Cargo Container X-ray Inspection Systems

OVERVIEW: Container inspection is categorized into three stages. In the initial stage, large-size X-ray DR (digital radiography) is used to inspect full containers sitting on their trailers. If that inspection identifies suspicious cargo, the trailer and container are relocated to a nearby inspection position for opening the container and inspecting all cargo inside. In the second stage, small-size X-ray DR equipment is used to inspect each cargo. If a suspicious cargo is detected here, it is then opened, the contents are extracted and checked by manual procedure. For cargoes that cannot be opened, such as religious statues or works of art such as sculptures, third-stage inspections are conducted using an X-ray (computed tomographic) scanner. Hitachi, Ltd. is the only manufacturer in the world that can provide the equipment needed in all three cargo-container inspection stages.

INTRODUCTION

A single container ship carries an average of 3,000–8,000 containers. To open each container and remove and inspect its cargo would be both time-consuming and unrealistic. In order to conduct inspections effectively and efficiently, large-size X-ray DR (digital radiography) equipment is used to inspect containers loaded aboard their trailers (see Fig. 1). For X-rays capable of scanning cargo inside a container — actually, a steel-walled box — a linear accelerator (linac) that generates 9 MeV (9 mega electron-volts) is used.

Fig. 1—Overall View of Container Inspection Center.
A container inspection center is often located near a seaport container terminal. The center consists of two types of inspection facilities. One is for inspecting cargo containers using large-size X-ray equipment while loaded on trailers. The other unit is for individual inspection of all cargo inside a container when the trailer X-ray inspection identifies a suspicious piece of cargo.

If the first inspection stage identifies suspicious cargo in a container, the trailer is driven to a nearby station in the inspection center where the container is opened and each piece of cargo inside is inspected using X-ray DR equipment. Suspicious cargoes detected in that inspection are then opened, the contents are extracted and checked manually. The equipment used in this second-stage inspection includes an X-ray tube that generates several hundred keV (kilo electron-volts).

For cargo that cannot be opened, such as religious statues or works of art, including sculptures, an X-ray CT (computed tomographic) scanner is used to create tomographic images for viewing. Since cargo in this third-stage inspection process is often made of metal or marble, a linac with energy of about 1 MeV is used.

X-ray scanning equipment is convenient to use because turning off the power source halts its operation. It is used in a wide range of applications.

The following paper introduces various types of inspection equipment.

OUTLINE OF X-RAY INSPECTION EQUIPMENT

X-ray Equipment for Inspecting Containers

(1) Outline of equipment

The X-ray equipment available for inspecting

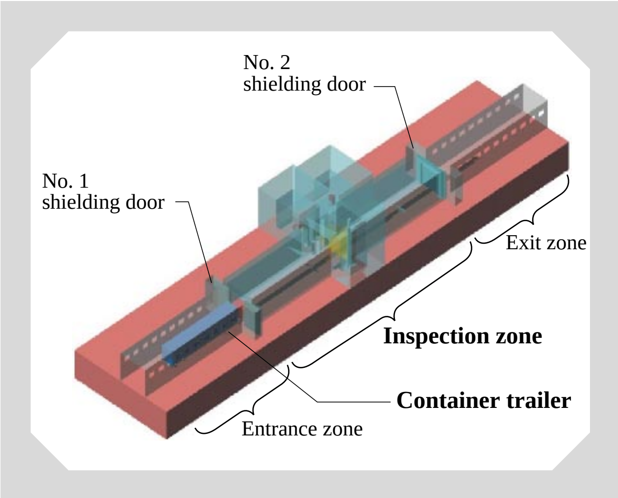


Fig. 2—Schematic of Facility and Equipment for X-Ray Inspection of Containers.
In the central inspection zone is X-ray inspection equipment for both horizontal and vertical inspections.

containers includes fixed type for use inside a building and mobile type used outside in the open. The power source for X-ray equipment used inside is 9 MeV and for that used outside—because there is no shield and in order to reduce the space for managing radiation—is somewhat low energy of 2.5 – 6 MeV.

Fig. 2 shows a typical facility for housing fixed-type inspection equipment. It has an entrance zone, an inspection zone, and an exit zone. The inspection zone is built of concrete, with shielding doors at its entrance and exit. The concrete structure prevents radiation leaks to the outside. In fact, the concrete is thicker in the areas nearest the X-ray source and X-ray detection equipment. The equipment and structures most closely related to the X-rays are the first shielding door at the entrance, the second shielding door at the exit, the X-ray source for horizontal inspections, the X-ray detector used for horizontal inspections, the X-ray source for vertical inspections, and the X-ray detector used for vertical inspections. The equipment used for conveying the trailer inside the structure includes the No. 1 and No. 2 trailer conveyors.

(2) Flow of inspection procedures

The container trailer driver drives the trailer to a designated position in the entrance zone, turns off the ignition, and alights from the vehicle. During the inspection he/she waits in a special waiting area in the exit zone. The No. 1 trailer conveyor located in the inspection structure's underground area raises the trailer's two front wheels in order to pull it forward. After the first shielding door opens, the trailer is pulled to the center of the inspection zone and halted. The No. 1 trailer conveyor is then removed from under the trailer's front wheels and returns to its original position in the entrance zone. At that point, the No. 2 trailer conveyor takes over by once again raising the trailer's two front wheels. After the No. 1 shielding door is closed the entire container is exposed to X-rays emitted from two directions relative to the direction the container is heading, horizontal and vertical. After the X-ray process ends, the No. 2 shielding door opens and the trailer is pulled into the exit zone. The waiting driver then boards the trailer and drives it from the inspection facility.

After the X-rays pass through the container and are attenuated, a detector detects and measures them. Depending on how strong the X-rays are the detector converts them into analog electric signals and transmits them to an image-processing computer. If the resultant images show suspicious objects in the container, additional processing raises the level of contrast sensitivity and enlarges the objects inside to determine what they are. The inspection images are transmitted to an electronic image data server, and the computer receiving the inspection data transmits the information to a data server. From there, the horizontal images, vertical images, and declared information are all transmitted to an inspector's computer monitor. Containers are inspected at the rate of 20/h.

(3) Conveying device

The trailer conveyor is fixed to a trailer's two front wheels and pulls the trailer forward. As the trailer is pulled forward at a set speed, the perpendicular X-ray beams from the vertical and horizontal X-ray sources pass through the container. The structure of the trailer conveyor is designed so as not to interfere with the X-ray inspections. An interlock control prevents the trailer conveyor from colliding with each other or with the shielding doors.

(4) Safety equipment

Safety equipment is installed to determine whether anyone is in the inspection zone, and an interlock prevents the X-ray equipment from operating when someone is detected. The following safety equipment is fitted to the facility:

(1) Buzzer for confirming that the driver has alighted from the trailer
(2) Safety confirmation device (device for confirming moving objects)
(3) Surveillance camera
(4) Emergency stop switch

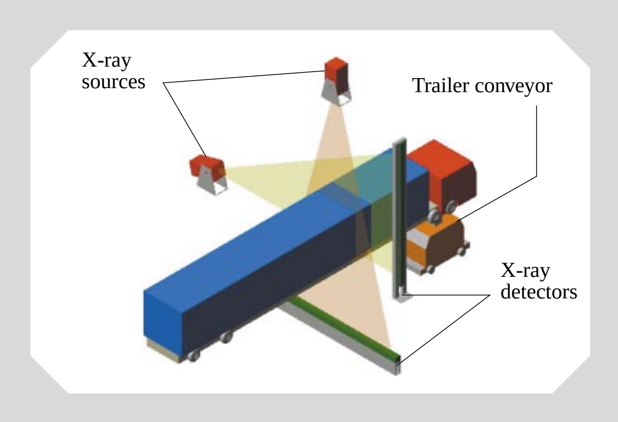


Fig. 3—Schematic of Container Inspection Equipment Used in Past.
A trailer conveyor in an underground pit was fixed to a truck's front wheels for pulling the truck and trailer forward.

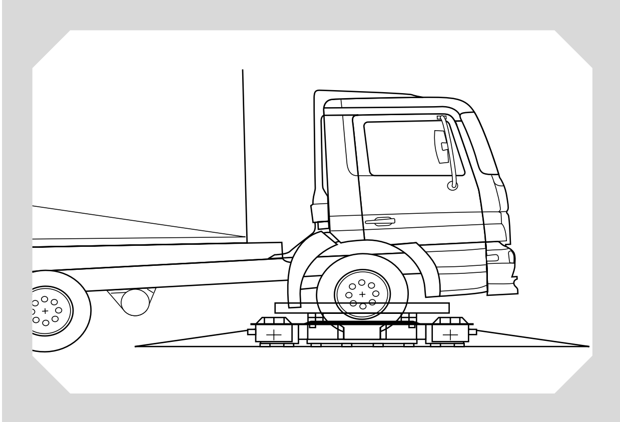


Fig. 4—Latest Container Trailer Conveying Device.
This trailer conveyor is aboveground. The trailer driver positions the two front wheels of the trailer on the dolly and stops the trailer. After he/she alights, the dolly pulls the trailer forward.

The shielding doors can be opened and closed at high speeds, but not so fast that they compromise safety. An interlock prevents X-ray exposure when the shielding doors are open.

(5) Central control equipment

When a container's cargo is being inspected, the status of various inspection equipment and devices is confirmed, such as the opening and closing of the shielding doors and the starting and stopping of the conveying device's operation. Safety is also confirmed through surveillance cameras, the progress of the inspection process is monitored, and directions are issued concerning operation. Central control displays show the status of inspections and allow the inspectors to simultaneously check the horizontal and vertical images and declared data. The image data from inspections can also be forwarded to other inspection sections and to the second-stage station where containers are opened and content of cargo is extracted and checked individually. Doing so makes it possible to conduct inspections of individual content of cargo efficiently. Information related to where suspicious items might be hidden can also be shared between inspection stations.

Outline of Latest Container Inspection Equipment

In the past, as shown in Fig. 3, the front wheels of a trailer were jacked up and its two front wheels were fixed to a conveying device in an underground pit. The trailer conveyor then pulled the trailer forward. Current equipment, however, as shown in Fig. 4, has the trailer conveyor moving forward aboveground. The trailer driver positions the trailer so that its two front wheels are on a dolly where they are then fixed. After the driver alights from the trailer the dolly pulls the trailer forward. The driver boards the trailer again after the inspection is completed and drives out of the inspection facility, with the trailer pulling the container across the dolly.

X-ray Equipment for Inspecting Cargo

(1) X-ray DR equipment for inspecting cargo

Compared to X-ray DR equipment used for inspecting containers, X-ray DR equipment for inspecting cargoes is much smaller but can inspect cargoes 2 m × 2 m in size with about a 2-ton mass. It uses an X-ray tube that emits energy of several hundred keV. Depending on the type of cargo, the energy can be adjusted in several steps. There are dual views of equipment, one for horizontal and the other for vertical inspections. Brightness can be adjusted, and pseudo-color and blow-up displays are possible. As shown in Fig. 5, X-ray radiation leaks are prevented through use of a shielding box and a double-layered lead curtain.

Because containers hold so much cargo, they are lifted by forklift, carried to the X-ray DR equipment, and placed on the entrance conveyor. The conveyor moves at a maximum speed of 18 m/s, allowing clear X-ray DR images even of cargo weighing as much as 2 tons. The equipment couples a small diameter roller conveyor or a belt conveyor easily penetrated by X-rays.

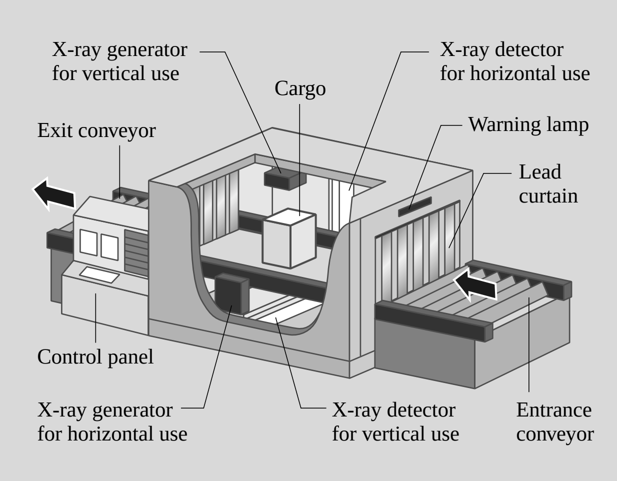
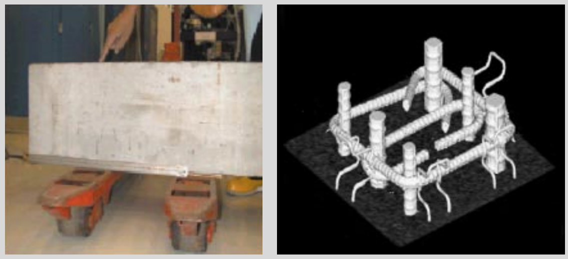
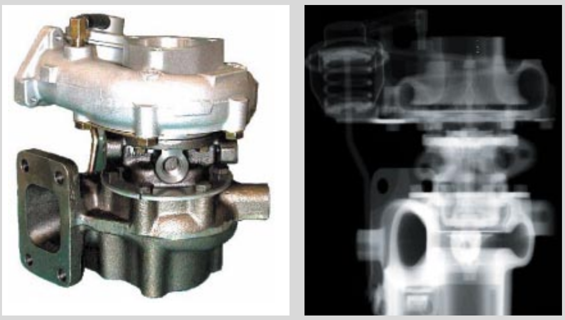


Fig. 5—X-ray DR Equipment for Inspecting Cargo.
Cargo is inspected vertically and horizontally using X-rays.



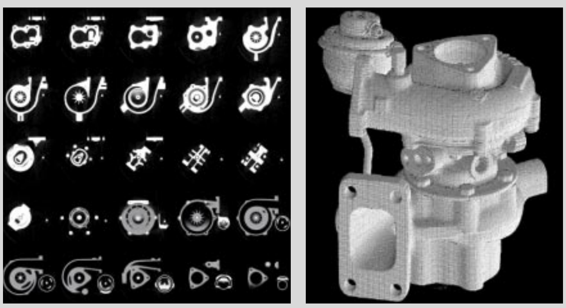
(a) Actual concrete block **(b) 3D image of steel reinforcements**

Fig. 8—Image of Steel Reinforcements Inside Concrete.
Using differences in density, images of the steel reinforcements inside concrete were extracted and a 3D image was displayed.



(a) Actual component **(b) DR image**

Fig. 6—Examples of DR Images of Automobile Component.
The DR image shows overlapping, much as X-ray images do.



(a) Tomographic image **(b) 3D image**

Fig. 7—Examples of Tomographic Images of Automobile Components and 3D Image.
There is no overlapping in the tomographic images; when they are layered they provide a 3D image.

(2) X-ray CT scanner equipment

Compared to X-ray DR inspection equipment, X-ray CT equipment is superior in one important way. As shown in Fig. 6, the image of the object being inspected using X-ray DR is overlapped while the tomographic image, as shown in Fig. 7 (a), displays a cross-section of the object, thus preventing overlapping and its accompanying monitoring difficulty. If tomographic images are layered, as in Fig. 7 (b), the object can be seen in a 3D image.

Many hospitals today use CT scanners to scan the human body. The scanners serve a role in early-stage discovery of disease. At airports, CT equipment is being used recently in systems for automatically detecting explosives in checked-in baggage, such as the EDS (explosive detection system). Relying heavily on the high-density data characteristic of CT devices, EDS has the function of identifying explosives. CT devices are the most effective non-invasive way of viewing the interior of cargo. Compared to CT devices used in the medical field or EDS, CT devices used for scanning cargo require high penetrability and the source of X-ray energy uses a linac of about 1 MeV.

With that amount of energy, as shown in Fig. 8, even images of the steel reinforcements inside concrete can be extracted from the dense X-ray data and displayed.

With CT devices, while the object being scanned is rotated a number of tomographic images are formed when the X-rays penetrate the object from different angles. The CT device used with large-size cargo takes 15 seconds to scan and produce one cross-section image. That is equivalent to the fastest scanning-type CT device used in industrial field. When using CT devices already installed, low-speed roller conveyors are used to prevent cargo 2-meters high or higher from toppling over. Throughput for those devices is about 10 pieces of large cargo per hour. High-speed conveyors can be used for normal-size cargo, however, providing a higher throughput.

Hitachi's CT device for use with cargo has been rated as providing the world's fastest performance. It utilizes industrial-use CT technology. Highly dependable results can be realized if the technology in this CT device is used for inspecting containers.

PERFORMANCE OF CONTAINER INSPECTION EQUIPMENT

The basic performance requirement of equipment used for inspecting containers is to display a clear image. Performance concerning three physical criteria determines the quality of the equipment: penetration, contrast sensitivity, and resolution. All three criteria relate closely to the number of photons in an X-ray.[1)]

Penetration is the most important of the three physical criteria. In order to increase the number of photons a source of high-energy X-rays must be provided.

Contrast sensitivity, the second most important criterion, plays an especially important role for differentiating among diverse types of cargo inside a container. The higher the contrast sensitivity the easier it is to detect suspicious low-density items. In order to achieve high contrast sensitivity it is necessary to have a large number of photons emitted. For that purpose a wide-area detector is most effective. Another method used for increasing the number of photons is to decrease the speed of the object being conveyed — the container — and to give several pulses of X-rays per detector.

Resolution, meanwhile, refers to the spatial clarity of the scanned object. If the object being inspected is large, for example, it is sufficient to determine only whether or not it is a suspicious object. For small objects, however, a high level of resolution is required[2)]. The narrower the pitch of the detector, the higher the resolution. But that also means fewer photons, so it becomes a trade-off with the above-mentioned wide-area detector. In that context, Hitachi developed two sets of detectors, giving its customers a choice, depending on use. One set emphasizes contrast sensitivity, and the other emphasizes resolution.

SPECIAL CHARACTERISTICS OF CONTAINER INSPECTION EQUIPMENT

All the components in latest container inspection equipment are located aboveground, including the conveying devices. For that reason no underground digging is needed for installation. That is a particularly attractive feature since container inspection centers are located near seaports, often on reclaimed land, so the less underground digging the better. Also, the dolly device for pulling the trailer is compact, allowing the main inspection building also to be compact, translating into less site area needed. Savings on space also mean easier expansion of facilities later.

There are two principal types of container inspections:
(1) One-direction type using horizontal X-ray, and
(2) X-rays provide dual views by sending in two perpendicular beams.

The dual-view method requires underground digging for the X-ray source room. Considering that cargo is usually stored in containers from the bottom to the top, a vertical X-ray source is set to emit X-rays from the bottom upward (see Fig. 9).

In order to ensure more throughput, container inspection equipment in the past used two sets of conveyance equipment, with one passing off baton style to the other. More recent equipment, however, uses a circulatory style so that even during times of maintenance one set of conveyance equipment enables inspection of a minimum of 12 containers per hour. Adding other sets of conveyance equipment will enable an inspection center to easily reach the world's highest level of throughput.

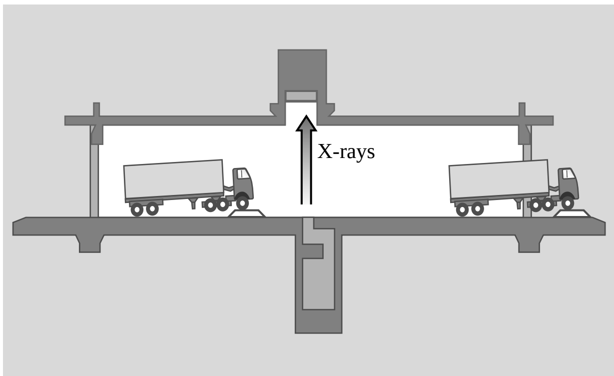


Fig. 9—Schematic View of Latest Container Inspection Equipment.
The trailer carrying the container are pulled forward using an aboveground conveying device, and the container is inspected from horizontal and vertical directions.

CONCLUSIONS

As with the inspection of checked-in baggage at airports, there are several stages in the inspection of containers at seaports. In the first stage, loaded containers are inspected as they sit on trailers, with the emphasis thus on high throughput. In the second stage, throughout drops as each content of cargo is inspected to confirm whether or not any suspicious cargo is in a container. In the final stage, throughput is low as CT devices are used to detect with high certainty any suspicious items.

Hitachi provides equipment and devices in all three of the above stages, making it possible to respond fully with solutions that fit each customer's objectives.

ACKNOWLEDGMENTS

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