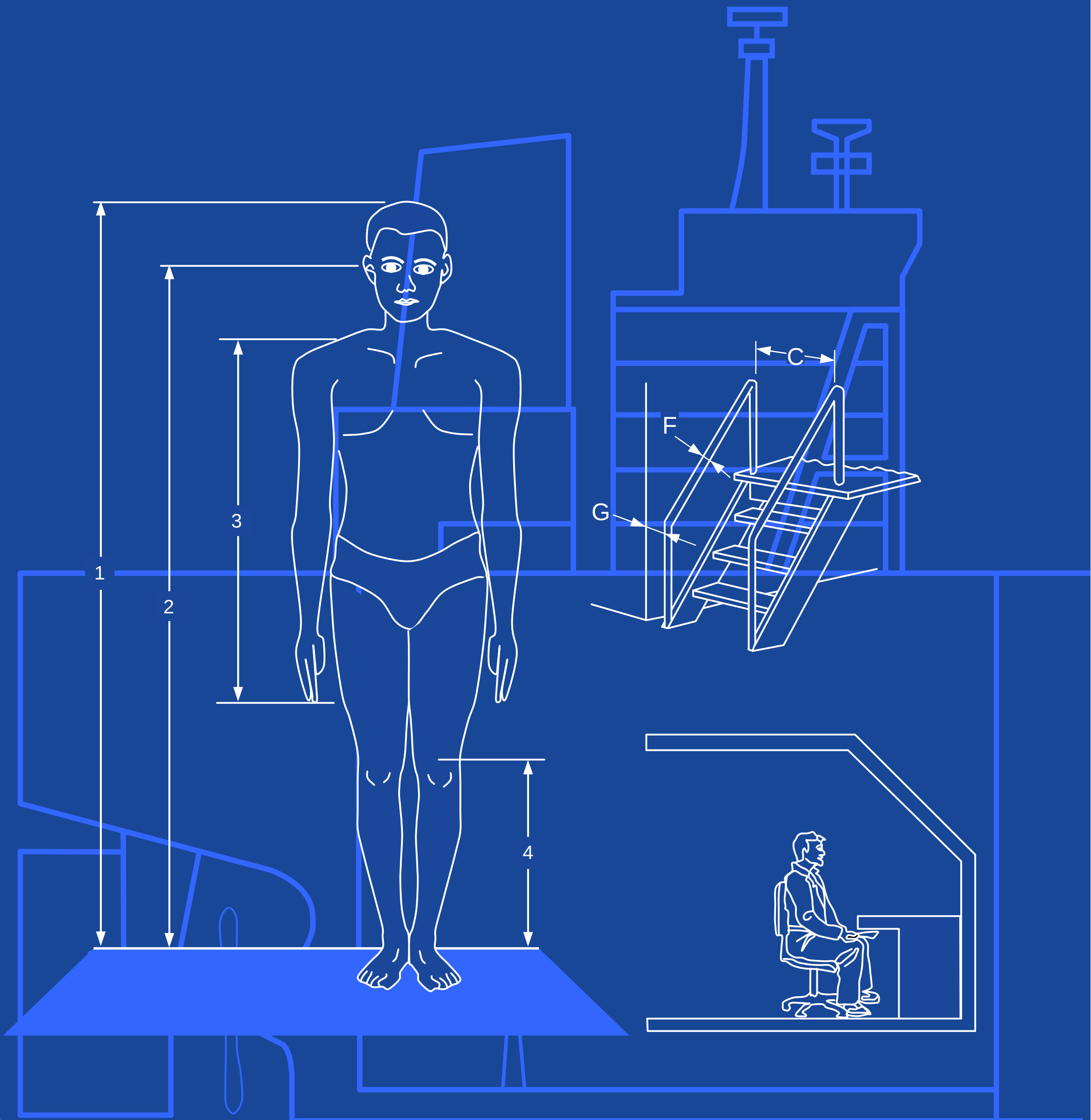
Guidelines for the Prevention of Human Error Aboard Ships

Through the Ergonomic Design of Marine Machinery Systems

March 2010



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GUIDELINES FOR THE PREVENTION OF HUMAN ERROR ABOARD SHIPS

THROUGH THE ERGONOMIC DESIGN OF MARINE MACHINERY SYSTEMS

CONTENTS

1 PURPOSE AND SCOPE

1.1 Purpose

Man-made causes are said to account for 80% of all marine accidents. An accident, however, generally occurs as the result of a combination of multiple causes; therefore, if improvements are made to eliminate these causes, the accident can be prevented. Even in cases where human error is the direct cause of an accident aboard a ship, there exists a part that can be ameliorated by strengthening the training and education of crew members, and a part that can prevent casualty by eliminating other indirect causes including hardware, such as equipment systems. The implementation of the International Safety Management Code (ISM Code), adopted by the International Maritime Organization (IMO) has played an important role in strengthening the training and education of crew members. In addition, the shipping industry, in recent years, has started becoming aware of the importance of human engineering considerations in the design and installation stages of marine equipment systems based on the concept that the design and arrangement of such systems wherein human error does not occur easily, or does not lead to a casualty even if it does occur, is important. The approach being adopted in this field has spread globally. For example, the American Society for Testing and Materials (ASTM) published the "Standard Practice for Human Engineering Design for Marine Systems, Equipment, and Facilities, F1166-07" in 2007, presenting the ergonomic design principles of marine equipment systems. The International Maritime Organization published the Guidelines on Ergonomic Criteria for Bridge Equipment and Layout in 2000 and these guidelines are being applied.

A smooth flow of information between: (1) crew members, (2) equipment systems and (3) crew members and equipment systems, is important for safe operation. The most important ergonomic element of these is the communication between operator and equipment. In other words, the ergonomic design of the interface is important for ensuring a smooth flow of information between man and machine. Ergonomic design is expected to make the working environment of marine equipment systems more effective and safe as well as minimize any reduction in the workability of crew members and occurrence of errors. In addition, the introduction of ergonomic design criteria may contribute to the standardization of controls, indicators, marking, coding, labeling and arrangement plans thus making usage more consistent. As a result, crew members can be easily trained to use equipment systems. Furthermore, much higher levels can be ensured by considering the convenience of maintenance and inspection at the design stage.

These guidelines emphasize the ergonomic aspects of marine machinery systems provided aboard ships, mainly in engine rooms, to ensure that due consideration is given to the mutual interaction between crew members and equipment systems in the design and installation stages.

These guidelines first focus on ergonomics and then give principles on how to implement design considerations for reducing human error. Next, several case studies from the view point of ergonomic design, and preventive design measures are given as reference.

1.2 Scope

These guidelines are anticipated to be used as a tool for considering the ergonomic elements of users by designers at shipyards, and as a reference for determining detailed specifications of ships by ship owners, performing routine maintenance and inspections, and for the operation of ships by crew members.

2 DESIGN CONSIDERATIONS FOR PREVENTING HUMAN ERROR

2.1 Causes of Human Error

As stated in the previous chapter, even if the direct cause of an accident is human error, finding and eliminating the root cause of such error is vital to preventing recurrence. As shown in Fig. 2.1.1, the factors related to the occurrence of human error can be broadly divided into the following: the human element, hardware factors, and organization and management factors. There is also a part that mutually affects all of these factors.

The human element includes awareness, experience, attentiveness, fatigue, desire, body size, body strength, stress, and so on.

Hardware factors include the design of equipment and devices, the layout and configuration of the workplace, related information, working environment, the state of maintenance and repairs, the availability of essential tools and materials availability, and so on.

Organization and management factors include the safety culture of an organization, work allocation, work procedures, communications, etc.

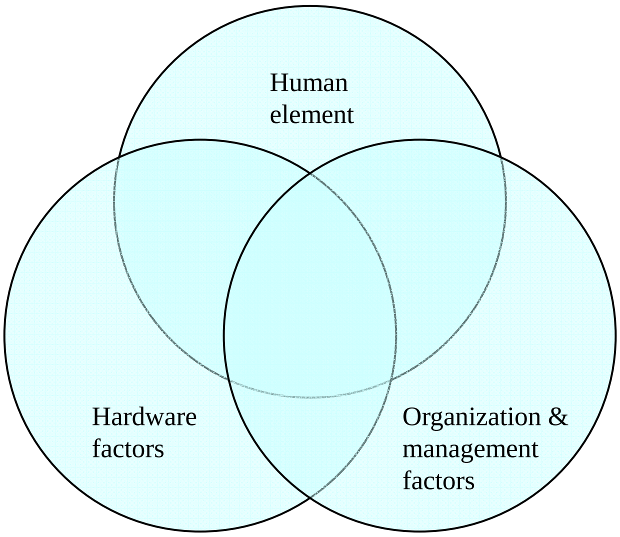


Fig. 2.1.1 Factors related to human error

To prevent human error, the factors mentioned above should be carefully borne in mind, and measures to remove the root causes that can lead to such human error should be adopted.

This chapter mainly focuses on hardware factors; how to reduce human error from the aspects of ergonomic design is described here. Ergonomic design refers to taking into account human knowledge, customs, physical and mental capacities and their limitations in consideration of the flow of work from user aspects such as installation, use and maintenance, and designing machinery or equipment accordingly. The three items that this chapter will primarily focus on are:

(1) Information display
(2) Prevention of incorrect operation
(3) Improvements in operability and working environment

2.2 Information Display

For a human to perform an action correctly, the following need to be implemented correctly: (1) detecting information; (2) understanding such information; (3) selecting an action; and (4) implementing such an action. Of these, "detecting information" is the starting point for correct action and is especially important. Even among the actual causes of an accident, there are many cases where humans are "unaware of" the existence of harm, the process to adopt for a specific task, or the differences in goods. Accordingly, transmitting vital information correctly to the user is extremely important in preventing such an "unaware of" situation. For this, it is also important that key information be displayed in a clear, simple and hard-to-miss manner. The following items (1) to (9) should be especially kept in mind when displaying information.

(1) The information display for preventing harm should not only display “riskiness” in terms of material and equipment properties, but should also display the harm considered in the stages of performing a task at appropriate locations. The display should clearly provide information such as the features of any possible harm and methods for avoiding such.

(2) The information display for identification should not only be identifiable in writing, but if possible, also by differences in color, size or shape. The construction of the display should preferably be such that it cannot be affixed in an incorrect position or in an incorrect direction.

(3) Information related to work, inspection and maintenance procedures should be displayed at working locations as much as possible and not just in manuals.

(4) An alarm information should be presented in such a way that the volume of any aural alarm or the brightness of any visual alarm cannot be mistakenly reduced.

(5) Information for accomplishing one job should be integrated and displayed as one group whenever possible, considering the sequence of work.

(6) The method and material used in a display should be durable so that readability can be maintained. The condition of a display should also be routinely checked so that readability is maintained, and if necessary, it should be replaced or repaired.

(7) Information should be given in a sequence that can be naturally read by all persons. That is, information is to be displayed from top to bottom and from left to right except when the information is set based on a user-specific reading sequence.

(8) Characters, display size, brightness and so on, should be such that the information can be read easily without straining oneself from the work location where such information is necessary.

(9) The method of displaying information including the use of abbreviations should be consistent for the entire ship.

2.3 Prevention of Incorrect Operation

Preventing the incorrect operation of important equipment is vital to preventing accidents. The causes leading to incorrect operation can be broadly divided into the following: a drop in attentiveness, a failure of cognition, memory error, and wrong selection. Even though improvements in education and training, labor conditions, etc., play an important part in ameliorating such causes, measures for improvements related mainly to hardware are described here. The following items (1) to (12) should be especially kept in mind for preventing incorrect operations.

(1) Install controllers at proper locations and in correct directions to reduce the risks of unintended contact.

(2) Ensure adequate resistance to controller operation to prevent any operation due to unintended movement.

(3) If necessary, provide interlocking mechanisms to ensure safety of operation.

(4) If necessary, incorporate operations that check a person's intention within controller operations such as "rotate and press" or "press and rotate."

(5) For important operations, provide covers or other physical barriers to restrict unintended access to controllers.

(6) Controllers throughout the ship which perform similar functions should have consistency in arrangement or direction.

(7) Controllers and equipment are to be installed such that a clear spatial relation exists between the two as far as possible.

(8) Controllers associated by function are to be arranged such that they are concentrated at one location, and sequential operations can be easily performed according to a specific sequence.

(9) The direction of operating a controller should be consistent for a specific function and specific operation. Generally, the direction of operation should coincide with the anticipated direction judging from the positional relationship between operator and controller.

(10) Adjacent controllers should be installed at an appropriate distance to prevent any inadvertent pressing of a button.

(11) Feedback should be provided by light, sound or voice if necessary for operation.

(12) The use of controllers that require delicate operations such as half-press should be avoided as much as possible.

2.4 Improvements in Operability and Working Environment

Operability, which includes things such as ease of operation and ease of access, has a large impact on user safety and maintainability. If operability is poor, the operator may be forced to use an awkward posture during operation. This heightens the risk of an accident occurring and therefore, should be adequately guarded against. It is also important to pay attention to the arrangement and layout of equipment so that adequate space exists for movement of persons and for operation as well as to ensure that there are no obstacles which may interfere with operation. In spaces where crew members are expected to reside for a long period, care should be taken to manage temperature, vibration, noise, ventilation and humidity so that crew members do not suffer from fatigue. Particular care is necessary with regard to the following items (1) to (13) for improving operability and working environment.

(1) Design and installation of equipment should be such that body size of the assumed user is considered and operation can be performed without adopting awkward postures.
(2) Determine the maximum operating force required for operation considering the assumed user's physical strength.
(3) Restrict the weight of heavy objects handled manually considering the physical strength of the assumed user. In principle, hoisting equipment should be installed to handle heavy objects that exceed such restrictions.
(4) As much as possible, stairs and step ladders should be installed in the fore and aft direction of the ship.
(5) Fixed footing should be provided for important valves considering operating frequency so that such valves can be operated easily.
(6) Heavy equipment should be installed considering not only ease of operation, but also their safe removal and re-installation during maintenance and repairs.
(7) Measures to prevent slippage should be provided in passageways, on steps and on floors. Items installed in exposed parts should especially have adequate friction even in the wet condition.
(8) Stays (side plates) of vertical ladders should be extended to an appropriate height from the upper deck or floor surface to enable safe usage.
(9) The step heights of stairs should be consistent throughout the ship, as much as possible.
(10) In principle, any differences in the level of passageways or floors that may lead to stumbling or tripping should be eliminated. Doorsteps (coamings, etc.) especially should not be provided at the edge of the upper floor surface of stairs.
(11) Guardrails should be of adequate height considering the center of gravity of a person and the swaying motions of the ship.
(12) Valves should be installed so that they are closed in cases where the operator rotates a valve in the clockwise direction when looking at the valve rod. Indicators should be provided so that open/close positions are easily understood.
(13) Items with pointed or sharp edges, moving or rotating parts, as well as sources of danger such as high voltage, high/low temperatures, toxic substances, etc., should be identifiable and measures taken to ensure that crew members do not come in contact with any of these items.

2.5 Countermeasure Selection

If ergonomic considerations are taken into account at the design stage, designs can be improved at little additional cost in most cases. In such cases, the inclusion of such considerations may be decided by common-sense judgments.

If measures are anticipated to be expensive, they may be selected based on the criteria of cost benefits using risk assessment methods. Risk assessment is a method for assessing the severity and occurrence frequency of a potential accident, and then determining the priority of countermeasures for preventing such an accident. Generally, risks may be divided into three ranks – high, medium and low – and the following measures adopted:

(1) For instances in the high risk category, countermeasures are necessary to reduce the risk regardless of the cost incurred.

(2) For instances in the medium risk category, appropriate countermeasures should be adopted based on the criteria of cost benefits.

(3) Instances in the low risk category are to be dealt with through continuous improvement.

Quantification of risk is not an absolute necessity and may be decided based on agreement with concerned parties as shown in Fig. 2.5.1. In this figure, the red zones are high risk areas, the yellow zones are medium risk and the gray zones are low risk areas.

			Severity				
			A	B	C	D	E
			Minor damage, no injury	Minor damage, minor injury	Reduced speed operation, medium level injury	Damage with requiring towing, major damage to system, serious injury	System fully damaged, fatalities or severe permanent disability
Occurrence frequency	5	Several cases occur on board ship in a year					
	4	Several cases occur in-house in a year					
	3	Has occurred in-house					
	2	Have heard about it occurring in the industry					
	1	Have not heard about it occurring in the industry					

Fig. 2.5.1 Example of risk assessment matrix

The analysis of cost benefits is meant to be used to decide the judgment standards related to the selection and adoption of countermeasures after estimating the costs required for such measures and effects such as the preservation of life and property brought about by adoption of such measures.

However, there are items that are difficult to assess by quantifying costs and effects due to such measures,[*] such as improvements in work efficiency or improvements in the social assessment of the company; therefore, adequate care needs to be taken when implementing quantitative assessment.

D. Beevis, I. M. Slade, "Ergonomics-costs and benefits", Applied Ergonomics 34, 2003, pp. 413-418.

3 EXAMPLES

When formulating safety measures for the future, it is vitally important to learn from the examples of the past. It is important not only to merely focus on individual examples, but also to add system-wide considerations, and to horizontally develop measures to prevent similar accidents. This chapter gives reference measures for design and introduces examples of improvements from the perspective of ergonomic design. Standards that can be used as reference for formulating countermeasures are also given.

3.1 Grounding of a Cargo Ship

(1) Overview[1)]

A general cargo vessel traveling on a river strayed from its course and ran aground. The vessel was being navigated under the pilot's instructions when the accident occurred.

The pilot navigating the ship in the manual mode had initially requested the master standing adjacently to change the steering mode to RIVERPILOT mode. The master, as instructed, changed over the mode selector switch (Fig. 3.1.1(A)). However, the ship did not respond even though the Follow-up/Riverpilot lever (Fig. 3.1.1(B)) was used. After the mode was returned from steering mode to manual mode, steering functions were restored, but there was insufficient time for the rudder to respond, and the vessel ran aground. Later an investigation was carried out, and when the prossibility that the master had inadvertently engaged AUTOPILOT and not RIVERPILOT as requested by the pilot was pointed out, the master denied having made such an error.

The mode of steering was controlled by a three way position selector switch, as shown in Fig. 3.1.1(A). An overview of the modes is given below.

MANUAL (Up): In this mode, the vessel can be steered by using a joystick lever. The rudder will move in response to the movement of this lever. In this mode, it is necessary to frequently refer to the rudder angle indicator (RAI) in order to confirm the rudder angle position.

FOLLOW UP (Down): In this mode, steering is accomplished using the Follow up/Riverpilot lever (Fig. 3.1.1(B)). The rudder will move in respose to a helm order until it reaches the selected angle. In this mode, however, the "rate-of-tiller" can be selected by using the button on the Autopilot control console panel (Fig. 3.1.1(C)), thus enabling follow up at a particular rate to be accomplished. This follow-up mode at a particular rate is normally called RIVERPILOT mode.

AUTOPILOT (Right): When this mode is selected, the current course is automatically maintained.

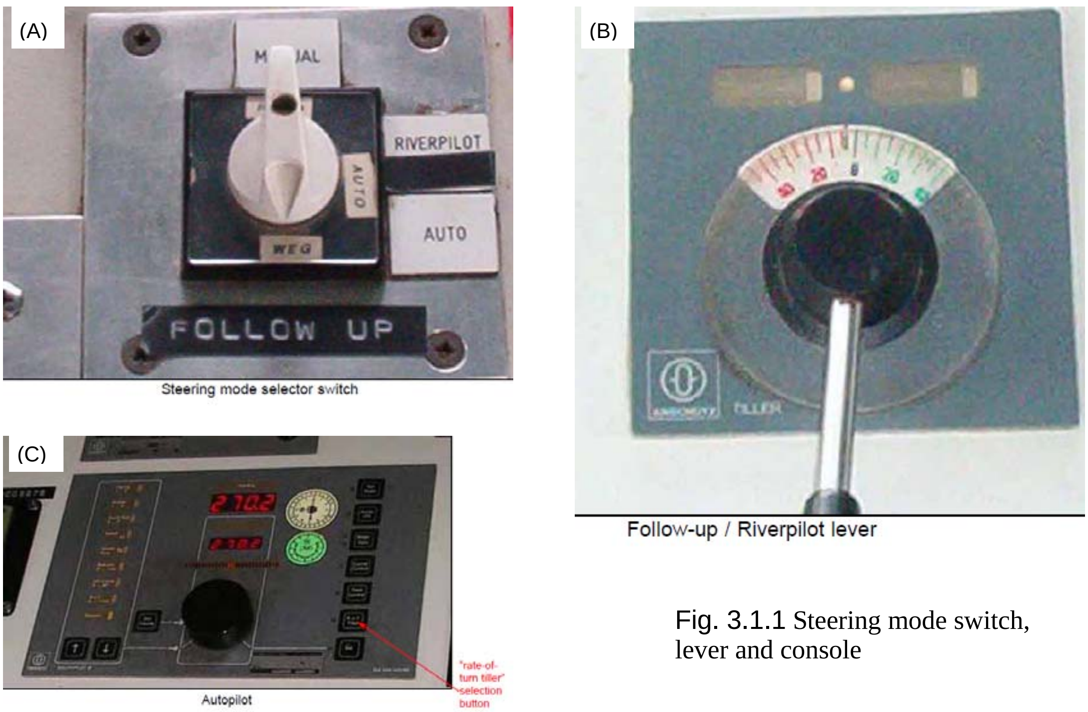


Fig. 3.1.1 Steering mode switch, lever and console

1) Source: Marine Accident Investigation Branch of UK, Report on the investigation of the collision of the general cargo vessel Orade with the Apex Beacon, River Ouse, 1 March 2005.

(2) Discussion

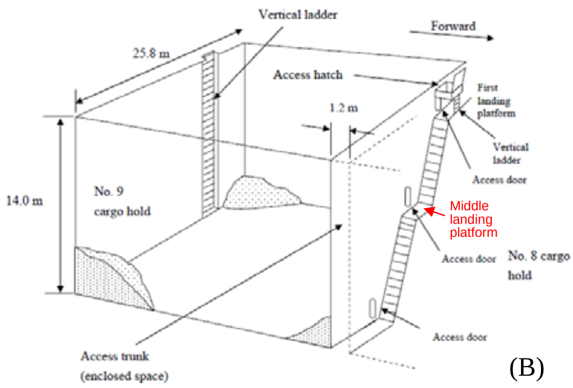
Although the operation of the RIVERPILOT mode was understood by both the pilot and the master, and it was one of the steering modes being used, the indication on the switch position display label shown in Fig. 3.1.1(A) was inadequate; a hand-made label had been affixed. Moreover, the hand-made label had been affixed incorrectly at the position of the AUTOPILOT mode; so even if the selector switch was turned in this direction, only the AUTOPILOT feature was available.

As design measures, the following may be considered: (1) Affix labels for steering mode selector switches that match actual steering operations (see ASTM F1166-07 15.4). (2) Check that if a crew member has been forced to make and provide the labels for the controller and indicator, such lables have been affixed at the correct positions. (3) Give voice feedback for operation (selected steering mode).

3.2 Lack of Oxygen

(1) Overview[1)]

On 16 November 2006, a bulldozer was lowered into the hold to collect the remaining wood pallets at the end of the cargo hold so that they could be unloaded. While an ordinary seaman and a bulldozer operator were descending the enclosed stair trunk (Fig. 3.2.1)A)), the seaman collapsed at the floor of the cargo hold and the bulldozer operator collapsed at the middle landing platform (Fig. 3.2.1(B)) of the staircase. Both men collapsed because they were overcome by a lack of oxygen. The accident was soon discovered, and the two persons were rescued, but the end result was that the seaman died and the bulldozer operator was seriously injured in the incident.



(B)

Fig. 3.2.1 Enclosed stair trunk and ladder landing platform

(2) Discussion

The warning sign "Low Oxygen Risk Area" had been painted on the tops of the access hatches of all enclosed stair trunks. At the time of the accident, however, these signs had faded and the wording could not be read. The display of warning information and maintaining its readability etc., are very important from the standpoint of safety.

As design measures, the following may be considered: (1) The material used for such signs should be able to withstand usage conditions, or its readability should be maintained by performing suitable maintenance (see ASTM F1166-07 15.1.11). (2) If there is any risk of overlooking signs, which may lead to significant danger, then signs should be put up at several locations so that information is properly conveyed.

1) Courtesy: Alert!-The International Maritime Human Element Bulletin, Issue No. 16 January 2008. Report of Investigation into the fatal accident on board the Hong Kong Registered ship “Saga Spray” on 16 November 2006.

3.3 Steam Burns

(1) Overview[1)]

On 10 April 2007, two crew members entered the funnel (Fig. 3.3.1(A)) of a container ship at anchor, went to the top platform (Fig. 3.3.1(B)) and started painting the main engine exhaust pipe in the funnel. Exactly at that time, an operating test of the boiler safety valve (Fig. 3.3.1(C)) was carried out for a classification society Boiler Survey, and steam was discharged from two safety valves for a duration of about 5 seconds at a pressure of 1.1 MPa. The result was that steam was directly discharged onto one of the crew members who suffered severe burns.

The two persons were aware of the risks of main engine exhaust, and had checked that the main engine was not working. However, they did not know that the pipe bent to 90 degrees and 0.5 m above the platform was a vent pipe of the boiler safety valve.

Fig. 3.3.1 Funnel, platform in funnel and boiler safety valves

1) Source: Australian Transport Safety Bureau, Marine Safety Investigation Report No. 239, August 2007.

(2) Discussion

Although frequent operation of the boiler safety valve does not occur, it should be borne in mind that it can activate at any time. For this reason, warning information must be displayed if the area near the boiler safety valve exhaust port vent pipe is likely to be accessed. Instructions to check that the boiler is not working at the time of access should also be given to any crew members scheduled to work in the vicinity.

As design measures, the following may be considered: (1) Display danger or warning labels at the vent pipes of the exhaust openings of boiler safety valves (see ASTM F1166-07 15,11.8.1). (2) Extend the vent pipes of the exhaust openings of boiler safety valves to outside of funnels to eliminate the source of danger.

3.4 Damage to Air Inlet Valve Seat

(1) Overview[1)]

During voyage, a rise in exhaust temperature and a drop in pressure in the No. 4 cylinder of diesel engine driving generator were found. The generator was stopped and inspected. The inspection showed that the intake valve had been incorrectly inserted on the exhaust valve side, and that the intake valve seat was damaged (Fig. 3.4.1).

The intake valve and exhaust valve have similar shape, and their sizes are almost the same. So, except for a slight difference in color due to the difference in materials used for each valve, it is difficult to differentiate the valves visually.

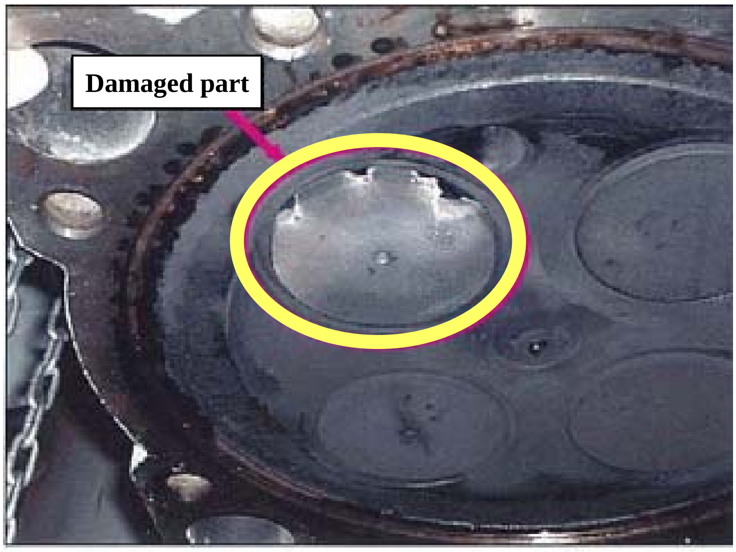


Fig. 3.4.1 Damaged valve seat of air inlet valve

(2) Discussion

Mistaking one item for another, especially in the case of items that are similar, is a frequently occurring human error; adequate care is necessary to prevent such errors.

As design measures, the following may be considered: (1) Adopt measures such as stamping the items to easily distinguish exhaust valves and intake valves. (2) Use valves of different shape or size to prevent the insertion of the wrong valve.

1) NYK LINE Safety & Environmental Management Group, Case Studies: Ship Engine Trouble

3.5 Cargo Oil Spill

(1) Overview[1)]

On 19 January 1994, the No. 5 port side and starboard side wing tanks of a tanker were being filled. At that stage, the officer of the watch closed the filling valve to the No. 5 port side wing tank. The result was that cargo oil with a flow rate of 1200 m^3/h flowed into the No. 5 starboard side wing tank and an overflow situation occurred (a plume of oil sprayed about five meters into the air from the P/V breaker valve). Because of over-pressure, the tank bulkhead between the No.4 starboard side wing tank and the No. 5 starboard side wing tank ruptured (Fig. 3.5.1(A)).

The tank level was continually monitored, and could be checked by computer as shown in Fig. 3.5.1(B) as well as by a digital display unit. However, although a combination of arbitrary tanks could be monitored on the computer, only one selected tank could be monitored on the digital display unit at a time. The information displayed was not by actual tank number but was by the channel number on the digital display unit.

The high high level alarm of each tank was set at 98% of the tank capacity, and it could not be changed. When an alarm activates in this system, the audible alarm on the main alarm panel of Fig. 3.5.1(B) is canceled by pushing a button on the same panel. Subsequently, the key on the computer remote from the panel must be pressed to accept the alarm.

As long as the alarm is not accepted, it continues to flash on the computer screen, but other audible alarms are OFF without exception. In this example, an alarm that had not been accepted earlier remained, so the audible level alarm did not activate; moreover, the level alarm flashing on the computer screen had very small characters and it could not be seen from the position of the officer of the watch.

1) Source: Australian Transport Safety Bureau, Marine Safety Investigation Report No. 63, November 1994.

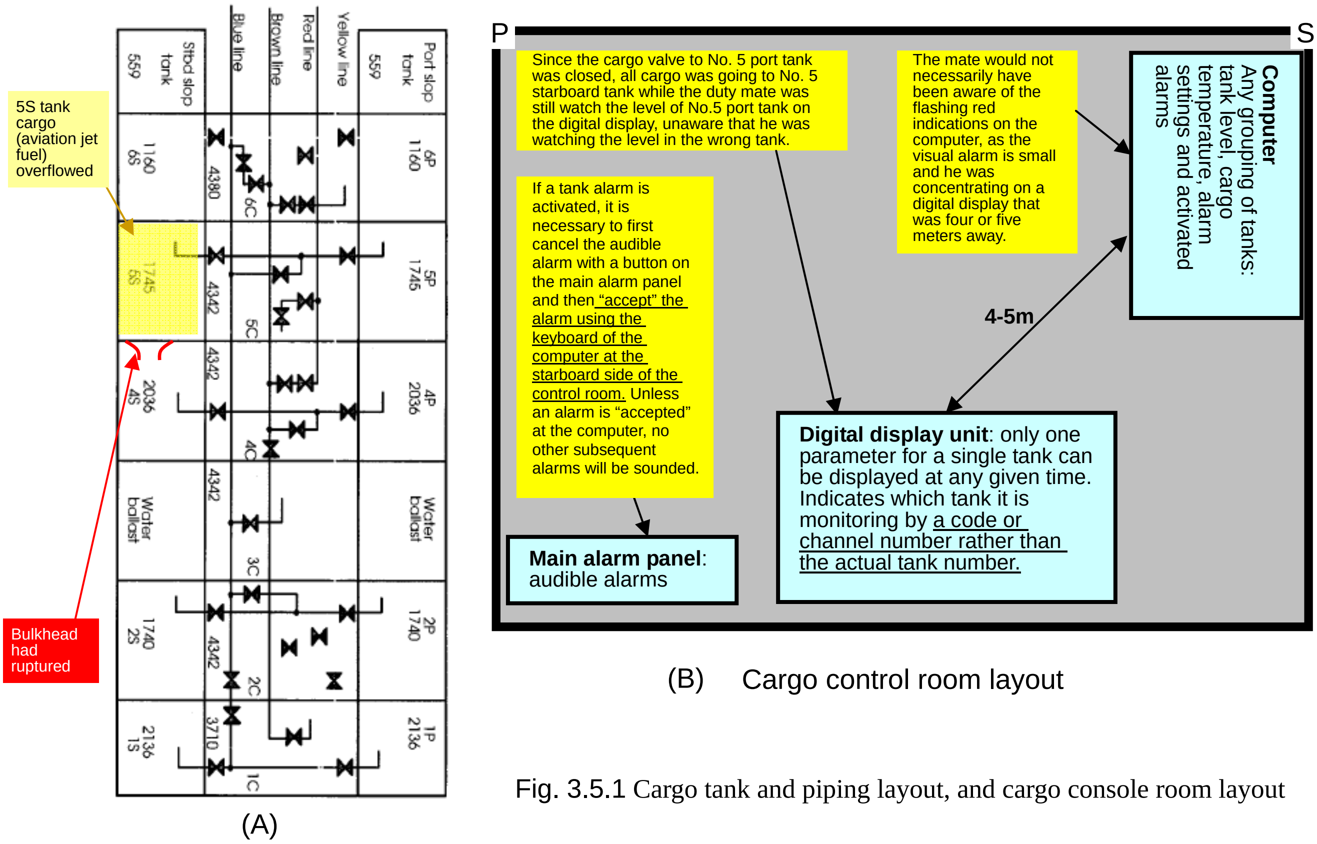


Fig. 3.5.1 Cargo tank and piping layout, and cargo console room layout

(2) Discussion

In this example, the alarms related to cargo operation controls were not integrated at one location, and the one person in charge found it difficult to monitor all the indicators. Moreover, the tank level display did not correspond directly with the tank number; thus adversely affecting the correct understanding of the situation.

As design measures, the following may be considered: (1) All visual displays related to cargo controls including alarms should be concentrated at one location as one group (see ASTM F1166-07 6.2.6). (2) The tank level display should correspond to the actual tank number.

3.6 Collision of Tanker with Jetty

(1) Overview[1)]

The control of the podded propulsion system for a product tanker was lost when approaching a jetty and the vessel collided with said jetty. Both the ship and the jetty suffered severe damage as a result of this accident (Fig. 3.6.1). The ship's podded propulsion system was designed so that if the main control system failed, an audio-visual alarm would activate and the system would automatically switch over to a backup system. However, since the ship was navigating at night when the accident occurred, the visible alarms were darkened and the audible alarms were inadequate to attract attention. For this reason, the handing over of control of the podded propulsion system to the backup system was discovered too late and there was not sufficient time to undertake avoidance measures.

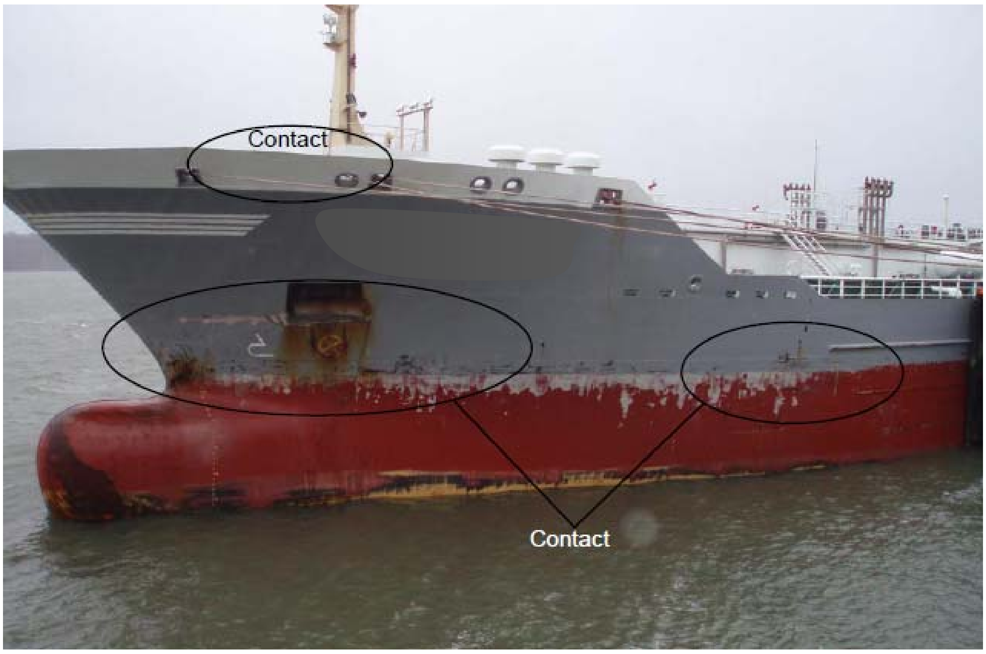


Fig. 3.6.1 Ship that suffered the accident

(2) Discussion

Undetected breakdowns of alarms or states in which alarms are not recognized even when they are activated are extremely dangerous. It is vitally important to confirm that alarms possess their inherent functions through normal inspections and checks and by design considerations.

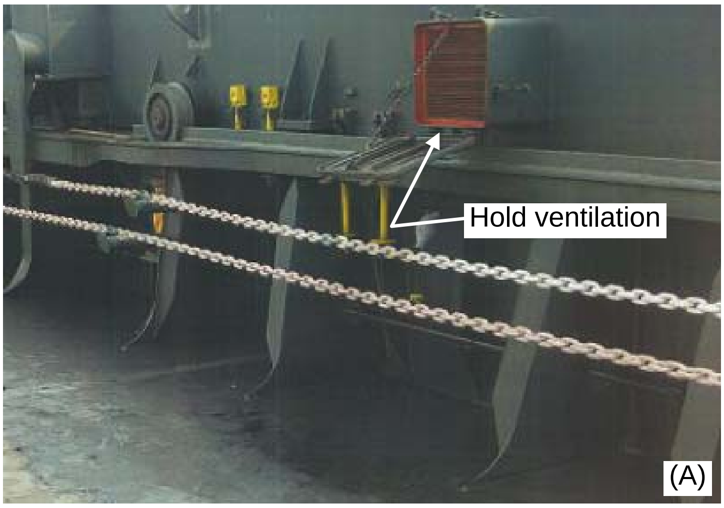
As design measures, the following may be considered: (1) Normal status displays should not be combined with visual alarms. That is, normal status displays and alarms should be separated. By doing so, if necessary (for instance, for night navigation), the visual alarms will be able to operate normally even when the normal status displays are darkened. (See ASTM F1166-07 7.2.3). (2) Audible alarms should be such that they can be distinguished from other alarms and noises (see ASTM F1166-07 7.3.7.2).

1) Source: Marine Accident Investigation Branch, UK, Report on the investigation of the loss of control of product tanker Prospero and her subsequent heavy contact with a jetty at the SemLogistics terminal, Milford Haven, 10 December 2006.

3.7 Damage to Cargo Hold during De-ballasting

(1) Overview

In a bulk carrier, the ballast water in the No. 6 ballast-cum-cargo hold was de-ballasted, but the vent opening shown in Fig. 3.7.1(A) was not opened. About an hour later, a crew member became aware that the vent opening was closed. During this one-hour period, damage occurred to the hatch coaming and the cross deck, which both became bent because of the negative pressure in the cargo hold. After the accident, the ship’s owner decided to display the label "Confirm that all ventilation covers/ manholes are OPEN before starting the ballasting/ de-ballasting operations" on the ballast control console, as shown in Fig. 3.7.1(B).



WARNING -CARGO HOLD BALLAST
Confirm that all ventilation covers/manholes are OPEN
Before the start of Ballasting / Deballasting operations (B)

Fig. 3.7.1 Hold vent opening

(2) Discussion

Displays to prevent risks are not only important for risks related to equipment (for instance, rotating bodies), and properties of material (for instance, toxicity), but are also important for warning about risks during work stages, and signs should be displayed at appropriate locations.

As design measures, the following may be considered: (1) The label "Confirm that all ventilation covers/ manholes are OPEN before starting the ballasting/ de-ballasting operations" should be displayed on the ballast control console. (2) The de-ballasting procedure, including check for opening the vent opening, should be displayed in bulleted format on the ballast control console. (3) An interlocking mechanism should be provided that ensures ballasting/de-ballasting cannot be carried out when the vent opening is in the closed condition.

3.8 Strainers for Unloading and Loading Cargo Exchanged by Mistake

(1) Overview

An LNG carrier berthed at an unloading terminal. The deck seamen moved to the port side manifold, and removed the strainer from its storage box to prepare for the unloading of cargo, and started to fit the strainer. The person in charge became aware that the shape of the strainer was different from the type normally used, and had the second officer check the specifications. However, the response from the second officer was that there were no problems, so the person in charge fitted the strainer without further confirmation. After completing the preparations, the cargo transfer was started at the full rate of 12,000 m^3 /h. A little while later, the person in charge again asked the Chief Officer about the specifications of the strainer. The Chief Officer, a bit suspicious, performed the check on site, and discovered that the strainer for loading cargo had been fitted instead. The Chief Officer immediately reported the incorrect fitting of strainer to the terminal side, received the approval of the terminal side and reduced the unloading flow rate. Subsequently, all concerned personnel had a discussion, decided to suspend the cargo unloading work, and stopped the cargo pumps. The time of departure from the port was delayed by six and a half hours as a result of suspending the unloading operation because the wrong strainer was fitted.

At the subsequent investigation, the direct cause of this accident was found to be the storage of the strainer for loading and the strainer for unloading in wrong storage boxes. That is, the strainer used for loading was stored in the storage box for unloading strainer, and the strainer used for unloading was stored in the storage box for loading strainer. Normally, since only one strainer is taken out at the unloading site, such errors in storage were not anticipated; however, it was found that maintenance work on the relevant strainer storage boxes had been performed about three months prior to this incident. At that stage, all strainers had been removed from the boxes, and it is highly probable that the strainers were replaced in the wrong boxes.

On the other hand, as shown in Fig. 3.8.1, the external appearance of the strainers for loading and unloading do not resemble each other so much that distinguishing one from the other is difficult. However, if the crew member sees only one of the two strainers, it is highly probable that the crew member does not have the knowledge to judge whether it is a strainer for loading or a strainer for unloading. An arrow indicating the direction of flow had been stamped on the handle of the strainer, but there was no name and name tag indicating its application. It is difficult to distinguish whether the strainer is meant for loading or for unloading from the direction of the arrow alone, especially if one is not particularly focused on identifying it.

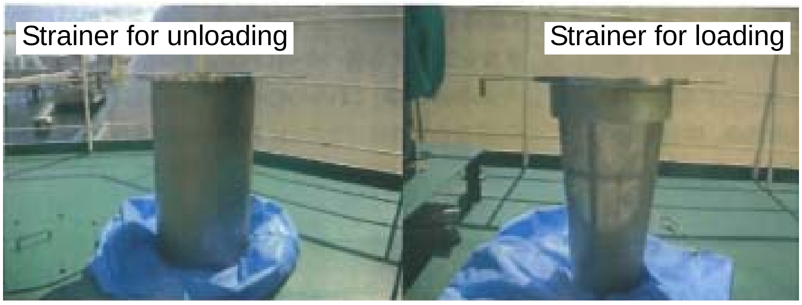


Fig. 3.8.1 Strainers for loading and for unloading

After the incident, the ship owner had a name tag affixed to each strainer as shown in Fig. 3.8.2, to distinguish the strainers easily, and also had a poster displayed on the manifold warning against fitting the incorrect strainer. To prevent storing the wrong strainer in the storage box on the opposite side, the storage boxes for loading and unloading strainers were distinguished by using different colors. Furthermore, the storage box for strainer for loading was modified considering the differences in shape of the respective strainers used for loading and unloading, so that the unloading strainer could not be stored by mistake in the storage box meant for strainer used for loading.

Fig. 3.8.2 Name tags for distinguishing strainers

(2) Discussion

The basic concepts to prevent mistakes in installing strainers are awareness and display of information by clearly distinguishable labels. Since color coding is intuitive and helps in easy identification, it is an effective method to prevent errors and should be implemented as much as possible.

As design measures, the following may be considered: (1) Display name tags for distinguishing items by color coding. (2) Modify the storage box for the strainer for loading and prevent physical storage in the wrong box. (3) As much as possible, use a construction so that the wrong strainer cannot be fitted on site. (4) Another possibility is to use a strainer with combined loading and unloading functions.

3.9 Leakage of Carbon Dioxide Gas used for Fire Extinguishing

(1) Overview[1)]

The chief engineer of a ship was conducting routine monthly checks of the fixed type carbon dioxide fire fighting systems in the engine room. The sleeve of his arm inadvertently got caught in the pilot CO_2 pilot bottle isolating valve. Unaware of this, the chief engineer had set the isolating valve to the partially open condition. In this condition, he opened the pilot CO_2 bottle pressure gauge isolating valve in order to confirm the pressure of the pilot CO_2 bottle. The activator of the main CO_2 bottle activated, the main CO_2 bottle started becoming pressurized, and CO_2 gas started leaking from the neck seal (Fig. 3.9.1) of one of the bottles. Fortunately, the chief engineer became aware of the CO_2 gas leak and took action, so the leak did not lead to a major accident.

Fig. 3.9.1 CO_2 bottle

(2) Discussion

The cause of a piece of equipment becoming activated by mistake as a result of unintentional contact is easy to visualize, but considerations for preventing such occurrences in the design or installation stage are generally inadequate. For important control equipment, it is essential to predict the results of physical contact with the item then formulate and implememt adequate preventive measures.

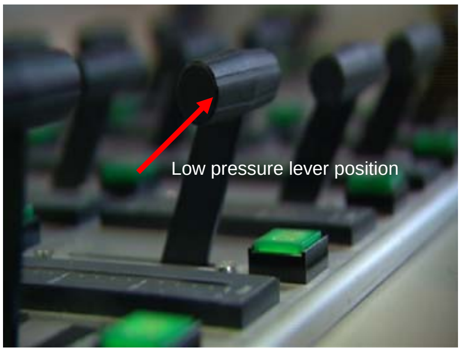
As design measures, the following may be considered: (1) Select appropriate locations and directions for CO_2 bottles in order to prevent unintentional physical contact with such bottles (see ASTM F1166-07 5.1.9). (2) Incorporate positive operations such as "press and twist."

1) Source: Marine Accident Investigation Branch of UK, Safety Digest 1/2006.

3.10 Chemical Spill

(1) Overview[1)]

Fig. 3.10.1 shows an unloading pump pressure control lever onboard a chemical tanker. The lever of this control device is slid forward or aft to start/stop the pump and adjust outlet pressure. Based on instructions from shore during unloading work on the ship, the person in charge lowered the pump pressure tentatively, but another crew member accidentally switched the lever to high pressure when he placed a measuring instrument on the panel. The result was that the shore unloading pipe ruptured, cargo with chemical substances spilled, and enormous cost was incurred in cleaning up the spill.



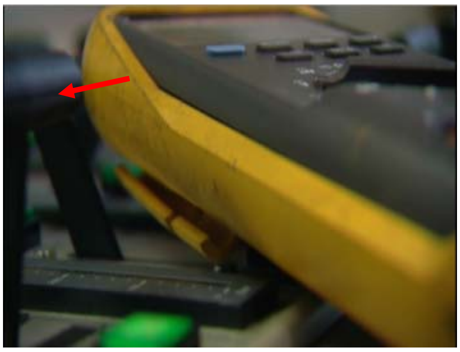


Fig. 3.10.1 Cargo pump pressure control lever

(2) Discussion

This example is similar to example 3.9. The cause was the unintentional movement of a lever that led to a mistake in the operation of equipment. Although the cause may be considered simple, adequate precautions are necessary.

As design measures, the following may be considered: (1) Protect the pump pressure control lever by a cover or some other physical barrier. (2) Provide adequate resistance to operate the pump pressure control lever. By doing so, even unintentional light contact will not cause the lever to be moved (see ASTM F1166-07 5.1.9). (3) Provide a locking mechanism for the pump pressure control lever.

1) Courtesy: UK P&I CLUB, images are extracted from the club's video footage-NO ROOM FOR ERROR with permission

3.11 Collision of Dive Support Vessel with Breakwater

(1) Overview[1)]

As shown in Fig. 3.11.1, a dive support vessel was in the process of entering the harbor. The master intended to switch from the "autopilot" mode to the “manual control” mode as the vessel made its way into the harbor, but a later investigation showed that he had pressed a different switch. The master steered the vessel assuming that he had already switched over to "manual control mode", but the vessel did not respond and collided with the breakwater.

Wrong Switch – Big Trouble

Narrative

A 9,000gt dive support vessel was in the process of entering harbour. Prior to entry, the master lined up the approach using the autopilot. He then switched to “manual control” as the vessel made her way in. Both stern azimuths appeared under control, since the vessel and heading were acting as desired.

However, as the vessel approached the breakwater, it became apparent to the master that she was setting to the north of the desired track. He then adjusted the vessel’s head with the use of the stern azimuths. The vessel did not respond, and continued to be set onto the breakwater. He then tried using the bow thrusters, but they were ineffective. In a last ditch attempt to prevent the vessel colliding with the breakwater, the master put the azimuth thrusters astern. However, his actions failed to prevent the vessel from making heavy contact with the breakwater on her starboard quarter. As a result, both the vessel and the breakwater overhang sustained damage.

Once control of the vessel was regained, it was discovered that the master had mistakenly pressed the wrong switch for “manual control”. This left the vessel in the autopilot mode as she entered the breakwater, and meant that she would not respond to his alterations of helm.

Once the error was detected and rectified, the vessel proceeded into harbour safely.

Fig. 3.11.1 Wrong switch

(2) Discussion

Other examples also have been reported wherein the wrong adjacent steering switch was pressed almost leading to a major accident. Similar to pressing the door opening/closing button by mistake, which occurs frequently in an elevator, there should always be an awareness of the danger of pressing a wrong adjacent switch.

As design measures, the following may be considered: (1) Differences should be provided in size, dimensions, color or sense of touch for important switches, such as a steering mode selector switch, so that control functions are clearly distinguished (see ASTM F1166-07 5.5). (2) Design should be such that operation is confirmed by voice.

1) Source: Marine Accident Investigation Branch of UK, Safety Digest 1/2005.

3.12 Elevator Shaft Accident

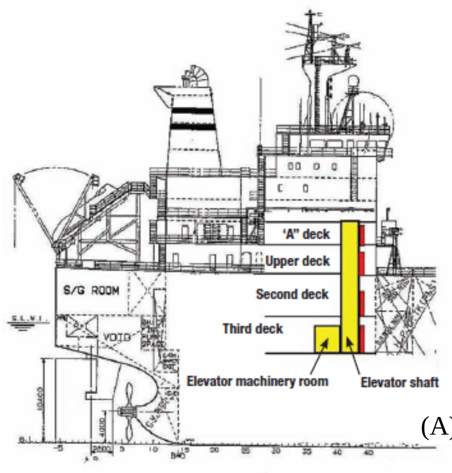
(1) Overview[1)]

On 17 January 2007, a problem was reported in the ship's elevator (see Fig. 3.12.1(A)) in a tanker berthed for discharging cargo. Investigation by the electrician and the third engineer revealed that the problem was with the second deck landing door.

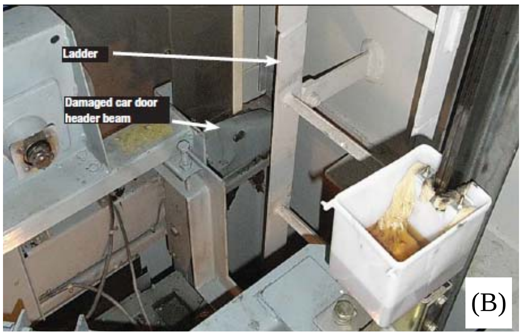
To perform repairs, the second engineer and the electrician firstly confirmed that they had placed the sign "Do not operate" at the entrance of the elevator on all the floors, and then went to the second deck and opened the elevator door. After both persons finished their examinations, the electrician stepped on the ladder (Figure 3.12.1(B) on the right) in the elevator shaft, and told the second engineer to close the doors.

However, immediately after the doors closed, the elevator car started traveling upward; the electrician was trapped between the elevator car and the ladder, and resulting in his death.

The elevator car travelled upward because somebody had pushed the button; this was confirmed from the records of the microprocessor control unit. That is, somebody had ignored or had overlooked the "Do not operate" sign, and had pressed the button.



(A)



(B)

Fig. 3.12.1 Elevator and vertical ladder in the elevator shaft

1) Source: Australian Transport Safety Bureau, Marine Safety Investigation Report No. 235, June 2007.

(2) Discussion

Reports of accidents such as carelessly removing the stopped condition of an elevator by using the emergency stop button have been reported elsewhere, as well. Foolproof measures are necessary because this type of accident can have disastrous results.

As design measures, the following may be considered: (1) Display of signs indicating "Under Repair/Inspection" should always be placed at the call button on each floor when repair/inspection is being performed. (2) Covers should be installed on call buttons to prevent incorrect operation (see ASTM F1166-07 5.1.9 and Fig. 3.12.2). (3) Provide a stop button especially for maintenance and inspection. The design should be such that the stop reset of this button can be made only by the operator who has stopped the operation.

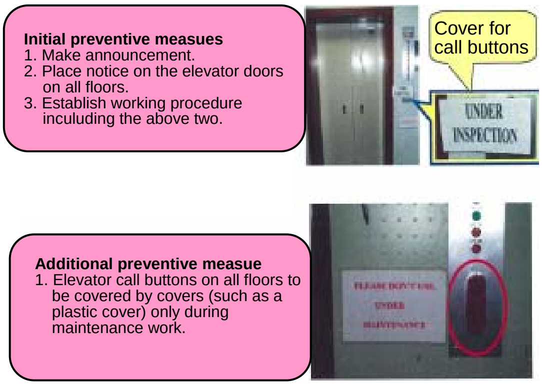


Fig. 3.12.2 Example of measure against incorrect operation of elevator by shipping company

3.13 Fall of a Fast Rescue Craft

(1) Overview[1)]

A newly-built 165-m long Ro-Ro vessel was undergoing various commissioning tests alongside. One of the tests was to launch a fast rescue craft (FRC) from a davit (see Fig. 3.13.1(A)) and to recover it. The FRC was connected by a single wire to the davit through a quick release hook (Fig. 3.13.1(B)). The hook was operated in the “off-load” mode so that when the FRC was lowered into the water, the hook automatically released once the weight of the FRC on the hook was reduced to less than 12 kg (after landing in the water).

In accordance with standard operating procedure, the FRC was lowered down to the embarkation deck where two of the crew members boarded it. From here, the FRC was lowered to 1 m above the waterline and the crew prepared for the final lowering and release of the hook.

At a height of 1 m above the waterline, the crew indicated to the winch operator that the FRC could be lowered into the water. The FRC then started to lower and almost immediately stopped. At this point, the quick release hook opened and the FRC fell into the water.

The slow speed operation of the winch was 0.6 m/s and the high speed was 1.3 m/s; these two modes were realized by a two-speed motor. The motor speed was controlled by one push button (Fig. 3.13.1(C)); when this button was partially depressed, low speed was selected; when fully depressed, high speed was selected.

Investigation later revealed that when the davit juddered, the hook changed to the off-load mode and automatically released the boat. Moreover, when the winch motor stopped (button released) from the high-speed condition (fully depressed), the davit assembly juddered considerably. This was also confirmed from tests. It was considered probable that the winch operator had depressed the button fully so the FRC was lowered in the high speed condition and then stopped. Therefore, the davit juddered considerably, and it is thought that this movement in the davit arm could have been sufficient to cause the off-load release hook to open automatically.

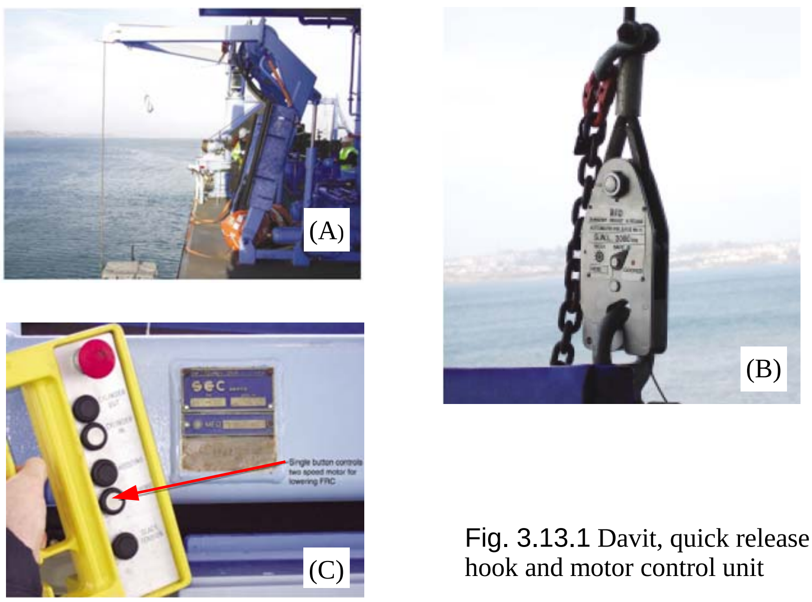


Fig. 3.13.1 Davit, quick release hook and motor control unit

1) Source: Marine Accident Investigation Branch of UK, Safety Digest 3/2006.

(2) Discussion

This accident is presumed to have occurred because of the change from high speed to an abrupt stop, causing vibrations which resulted in the off-load condition. It is also concluded that an operating mode not originally anticipated occurred because of the incorrect operation of the push button. A push button having multiple functions depending on how far the button is depressed is not recommended because buttons with such specifications are likely to cause errors.

As design measures, the following may be considered: (1) The control device operation should be checked not only in the assumed operating modes but also in all operations that can be anticipated (for instance, from high speed to abrupt stop as in this example). (2) The motor switch should be controlled by a rotation selector switch (see ASTM F1166-07 5.6.7.1).

3.14 Engine Room Fire

(1) Overview[1)]

An engine room fire broke out onboard a cargo ship. The fire caused major damage to the engine room machinery and equipment (Fig. 3.14.1(A)). The cause of the fire was determined to be the loosening and displacement of a securing plate for a main engine fuel pump inlet pipe. The fuel pipe became displaced because of this, and fuel at a pressure of 5 bars and a temperature of 100˚C spewed out, came into contact with the surface of an exhaust gas pipe at a high temperature, and ignited.

Investigation after the accident revealed that the fuel inlet pipe securing plate was incorrectly fitted – the plate was reversed. (See Fig. 3.14.1(B)). Owing to this mistake, the cap screws were only screwed into the fuel pump block by 2 and 1⁄2 turns, as opposed to 8 and 1⁄2 turns when correctly fitted. It is likely that the securing plate worked loose due to vibration and became displaced.

The fuel pump had been replaced five months earlier; during this replacement, it is likely that the plate was incorrectly fitted in the reversed direction.

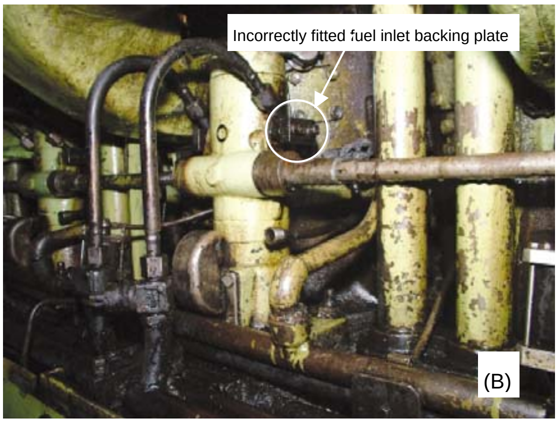


Fig. 3.14.1 Burnt-out engine room and mistakenly fitted securing plate for securing fuel inlet pipe

(2) Discussion

Fitting the wrong parts or fitting parts in the wrong direction or wrong position frequently occurs during the replacement or restoration of opened-up equipment or machinery. It is likely that in this accident, the front side of the securing plate was counterbored (if done correctly), and screws could be tightened up to 8 turns. However, since the front and rear sides were reversed, the number of turns of the screw became smaller by an amount corresponding to the depth of the counterbored part. To prevent similar accidents, measures are necessary to identify parts and to confirm their correct position and direction. It is also important to design parts with shapes so that they cannot be fitted in the reverse direction.

As design measures, the following may be considered: (1) Identify the front face of the securing plate by stamping and so on. (2) If front and rear sides are reversed, the securing plate and the counterbore depth may be adjusted so that the screw cannot be turned to ensure by shape that a mistake does not occur when re-fitting the part. (See ASTM F1166-07 17.6.1.2)

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1) Source: Marine Accident Investigation Branch of UK, Digest 2/2006.

3.15 Breakdown of Connecting Rod together with Engine Crankcase

(1) Overview[1)]

While alongside, a "bang" was heard in the main machinery space of a Ro-Ro ferry, and soon after, the fire alarm activated. Checks revealed that a fire had broken out near the diesel-driven generator during its operation.

After extinguishing the fire, damage was found in the No. 6 cylinder unit, as shown in Fig. 3.15.1. This was a so called "breakdown of the connecting rod together with the crankcase" accident.

The cause of the accident was as follows: since the lower side shell of the crankpin bearing was fitted on the upper side and the upper side shell was fitted on the lower side, the supply of lubricating oil to the crankpin bearing and the supply of cooling oil to the lower part of the piston were prevented. This caused the piston to heat up, and become stuck to the cylinder liner. In this condition, the crankshaft continued to rotate, so the bolts at the big end of the connecting rod fractured, resulting in the breakdown of the connecting rod together with the crankcase.

Fig. 3.15.1 Damaged piston liner and connecting rod

(2) Discussion

Similar to example 3.14, this accident also occurred due to a mistake in the re-fitting of a part during the restoration of opened-up machinery. To prevent similar accidents, measures are necessary to identify parts and to confirm their correct position and direction. It is also important to design parts with shapes so that they cannot be fitted in the reverse direction.

As design measures, the following may be considered: (1) Clearly indicate distinguishing information by stamping on the part or by other means. (2) Use a shape that does not allow for making mistakes in direction when re-fitting the part (see ASTM F1166-07 17.6.1.2).

1) Source: Marine Accident Investigation Branch of UK, Safety Digest 3/2004.

3.16 Valve Installed at an Inappropriate Location

(1) Overview[1)]

In order to manually open the air starting valve of the main engine onboard a merchant ship, the operator had to operate the valve by standing on the electric motor of the turning gear, as shown in Fig. 3.16.1.

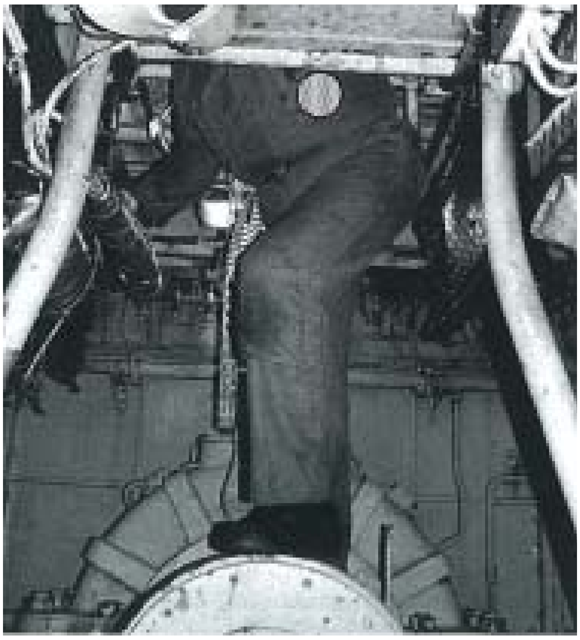

Fig. 3.16.1 Poor installed location of valve

(2) Discussion

Valves is said to be the most frequently operated pieces of equipment on a ship; so their operability must be properly considered. For valve operations as mentioned above, the operator is forced to adopt an awkward posture; thus, the risk of operational error or injury increases. It is important in principle, to install a valve at a location so that the operator can operate it easily instead of standing on some machinery or equipment to operate it.

As design measure, the piping can be routed so that the valve can be installed at an easily operable location.

1) Source: Reproduced with the kind permission of the Royal Institute of Naval Architects from the paper, *Control Rooms Human Factors* by M Andersson and Margareta Lützhöft, International Conference on human factors in ship design & operation, March 2007, London, UK.

3.17 Valve Installed in an Inappropriate Direction

(1) Overview[1)]

The main steam outlet valve onboard a merchant ship had to be operated by the operator climbing a ladder and operating it from an unstable position, as shown in Fig. 3.17.1.

Fig. 3.17.1 Poor installed direction of valve

(2) Discussion

Valves are said to be the most frequently operated pieces of equipment on a ship; so their operability must be properly considered. The operability of a valve not only depends on the location where it is installed, but also on the direction of installation; so care is necessary when installing a valve. In this example, the valve rod is vertical, and thus somewhat difficult to operate.

As a design measure, the valve may be fitted by rotating it by 90 degrees so that the wheel faces the operator in a horizontal direction.

1) Source: Reproduced with the kind permission of the Royal Institute of Naval Architects from the paper, *Control Rooms Human Factors* by M Andersson and Margareta Lützhöft, International Conference on human factors in ship design & operation, March 2007, London, UK.

3.18 Fall into a Tank

(1) Overview[1)]

On 9 March 2006, three crew members of a bulk carrier were working inside the forepeak tank. At around 1545 hours, one of the crew members, while cleaning the end of the stringer, fell to the bottom of the FPT and was killed (see Fig. 3.18.1). It is likely that said crew member slipped and fell over the guardrail to the bottom of the tank. The contributing factors of the accident may include the following: (a) the other two crew members were using the portable light at the time of the accident, so the surroundings may have been dark; (b) the ship was navigating at full speed, so the pitching and rolling motions may have been excessive; (c) the floor surface of the stringer was wet and slippery.

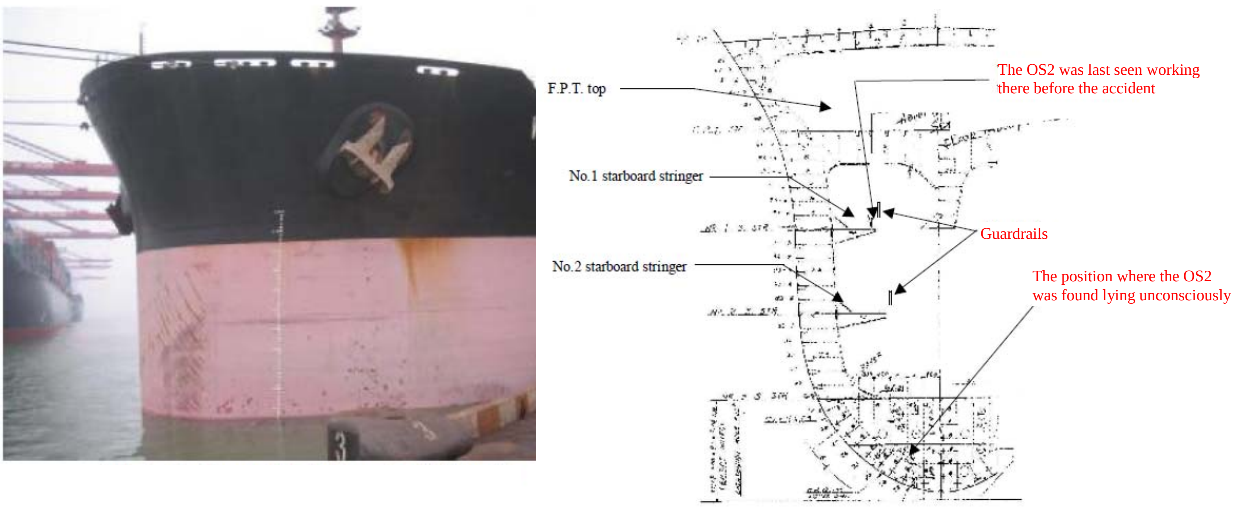

Fig. 3.18.1 Fall into a tank

(2) Discussion

Problems in safety management, such as the inadequate illumination of tanks, are evident in this accident. However, the height of the guardrails in the tank was also inadequate, and did not prevent the fall. Considering this accident, it is important to install guard rails with adequate height at overhead locations even if such locations are rarely accessed by workers (see ASTM F1166-07 11.13.3).

A design measure that can be considered to prevent this accident is to install handrails of adequate height in the tank.

1) Source: The Hong Kong Special Administration Region Marine Department Marine Accident Investigation Section, Report of investigation into the fatal accident on board the Hong Kong registered ship m.v. “Winner” on 9 March 2006.

3.19 Fall off a Ladder onto the Deck Below

(1) Overview[1)]

To repair the solenoid coil of the brokendown starboard side crane of a container ship, the electrician went down the ladder shown in Fig. 3.19.1. The deck was wet due to rain and, therefore, slippery. The electrician slipped and fell on to his back, striking his head. An hour later, he was pronounced dead.

Fig. 3.19.1 Fall on deck

(2) Discussion

Sometimes accidents such as slipping and falling on ladders and decks are reported. Ladders exposed to the atmosphere are likely to become slippery because of rain. It is important, therefore, that passageways, working platforms, and floor and landing platforms of ladders should, in principle, be provided with measures to prevent slipping to the degree that feet do not slip even in if these areas are wet.

As a design measure, anti-slip measures such as sand mixed in paint and coated on the deck parts where ladders end may be provided.

1）Source: Marine Accident Investigation Branch of UK, Safety Digest 3/2004.

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