nevertheless, local computations are required on-board the vehicles, both for safety reasons and to simplify the operator's job. This problem is tackled in Section 7.

(Partially) autonomous vehicles rely strongly on the type of power supply used. Autonomous (e.g., batteries) and umbilical solutions are compared in Section 8.

Robustness of the studied system requires automatic error recovery and teleoperated rescue capabilities. Some guidelines for the consequences of different types of failures and the corresponding rescue operations are given in Section 9.

Conclusions regarding the different options presented on the text are drawn in Section 10. Finally, the document ends with an Appendix with a list of identified industrial solutions related to the topics used to evaluate the flexible guidance, navigation and docking concepts discussed on the text.

2 The Platform – Traction and Kinematics

There are several reasons why traction and kinematics of transport vehicles should be studied. Along the path from the VV to the HCB there are circular arcs of different radius (e.g., around the galleries, connecting docking ports with main path). Docking operations may require vehicle manoeuvres, should hard guidance solutions be discarded. As the containers only have a service door, the vehicles must be able to reverse direction in order to always head to the docking ports with the containers door on the front side. Enough space to do the reversal turn is required somewhere in the way to the Hot Cell Building. If this space cannot be provided, a turntable must be used. Vehicles must also be able to move forward and backwards.

In this section, different kinematic structures, combined with different traction and steering options, are studied. AGVs, Mobile Robots and Mixed vehicles may have anyone of these structures. The spanned areas when turning, minimum turning radius and need for manoeuvres are analyzed.

2.1 Kinematic Structure

The kinematic structure of the platform is a very important issue. Trajectory topology and docking procedures strongly depend on it. The structures analyzed applies to AGVs, mobile robots and to mixed type vehicles. The kinematics of the platform depends on the type of traction and steering used. Three different structures are analyzed here: cart like vehicles (similar to tricycle), rombic configuration with differential steering and rombic configuration with one drive and steering wheel plus a steering wheel.

Cart

Cart like vehicles are similar to cars regarding its traction and steering systems (Figure 1). To carry heavy loads, more wheels are needed (as in trucks) bringing problems to the steering system (some wheels will slide sideways). To overcome this problem, it is possible to steer all the wheels but this leads to a much more complex steering system. These vehicles are not well suited to be bidirectional (move forward and backward) because of its lack of symmetry.

Cart like vehicles are equivalent to tricycle vehicles when the relation between the steering angles of both wheels (see Figure 2) is given by the equation (1), [Everett].

$$\cot\theta = \cot\theta_i + \frac{d}{2l} = \cot\theta_o - \frac{d}{2l} \tag{1}$$

The curvature radii relative to the mid point between the fixed rear wheels and an equivalent front steering wheel (see Figure 2) are given by

$$R = \frac{l}{\sin\theta}\,, \quad r = \frac{l}{\tan\theta} \tag{2}$$

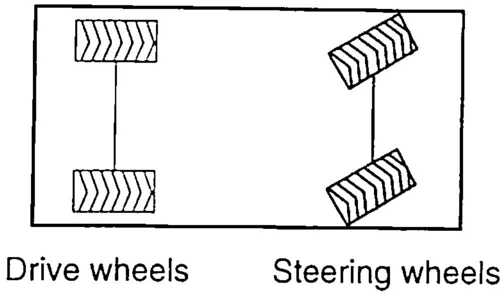

Figure 1: Cart like vehicle

Steering angle (θ) [°]	Distance btw. axis (l) [m]	Curvature radius (r) [m]	Curvature radius (R) [m]
45	7.0	7.00	9.90
45	6.0	6.00	8.49
30	7.0	12.12	14.00
30	6.0	10.39	12.00

Table 1: Curvature radii of cart vehicle

Minimum turning radius is given by

$$r_{min} = \frac{l}{\tan \theta_{max}} \tag{3}$$

Table 1 presents some radii of curvature for different steering angles and distance between axis.

Differential steering

Rombic vehicles with differential steering are based on two independent drive wheels (Figure 3) with steering achieved by applying different velocities to each drive wheel. Drive wheels' axles must be aligned with each other and must be placed at the center of the vehicle in order to decrease spanned areas. With this structure, casters are needed to support the vehicle.

This type of vehicles has the capability to move forward and backward. Their structure is not well suited for long vehicles due to the long distance between the corners and the center of rotation (mid point of the axis between the the two drive wheels) meaning that large areas will be spanned when changing direction (e.g., switch from radial path to a circular path). Differential steering vehicles may rotate over its center of rotation. However, this movement is not advisable because of the strains caused to vehicle structure and drive wheels.

For this type of vehicle, the curvature radius of a trajectory is related with the linear

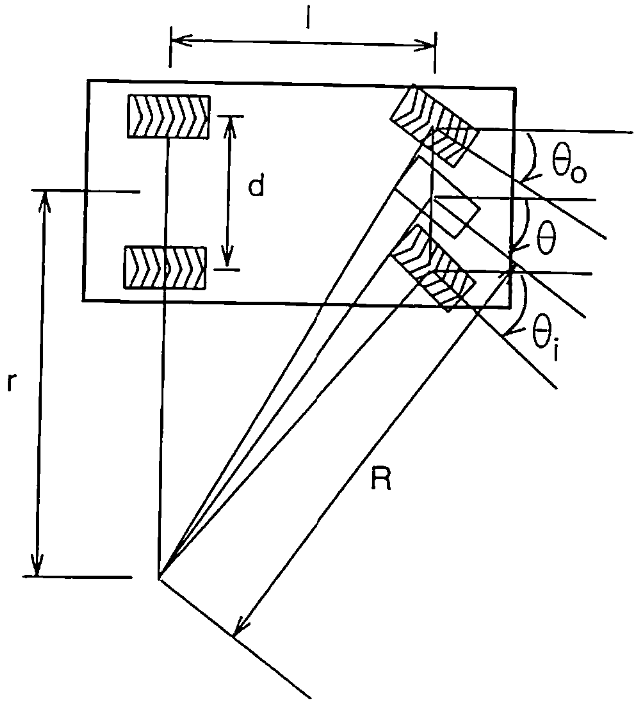

Figure 2: Cart variables

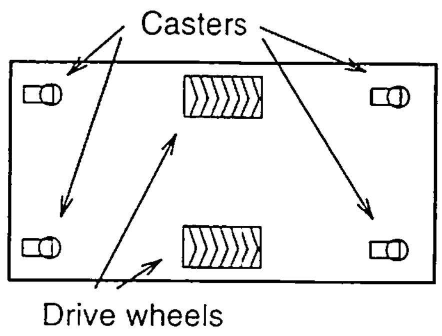

Figure 3: Differential steering

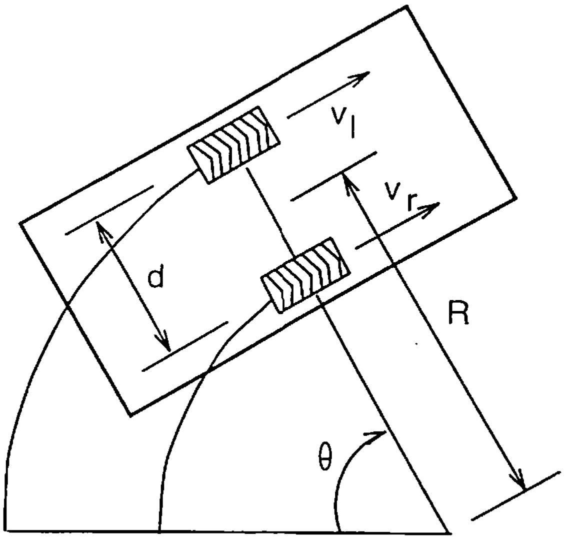

Figure 4: Differential steering

v_r [cm/s]	v_l [cm/s]	Distance between wheels (d) [m]	Curvature radius (R) [m]
28	28	Any	∞
28	-28	Any	0
28	0	4	2.00
28	0	2.5	1.25
28	14	4	6.00
28	14	2.5	3.75

Table 2: Curvature radii of differential drive vehicle

velocities of both wheels being given by

$$R = \frac{\left(1 + \frac{v_r}{v_l}\right)\frac{d}{2}}{1 - \frac{v_r}{v_l}} \tag{4}$$

where v_r and v_l are the velocities of the left and right wheels respectively, and d is the distance between wheels (see Figure 4).

There is no minimum radius of curvature constrain for these vehicles as they can rotate over themselves.

Table 2 presents some radii of curvature for different velocities of the wheels and distances between them. In the table, infinity (∞) radius of curvature means straight line trajectory and 0 meters means rotation over itself. Notice that a 5m curvature radius is required to change from a circular path on a gallery to a radial path towards a docking port.

Rombic

The third type of vehicle has a rombic configuration with two independent steering

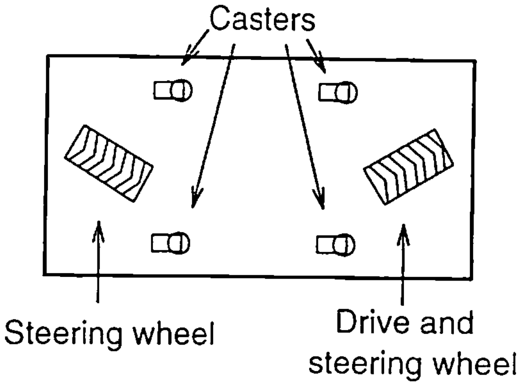

Figure 5: Rombic vehicle

wheels placed one in the front and the other in the back of the vehicle (Figure 5). One or both of these wheels is also the drive wheel. The vehicles have also casters to support and stabilize them. By using front and rear track sensors, they are well suited for track following. They have the capability to change direction in limited spaces and thus may change between radial and circular paths. Because of its symmetry, this type of vehicle is capable to move forward and backward.

Relations between steering angles of each wheel and radius of curvature are as follows:

$$r_f \sin\theta_f + r_r \sin\theta_r = l \tag{5}$$

$$r_f \cos\theta_f = r_r \cos\theta_r \tag{6}$$

where f denotes front steering wheel and r denotes rear (see Figure 6).

If $\theta_r = \theta_f = \theta$, curvature radius ($r = r_r = r_f$) is given by

$$r = \frac{l}{2\sin\theta} \tag{7}$$

Minimum radius of curvature is given by

$$r_{min} = \frac{l}{2\sin\theta_{max}} \tag{8}$$

Table 3 presents some radii of curvature for different steering angles (same for both steering wheels) and distance between axis.

Note that the radius of the circular path around the galleries is 37 meters, this justifying its use in several situations. Also notice that a 5m curvature radius is required to change from a circular path on a gallery to a radial path towards a docking port.

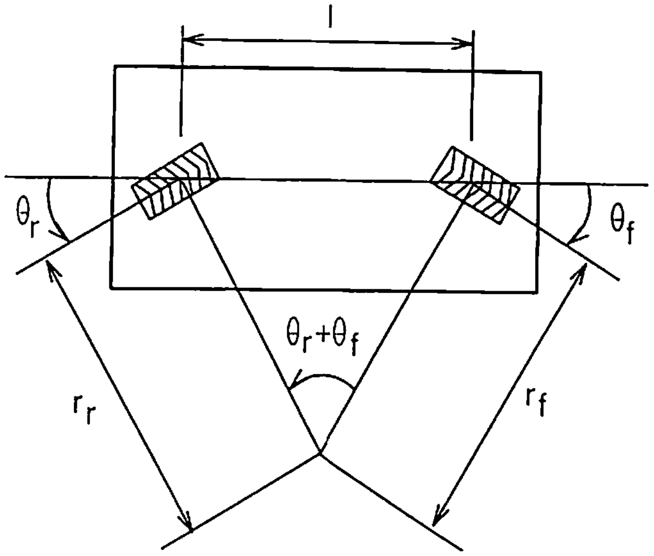

Figure 6: Rombic vehicle

Steering angle (θ) [°]	Distance between axis (l) [m]	Curvature radius (r) [m]
45	7	4.95
45	6	4.24
45	5	3.54
30	7	7.00
30	6	6.00
30	5	5.00
3.87	7	37.00
4.65	6	37.00
5.43	5	37.00

Table 3: Curvature radii of rombic vehicle

2.1.1 Free Wheels *vs.* Air Cushions

Both differential steering and rombic vehicles use casters to support them. An alternative to free wheels are air cushions. Air cushion vehicles are supported by a cushion of pressurized air, separating the vehicle from the supporting surface, and providing the vehicle with a suspension system. Comparison between the use of free wheels and air cushions is made in the sequel by discussing advantages and disadvantages of both solutions. The control of air cushion vehicles is discussed in a separate subsection, due to their unique characteristics, caused by a very reduced friction, associated to small supporting surface contact.

Free wheels

Advantages

- Safer - the platform is always supported by the wheels so it is easier to rescue (pushing or pulling the vehicle);

Disadvantages

- High contact loads lead to high friction between the wheels and the floor (implying more power to the steering and traction motor)
- No industrial application has been identified for the loads specified (80 tons);

To be determined

- How much power is needed to the traction and steering motors;

Air cushions

Advantages

- Lower contact loads (meaning less power to steering and traction motors);
- Industrial applications have been identified (see Appendix);

Disadvantages

- Inertial forces difficult to handle, due to much lower friction;
- Requires air compressor;
- Requires flat and smooth floor;

To be determined

- Number of air cushions and their lifting capabilities necessary to lift a 80 ton vehicle;
- How many air cushions are needed and where to place them on the vehicle in order to overcome the problems raised upon structural gaps and entering and leaving the lift;
- How to overcome the umbilical cables of compressed air problem:
    - Possibility to put the air compressor on the vehicle;
- Required air flow;
- Power consumption of the air compressor;
- How much power is required to the drive and steering motors; Industrial suppliers specify that "Because operation is nearly frictionless, force required is about 1 pound per 1000 pounds of load" (see Appendix).
- How does the high quantity of air used in the air cushions interact with HVAC (Heating, Ventilation and Air Conditioning);
- How to rescue a vehicle with an air compressor failure? A possibility is to have an air compressor on-board of the rescue vehicle and connecting it to the stopped vehicle.

2.1.2 Guidance Control Using Air Cushion

The control of air cushion vehicles has special characteristics. The contact between the vehicle and the supporting surface is reduced by the cushion, while the inertia associated to the load remains there to be controlled, especially when high curve velocities (and thus high centrifugal accelerations) and/or small turning radius are required (see Figure 7). When the load is heavy, as in the current problem, centrifugal forces may become large and difficult to control, even at low velocities.

Practical air cushion solutions exist since the 1950s. Directional control methods include the use of air rudders, differential thrust propellers, rotating pylons and puff-ports [Wong-a]. However, using a steering wheel as a directional control device has also been found as an effective solution [Wong-b].

An important point regarding vehicle docking is the availability of design methods (differential pressure and differential area) capable of achieving stability of an air cushion vehicle in roll and pitch [Wong-a]. Those methods have been used in commercial applications (e.g., skirt systems of British Hovercraft Corporation [Sullivan]). When docking to some of the VV ports, the casks must compensate for position and orientation misalignments between its own building and the VV building — where the docking port is located

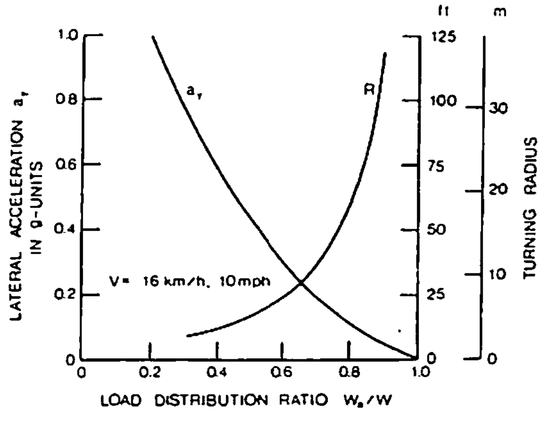

Figure 7: Lateral acceleration and minimum turning radius of an air-cushion vehicle with tires for directional control in clay. W_a is the load supported by air cushion, while W is the vehicle normal load, i.e., $W_a/W = 1.0$ is the most difficult case to control directionally. Reprinted from [Wang-a].

(see Section 6). The problem will be simplified if the cask itself is stable in pitch and roll with respect to its own supporting building, making the docking control task easier.

Commercial air cushion based AGVs have been identified (see Appendix - Solving OY). According to a well established manufacturer[4], a fully autonomous 80 ton typical ITER RH cask equipped with a rotating laser system[5], associated to retroreflectors installed on the building walls, would be capable of handling 5 meter radius curves. When the vehicle is stopped, a deviation less than $\pm 10mm$ from the actual location would be obtained with such a system. When following pre-programmed paths, the deviation would increase to less than $\pm 30mm$ (at 1 m/s), due to guidance control errors.

These figures show no problems concerning ITER building dimensions along the path between the HCB and the VV. The total vehicle weight would be increased to 120 ton.

2.2 Trajectory Topology *vs.* Kinematic Constrains

Graphical simulations of the vehicles were made to show the spanned areas of each type of vehicle. Trajectories refer to a) cart vehicles, b) differential steering vehicles and c) rombic vehicles.

The vehicle dimensions used in these simulations are $8m \times 4m$ (see Figure 8). Cart vehicles have their axles one meter away from edges; differential drive have a center axle; rombic vehicles have their steering wheels half a meter away from the vehicle front and

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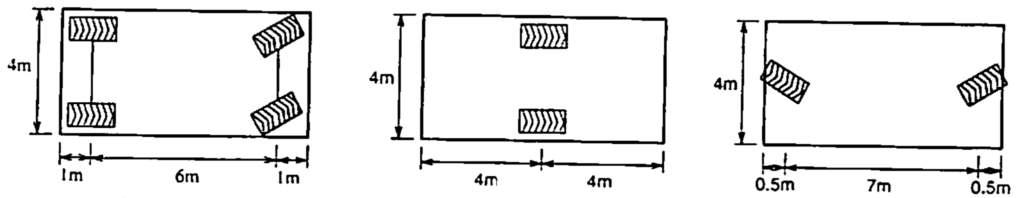
[4] This information was based on e-mail exchange with the Swedish company NDC, manufacturer of AGV hardware and software.

[5] This type of sensor will be further detailed in Section 6.



a) Cart b) Differential drive c) Rombic

Figure 8: Vehicle dimensions used in the simulations.

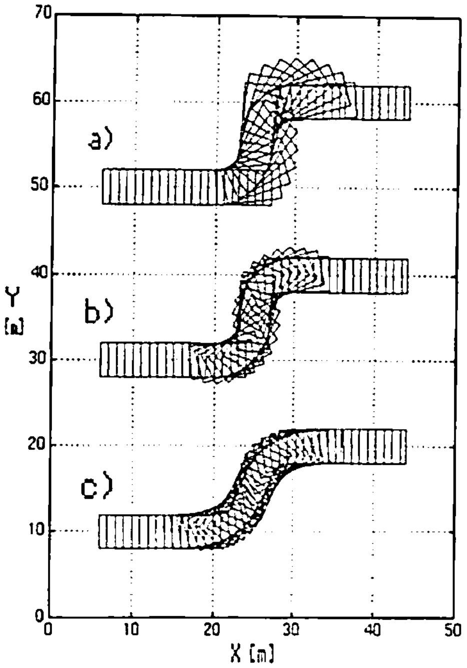


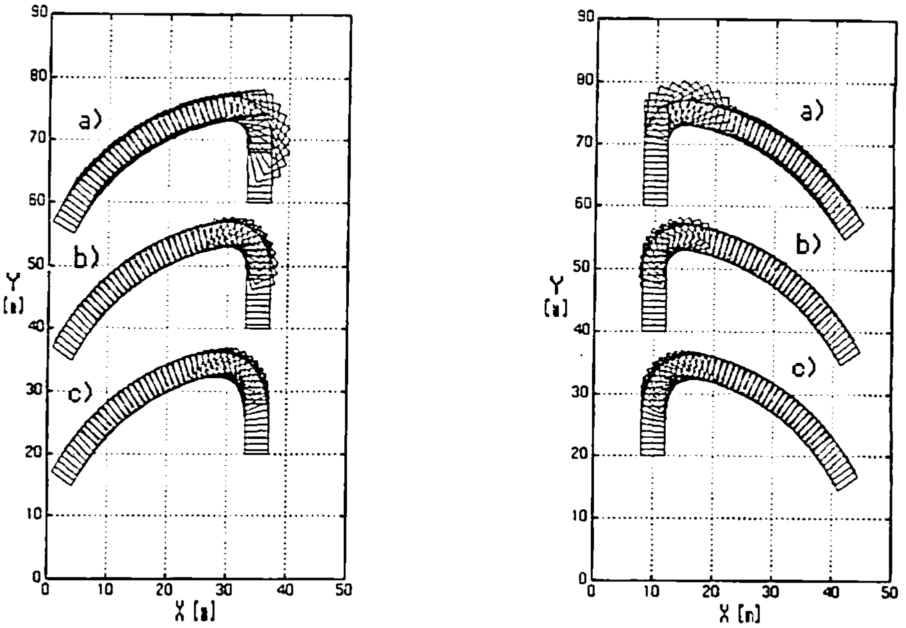
Figure 9: Trajectory 1. a) Cart, b) Differential steering, c) Rombic.

rear.

The vehicles motion over three different trajectories is shown in Figures 9 and 10. Trajectories simulated are composed of the following segments:

- Line segments;
- Circular arcs with 5 meters radius – to do turns (e.g., change between radial and circular movements);
- Circular arcs with 37 meters – circular movements in VV's galeries.

Trajectory 1 is composed of one line segment followed by two circular arcs with a 5 meters radius and ended with another line segment (see Figure 9).



Trajectory 2 – Entering a port

Trajectory 3 – Leaving a port

Figure 10: Trajectories to enter and leave a port of the VV. a) Cart, b) Differential steering, c) Rombic.

Trajectory 2 simulates the entrance in a port of the VV. It switches from a 37 meters radius circular path to a radial path by following a circular arc with a 5 meters radius.

Trajectory 3 corresponds to leaving a port of the VV. It switches from a radial path to a circular path with a 37 meters radius by following a circle arc with a 5 meters radius.

Trajectories 2 and 3 are represented in Figure 10.

Tables 2 and 3 show that both differential steering and rombic vehicles are capable of executing circular trajectories with a 5 meter radius, thus being able to switch between circular paths in the galleries to radial paths towards docking ports.

When trajectory is a line segment, both vehicles span an area with the same width of the vehicles. When following a circular arc with a 5 m radius, the areas spanned by the vehicles are wider than when following a line segment. For $8m \times 4m$ vehicles, and with the geometry displayed in Figure 8, the width of the spanned area when in a 5 m circular arc is similar: 5.06 m for differential steering vehicle and 5.28 m for rombic. Nevertheless, it is also important to quantify the maximum deviation of each vehicle from the designed path. The distances from the center of the spanned areas to the 5 m radius circular arc are:

Differential steering: 0.53 m to the outer side;

Rombic: 0.79 m to the inner side.

Therefore, even though the rombic structure has a slightly larger deviation, this is compensated by the fact that the switching from a circular arc to a line segment is smoother (see Figure 9).

3 Guidance and Navigation

This section describes existing solutions for guidance and navigation systems for mobile platforms. The role of these modules on the correct operation of the vehicles is represented in Figure 11.

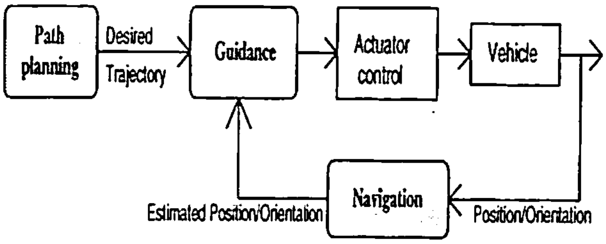


Figure 11: Block diagram of guidance and navigation systems

General navigation systems determine the current platform's position and orientation on a world frame, based on sensor data. The guidance module compares the vehicle actual location with the desired location along the reference path and dispatches motion commands aiming at minimizing the error. The path planning module represented in Figure 11 establishes the desired trajectory from the initial location to the goal.

The implemented methodology for planning a path strongly depends on the type of transportation solution under consideration, e.g., AGV , Mobile Robot or Mixed Vehicle. In the case of a vehicle acting as an AGV, a net of pre-defined paths are established beforehand. The path planning implements an optimization procedure that chooses an optimal path within the net (e.g., the shortest one, the fastest one) taking into account the overall status of the system (e.g., traffic, blocked paths). If the vehicles are acting as Mobile Robots, geometric and kinematic constraints are taken into consideration to plan a short and smooth path between the initial location and the goal.

Guidance, herein understood as the path execution, strongly depends on the type of vehicle kinematics and on the sensors that locate the vehicle relative to the planned path. Guidance also includes the actions for motor control, that will not be considered on this report.

Navigation aims at localizing the platform. Its complexity and sensor requirements strongly depends on the type of transportation solution adopted. The localization of an AGV is a two-dimensional variable, that describes its pose along the wire. On the contrary, to correctly localize a Mobile Robot, position (x, y) and orientation (θ) have to be specified, requiring more complex sensors and elaborated signal processing algorithms.

Path planning for Mixed Vehicles requires the application of the two methodologies above, as well as special procedures for the transition between different guidance and navigation solutions. The particular topic raised for Mixed Vehicles in terms of path planning is the definition of smooth trajectories for leaving and entering into a physical fixed path. As an example, a Mobile Robot may become an AGV near a docking port, but it must first detect and reach the track.

The requirements of the guidance and navigation systems include, [Hollier]:

- To guide a vehicle between two points within the work space reliably and accurately enough to avoid the known obstacles (walls, pillars, machines);
- To provide precise maneuvering of platform in the vicinity of load ports and deposit ports;
- To provide a base for efficient traffic control that might involve a large number of vehicles;
- To meet safety requirements for protection of infrastructure (including vehicle and its load) and other materials;
- To allow teleoperation and autonomous control;
- To allow the operator to resume system's control at any instant.

When choosing a guidance system and a navigation system several issues must be considered: range, accuracy, flexibility, reliability, robustness, complexity of the control system, vehicle equipment cost, cost of the off-board equipment that will be installed to support navigation and guidance and others. Some of these features are closely related with the type of platform used, which also depends on the type of guidepath.

The open possibilities for guidepaths are the following:

- Physical guidepaths:
    - Mechanical guidepaths - e.g., rail;
    - Optical/Chemical/Magnetic guidepaths;
    - Inductive guidepaths;
- Virtual guidepaths
- Mixed guidepaths

In Physical guidepaths the complete net of possible trajectories is specified at floor level. Virtual guidepaths have no physical implementation on the environment being defined at computer level based on optimization procedures. On the mixed guidepath implementation, the vehicle will have guidance and navigation capabilities to either follow a physical and a geometric path. Situations are foreseen where the platform follows a physical path during part of its global trajectory, but leaves it and recovers it again later on. Decision on which operation mode to choose depends on the vehicle and the overall system actual status.

Mechanical guidepaths will not be considered in the sequel, because this corresponds to the "hard guidance" concepts studied elsewhere [TCS].

3.1 Guidance

Guidance, considered as path execution, strongly depends on the type of guidepath. In the sequel, the various physical and geometric guidepaths are analyzed and compared.

Teleoperation of the vehicle should be made at different levels of autonomy. The operator may wish to just define the vehicles trajectory (based on either a virtual or physical path) and order its execution, or he/she may wish (or need) to precisely steer the platform. Information on the status (e.g., location) of the platform will be provided by the communication system and by vision cameras installed all around the environment. In any case, a low level obstacle detection system will be active on the platform (see 3.4), either to automatically circumvent the obstacle or to switch from high to low autonomy mode.

3.1.1 Optical Guidepath

In this concept, the vehicle follows a track painted on the floor. This solution has been used by AGVs for years in industry and has achieved good results, [Hammond]. Usual sensors for track detection are near-infrared detectors, mounted in pairs on the vehicle's chassis. The differential component of the two received signals is a measure of the platform's deviation from the line painted on the floor, thus providing feedback information for the control system.

Similar concepts are those based on Chemical and Magnetic guidepaths. In those cases, the path geometry is displayed on the floor through chemical and magnetic components, [Everett]. Special purpose sensors, giving a differential measure of the deviation are similarly used on a differential based guidance system.

Magnetic fields of the reactor are foreseen to raise hard problems if magnetic guidepaths are used. Therefore, this solution will no longer be considered. Chemical guidepaths and the corresponding detectors might have a difficult maintenance, together with the fact that they might be invisible which makes them of no use when teleoperation mode is being used.

Passive transponders are usually associated with this concept for absolute localization done at discrete points. Known solutions combine transponders with odometry.

The following lines exclusively refer to optical guidepaths.

Advantages

- It is immune to magnetic fields;
- It is easy to install and change – flexible;
- Excellent range, long paths can be followed with no problems [Hollier];

- Vehicle equipment has low cost;
- Equipment outside the vehicle is extremely low cost;

Disadvantages

- The track cannot be used for communications;
- A clean environment is necessary;
- In order to keep track definition, maintenance must be periodically done.
- Reliability and robustness are not strong points since the guidepath is vulnerable to external actions [Hollier]. Path may be damaged by scratches from the vehicles' wheels. If a vehicle loses the path, it will be very difficult to automatically recover it; in this case teleoperation is required.

To be determined

- How to choose the way at crossroads?
  Some possibilities are:
  - Operator control;
  - Use of different colors in the tracks together with localization and a ruled based system;

3.1.2 Inductive Guidepath

On the inductive guidepath strategy, one or more wires are buried on the floor, along all the desired geometric trajectories that the vehicles might follow. A low-voltage, low-current low-frequency ac signal is conducted through the wire, generating a small electrical-magnetic field radiated from the wire.

Two joint coils are placed on the vehicle, near the wire. The difference between the inducted voltage on both coils is used on a differential guidance control system.

This concept is very common in industry. It leads to very reliable guidance systems and has been used in industry for years with very good results. Several vehicles can share the same wire. Crossroads can be overcomed if different frequencies are used for each path.

Passive transponders with or without further continuous localization are also used with this concept for absolute localization and can help choosing between two alternative paths.

In a complex environment with transportation tasks from/to many different locations, there are certainly points where options have to be made on which trajectory to follow, (e.g., leaving the circular trajectory along the gallery to approach a docking port). Known solutions install wires with different frequencies to cover all the possible options in a crossroad. Together with a localization system, (e.g., transponders accurately placed) the guidance system will change the frequency tuned by the steering detectors.

Advantages

- The wire used for magnetic field generation may carry other signals between the platform and control center, thus providing continuous communication support;
- Good accuracy [Hollier];
- Reliability is excellent – as the guidepath is buried into the floor, it is protected from exterior actions [Hollier]. Note that this does not prevent easy teleoperation along the wire.
- Vehicle equipment has low cost – limits to coils, signal amplifiers and filters.

Disadvantages

- When acting exclusively as an AGV, vehicle autonomous maneuvers are limited to a small vicinity of the wire – low flexibility. Therefore, in the case of an autonomous AGV, robustness is low.
- Is is sensible to external magnetic fields;
- The insertion of wires in the floor can be difficult to do, eventhough there are special purpose installation machine/tools for it;
- This is a non-flexible guidance system. Once a path is established, changing it requires changes to the floor;

3.1.3 Virtual Guidepath

When there is no physical path defined on floor level, the guidance module will steer the vehicle along a geometric trajectory defined at the centralized computer and based on any optimal procedure. This procedure takes into account the map of the environment, the transport cask actual location, the desired location and the platform's dimensions and kinematics. When this situation arises, it is said that the vehicle performs as a Mobile Robot.

During path execution, changes may be made, in real time and in an automatic way, to the previously defined geometric trajectory. Those changes result from the detection of any unexpected obstacle (i.e., obstacle not represented on the a priori map) or from large deviations between the actual location and the planned trajectory.

Virtual guidepaths can always be followed through the action of the operator in teleoperation mode.

Advantages

- High flexibility to overcome unexpected obstacles, e.g. a stopped platform in front;
- No physical installation is required for trajectory definition;
- Copes with new transportation situations;
- High flexibility for rescue platforms;
- In areas with sufficient empty space, traffic congestion is better solved than with physical fixed paths;

Disadvantages

- Navigation and Guidance along a virtual guidepath are more complex than with a physical path;
- Special purpose devices/sensors might be installed besides those considered for physical guidepaths;
- Localization errors, namely from orientation, tend to be larger than for a physical guidepath;
- Docking procedures for a platform approaching the docking port along a virtual guidepath are usually more complex than those required for an approach along a physical guidepath;

3.1.4 Mixed Guidepath

This concept aims to provide the best of two systems, i.e., accuracy and simplicity along a fixed physical path and flexibility to travel out of the physical path whenever necessary (e.g., to overcome unexpected situations) and to resume again on the physical path some distance away.

Should a flexible guidance transportation solution be adopted for ITER RH system, it is proposed to use fixed guidepaths whenever possible and virtual guidepaths in special situations. This need may arise if a vehicle has a malfunction, stops and occupies the fixed guidepath.

When approaching docking ports a fixed guidepath can be of extreme use once it allows very precise docking of the vehicle.

The flexiblibity provided by a mixed guidepath methodology, is also extremely important for the rescue platforms. Those must have the capacity to free travel in the work space being thus free from fixed guidepaths. Nevertheless, they may have to switch to a physical guidepath tracking mode on the final stage of a rescue operation. To do so, the vehicle must be capable of switching between operation modes by the use of external information (e.g., passive landmarks placed close to reentry points).

Advantages

- Those of the Virtual and Physical Guidepaths;

Disadvantages

- Those of the Virtual Guidepath in terms of localization procedures, and localization sensors;
- Complex procedures for defining the best path back to the physical guidepath;
- Navigation and guidance are more complex, since they require the coordination of a larger number of sensors and of the switching between operation modes.

3.2 Path Planning

For the three types of guidepaths, optimization procedures are the base for the path planning module. Several known and tested path planning solutions and algorithms are available.

Even in a teleoperation mode, the path planning module may support the operator on the choice of a path leaving the final decision on either accepting it or defining a new one to the operator.

To cope with unexpected situations, path planning will be implemented, in real time, to allow the obstacle circumvention in the case of virtual guidepaths.

Other distinctions can be made on static *vs* dynamic guidepaths, where static goes for only one guidepath between the end-points of an AGV travel and dynamic refers to a real-time decision between several available guidepaths.

3.3 Navigation Systems

Navigation Systems aims at localizing mobile platforms (AGV type or Mobile Robot type) during its operation. Localization requirements and accuracy depends on the type of guidepath and on the type of vehicle. It might be done continuously or at discrete points.

The most reliable and cheap discrete localization system is based on passive transponders buried on the floor of the environment.

The most common methodologies/sensors for continuous localization includes:

- Dead Reckoning;
  - Odometry
  - Inertial navigation;
- Landmark navigation;
  - Natural Landmarks;
  - Artificial Landmarks;

3.3.1 Dead-Reckoning

Dead reckoning is a simple mathematical procedure for determining the present location of a vehicle by using available information about known course and velocity over a given time length [Everett]. It can be implemented in several ways. This concept has been used for years in industry and has achieved good results.

3.3.1.1 Odometry

Odometry is the simplest implementation for dead reckoning. Its basic principle is to acquire and process information which is proportional to traveled distance. This information might be an electrical analog signal, for potentiometers synchros and resolvers, and electric pulses for the remaining list shown below.

- Brush encoders;
- Potentiometers;
- Synchros and Resolvers;
- Optical encoders;
- Magnetic encoders;
- Inductive encoders;
- Capacitive encoders;

One must note that some of these sensors, namely synchros, resolvers, magnetic encoders, use magnetic fields and alternating current (AC) sources in their measures which might be affected by the environment and lead to localization errors. Therefore this set will no longer be considered.

Optical encoders are the most used implementation and will be analyzed in the following. Optical encoders appear in two configurations, absolute and incremental. Absolute encoders measure absolute angular position and infer velocity. Incremental encoders measure rotational velocity and infer relative position.

Usually, odometry localization systems suffer from cumulative errors, thus requiring a periodic error reset based on a more powerful localization system. Combined with other sensors it is possible to build very accurate localization systems. This concept has been used for years in industry with good results. Usually it is combined with other sensors, (e.g., transponders, landmark based localization).

For the problem under consideration, very accurate stopping locations are required at the docking ports. After docking has been accomplished, error location is within the specified requirements and therefore odometry error reset may be done at those locations.

Advantages

- Optical encoders are extremely low cost;
- Good short-term accuracy. Accumulated errors must be reset periodically;
- Simplified navigation;
- No external equipment needed;

Disadvantages

- The accumulation of orientation errors causes large position errors which increase proportionally with the distance traveled - odometry has low range by itself;
- Low reliability:
    - Surface roughness and ondulations can cause distance to be over estimated;
    - Wheel slippage can cause distance to be under estimated;
- Load variations may introduce additional errors;

3.3.1.2 Inertial Navigation

Inertial navigation is an alternative method for enhancing dead-reckoning [Borenstein]. The principle of operation involved in inertial navigation is the continuous measure of accelerations in each of the three directional axes, and the integration over time to derive velocity and position. This system was initially developed for aircrafts and submarines. Sensors used for inertial navigation are accelerometers and gyroscopes, where gyros provide the angular rate and accelerometers provide the velocity rate information.

This concept has been used in industry with good results.

Advantages

- These sensors are self-contained i.e., no external motion information is needed for positioning;
- Provides fast, low-latency dynamic measures;
- One sensor gives position, velocity and acceleration;
- Inertial navigation gives accurate short-term information;
- Allows very flexible systems - virtual guidepaths;
- Has been used in industrial applications [see Appendix];

Disadvantages

- Gyroscopes are expensive;
- Some gyroscopes are sensible to magnetic fields;
- Angular rate data and linear velocity rate data must be integrated once and twice (respectively), to provide orientation and linear position, respectively. This implies error propagation and consequent localization errors that grow with time and distance traveled. To have very precise measures, error resetting must be done periodically. This can be achieved with passive transponders;
- Accelerometers have very poor signal-to-noise ratio at lower accelerations;
- Accelerometers are sensitive to uneven floor;

3.3.2 Landmark Navigation

This concept is based on the detection of distinct features in the environment (landmarks), whose absolute position is previously known and relative to which a robot can localize itself [Borenstein], providing position and orientation.

Landmarks can be of two types: natural and artificial.

- Natural landmarks are objects that have a function other than robot localization, e.g., doors and walls.

- Artificial landmarks are specially installed in known places of the environment and are only used for robot localization. They can be either:
  - active - beacons, emitters. As this option requires that active components are installed all around the environment, it was discarded due to a difficult maintenance. Instead, it was chosen to place all active components on-board the platform.
  - passive - made of some special materials, (e.g. retroreflective material) are easy .to detect since they are designed for optimal contrast.

A wire buried on the floor or a line painted on the floor, for the case of physical guidepath, may also be considered as artificial landmarks relative to which the platform's location is evaluated.

Landmark navigation basic devices are vision cameras, rangefinders (time-of-flight) and lasers. They detect landmarks by contrasting them against their background.

A landmark-oriented positioning takes the following steps:

1. Acquire sensory information (with optical camera, rangefinder or laser);
2. Detect landmarks in sensed data, using a feature extractor;
3. Establish a correspondence between sensed data and the stored map;
4. Calculate position and orientation;

3.3.2.1 Artificial Landmarks

This concept has been used in industrial applications with very good results. The sensor of choice for artificial landmarks is a rotating laser emitter/receiver. A horizontal laser beam is emitted and then reflected by landmarks. Based on the received signal, the system can determine the relative orientation between the landmark and the vehicle. Position and orientation of the vehicle on a global frame are then computed by a coordinate transformation. Notice that a landmark map (landmark absolute positions) has to be kept in memory. See the Appendix for details on a commercial system.

Advantages

- Robust to magnetic fields;
- Long range. Given that the laser beam may have ranges up to 20-50m, there will be no problem to install visible artificial landmarks, on the studied environment;
- High reliability;
- Easy installation. It requires only the installation of artificial landmarks on the walls and software installation;

- Landmarks are passive and inexpensive (e.g., a strip of reflective material);
- Laser is very accurate. The accuracy of the state of the art laser systems can go up to 2-3 mm;

Disadvantages

- Laser systems are expensive;
- Requires complex computations – triangulation;
- By itself it can not give absolute position (only position relative to the landmarks on his sight). Usually it is combined with absolute positioning systems like odometry and passive transponders;
- A map must be stored in memory;

To be determined

- Robustness to reflectors loss;
- How many reflectors are needed for a good coverage and where to place them;
- If landmarks have no associated code, ambiguity may arise when the vehicle travels in regions with symmetric geometry, namely in the galleries.

3.3.2.2 Natural Landmarks

This concept has been used in industry. If natural landmarks are used, sensors usually chosen are computer vision and time-of-flight rangefinders. This comes from the fact that natural landmarks are hard to detect and those sensors provide rich information. Inside rangefinders two distinctions can be made: laser rangefinders and infra-red rangefinders (IR). Laser rangefinders are more accurate than IR but cost much more.

Advantages

- Robust to magnetic fields;
- Good range;
- Natural landmarks are inexpensive;
- Neither special adaptation of the environment, nor special installation of sensors is required. Only the software installation and sensor assembly on the vehicles are needed;

Disadvantages

- Computer vision systems and rangefinders are expensive;
- Complex computations (e.g., feature extraction);
- Only position relative to landmarks in the sensor range can be determined. Absolute position in a world frame is computable only if the landmarks are distinct.
- A map must be stored in memory;
- Sensor performance is very sensitive to its placement, especially in long vehicles;
- Environment changes (and other vehicles occlusions) may have severe consequences;

3.3.3 Passive Transponders in Navigation

Navigation procedures based on dead-reckoning accumulate errors which are cumulative with distance traveled. If not reset periodically these errors lead to large position and orientation errors. To reset these errors an absolute positioning system must be available.

Passive transponders are an efficient way to do that absolute localization, at discrete locations. These transponders have very small dimensions (e.g., cylinder with 5cm height and 2cm diameter), and are buried on the floor. When excited by the radiation emitted by an antenna fixed on the vehicle's structure, they radiate their unique code. This, together with the a priori knowledge of transponder installation around the environment, provides a rough estimation of the vehicle's position.

Transponders are very well suited to be placed along a physical guidepath, in the vicinity of special locations, where decisions will have to be made. For example transponders should be placed before crossroads for the correct selection of the steering frequency, in the vicinity of a docking port for velocity decrease.

Advantages

- Passive, low cost and reduced dimension sensors;
- Gives absolute position, given that each transponder has a different code;
- High reliability;
- Is very well suited for a rough positioning along a physical path;
- Easy installation;
- Has been used in industrial applications [see Appendix];

Disadvantages

- Cannot be read unless the corresponding antenna, placed on the platform, is very close to the transponder;
- Low positioning precision;
- Does not provide orientation estimation, which is required for the correct control along virtual paths;
- A map with the indication of all the transponders and the corresponding code must be kept in memory;

To be determined

- Influence of external magnetic fields on reading range.

3.4 Obstacle Detection

To avoid vehicles colision, obstacle detection systems must be provided. These sensors provide information on the free space around them and depending on the type of sensor used, different areas may be covered and different ranges may be sensed to detect the presence of any object that may obstruct the way of the vehicle.

Diferent priorities can be assigned to each obstacle sensor, depending on its range and covered area. Thus, short range obstacle detectors must have higher priorities and long range detectors have lower (e.g., a high priority allows bumpers to stop a vehicle if contact is sensed).

Possible obstacles are:

- Other vehicles. This may emerge if the control system makes the vehicles travel close to each other or if there is a stopped vehicles in the path.
- Wall and collums. Those may be seen as obstacles if guidance and navigation fail. In this situation the vehicle would get out of route and collide with something if there were no obstacle detection.

Usual obstacle detectors used in industry are:

- Ultra sonic devices (Sonar). Provide good medium range information. Cover conic areas with an aperture of ±30°.
- Infrared detectors. Are very good at short range distances. Performance strongly depends on obstacle reflectivity.

- Laser detectors. Cover large distances [15m] with good accuracy. Covers semi-circular areas [up to 350 m^2]. See Appendix for identified industrial applications.
- Bump sensors. These are essential as a last resort, since they provide information only after colision has occurred.

4 Remote Handling Logistics for Flexible Cask Guidance

Simulations were made to enhance the potential advantages of flexible guidance systems in what concerns logistics. The study concerns divertor cassettes transference from the four VV ports of the divertor level and simulates a complete transfer cycle. At the beginning of a transfer cycle, four vehicles are at VV ports loaded with divertor cassettes and four vehicles are at HCB ports unloaded and ready to move. At the end, these two sets are completely transferred.

Each simulation shows the total time spent in a transfer cycle for a particular set of constraints. This allows the discussion of the solution's performance and may lead to suggestions of locations where changes to the building may improve component transfer operations, to the discussion on the number of docking ports on the HCB, or to the adoption of movement policies in the galleries. For explanation purposes, the simulation studies were developed together with a time-scaled graphical animation that, for each considered situation, shows the evolution over time of each cask along the layout.

In order to analyse system performance, combinations of two different scenarios were examined:

- Bidirectional *vs* unidirectional cask motion in the gallery;
- One cask moving at a time or more than one cask moving simultaneously.

A bidirectional path and an unidirectional path are physically the same. A bidirectional path is a path where vehicles are allowed to move in both directions. Bidirectional path in the gallery means that vehicles may move in clockwise or anticlockwise directions. Bidirectional capabilities are, thus, a property of the vehicles and not of the path itself. When bidirectional motion in the gallery is allowed, each cask moving between a VV port and the lift chooses the shortest path. In the simulations, when only unidirectional motion is allowed in the gallery, its direction is assumed to be anticlockwise. Due to gallery symmetry, clockwise direction should give the same results.

Crossovers are defined as the situation when two casks pass close to each other in opposite directions. With this definition, crossovers may only occur when two ore more casks are allowed to move simultaneously.

The distances considered in the simulations were taken from the [DDD] drawings:

- Gallery path radius: 37m;
- Distance from gallery path do VV docking port: 12m;
- Distance from lift to HCB transfer corridor: 25m;
- Length of transfer corridor: 25m;

The time spent to overcome the lift was taken from Figure 7 (Typical cask transfer allowing sequential use of the gallery lift) of [RRHLS]:

- Position on lift and secure: 10 minutes
- Travel between levels: 10 minutes
- Release and free from lift: 10 minutes

The assumed casks velocity was 0.125 m/s. This velocity leads to travel times similar to those presented in [RRHLS].

The simulations were also based on the following assumptions:

H1 At the beginning of the transfer cycle, all the casks are undocked, i.e., ready to start moving. The vehicles at the VV ports are loaded with divertor cassettes and the vehicles at the HCB ports are unloaded and ready to move.

H2 During the transfer cycle, neither docking or undocking operations and loading or unloading of components take place.

H3 There is a turntable in the lift so that transfer casks may turn to approach the ports (at VV or HCB) with the correct orientation, i.e., cask's door facing the port door.

For the graphic display of the simulations, a square schematic representation of the gallery (Figure 12) is used to simplify implementation, although maintaining the correct perimeter length.

The initial position of each cask for all the simulations is shown in Figure 12. Casks 1,2,3 and 4 belong to set 1. Casks 5,6,7 and 8 are also named as casks 1, 2, 3 and 4 of set 2. When not otherwise mentioned, the order in which casks are transferred between VV ports and HCB ports is 1-5, 2-6, 3-7 and, finally, 4-8.

From the assumptions H1 and H2, the simulations do not depend on the duration of docking or undocking cask operations, loading, unloading or other operations on the components. Considering the existence of a turntable in the lift (H3), simulations do not care about transfer cask orientation neither to its necessary changes. This task, when required, is left to the management operator.

The different simulations carried out are summarized in Table 4. Each one has a reference label to simplify the comparison among results.

In situation **B.1**, casks may crossover between the lift and the HCB transfer corridor. In **B.2**, casks are allowed to wait in the gallery when they are willing to use the lift to go up, while another one is coming down. **B.3** is the combination of **B.1** and **B.2**.

In the simulation results, the values of several different variables are presented with the following meanings:

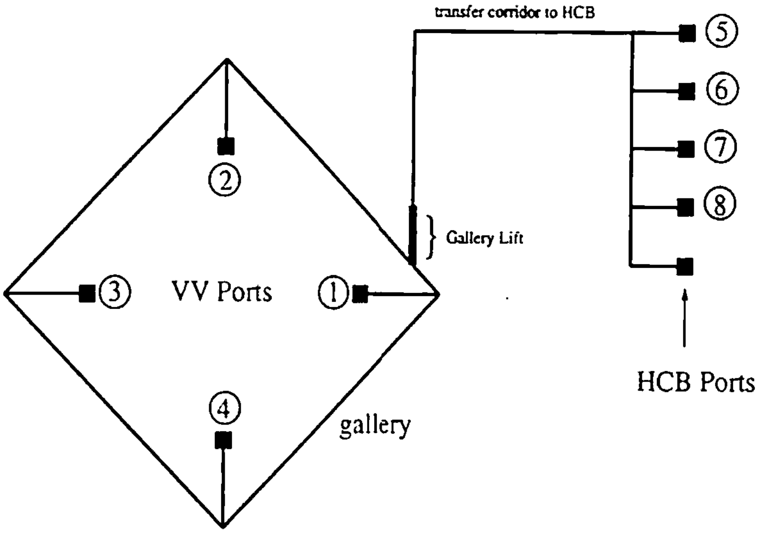


Figure 12: Schematic representation of the simulation for animation purposes. Initial stage of transfer cycle.

One cask moving at a time A	Unidirectional motion in the gallery A.1	
	Bidirectional motion in the gallery A.2	
More than one cask moving simultaneously B	Cask crossovers B.1	Unidirectional motion in the gallery B.1.1
		Bidirectional motion in the gallery B.1.2
	Waiting state in the gallery near the lift interface B.2	Unidirectional motion in the gallery B.2.1
		Bidirectional motion in the gallery B.2.2
	cask crossovers and waiting state B.3	Unidirectional motion in the gallery B.3.1
		Bidirectional motion in the gallery B.3.2

Table 4: Table showing the different simulations and their reference labels.

- **Total transfer time** – Time needed to accomplish a complete transfer cycle.
- **Waiting time** – Time spent by each cask waiting for other cask at a crossover location or in the gallery near the lift due to traffic constraints. The total waiting time is the sum of all casks' waiting time. It should be stressed that during a waiting period, a cask is stopped at a place different from a port or the lift, with low power consumption and reduced safety problems.
- **Moving time** – Time spent in motion by each cask plus the time spent entering and leaving the gallery lift (20 minutes). Total moving time is the sum of all casks' moving time.
- **Distance** – Distance travelled by each cask. Total travelled distance is the sum of all casks' travelled distance.

4.1 One cask moving at a time (A)

With only one cask moving at a time, no traffic problems arise, all the paths being free to be used by the moving cask. The first consequence of this is a null waiting time for all casks.

The first step is to move a loaded cask from the VV to the HCB. In this situation, there are four unloaded vehicles in the HCB ports. Therefore, a fifth port at the HCB must be available to park the first loaded vehicle, just arrived from the VV.

The initial position of each cask is shown in Figure 12 and the order in which casks are transferred between VV ports and HCB ports is 1-5, 2-6, 3-7 and, finally, 4-8.

Unidirectional motion in the gallery (A.1)

In Figure 13, the results of the cask transfer simulation are presented for the case when only unidirectional motion is allowed in the gallery.

The total transfer time is 7h24m38s. The consequences of having only one cask moving at a time are null waiting time for all casks and total moving time equal to total transfer time. Total travelled distance is 1714 meters.

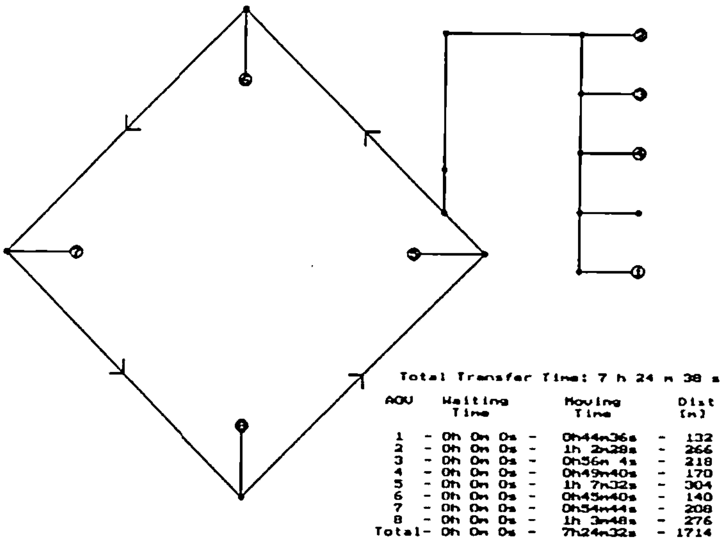
This simulation gives results similar to those presented in [RRHLS]. Note that cask and lift velocities were tuned to give those results because [RRHLS] was the only source of information on transfer timings. Also, matching velocities with [RRHLS] results allows the comparison between different strategies based on the same a priori assumptions.

Bidirectional motion in the gallery (A.2)

With bidirectional motion in the gallery the results of the simulation are those presented in Figure 14. The total transfer time is 6h22m46s. Null waiting time for all casks and total moving time equal to total transfer time are, once again, consequences of having only one cask moving at a time. Total travelled distance is 1250 meters.

Discussion

Cask	Direction of movement in the gallery
1	anticlockwise
2	anticlockwise
3	anticlockwise
4	anticlockwise
5	anticlockwise
6	anticlockwise
7	anticlockwise
8	anticlockwise

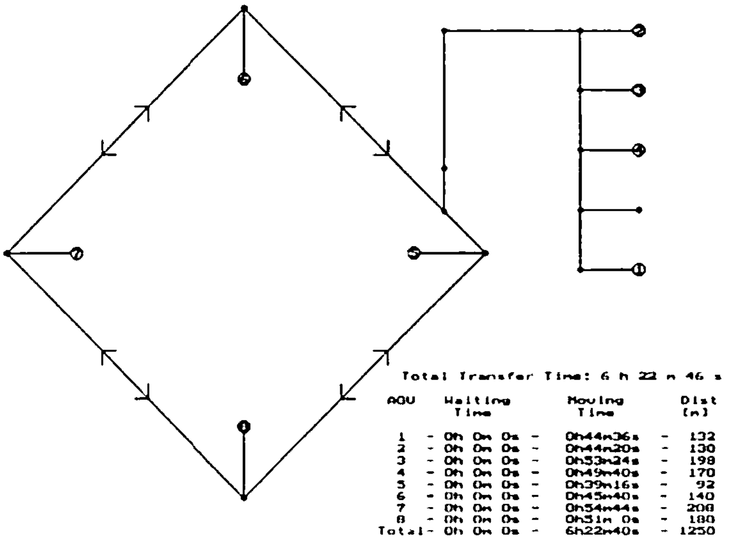


```
Total Transfer Time: 7 h 24 m 38 s
AGV    Waiting            Moving        Dist
        Time               Time          (m)

  1   - 0h 0m 0s  -    0h44m36s   -   132
  2   - 0h 0m 0s  -    1h 2m28s   -   266
  3   - 0h 0m 0s  -    0h56m 4s   -   218
  4   - 0h 0m 0s  -    0h49m40s   -   170
  5   - 0h 0m 0s  -    1h 7m32s   -   304
  6   - 0h 0m 0s  -    0h45m40s   -   140
  7   - 0h 0m 0s  -    0h54m44s   -   208
  8   - 0h 0m 0s  -    1h 3m48s   -   276
Total- 0h 0m 0s  -    7h24m32s   -  1714
```

Figure 13: Simulation results for unidirectional motion in the gallery and one cask moving at a time. Final stage of transfer cycle.

Cask	Direction of movement in the gallery
1	anticlockwise
2	clockwise
3	clockwise
4	anticlockwise
5	clockwise
6	anticlockwise
7	anticlockwise
8	clockwise



```
Total Transfer Time: 6 h 22 m 46 s
AGV    Waiting            Moving        Dist
        Time               Time          (m)

  1   - 0h 0m 0s  -    0h44m36s   -   132
  2   - 0h 0m 0s  -    0h44m20s   -   130
  3   - 0h 0m 0s  -    0h53m24s   -   198
  4   - 0h 0m 0s  -    0h49m40s   -   170
  5   - 0h 0m 0s  -    0h39m16s   -    92
  6   - 0h 0m 0s  -    0h45m40s   -   140
  7   - 0h 0m 0s  -    0h54m44s   -   208
  8   - 0h 0m 0s  -    0h31m 0s   -   180
Total- 0h 0m 0s  -    6h22m40s   -  1250
```

Figure 14: Simulation results for bidirectional motion in the gallery and one cask moving at a time. Final stage of transfer cycle

Bidirectional motion in the gallery reduces about one hour the total transfer time and reduces the total travelled distance from 1714 to 1250 meters, because the shortest gallery path to/from the lift is chosen for each cask. These reductions do not impose any safety decrease, since only one transfer cask is moving at a time.

4.2 More than one cask moving simultaneously (B)

Increasing the number of casks moving simultaneously is expected to decrease total transfer time. However, when more than one cask moves at a time, traffic congestions may arise. Three different solutions to handle this problem are analysed:

- Cask crossover using an extra path between the gallery lift and the HCB;
- Cask waiting state in the gallery, near the lift;
- Combination of the first two solutions, i.e., cask crossover and waiting state.

Due to structural constraints, the best place to create the extra path that allows cask crossover seems to be in the way between the gallery lift and the HCB transfer corridor as illustrated in Figure 15. The actual stage of Tokamak Building design does not accommodate that extra path. The required space will impose some changes in the laydown hall level between the gallery lift and the transfer corridor. Should a flexible guidance system be used, space for two near parallel paths is required. For instance, if inductive guidepath is used, two wires (one per path) should be installed.

In situation B, a cask remains at a waiting state in the gallery (near the lift) when it is willing to use the lift to go up and another cask is already using the lift to come down. If only unidirectional motion is allowed in the gallery, this situation will require no manoeuvres, as referred in Figure 16 for the possible situations when (a) the lift occupies the gallery, (b) the lift is apart from the gallery.

Bidirectional motion in the gallery is used to minimize the travelled distance between each VV port and the lift entrance. The minimum distance path is the one to be followed by the cask leaving the VV port (and going to the HCB) and also by the cask that left the HCB and travels towards that VV port. If the first cask, (VV ⟶ lift), travels clockwise in the gallery, the second one, (lift ⟶ VV), will have to travel anticlockwise on the same physical path. Being so, this strategy requires manoeuvring as illustrated in Figure 17. Such manoeuvres are only possible if the lift is not in the gallery, but at some distance from it, in order to allow casks to pass by the lift.

With more than one cask moving simultaneously, when one cask leaves a VV port, another cask leaves an HCB port, freeing it. Thus, the complete transfer operation can be accomplished with only four ports in the HCB.

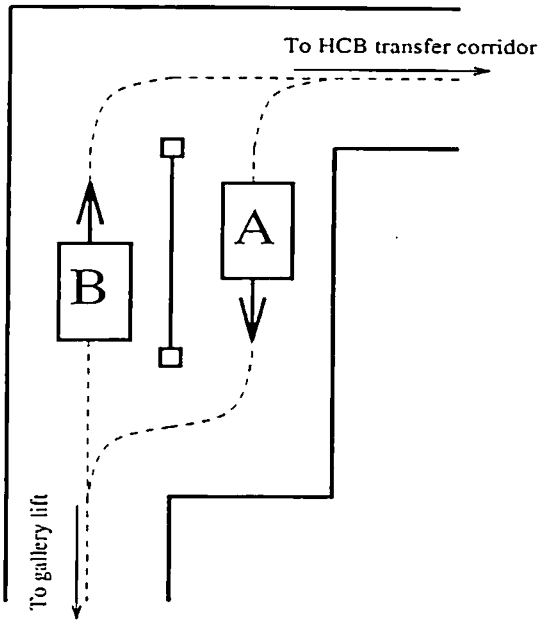
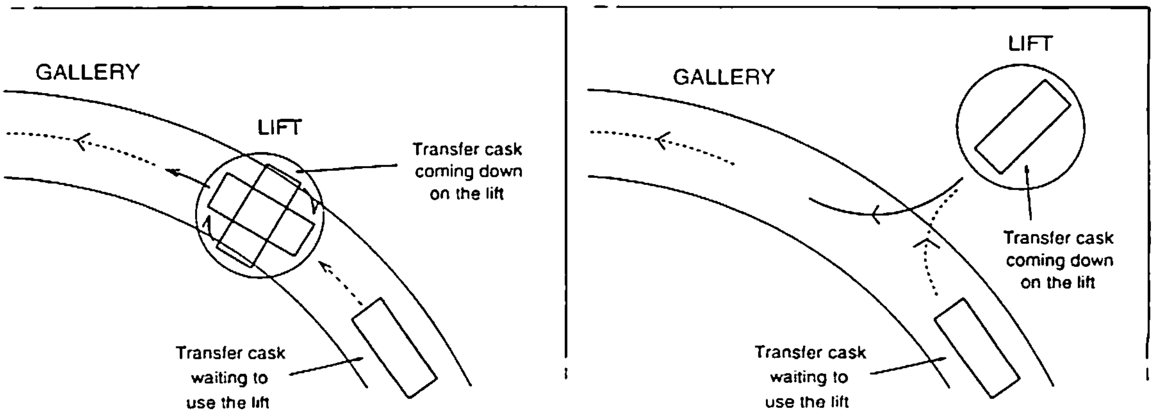
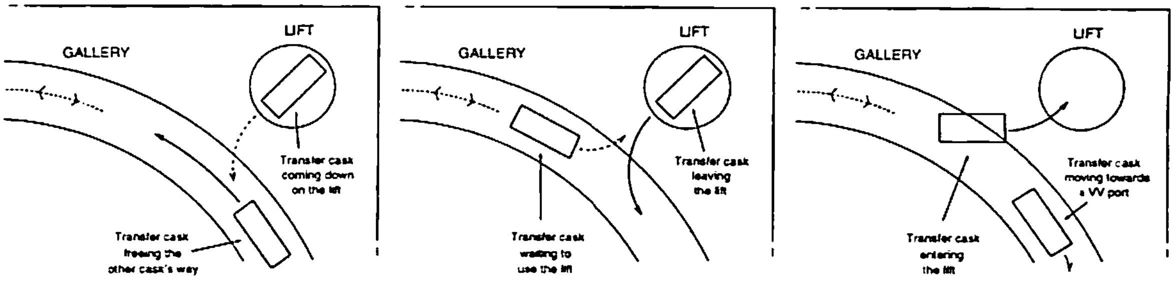


Figure 15: Schematic representation of two paths between lift and transfer corridor.



(a) The lift occupies the gallery (b) The lift is apart from the gallery

Figure 16: Waiting state when only unidirectional motion is allowed in the gallery.



(a) Step 1 (b) Step 2 (c) Step 3

Figure 17: Waiting state and manoeuvring when bidirectional motion is allowed in the gallery.

4.2.1 Cask crossovers between the lift and HCB corridor (B.1)

The simulations consider the situation when two casks (the one leaving a VV port and the one moving towards that port) move simultaneously. As the only considered possibility for crossover is on the way from the gallery lift to the HCB transfer corridor (see Figure 15), the lift is first used by the cask going up. The two physical paths represented on Figure 15 support the crossover, no manoeuvres being required.

The initial position of each cask is shown in Figure 12 and the order in which casks are transferred between VV ports and HCB ports is 1-5, 2-6, 3-7 and, finally, 4-8.

Unidirectional motion in the gallery (B.1.1)

Figure 18 presents the results of the simulation with crossovers between the lift and the HCB corridor and when only unidirectional motion is allowed in the gallery (see Figure 15). It shows that the total transfer time is 6h16m32s, the total waiting time of the casks are 2h24m48s and the total moving time is 7h23m12s. The total travelled distance is 1704 meters.

Bidirectional motion in the gallery (B.1.2)

If bidirectional motion is allowed in the gallery, the results are presented in Figure 19. It shows that the total transfer time is 5h14m40s, the total waiting time of the casks are 2h04m00s and the total moving time is 6h21m20s. The total travelled distance is 1240 meters.

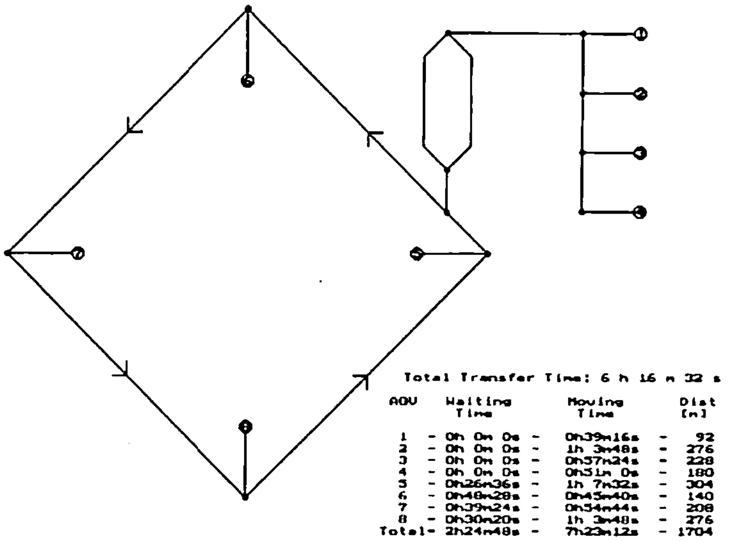
Discussion

The total travelled distances in simulations B.1.1 and B.1.2 are 10 meters smaller than those of simulations A.1 and A.2, respectively, because with casks moving simultaneously only four ports are required in the HCB.

These simulations show, once again, that it is advantageous to allow bidirectional motion in the gallery, as far as total travelling time is concerned.

Only the casks moving from the HCB to the VV have waiting times - each of them has to wait between the HCB corridor and lift for a cask coming from the VV.

Cask	Direction of movement in the gallery
1	anticlockwise
2	anticlockwise
3	anticlockwise
4	anticlockwise
5	anticlockwise
6	anticlockwise
7	anticlockwise
8	anticlockwise

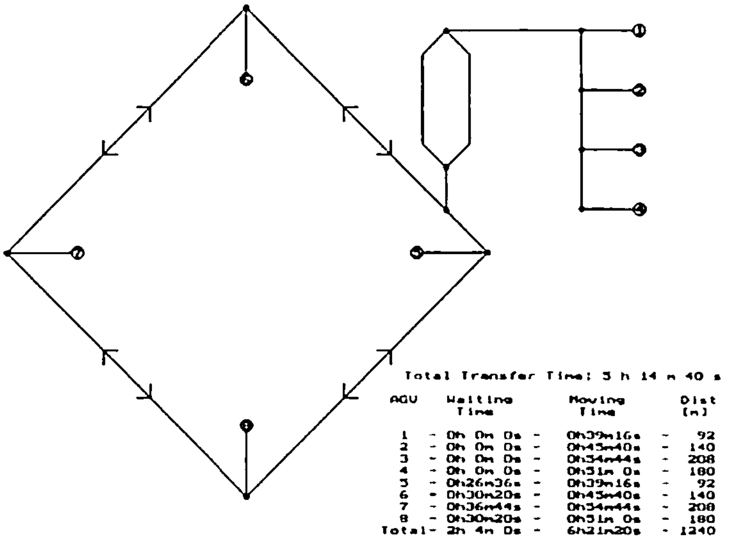


```
Total Transfer Time: 6 h 16 m 32 s
AGV    Waiting        Moving       Dist
        Time           Time        [m]

 1   - 0h 0m 0s -   0h39m16s   -    92
 2   - 0h 0m 0s -   1h 3m48s   -   276
 3   - 0h 0m 0s -   0h37m24s   -   228
 4   - 0h 0m 0s -   0h31m 0s   -   180
 5   - 0h26m36s -   1h 7m32s   -   304
 6   - 0h48m28s -   0h45m40s   -   140
 7   - 0h39m24s -   0h34m44s   -   208
 8   - 0h30m20s -   1h 3m48s   -   276
Total- 2h24m48s -   7h23m12s   -  1704
```

Figure 18: Simulation results for cask crossovers between the lift and HCB corridor and unidirectional motion in the gallery. Two casks moving simultaneously. Final stage of transfer cycle.

Cask	Direction of movement in the gallery
1	anticlockwise
2	clockwise
3	clockwise
4	anticlockwise
5	clockwise
6	anticlockwise
7	anticlockwise
8	clockwise



```
Total Transfer Time: 5 h 14 m 40 s
AGV    Waiting        Moving       Dist
        Time           Time        [m]

 1   - 0h 0m 0s -   0h39m16s   -    92
 2   - 0h 0m 0s -   0h45m40s   -   140
 3   - 0h 0m 0s -   0h34m44s   -   208
 4   - 0h 0m 0s -   0h31m 0s   -   180
 5   - 0h26m36s -   0h39m16s   -    92
 6   - 0h30m20s -   0h45m40s   -   140
 7   - 0h36m44s -   0h34m44s   -   208
 8   - 0h30m20s -   0h31m 0s   -   180
Total- 2h 4m 0s -   6h21m20s   -  1240
```

Figure 19: Simulation results for cask crossovers between the lift and HCB corridor and bidirectional motion in the gallery. Two casks moving simultaneously. Final stage of transfer cycle.

4.2.2 Cask waiting state in the gallery near lift (B.2)

The simulations for situation B.2 consider that a single pair of casks leaving/reaching a specified VV port is moving at a time, this coinciding with the assumptions made for situation B.1.

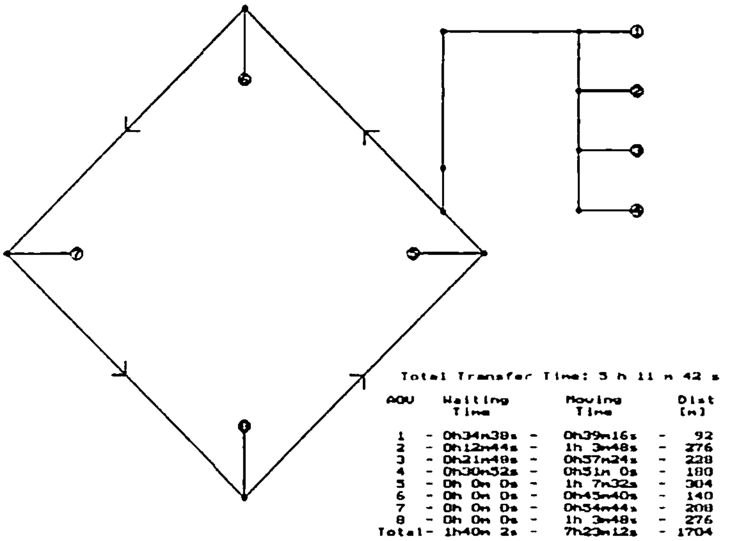
When B.2 is considered, the two referred casks will have to cross each other at the gallery level, near the lift. Therefore, the cask travelling from the HCB to the VV port will be the first to use the lift, while the second cask (the one that left the VV port) will be waiting near the lift to go up.

The initial position of each cask is shown in Figure 12 and the order in which casks are transferred between VV ports and HCB ports is 1-5, 2-6, 3-7 and, finally, 4-8.

Unidirectional motion in the gallery (B.2.1)

With cask waiting state in the gallery near the lift and with unidirectional motion in the gallery, the simulation results are those presented in Figure 20. Total transfer time is now 5h11m42s, total waiting time is 1h40m02s and total moving time is 7h23m12s. The total travelled distance is 1704 meters.

Cask	Direction of movement in the gallery
1	anticlockwise
2	anticlockwise
3	anticlockwise
4	anticlockwise
5	anticlockwise
6	anticlockwise
7	anticlockwise
8	anticlockwise



```
Total Transfer Time: 5 h 11 m 42 s

AGV     Waiting        Moving       Dist
         Time           Time         [m]

 1   - 0h34m38s -   0h39m16s   -     92
 2   - 0h12m44s -   1h 3m48s   -    276
 3   - 0h21m48s -   0h57m24s   -    228
 4   - 0h30m52s -   0h51m 0s   -    180
 5   - 0h 0m 0s -   1h 7m32s   -    304
 6   - 0h 0m 0s -   0h45m40s   -    140
 7   - 0h 0m 0s -   0h54m44s   -    208
 8   - 0h 0m 0s -   1h 3m48s   -    276
Total- 1h40m 2s -   7h23m12s   -   1704
```

Figure 20: Simulation results with casks waiting state in the gallery near lift and unidirectional motion in the gallery. Two casks moving simultaneously. Final stage of transfer cycle.

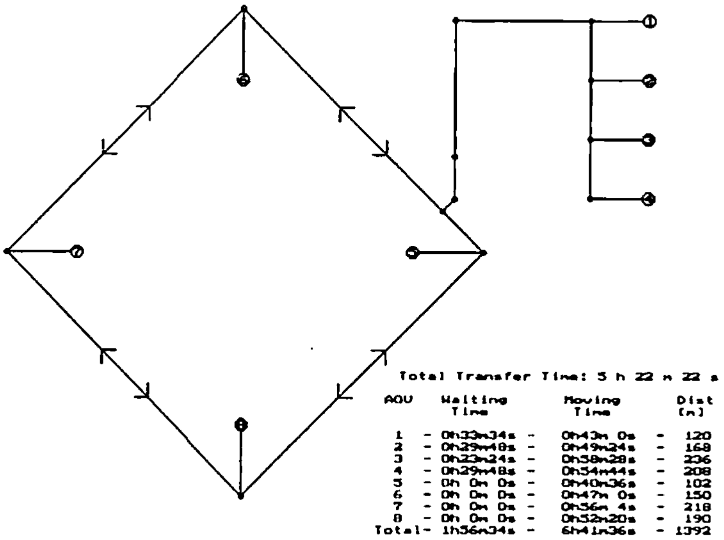
Bidirectional motion in the gallery (B.2.2)

Allowing bidirectional motion in the gallery, the results are those presented in Figure 21. Here, total transfer time is 5h22m22s, total waiting time is 1h56m34s and total moving time is 6h41m36s. The total travelled distance is 1392 meters.

Discussion

When waiting states are allowed in the gallery near the lift but not crossovers between

Cask	Direction of movement in the gallery
1	anticlockwise
2	clockwise
3	clockwise
4	anticlockwise
5	clockwise
6	anticlockwise
7	anticlockwise
8	clockwise



```
Total Transfer Time: 5 h 22 m 22 s
 AGV   Waiting        Moving       Dist
        Time           Time         (m)

  1   - 0h33m34s -   0h43m 0s   -   120
  2   - 0h29m48s -   0h49m24s   -   168
  3   - 0h23m24s -   0h38m28s   -   236
  4   - 0h29m48s -   0h54m44s   -   208
  5   - 0h 0m 0s -   0h40m36s   -   102
  6   - 0h 0m 0s -   0h47m 0s   -   150
  7   - 0h 0m 0s -   0h36m 4s   -   218
  8   - 0h 0m 0s -   0h52m20s   -   190
Total- 1h36m34s -   6h41m36s   -  1392
```

Figure 21: Simulation results with casks waiting state in the gallery near lift and bidirectional motion in the gallery. Two casks moving simultaneously. Final stage of transfer cycle.

the lift and the HCB corridor, the advantage of bidirectional motion in the gallery concerns only the total travelled distance. The smaller travelled distance requires, however, manoeuvres for the casks going up.

When bidirectional motion in the gallery is allowed, the total transfer time becomes slightly higher. This is due to the 10 meters path introduced between the gallery and the lift that are not compensated with a length reduction of other paths.

4.2.3 Cask crossovers between the lift and HCB corridor and casks waiting state in the gallery near lift (B.3)

In this case, a combination of cask crossovers between the lift and the HCB transfer corridor and cask waiting states in the gallery near the lift is used to solve traffic congestions. Being so, the first cask to use the lift is not constrained, i.e., for each pair of casks to transfer, both the cask coming from the HCB and the cask coming from a VV port may be the first to use the lift.

To optimize its usage, the lift carries a cask for every trip. Thus, if the last cask to use the lift was coming down, the next cask to use it is one willing to go up. Therefore, the first cask to use the lift – the cask coming from the HCB or the one that left a VV port – is the same for all pairs of casks to transfer.

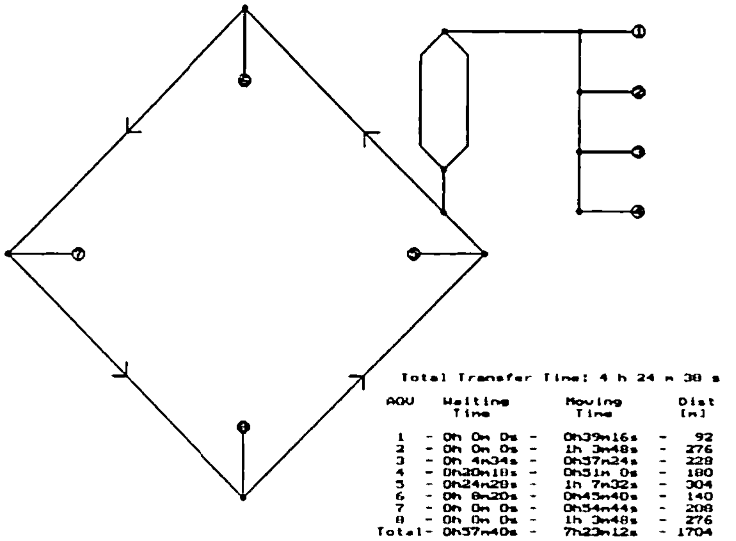
The order in which the pairs of casks should be transferred also affects the total transfer time, though in some cases by a very small amount. To optimize once again lift usage, the first pair to transfer should be the one with casks initial location closer to the lift. The last pair to transfer should have casks destinations close to the lift to minimize the time consumed with the lift already stopped. Confirmed through experiments, the shortest time consuming transfer cycle is accomplished when the order to transfer pairs of casks is 1-5, 4-8, 3-7 and finally 2-6.

The results presented in the sequel correspond to the best schedule of cask pairs being transferred with the initial position of each cask shown in Figure 12.

Unidirectional motion in the gallery (B.3.1)

Figure 22 presents the results of the simulation having crossovers in the gallery near the lift and between the lift and the HCB corridor and having unidirectional motion in the gallery. Total transfer time is 4h24m38s, total waiting time is 57m50s and total moving time is 7h23m12s being the total travelled distance 1704 meters.

Cask	Direction of movement in the gallery
1	anticlockwise
2	anticlockwise
3	anticlockwise
4	anticlockwise
5	anticlockwise
6	anticlockwise
7	anticlockwise
8	anticlockwise



```
Total Transfer Time: 4 h 24 m 38 s

AGV    Waiting        Moving        Dist
        Time           Time          [m]

 1   - 0h 0m 0s  -  0h39m16s  -    92
 2   - 0h 0m 0s  -  1h 3m48s  -   276
 3   - 0h 4m34s  -  0h37m24s  -   228
 4   - 0h30m18s  -  0h51m 0s  -   180
 5   - 0h24m28s  -  1h 7m32s  -   304
 6   - 0h 8m20s  -  0h43m40s  -   140
 7   - 0h 0m 0s  -  0h54m44s  -   208
 8   - 0h 0m 0s  -  1h 3m48s  -   276
Total- 0h57m40s  -  7h23m12s  - 1704
```

Figure 22: Simulation results for cask crossovers between the lift and HCB corridor, waiting states in the gallery near lift and unidirectional motion in the gallery. Two casks moving simultaneously.

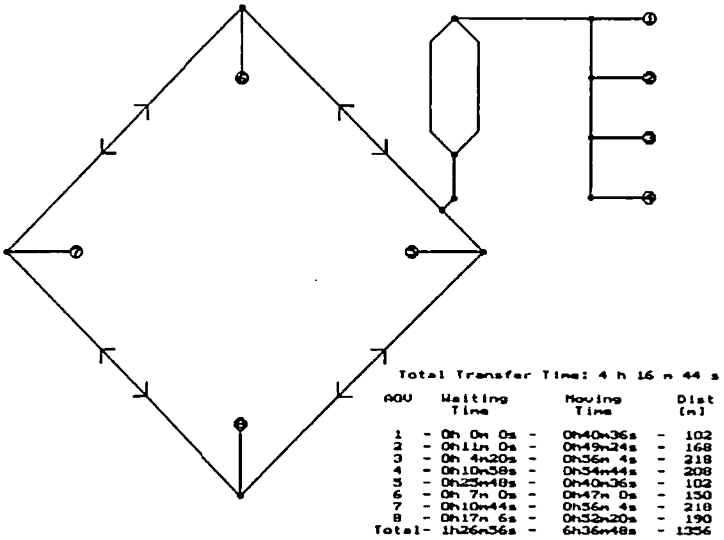
Bidirectional motion in the gallery (B.3.2)

Allowing bidirectional motion in the gallery, two simulations were done with two and four as the maximum number of casks moving simultaneously.

With two casks moving simultaneously, total transfer time is 4h16m44s, total waiting time is 1h26m56s and total moving time is 6h36m48s. The total travelled distance is 1356 meters (see Figure 23).

Under this simulation scenario, the possibility of simultaneously moving four casks was also tested, in order to check whether it was advantageous to reduce total transfer time. With four casks moving simultaneously, total transfer time is 4h16m44s, total waiting time is 7h36m28s and total moving time is 6h36m48s. The total travelled distance is 1356 meters (see Figure 24).

Cask	Direction of movement in the gallery
1	anticlockwise
2	clockwise
3	clockwise
4	anticlockwise
5	clockwise
6	anticlockwise
7	anticlockwise
8	clockwise

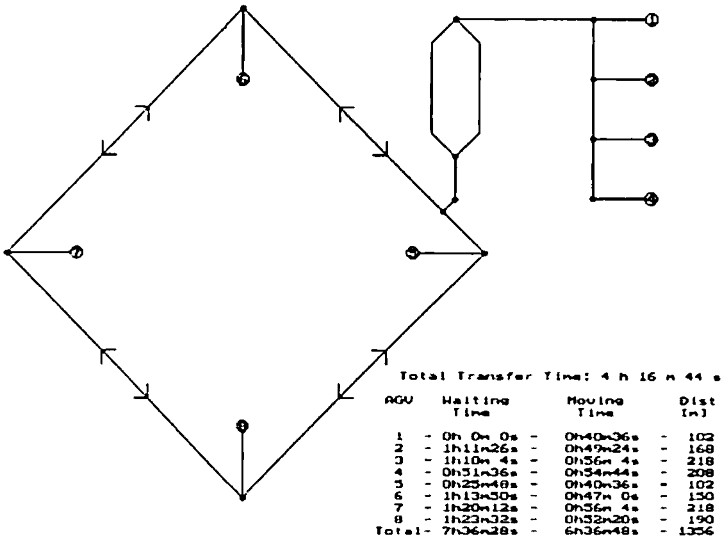


```
Total Transfer Time: 4 h 16 m 44 s
AGV   Waiting        Moving      Dist
       Time           Time        [m]

 1   - 0h 0m 0s  -   0h40m36s  -   102
 2   - 0h11m 0s  -   0h49m24s  -   168
 3   - 0h 4m20s  -   0h36m 4s  -   218
 4   - 0h10m58s  -   0h34m44s  -   208
 5   - 0h25m48s  -   0h40m36s  -   102
 6   - 0h 7m 0s  -   0h47m 0s  -   150
 7   - 0h10m44s  -   0h36m 4s  -   218
 8   - 0h17m 6s  -   0h32m20s  -   190
Total- 1h26m36s  -   6h36m48s  -  1356
```

Figure 23: Simulation results for cask crossovers between the lift and HCB corridor, waiting states in the gallery near lift and bidirectional motion in the gallery. Two casks moving simultaneously.

Cask	Direction of movement in the gallery
1	anticlockwise
2	clockwise
3	clockwise
4	anticlockwise
5	clockwise
6	anticlockwise
7	anticlockwise
8	clockwise



```
Total Transfer Time: 4 h 16 m 44 s
AGV   Waiting        Moving      Dist
       Time           Time        [m]

 1   - 0h 0m 0s  -   0h40m36s  -   102
 2   - 1h11m26s  -   0h49m24s  -   168
 3   - 1h10m 4s  -   0h56m 4s  -   218
 4   - 0h51m36s  -   0h54m44s  -   208
 5   - 0h25m48s  -   0h40m36s  -   102
 6   - 1h13m50s  -   0h47m 0s  -   150
 7   - 1h20m12s  -   0h56m 4s  -   218
 8   - 1h23m32s  -   0h32m20s  -   190
Total- 7h36m28s  -   6h36m48s  -  1356
```

Figure 24: Simulation results for cask crossovers between the lift and HCB corridor and in the gallery near lift and bidirectional motion in the gallery. Four casks moving simultaneously.

Discussion

In this case, bidirectional motion in the gallery brings major reductions to the total transfer time and to the total travelled distance.

With bidirectional motion in the gallery, the increase from two to four, on the number of casks moving simultaneously, leads to no advantage: the total transfer time, the total moving time and total travelled distance remain the same. However, the total waiting time changes (from 1h26m for two casks to 7h36m for four casks). This is due to the fact that with two casks moving simultaneously, the lift is already continuously used. The main conclusion is that the lift, namely the total time spent on lift related operations, is the major bottleneck of the whole system.

4.3 Comments and conclusions

In this sub-section, some comments and conclusions are presented regarding the results of the simulations on cask transfer. To simplify the analysis, a summary of system performance for each simulation is presented in Table 5.

Simulated situation			Transfer time	Travelled distance
One cask moving at a time A	Unidirectional motion in the gallery A.1		7h24m38s	1714 m
	Bidirectional motion in the gallery A.2		6h22m46s	1250 m
Two casks moving simultaneously B	Cask crossovers B.1	Unidirectional motion in the gallery B.1.1	6h16m22s	1704 m
		Bidirectional motion in the gallery B.1.2	5h14m40s	1240 m
	Waiting state in the gallery near the lift interface B.2	Unidirectional motion in the gallery B.2.1	5h11m42s	1704 m
		Bidirectional motion in the gallery B.2.2	5h22m22s	1392 m
	cask crossovers and waiting state B.3	Unidirectional motion in the gallery B.3.1	4h24m38s	1704 m
		Bidirectional motion in the gallery B.3.2	4h16m44s	1356 m

Table 5: Simulations and results.

If neither cask crossovers between the lift and the HCB transfer corridor nor cask waiting states in the gallery are allowed, it is not possible to have more than one cask moving at a time. In this case (simulations **A.1** and **A.2**), the total moving time equals total transfer time and no waiting time exists.

When more than one cask is allowed to move simultaneously, only four ports are needed in the HCB. In this case, total transfer time is smaller than total moving time because there are simultaneous movements.

With bidirectional motion in the gallery, total travelled distance is significantly reduced because each casks uses the shortest path between the lift and the VV port. Generally, bidirectional motion also reduces total transfer time. The management effort increases because, for each vehicle in the gallery, the direction it should move towards must be decided. Nevertheless, personal stress is reduced due to smaller transfer time.

When bidirectional motion in the gallery and cask waiting states in the gallery near the lift are allowed total travel distance slightly increases, due to manoeuvres.

Both cask crossover between lift and HCB corridor and cask waiting states in the gallery cause increased management effort, because operators must decide which cask should move and which cask should wait. This decisions may be suggested by an automatic system, thus reducing human error probabilities.

The smallest transfer time occurs when cask crossovers and waiting states are allowed (simulation B.3.2). With two casks moving simultaneously, the lift is optimally used. Therefore, allowing four casks to move simultaneously does not improve transfer time.

Reducing the total travelled distance is an important achievement because it leads to higher power autonomy of the casks and/or lower capacity (thus lighter) batteries. It also decreases fault probability of vehicles increasing their reliability.

Smaller total transfer time means more access time to the VV building that can be used for other operations, e.g. maintenance. It also increases power autonomy and/or allows lighter batteries. Battery charging may also take place in the time left. It should be noted that reductions on total transfer time were obtained without increasing vehicles velocities.

Two major conclusions were taken from the simulations:

- The gallery lift is the major bottleneck of the whole system. The smaller transfer time is obtained when lift is optimally used. This occurs when it is always occupied, i.e., when a cask leaves it another cask is already waiting to use it. Should lift performance be improved, transfer times would decrease in all studied cases.
- Bidirectional motion in the gallery reduces total travel distance and, consequently, total transfer time.

5 Communication With the Vehicles

This section covers several communication systems identified in industry. The aim of these systems is to provide a continuous, bidirectional and reliable way to communicate with all vehicles, at every location, so that orders can be sent to the vehicles and information can be gathered from them (e.g., battery status, speed).

5.1 Communications Via Electrical Cable (inductive guidepath)

This is a common communication system used in industry [Hammond]. There are two approaches to this problem: one relays on communication through the same wire that carries the guidepath signal (continuous communication - multiplexing); the other makes use of two extra wires, one for emission and other for reception. This late option is usually discrete i.e. emission/reception antennas are placed at predefined places. This last option is further discarded because it does not allows teleoperation.

Advantages

- A single physical system is used for vehicle guidance and communications;
- Industrial applications have been identified (see Appendix);
- Being buried beneath the floor, the system is immune to external aggressions and thus reliable;

Disadvantages

- Cannot be used without care near magnetic fields (e.g., large motors);
- It is suitable for use with inductive guidance only;
- If there is a problem with the cable, communications and guidance are lost;
- Vehicle control has to be very accurate, in order to keep the vehicle near the track - low flexibility. This does not allow continuous communication with mixed type vehicles when they are not on the fixed track.

5.2 Infrared (IR)

Infrared communications are usually used in discrete communication systems, where vehicles communicate only at predefined communications stations.

Advantages

- High immunity to electrostatic and magnetic noise;
- Industrial applications have been identified (see Appendix);

Disadvantages

- Short distances;
- Directional;

To be determined

- Immunity to natural and artificial light;
- Bandwidth;

5.3 Radio Link

This concept is currently used in many industries, with good results. Wireless ethernet links are the favorite and will be analyzed further.

Advantages

- Allows bidirectional communications;
- Very simple to install;
- Omnidirectional (in a spatial way);
- Does not imply physical links to the vehicle;
- Simplifies communications because a vehicle can be seen as a node in the vehicles network;
- Large bandwidth [10-100 Mbits];

Disadvantages

- Short distances – to allow communications in all locations, antennas must be placed in strategic points;
- Low immunity to electrostatic and magnetic noise;

5.4 Umbilical Cable

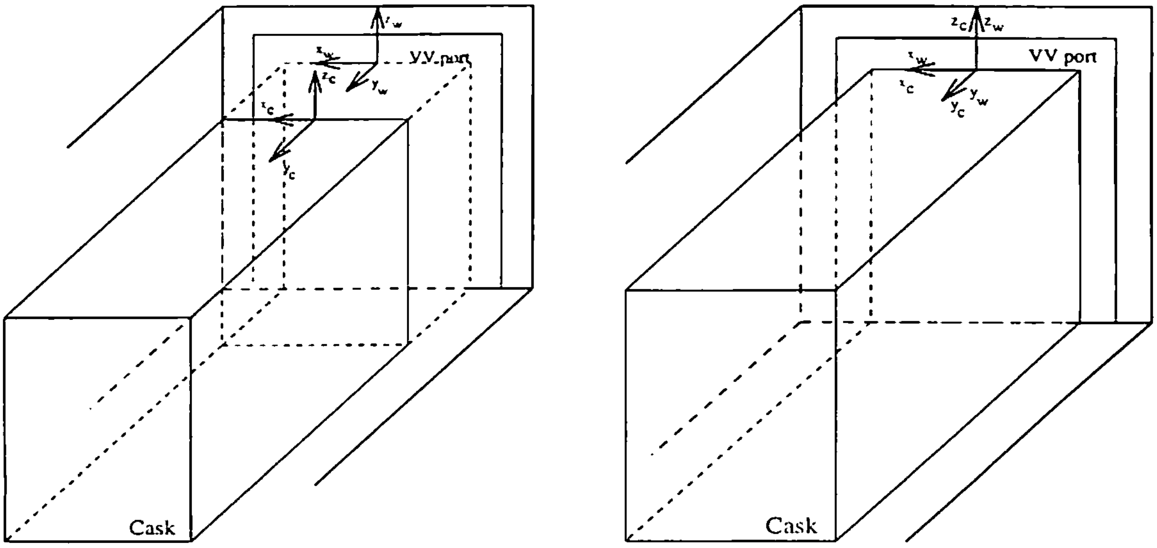
This option is not to be considered further since it implies a physical link to the vehicles, which reduces flexibility.

6 Docking

To dock a RH transport cask on the docking ports, both in the VV building and the HC building, precise positioning must be available in the vicinity of these ports.

When docking a mobile platform to a docking port, there will always be small position and orientation errors in the vicinity of the docking port. This small error will exist for any type of guidance solution used to approach the docking port (optical, inductive, virtual or mixed guidepath). Note that when approaching the docking port, the vehicle is aligned with the path used by the guidance system. Therefore, the error in position and orientation will be as small as the guidance error (less than 1 centimeter in position with a *laser* system - See Appendix (NDC)). Besides position and orientation errors induced by the navigation system, the VV building may move with respect to the building where the RH transfer cask operates. As a consequence of both types of errors, there must be special equipment to assist the docking procedures. Docking equipment must be able to provide information on vehicle displacement relative to the VV building and on the misalignment between buildings, so that the vehicle can be steered to align itself accurately with the docking port.

Figure 25 shows a schematic representation of a) a cask approaching a docking port, and b) a cask docked to a docking port. Note that in each of those figures there are two frames. One of the frames is linked to the cask $\{C\}$ and the other one is linked to the docking port ($\{W\}$ - world frame). A cask is considered docked when its frame $\{C\}$ is perfectly coincident with the world frame.



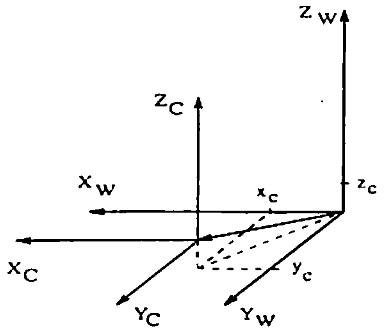
a) Cask approaching docking port.

b) Cask docked.

Figure 25: Docking phase

In this particular problem, six degrees of freedom (dof) misalignments (3 dof in position and 3 dof in orientation) may occur in the general case. The six degrees of freedom are represent by x, y, z for position, and *roll*, *pitch* and *yaw* for orientation (See Figures 26 and 27).

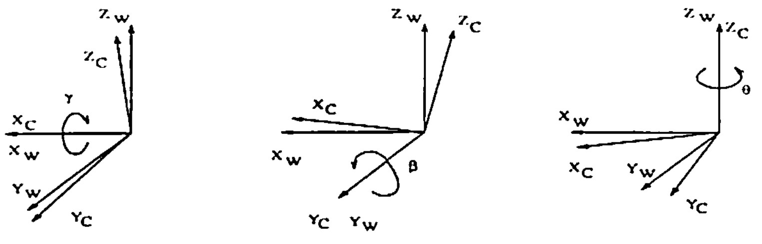
Figure 26 shows a schematic representation of the effect of buildings plus vehicle misalignment concerning position.



Translation

Figure 26: Schematic representation of translation misalignment

Figure 27 presents a schematic representation of the contributions to the orientation misalignment that may exist between the two frames. In these figures the frames are shown with coincident origins, which corresponds to null position error.



a) Roll b) Pitch c) Yaw

Figure 27: Schematic representation of possible rotational misalignment

Figure 28 presents a schematic representation of the misalignments presented in Figure 27 when applied to the buildings, and represented as seen by someone in the gallery.

The rotational misalignment of the buildings may be a combination of three different movements [6]:

- *Roll* - The frame $\{C\}$ rotates over X_W (See Figure 27 - a). The vertical axis of both frames are no longer aligned and therefore the planes containing the transfer

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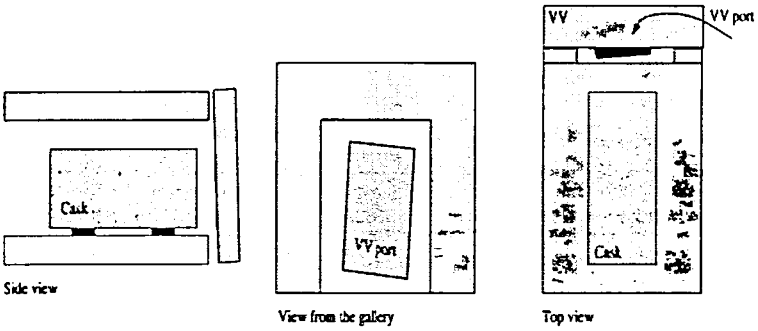
[6] Different notations for these angles are also used.



a) Roll b) Pitch c) Yaw

Figure 28: Schematic representation of buildings misalignment, seen from the gallery

cask door and the VV docking port are no longer parallel. See Figure 28 - a, where representation is done as seen from the gallery.

- *Pitch* - The frame $\{C\}$ rotates over Y_W (See Figure 27 - b). Therefore, the vertical axis of both frames are no longer aligned, eventhough the cask door and the VV docking port remain parallel. The referred planes are parallel, but the four borders of both doors do not coincide. See Figure 28 - b, where representation is done as seen from the cask.

- *Yaw* - The frame $\{C\}$ rotates over the Z_W axis (See Figure 27 - c) and, eventhough the vertical axis Z_W and Z_C remain coincident, the planes containing the transfer cask door and the VV docking door are no longer parallel. In fact, in this situation the horizontal borders of both doors are oblique, while the vertical borders remain parallel. See Figure 28 - c, where representation is done as seen from the gallery.

The vehicle steering equipment can only correct the *Yaw* angle, θ, and the translational error in the $x-y$ plane. Other strategies must be used to correct eventual misalignments in *roll*, *pitch* and the translational error in z. Other strategies must be used to correct eventual misalignments in *roll*, *pitch* and on the translational error in z. A possible solution is to use hydraulic actuators. With four hydraulic lifts in the vehicle, arranged in such a manner that they can change the container orientation (e.g., if placed in the corners), the *roll* and *pitch* effects can be corrected. With these actuators, the z component of the container can also be corrected. Note that this type of solution can only correct small misalignments.

6.1 Docking Procedure

In order to accomplish precise location relative to the docking door at VV building, a *laser* based system associated with triangulation is suggested. The information provided by this system is then used by the transfer cask controller (e.g., a teleoperator) in such a way that a minimum number of manoeuvres are executed to decrease the docking error. The use of triangulation in docking mobile platforms can be found in industrial applications (See Appendix) and is further detailed in sub-subsection 6.2.

As stated before, to dock a RH transfer cask, the cask and the docking port door must be parallel and aligned. To assure that these surfaces are in docking conditions, the use of triangulation based on a three *laser* system, combined with passive retroreflectors is proposed. This system is described in the sequel.

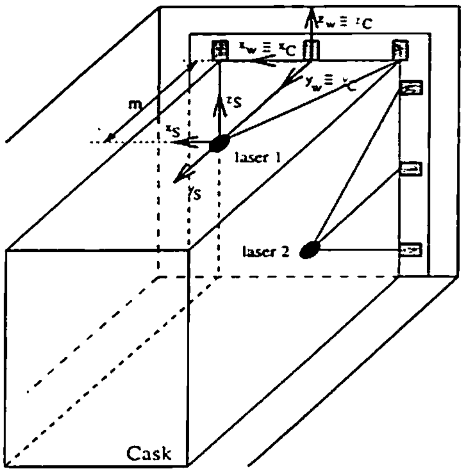


Figure 29: Laser systems and associated frames in a precisely docked cask

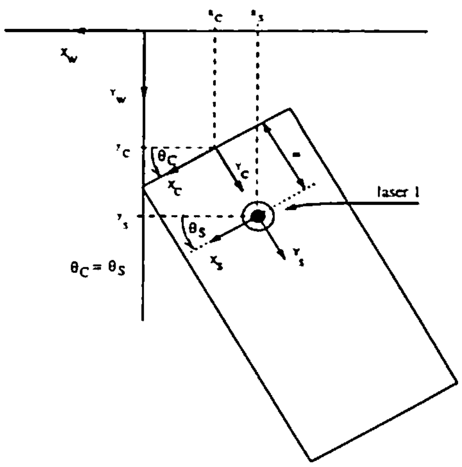


Figure 30: Position and orientation on $x-y$ plane

The proposed *laser* system is used as follows: a *laser* sub-system is placed at the top of the vehicle ($laser_1$). On the vehicle sides, two other *laser* sub-systems are placed ($laser_2$ and $laser_3$), one at each side, as illustrated in Figure 29[7]. Due to technological limitations, a minimum distance between the *laser* diode and the retroreflector is imposed. Therefore, the *laser* sensors must to be placed some fixed distance (m) apart from the transfer cask border. In the sequel, $laser_1$ is studied in detail. The study is directly applied to $laser_2$ and $laser_3$.

The frame associated with $laser_1$, referred as $\{S\}$ in Figure 29, is related to the cask frame $\{C\}$ by a translation m along Y_C. This coordinate transformation between the sensor frame $\{S\}$ and the vehicle frame $\{C\}$ is illustrated in Figure 30, being given by,

$$\left\{ \begin{array}{lcl} \theta & = & \theta_c = \theta_s \\ x_c & = & x_s + m \cdot \sin(\theta) \\ y_c & = & y_s - m \cdot \cos(\theta) \end{array} \right. \tag{9}$$

---

[7] Note that only one lateral sub-system is represented in the figure. This was done for the sake of simplicity.

Sub-system	Information
$laser_1$	x_s, y_s and $Yaw(\theta_s)$
$laser_2$	y_2, z_2 and $Roll_2(\gamma_2)$
$laser_3$	y_3, z_3 and $Roll_3(\gamma_3)$

Table 6: Information obtained from the *laser* sub-systems

Table 6 summarizes the information obtained by the three *laser* sub-systems, after processing the corresponding measurements. The casks absolute orientation in terms of $roll(\gamma_s)$, $pitch(\beta_s)$ and position in terms of z_s can be evaluated from the combined information of $laser_2$ and $laser_3$, as follows:

$$z_s = \frac{z_2 + z_3}{2} \tag{10}$$

$$\beta_s = Pitch = \arcsin(\frac{z_2 - z_3}{CW}) \tag{11}$$

$$\gamma_s = Roll = \frac{\gamma_2 + \gamma_3}{2}, \tag{12}$$

where CW represents the vehicle width.

Note that y_2 and y_3 might also be used to obtain a redundant evaluation of y_s.

The proposed docking procedure is implemented along the following lines: the transfer cask approaches the vicinity of the docking port in a fixed guidance mode. When in the near vicinity, and as soon as the laser sensors are able to detect the retroreflectors, the control is switched to a sensor-based mode. In fact, the vehicle can no longer follow the hard path defined in the gallery, since it will have to accurately dock to a VV port door and this door, being in a different building structure, may present misalignment in z, *roll* and *pitch*. In the sensor-based mode, the controller uses the knowledge of its location with respect to the VV docking door, to head towards this door.

6.2 Triangulation

Triangulation is a mathematical procedure developed to evaluate position and orientation based on angles measured to points whose absolute location is known. In a 2D world, three angles are enough for absolute localization, where absolute localization refers to position and orientation. This concept is widely used in mobile robotics and will be further detailed.

The proposed triangulation scheme is illustrated in Figure 31. Measurements are done with a *laser* device that obtains the angles with which three collinear retroreflective marks placed on previously known locations are detected. From the measured angles and the previously known distances between reflectors (d), position and orientation are unambiguously calculated.

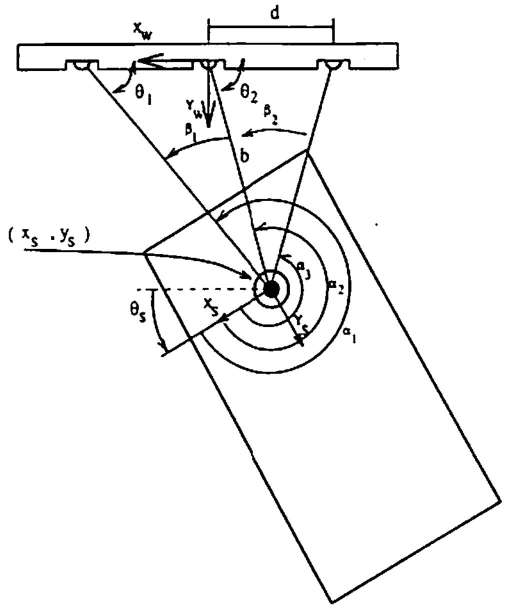


Figure 31: Triangulation setup

Given the position of the three collinear reflective marks and the measured angles to each of them, α_1, α_2, α_3, the following relations can be established (See [IRIL] for extra details):

$$\beta_1 = \alpha_1 - \alpha_2 \tag{13}$$

$$\beta_2 = \alpha_2 - \alpha_3 \tag{14}$$

$$\tan(\theta_2) = \frac{2 \cdot \tan(\beta_2) \cdot \tan(\beta_1)}{\tan(\beta_2) - \tan(\beta_1)} \tag{15}$$

$$\theta_1 = \theta_2 - \beta_1 \tag{16}$$

$$x_s = -b \cdot cos(\theta_2) \tag{17}$$

$$y_s = -x_s \cdot tan(\theta_2) \tag{18}$$

Rearranging the previous expressions so that they do not depend on b leads to

$$x_s = -\frac{d}{\tan(\beta_1)} \cdot \frac{\tan(\theta_2) - \tan(\theta_1)}{1 + \tan^2(\theta_2)} \tag{19}$$

$$y_s = \frac{d}{\tan(\beta_2)} \cdot \frac{\tan(\theta_2) - \tan(\theta_1)}{1 + \tan^2(\theta_2)} \cdot \tan(\theta_2) \tag{20}$$

$$\theta_c = \theta_s = 2\pi - \alpha_1 - \theta_2 + \beta_1 \tag{21}$$

The above equations yield the unambiguous computation of position (x_s and y_s) and orientation (θ_s) of the $\{S\}$ frame with respect to the $\{W\}$ frame, in a 2D world, based only on three measured angles (α_1, α_2 and α_3). Note that the $\{S\}$ frame and the $\{C\}$ frame are related by a fixed transformation that does not depend on cask location relative to the world frame.

In order to obtain good estimates of position and orientation, accurate measurements of the angles α_1, α_2 and α_3 must be provided. To obtain such measurements, a rotating *laser* system is proposed. In the sequel this system if further detailed.

Equations (19) - (21) were derived in an ideal situation when no *roll* or *pitch* error occur. In the particular docking problem under study, building misalignments will most likely introduce non null *roll* and/or *pitch* angles during the docking approach phase relative to the $\{W\}$ frame. In that case, the angles readings will have some noise introduced by those rotations. Since the orientation errors are small (they reflect the buildings misalignments), the introduced noise will not have large amplitudes.

6.2.1 The rotating *Laser* device

Figure 32 shows a schematic representation of a typical industrial *laser* unit. This sensor is based on the following principle: while rotating at constant speed, a *laser* beam is emitted by a special device which is also the receiver. For each rotation step the *received signal* is measured and stored. Therefore, at each rotation it is possible to know the angular displacements that correspond to the maximums in received energy. These maximums correspond to the reflectors angular positions relative to the sensor location. Note that these systems do not usually cover the entire 360 degrees range. A typical window range can usually go from 90 degrees to 120 degrees.

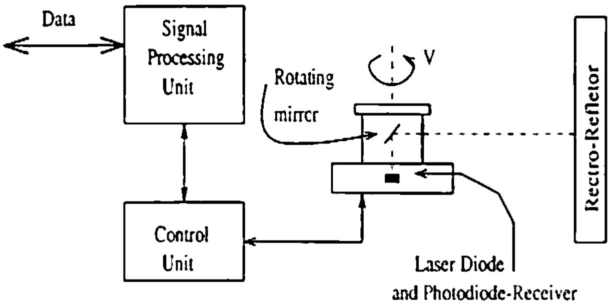


Figure 32: Typical *laser* unit

In a particular industrial sensor (See Appendix - Robosoft/Lasernet), the sensor can count 61440 pulses per revolution which leads to $\frac{360}{61440} \simeq 0.006°$ per pulse. With a 90 degrees window, the rotating *laser* can only count 15360 pulses to detect the reflectors.

Retroreflector

Associated to the proposed *laser* system there are retroreflectors. These are special devices that have the physical property of reflecting the incident light along the same direction of the corresponding incident ray. If using cylindrical retroreflectors, the measured angles are always referring to the center of the cylinder.

Calibration of *Laser* system

The performance of the triangulation system is highly dependent on the *laser* system calibration. Therefore, a special attention must be given to this issue. In order to accomplish the docking specifications both the retroreflectors placement and the *laser* sensors placement on the vehicles must be as precise as possible.

6.2.2 Errors in triangulation

When using a triangulation scheme to measure position and orientation, a common source of error is noise in the measured angles. Therefore it is important to know how a small error in one, two and/or three of the measurements affect the estimated position and orientation. To evaluate the effects of those errors, simulations were made. Note that the consequences of measurements errors on location evaluation are also a function of the distance between reflectors and of the distance from the *laser* sensor to the reflectors wall, as displayed in equations (13)-(18).

The graphics presented in Figures 33, 34 and 35, taken from the simulations, show the effects of errors in measurements for various geometric configurations. All of them are referred to the relations between the frames $\{S\}$ and $\{W\}$. It was considered that the platform real position was such that the center of the $laser_1$ is placed at ($x_s = 0$, $y_s = \ell \geq m$, $\theta_s = 0°$)[8] with no *roll* or *pitch* errors. Then noise was added to angle measurements taken from that location. The amplitude of the introduced noise was calculated from the resolution presented in the specifications of a commercial *laser* system. In that system, the resolution is 0.006°. The introduced noise has 0.024° maximum amplitude being added in steps of 0.006° (four steps).

Results are presented in the following way: For different values of ℓ, the distance from the *laser* sensor to the wall, several simulations are presented. For each simulation, the distance between reflectors (d) takes the values $50cm, 100cm$ and $150cm$. For each of these cases, two figures are presented, one for position and another for orientation.

Figures 33 shows the situation in which the sensor is placed 200 centimeters from the wall and the distance between reflectors (d) is 50 (a, b), 100 (c, d) and 150 (e, f) centimeters. It can be seen that the absolute errors in position and orientation decrease when the distance between reflectors gets larger.

Figures 34 shows the situation in which the sensor is placed 100 centimeters from

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[8] See Figure 29.

the wall and the distance between reflectors (d) is 50 (a, b), 100 (c, d) and 150 (e, f) centimeters.

Figure 35 shows the situation in which the sensor is placed 50 centimeters from the wall.

The simulations done (Figures 33, 34 and 35) show that the placement of the *laser* sensor is extremely important for the global performance. If the sensor is too far from the wall where the reflectors are placed, a small error in the measurement is amplified. On the other hand, if the sensor is too close there may be problems when the cask gets too close to the docking port because there is a minimum operation distance between the *laser* sensor and the retroreflective reflector. A typical minimum distance is 30 centimeters (See Appendix - Robosoft/Lasernet).

The presented figures also show that the errors in x_s are much reduced if distance between reflectors (d) is larger. On the other hand, it can be seen that the error in y_s is greatly influenced by the distance (ℓ) between the *laser* sensor and the reflectors wall. Table 7 summarizes the maximum deviations from the nominal values for x_s, y_s and θ_s.

ℓ [m]	d [m]	$x_s \pm \Delta x$ [m]	$y_s \pm \Delta y$ [m]	$\theta_s \pm \Delta\theta$ [degrees]
2.0	0.5	0.0 ± 0.0141	2.0 ± 0.0018	0.0 ± 0.396
2.0	1.0	0.0 ± 0.0042	2.0 ± 0.0010	0.0 ± 0.108
2.0	1.5	0.0 ± 0.0023	2.0 ± 0.0009	0.0 ± 0.054
1.0	0.5	0.0 ± 0.0021	1.0 ± 0.0005	0.0 ± 0.108
1.0	1.0	0.0 ± 0.0008	1.0 ± 0.0004	0.0 ± 0.036
1.0	1.5	0.0 ± 0.0006	1.0 ± 0.0005	0.0 ± 0.022
0.5	0.5	0.0 ± 0.0004	0.5 ± 0.0002	0.0 ± 0.036
0.5	1.0	0.0 ± 0.0002	0.5 ± 0.0003	0.0 ± 0.018
0.5	1.5	0.0 ± 0.0002	0.5 ± 0.0003	0.0 ± 0.014

Table 7: Comparative table on location errors

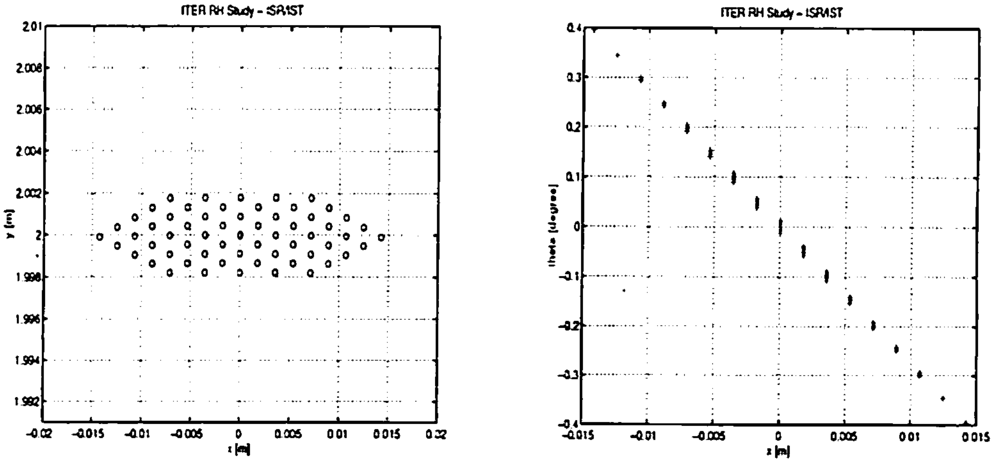
Simulations have shown that if the distance between reflectors is $d = 150$ centimeters, a value between $\ell = 50$ centimeters and $\ell = 100$ centimeters is a good choice for sensor placement. This value has a good compromise distance/performance.

Error propagation in this particular problem

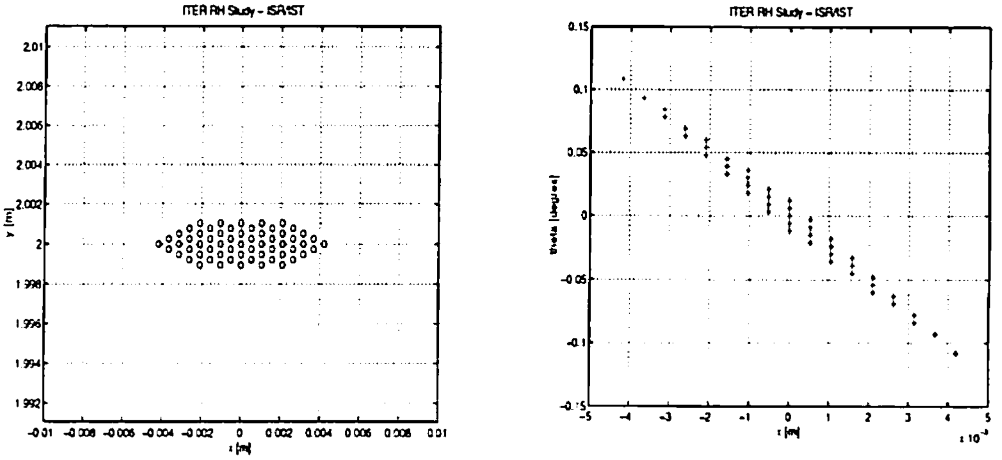
The results just presented refer to the location of the *laser*$_1$ relative to the VV docking port, or, stated in a more formal way, of the location of the $\{S\}$ frame relative to the $\{W\}$ frame.

As mentioned before, the vehicle frame $\{C\}$ and the sensor frame $\{S\}$ do not have coincident origins (See Figure 30). Therefore, besides knowing the effects of small errors in position and orientation in the $\{S\}$ frame, it is important to know their effect when propagated to the vehicle frame $\{C\}$. Once again only the effects of errors in one of the *laser* systems will be studied. For simplicity *laser*$_1$ is used.

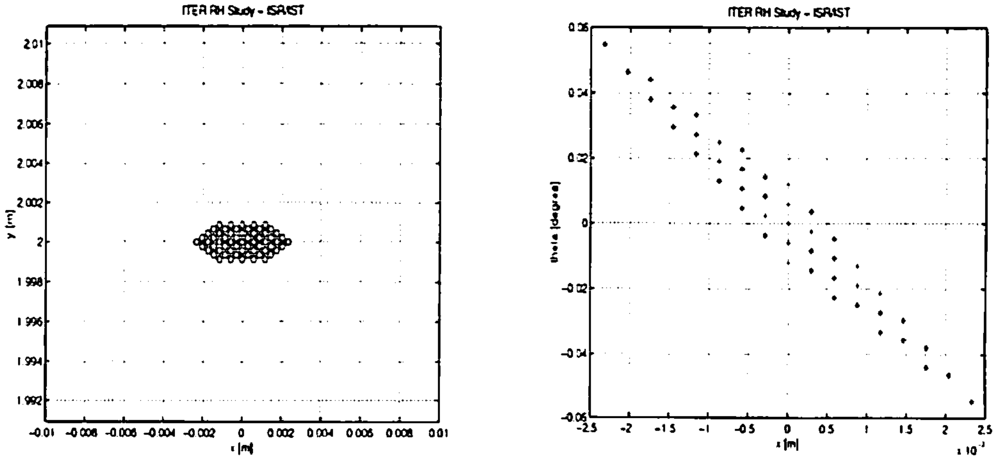
y_s=200 centimeters.



a) d=50 centimeters b) d=50 centimeters



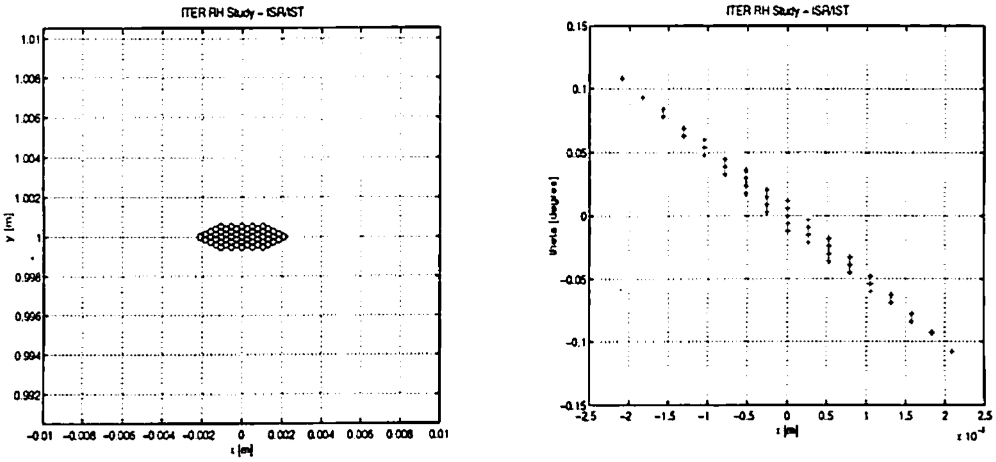
c) d=100 centimeters d) d=100 centimeters



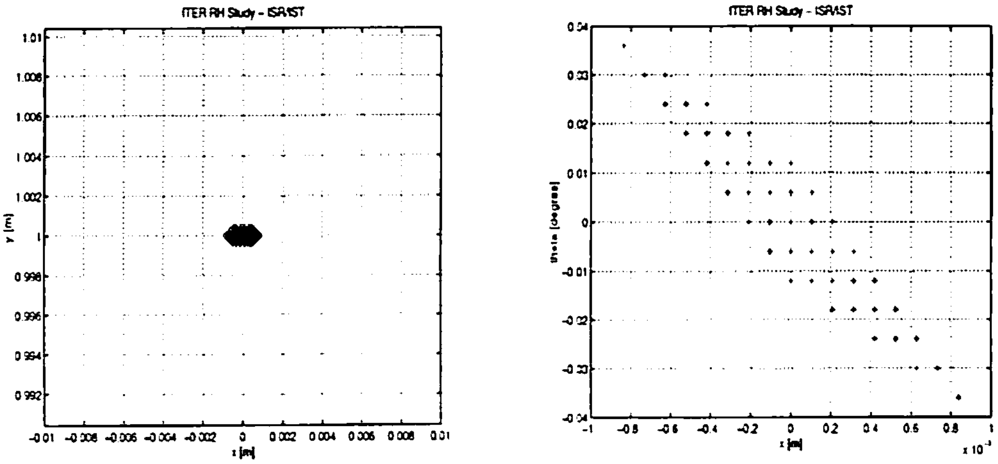
e) d=150 centimeters f) d=150 centimeters

Figure 33: Simulations made with sensor 200 centimeters from the wall

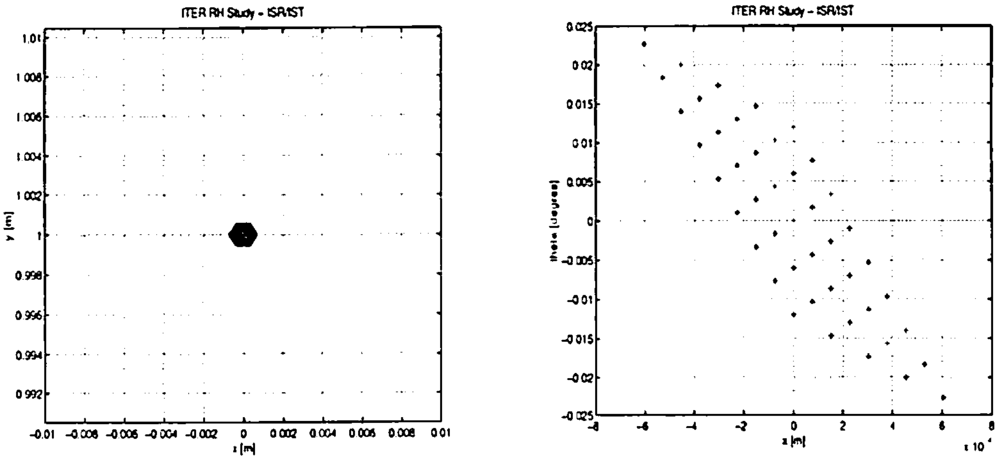
y_s=100 centimeters.



a) d=50 centimeters b) d=50 centimeters



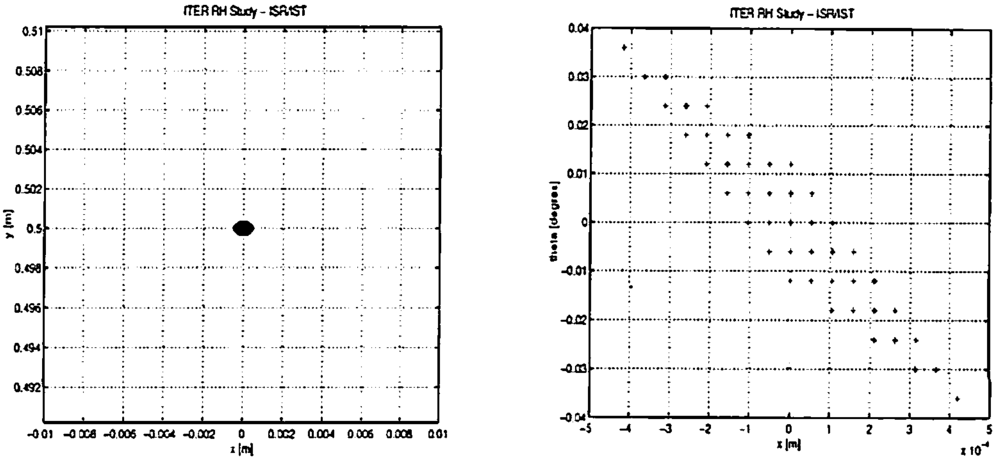
c) d=100 centimeters d) d=100 centimeters



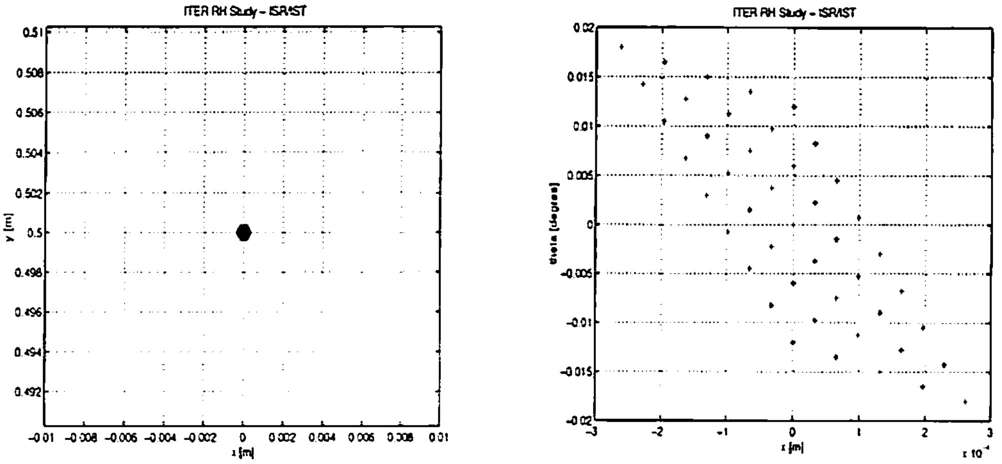
e) d=150 centimeters f) d=150 centimeters

Figure 34: Simulations made with sensor 100 centimeters from the wall

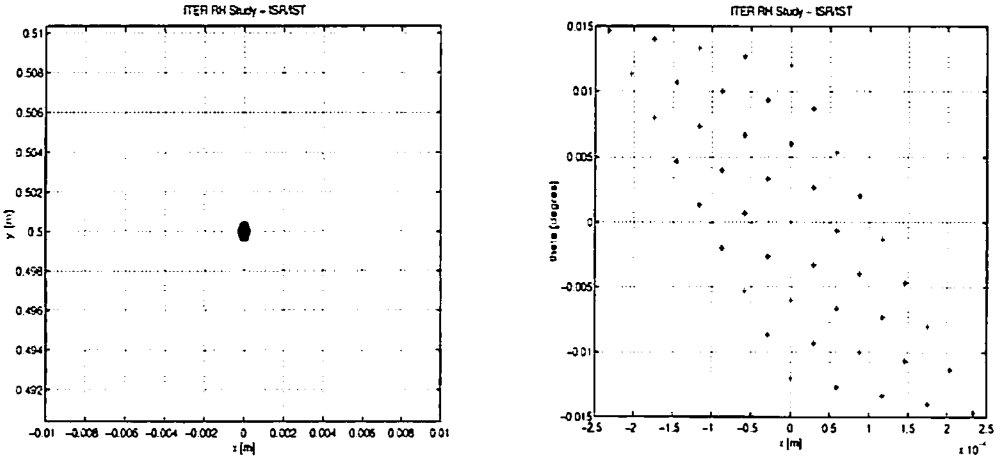
y_s=50 centimeters.



a) d=50 centimeters b) d=50 centimeters



c) d=100 centimeters d) d=100 centimeters



e) d=150 centimeters f) d=150 centimeters

Figure 35: Simulations made with sensor 50 centimeters from the wall

The set of equations (22),

$$\begin{cases} \theta &= \theta_c = \theta_s \\ x_c &= x_s + m \cdot \sin(\theta) \\ y_c &= y_s - m \cdot \cos(\theta) \end{cases} \tag{22}$$

represent the coordinate transformation between the sensor frame $\{S\}$ and the vehicle frame $\{C\}$. For a nominal situation in which $x_s = 0$, $y_s = m$ and $\theta_s = 0$ and assuming that Δx_s,.Δy_s and $\Delta\theta_s$ are the errors in position and orientation wields,

$$\begin{cases} x_s &= 0 + \Delta x_s \\ y_s &= m + \Delta y_s \\ \theta_s &= 0 + \Delta\theta_s \end{cases} \tag{23}$$

which replaced in (22) and considering that the orientation deviation is small, *i.e.*,

$$\cos(\Delta\theta) = 1, \qquad \sin(\Delta\theta) \simeq \Delta\theta, \tag{24}$$

leads to the errors on the $\{C\}$ frame around the nominal solution $x_c = 0$, $y_c = m$ and $\theta_c = 0$,

$$\begin{cases} \Delta x_c &= \Delta x_s + m \cdot \Delta\theta \\ \Delta y_c &= \Delta y_s \\ \Delta\theta_c &= \Delta\theta_s \end{cases} \tag{25}$$

From equation (25) it is clear that small errors in θ are amplified by a factor proportional to the distance (m) between the vehicle frame and the sensor frame.

Example: Considering $m = 50$ centimeters and $d = 150$ centimeters, the maximum θ deviation is $\theta = 0.014°$. From equation (25) and the data presented in Table 7, one gets,

$$\begin{cases} \Delta\theta_c &= \pm 0.014° \\ \Delta x_c &= 0.0002 + 0.5 \cdot 0.014 \cdot \frac{\pi}{180} \simeq 0.0004[cm] \\ \Delta y_c &= 0.0003[cm] \end{cases} \tag{26}$$

6.3 Discussion — Conclusions

In this section we proposed an active solution for the ITER RH cask docking problem, based on three rotating laser systems located on the RH casks and nine retroreflectors located on the docking port (VV building side). The complete system is capable of providing to a teleoperator the position and orientation (localization) of the cask with respect to the VV docking port (located in different buildings) based on a triangulation method.

The localization errors were quantified based on the resolution of a typical commercial rotating laser system associated to three retroreflectors. Simulations for different distances between collinear retroreflectors and distances between the three retroreflectors and the emitting laser, led to the conclusion that it is possible to design such a system to assist the teleoperator with localization errors within ITER specifications for docking ($\pm 5mm$, see [JAHT]).

The results obtained are based on an error assumption for the laser system that must be verified in practice. The localization errors obtained are reasonably better than those claimed by similar commercial systems *used for navigation and guidance along a path* (see Appendix). However, it should be pointed out that the *docking problem* has special characteristics which clearly improve the performance of the localization system: the rotating laser and the retroreflectors are located within a small area (rectangle with 1–2 meter sides) and the manoeuvres are made at slow velocities. Actually, to validate our simulation, we increased the distances between retroreflectors and between those and the laser system to 5-10 meter, and accuracies similar to the described by well established manufacturers were obtained.

It is important to mention that final accuracy is also dependent on the resolution of the actuation systems used. This is a topic which deserves further study. Based on the localization information, the sequence of docking operations to be undertaken by a teleoperator, and the corresponding actuators, should be the following:

1. *roll* and *pitch* corrections by hydraulic actuators;
2. z corrections by hydraulic actuators;
3. x, y and *yaw* corrections by the steering/driving wheels.

The main advantage of active docking over its passive counterpart is the possibility of remote assisted, *vs* local, hands-on operation. In the former, the localization information may be complemented by suggestions to the operator on the required corrections. In the latter, passive compliance and contact between the cask and the docking port are requirements for the success of the docking operation.

Also, there is some redundancy on the computation of the localization errors (e.g., y, may be determined by the top laser system and from a combination of the information provided by the two lateral laser systems). This increases the robustness of the information provided to teleoperator to assist her/him in the correction manoeuvres.

7 On-board Computers

Although a centralized control system is required, some tasks should be performed locally. This frees central computers from low-level processing, distributes information over the system, lowers required bandwidth and raises reliability. Central computers monitor all actions and perform high level tasks (e.g., path planning). Teleoperation, a strong requirement of the ITER RH transport system, is based on a central computer. Operators should be able to intervene at different levels - from a high-level order as dock to a low-level command as steer the vehicle 20°. This is easier to implement if the vehicles have some on-board intelligence which can handle this kind of low level tasks. On-board intelligence can be spread over the system, by distributing the tasks over different computers running simultaneously.

Examples of on-board computers tasks are:

- Acquire sensor data and pre-process it (e.g., noise filtering and feature extraction).
- Communications management;
- Motor control - steering and driving.
- Battery level monitoring;
- Obstacle detection. When processing data from obstacles on the vehicle near vicinity, action has to be taken in a short time interval which may not be compatible with the time interval spent to communicate with the central computers.
- Emergency procedures (e.g., power down motors in case of collision);
- Docking manoeuvres. In this task, attention must be given to several sensors that measure positioning, orientation, velocity, etc. When docking, real-time requirements are strong, making control over a communication system too difficult;

Note that whenever necessary, central processors ask for information stored in local processors (e.g. speed and position). Local processors also send information to the central whenever necessary, e.g., if an obstacle is detected.

8 Power Supply

Vehicles power supply are divided in two concepts: autonomous and umbilical. These concepts differ mainly in provided flexibility.

8.1 Autonomous Power Supply

Autonomous power supply is based essentially in batteries that store all the energy necessary to supply all the vehicle components (controllers, motors, communications systems, etc.). This concept has been used in industry for years. Industrial application of battery based mobile platform up to 35ton has been identified (see Appendix).

Advantages

- Vehicles may move freely without constraints – flexibility;

Disadvantages

- Batteries must be recharged when necessary;
- Recharge time may be long (depending on batteries used);
- Vehicle volume and weight increases;

To be determined

- Type of batteries to use;
- Battery capacity to install;
- Where to put recharge ports;
- Instead of recharging on-board, is it possible to replace discharged batteries by fresh ones?

8.2 Umbilical Power Supply

Umbilical power supply must be used in special situations, e.g. when the amount of power needed can not be supplied by batteries. Other uses arise in confined spaces, when there are no need to do long movements. Air supply for air-cushions is usually done this way.

Advantages

- Power is less likely to fail;
- Umbilical cord can be used for communications - large bandwidth (see Section 5);

Disadvantages

- A physical link is established, constricting movements;
- Workspace is largely reduced;
- Relevant problems arise if long paths are necessary;
- This concept is not suited for workspaces spread along several floors - litf problem;

To be determined

- How to overcome lift;
- Is it possible to change between umbilical cables during operations? (There is a long distance from the VV to the HCB.)

9 Rescue

Rescue capabilities are a major requirement of this project. Although all the systems are highly reliable, faults may occur during operation. Since transport vehicles are not shielded, human access is prevented. If a problem arises during transport operations, teleoperated rescue must be possible.

Rescue systems are divided in:

- Static equipment;
- Rescue vehicles;

These item are analyzed in the following two sections.

9.1 Static Equipment

Static equipment lays in the building and is intended to support rescue operations.

Several items are identified as static rescue components, namely:

- Video cameras, deployed in the building in such a way that a complete coverage is achieved. This allows operator to monitorize all transport operations and help if a rescue situation arises.
- Flexible flat cable festoon system in all floors, with electrical power, compressed air and communication signals. This may be useful in the case of vehicles power loss. In this situation these cables are connected to the vehicle, which then proceeds with human operator control. These cables are disconnected after entering the elevator.

9.2 Rescue Vehicles

Rescue vehicles are an essential item to accomplish teleoperated rescue operations. These vehicles must be equipped with special tools in order to provide an efficient rescue solution in case of vehicles malfunction. Some of these tools and other features are:

- Extra communication channels with high bandwidth;
- On-board cameras for operations monitoring;
- Teleoperated manipulator(s);
- Extra power supplies;
- Capacity to pull or push transport vehicles;

- Air compressor, should air cushions be used;

Should only one elevator be used, and if a vehicle failure occurs when entering the elevator, it is not possible to use it to transport a rescue vehicle. Therefore, each level of the TB must have a rescue vehicle.

In case of complete vehicle failure, the cask must be decoupled from the container. The rescue vehicle may then pull the stopped vehicle from below the container, leaving the container behind. If the stopped vehicle is in the TB, it must be pulled into the elevator. The elevator will lift it to the desired level and other rescue vehicle will push or pull it from there.

In case of power failure or air pressure loss, the rescue vehicle may deliver the necessary power and/or compressed air to move the stopped vehicle out of the gallery or elevator. To make rescue vehicles smaller, rescue ports may exist in the building, providing electrical power and compressed air cables. Rescue vehicles may then dock to these ports, pick up the cables, approach the stopped vehicle and connect the umbilical cable to it.

To push or pull a malfunctioning vehicle, its wheels must be decoupled from motors to avoid slippage. This allows a better control when moving the vehicle. To decouple the wheels, a mechanical solution like a gearbox may be used.

10 Conclusions

This report introduced a conceptual study on flexible guidance, navigation and docking solutions for the remote transport system to be used in the International Thermonuclear Experimental Reactor (ITER).

The study focused on flexible solutions, as opposed to "hard" solutions — such as rails for guidance or hands-on contact compliance for docking. Three major flexible concepts (AGVs, Mobile Robots and Mixed Vehicles) were discussed and evaluated in terms of different vehicle's traction and kinematic structures, guidance and navigation strategies, logistics, communication systems, localization for docking and power supply requisites. Major issues considered in the comparison between the optional concepts were safety during motion, avoidance of active sensors in the building, reliability, robustness, automatic error recovery and teleoperated rescue capabilities.

The results of our study — mostly supported by identified industrial solutions — confirm the potential of any of the three proposed concepts to display higher flexibility and thus higher robustness concerning automatic error recovery and teleoperated rescue operations, as compared to hard guidance solutions. Whenever required, path modification is simpler (either for long-term plant re-design or for short term emergency handling) and a larger number of rescue options are available. Docking may also be teleoperated, with an automatic localization system providing to the operator accurate position and orientation measurements, as well as assisting her/him with suggestions on the corrections to undertake.

Flexibility concerns both cask transfer travelling — during which navigation and guidance are key factors — and cask docking — involving self-localization and teleoperation. Flexible guidance requires enough space in the way from the VV to the HCB for transport vehicles to cross over and/or for transport vehicles/rescue vehicles to overcome vehicles stopped due to any malfunction. Therefore, larger corridors are required to take advantage of the flexibility. On the actual stage of the building design [DDD 6.2], cross over of transport vehicles can only be achieved on the passage from the TB to the HCB. There is also the possibility of a cask waiting to go up near the lift in the gallery, while another cask is coming down. The use of the two cask crossover locations, together with bidirectional motion in the galleries, allow a considerable reduction of the time required to accomplish a complete transfer cycle, by making the simultaneous motion of two casks possible. Increasing the number of simultaneously moving casks is not advantageous, as long as only one lift is available. Our simulations showed that the lift is the bottleneck of the RH cask transportation system.

Furthermore, flexible solutions require smaller curvature radii for manoeuvres and turns (e.g. from a circular path in the galleries to a radial path towards a docking port). One important consequence of this is the possibility of avoiding turntables to reverse the vehicles heading.

Among the flexible concepts proposed, we concluded that the performance of Mixed Vehicles would be the best. Even though their control is more complex, they share the advantages of the other two solutions, with increased flexibility. A vehicle designed under this concept might work as an AGV most of the time, switching to a Mobile Robot if required (e.g., to overcome a stopped vehicle). Rescue vehicles might be built under the same concept, allowing free roaming or AGV-like motion along the path towards the rescue site, with the advantage of higher manoeuvrability during rescue operations.

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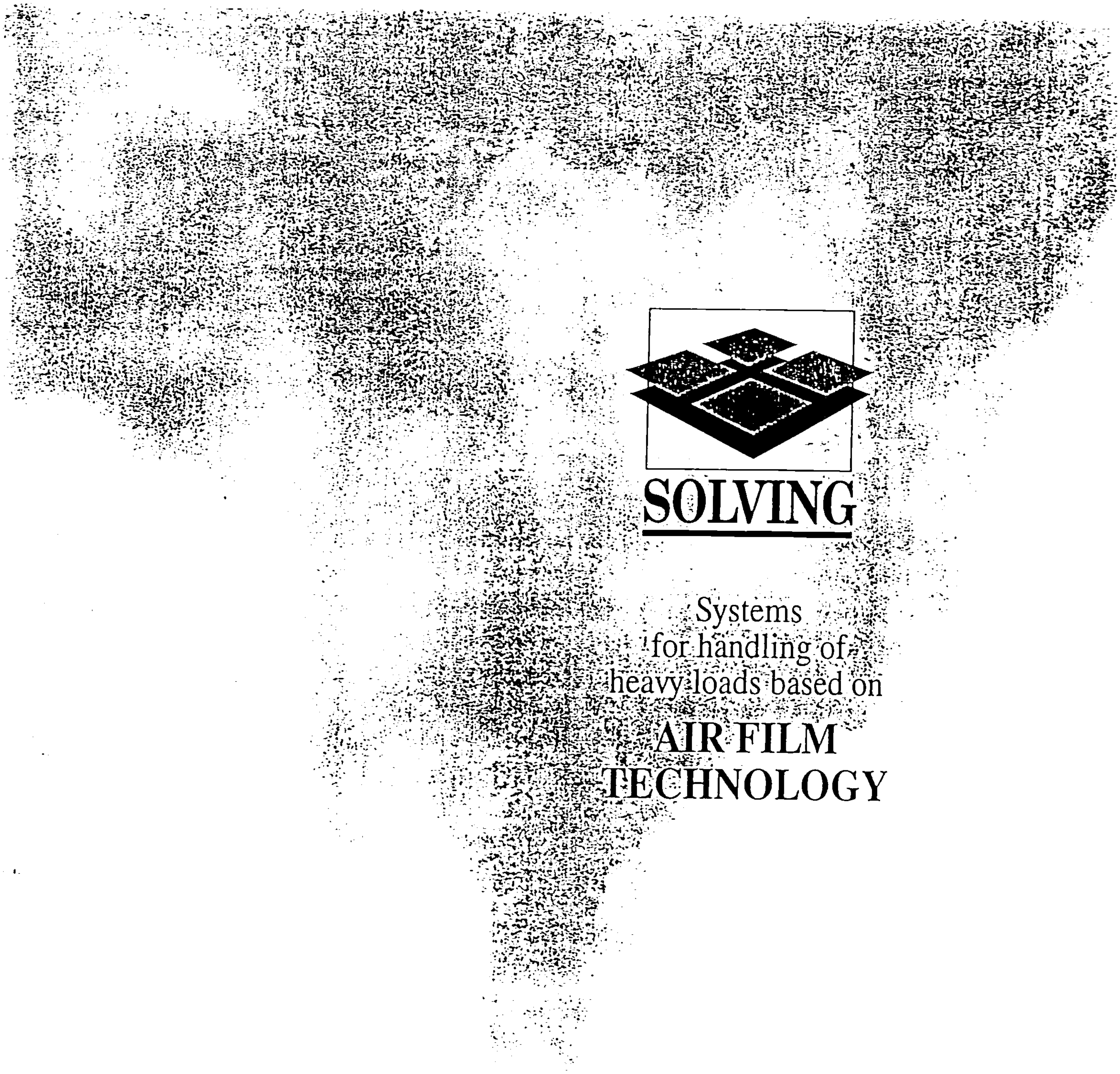
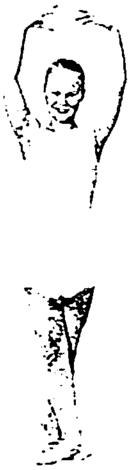
A Appendix - Identified Industrial Solutions

A.1 Air Cushion System



SOLVING

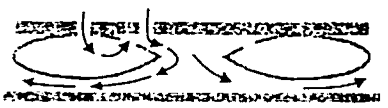
Systems
for handling of
heavy loads based on
**AIR FILM
TECHNOLOGY**



There had to be a better way!

Early in the 1930's, experiments with air cushion devices began in Finland. In the 1950's, air cushion technology was developed for hovercraft in England and in the 1960's for internal industrial moves in the U.S.A.

Air flotation is achieved by compressed air being forced out through the air cushion element between load and floor. In this way, friction is reduced to a minimum, allowing large loads to be moved with very little force.



Over the years, air flotation has developed and our systems are now used in various industries for the handling of loads such as steel/paper rolls, engines, transformers, vehicles, ship modules etc. This technology is also used in theatres and in multipurpose halls.

Solving, established in 1977, is today one of the leading manufacturers and developers of material handling systems based on air film technology. The company has production plants in Finland and Sweden, representatives in Europe, USA and the Far East.

Customer-oriented air bearing systems

For heavy industrial moves Solving's material handling systems, based on air film technology, are revolutionary.

The system is flexible and environmentally safe. It makes no noise and discharges no exhaust gas, the driving power being air. Air bearing transporters are safe and easy to control, they require practically no maintenance and eliminate floor wear.

Flexible system

Industries have varying transport needs. Our air bearing systems are designed to fulfil the requirements of each customer. In order to keep costs low, we have developed a felxible system based on standard components. these can be combined for customer's needs.

Solving key component

The air bearing element is the key component in an air bearing system. We develop and manufacture our elements, which consist of a unique, reinforced rubber membrane welded on a plate. The Solving air bearing element has low friction, high durability and high chemical strength. In the manufacture, international quality standards are followed.

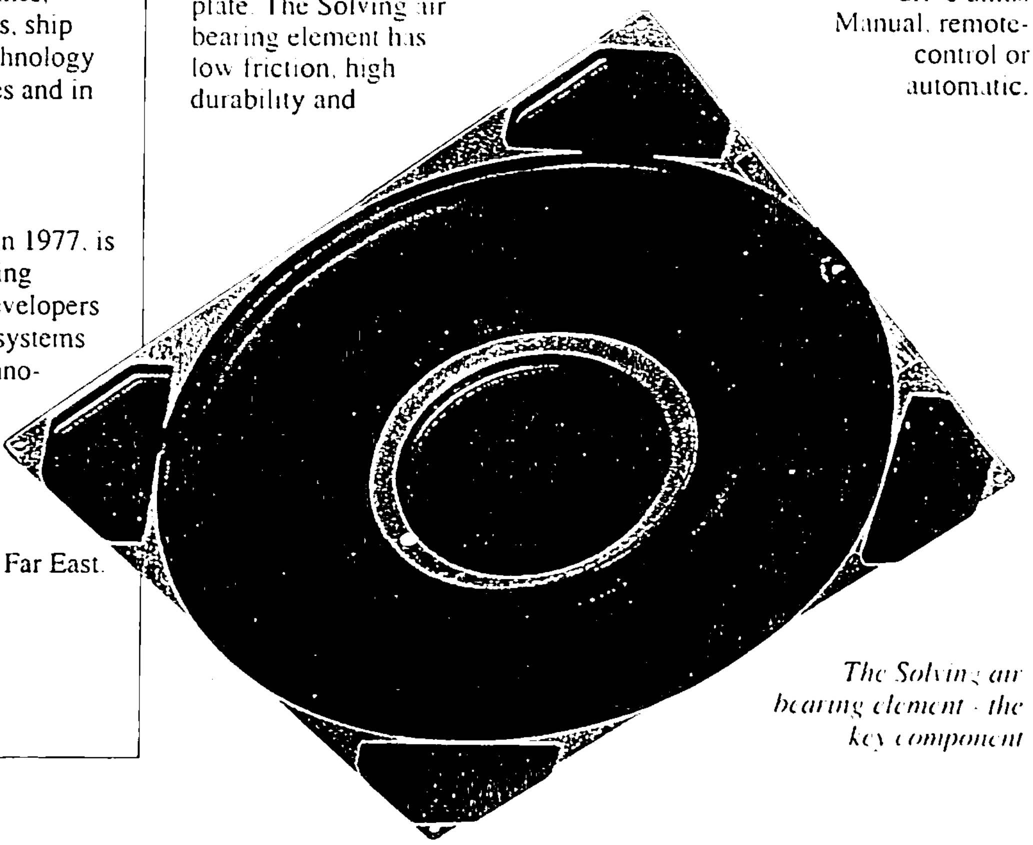
Standard component

Solving's air bearing systems are assembled from tested standard components. For the customer this means safety, reliable deliveries and low costs. Our standard components are:

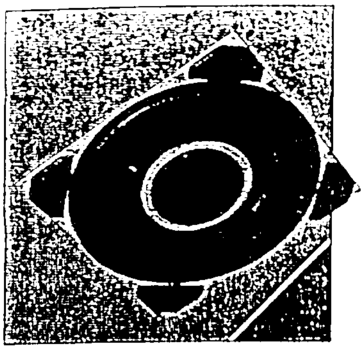
Air bearing element.
Available in different sizes with capacities from 250 kg to 40 000 kg.

Drive unit.
Consists of an air or electric motor that drives the air film transporter with an adjustable speed by means of a friction wheel.

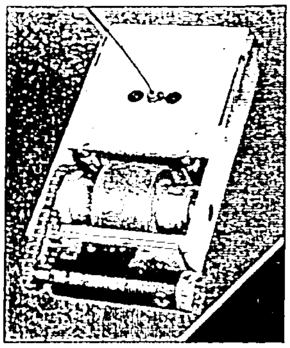
Control system.
The system regulates the air pressure and flow to the air bearing elements and drive units. Manual, remote-control or automatic.



The Solving air bearing element - the key component



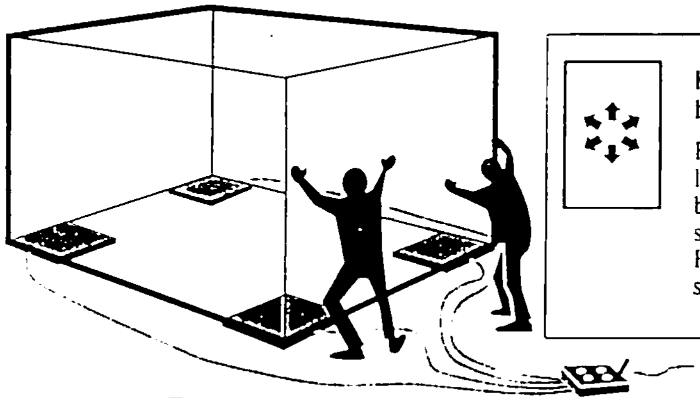
Air bearing element



Drive unit

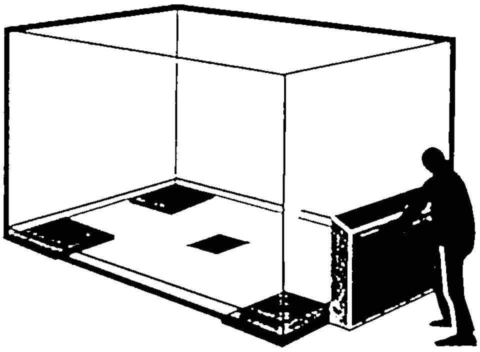
Control system

By combining various types of our standard components, we build up a Solving air film system which can be varied in different ways according to the needs of the customer.



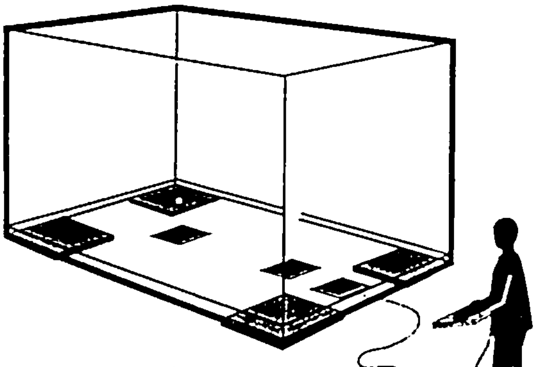
Handling system based on air bearings

For occasional moves of heavy loads. Consists of individual air bearing modules or planks with several air bearing elements. Handles loads from one to several hundred tonnes.



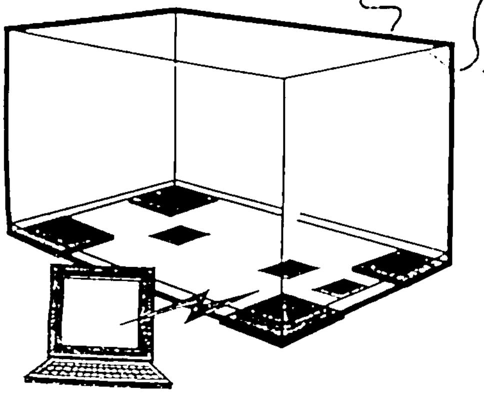
Direct-controlled air film transporter

For the handling of lighter loads placed directly on a transporter or a load pallet. Controlled by the operator from a control console. With or without drive unit.



Remote-controlled air film transporter

For the handling of heavier loads. Controlled from a portable remote-control unit with a cable or via radio. Double drive units are used in most cases.



Automatically controlled air film transporter

A transport system without driver (AGV) for heavy loads moved frequently. Mechanical or inductive control depending on the layout. Built-in safety system.

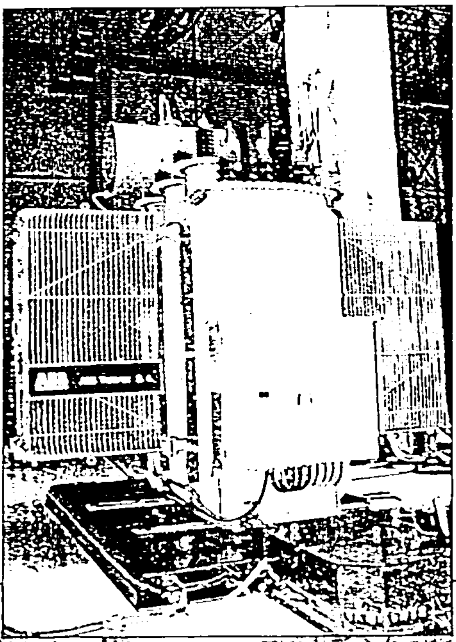
We have achieved our quality by years of practice and hard work.

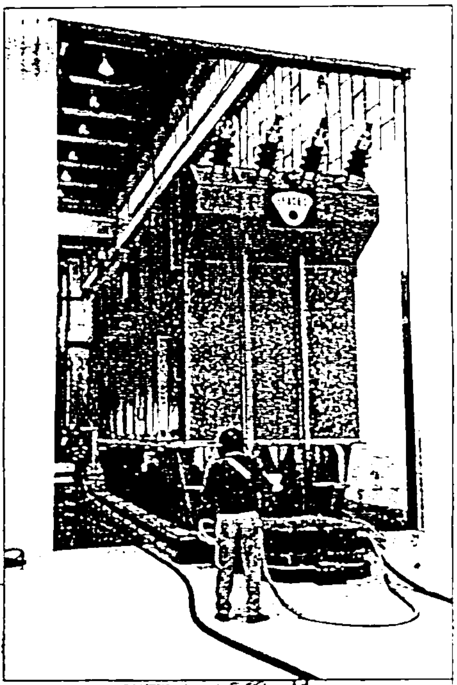
Heavy electrical industry

Solving has developed special air film systems for the electrical industry. The air film transporters can be controlled with precision and are used for assembly of windings, transformer cores and other heavy components. Another application is movement of transformers and cable drums in test rooms.

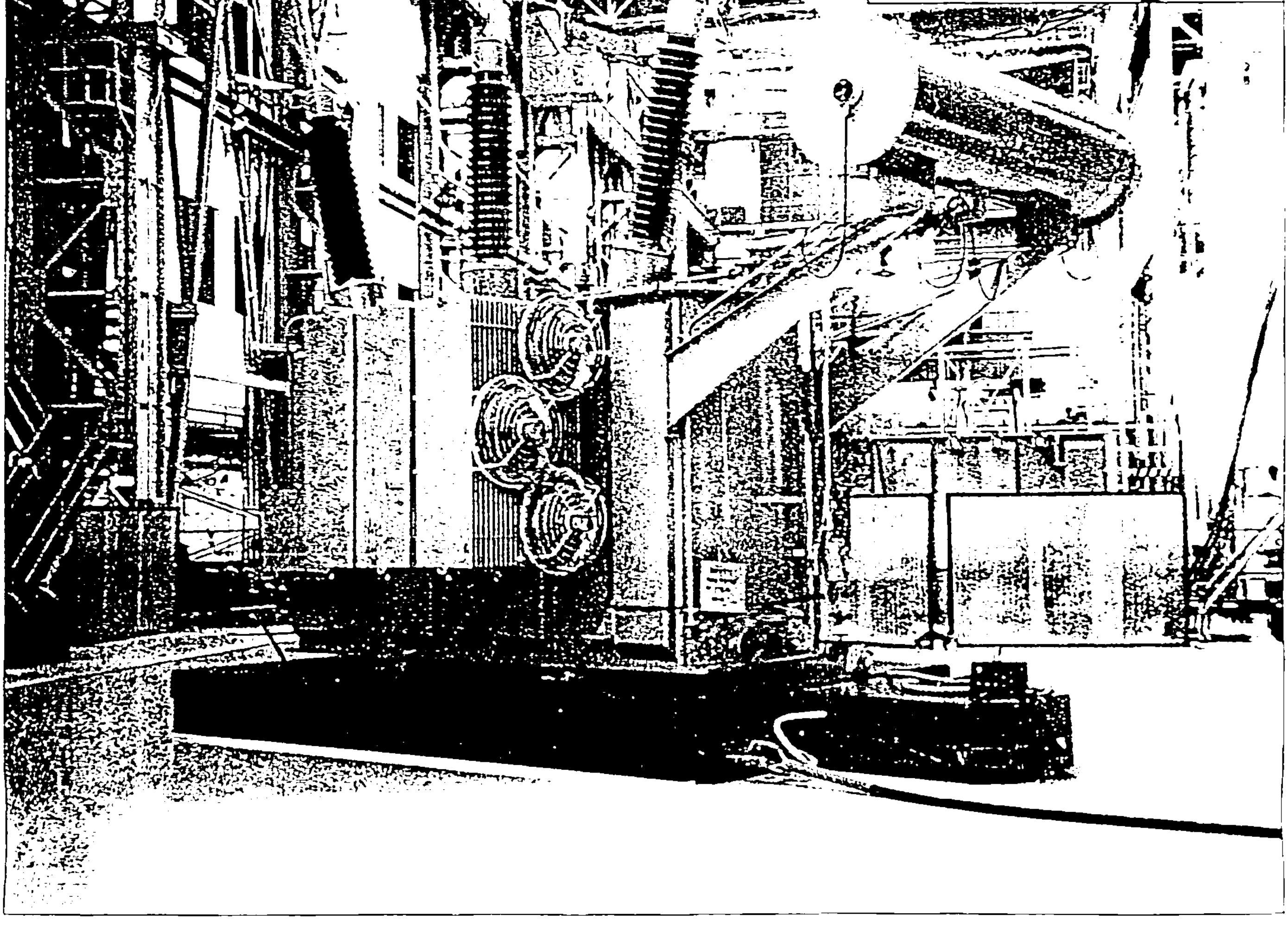
The transformer is placed directly on the air film transporter. ►

Transformer manufacturers were among the first to start using air film technology for the movement of products in their production. One of the most important forerunners in this field is ABB with factories all over the world. Over the years, Solving has delivererd to ABB various types of equipment with loading capacities up to several hundred tonnes.





Solving air film pallets for handling transformers 80-450 tonnes.

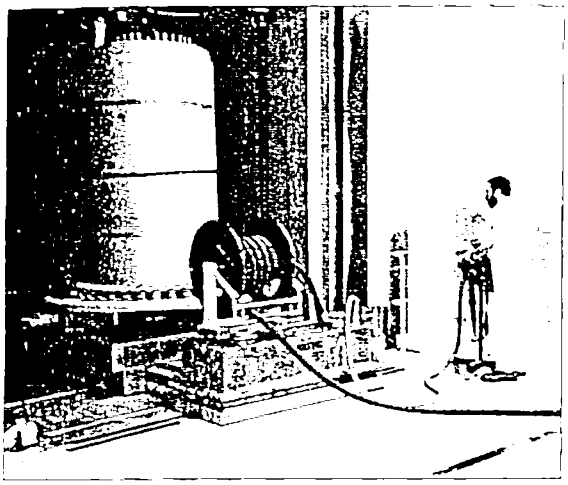


Transformer on load pallet is moved with a remote-controlled Solving air film transporter equipped with an external drive unit

Equipment for handling electric motors, generators and cable drums has been delivered to Siemens AG, KWO-Kabel GmbH, ABB and NKT a/s.

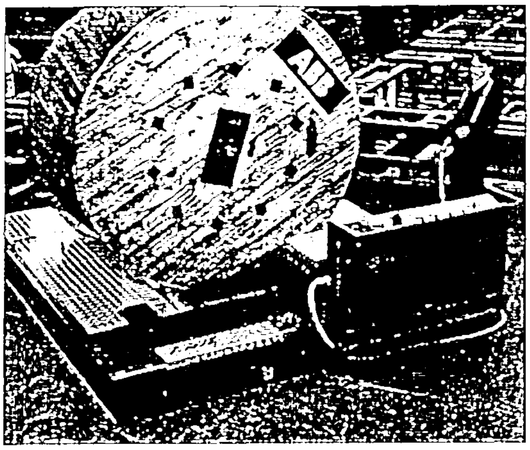
Economic profit

Solving´s air bearing systems are very competitive in heavy industries, loads are easily moved with an air film transporter. Therefore only lighter components need to be collected with an overhead crane, which leads to reduced investment costs.

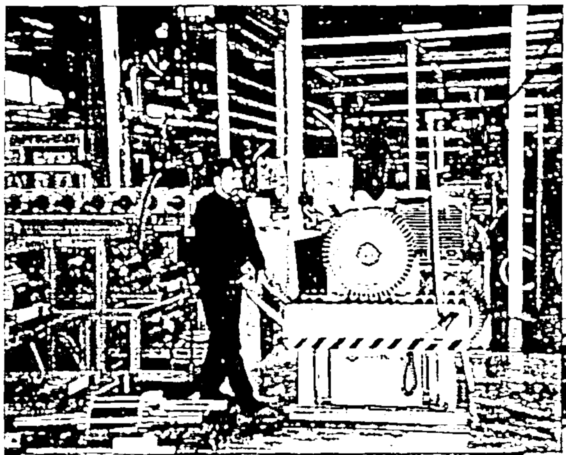


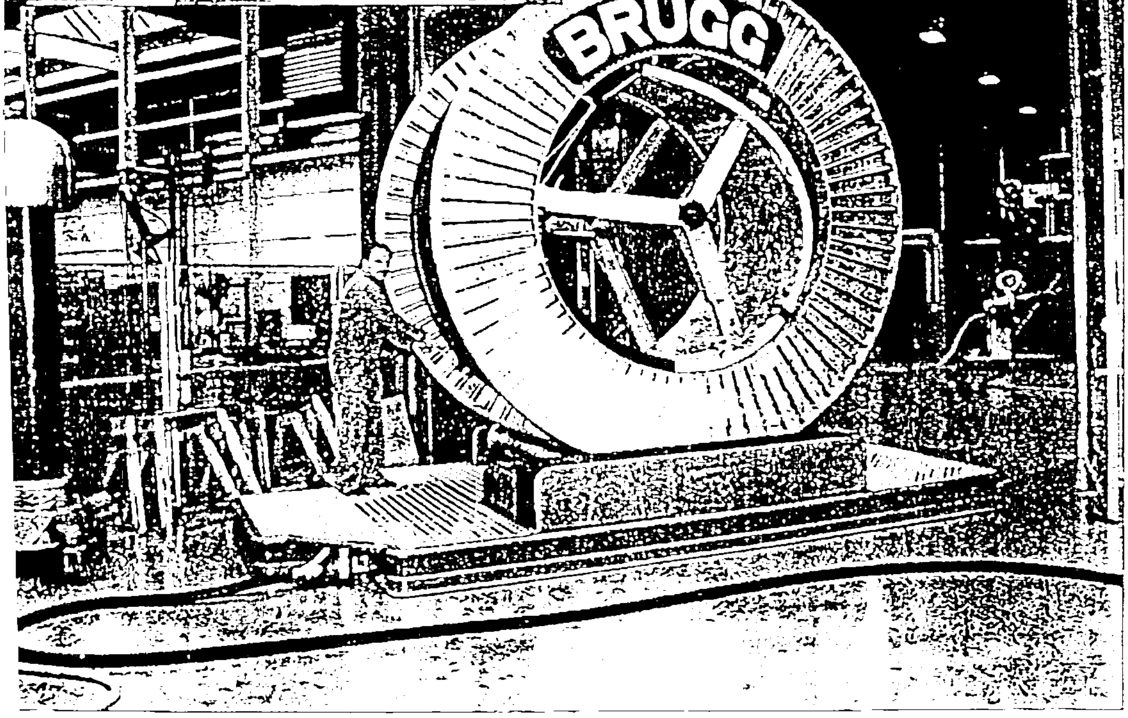
◄ *Transformer windings are driven into the hardening furnace on an air film transporter.*

▼ *A U-shaped air film transporter lifts the cable roll directly off the floor.*



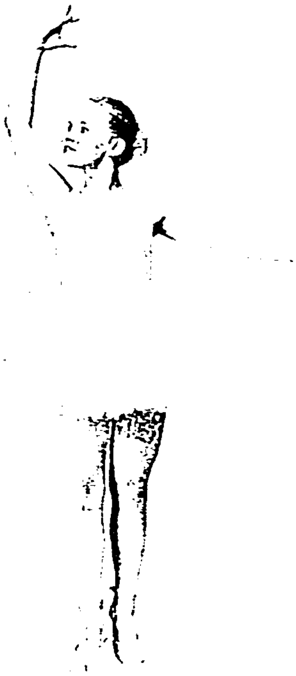
▼ *Electric motors are easily moved between various working stations.*





remote-controlled air film transporter with built-in rotation for high voltage laboratories.

Knowledge
and
experience
make the
big and heavy
light and easy.



REFERENCES

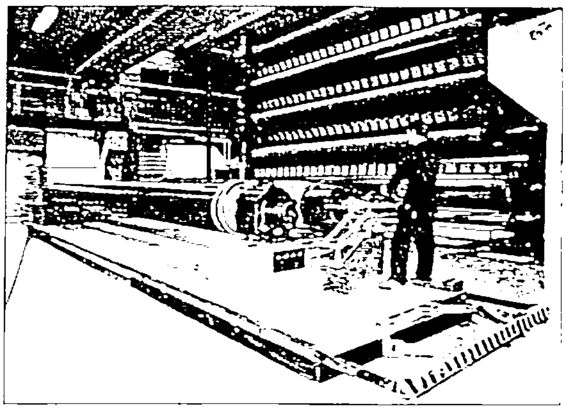
Paper and graphic industry

Solving has developed several handling systems for removing roll wrappers and supplying rolls into printing machines, for automatic handling of paper rolls between machine and store, and automatic systems for the transport of tambour rolls from paper machine to slitter.

Industries with production lines requiring continuous movement, accessibility, safe handling and low service costs. Users of Solving air film transporters in the paper industry are United Papermills Oy, Rafatec Ltd, Nordland Papier GmbH and Fasson S.A.

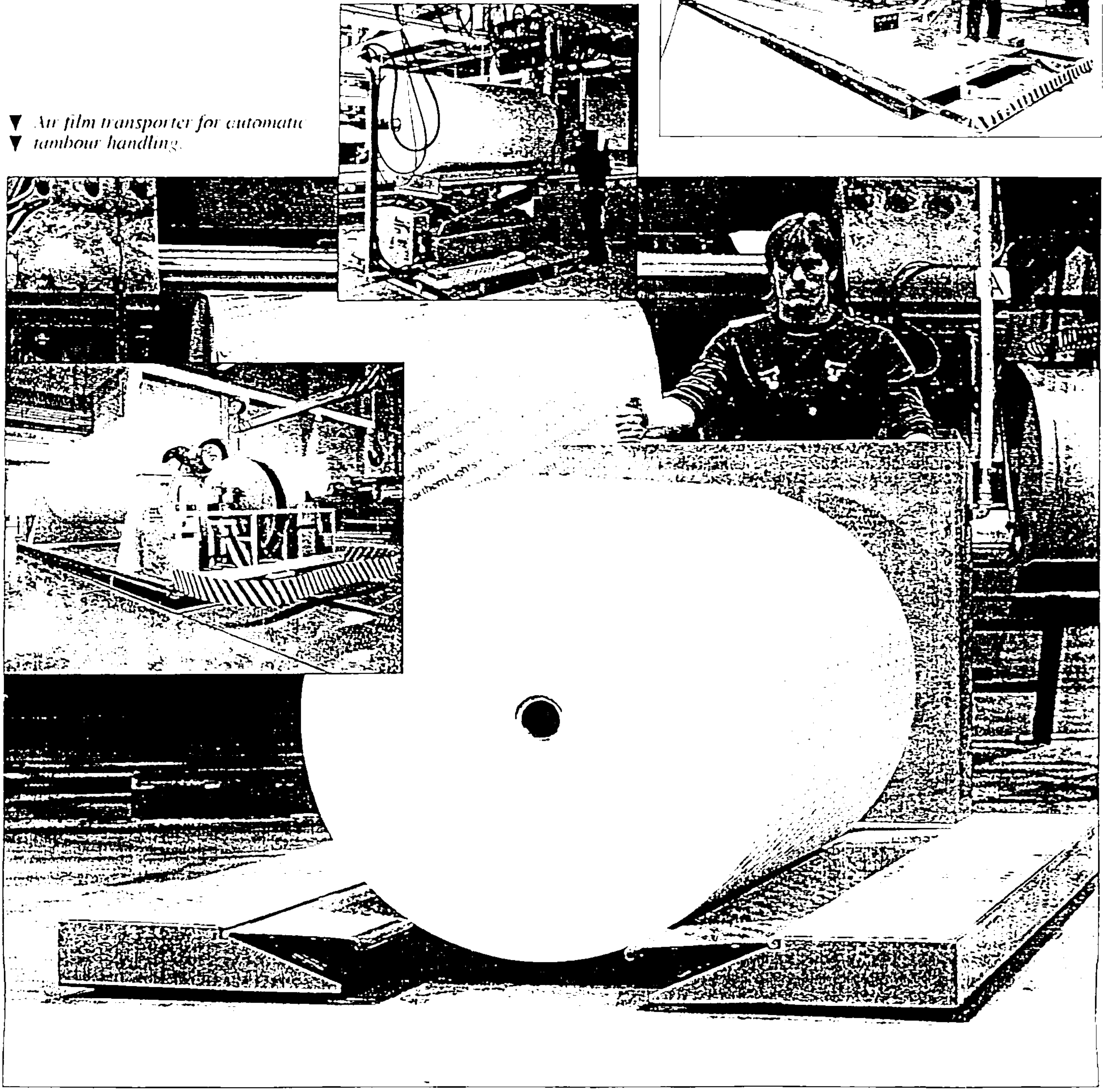
In the graphic industry, Solving air film transporters are used by Helprint Oy, Gruner + Jahr GmbH, Axel Springer Verlag AG and Falukuriren AB.

Remote-controlled air film transporter for handling calanders up to 80 tonnes.



Automatically controlled Solving air film transporter equipped with lifting table.

▼ *Air film transporter for automatic*
▼ *tambour handling.*

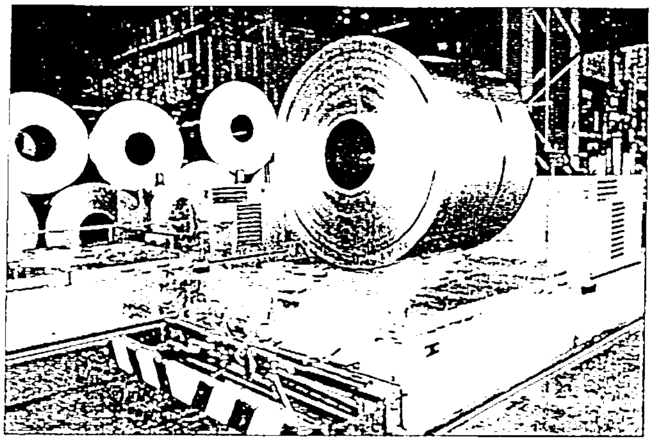


A U-shaped direct-controlled Solving air film transporter for supplying paper rolls into printing machine

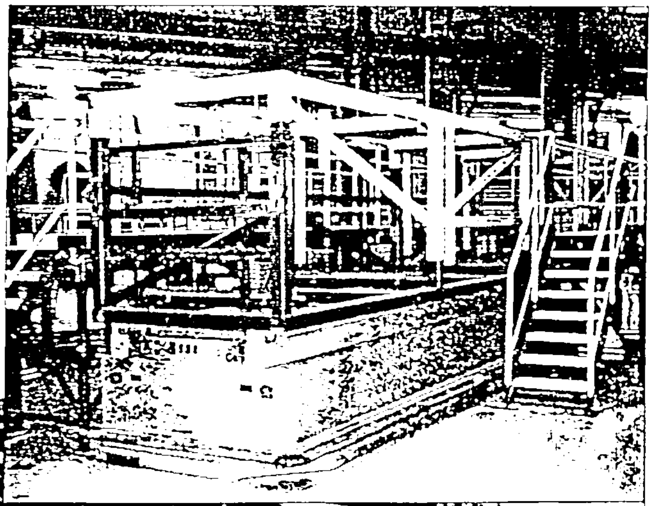
Heavy workshop and steel industry

Solving's automatic air film systems (AGV) and remote-controlled air film transporters are used in steel works, shipyards and the offshore industry for handling loads up to several hundred tonnes.

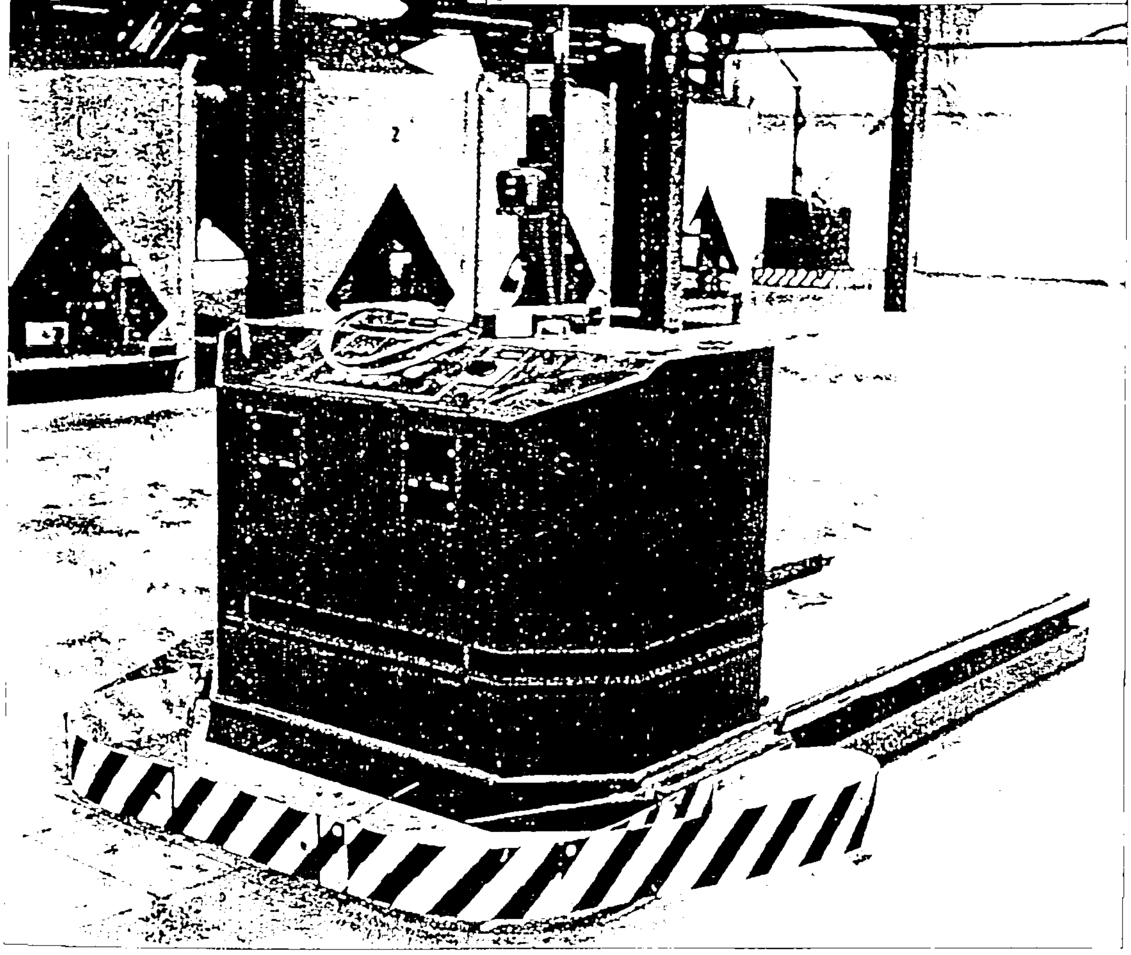
Users are Hoganäs AB, Cockerill-Sambre, A Ahlström Oy, Aker Contracting a/s, Norsk Hydro a/s and Fincantieri S.p.A.



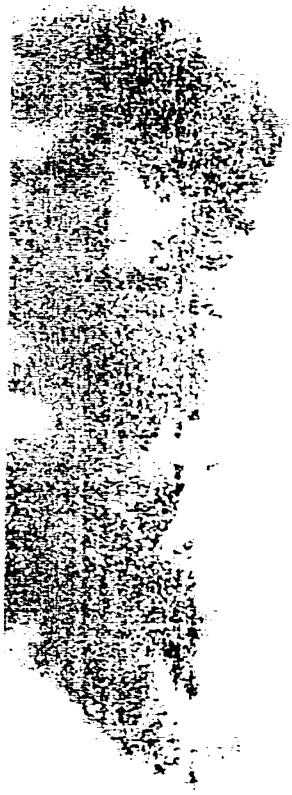
Diesel-powered Solving AGV-transporter for coil handling.



Solving AGV-transporter for automatic ▶ handling of a 20 ton condenser between welding stations



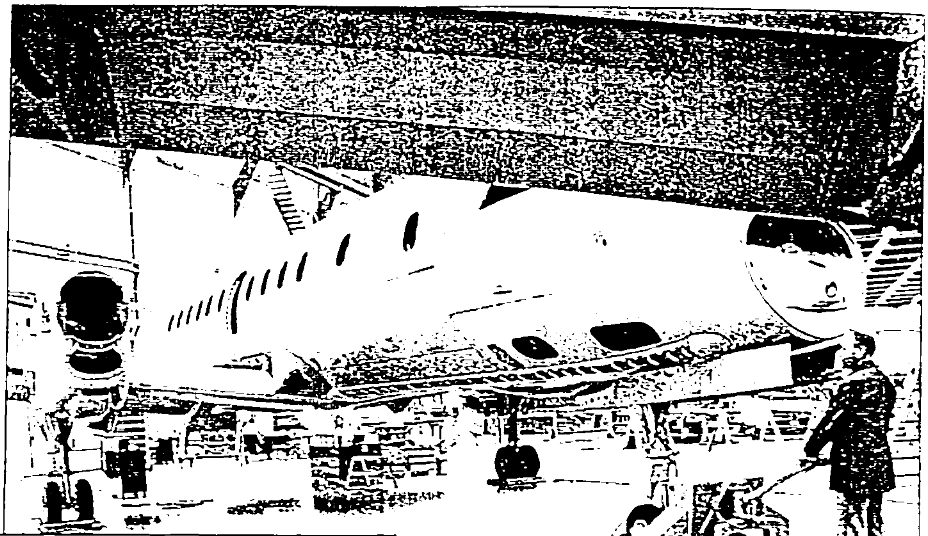
AGV-system with six Solving transporters for automatic handling of metal powder containers



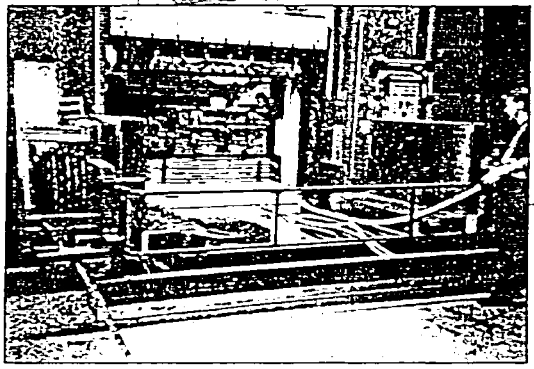
The whole requires every detail to be performed with care and precision.

Workshop and motor industry

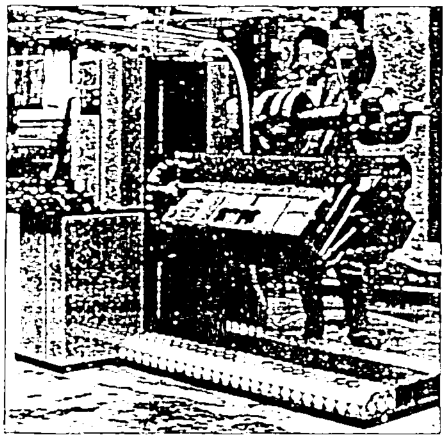
In the workshop and motor industry, Solving's air film systems allow for more flexible production, better working environment, ergonomics and more efficient group assemblies. Solving's new technical solutions also lead to better productivity and give more *responsibility* to the employees.



▲ *Assembly of aircrafts on air film transporters*



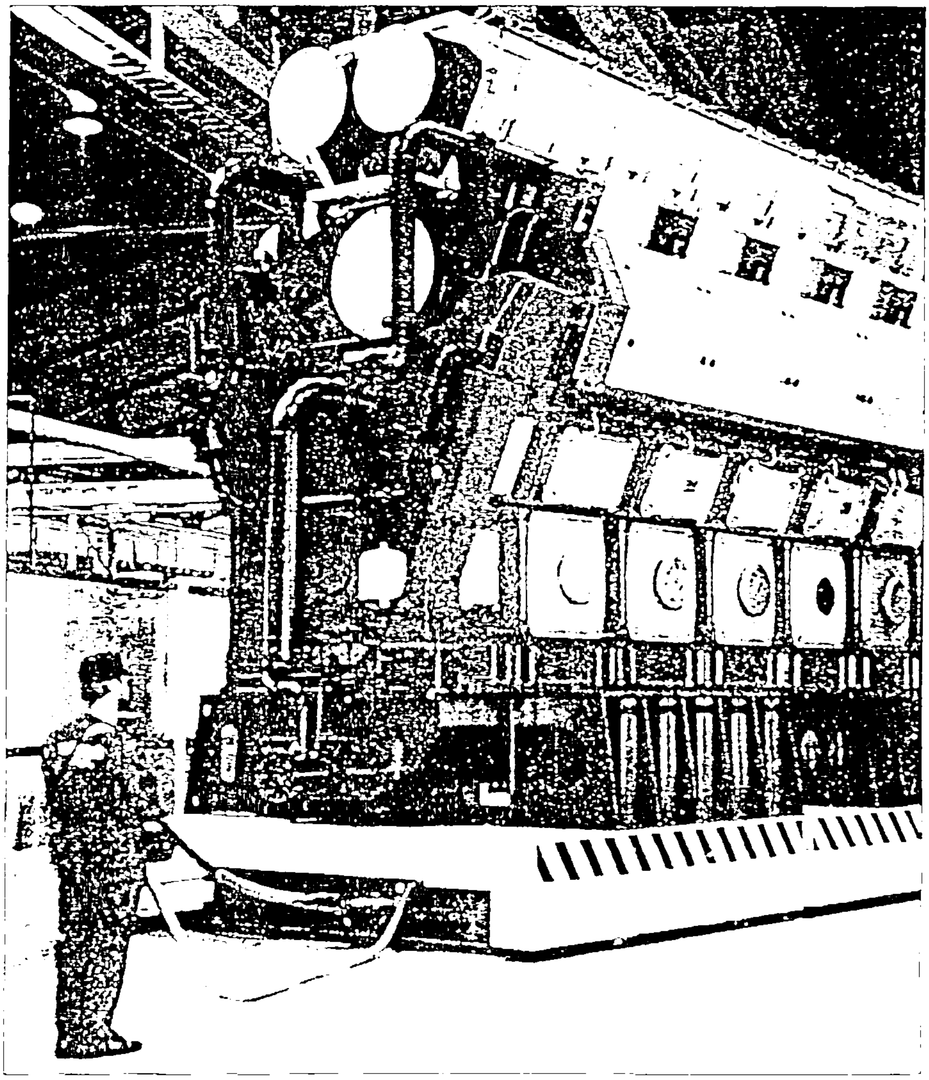
◄ *System for die-changing in hydraulic presses*

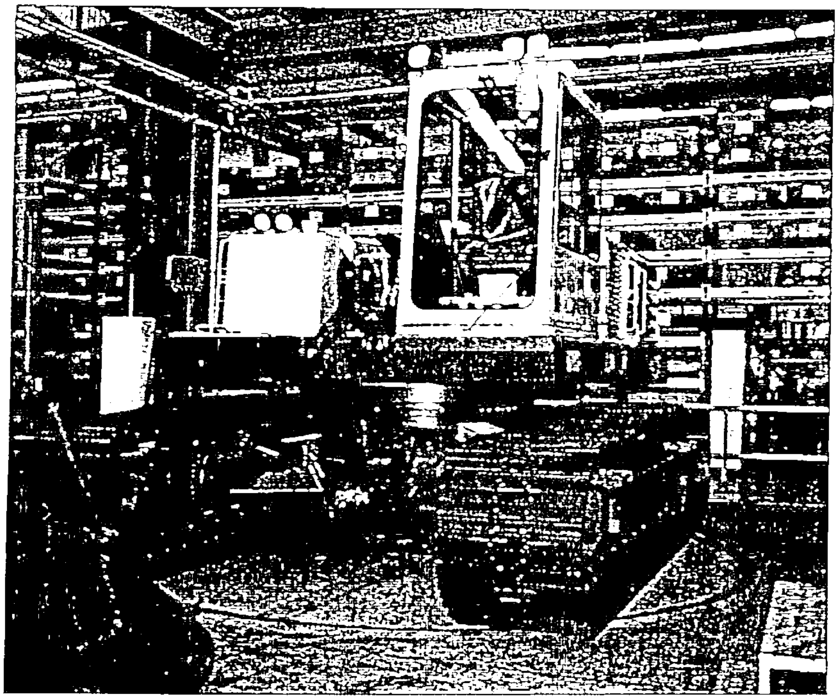


Air film transporter with built-in lifting and rotation for assembly of motors.

Solving's air film transporters are used for the assembly and transportation of engines, axles, lorries and excavators by Scania AB, Wärtsilä Oy, Volvo AB and VME. Equipment for the handling of tools, loaders, trains and aircraft have been delivered to several manufacturers in Europe and U.S.A.

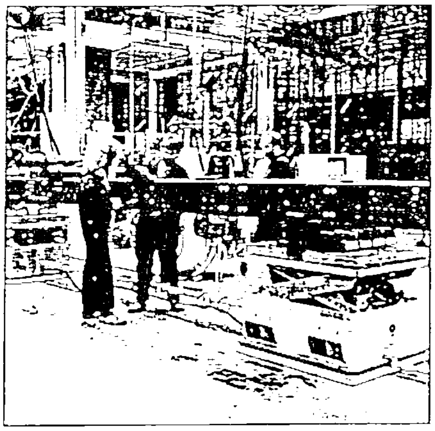
Remote-controlled Solving air film ► *transporter for handling diesel engines up to 250 tonnes*



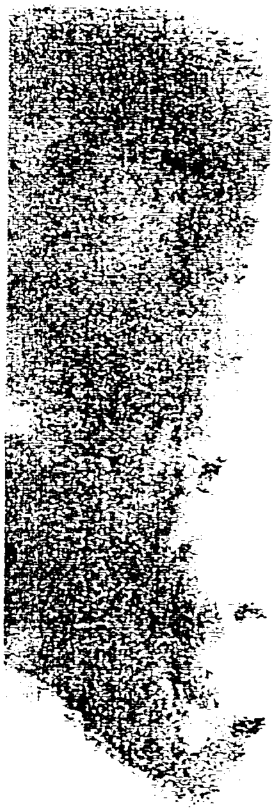


Turntable on air bearings for turning excavator on assembly line.

Solving air film transporters for handling and assembly of axles and frames in motor industry.



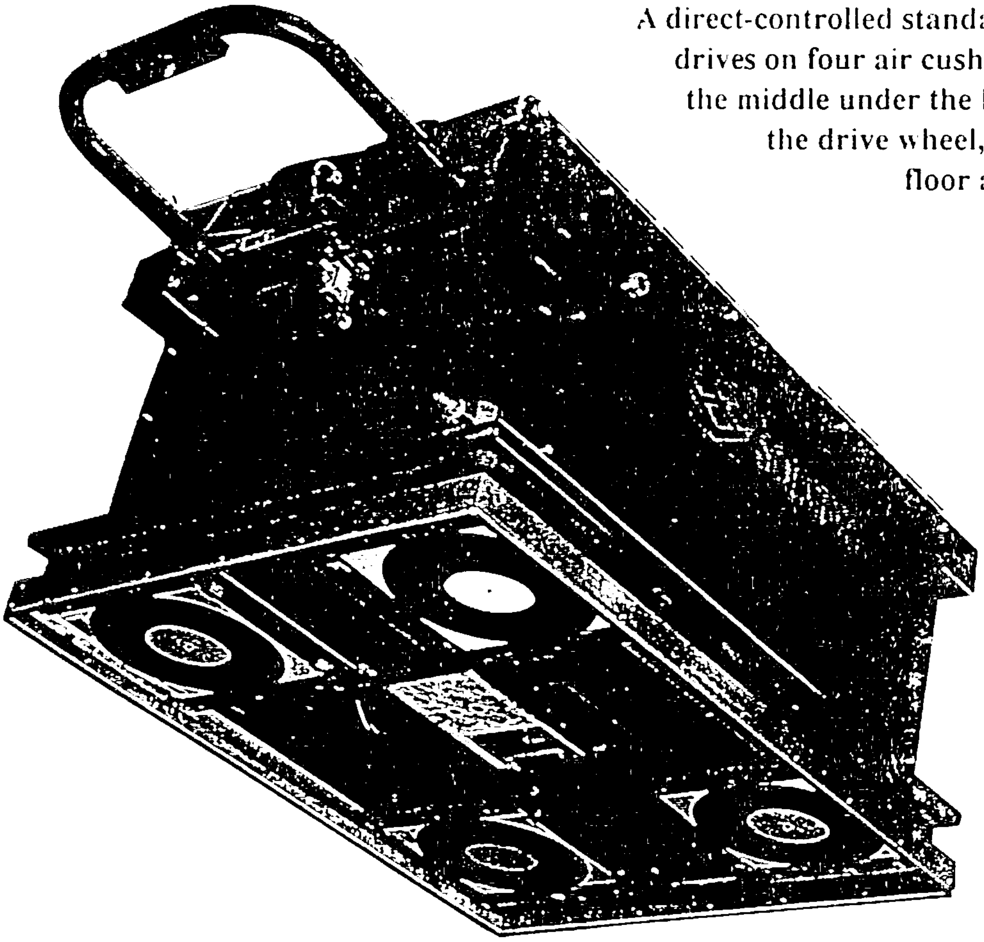
Handling of components and train wagons with Solving air film transporters.



The best reward is the satisfaction of a job well done.

Solving air film system

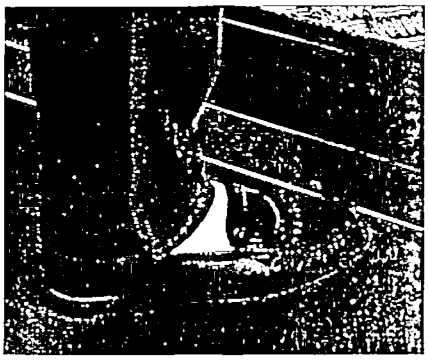
How the transporter operates



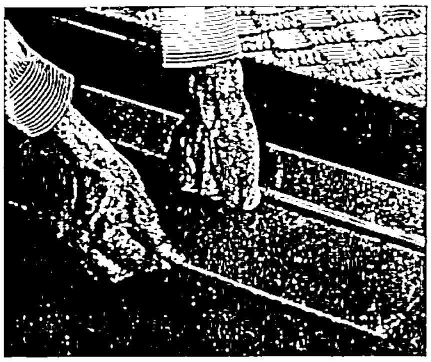
A direct-controlled standard Solving air film transporter drives on four air cushions. The drive unit is placed in the middle under the load. The transport direction of the drive wheel, speed and pressure against the floor are controlled from the console.

Due to the near frictionless nature of the air bearing on a smooth, sealed floor, it is essential that the load is guided and controlled. This is achieved either manually, using a guide wheel or a drive unit.

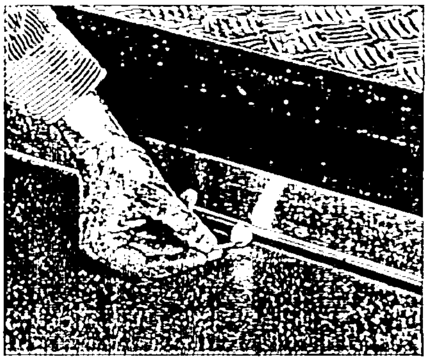
Heavy loads often require two drive units built-in to the transporter.



Air film transporters are extremely safe both for the operator and the load. - The safety guard eliminates squeezing injuries and prevents loose particles from entering under the transporter, which might disturb the function of the air film elements.



The air film transporters require a minimum of maintenance. - To change or service the element, lift the safety guard, release the locking and pull out the element without unloading the transporter.



The air cushions make no noise! Due to the low working pressure of the air film elements, the thin film of air and the construction of the transporters, the speed of the escaping air is very low.

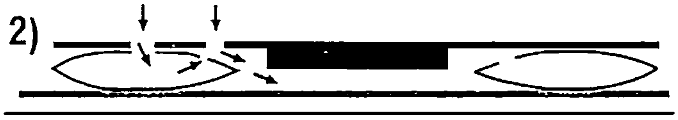
How the element operates

When introducing the compressed air supply, the following sequences of events takes place:

1)

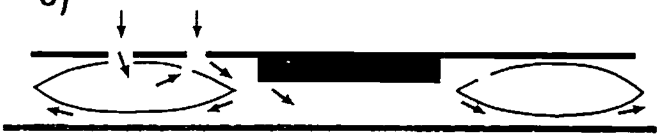
The circular reinforced rubber bellows inflates and fills the gap between the mounting plate and the floor.

2)



As the pressure increases, the mounting plate lifts off the floor.

3)

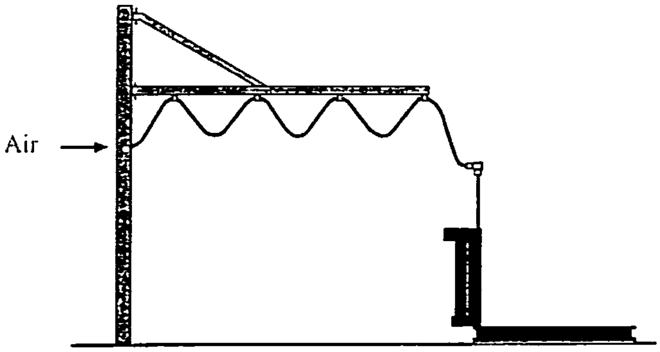


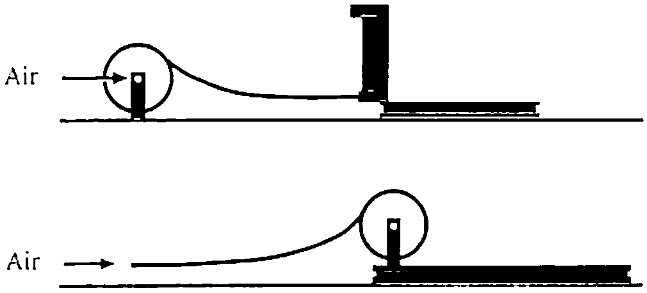
When the pressure in the bellows is higher than the counterpressure of the load, the air flows out from the bellows forming a thin air film on which the load floats practically friction-free.

Air supply

Normal shop air can be used. Custom-built air transfer systems are available.

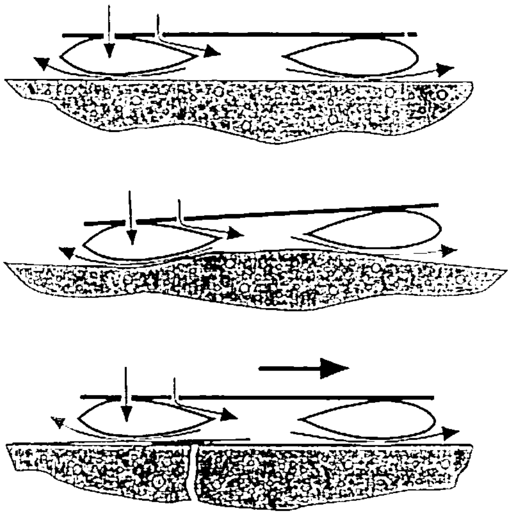
Air supply to the tranporter can be from either a hose reel or a fixed point.

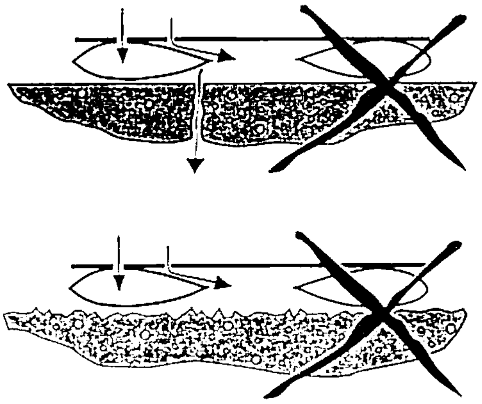




Floor

The light weight of the air film transporters and the capability of the air bearing elements to spread the load over a large surface, stress the floor much less than conventional wheel transporters.



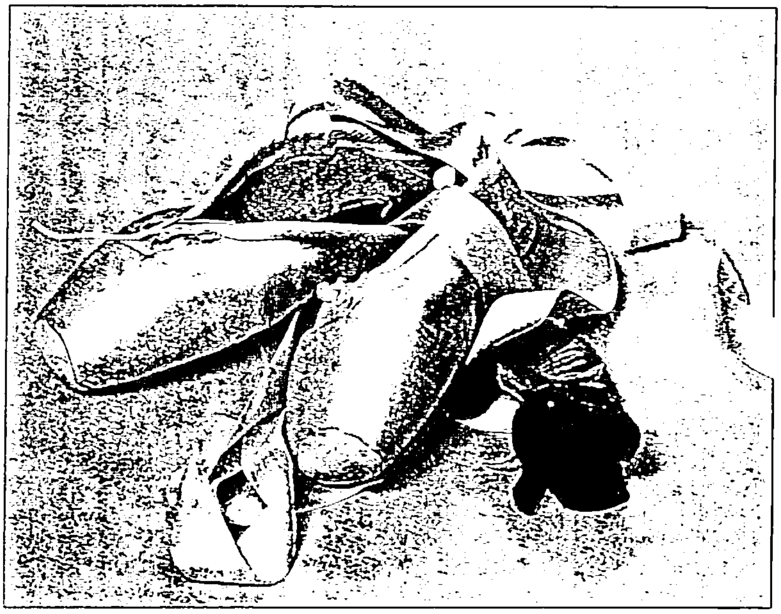


The air film system requires a smooth, continuous, sealed floor. Loads must be controlled on inclines. For frequent moves, the floor surface should be power floated concrete, polymer or epoxy resin. For occasional moves steel or vinyl sheets can be used.

When an artist fascinates the audience with his skill, one easily forgets the years of training and discipline behind the seemingly easy performance.

The same goes for a successful company. In order to obtain quality, years of product development and hard work are required.

The artist and the company are also united by the fact that both of them want to repeatedly offer the audience - or their customers - the very best they have.



Solving is an expert in custom-made air film systems. If you need a flexible solution for your material handling problems - contact us or one of our representatives.

SOLVING

LOADS FLOATING ON AIR

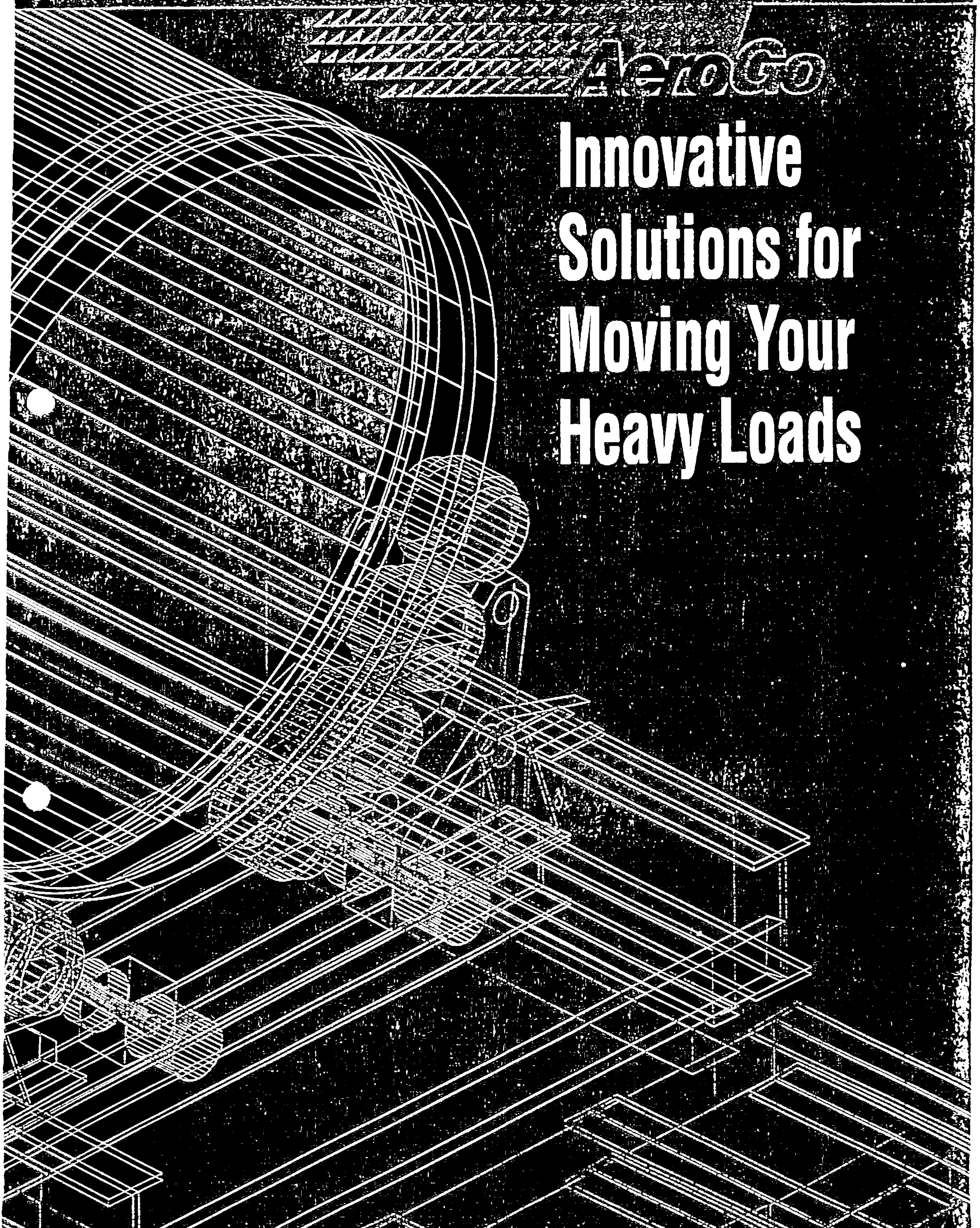
Ab SOLVING Oy, P.O.Box 98, FIN-68601 Pietarsaari, FINLAND
Tel. +358-6-724 6577 Fax +358-6-723 2570

Representative:

uced in Finland 1994 [illegible] raphic design: Studio BKB Print Arkmedia

AeroGo

Innovative Solutions for Moving Your Heavy Loads



Anything is possible

When the most respected companies in the world face difficult load moving challenges, they go with Aero-Go.

For over 25 years, Aero-Go has been a world leader in the design and manufacture of load moving systems for industry, construction, manufacturing and aerospace.

Engineering innovative, effective solutions to meet the precise requirements of our customers keeps us at the leading edge of material handling technology. Our unsurpassed technical expertise means we can provide cost-efficient, practical answers — even when your load moving task seems nearly impossible.

Whether you're moving 500 pounds or 5,000 tons, we're ready to engineer and manufacture the special system for your unique needs — or to offer you the finest range of standard load moving equipment in the world.

No load is too heavy, no application too tough

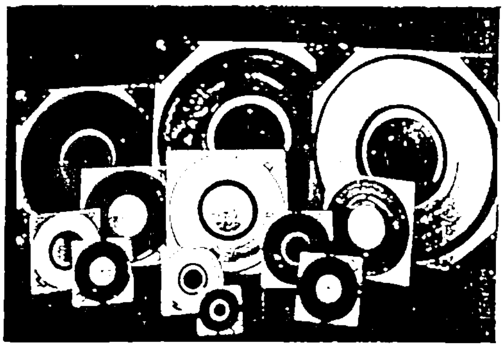
Aero-Go offers you heavyweight experience. We've built specialized carts for 100,000-pound dies. We've also launched cargo ships, moved 4,500-ton stadium sections, and transported aerospace rocket boosters. All effectively, efficiently, on time, and on budget. Aero-Go equipment routinely moves manufacturing fixtures, printing presses, bulky paper rolls, jet engines, and other heavy loads too numerous to mention.

Since 1967, when Aero-Go received rights to patents developed by the Boeing Commercial Airplane Company, our engineers have perfected Aero-Caster® fluid film technology, which today sets the load moving standard for the world.

Our engineering expertise doesn't end with air bearings. We're specialists in the design of virtually every type of load moving equipment, including wheeled and rail systems.

Whatever your needs, our technical staff will work with you to recommend the most effective solutions to meet your job specifications.

Ships weighing thousands of tons are launched smoothly with Aero-Go fluid film technology.



Aero-Casters® come in a variety of sizes, fabrics and models for virtually any load moving application.

Aero-Go automated Quick Die Change systems change heavy dies in under three minutes.

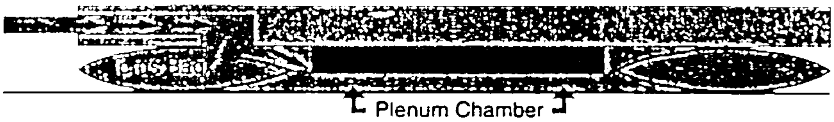
The world's leading companies are AERO-GO customers:

ABB
AeroJet
Abbott Labs
Alcoa
Amtrak
B.F. Goodrich
B.M.W.
Bell Helicopter Textron
Boeing
Boise Cascade
Carrier
Caterpillar Tractor
Chrysler
Daimler Benz
Deutsche Airbus
Europropulsion
Ford
General Dynamics
General Electric
General Motors
Goodyear Tire & Rubber
International Paper
John Deere
Kimberly Clark
Martin Marietta Aerospace
McDonnell Douglas
NASA
Northern Telecom
Pratt & Whitney
Quaker Oats
R.J. Reynolds
Sperry New Holland
Textron Aerostructure
Thiokol
Weyerhaeuser
...and many others

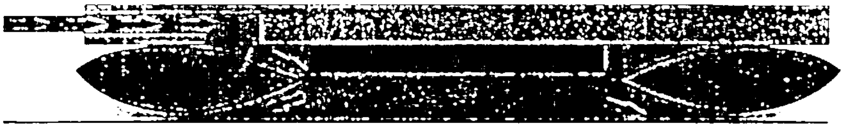
How our unique AERO-CASTER® works

With fluid film technology, one person can easily move tons. Aero-Casters use compressed air (or, occasionally, liquids) to actually float heavy loads on a thin fluid film.

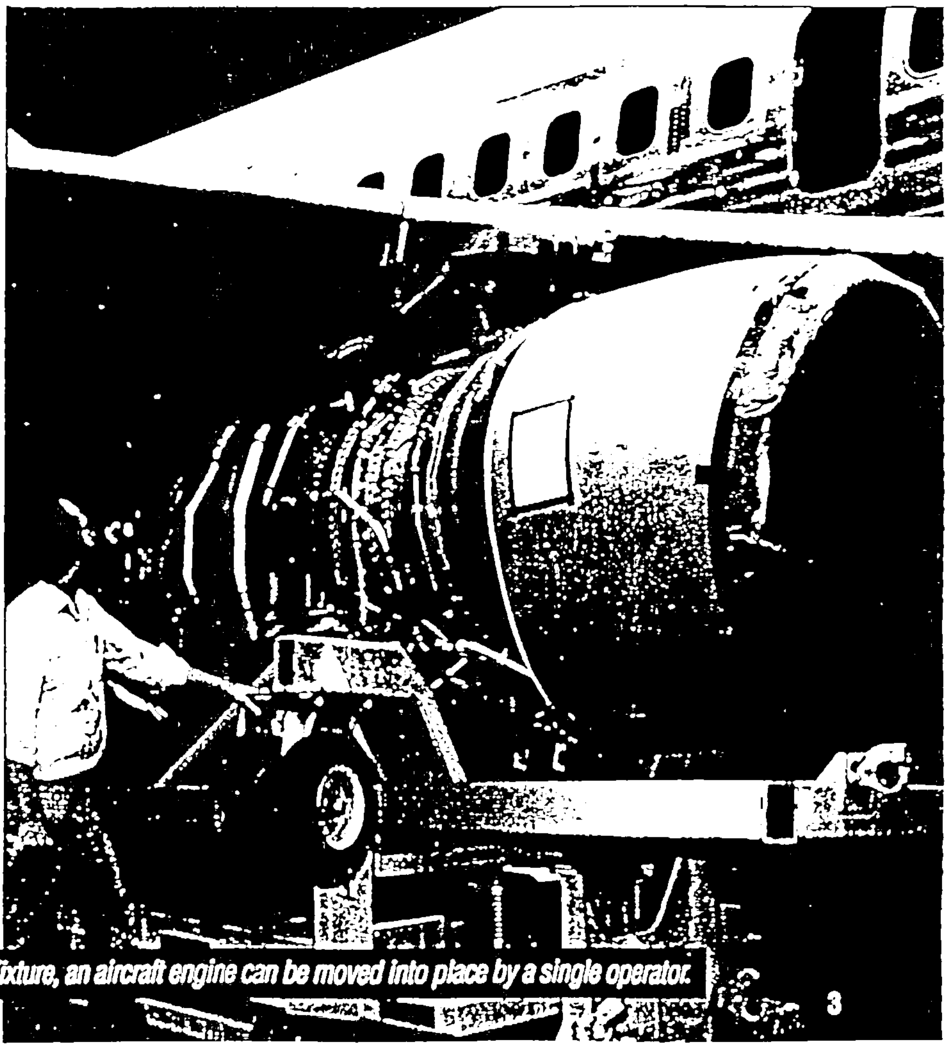
Step 1: Prior to inflation, the Aero-Caster is solidly supported by "landing pads." These pads protect the Aero-Caster's torus bag (similar to an inner tube) from being crushed when the load is at rest.



Step 2: When standard shop air (or liquid) is pumped into the Aero-Caster, the torus bag inflates, creating a seal against the floor surface.



Step 3: When air pressure within the plenum chamber is sufficient to offset the load's weight, air slowly and evenly escapes between the flexible torus bag and the floor. The load is literally floated on a thin, frictionless cushion of air or liquid, .003 to .005 inches thick. (Note: Aero-Casters are generally used in sets of three or more.)



With an Aero-Go Engine Installation Fixture, an aircraft engine can be moved into place by a single operator.

Innovative load moving equipment for standard applications

Aero-Go's standard products offer effective material handling solutions for everything from bulky paper rolls to heavy equipment and manufacturing assemblies. Our patented Aero-Caster® air bearings offer many advantages:

MINIMAL EFFORT. Because operation is nearly frictionless, force required is about 1 pound per 1,000 pounds of load.

MANEUVERABLE LOADS. Omni-directional movement saves time, effort and manpower.

SAFETY. Eliminating overhead equipment removes danger from falling loads.

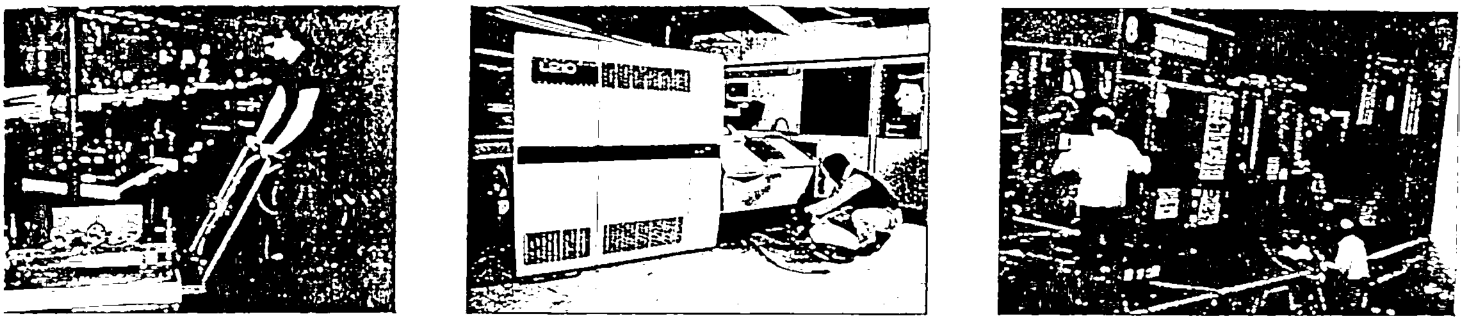
NO DAMAGE TO FLOORS. Stress is evenly distributed so expensive structural reinforcement usually isn't necessary. And Aero-Casters won't damage floor surfaces.

REDUCED COSTS. An Aero-Caster solution often costs one-tenth the price of an overhead crane or other load moving system.

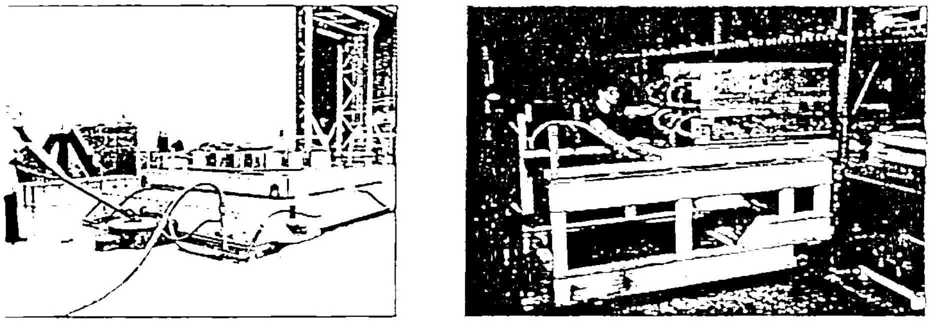
AERO-GO's versatile lines of standard products are used every day to...

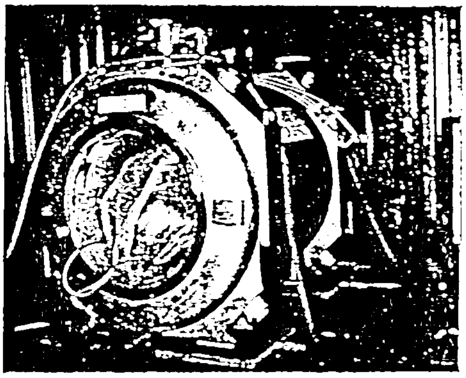
- Transport and install heavy equipment
- Convey assemblies through production lines
- Move finished products to shipping or storage
- Eliminate outside rigging expenses
- Isolate sensitive calibration equipment from vibrations
- Move delicate high-tech equipment
- Transport loads in clean-room environments
- Move production equipment for flexible manufacturing
- Carry bulky paper rolls
- Reduce the risk of injuries in manual load handling
- Provide greater safety for use around volatile substances

A standard Aero-Go Load Module System® features rugged Aero-Caster® air bearings, color-coded hoses, and a compact, easy-to-use control console.

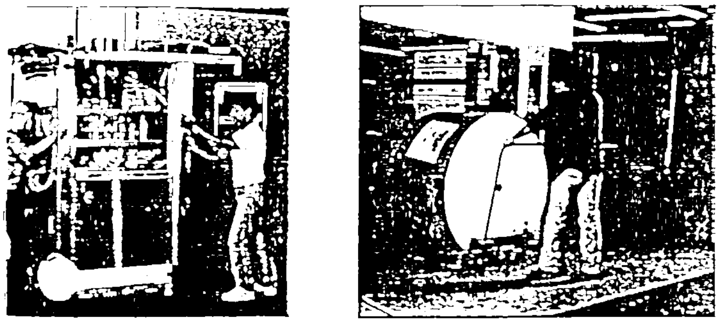


Aero-Planks®: Fast, cost-effective movement for manufacturing, high-tech and rigging applications.

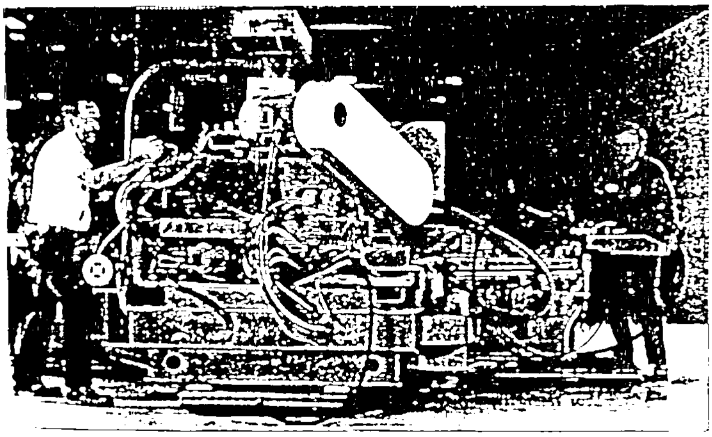


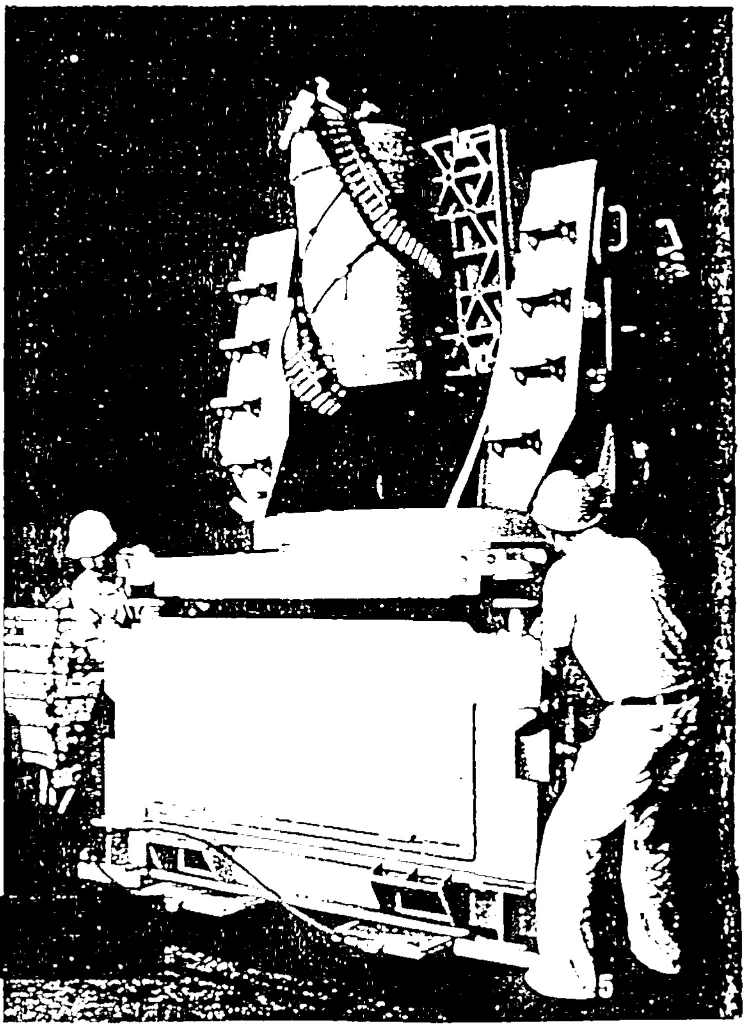


Pallets®: Versatile and rugged to transport heavy loads in almost any industrial environment.



ro-Go products: For moving delicate equipment or heavy paper rolls.





Load Module Systems®, (above, right, & above-right): For easily transporting and maneuvering any massive load.

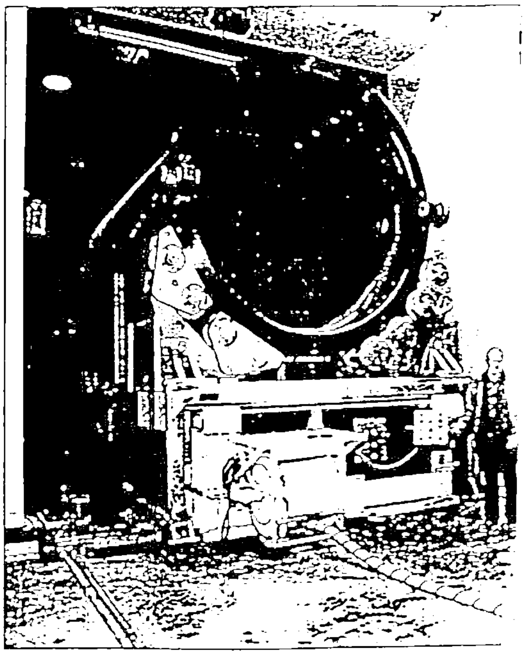
Custom-engineered solutions for unique needs

Aero-Go engineers and manufactures a wide variety of specialized equipment for industrial and aerospace applications. Whether the solution for your special load moving application is simple or requires an entire turnkey system, Aero-Go will design the fluid film, wheeled or rail system to meet your exact specifications.

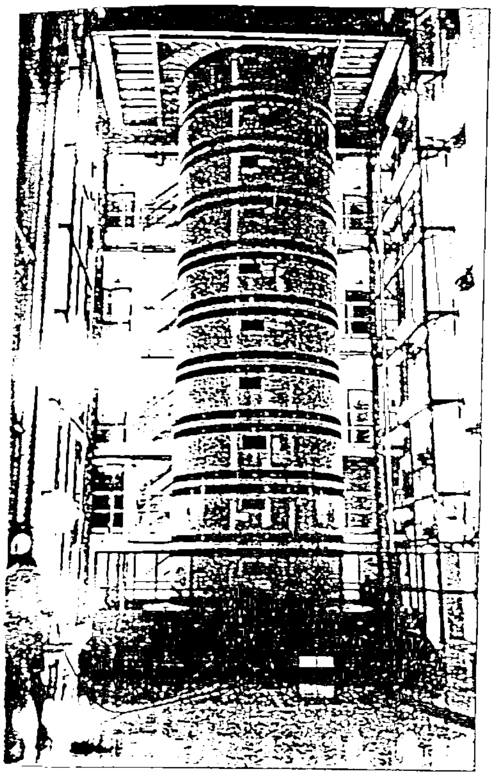
AERO-GO specially engineers innovative systems to...

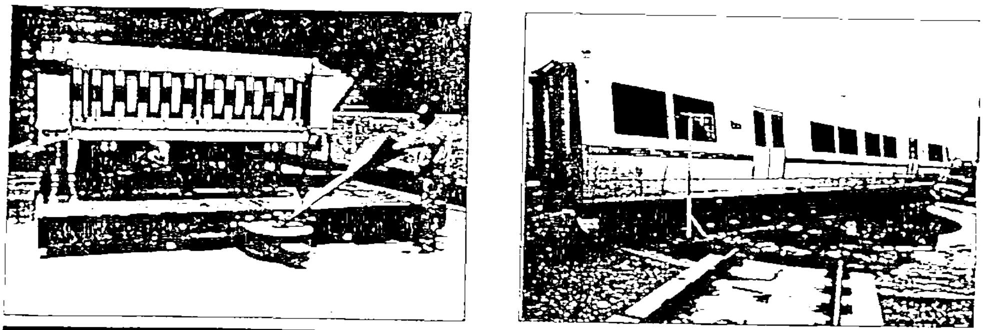
- Change 100,000-pound dies in three minutes or less
- Transport jet engines, rocket segments and other aerospace / defense equipment
- Carry heavy assemblies through production lines
  Transport enormous equipment for one-time specialized moves
- Move production equipment for flexible manufacturing
- Launch ships and move segments of ship hulls in assembly
- Transport electrical switch gear and transformers
- Move sets and seating in theaters
- Convey equipment on and off coordinate measuring devices
- Move injection molding machines
- Insert large concrete pipes into sewer tunnels using special curved air casters
- Transport paper rolls of unusual sizes or shapes
- Solve difficult load moving challenges in almost any environment

WE'RE READY TO HELP. At Aero-Go, we have the know-how to design and manufacture the high quality load moving equipment you need. Call us today to discuss your special applications.

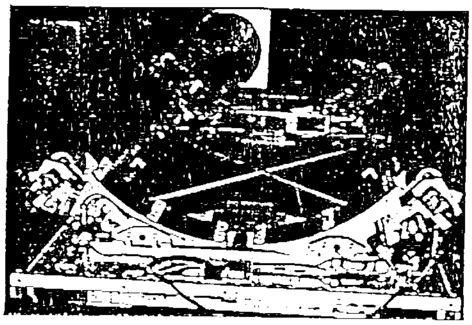


Aero-Go designs shield doors and rocket transporters for difficult aerospace applications.

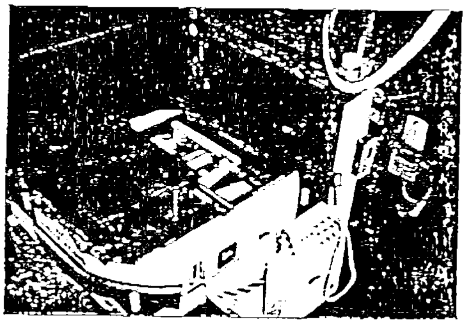




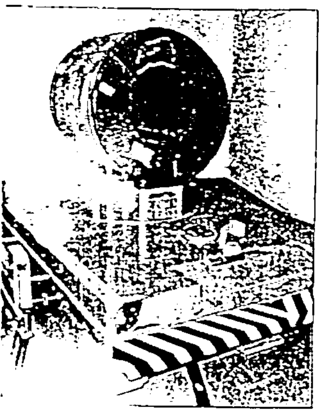
Transporters for transformers ... and turntables for trains.



Specialized systems move (left) and rotate (right) rocket segments.

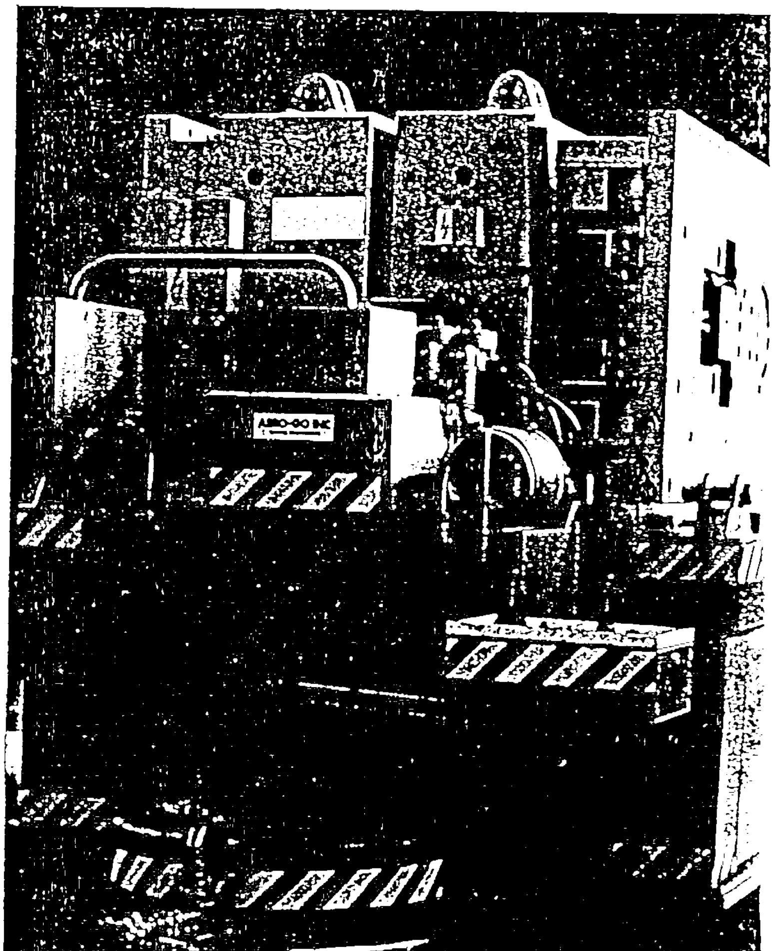


Systems for quick die change.



Guided Vehicles.

Custom transporters and skids.



Systems to rapidly change large injection molds.

Equipment for applications from theatrical to manufacturing.

Load Module™ Systems

Load Module™ Systems utilize the efficiency of fluid film technology to actually float heavy loads on a near-frictionless film of air. With Aero-Go Load Modules, one person can easily move thousands of pounds.

Versatility and Efficiency

Load Modules combine simplicity of operation with extreme versatility. Load movement is easy, exceptionally smooth, omni-directional and can be performed anywhere in the work environment where there is an adequate floor surface. Operation in tight spaces is a breeze.

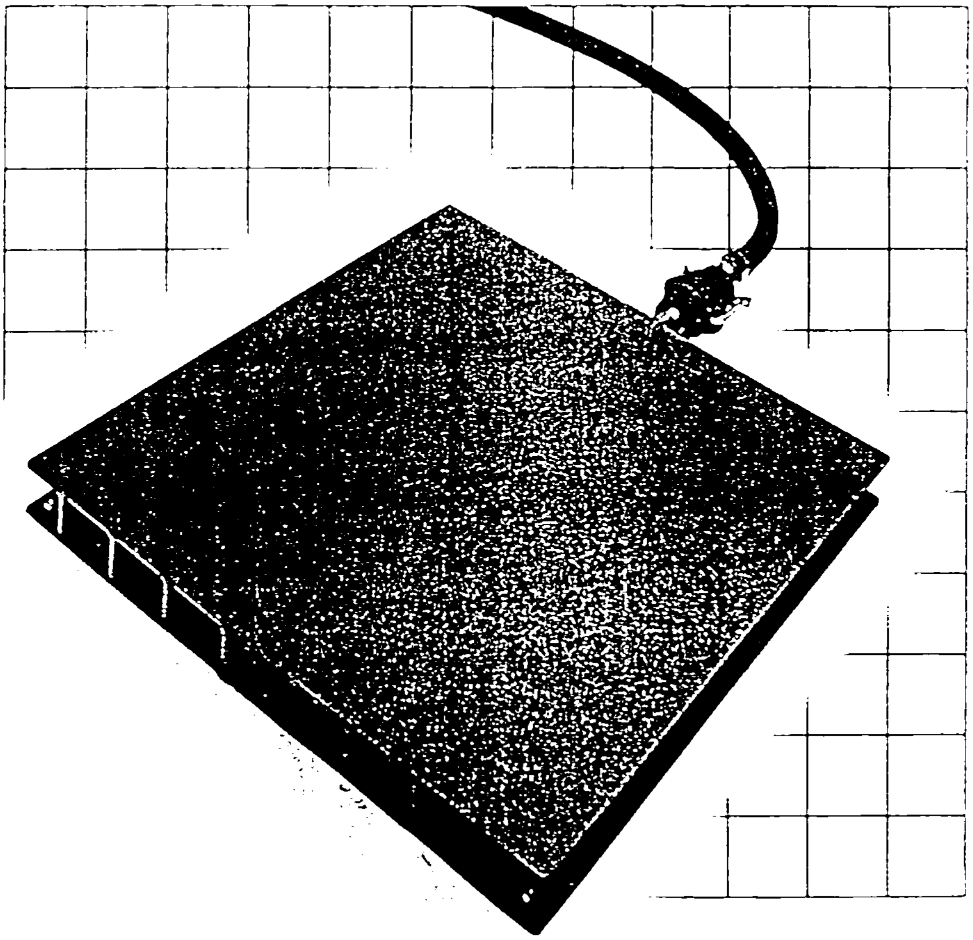
Load Module Aero-Casters® distribute the load weight over a greater surface than with rollers or wheels, spreading any stress evenly on the floor. This eliminates damage to the floor and the need for expensive tracks, reinforced floors and building structures.

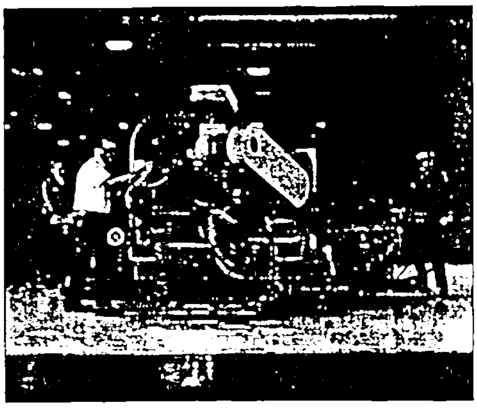
Aero-Go systems are more cost-effective than traditional load movement methods. Your own personnel can quickly learn to utilize the system. And, since there are no moving parts, maintenance costs stay low.

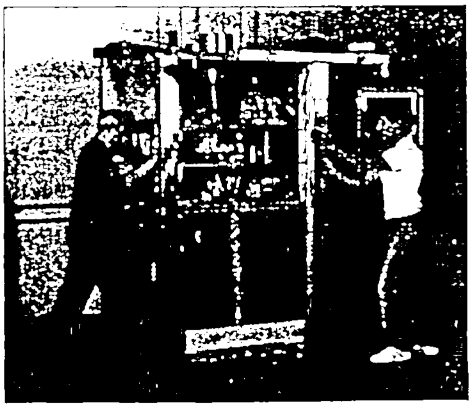
Load Modules are easily portable and can be positioned under the load according to weight distribution on load support points. This minimizes stress on the load structure.

Unlimited Applications

Load Modules are manufactured to stand up to the most demanding applications. They are perfect for the movement of massive loads from assembly to shipping, for plant start-up or relocation, or for the repair of large and bulky items such as heat exchangers and transformers. Load Modules are ideal for jacking or rotating assemblies, precisely aligning machines over footings, moving modules, and rearranging entire production lines.







LOAD MODULE™ SYSTEM SPECIFICATIONS

Model (Insert N, T or U Code) (4)	System Capacity lbs (kg) (1)	No. and Model of Load Modules (4)	Dimensions of each Load Module inches (mm)	Effective Lift Height inches (mm)	Req'd size plant air hookup (NPT) inch (5)	Control Console	Rated Operating Pressure psig (kg/cm²) (2)	Recommended Air Volume scfm (L/sec) (3)	Equipment Net Weight lbs (kg)
4K8___L	2,000 (900)	4-K8___	8" x 8" x 1-7/8" (203.2 x 203.2 x 47.6)	3/8" (9.5)	3/4	BN44	12.5 (.88)	42 (20)	85 (39)
6K8___L	3,000 (1,350)	6-K8___	8" x 8" x 1-7/8" (203.2 x 203.2 x 47.6)	3/8" (9.5)	3/4	BN46	12.5 (.88)	63 (30)	125 (57)
4K12___L	8,000 (3,600)	4-K12___	12" x 12" x 1-7/8" (304.8 x 304.8 x 47.6)	3/4" (19.1)	3/4	BN44	25.0 (1.75)	84 (40)	90 (41)
6K12___L	12,000 (5,450)	6-K12___	12" x 12" x 1-7/8" (304.8 x 304.8 x 47.6)	3/4" (19.1)	3/4	BN46	25.0 (1.75)	126 (60)	130 (59)
4K15___L	14,000 (6,350)	4-K15___	15" x 15" x 1-7/8" (967.7 x 967.7 x 47.6)	7/8" (22.2)	3/4	BN44	25.0 (1.75)	98 (46)	105 (48)
6K15___L	21,000 (9,500)	6-K15___	15" x 15" x 1-7/8" (967.7 x 967.7 x 47.6)	7/8" (22.2)	3/4	BN46	25.0 (1.75)	147 (69)	155 (70)
4K21___L	28,000 (12,700)	4-K21___	21" x 21" x 2" (533.4 x 533.4 x 50.8)	1-1/8" (28.6)	3/4	BN44	25.0 (1.75)	112 (53)	150 (68)
6K21___L	42,000 (19,000)	6-K21___	21" x 21" x 2" (533.4 x 533.4 x 50.8)	1-1/8" (28.6)	1	BN46	25.0 (1.75)	168 (79)	220 (100)
4K27___L	48,000 (21,700)	4-K27___	27" x 27" x 2-7/16" (685.8 x 685.8 x 61.9)	1-3/8" (34.9)	1	BN64	25.0 (1.75)	126 (60)	270 (123)
4K21___HDL	56,000 (25,500)	4-21___HD	21" x 21" x 2" (533.4 x 533.4 x 50.8)	1-1/4" (31.8)	1-1/4	BN64	50.0 (3.5)	210 (99)	170 (77)
6K27___L	72,000 (32,500)	6-K27___	27" x 27" x 2-7/16" (685.8 x 685.8 x 61.9)	1-3/8" (34.9)	1	BN66	25.0 (1.75)	189 (89)	400 (182)
4K3___L	80,000 (36,500)	4-K36___	36" x 36" x 2-11/16" (914.4 x 914.4 x 68.3)	1-3/4" (44.5)	1-1/4	BN64	25.0 (1.75)	168 (79)	425 (193)
6K21___HDL	84,000 (38,000)	6-K21___HD	21" x 21" x 2" (533.4 x 533.4 x 50.8)	1-1/4" (31.8)	1-1/4	BN66	50.0 (3.5)	315 (149)	245 (111)
4K27___HDL	96,000 (43,500)	4-K27___HD	27" x 27" x 2-7/16" (685.8 x 685.8 x 61.9)	1-1/2" (38.1)	1-1/4	BN84	50.0 (3.5)	280 (132)	300 (136)
6K36___L	120,000 (54,500)	6-K36___	36" x 36" x 2-11/16" (914.4 x 914.4 x 68.3)	1-3/4" (44.5)	1-1/4	BN66	25.0 (1.75)	252 (119)	625 (284)
6K27___HDL	144,000 (65,500)	6-K27___HD	27" x 27" x 2-7/16" (685.8 x 685.8 x 61.9)	1-1/2" (38.1)	1	BX86	50.0 (3.5)	420 (198)	445 (202)
4K48___L	160,000 (72,500)	4-K48___	48" x 48" x 2-11/16" (1219.2 x 1219.2 x 68.3)	2-5/8" (66.7)	1-1/4	BX84	25.0 (1.75)	182 (53)	725 (329)
6K48___L	240,000 (109,000)	6-K48___	48" x 48" x 2-11/16" (1219.2 x 1219.2 x 68.3)	2-5/8" (66.7)	1-1/2	BX86	25.0 (1.75)	273 (129)	1,085 (493)
4K48___HDL	320,000 (145,000)	4-K48___HD	48" x 48" x 2-11/16" (1219.2 x 1219.2 x 68.3)	3" (76.2)	1-1/4	BX84	50.0 (3.5)	350 (165)	785 (356)
6K48___HDL	480,000 (218,000)	6-K48___HD	48" x 48" x 2-11/16" (1219.2 x 1219.2 x 68.3)	3" (76.2)	1-1/2	BX84	50.0 (3.5)	525 (248)	1,190 (540)

Load must be positioned so individual bearing capacities are not exceeded.

Recommended supply pressure: 25 psig above rated operating pressure.

At maximum load on required smooth-troweled and sealed concrete or equivalent.

Select Standard, Tuffcoat,™ or Urethane series Aero-Casters according to application requirements. See publication 7011 for selection criteria. For mod[illegible]mber, insert N (Standard), T (Tuffcoat), or U (Urethane) in the blar[illegible]ed above.

Recommended for air supply hose lengths up to fifty (50) feet, consult Engineering Bulletin for longer lengths.

TANDARD EQUIPMENT:

Four (4) or six (6) Load Modules.

Control console with regulators to control pressure/volume to each Aero-Caster.

Four (4) or six (6) interconnecting hoses 20 ft. each).

uick disconnect fittings for all hoses.

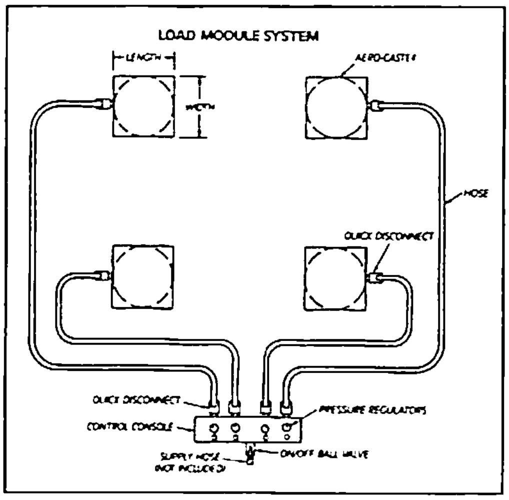
n/off ball valve for system control.

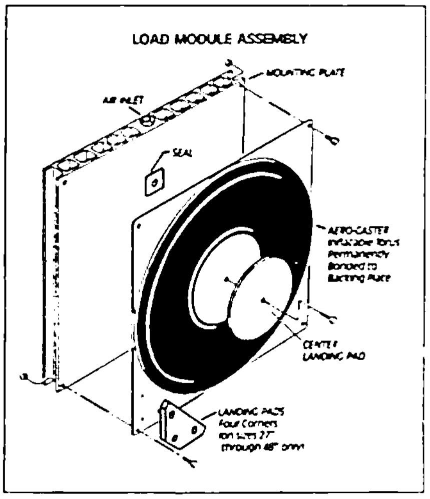
ealer start-up on-site.

PTIONS:

leavy-duty Aero-Pack storage cart includes art, manual rewind hose reel with 75′ upply hose and fittings.

conomy cart with removable lockbar.





AeroGo, Inc.

1170 Andover Park West • Seattle, WA 98188-3909
Toll Free: (800) 426-4757 • (206) 575-3344
Telefax: (206) 575-3505

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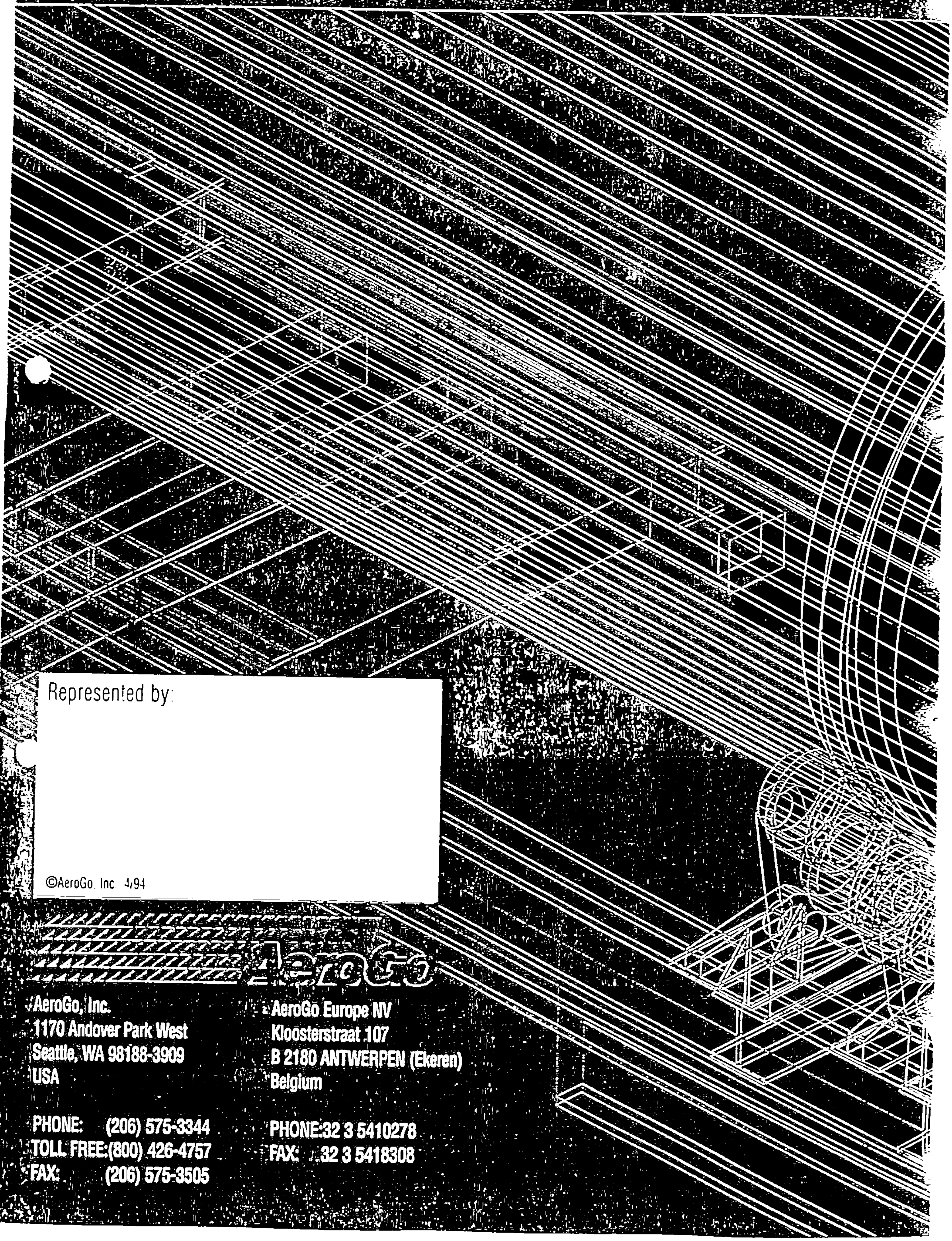

Represented by:

AeroGo

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AeroGo Europe NV
Kloosterstraat 107
B 2180 ANTWERPEN (Ekeren)
Belgium

PHONE:32 3 5410278
FAX: 32 3 5418308

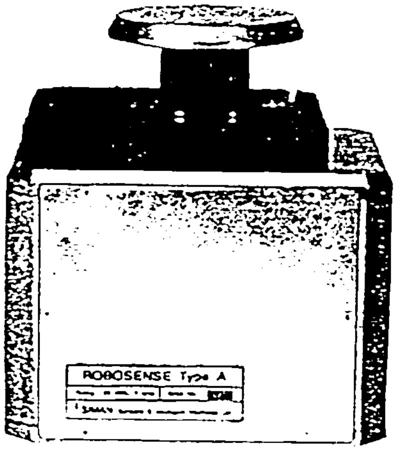
A.2 Navigation Systems

Robosense

Manufactured by ISIMAN ltd (Israël)

General Features

ROBOSENSE is the state-of-the-art extended-range intelligent navigation system for fast autonomous vehicles.
Built according to the specifications of leading robot developers, and using Time-of-Flight GaAs Laser technology for range and angle measurements, ROBOSENSE extends the horizons of mobile robots .
ROBOSENSE, as an electro-optical navigation system for autonomous vehicles, computes position and orientation by matching the measured instantaneous location with the site map stored in the system's memory.
The system provides navigation data to the vehicle's main computer, where it is processed with the mission planning instruction and the controlling functions to produce the driving and steering commands.



Ordering Information

Part#

280	Robosense
328	Kit Robosense (Robuter)

Technical Specifications

- Vehicule Speed : Up to 3m/sec, 180°/sec turn rate
- Communication : RS-232, full-duplex
- Sizes : 160 X 205 X 170 mm
- Weight : 2,5 Kg
- Power : 24VDC, 1A
- Standard features : Mapping, Positioning, confidence Level Reporting

Accuracy

- Position : 2,5 cm at maximum vehicle speed
- Heading : 0,3°
- Navigation : absolute .No drift

Processors

- Laser Controller : CPU 8751
- Navigation Computer : CPU 80386/25 MHz

Laser

- Type : GaAs, pulse
- Field of View :180° to 360°
- Rotations/Sec :10
- Range : up to 20 m
- Update Rate : up to 40Hz
- Safety : Meets ANSI Z-136, Class 1

October 96

2001

Localization & guiding systems

Robolase

Manufactured by ROBOSOFT (France)

General Features

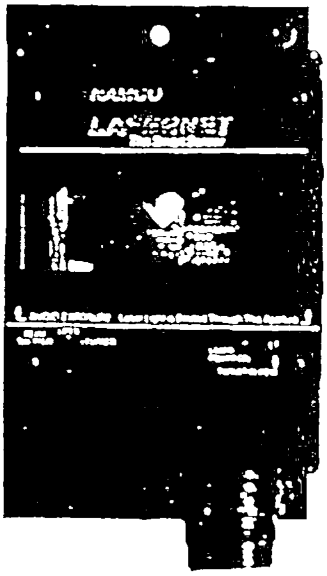
ROBOLASE™, this Absolute Localization kit is made of a VME 68040 CPU board running under a real-time Operating System, Albatros™, a Lasernet™, a versatile, intelligent optical sensor and reflective beacons.

The Lasernet™ can determine the angle and the distance to this beacon.

Processing information issued by the Lasernet™, ROBOLASE™ enables to get absolute positioning information.

Applications

- industrial piloting
- guidance applications
- mobile robotics



Ordering Information

Part#

255	Kit Absolute Localization (Robuter)
279	Robolase™

Technical Specifications

Absolute localization kit

- Range : from 0.3 m to 6 m
- Field of view : - 55° to + 55°
- Accuracy : from 2 mm to 5 cm (depending on the position of the Lasernet to the target)
- Positioning information : cartesian coordinates (X, Y, theta) according to pre-defined reflective targets

Computing environment

- VME 68040 CPU, 25 MHz, 1Mo DRAM, 512 Ko SRAM
- Communication : RS-232 serial port
- Transmission rate : 9600 bauds
- Real-Time Operating System : Albatros
- Command : LNET

Lasernet

- Power voltage : 24 V DC
- Current consumption : 0.33 A
- Operation temperature : 0°C to 50°C
- Size : 215 X 128 X 80 mm
- Weight : 1 650 g

Laser

- Type : HeNe, scanned laser
- Maximum Output Power : 0.25 mW
- Safety : Class 2
- Caution : avoid direct exposure to beam
- Wavelength : 632.8 nm (red light)

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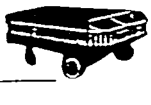


3 - PRINCIPE DE FONCTIONNEMENT

3.1 - Principe

Le capteur LASERNET™ comprend un laser hélium-néon et un système optique associé, un miroir rotatif chargé du balayage, plusieurs photodétecteurs pour la réception du signal lumineux et la synchronisation, un microprocesseur pour l'analyse des signaux lumineux, plusieurs types de sorties, et un port de communication série. Le principe de fonctionnement est schématisé dans la figure ci-dessous.

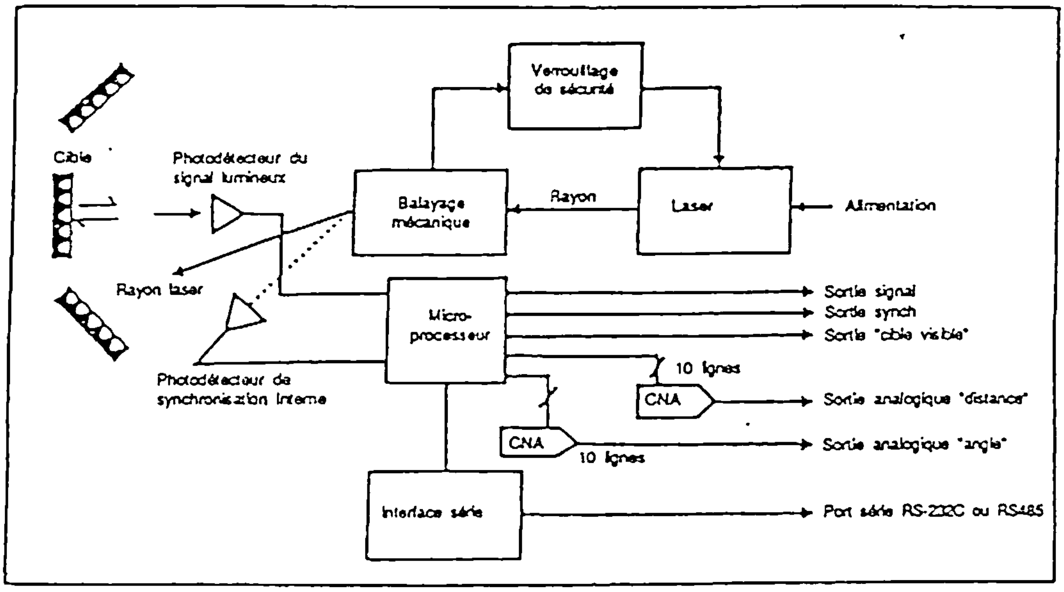


Figure 3.1 - Principe de fonctionnement

Le laser émet en continu un rayon parallèle de lumière rouge, qui est réfléchi par des miroirs fixes sur un miroir rotatif qui tourne à une vitesse angulaire constante de 20 balayages par seconde. Le rayon réfléchi par le miroir rotatif arrive d'abord sur un photodétecteur interne de synchronisation (P2), qui permet de déclencher les traitements chronométriques. Ensuite, le miroir continue à balayer le rayon à travers la fenêtre du LASERNET, sur un champ de vision de 113 degrés environ.

Selon l'application, il peut y avoir un ou plusieurs rétroréflecteurs cibles (8 maximum) situés dans l'espace balayé. Les rétroréflecteurs ont la propriété physique de réfléchir la lumière sur la même trajectoire que la lumière incidente. Ainsi, lorsque le rayon de balayage atteint l'une de ces cibles, il est renvoyé directement sur la même trajectoire vers le LASERNET, où il est recueilli par le même miroir rotatif qui le renvoie vers la source laser. Cependant, il se produit une légère dispersion de la lumière renvoyée; de ce fait une partie du rayon de retour est capté par le photodétecteur de signal lumineux (P1). Le signal électrique généré par ce photodétecteur est amplifié et converti en onde carrée qui sera ensuite exploitée par le microprocesseur pour l'analyse chronométrique.

Les LASERNET Multicibles traitent un maximum de huit cibles. Les LASERNET Plage Étendue utilisent les mêmes types de cibles que les modèles Standard, mais sur une distance allant jusqu'à 15 mètres environ.

Le microprocesseur calcule une paire de valeurs distance/angle, et envoie les résultats à deux convertisseurs numérique-analogique à 10 bits, qui fournissent les informations distance et angle sous forme de signaux analogiques (0 à 10 V cc). L'utilisateur dispose également d'un certain nombre de signaux de contrôle et d'un port série pour le transfert des valeurs chronométriques à un équipement externe.

3.1.1 - Micrologiciel Intégré

Le LASERNET comporte un microprocesseur à 8 bits, responsable de toutes les opérations de contrôle interne, d'analyse des cibles et de communication. Le micrologiciel interne comprend plusieurs compteurs "chien de garde" qui permettent de remettre le système à zéro quand une erreur logicielle vient bloquer le système après un délai prédéterminé.

3.1.1.1 - Microcontrôleur

Le LASERNET utilise un microcontrôleur Hitachi à 8 bits, avec une mémoire ROM (lecture uniquement) de 16K et une mémoire RAM (lecture et écriture) de 512 octets. Une mémoire RAM non-volatile de 256 octets sauvegarde les paramètres du système lorsque l'appareil est éteint. Ainsi, le LASERNET se souvient des paramètres utilisateur et n'a pas besoin d'être reprogrammé chaque fois qu'il est mis sous tension, à moins que l'utilisateur veuille modifier certaines valeurs.

3.1.1.2 - Contrôle du moteur de balayage

Lors de la mise sous tension, le microcontrôleur se charge de mettre le moteur en marche. Pendant sa phase d'accélération, le moteur génère un signal carré, d'une fréquence de 4 impulsions par tour, utilisé comme signal d'asservissement de vitesse. Pendant cette phase, le laser reste éteint. Lorsque le moteur atteint la vitesse prédéterminée de 22 tours par seconde, le laser s'allume; à partir de ce moment, une photocellule de synchronisation capte le rayon laser réfléchi par le miroir tournant et fournit la vitesse moteur sous forme d'un signal de synchronisation d'une fréquence d'une impulsion par tour. Dorénavant, l'asservissement de la vitesse du moteur est contrôlé exclusivement par le signal SYNC de la photocellule de synchronisation, et non plus par le signal généré par le moteur. Chaque fois que la vitesse du moteur tombe au dessous du seuil de 18,9 tours par seconde, le microcontrôleur détecte cette baisse et éteint le laser par mesure de sécurité. En temps normal, le microcontrôleur compare les durées réelle et nominale de chaque tour moteur, et corrige les légers écarts de vitesse en agissant sur l'alimentation moteur. De cette façon le microcontrôleur effectue une fonction d'asservissement de vitesse en boucle fermée.

Des secousses externes peuvent altérer la dynamique de l'ensemble moteur-miroir et provoquer des variations instantanées de la vitesse du moteur. Bien que l'inertie tende à réduire la variation de vitesse, cette variation peut quand même se produire et entraîner des erreurs de données. Par la suite, nous étudierons la fonction TOLÉRANCE VITESSE. Cette fonction détecte l'écart de vitesse, le compare à une valeur paramétrable, et inhibe la sortie de données si l'erreur de vitesse dépasse un seuil prédéterminé.

3.1.1.3 - Détection des cibles

Une fois le LASERNET en marche, une photocellule se charge de détecter le rayon lumineux réfléchi par des rétroréflecteurs cibles situés dans le champ de vision de l'appareil. Le signal généré par la photocellule constitue une des entrées compteur du microcontrôleur. Chaque fois que ce signal change d'état, le microcontrôleur enregistre en mémoire la valeur d'un compteur en roue-libre. Un front montant indique le flanc avant d'une cible, tandis qu'un front descendant indique le flanc arrière.

Le microcontrôleur utilise l'ensemble des valeurs enregistrées pour analyser la position des cibles. On peut le programmer pour filtrer les cibles selon plusieurs critères: cible à cheval sur l'une des limites du champ de vision, cible trop petite, cible non déclarée "active", etc. Par exemple on peut demander au microcontrôleur de ne prendre en compte que la cible la plus près. A partir des valeurs enregistrées, le microcontrôleur peut déterminer la distance et la position angulaire du bord gauche, du bord droit ou du centre de chaque cible. Il peut même effectuer des contrôles de cohérence de données (par exemple, erreur de tangente: largeur de cible n'est pas une fonction linéaire de la différence angulaire entre les deux bords).

3.1.2 - Calcul de la distance et de l'angle

Un tour de moteur de balayage correspond à un compte horloge interne de 61440. Le LASERNET a donc une résolution théorique de 360°/61440, ou 0,006 degrés environ. Un champ de vision de 90° aura un compte maximum de 15360.

Le LASERNET enregistre en mémoire les valeurs horloge correspondantes aux flancs droit et gauche de chaque cible détectée. La différence entre ces deux valeurs représente la largeur de la cible. Mais, pour une cible de largeur donnée cette valeur sera inversement proportionnelle à la distance du LASERNET à la cible. Plus la différence entre le bord droit et le bord gauche est grande, plus la cible parait large, ce qui veut dire que la cible est plus près du LASERNET.

Le LASERNET enregistre aussi en mémoire une valeur qui indique le début du champ de vision. La différence entre la valeur "bord d'attaque" de la cible et le début du champ de vision représente la position angulaire de la cible par rapport au début du champ de vision. Des options logicielles permettent de calculer la position angulaire en fonction du bord gauche, du bord droit ou du centre de la cible.

Les valeurs "distance" et "angle" de toutes les cibles actives sont disponibles sur le port série du LASERNET. Les valeurs "distance" et "angle" de la première cible active sont également disponibles sur les sorties analogiques.

3.1.3 - Intensité optique de réserve

Le LASERNET incorpore un système optique sophistiqué qui utilise des filtres dichroïques capables de filtrer toute longueur d'onde sauf celle émise par le laser hélium-néon. Le système est donc insensible à l'éclairement ambiant.

Le LASERNET série LN110 a été conçu pour fonctionner à une distance nominale de 6 mètres avec le rétroréflecteur EP175-31900, de 100 mm de largeur. On suppose que le réflecteur et la fenêtre du LASERNET sont propres, ainsi que l'air ambiant. Dans ces conditions, l'intensité optique de réserve du LASERNET peut augmenter la distance de travail de 50% à 100%. En d'autres mots, la lumière renvoyée aura une intensité lumineuse de 50% à 100% supérieure au minimum nécessaire pour sa détection. Le LASERNET série LN120 a été conçu pour fonctionner à une distance nominale de 15 mètres avec le même rétroréflecteur. Ce modèle a une intensité optique de réserve de 40% à 100%.

De nombreux facteurs, tels que pollution atmosphérique, réflecteurs ou fenêtre sales, utilisation d'autres types de rétroréflecteurs, peuvent réduire l'intensité optique de réserve et même diminuer la distance de travail au dessous de sa valeur nominale (6 ou 15 mètres selon le modèle de LASERNET). Chaque type de rétroréflecteur a ses propres caractéristiques d'atténuation optique. Le coefficient de réflectivité est fonction de l'angle d'incidence.

3.1.4 - Signaux analogiques

L'utilisateur dispose de deux signaux analogiques, "distance" et "angle" pour des applications simples de contrôle. Chaque signal est généré par un convertisseur numérique-analogique à 10 bits, ce qui veut dire que la plage de tension 0 à 10 V comprend 1024 valeurs discrètes. Dans le cas de cibles multiples, les sorties analogiques correspondent à la première cible active. Chaque sortie est capable de fournir un courant de 5 mA max et possède son propre potentiomètre d'étalonnage pour le réglage de la valeur pleine échelle. La sortie "distance" peut être réglée entre -100% et +500% environ, et la sortie "angle" entre -100% et +30% environ.

La champ de vision du LASERNET peut être réglé entre 90° et 10°. Si le champ de vision est différent de 90°, la sortie analogique "angle" est réglée en conséquence. Par exemple, pour un champ de vision de 10°, la sortie analogique de 0 à 10 V correspondra à des angles de -5° à +5°.

3.1.5 - Aspects chronométriques

Le LASERNET est basé sur un système de balayage à course libre, où le microcontrôleur est cadencé par la période de rotation du rayon laser. Pendant que le rayon laser balaie les 90 degrés du champ de vision, le LASERNET recueille des informations. Pendant les 270 degrés restants, le microcontrôleur traite les informations recueillies et prépare le transfert de données en réponse aux demandes reçues via le port série. Si le LASERNET reçoit une demande d'information pendant le balayage du champ de vision, il enregistre la demande mais n'enverra la réponse qu'à la fin du balayage. Ainsi, le microcontrôleur envoie toujours les données les plus récentes.

Cependant, le LASERNET doit réaliser un certain nombre d'opérations pendant qu'il recueille des données, ce qui entraîne des pénalités de traitement logiciel. Par exemple, bien que la résolution théorique soit très fine, l'appareil ne peut pas traiter les cibles dont la taille est inférieure à un seuil minimum. En effet, la cible doit être suffisamment large pour être balayée pendant 50 microsecondes au moins, ce qui correspond au temps nécessaire au microprocesseur pour achever ses tâches de fond. Puisque le moteur effectue un tour chaque 50 millisecondes, le balayage des 90° degrés du champ de vision dure 50/4 = 12,5 millisecondes. Or, pour être détectée, la cible doit être éclairée par le rayon laser au moins pendant 50 microsecondes (0,050 millisecondes), ce qui veut dire que sa largeur doit représenter au moins 0,05/12,5 de 90°, soit 0,36 degrés. A une distance de 6 m, ceci se traduit par une largeur de 40 mm environ. Cependant, il ne faut pas confondre cette restriction de la taille minimale des cibles avec la résolution des mesures en tant que telle, celle-ci étant de 0,006° (0,6 mm environ).

Les pénalités de traitement logiciel entraînent une autre contrainte qui exige que l'espacement entre cibles multiples soit aussi de 0,36° minimum. En d'autres termes, à une distance de 6 mètres les cibles doivent avoir une largeur minimale de 40 mm et être séparées de 40 mm au moins. Si, à 6 m, deux cibles (de largeur supérieure à 40 mm) ont un espacement inférieur à 40 mm, le LASERNET les considère comme une seule cible ayant une largeur égale à la distance entre les bords externes.

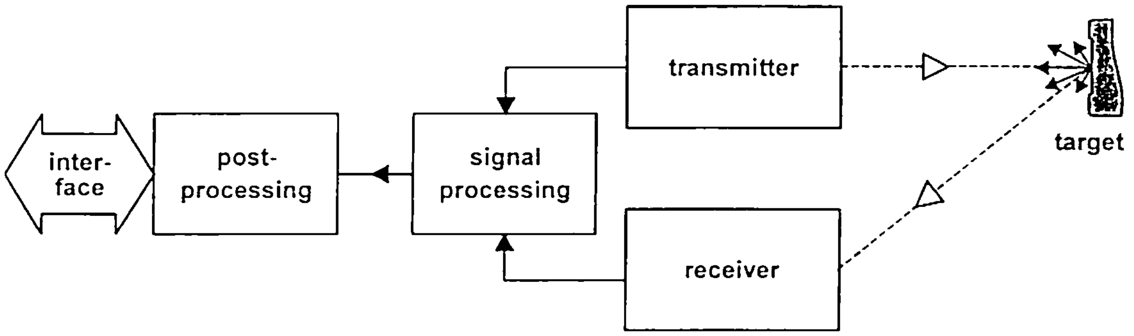
3.1.6 - Discrimination de largeur d'impulsion

Il peut arriver que le LASERNET capte des impulsions lumineuses de très courte durée, provenant de réflexions parasites ou de sources lumineuses externes. Comme de telles impulsions peuvent interférer dans le fonctionnement normal du LASERNET, l'appareil intègre plusieurs niveaux de discrimination de largeur d'impulsion. Le premier niveau de discrimination est constitué par le fait que le LASERNET ignore, à cause des pénalités de traitement logiciel, les impulsions inférieures à 50 microsecondes (séparées de 50 microsecondes au moins); en d'autres termes, il ignore les impulsions de largeur inférieure à 0,36° (voir ci-dessus). La discrimination intrinsèque de 50 microsecondes peut être augmentée à 100 microsecondes en activant l'option "filtre 100 microsecondes" (bit H6). Le deuxième niveau de discrimination est fourni par l'option logicielle "premier front montant / dernier front descendant", pour la définition des cibles dans le cas d'applications cible unique. Ce deuxième niveau de discrimination permet d'éliminer l'effet de modulation dû à la structure cellulaire de certains rétroréflecteurs quand ils sont situés près de l'instrument. En mode multicibles, un troisième niveau de discrimination est fourni par une option logicielle qui permet d'ignorer toutes les cibles dont la largeur (déterminée par la mesure de distance) est inférieure à un seuil prédéterminé. Les fonctions logicielles mentionnées ci-dessus seront étudiées dans la suite du document.

Key Features of a Pulsed Laser Sensor

Principle:

- Time-of-flight method
- Near-infrared wavelength
- Pulsed diode laser transmitter
- Sensitive narrow-band optical receiver
- Single pulse or multiple pulse signal detection
- Microprocessor-based post-processing and interfacing
- As far as appropriate: opto-mechanical scanning mechanism



Advantages:

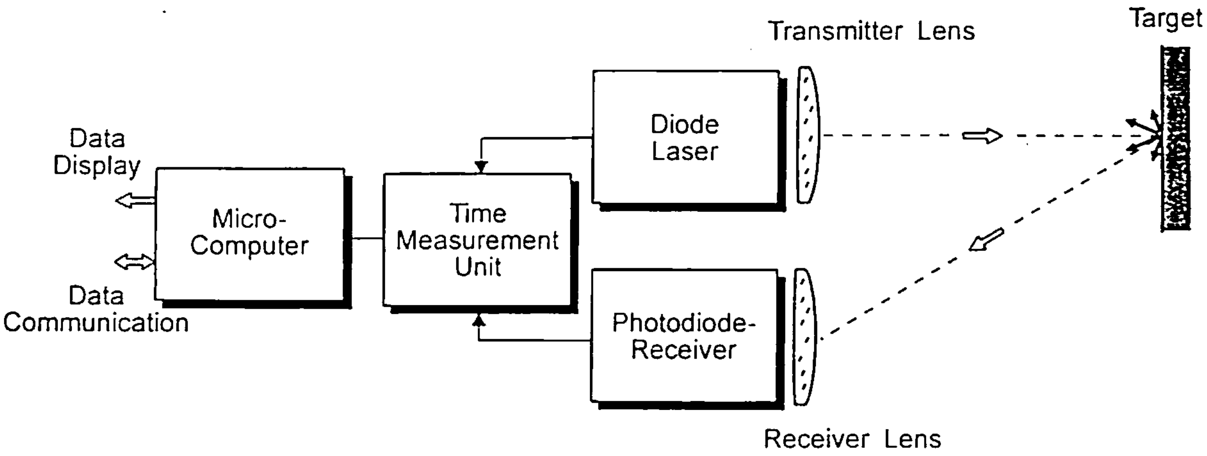
- Small size
- High reliability
- High interference immunity
- High accuracy
- Long range
- Quick data acquisition
- Highly collimated measuring beam
- Excellent cost / performance ratio

Trade-Off: reduction of the maximum range due to

- Very bright daylight
- Bad visibility
- Dirty or dusty front lenses

Operation of a Pulsed Laser Distance Meter

An electrical pulse generator periodically drives a semiconductor laser diode sending out infrared light pulses, which are collimated by the transmitter lens. Via the receiver lens, part of the echo signal reflected by the target hits a photodiode which generates an electrical receiver signal. The time interval between the transmitted and received pulses is counted by means of a quartz-stabilised clock frequency.
The calculated range value is fed into the internal microcomputer which processes the measured data and prepares it for range (and speed) display as well as for data output.



The modern instruments of series LD90-3 and LASER SCOUT allow the choice between four different data processing programs, according to the prevailing conditions and requirements:

The program FAST enables the quickest possible measurement at undisturbed conditions simply by averaging the single-pulse distance values which are acquired within the selected measuring time.
The program STANDARD provides a very useful clutter suppression: occasional echo signals caused not by the target itself but by backscattering of particles between target and instrument (e.g. clouds of material in a dusty silo, or raindrops and snowflakes in free air) are eliminated and not taken into account.
The program MAXIMUM DISTANCE is optimized for undisturbed level measurements in a silo at the cost of a slightly higher acquisition time.
The program MINIMUM DISTANCE is ideal for measurements to small targets which are not easy to aim at, as it eliminates background echoes.

Reflectivity of Various Surfaces / Materials

The amount of light that is returned from a target's surface is characterised by the reflection coefficient ρ. For a diffusely reflecting target, the maximum value of ρ is 100 %. For mirror-like or retroreflecting targets, the (theoretical) value of ρ can exceed 100 % by far. The reflection coefficient is, of course, depending on the wavelenght also.

Diffusely reflecting surfaces / materials [1]

MATERIAL	REFLECTIVITY ρ
White paper	up to 100 %
Dimension lumber (pine, clean, dry)	94 %
Snow	80 - 90 %
Beer foam	88 %
White masonry	85 %
Limestone, clay	up to > 75 %
Newspaper with print	69 %
Tissue paper, two ply	60 %
Deciduous trees	typ. 60 %
Coniferous trees	typ. 30 %
Carbonate sand (dry)	57 %
Carbonate sand (wet)	41 %
Beach sands, bare areas in dessert	typ. 50 %

MATERIAL	REFLECTIVITY ρ
Rough wood pallet (clean)	25 %
Concrete, smooth	24 %
Asphalt with pebbles	17 %
Lava	8 %
Black neoprene	5 %
Black rubber tire wall	2 %

Glossy, mirror-like or retroreflecting surfaces / materials [1]

MATERIAL	REFLECTIVITY ρ
Reflecting foil 3M2000X	1250 %
Opaque white plastic [2]	110 %
Opaque black plastic [2]	17 %
Clear plastic [2]	50 %

Note:

[1] Values of reflectivity given for a wavelength of about 0.9 micrometers

[2] For materials with shiny or glossy surfaces, the reflectivity figure represents the maximum light return, with the sensor beam exactly perpendicular to the material surface.

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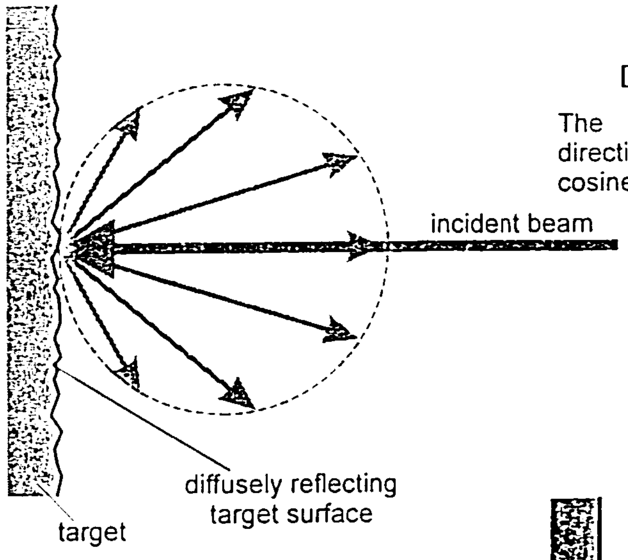
Reflectivity of Various Surfaces / Materials

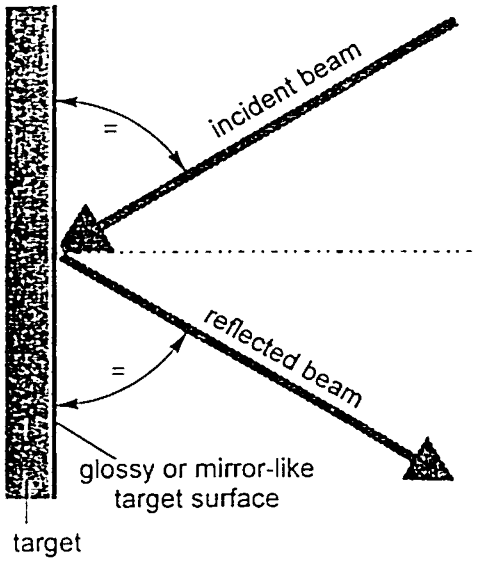
Diffuse reflection:

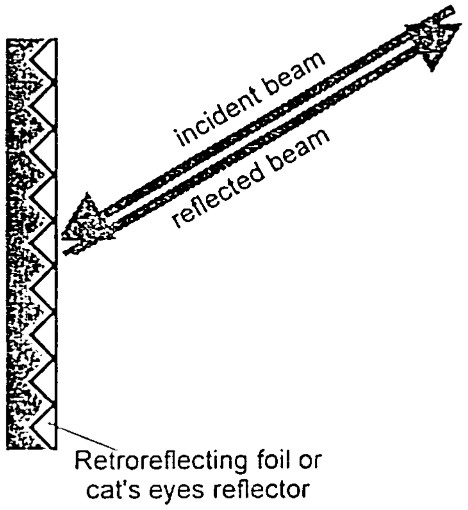
The signal is reflected omni-directionally according to Lambert's cosine law



Mirror-like reflection:

The angle of the reflected beam with respect to the targets surface is equal to the angle of incidence. Incident beam and reflected beam lie in the same plane.





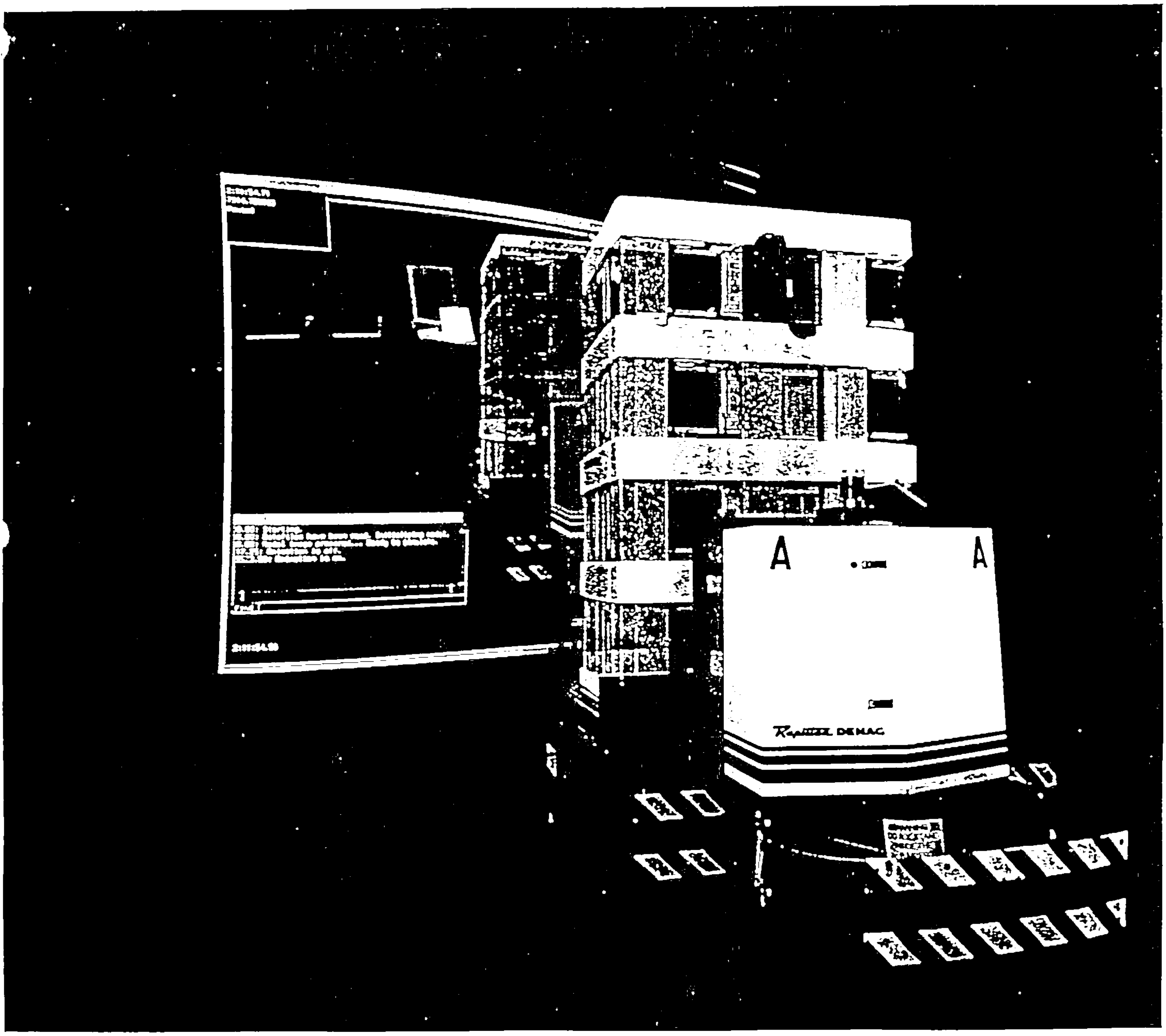
Retroreflection:

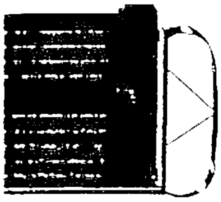
The retroreflected beam is returned in the same direction from which the incident beam came. This property is maintained over a wide range of directions of the incident beam.

Rapistan DEMAG

Virtual Path™ Guidance

Non-Wire Guidance Control for AGVs

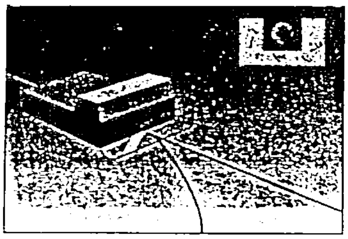




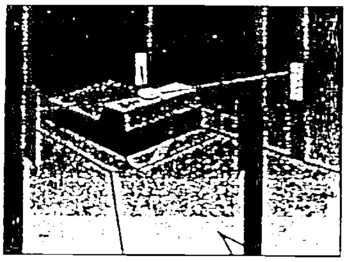
VIRTUAL PATH GUIDANCE

The next generation AGV control system

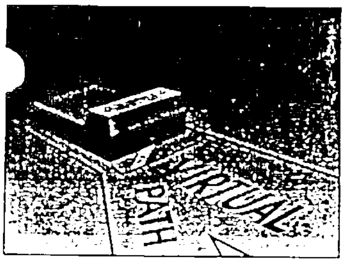
AGV Guidance A Brief Background



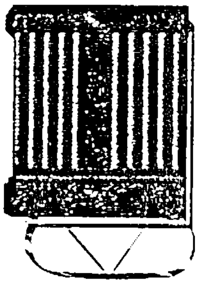
1954. Introduction of wire guidance AGV systems.



1985. Early attempts at non-wire guidance. AGV systems were equipment dependent, requiring targets, grids or chemical paths.



1994. Virtual Path Guidance system from Rapistan Demag, the first autonomous AGV control system.



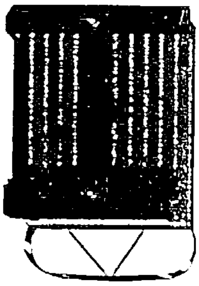
Rapistan Demag offers a major advancement in non-wire automatic guided vehicle technology—a new-generation guidance control system that is simple, easy to install and provides long term flexibility.

Called Virtual Path Guidance, the concept brings together existing AGV control technology, proven Rapistan Demag vehicle designs and a modular navigation system that operates:

- Without wires
- Without targets
- Without electrical in-floor responders
- Without chemical paths or grid layouts

Virtual Path Guidance uses existing and field proven smart AGV control logic in a convenient package. Traffic control, routing, and real-time constant communication are incorporated through an onboard guidance system that functions autonomous from floor surface or plant environment.

Virtual Path Guidance allows you to establish any type of travel pattern you require. Paths are quickly and easily created using widely accepted and understood DOS-compatible AutoCAD software.

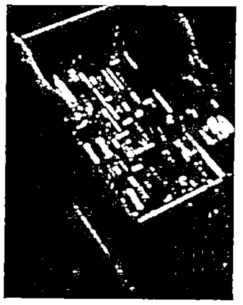


The inherent flexibility of Virtual Path Guidance technology makes it a reusable asset that allows you to establish an AGV route anywhere you need one. And since there is no installed path, configuration is easy and can be completed without disrupting plant operations.

The product of Rapistan Demag's 40-year history of ongoing AGV development, Virtual Path Guidance is a bold step forward in AGV system application.

The heart of the system: the gyro module

Virtual Path Guidance is made possible by the use of a gyroscope navigation module perfected for high-profile commercial and military applications. Used where pinpoint accuracy is critical, this technology provides a number of practical advantages:

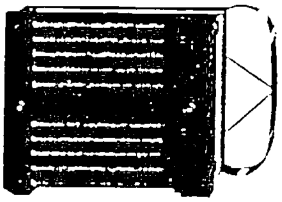


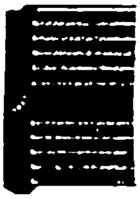
Plug in/bolt-on modularity.

High Mean Time Between Failure. Military reliability is built into each unit.

Adjustment free. The unit responds to the CAD program instructions and does not require any manual adjustment.

Virtually autonomous. No wires, targets or responders are needed for operation. And the system can go anywhere in your plant regardless of floor composition.



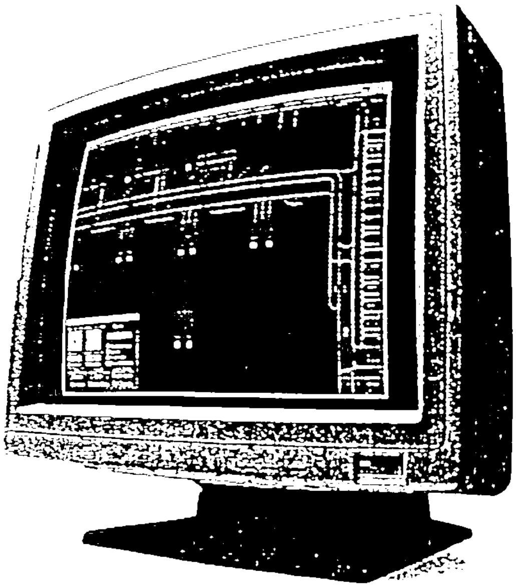


Installs in 3 easy steps

How the Virtual Path Guidance System Works

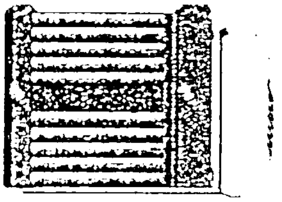
An AGV enters the path layout at any initialization point, automatically synchronizing the navigation computer to exact location. From this point, onboard modules measure the rate of change of AGV velocity. This is translated into distance and direction by the navigation computer, compared with the AutoCAD path layout file, and converted into steer commands.

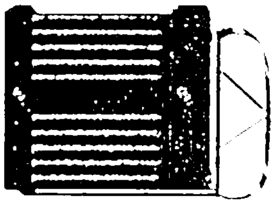
Virtual Path Guidance is quick and easy to install. Here is a brief walkthrough of the major tasks:

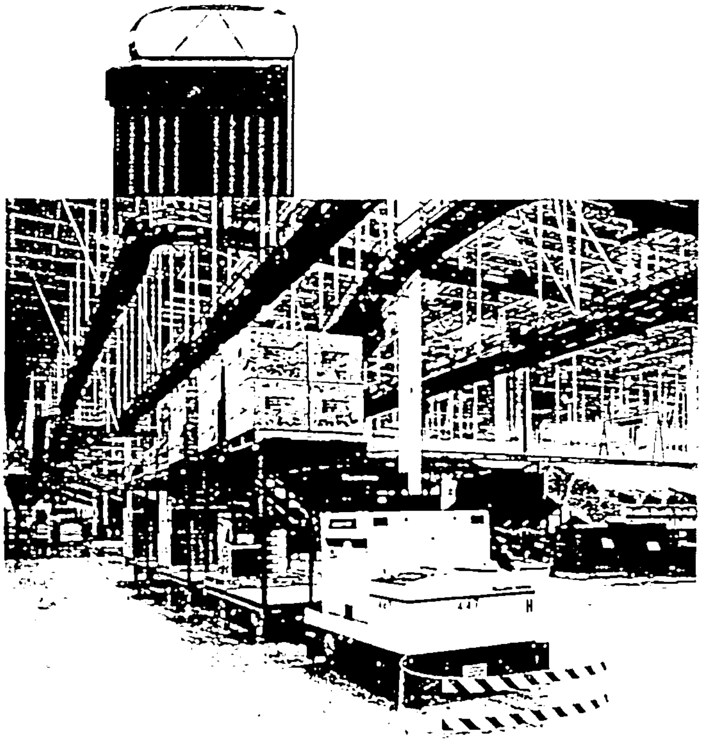


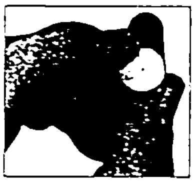
1 Generate the AGV path file on AutoCAD

The AGV path is created using AutoDESK's AutoCAD software, a DOS-compatible open architecture system. This path can be downloaded to any AGV in the system.

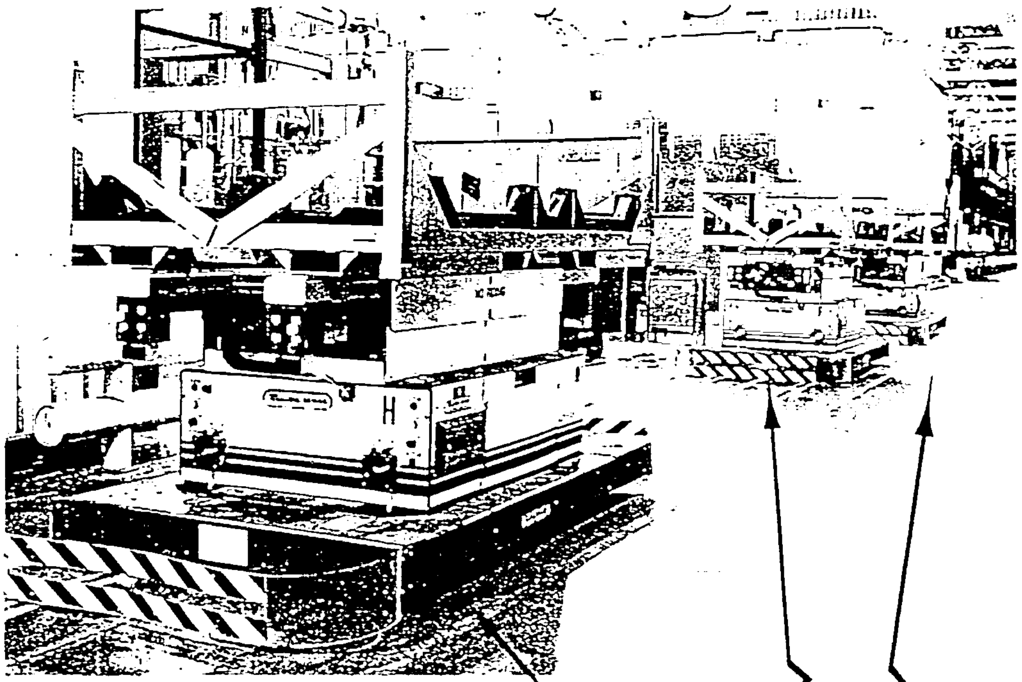


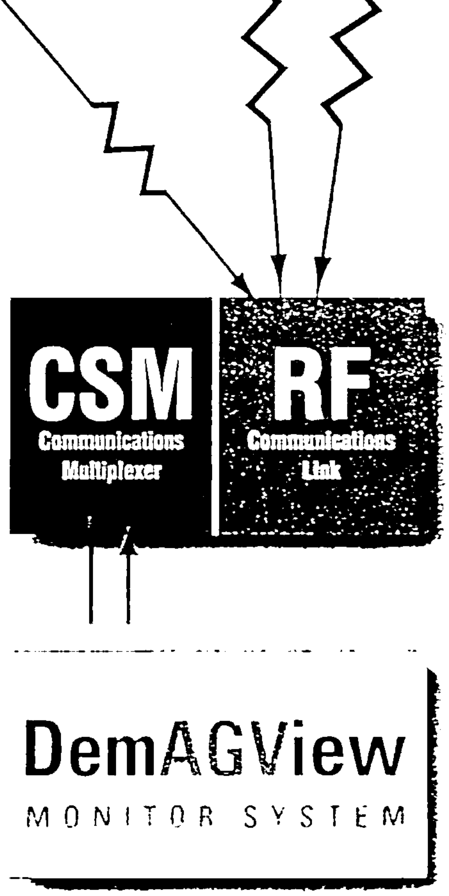






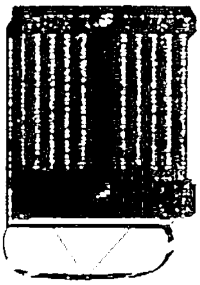
2 Install reference points. Once the path is determined, reference points are placed approximately 50 feet apart. Their locations are downloaded into the AGVs and combined with the AutoCAD path file. The reference points provide absolute position feedback to the AGV, allowing any slight course deviations to be detected. The AGV executes minor course adjustments as needed. Safety is ensured by automatic shutdown should a deviation exceed a pre-set maximum for a prescribed route.

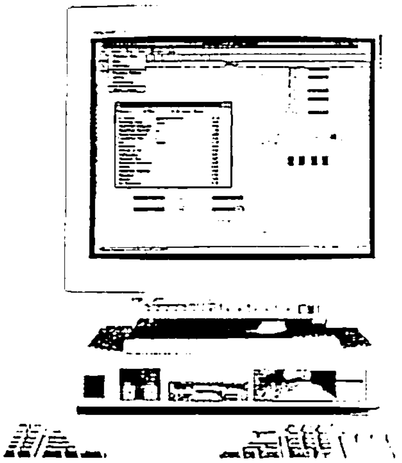




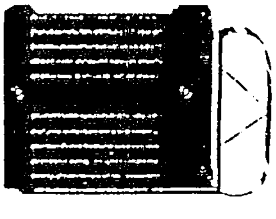
3 Install the CSM communication multiplexor

Each AGV needs to know the location and status of other units in the system to accurately make its own traffic control decisions. This is handled by the Constant System Monitor (CSM), a communications multiplexer that re-transmits, via RF, location and status information from each AGV to all other AGVs in the system. A scheduling PC can be added if a remote call/dispatch system is required. Controls can also be networked with a Windows™ format DemAGView color graphics system monitor for enhanced operations management.





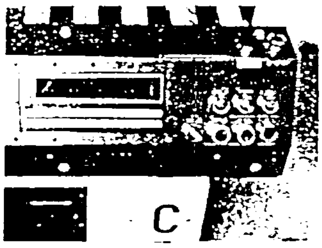
DemAGView systems monitor enhances operations management



The Onboard AGV Control Package

The Benefits

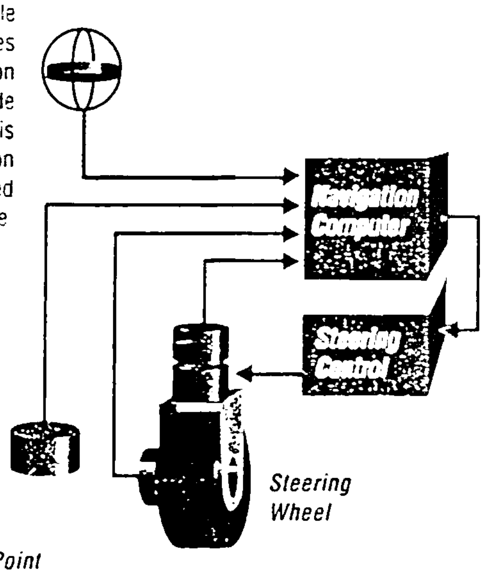
Rapistan Demag's Virtual Path Guidance technology is a distributed intelligence, or smart-based system. This means that each AGV operates independently, via smart onboard navigation controls. The primary advantages of this system include:



- *Onboard dispatching.* Available for primary and back-up modes of operation.
- *Refined diagnostics.* Smart-based systems are self-contained. This allows for more extensive diagnostic capabilities onboard the AGV via an English display panel.
- *Enhanced traffic and routing control.* Decentralized approach eliminates a single point of failure for system traffic and routing control.

The Modules

Non-wire AGVs using Virtual Path Guidance are equipped with navigation control modules that greatly reduce vehicle and system hardware by eliminating the wire guidance sensor, separate transmit/receive antenna, responder antenna, in-floor responders and PC boards. These modules include:



Gyroscope Indicates direction change in angle increments. Interfaces with the navigation computer to provide heading data. Data is updated for comparison to AutoCAD generated path file.

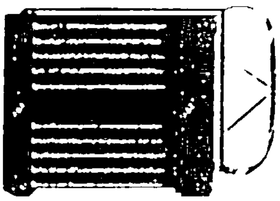
Navigation Computer. An industrial PC card is used to process guidance inputs and generate appropriate steering commands.

Steer Position Sensor. Measures the angle of the steered wheels left or right from center.

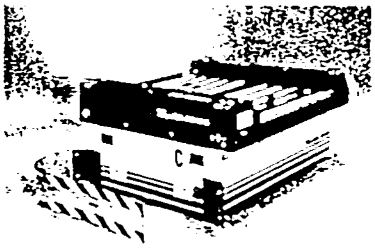
Steering Wheel

Reference Point Sensor. Reads the reference points in the floor.

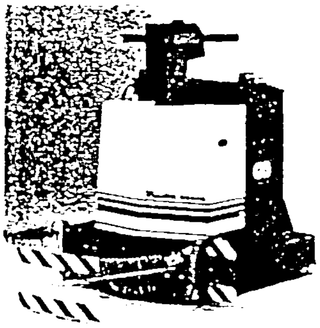
Distance Encoder. Measures the distance traveled by an AGV.



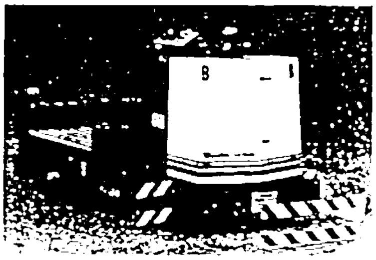
For all Rapistan Demag AGV Models



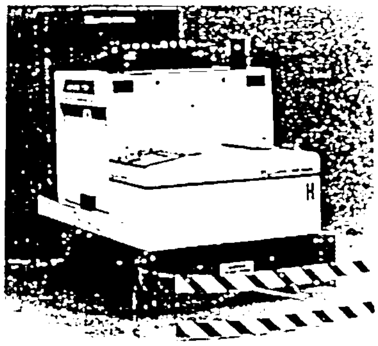
DC-30 Compact Carrier



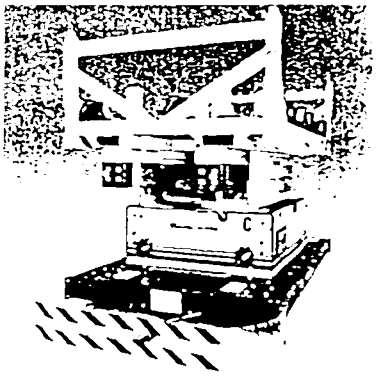
DT-24 Compact Tugger



DL-40 Low Profile Carrier

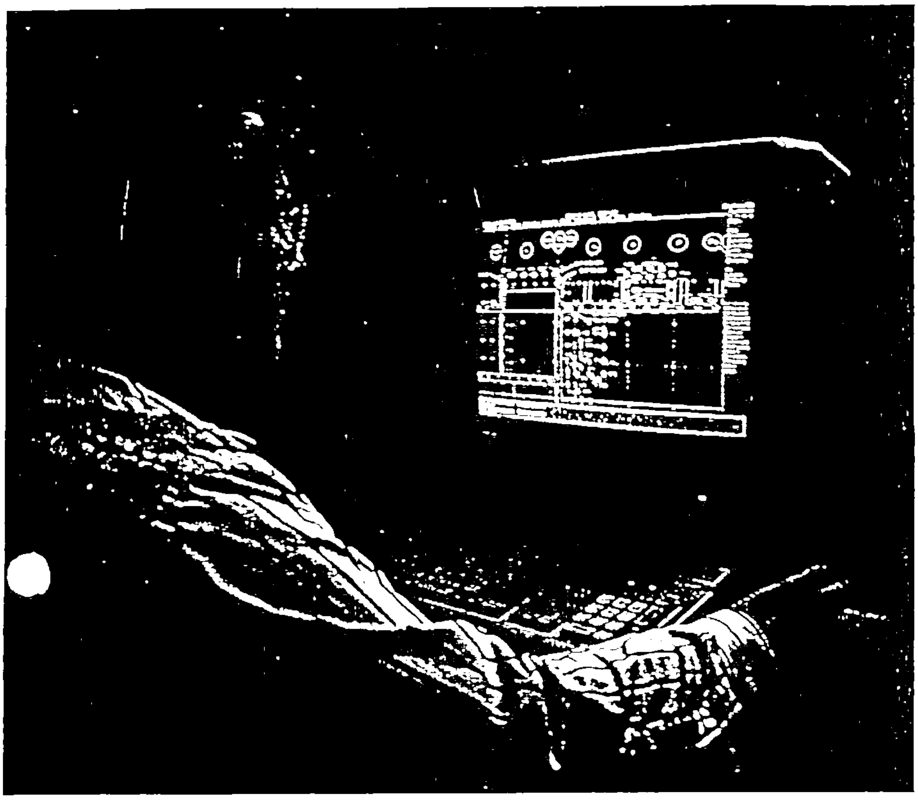


DT-60/100 Heavy-Duty Tugger



DC-40/1000 Heavy-Duty Carrier

AGV Path Flexibility



AutoCAD files are modified to reflect new guidepath layout and then downloaded to the AGVs.

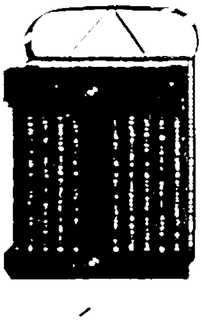
With a few basic steps, a Virtual Path Guidance System can be reconfigured.

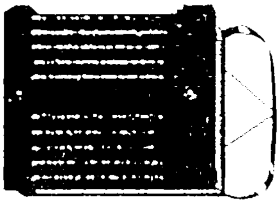
Modification Steps

To add or significantly change a path, take the following steps.

1. *Determine the path change.*
2. *Make the change via AutoCAD.*
3. *Update configuration tables.*
4. *Download new AGV path file to all AGVs in the system.*

Note: Manufacturer
reserves
the right to
modify specifications.





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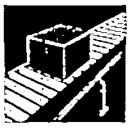

Distribution Conveyor Systems

In-Process Conveyor Systems

Automatic Guided Vehicle Systems

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Air Cargo and Baggage Handling Systems

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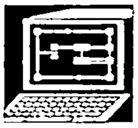
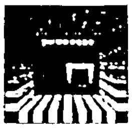
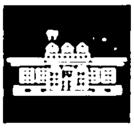


Simulation Services



Integration Controls and Software

Maintenance Parts and Service



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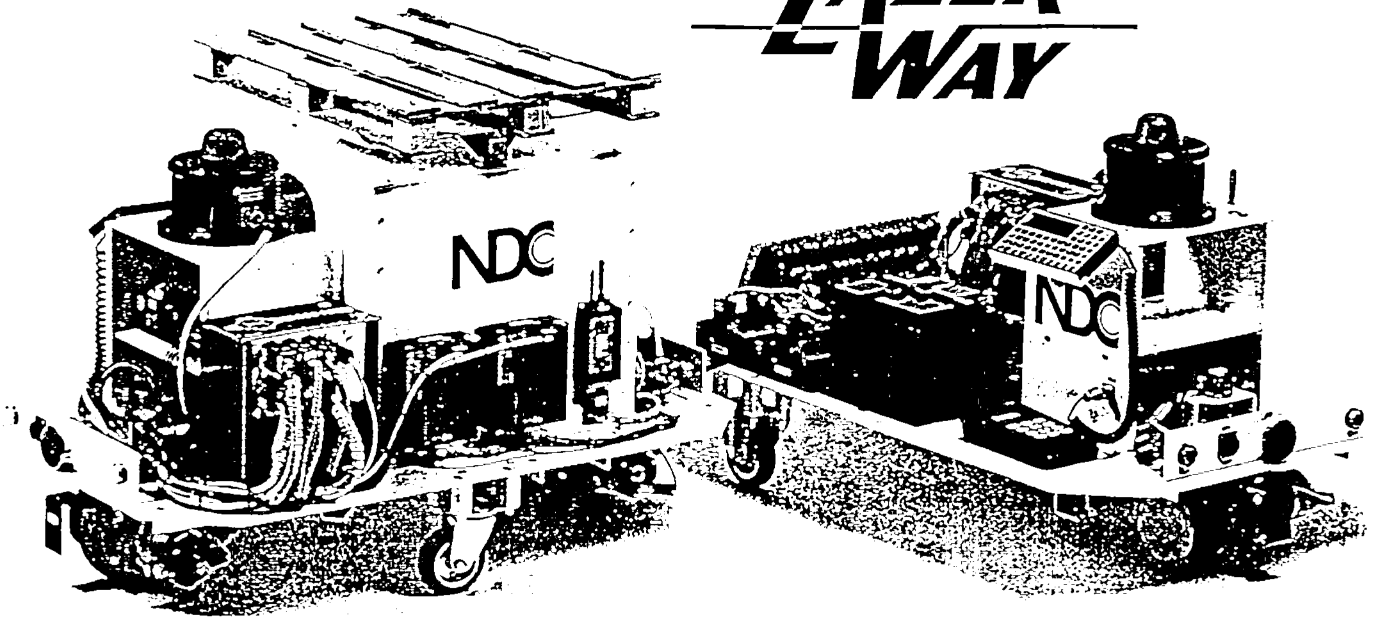
Fax: 52-5-394-4992

Litho in U.S.A. Form 20050 6/96

Laser navigation for automated vehicles

LAZER WAY™



Two of NDC's demonstration / education vehicles; to the left a dual steer / drive vehicle (QUAD) with load handling. To the right a single steer / drive vehicle.

Lazerway navigation is a combination of laser measurement and odometry. The onboard laser scanner detects the position of simple, standardized reflective strips, mounted on walls and equipment in the proximity of the vehicle driveway.

Lazerway makes it possible to use the standard NDC System Seven for laser navigation.

The Lazerway enables free range navigation i.e. physical floor reference points, wires or position-IDs are not required.

Through a wide range of extra features, extensive support and high reliability, the NDC vehicle controller (ACC70) provides great possibilities for LGV systems. The ACC70 offers modular solutions for advanced vehicle control and load handling.

Using the ACC70, the vehicle can be controlled in four different steer modes:

- Single steer/drive
- Dual steer/drive
- Differential drive
- Quad directional drive

The ACC70 supports radio and IR communications for laser guided systems.

It also supports continuous full-duplex inductive communication which is standard for wire-guided systems.

Optional serial communication ports are available that support different protocols e.g for bar code scanners.

The ACC70 also has powerful PLC support including timer functions, able to handle up to 896 digital I/Os.

Additional I/Os are installed by using I/O expansion units.

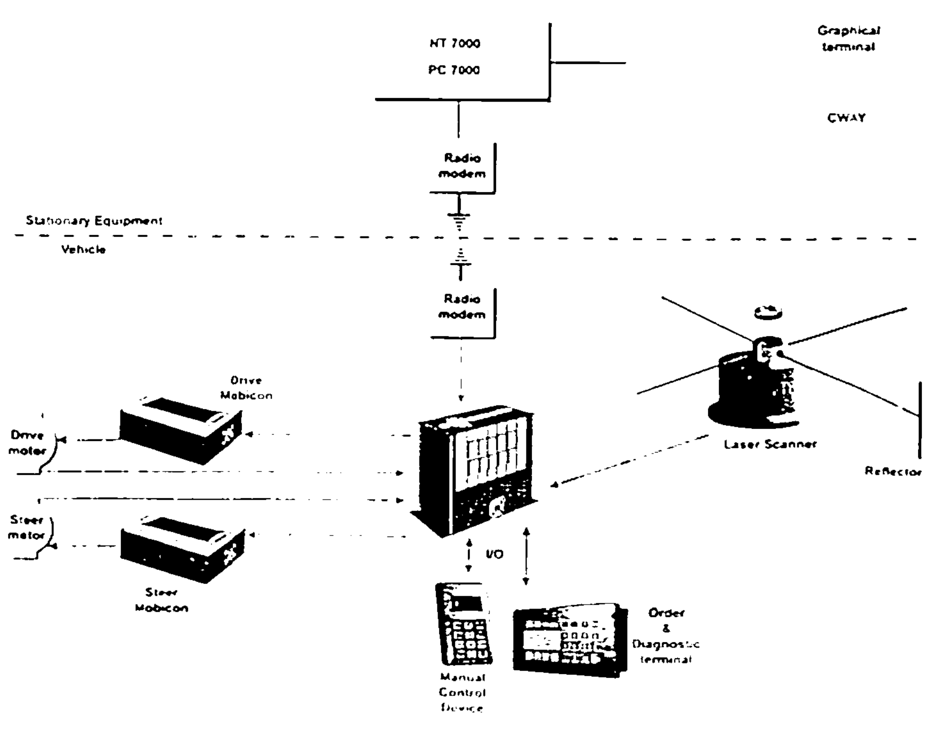
A map of the entire route layout is stored in the ACC70, which means that the vehicle can find a path to any destination in the layout by itself. The navigation map is easily generated from a CAD drawing with the Layout & Reflector Definition Program.

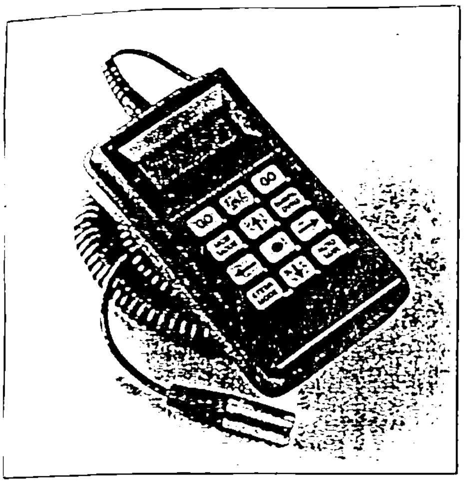
The ACC70 offers a wide range of status monitoring and diagnostic procedures for faster and easier troubleshooting. It also supports manual control devices/onboard operator control panels.

The ACC70 is customized for each system's specific requirements with the ACC70 Definition Program.

All definition programs run on standard PC models.

System overview





MCD
Manual Control Terminal

The MCD makes it possible to manually control both the steer and drive functions on the load handling equipment of a laser guided vehicle. The MCD is connected to the ACC70 vehicle controller via one plug-in chassis connector.

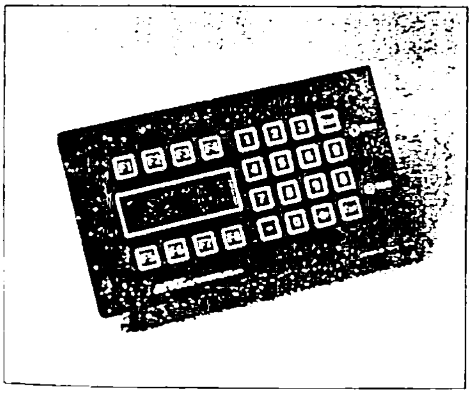
The MCD has four different modes:

Automatic mode. The LGV is independent of any instructions from the operator MCD.

Semi-automatic mode. The LGV speed and direction are determined by the user via the MCD. The LGV is automatically guided by the laser to the path. If no path is found, the vehicle can be guided by the operator.

Manual mode. The operator controls all vehicle activities via the MCD. The vehicle is no longer guided by the laser system.

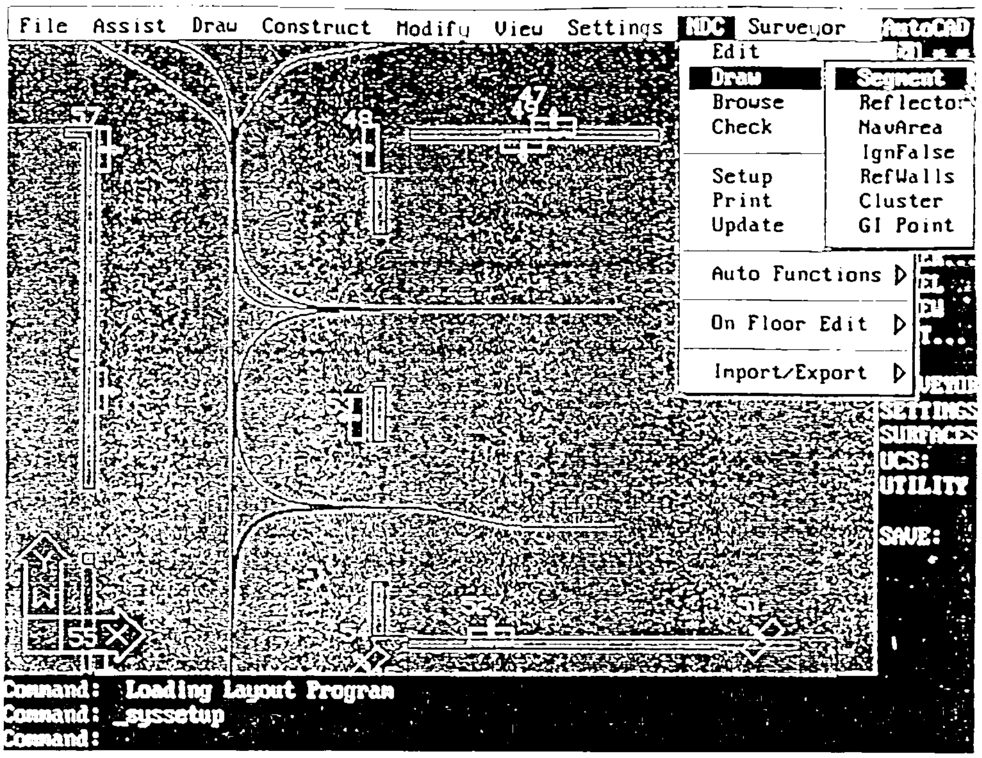
Load handling mode. The operator controls conveyors, lift tables, etc., mounted on the vehicle.



Operator interface

[illegible] OP7 is an operator terminal for connec- [illegible] the ACC70. It increases the capability [illegible] intervention and control of vehicle functions. Depending on the application the OP7 can be used for different tasks:

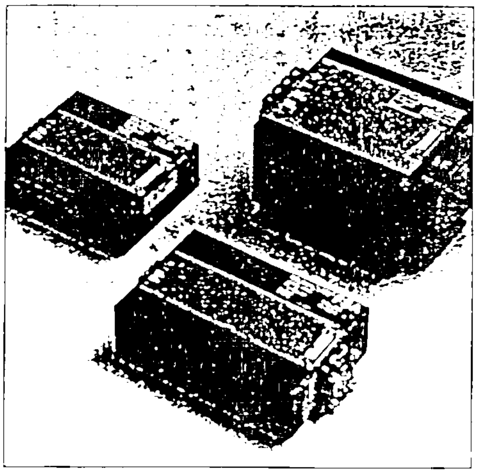
- Supervision of vehicle status and event [illegible]
- [illegible] of vehicle functions
- [illegible] I/O status



```
Command: Loading Layout Program
Command: _syssetup
Command:
```

Definition Program

In order to make the application programming of NDC products as user friendly as possible, menu based definition programs are used. There are separate definition programs for the Vehicle controller (ACC70), Master Controller (NT/PC), Operator Interface (CWAY) and Layout (runs under AutoCAD 386 Release 12 for DOS).



Mobicon
FSA Servo Amplifiers

The Mobicon Servo Amplifier operates on the chopper principle (transistor pulsing of motor current) and uses fixed battery supplied voltage to power a DC motor with variable voltage. The FSA Mobicon has four quadrant control, which means that the FSA unit controls the speed and acceleration/deceleration of a motor in both forward and backward direction without the use of contactors.
The FSA Mobicon can be used for encoder feedback, as well as for armature feedback.

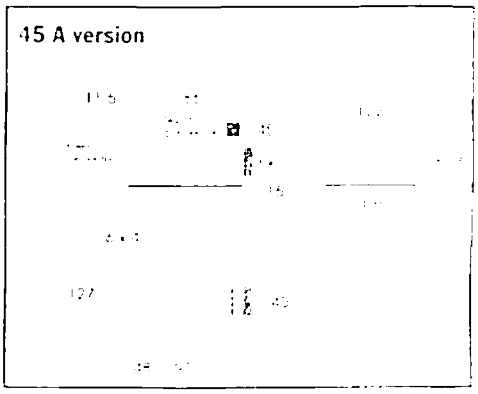
To make the FSA as flexible as possible, all control connections [illegible] externally

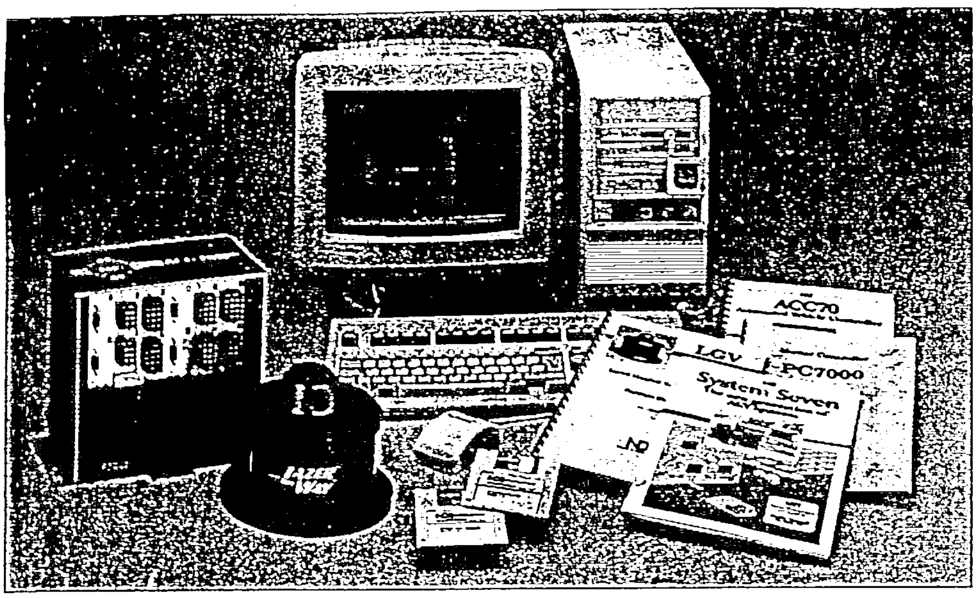
This new Mobicon type FSA is based on Field Effect Transistors (FET), and therefore needs less cooling, which results in a more compact design. The FSA Mobicons are available in the following versions:

FSA23	(23 A max. current	10 A continuous)
FSA45	(45 A max. current	20 A continuous)
FSA80	(80 A max. current	40 A continuous)
FSA150	(150 A max. current	75 A continuous)
FSA200	(200 A max. current	100 A continuous)

Features:

- High efficiency, exceeding 90 %
- Variable current limits
- Feedback by tachometer or armature
- Short-circuit protection
- Power transistor over-load protection
- Maintenance free, solid state technology
- Over and under voltage protection
- ESD protection
- Overheating protection
- Forced cooling by fan (FSA45, FSA80, FSA150 and FSA200)


45 A version



NT 7000

NT 7000 is a Master Controller program for an NDC System Seven for Windows NT 3.5. It is a powerful LGV system order manager and traffic controller. It has advanced diagnostic and statistic functions.

NT 7000 is designed to work with automatic guided vehicles equipped with the ACC70.

The program is run on a standard PC equipped with 1-5 NDC PC COM card(s).

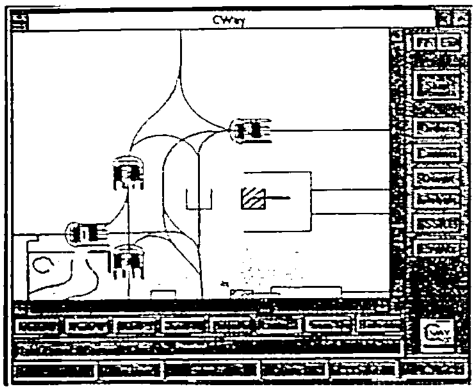
This Master Controller is especially applicable for medium and large sized AGV systems (inductive, laser or other guidance systems) and can be used for stand alone applications, as well as together with a host computer.

NT 7000 controls up to 50 vehicles in the system as standard, and can be expanded.

The 20 communication channels are intended for Host computer communication, vehicle communication (max 16 channels), CWAY and 1-[illegible] multidrop lines for digital I/O units (BIV3, SC[illegible] or SIOX).

Features:

- Has highly sophisticated tools for vehicle control and traffic regulation
- Equipped with various standard protocol drivers for connection of host computers or parallel systems
- Easy to program using the C7 Definition program
- Supports user-defined transport sequences
- Dynamic optimization, allocation and reallocation of traffic
- Built-in system-on-line diagnostics
- Supports CWAY graphic monitoring of the system activities
- Possible to operate in different modes to adapt to around the clock variations in the traffic
- Network communication
- Multitasking environment. CWAY and host software run simultaneously with NT 7000.



CWAY

CWAY is the operator interface program for an NDC AGV System Seven which runs under MS Windows. The program is used on a standard PC.

Using a layout diagram and tables, CWAY makes it possible for total operating control over the AGV system.

The graphically displayed layout can be zoomed in 8 preselected levels using command buttons, and also panned in normal Windows fashion. The layout used in CWAY is created by the layout program.

Diagnostic functions at both system and vehicle level ensure good system overview and considerably reduce troubleshooting.

CWAY communicates with the Master Controller via the NetBios networking protocol or serial line.

Features:

- Graphic display of the LGV system generated from AutoCAD drawings
- Total LGV supervision from the graphic display
- Multiple display of different types of tabular data simultaneously
- Excellent diagnostic possibilities on both system and vehicle levels
- Vehicle movement shown in different zoom levels
- Vehicle status clearly displayed with different colours
- Connection with the Master via NetBios or serial line
- Online help

Technical data NT 7000

Communication capacity
Maximum capacity:
20 channels (4 ch/PCCOM card, max. 5 cards)

Software interface
ACI (host computer) interface
CWAY (operator) interface
SSIO interface
Multidrop line
TCP/IP, NetBios

Interface types
Ethernet, TokenRing
RS-432
RS-422
RS-485
20 mA current loop

SSIO lines
Max. 16 channels

Vehicles

Vehicles	50
Vehicle types	8

Numbers of vehicles per type: user selectable

Master parameters
Simultaneous execution, 50 orders
Nodes, 999 per AGV system
Home positions, Selectable
Addressable positions: 2 500, depending on system design

Computer recommendations
Pentium 90, 16 Mb RAM
Diskette drive 3 1/2" 1.44 Mb
One parallel port (1.5 mA at 3V) for NDC Software Protection Device
One full length slot for each PCCOM card (max. 5 cards)

Software Protection
The software is protected by a hardware key (NDC Software Protection Device), which requires a SW Protection key code for the program to start.
The key code is unique for each application and gives access to the purchased system configuration (number of vehicles, etc.)

Netzler & Dahlgren Co AB
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Phone: +46 31 - 93 80 00
Fax: +46 31 - 93 81 00
info@ndc.se
http://www.ndc.se

NDC AUTOMATION INC.
3101 Latrobe Drive
Charlotte NC 28211-4849, USA
Phone: (704) 362-1115
Fax: (704) 365-8468
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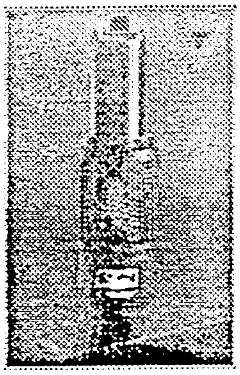
HelpMate
Robotics Inc

The Standard In
Robotics Research Toolkits

RANGE SENSORS

LightRanger Optical Radar



LightRanger is an optical radar (LIDAR) system for indoor range measurement. The eye-safe infrared laser beam is reflected from a spinning, nodding mirror for panoramic, spiralling 3-D coverage of range, bearing and elevation. Time-of-flight signals are processed locally on a built-in microprocessor which sends range/bearing/elevation data streams to an ethernet port. This port also accepts user commands for motor speed and sampling rates.

The compact size of LightRanger is ideal for mobile robot navigation, and the range image is far superior to sonar.

LightRanger comes with a library of functions for control communications, image capture and display. The library is accessible in DOS or UNIX environments, communicating over the ethernet interface to LightRanger.

LightRanger meets both European and U.S. Class I eye-safety requirements.

Specifications:

Range:	.125 meters to 10 meters
Resolution:	5 mm@1meter, 100mm@10meters
Angular Resolution:	0.5°
Field of View:	330° azimuth (horizontal) 45° elevation (vertical)
Azimuth Sweep Rate:	300-600 rpm
Elevation Nod Rate:	45° cycle per 10 revolutions azimuth
Data Interface:	Ethernet
Data Reporting Rate:	1800 readings/second
Dimensions:	13cmx13cmx35cm (optical scanning unit) 35cm x 26cm x 6cm (electronics)
Weight:	2 Kg (optical scanning unit)
Wavelength:	780 nm (infrared)
Optical Output Power:	6mW
Optical Output Beam:	12.0 mm diameter
Power Requirements:	0.5A@12VDC 0.1A@5VDC

[Light Ranger] [SonaRanger]

FOR INFORMATION CONTACT:
Carl Weiman at E-mail: Toolkit@HelpMate.com or Telephone: (800) 733-4872, Ext. 322

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PMH

Wire Guidance

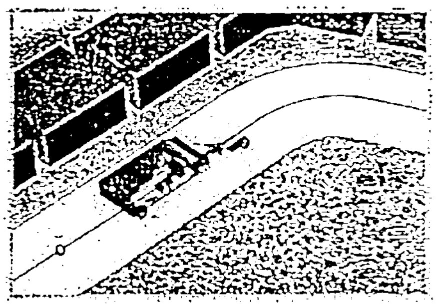
Guidance Systems

Wire guidance (inductive guidance) is a dependable and accurate active guidance method for manual and automatic vehicles. Features include precision electronics and antenna to determine the exact location of the signal center, measuring hight, side, and angle from the embedded wire carrying the frequency.

Wire guidance allows the vehicle to acquire the guide path, steering the vehicle toward the wire automatically from angles up to 70 degrees. Suitable for all vehicles requiring precise position orientation (skew) or traveling at greater speeds.

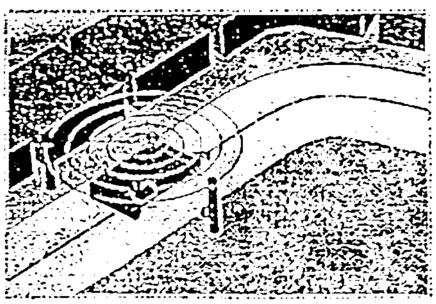
Magnetic Navigation is employed when the following criteria are met:

- for plants in which magnets can be installed in the floor
- for longer distances that are traveled by relatively few vehicles
- when a flexible guidance system is required
- when cable ducts, grids or steel plates interrupt the floor surface
- when it is not possible to install suitable reference marks on walls or columns



Laser Navigation is employed when the following conditions exist:

- for plants in which the floor may not be damaged mechanically
- when reflectors can be installed
- when the greatest possible flexibility in a guidance system is required
- when the floor surface has magnetic properties



Rail Guidance is for manually operated vehicles only. Trucks are fitted with guide rollers which engage rails installed at a specified width for the intended vehicle. This form of guidance generally required the loads to be placed above the floor level.

Professional Materials Handling Co., Inc.
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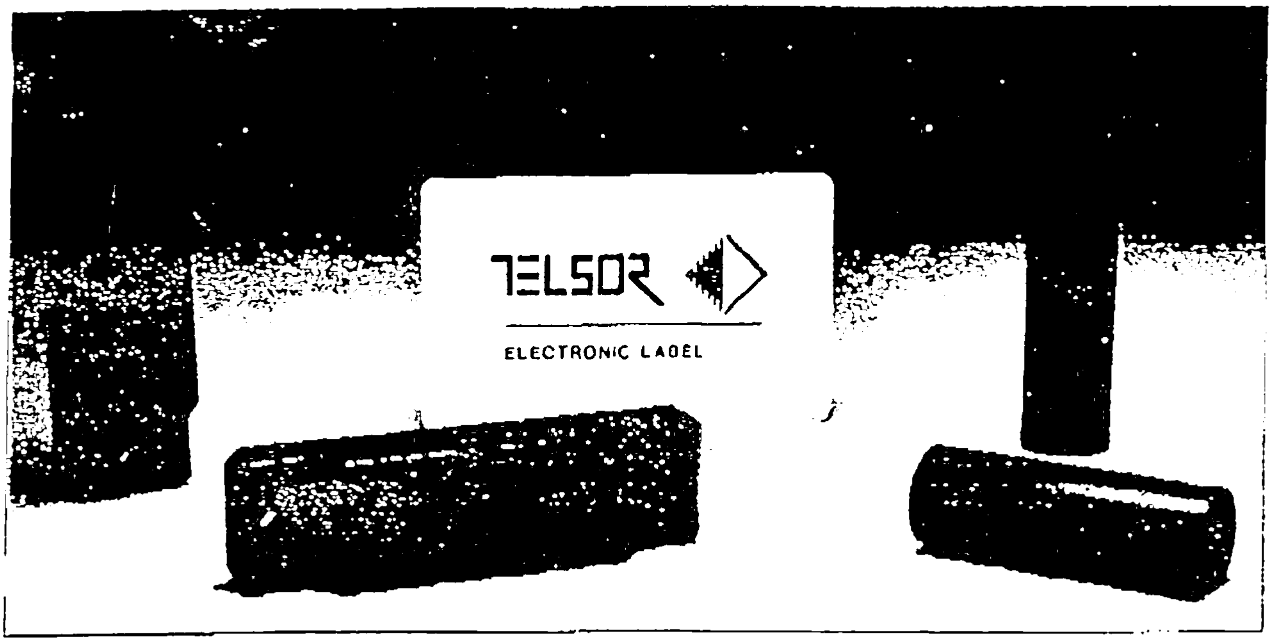
Transponder Model 1781, 1783, 1787



TELSOR®'s "Electronic Labels" provide flexible and reliable information sources. Using Radio Frequency technology, informative data can be transmitted without line-of-sight or harsh environment constraints. These transponders are designed to meet a variety of applications in automated warehouses and manufacturing environments.

TELSOR®'s family of transponders from left to right:

1. The Model 1781 Molded Transponder is a preprogrammed unit that can be attached directly to a metal surface. The 1781, a completely sealed unit, is ideal as a "license plate" when only a unique number is required. The 1781 comes in two options; a polyurethane oil resistant housing for use in harsh manufacturing environments; and vibrathane, an FDA approved material for use in any food processing environment.

2. The Model 1783 thin-line transponder is a credit card configuration which is both programmable and reprogrammable. Information is the key word for the 1783. Programming the transponder is made simple with TELSOR®'s Model 3010 Programmer.

3. Model 1787 is a one-time programmable transponder ideal when specific information is required. The unit is programmed with any combination of 16 alpha/numeric characters. Polyurethane encapsulation seals the transponder to guarantee long life. This transponder can be easily installed in either the floor or pallet. This unit is also available in "kit" form for programming by the user prior to encapsulation.

Transponder Characteristics and Features

- 16 ASCII Characters
  Passive — No Battery Required
- Non-Contact Readability
- High Data Transfer Rate
- Rugged Enclosures
- 10+ Years of Data Retention
- Error Rate of Less Than 1 in 100,000,000,000,000 Reads

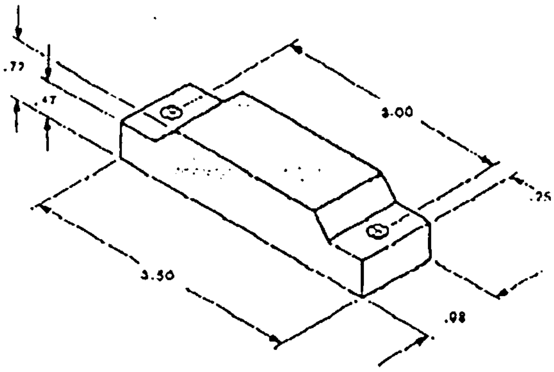
Specifications — Model 1781

Temperature Range:
Operating: −20° to +70° C
Non-Operating: −20° to +100° C

Read Distance:
Application specific, with no minimum requirements

Exterior Construction:
Polyurethane for oil resistant transponder or
Vibrathane for food processing applications

Weight:
3.5 oz.



Ordering Information

Part Number	
600-0015-00	Transponder, Molded: Preprog., FDA
600-0015-01	Transponder, Molded: Preprog., Oil Resistant

Specifications — Model 1783

Temperature Range:
Operating: −20° to +70° C
Non-Operating: −20° to +100° C

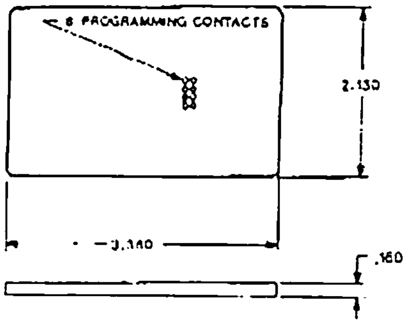
Read Distance:
Application specific, with no minimum requirements

Exterior Construction:
Polycarbonate, UV Stabilized

Weight:
0.7 oz.

Reprogramming Cycles:
1000+

Programming Time:
800 milliseconds



Ordering Information

Part Number	
600-0007-00	1783 Transponder, Thinline Reprogrammable 128 bit, durable, premium

Product Accessories

Part Number	
600-0001-00	TELSOR® Logo Label: TLT, Permanent
600-0001-01	TELSOR® Logo Label: Removable (Custom labels using customer supplied artwork can be ordered)

Specifications — Model 1787

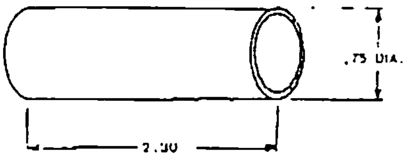
Temperature Range:
Operating: −20° to +70° C
Non-Operating: −20° to +100° C

Read Distance:
Application specific, with no minimum requirements

Exterior Construction:
Enclosure - Epoxy, unfilled
Encapsulant - Polyurethane

Weight:
1.5 oz.

Programming Time:
800 milliseconds



Ordering Information

Part Number	
600-0017-00	Transponder, encapsulated, factory programmed, 128 bit
799-0003-00	Transponder, encapsulated, kit form

For additional product information and pricing data,
please contact the Marketing Department.

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6786 S. Revere Parkway
Englewood, Colorado 80112
(303) 790-8877
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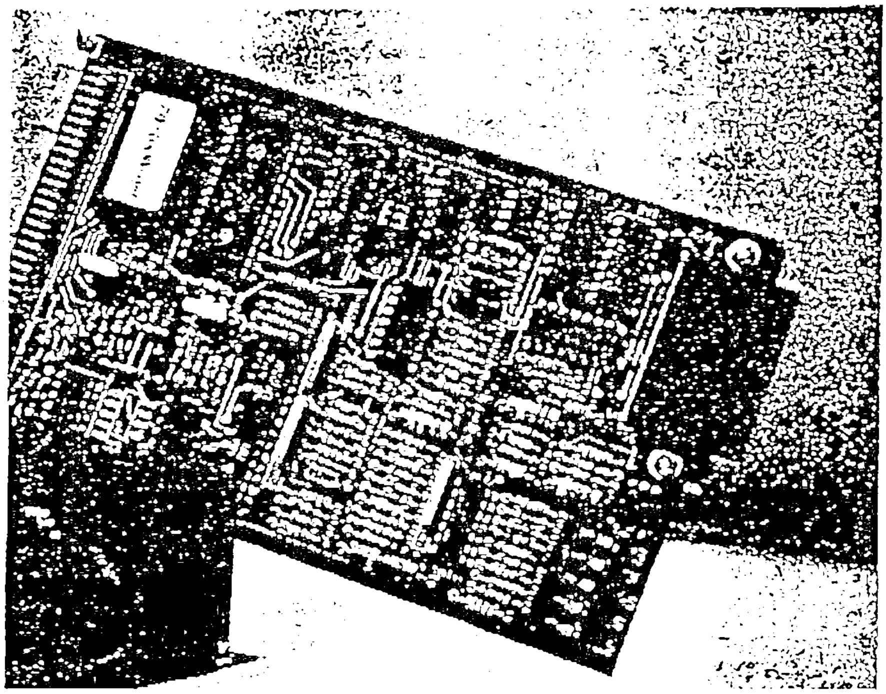
Interface Model 2002



The Interface Model 2002 provides a standard interface to allow simple integration into a wide variety of computer networks. The 2002 amplifies, filters, conditions and detects the data signals relayed by any of TELSOR's® compatible sensors. An advanced error detection algorithm provides error-free operation. Valid information received is sent to the host computer system via an asynchronous serial bit data stream. The driver/receiver interface accepts RS-232-C/RS-422-A format and operates in continuous or polled mode. All messages are transmitted in printable ASCII Characters. The Eurocard format, paired with the single supply voltage requirements, simplify its integration into existing installations. Connection to the sensor is made using low-cost, shielded twisted-pair cables. An enclosure for mounting in industrial environments is available.

Features

- Interfaces to Virtually Any Computer System
- Eurocard Format
- RS-232-C/RS-422-A Compatible
- Selectable Baud Rates
- Single Supply (+5V) Operation
- Internal Self Test
- No Adjustments

Specifications

Protocol: Full-duplex; Stop, parity bits (selectable)
Serial Data Rate: 110-19200 baud (selectable)
Label Report Repetition Rate: Up to 17 reports/sec at 19200 baud
Data Storage: 4 readings (polled mode)
Error Rate: Less than 1 in 10^{14} readings
Connectors: DB-25S, DIN 41612 Type C
Temperature Range:
  Operating: -40° to +55°C
  Non-Operating: -55° to +85°C
Power Requirements: +5VDC +/- 5% @ 250 mA (maximum)
Control Signals: DSR, CTS, DTR
Weight: 5.5 oz.

Ordering Information

Part Number	
710-0004-01	PCB Assembly, Reader Interface, RS-232-C/RS-422-A

Product Accessories

Part Number	
700-0001-00	Enclosure Assembly Eurocard With 25 Pin D Cutout
720-0002-00	Power Supply, Wall Mount: 5VDC/600mA, Screw Terminal

For additional product information and pricing data, please contact the Marketing Department.

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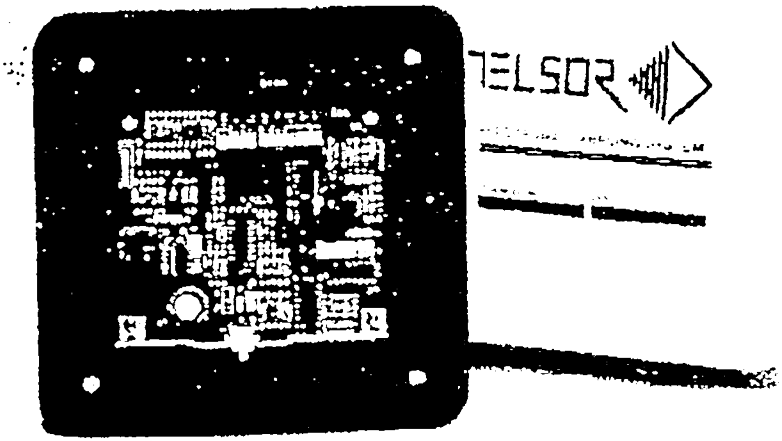
Sensor Model 1880



The Sensor Model 1880 is a versatile, low power unit including electronic circuitry and an integrated antenna.

The 1880 operates as both a transmitter and receiver. The sensor emits a low-frequency electromagnetic field at 148 KHz to energize and activate a TELSOR® electronic label in the vicinity of the sensor. Once the electronic label is energized, it modulates the field in accordance with data stored in its memory. The sensor detects, amplifies and filters this modulation and relays it to the interface unit for use by a host computer, process controller, or display and storage device.

The 1880 is simple to use and install. The printed circuit board assembly is ideally suited for proximity detection used for security and access control applications. The Model 1880 is also available with a water-resistant enclosure. Optional mounting assemblies are available for integration into automated equipment (AGVs, AS/RS, etc.). The 1880 can be cabled a distance of 5000 feet from the interface unit with no degradation in its performance.

Features

- FCC Certified
- Designed for a Wide Range of Uses
- Low Power Requirements, AC/DC and Regulated or Unregulated Power
- Packaged for Versatile Mounting

Specifications

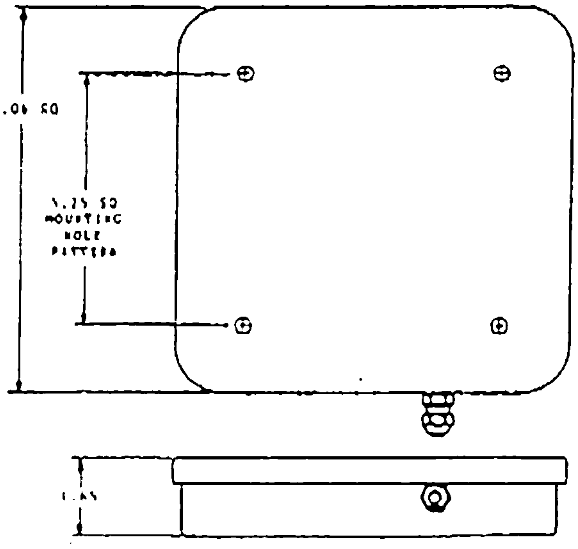
Operating Frequencies: 148 KHz (Transmit), 37 KHz (Receive)
Remote Enable: 5 mA, Opto-isolated
Output: 75 ohms, Balanced
Operating Distance: Up to 10" (depending on label type and orientation)
Cabling Distance: 5000' (with shielded, twisted-pair cable)
Connectors: Angle entry terminal strip
Voltage: Unregulated DC supply: +18 to +32VDC
Unregulated AC supply: 24V (+10-20%) RMS; 47-63 Hz
Current: 200 mA (max.), 150 mA (typ.)
Temperature Range:
  Operating: -40° to +55°C
  Non-Operating: -55° to +85°C
PCB Dimensions: 7.0" x 7.0" x 1.3"
Weight: 7.0 oz.

Ordering Information

Part Number	
710-0005-00	PCB Assembly, Sensor Integrated Antenna, AC/DC
800-0006-00	Sensor Assembly, Integrated Antenna AC/DC, with Enclosure

Product Accessories

Part Number	
800-0001-00	Mounting Assembly Sensor, Automated Equipment (2 required)



For additional product information and pricing data,
please contact the Marketing Department.

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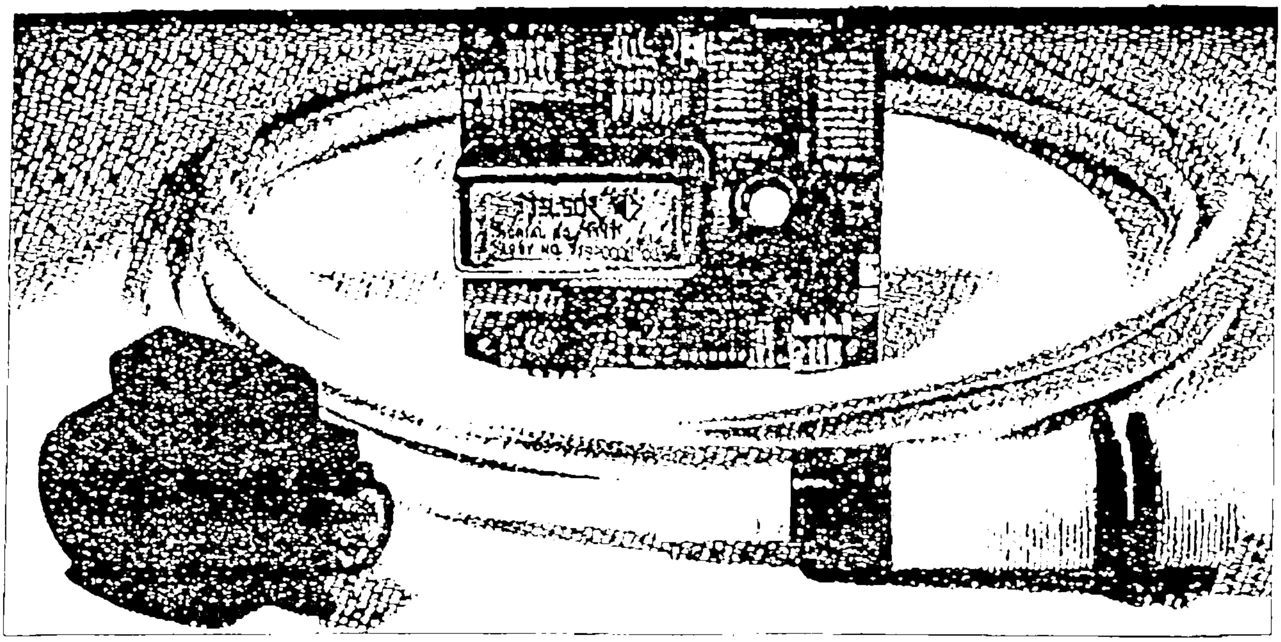
A.S.R.S. Model 4000
(Adaptable Sensor Reader System)



The A.S.R.S. Model 4000 is a unique RFID unit that combines the functions of a low-powered sensor and a reader onto a single printed-circuit card assembly. Acting as a sensor, the 4000 provides a low-frequency electromagnetic field to energize a RFID Label in the vicinity of an external antenna. Acting as a reader, the response from the RFID Label is detected, filtered, amplified and then transmitted to interfacing equipment. For industrial applications such as inventory tracking, work-in-progress monitoring, and automated data collection, the Model 4000 excels.

To allow easy integration with existing systems, the Model 4000 comes standard with an RS-232 or RS-422 output. All messages are transmitted in printable ASCII characters.

The 4000 can be mounted in a user-supplied enclosure or in an optional enclosure supplied by TELSOR. The 4000 is especially adaptable in applications where a remote antenna is desired. External antennae, such as the tubular antenna and surface mount housing (shown above), are provided as user options. See Ordering Information on reverse side for details.

Features:

- Built-in Self Test
- Single PC Card for Sensor and Reader
- RS-232-C or RS-422-A Compatible Output
- Selectable Output Data Rates and Formats
- Single Supply (+12V) Operation
- No Adjustments
- Able to Power Remote Antennas
- Circuitry Provided for Remote Valid-read Indicator
- On-board Valid-read Indicator
- Automatic "Brown-out" Recovery

Specifications

Data Output:
- Hardware Configuration:
  - Half-Duplex, DTE, RS-232-C or RS-422-A
  - Signal Lines: TxD, RxD, CTS, RTS, DTR (RS-232-C only)
- Data Transfer Rate:
  - 110-9600 baud (selectable)
- Data Format: (selectable)
  - 7 bits with even or odd parity
  - 7 or 8 bits with no parity

Valid-Read Output:
When ON, output can supply +12VDC and ground to non-inductive 100mA (maximum) load.

Label Report Repetition Rate:
Up to 13 reports/sec at 9600 baud

Label Reading Distance:
Up to 6" using 719-0013-00 Antenna Assembly and Model 1783 RFID Labels

Number of Reportable Label Characters:
16 characters

Read Error Rate:
Less than 1 in 10^{14} readings

Power Requirements:
- Voltage: 12VDC (8-14VDC)
- Current: RS-232-C Option:
  - 250mA (typ), 350mA (max)
  - RS-422-A Option:
  - 400mA (typ), 500mA (max)

Operating Frequencies:
148KHz (transmit), 37KHz (receive)

Antenna Connector:
Angle-entry terminal strip

Power and Data Connector: 12 contact
Locking header, 0.1" centers

Valid-Read Output Connector: 2 contact
Locking header, 0.1" centers

Temperature Range:
- Operating: RS-232-C Option:
  - -40 to +55° C
  - RS-422-A Option:
  - 0 to +55° C
- Non-Operating: -55 to +85° C

PCB Dimensions:
- PCB: 4.35" L x 3.75" W x 0.85" H
- Enclosure: 4.8" L x 4.8" W x 2.2" H

PCB Weight:
5.4 oz.

Ordering Information

Part Number	
	Printed Circuit Board Assembly
711-0003-00	A.S.R.S. 12VDC, RS-232
711-0003-01	A.S.R.S. 12VDC, RS-422
	Assemblies Including Cabling, Antenna, and Enclosure
800-0014-00	RS-232-C with tubular antenna assy
800-00[illegible]4-01	RS-422-A with tubular antenna assy
800-0014-02	RS-232-C with surface mount antenna assy
800-0014-03	RS-422-A with surface mount antenna assy

Product Accessories

Part Number	
720-0004-00	Power Supply, Wall-Mount: 12VDC/500mA, Screw Terminal
719-0013-00	Antenna Assembly, Tubular, 30mm OD x 135mm L
719-0015-00	Antenna Assembly, Surface Mount, 5cm x 5cm
730-0005-12	Cable Assembly, Molded, 12 ft.

For additional product information and pricing data, please contact the Marketing Department.

TELSOR® Corporation
6786 S. Revere Parkway
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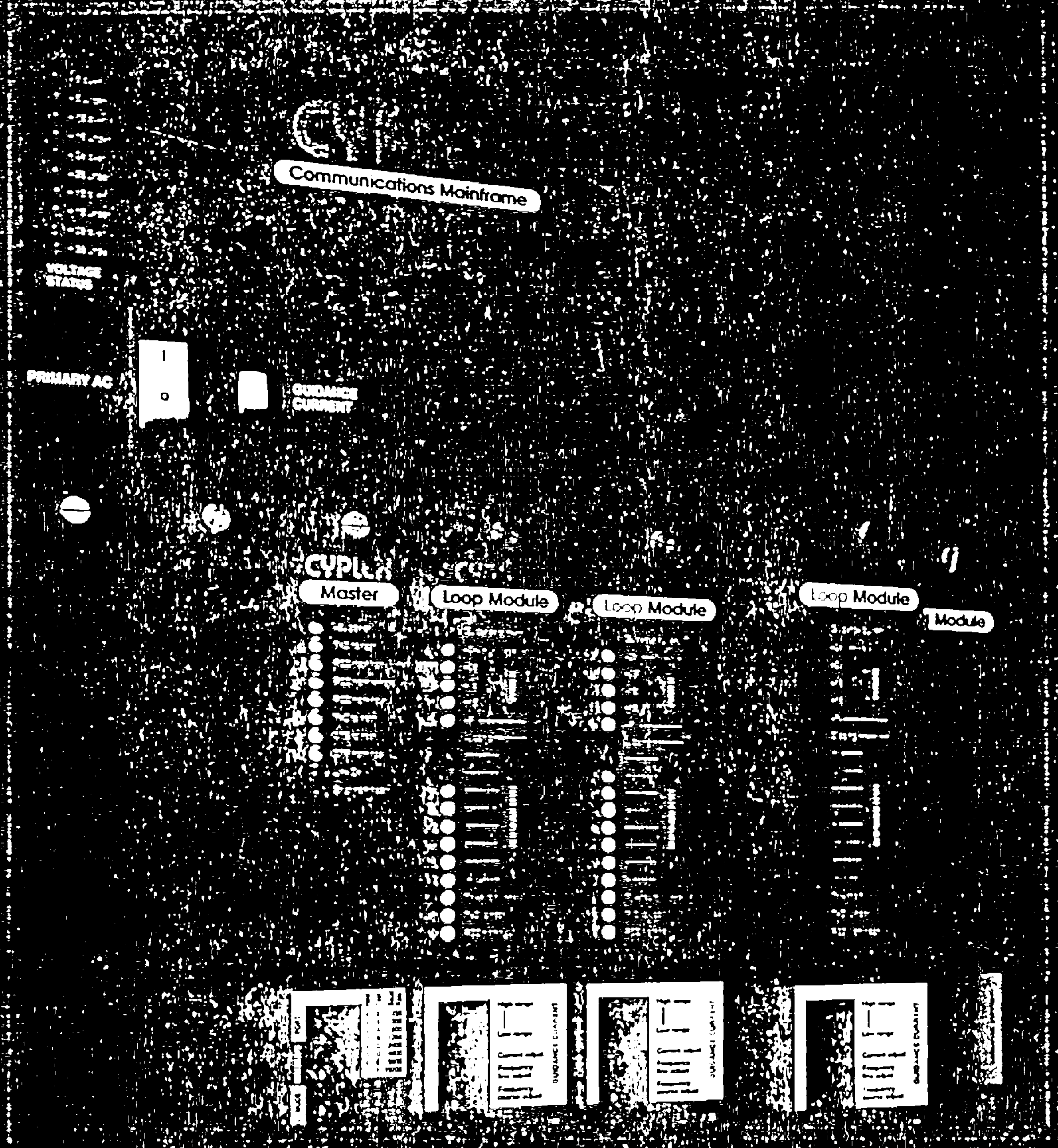
5/88

A.3 Communication Systems

High Performance AGV Guidance and Communications



CYPLEX

PROVEN PERFORMANCE AND RELIABI

CYPLEX understands AGV systems. Reliability, performance, and cost effectiveness are equally important factors in selection of the right AGV system for your material handling system. CYPLEX has developed a communication and guidance system that is unmatched in the industry in all three aspects.

With years of experience in material handling communication systems and dozens of installed AGV systems, the CYPLEX system is a proven product. This latest version is another step in making AGV technology simpler, easier to use, and more reliable.

System Overview

In the CYPLEX system, communication and guidance occur over a single wire buried in the floor. Communications takes place at 230 KHz at a data rate of 19,200 bps. The guidance frequency is user selectable on each floor loop.

The system uses a Master-Slave configuration to achieve optimum communications performance. The CYPLEX Master interfaces via either RS-232C or RS-422A to a host computer. Information is transmitted from the Master over the floor network. The Master is capable of several communication modes, including system polling, transparent data exchange with any vehicle, and built-in system diagnostics. Reliable data transmission is assured by using CYPLEX's patented digital signal processing technique, with a calculated bit error rate of one in every two years of operation.

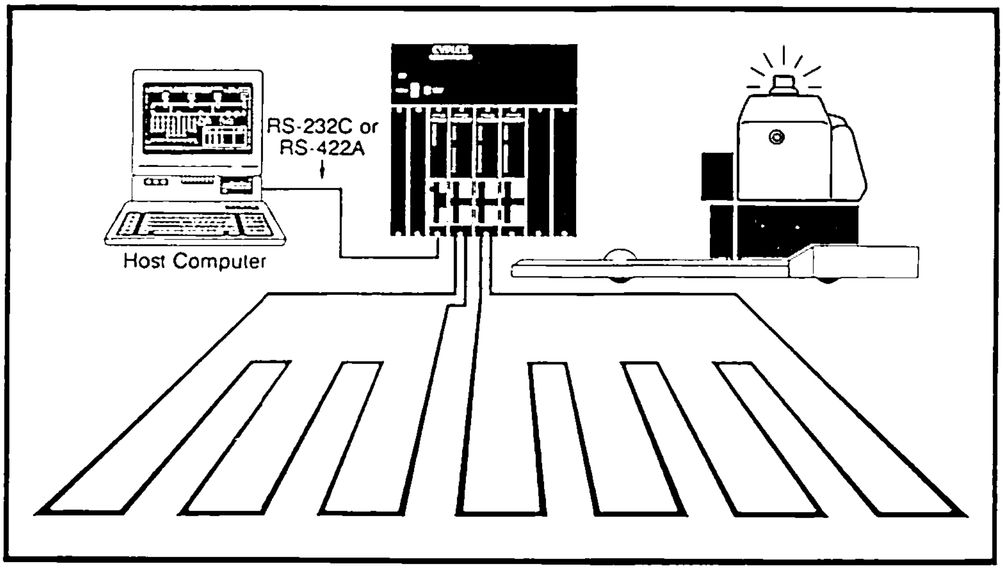
Each vehicle is equipped with a CYPLEX Slave Modem and CYPLEX Communications Antenna. The antenna mounts on the base of the vehicle, within six inches of the floor wire. A switch setting on the Slave Modem, which is wired to the vehicle controller, gives each vehicle a specific address.

System Benefits

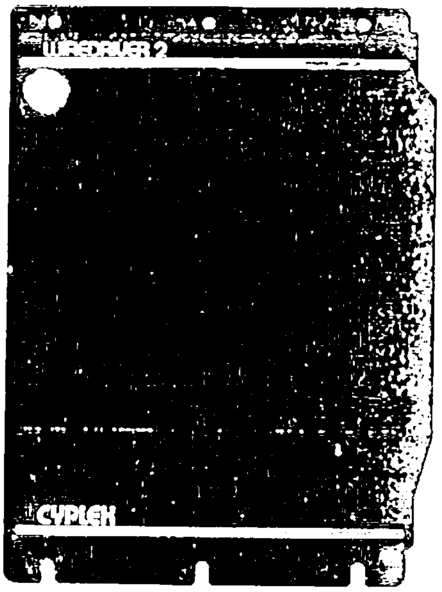
Increased Vehicle Productivity—Vehicles work harder with CYPLEX. The time needed to assign tasks to vehicles is virtually eliminated. Vehicles don't need to return to a central communications station. In larger systems, fewer vehicles may be required to meet system throughput requirements resulting in a substantial savings!

Task Priority Can Be Changed—If a higher level task comes up, vehicles can be instructed to change their job

Typical System Configuration



Vehicle Equipment



Vehicle Slave Modem

Each Vehicle Slave Modem is individually addressable by means of a dip switch setting. The system provides 255 addresses per zone. The Vehicle Slave Modem is available as a PCB with mounting hardware, enclosed in a drip proof case, as an IBM PC card, or integrated with the AGV Electronics Vehicle Controller.

Communications Antenna

The CYPLEX Communications Antenna mounts on the base of the vehicle, within six inches of the floor wire. It is capable of being mounted in several positions, allowing flexibility in vehicle design. On vehicles capable of guiding off multiple guidance antennas, additional Communications Antennas can be used as well.

Y

d respond to the new task, anywhere the system.

nited Path Requirements—In systems ere limited space exists, the CYPLEX stem data rate speeds up traffic man-jement resulting in tighter vehicle ocking.

nergency Situation Correction—When hicles unexpectedly stop, or are stopped an operator, continuous communica-ns helps correct the situation quickly. e emergency is detected within sec-ds in the next polling cycle, rather than iting up to a minute before the vehicle pears at the next check point.

mmunications Mainframe enefits

sy Installation—The CYPLEX Com-nication Mainframe is designed to make installation easy. Once mounted in a standard equipment cabinet or 19″ rack, each Module takes about thirty seconds to install or replace! The backplane, designed specifically for AGVs, eliminates all wiring to the individual modules.

Quick System Set Up—The CYPLEX system requires a minimum of on-site setup. Frequency and levels are clearly identified and easily set.

Flexibility—With the CYPLEX Communications Mainframe, you install only as many modules as your system requires. Whether you require communications, guidance, or both, CYPLEX meets your needs in the most cost effective manner.

Rapid Fault Identification—LED indicators show power supply status on each voltage output, signal strength and communication quality on each floor loop, and status of the Host-Master interface. Faults can be identified at a glance, and immediately isolated to a quickly replaced module. This minimizes system downtime.

Diagnostic Software Package—CYPLEX provides a diagnostic port on the backplane, which allows local access to the CYPLEX Master and its built-in trouble shooting functions.

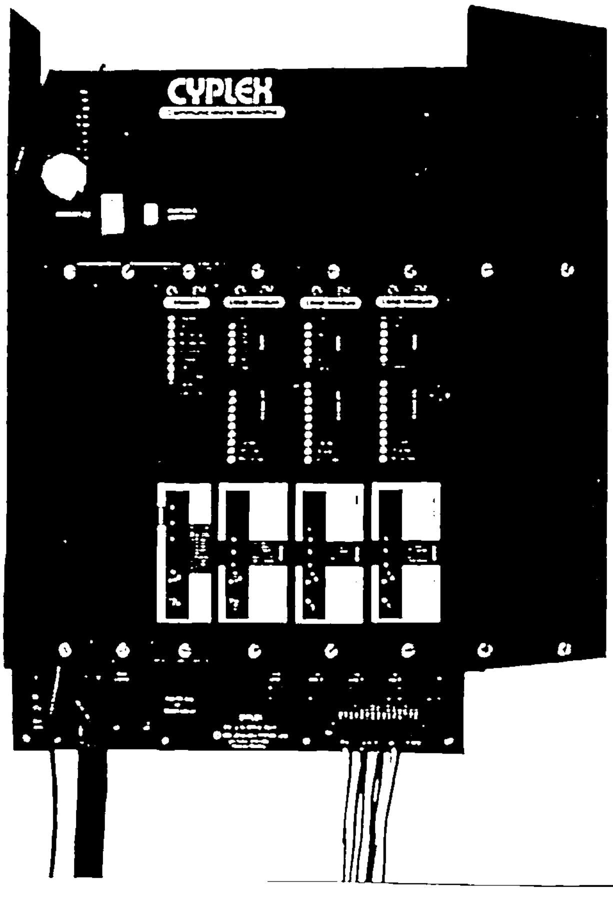
Reduced Spares Requirements—Elimination of separate modems and guidance line drivers cuts their spare requirements in half! There is less hardware on the shelf and fewer dollars tied up in inventory.

Security—The CYPLEX Communications Mainframe adjustments can be covered and sealed, preventing unauthorized tampering.

ead End Equipment

mmunications Mainframe

e Communications Mainframe consists of a backplane specifically signed for AGV communications, a power supply assembly, and a dular enclosure. Each Communications Mainframe can support ner or both communications and guidance on up to five floor ps. Multiple Communications Mainframes can be daisy chained arger systems.

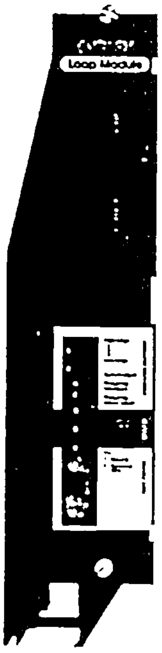


Master Module

The Master Module interfaces to the host computer via an RS-232C or RS-422A link. It handles all system Local Area Network functions, including establishing the various communication modes, error identification, and data retransmission. In systems with more than one Communications Mainframe, a Remote Head End Module is used in place of the Master Module in the additional Mainframes. Communication between the Master and Remote Head End Module is via an error corrected, opto-isolated link.

Option Slot

The Communications Mainframe has a spare slot available for a variety of options These include a built-in IBM-PC for traffic management and a telephone modem for remote monitoring and troubleshooting of the AGV system.



Loop Module

Each Loop Module provides both communication and guidance on a single floor loop Advanced diagnostics allow easy analysis of floor loop characteristics, such as signal strength and phase angle Guidance frequencies are set by first selecting a range with a dip switch, and then fine tuning with a potentiometer. Loop Modules are available in a guidance only version as well

Host Interface:	Standard RS-232C or RS-422A
Configurations:	Baud rate to host: 150 bps to 19,200 bps Parity: Odd, even, none Word Length: 7 or 8 bits Normal or Test Mode Operations Address on Network: 00-FF
Units in Network:	Master and up to 255 Slaves (Vehicles) per zone. Up to 20 floor loops per zone (5 loops per cabinet)
Power Requirement:	105/125 VAC strappable to 210/250 VAC, 47–63 Hz
Mounting:	19" rack mount or Mount in Hoffman Enclosure A-363016LP, or equivalent using Hoffman Mounting Plate A-36P30, or equivalent
Environment:	Maximum temperature: 65 degrees C Maximum humidity: 95%, non-condensing
Guidance Frequency:	1.0–6.0 KHz, ±1% (–001 rev.) 1.0–12.0 KHz, ±1% (–002 rev.) 1 Amp maximum power per loop ±1.0% stability over time and temperature
Guidance Range:	6,000' Maximum, 3,000' Recommended Longer loops can be subdivided

CYPLEX AGV Options

A CYPLEX test cart is available as an option. The Test Cart allows orderly check-out of the floor early in the system installation, prior to AGV delivery. It consists of a cart, CYPLEX Communications Antenna, CYPLEX Slave with special firmware, oscilloscope, and battery pack. When used in conjunction with a CYPLEX Master in test mode, communications and guidance throughout the entire floor can be verified quickly and easily.

CYPLEX

18 Clinton Drive Hollis, NH 03049 USA
Phone: (603) 882-8104 Fax: (603) 882-9539

Aironet™

ARLAN 630

Wireless Ethernet Access Point

- Provides wireless LAN access to Ethernet for computers equipped with ARLAN wireless network adapters or OEM radio modules.

- Features second generation multi-channel Direct Sequence Spread Spectrum radio technology for worldwide operation, with data rates up to 2 Mbps per channel.

- Patented Microcellular Architecture for unmatched roaming and power management.

- Auto-detects wired LAN failure and dynamically switches to wireless repeater mode.

- Remote wired or wireless system configuration, diagnostics, optimization, and management via Telnet, FTP, or SNMP.

- Supports campus wide fault tolerant wireless LAN design with dynamic load balancing.

- Self-configuration and firmware upgrade via BOOTP facilities enterprise version control and maintenance.

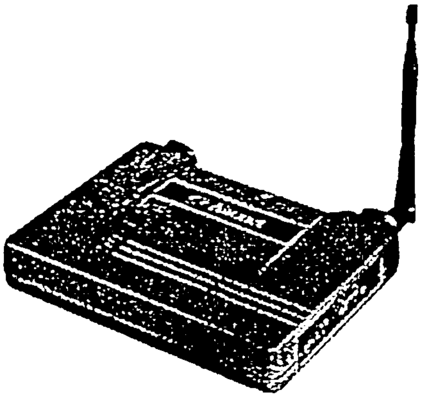
- Modular design provides easy migration path to alternative radio technology or wired LAN infrastructures.

- Resident agent is compliant with SNMP MIB I, MIB II, and ARLAN Enterprise MIB standards.

- Efficient, compact, and rugged one-piece design is equally suited for the office or the factory.

Representing Aironet's second generation of Ethernet access point technology, the ARLAN 630 was designed for the mobile user and provides unmacthed flexibility and capability in wireless LAN performance. It is equally suited for vertical market environments such as retail stores, warehouses, factories, and hospitals: or horizontal market applications found in the office.

Using patented spread spectrum radio technology, originally developed by the U.S. military for fast, secure, and reliable communications, the ARLAN 630 can be equipped with either a 900 MHz or 2.4 GHz radio. Placed anywhere along an Ethernet LAN, it allows wireless stations in it's coverage area transparent access to the corporate network. Combined with Aironet's patented Microcellular Architecture, several ARLAN 630 units can form a multiple building, indoor and/or outdoor wireless network while providing the mobile user seamless roaming and power management throughout the coverage area.



ARLAN 630 Specifications

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ARLAN 630 Specifications

PERFORMANCE MODEL 630-900

Data Rate per Channel: (Min/Max)	215 Kbps/860 Kbps (FCC, Canada) 172 Kbps/215 Kbps (Australia)
Number of Channels:	12 (FCC, Canada) 7 (Australia)
Wireless LAN Capacity Per Microcell:	860 Kbps (4 Ch. @ 215 Kbp
CPU:	25 Mhz Motorola 68360

RANGE

Typical coverage per microcell*:	7,000 sq. m. (75,000 sq. ft.)
Omni-Directional range, Indoors*:	Up to 300 m. (1,000 ft.)
Omni-Directional range, Outdoors*:	Up to 600 m. (2,000 ft.)
Directional range*:	Up to 10 Km (6 Mi.)
Output power:	1 Watt EIRP
Standard Antenna:	2.15 dBi Dipole
Optional Antennas:	3 dBd Omni, 6 dBd Patch, 6 dBd Yagi
Antenna Connection:	Reverse Polarity TNC (RP-TNC)

PERFORMANCE MODEL 630-2400

Data Rate per Channel: (Min/Max)	1 Mbps / 2 Mbps (FCC, Canada, ETSI, Japan)
Number of Channels:	5 (FCC, Canada, ETSI) 1 (Japan)
Wireless LAN Capacity Per Microcell:	6 Mbps (3 Ch. @ 2 Mbps) (FCC, Canada, ETSI) 2 Mbps (1 Ch. @ 2 Mbps) (Japan)
CPU:	25 Mhz Motorola 68360

RANGE

Typical coverage per microcell*:	4,500 sq. m. (50,000 sq. ft.)
Omni-Directional range, Indoors*:	Up to 150 m. (500 ft.)
Omni-Directional range, Outdoors*:	Up to 300 m. (1,000 ft.)
Directional range*:	Up to 5 Km (3 Mi.)
Output power:	100 mW EIRP

Standard Antenna:	2.15 dBi Dipole
Optional Antennas:	3 dBd Omni, 6 dBd Patch, 13.5 dBd Yagi
Antenna Connection:	Reverse Polarity TNC (RP-TNC)

NETWORK SUPPORT

Wired LAN Protocol:	IEEE 802.3 CSMA/CD and Ethernet Blue Book
Wired LAN Connections:	10Base2 (Thin/BNC), 10Base5 (Thick/AUI), 10B
Wired LAN capacity:	10 Mbps
Wired LAN Filtering:	Intelligent packet filtering by network addr
Wireless LAN Protocol:	Patented Microcellular Architecture (TMA) ba
Wireless LAN Roaming:	Fully supported via Patented Microcellular A
Wired Access Points per LAN:	Unlimited
Wireless Access Points per LAN:	Unlimited
Users per Access Point:	2048

CONFIGURATION AND MANAGEMENT

Local Configuration via:	System Console Port (Serial RS-232C DB-9 Fem
Remote Configuration via:	Any wired or wireless LAN station via Telnet
Automatic Configuration via:	BOOTP
SNMP Compliance:	MIB 1, MIB 11, and ARLAN Enterprise MIB
Data Security and Integrity:	Direct Sequence Spreading with over 16 Milli
User Privelege:	Password Protected
Flash ROM:	256 KB for Configuration Tables and Firmware
System RAM:	1 MB Standard
LED Indicators:	System Status, Ethernet Activity, Wireless L

PHYSICAL CHARACTERISTICS

Dimensions (Width x Depth x Height):	20 cm x 15 cm x 5 cm (7.8 in. x 5.9 in. x 1.
Weight:	0.7 Kg (1 lb. 8 oz.)
Temperature Range:	0 C to 40 C (32 F. to 104 F.)
Power Supply:	90 - 260 V.A.C., 50/60 Hz, 18 V.D.C. @ 1 A
Warranty:	One Year Parts and Labor returned to Factory
Approval:	FCC Part 15, SubPart B, Class A FCC Part 15.247

* Wireless LAN coverage is a function of the antenna gain, placement, and type as well as building construction and density. For optimum results in difficult environments please contact Aironet or NTS for a professional Site Survey. In our constant effort to improve products and systems, Aironet Wireless Communications Inc. reserves the right to change or modify features and specifications without notice. NOTICE: Some of the product names used herin are for identification purposes only and may be trademarks of their respective companies.

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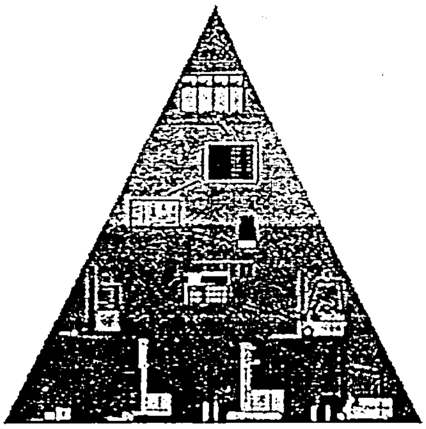
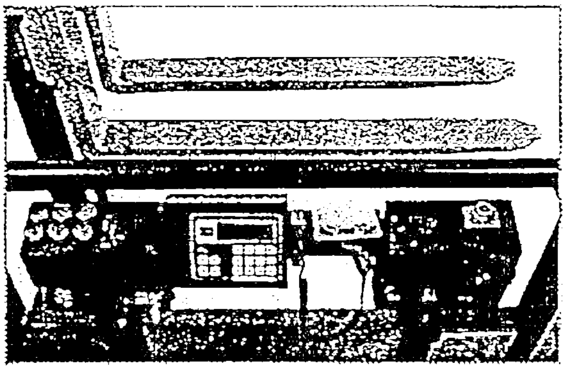
PMH

Data Communication



Infrared technology is the perfered method of communication for wireless data communication in plants and warehouses. It is used to transmit data between computers, lift trucks, terminals, bar code readers and electronic instruments.

Infrared communication is very fast, reliable, and secure undisturbed by IC engines, electric motors, steel structures and RF noise pollution. Infrared communication technology does not affect transducers and other sensitive sensors found on todays manufacturing floors.



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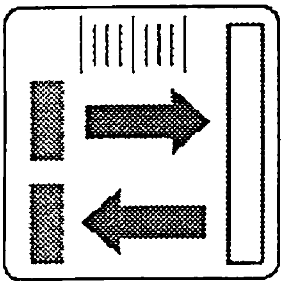
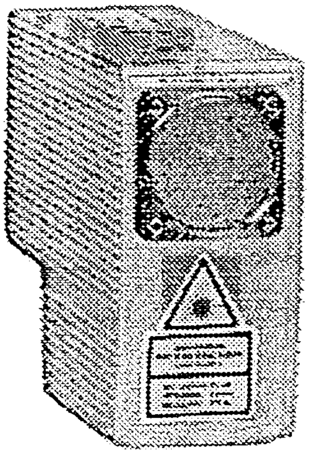
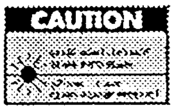
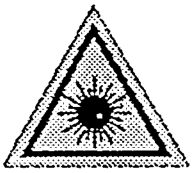
A.4 Obstacle Detectors

DME 3000
Distance Measurement Sensor









DME 3000 Technical Data

Dimensions in mm (in) 1)	54x105x138 (2.12x4.13x5.43)
Supply Voltage	18 to 30 V DC
Enclosure Rating	IP 65; NEMA 4
Ambient Operating Temperature	-10 to +45 degrees C (+14 to +113 degrees F)
APPROVALS	
CE	
Maximum Range in m (ft)	
Range (reflector mode) in m (ft)	0 to 500 mm (0 to 1640)
Switching Outputs	B (PNP / NPN)
Analog Output	
Switching Frequency	
Light Source	red laser (class 2)
Interface	RS 422 / SSI adjustable
Type of Connector	QD
Resolution in mm (in)	1 (.04)
Number of Colors	
Accessories	5, 6

1) width x height x depth in mm (in)

2) cable, quick disconnect (QD) or terminal chamber

3) AO = alarm output

4) TI = test input

5) also available as contrast scanner

DME 2000 Technical Data

Dimensions in mm (in) 1)	54x105x138 (2.12x4.13x5.43)
Supply Voltage	18 to 30 V DC
Enclosure Rating	IP 65; NEMA 4
Ambient Operating Temperature	-10 to +45 degrees C (+14 to +113 degrees F)
APPROVALS	
CE	
Maximum Range in m (ft)	100 to 2047 (3.94 to 80.6)
Range (reflector mode) in m (ft)	.1 to 130 (3.9 to 430 ft.)
Switching Outputs	PNP
Analog Output	0 to 20 mA / 4 to 20 mA
Switching Frequency	-
Light Source	red laser (class 2)
Interface	RS 232
Type of Connector	QD
Resolution in mm (in)	1 (.04)
Number of Colors	
Accessories	5, 6, 4

1) width x height x depth in mm (in)

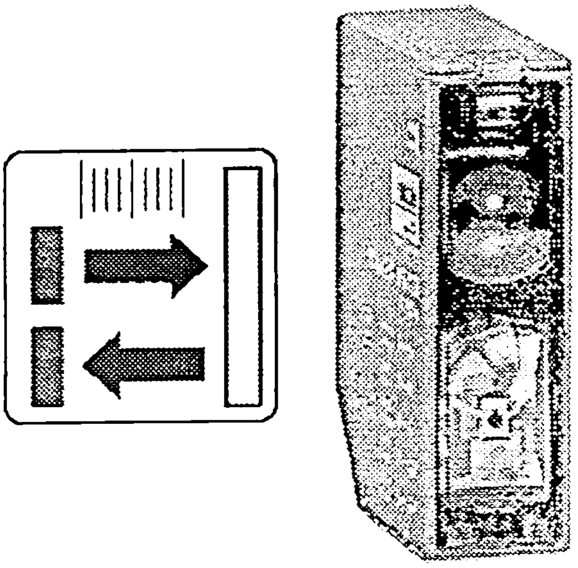
2) cable, quick disconnect (QD) or terminal chamber

3) AO = alarm output

4) TI = test input

5) also available as contrast scanner

WTA 24
Distance Measurement Sensor



WTA 24 Technical Data

Dimensions in mm (in) 1)	27x88x65 (1.06x3.46x2.56)
Supply Voltage	12 to 30 V DC
Enclosure Rating	IP 67; NEMA 6
Ambient Operating Temperature	-10 to +55 degrees C (+14 to +131 degrees F)
APPROVALS	
CE	
Maximum Range in m (ft)	250 to 350; 600 to 1200; 1000 to 3000
	(9.9 to 13.8; 23.6 to 47.2; 39.4 to 118.1)
Range (reflector mode) in m (ft)	
Switching Outputs	2 x PNP
Analog Output	4 to 20 mA
Switching Frequency	100 Hz to 10 Hz
Light Source	IR
Interface	
Type of Connector	QD
Resolution in mm (in)	0.5; 9; 100; (.02; .35; 3.94) 5)
Number of Colors	
Accessories	6, 4

1) width x height x depth in mm (in)

2) cable, quick disconnect (QD) or terminal chamber

3) AO = alarm output

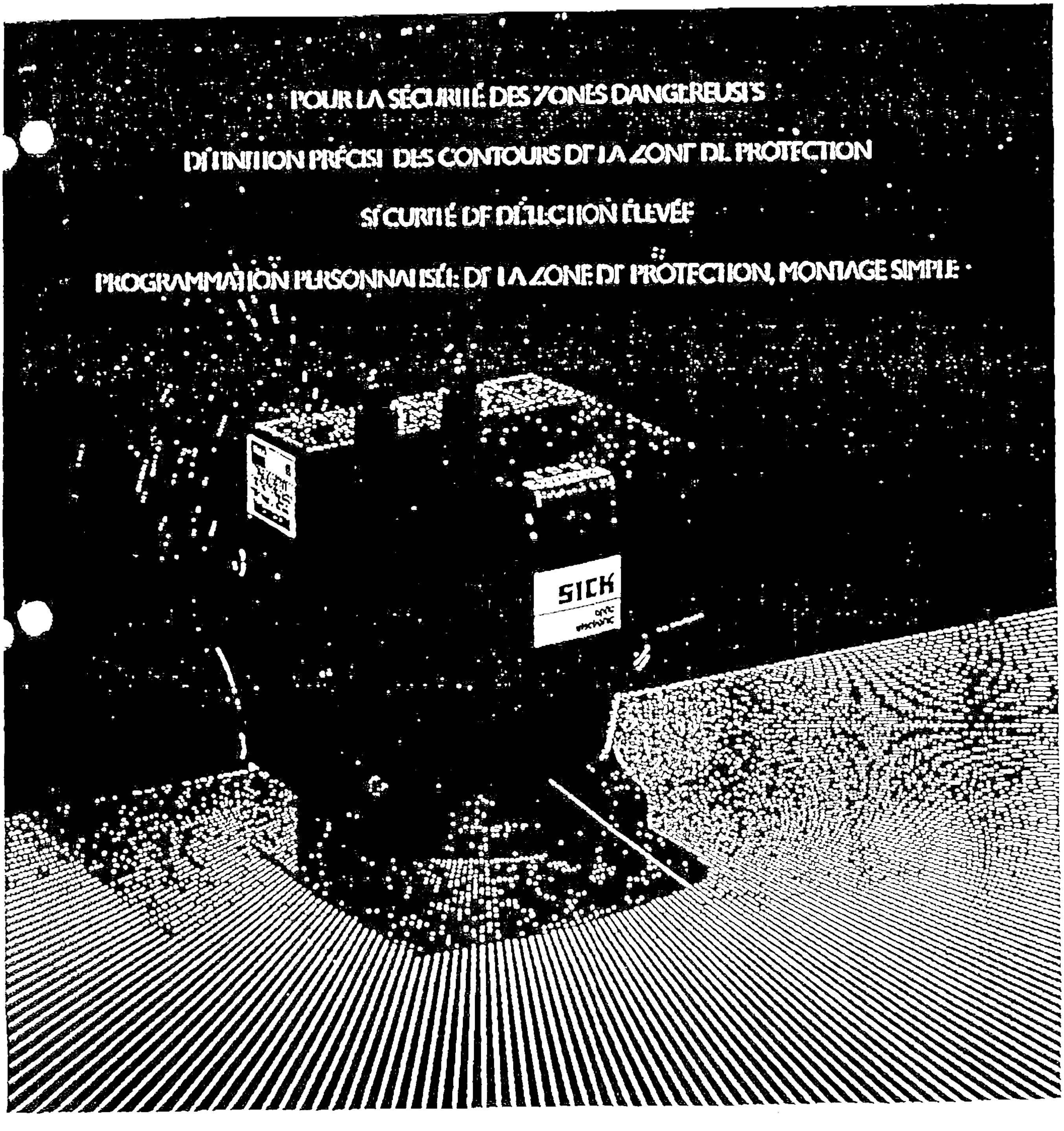
4) TI = test input

5) also available as contrast scanner

OCTOBRE 1995

INFORMATION PRODUIT

Scrutateur Laser
PLS



SICK

PLS – le scrutateur laser de SICK

A l'aide d'un rayon infrarouge, le PLS balaye son environnement sans contact. Il n'a besoin ni de réflecteur, ni de récepteur séparé. Ce qui présente des avantages importants :

- La zone de protection peut être adaptée avec précision à la zone de danger.
- Les frais de montage sont réduits.
- Les installations mécaniques supplémentaires qui perturbent souvent le déroulement du travail disparaissent.

Le PLS ne nécessitant pas de réflecteur, il peut être facilement déplacé. Avec son large champ de protection, il est particulièrement adapté non seulement pour la sécurité des systèmes de transport sans conducteur, mais également pour l'assistance à leur navigation.

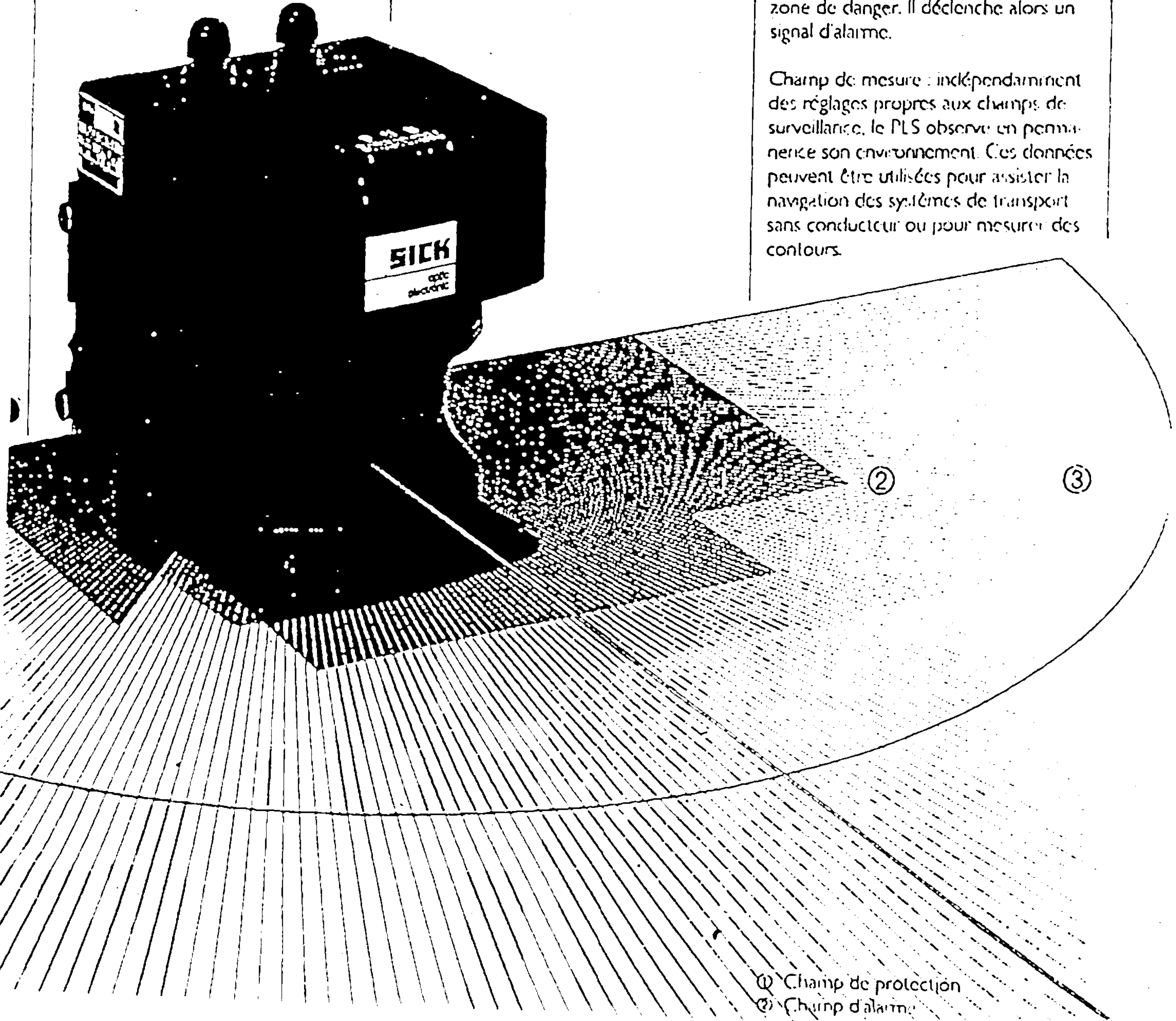
Insensible aux champs magnétiques, aux variations de température ou à la différence de réémission des matériaux, le PLS surveille son environnement comme un radar opto-électronique. Il est donc absolument fiable.

Le PLS divise la zone à surveiller en trois champs : le champ de protection, le champ d'alarme et le champ de mesure.

Si le PLS détecte une présence dans le champ de protection (zone de danger), tous les mouvements dangereux de la machine ou du système de transport sans conducteur sont immédiatement stoppés.

Le PLS peut détecter les présences dans le champ d'alarme, même si les personnes se situent en dehors de la zone de danger. Il déclenche alors un signal d'alarme.

Champ de mesure : indépendamment des réglages propres aux champs de surveillance, le PLS observe en permanence son environnement. Ces données peuvent être utilisées pour assister la navigation des systèmes de transport sans conducteur ou pour mesurer des contours.



① Champ de protection
② Champ d'alarme

Améliorez la sécurité avec le PLS

3finition du champ de ·otection à l'aide d'un giciel convivial

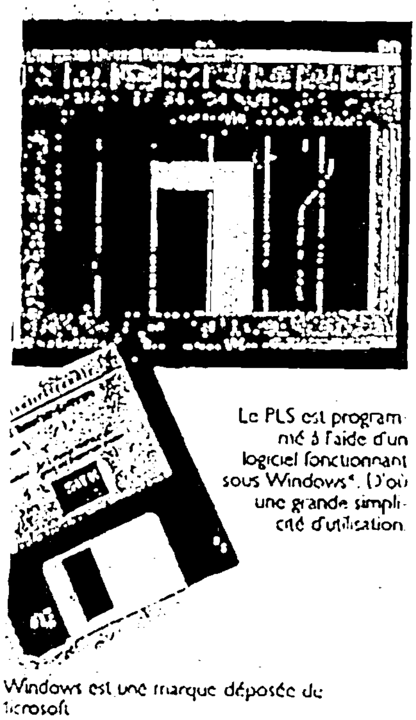
ec un rayon d'environ 15 mètres, le 5 couvre une zone semi-circulaire de 0 m². A l'intérieur de cette zone, il possible de définir deux zones de veillance personnalisées. Vous pouvez ur ce faire utiliser votre ordinateur bureau ou votre ordinateur portable.

ur f--ilter la programmation du PLS, us a ...s développé le logiciel sous indows. Il existe trois méthodes de ogrammation :

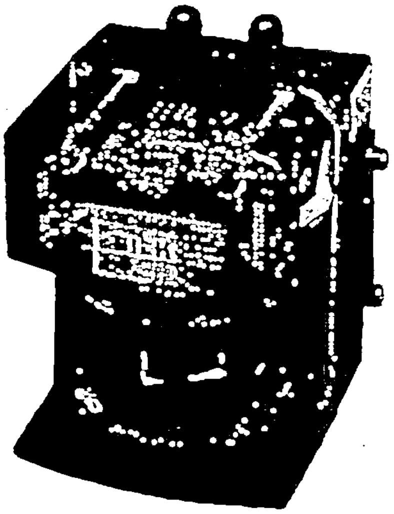
- Le mode d'apprentissage (teach-in)
- L'entrée des données graphiques
- L'entrée des coordonnées

n champ de vision sans faille

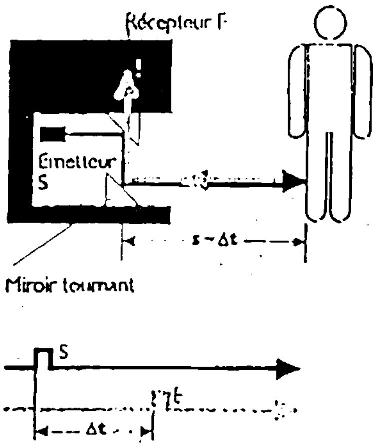
: PLS surveille non seulement les dif-rents champs de protection, mais galement son propre fonctionnement. in de conserver un champ de vision nstant, le système contrôle par emple l'encrassement de la fenêtre ontale via un quadruple réseau optique : sécurité. De même, les fonctions ectroniques sont autocontrôlées. Les cuits à microprocesseur et les circuits tégrés ASIC assurent l'extrême fiabi-é d ..S. Des sorties de sécurité à mi-conducteur permettent un raccordement direct sur les commandes des machines ou sur les API.



Le PLS est programmé à l'aide d'un logiciel fonctionnant sous Windows*. D'où une grande simplicité d'utilisation.



Le PLS est un détecteur fonctionnant selon le principe de la mesure du temps de vol de la lumière. Une impulsion lumineuse très courte est émise. Le rayon lumineux est dévié par un miroir tournant et couvre ainsi une surface semi-circulaire. Au même moment, un "chronomètre électronique" est déclenché. Si le rayon lumineux rencontre un obstacle, la lumière rétrodiffusée est captée par le détecteur et le "chronomètre" est arrêté. La distance par rapport à l'objet réfléchi est calculée en fonction du temps écoulé entre l'émission et la réception de l'impulsion.

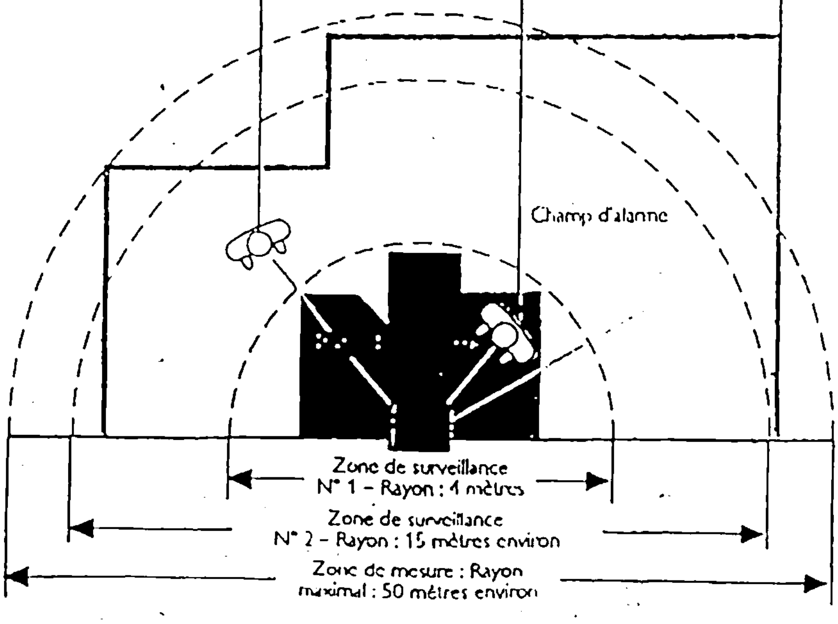


La position exacte de l'objet peut également être déterminée grâce aux informations angulaires associées au rayon de mesure. Si la distance calculée est inférieure à celle correspondant à la limite du champ de protection ou d'alarme, le PLS stoppe la machine ou déclenche un signal d'alarme.

Le champ d'alarme sert à déclencher une réaction progressive du système

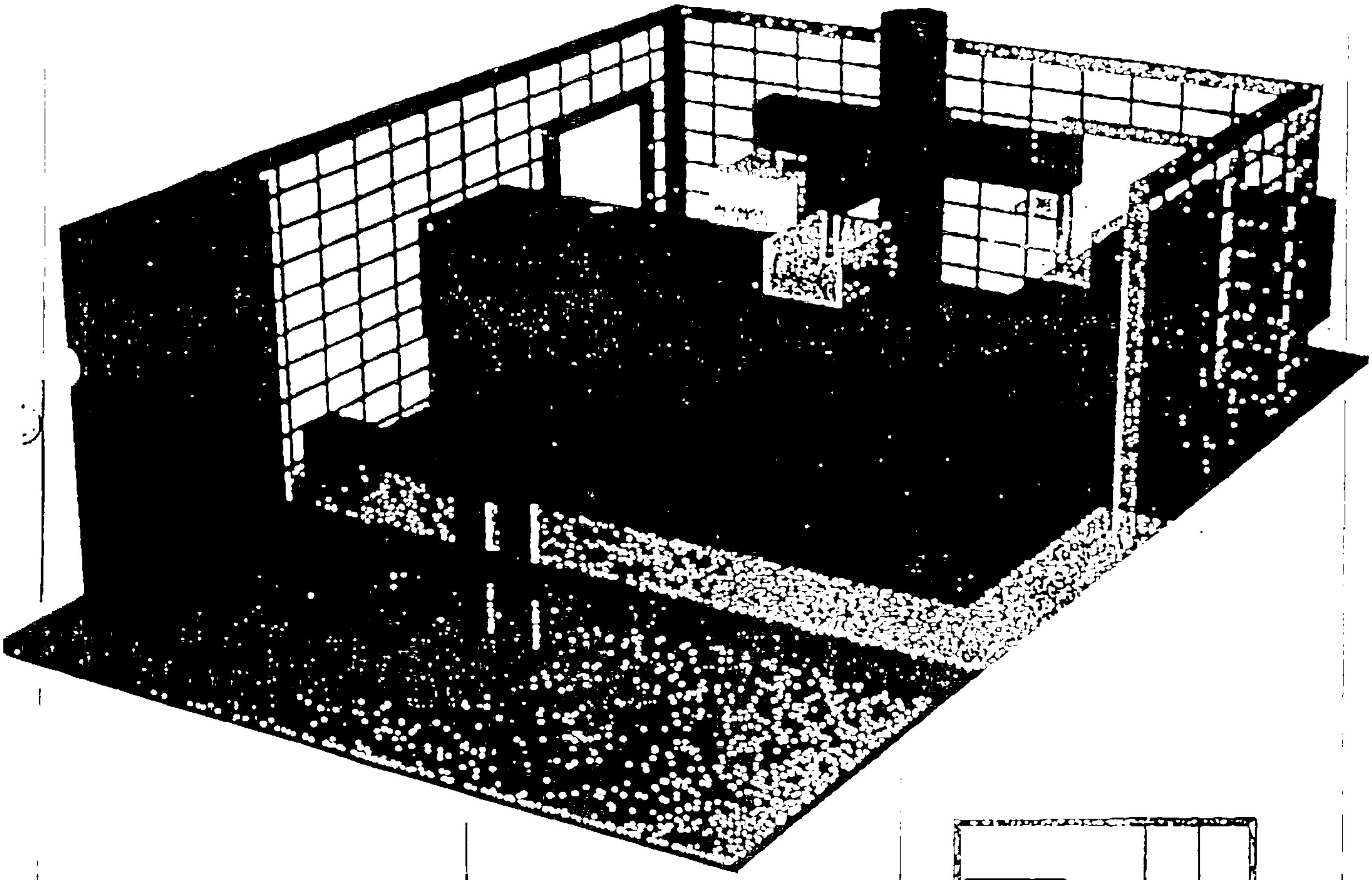
Si une personne pénètre dans le champ de protection, le PLS stoppe la machine. Cette zone peut être définie sur un rayon de 4 mètres.

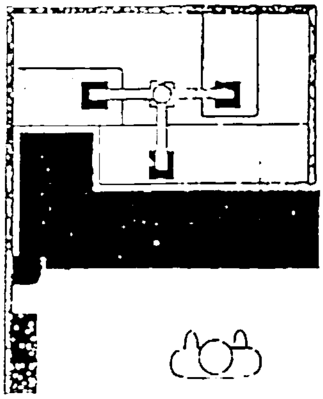
Le champ de mesure d'un rayon maximal de 50 mètres fournit des données sur l'environnement rencontré. Elles peuvent être utilisées par exemple pour la navigation des systèmes de transport sans conducteur ou la mesure des contours.



Windows est une marque déposée de 1icrosoft

Le PLS assure une protection efficace des personnes





Si une personne s'approche d'une installation dangereuse, le système l'avertit dans un premier temps. Si la personne pénètre quand même dans la zone de danger, le PLS stoppe la machine.

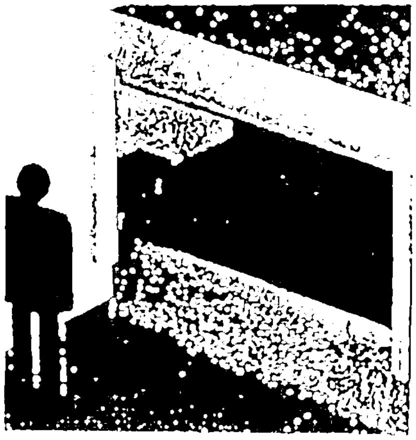
Évitez les arrêts de machine inutiles par une protection adaptée des zones dangereuses.

Les zones dangereuses n'obéissent pas aux normes. Elles sont de dimensions différentes et couvrent souvent des surfaces aux contours irréguliers. Avec le PLS, vous avez la possibilité de définir deux champs de protection qui auront chacun une fonction correspondant à leur hiérarchie.

Si une présence est détectée dans le champ de protection, le PLS stoppe la machine. Si une présence est détectée dans le champ d'alarme, le PLS avertit du danger et d'une possible interruption du fonctionnement de la machine.

Les avantages offerts par le PLS par rapport aux dispositifs de sécurité tactiles ou mécaniques sont évidents : puisqu'il n'y a aucun contact, aucune usure due à des contraintes mécaniques n'est possible. Le PLS est donc plus fiable que les systèmes tactiles. De structures mécaniques et les autres installations qui perturbent le bon déroulement du travail ne sont plus nécessaires. Les champs de protection peuvent être librement traversés.

Il est également très simple de changer le dispositif de place ou de modifier le contour des zones dangereuses. Ces modifications peuvent être effectuées sur site à l'aide du logiciel. Et, à la différence des autres solutions optoélectroniques, le PLS n'exige pas l'installation de réflecteurs ou de récepteurs séparés.



Le PLS facilite par exemple la surveillance interne des presses de grande dimension. Le démarrage de la presse n'est possible que lorsque l'intérieur du local est vide.

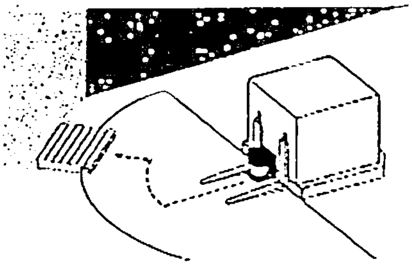
Le PLS améliore la sécurité et l'efficacité du guidage d'un chariot automatique

Avec le PLS, vous améliorez la sécurité et les performances de votre système de transport sans conducteur.

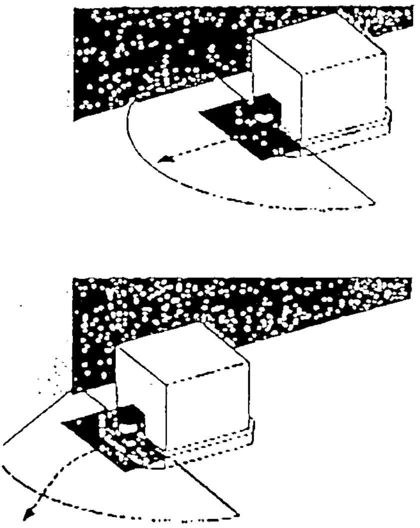
Les systèmes de transport sans conducteur sont confrontés à un dilemme : soit ils se déplacent lentement et ne représentent pratiquement aucun danger pour les personnes, mais ils sont alors peu productifs ; soit ils se déplacent à une vitesse élevée, mais dans ce cas, ils ne doivent pas mettre en danger le personnel. Le PLS vous apporte la solution :

Grâce à son large champ de sécurité, il offre la protection requise contre les accidents. Il oblige le système de transport sans conducteur à s'arrêter à temps. Il remplace les systèmes tactiles sujets aux pannes. Le principe du balayage sans contact exclut les accidents dits "induits" (causés par la frayeur du contact). L'importance de la surface couverte par le champ de protection permet pour la première fois d'atteindre des vitesses élevées et de charger le système de transport de façon plus efficace.

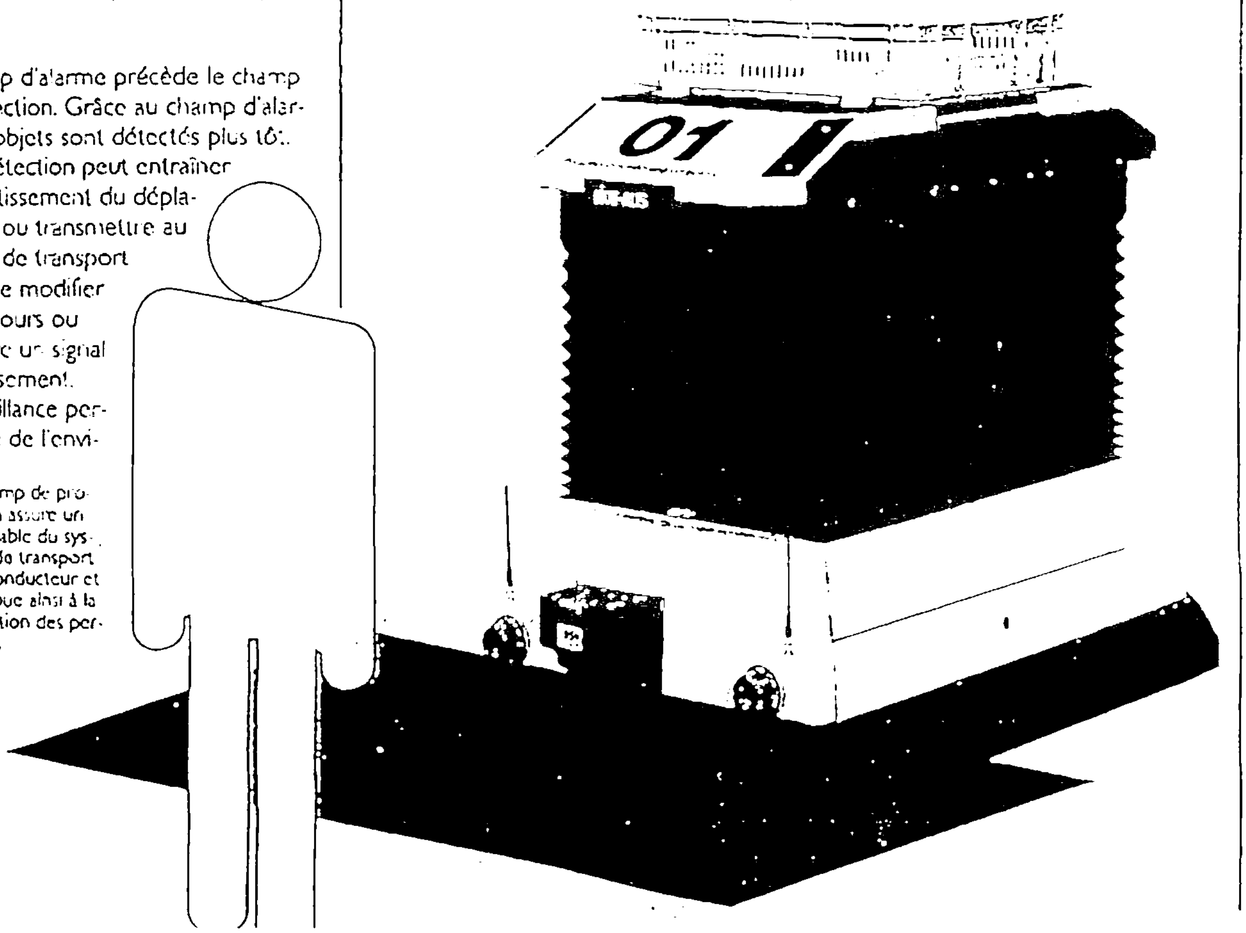
Le champ d'alarme précède le champ de protection. Grâce au champ d'alarme, les objets sont détectés plus tôt. Cette détection peut entraîner un ralentissement du déplacement, ou transmettre au système de transport l'ordre de modifier son parcours ou d'émettre un signal d'avertissement. La surveillance permanente de l'environnement et le long rayon d'action du PLS permettent également de mettre en place une assistance à la navigation. Les données concernant les contours de l'environnement "détecté" sont transmises par une interface série au calculateur de bord. Celui-ci peut ainsi mettre à jour son propre système de navigation. De plus, il est possible avec le PLS de déterminer, par exemple, la position et la taille des marchandises à transporter, de façon à permettre au système de transport de les prendre en charge correctement.



Le PLS détermine la position exacte des marchandises (position en biais ou perpendiculaire). En se référant à ces données, un système de transport sans conducteur peut être guidé dans la position de chargement adéquate (approche automatique).



Le PLS fournit en permanence au calculateur de bord du système de transport sans conducteur les données concernant l'environnement observé. Le système de transport arrive ainsi rapidement et en toute sécurité à destination. Le champ d'alarme peut être à tout moment modifié par le calculateur du véhicule et être ainsi adapté au parcours



Le champ de protection assure un arrêt fiable du système de transport sans conducteur et contribue ainsi à la protection des personnes

Le logiciel du PLS : facile à apprendre

La programmation du PLS : conviviale et peu exigeante en matériel

Même sans vous aider du manuel, vous arriverez facilement à de bons résultats : le logiciel du PLS fonctionne sous Windows et vous propose une aide à chaque étape de la programmation. Vous pouvez aussi choisir une exécution guidée du programme : le programme effectue dans l'ordre toutes les [illegible]es nécessaires à une définition correcte du champ de protection. Dans tous les cas, le logiciel du PLS vous indiquera de façon conviviale et précise comment arriver rapidement au but.

Connectez ensuite votre ordinateur de bureau ou votre ordinateur portable au PLS et chargez le logiciel. Le programme vous propose trois méthodes pour définir les différents champs de protection :

Mode d'apprentissage

Si vous choisissez ce mode, le PLS "apprend" automatiquement l'environnement fixe qui l'entoure. Le cas échéant, un opérateur peut indiquer au PLS les limites du champ de protection en se déplaçant à l'extérieur de la zone qu'il désire circonscrire. Il est possible à tout [illegible]ment de modifier ces limites par l'introduction de données graphiques ou de coordonnées.

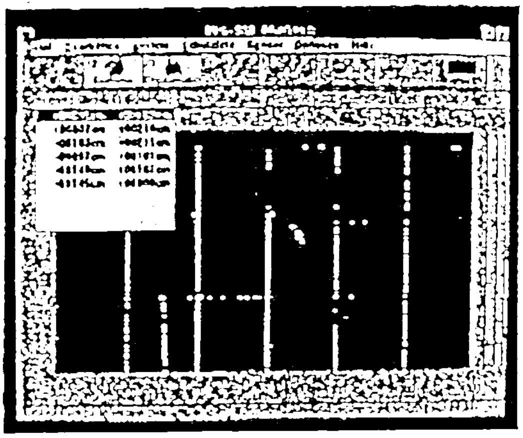
Entrée de données graphiques

A l'aide de la souris, cliquez dans le système de coordonnées affiché, et dessinez ainsi les champs de protection et d'alarme.

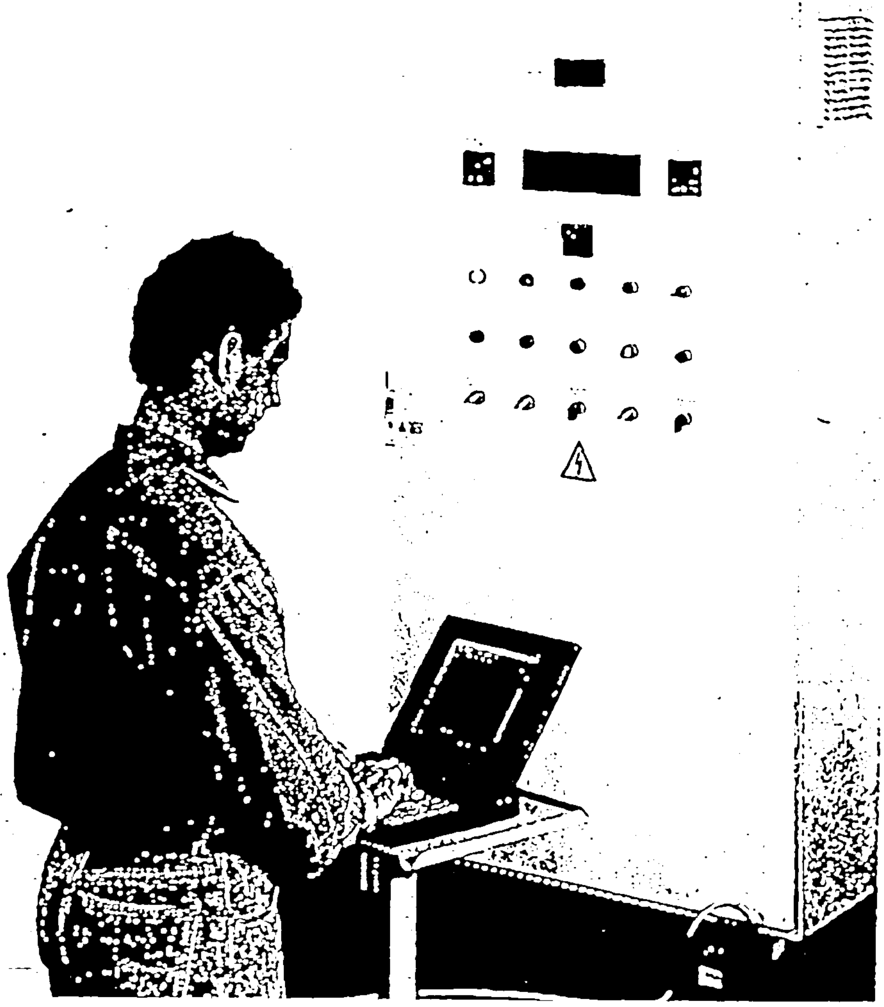
Entrée des coordonnées

Indiquez les coordonnées numériques des extrémités du champ de protection et d'alarme.

Lorsque les champs de protection sont programmés, vous pouvez réinstaller votre ordinateur à sa place. Le PLS conservera les données en permanence dans sa mémoire, même en cas de coupure de courant. Vous pouvez bien sûr stocker les données sur disquettes. Mais vous pouvez aussi modifier rapidement et simplement les champs de protection définis quand vous le désirez. Evidemment, toutes les données sont protégées par des mots de passe contre les manipulations éventuelles.

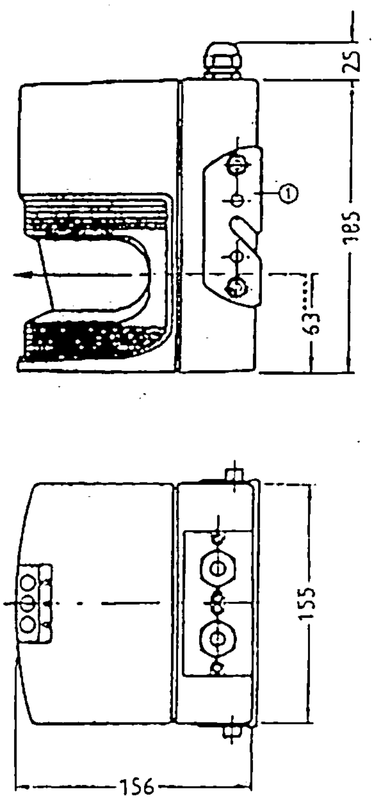


Le logiciel du PLS peut être utilisé après un court apprentissage. Les principales fonctions sont accessibles par des boutons affichés à l'écran.



Caractéristiques techniques

Dimensions du PLS



① système de fixation 1 (accessoire)

Caractéristiques techniques du PLS

Champ de protection

Portée :	Rayon de 4 m maxi
Temps de réponse :	≤ 80 ms
Réémission minimale :	1,8 %
Résolution :	≥ 70 mm (à une distance de 4 m)
Sortie :	2 sorties de sécurité à semi-conducteur PNP, 24 V / 250 mA
Classe de sécurité :	4 selon DIN 19250 (approuvé BIA, certifié BG 1994), corresp. avec la classe 3 pr EN 954

Champ d'alarme

Portée :	Rayon de 15 m environ
Réémission minimale :	voir diagramme A
Résolution :	voir diagramme B
Sortie :	sorties de sécurité à semi-conducteur PNP 24 V / 100 mA ou via interface série

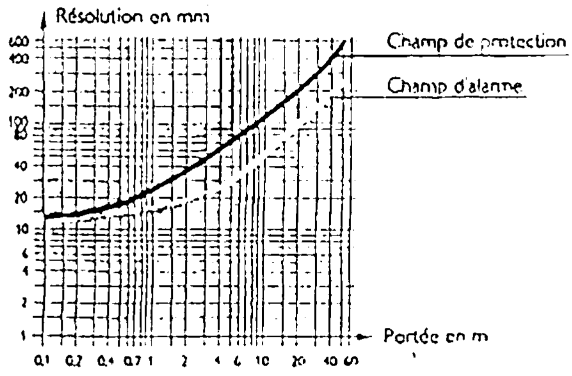
Champ de mesure

Portée :	Rayon de 50 m environ, voir diagramme A
Résolution angulaire :	0,5°
Réémission :	voir diagramme B
Précision de la mesure de distance :	± 50 mm
Durée du balayage :	40 ms

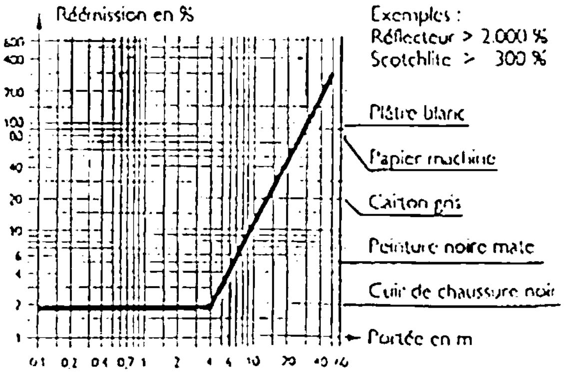
Caractéristiques générales

Angle de balayage :	180° maximum
Tension d'alimentation :	24 Volts ± 15 %
Puissance absorbée :	≤ 17 W, + charge au niveau des sorties : DC 24 Volts maxi / (2 x 250 mA + 100 mA)
Interfaces :	RS 232 ou RS 422, au choix
Classe laser :	1
Type de protection :	IP 65
Températures de fonctionnement :	de 0 à + 50° C
Températures de stockage :	de - 30 à + 70 °C
Poids :	4,5 kg

Diagrammes de résolution et de réémission



A : Résolution en fonction de la portée



B : Réémission minimale en fonction de la portée

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