DEVELOPMENT OF SAFETY TECHNOLOGY TO ENSURE SAFETY OF TWO OR MORE OPERATORS IN HAZARDOUS AREAS BY PREVENTING ERRONEOUS RESETTING

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Abstract
In Human Machine Interface environments, safety measures are required in various situations to prevent inadvertent machine startup. Even though a production system is highly automated, there may still be many cases where the operators need to enter the hazardous areas, and safety measures corresponding to risk levels must be provided for a variety of situations where any human error could cause the machine to start unexpectedly. In this paper, we report on the effectiveness of installing padlocks on the interlocking devices as a safeguard and also on the emergency stop switches as a complementary protective measure, which are among the safety measures described in ISO 12100 standard, for reliably preventing machinery from hazardous startup.

1. Introduction

In HMI (Human Machine Interface) environments of various industrial fields such as factory automation, increased efforts have been made in recent years to improve usability and safety. In Japan, safety requirement for machinery and equipment has changed substantially over the past several years with the issuance of "Guidelines for Comprehensive Safety Standards of Machinery" by the Labour Standards Bureau of the Ministry of Health, Labour and Welfare, the issuance of the JISB 9700 standard "Safety of Machinery – Basic concepts, general principles for design" which conforms to International Safety Standard ISO 12100, and the promulgation on April 1, 2006 of the Revised Industrial Safety and Health Law [1, 11-16]. While the Revised Industrial Safety and Health Law requires performing risk assessment as an obligatory effort, Labour Standards Bureau has issued "Guidelines for Assessing Risks and Hazards" which indicates that risk assessment is needed in a mandatory manner in actual worksites [9-10].

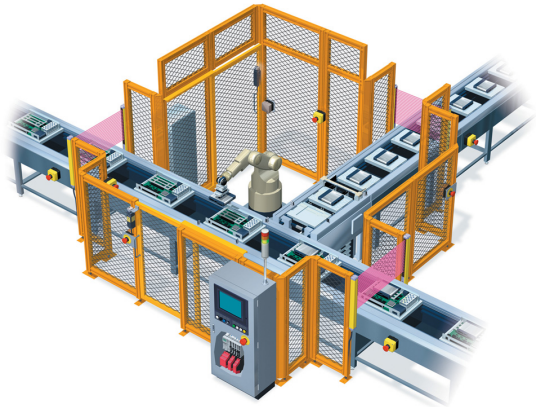


Figure 1. An Example of Automated Production System

Under the theme of "Creation of the optimum human-machine interface," we have been actively presenting proposals and reports concerning concept and development work for safety components that can be used for risk reduction. In this paper, we analyze how installing a padlock on the door interlock device as a safety product for safeguarding and also the emergency stop device as a safety product of complementary protective measure can ensure the safety for the two or more operators in hazardous area. We also report on the effectiveness of applying padlockable structure to safety products [12-13].

2. Safety Issues when Two or More operators Work in a Hazardous Area, and Solutions

Even if a machine system is highly automated, there are many situations where operators must work in hazardous areas as illustrated in Figure 1. For example, when changing the settings or performing repair and maintenance, as well as for emergency work in case of a breakdown, the operator is forced to approach a hazardous area, thus there is a high risk of serious accident for the operator if the machine starts unexpectedly. If there is only one operator involved, safe operation is ensured by the safety product which keeps the machine stopped. However, when there are two or more operators at

the same time, there is a case of operators being exposed to hazards, as described below and illustrated in Figure 2 (a) [12-13].
(1) When Operator Z opens the guard door for machinery maintenance and for other reasons, the door interlock devices keeps the machinery stopped.
(2) Operator Z enters the hazardous area for operation, leaving the guard door open.
(3) Operator Y arrives, and not knowing that operator Z is inside the hazardous area, closes the door which starts the machinery. Operator Z is injured.

This is an actual example of unfortunate accident at a worksite, and more accidents could occur along with the mobility of operators.

Figure 2 (b) shows the situation where the operator works safely by installing a padlock before entering the hazardous area.
(1) Operator Z engages a padlock on the door interlock device and enters the hazardous area for operation.

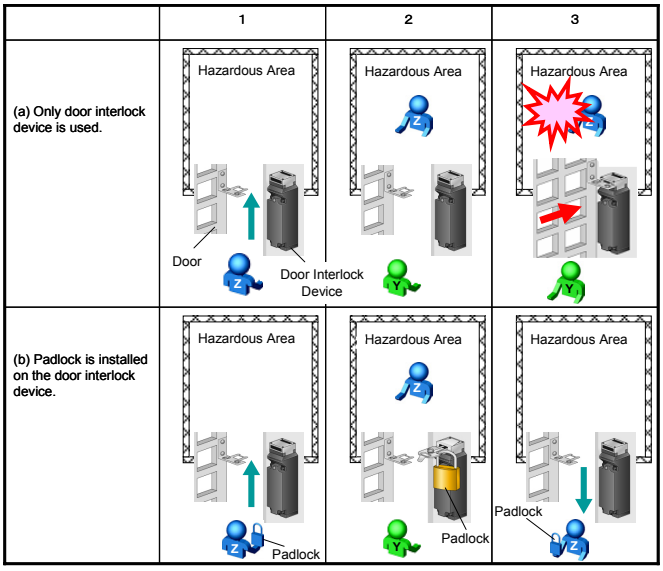


Figure 2. Comparison of Operation in Hazardous Areas - with and without Padlock

(3) Operator Y arrives, and notices from the padlock on the door interlock device that Operator Z is inside the hazardous area. Or, Operator Y does not notice about Operator Z and attempts to close the door, but the padlock prevents it, therefore the machinery cannot be restarted.

In the latter case with a padlock installed on the door interlock, the operator can safely work inside the hazardous area.

In addition, as the system becomes larger, there will be more cases where more than two operators enter the hazardous area. In such cases, all of the operators who approach the hazardous area should install their own padlocks on the door interlock device, so the machinery cannot run unless his padlock is disengaged, namely until all of the padlocks are disengaged. This way the safety of all operators is guaranteed. The procedure for two or more operators to enter the safety guard for operation is described below and illustrated in Figure 3.
(1) When Operators X, Y and Z open the door to the hazardous area to perform machinery maintenance, the door interlock device keeps the machine stopped.
(2) Each of the operators installs his own padlock on the door interlock device before entering the hazardous area.
(3) Because the padlocks are installed on the door interlock device, the door cannot be closed and the operators can safely work in the hazardous area.
(4) When their work is completed, Operators X and Y leave the hazardous area, and remove the padlocks they have attached to the door interlock device. Operator Z is still inside the hazardous area and Operator Z's padlock is still also engaged, therefore the door cannot be closed and Operator Z can safely work in the hazardous area. Also, Operators X and Y can recognize that Operator Z is still in the hazardous area.
(5) Operator Z leaves the hazardous area and disengages the padlock from the door interlock device, and finally the door interlock device is unlocked, enabling the door to be closed [12].

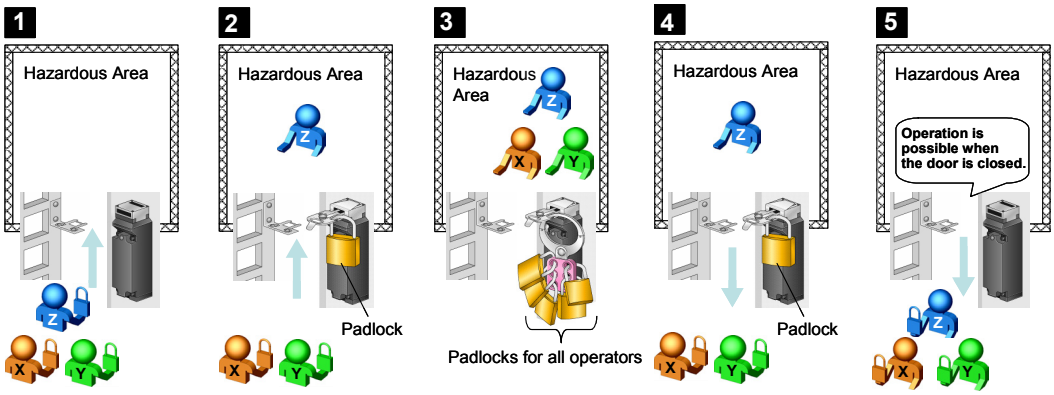


Figure 3. Padlocks Providing Safety to Multiple Operators in Hazardous Area

3. The Added Safety Functions of a Padlockable Door Interlock Device

The door interlock device has an important function of three-step method of safety measures prescribed by ISO 12100 [1, 16]. The safety switch used in the door interlock device opens and closes its contact by means of the insertion and removal of a dedicated actuator. As the actuator fastened to the door is inserted and removed by opening and closing the door, the safety switch functions as a door interlock device.

There are important safety requirements for a safety switch which has the important role of preventing the operator from approaching machinery while it is running and hazardous. One requirement is "direct opening action" based on International Safety Standard IEC 60947-5-1 Attachment K, which requires that when the door is opened, the contacts are securely separated so that the safety control circuit is shut down. Another requirement is "defeat prevention" based on ISO 14119, 5.7.1, a means of construction that can be operated only by the proprietary actuator, and cannot be operated by hand or by a readily available object (such as screws, needles, sheet-metal pieces, keys, coins, tools) [4, 6, 16].

In the case of machine tools such as a machining center or lathe turning machine, the rotating tools or the objects being machined might not stop immediately when the power is shut down, thus there may be a hazard associated with inertial movement of the tools and the objects. For example, the door is opened and the door interlock device shuts down the safety circuit, yet the moving parts cannot stop completely or slow down to a safe speed by the time the operator arrives at the hazardous machine's moving parts. For this case, a lockable door interlock device is necessary in order to prevent the operator from approaching the hazardous area by way of locking the door until the machinery is stopped completely or slowed to a safe speed. A solenoid-type safety switch is used for this purpose [1, 6, 16].

The padlockable safety switch presented here can prevent an operator from being confined inside the safety fence, without losing any of the functionality of a conventional safety switch. As shown in Figure 4, the operator who has opened the door installs a padlock hasp on the actuator entry slot of the safety switch, and locks with a padlock before entering the guarded area. With a safety switch that has a padlock hasp blocking the actuator entry slot, the actuator cannot be inserted and the door cannot be closed, therefore the machine cannot be started. Since the safety switch is always installed near the door entry, there is also an added advantage that operators can easily engage the padlock before entering the guarded area. The procedure for mounting the padlock hasp on the safety switch and engaging the padlock is shown in Figure 5 [12]. A padlock hasp can accommodate several locks, and for cases where more operators are involved, an auxiliary fitting can be mounted on the padlock hole of the hasp, and installing padlocks on the auxiliary fitting ensures the safety of additional workers.

The door-handle type safety switch shown in Figure 6 provides an improved usability as a human interface. Turning the door handle removes the actuator from the safety switch, and the door can then be pulled open. Furthermore, the padlock engaging method of this type does not require attaching a separate hasp. Closing a shutter incorporated in the safety switch allows padlocks to be installed, making this switch suitable for large equipment which may require two or more operators to work inside the guarded area.

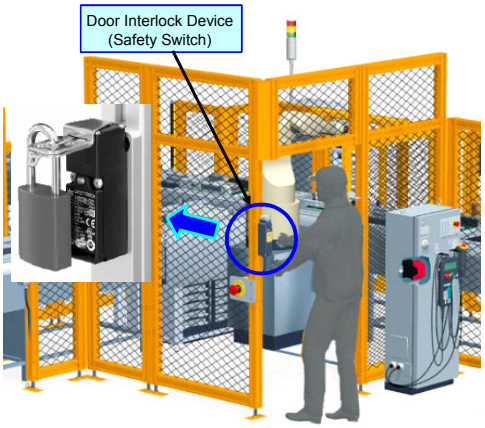


Figure 4. Prevention of Machine Start-up with Door Interlock Device when Entering the Guarded Area

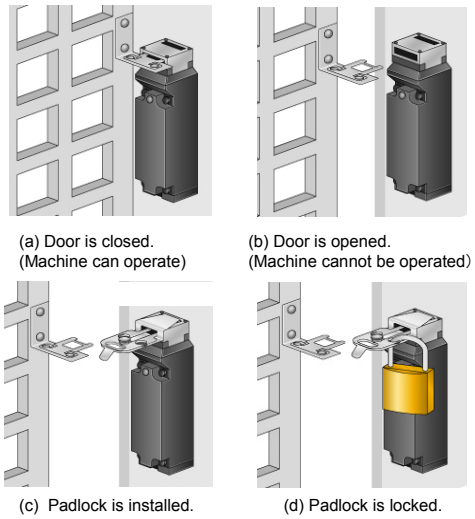
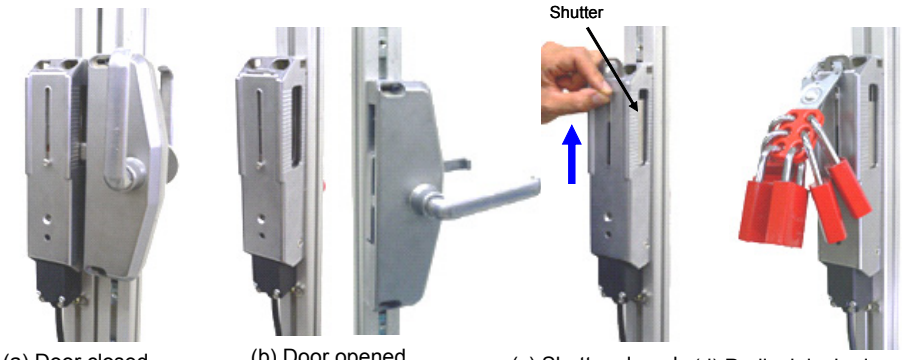


Figure 5. Padlock Locking Procedure on Safety Switches.

4. A Padlockable Emergency Stop Device and its Added Safety Functions

Padlocking is also effective with an emergency stop device, which is a human interface for transmitting a stop command to the machine and is a complementary protective measure of the three-step method.

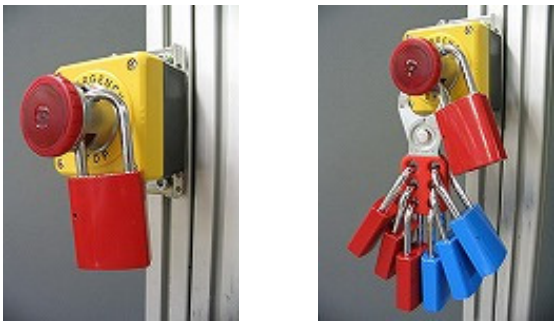


(a) Door closed (Machine can operate) (b) Door opened (Machine cannot operate) (c) Shutter closed (d) Padlock locked

Figure 6. Door-handle Type Padlockable Safety Switch

The emergency stop switch used in an emergency stop device is subject to strict constructional requirements under the international safety standards ISO 13850 and IEC 60947-5-5. This is because the emergency stop device is the last means available for ensuring the safety of the operator, and when activated, it must be able to reliably transmit the stop command to the machinery in any situation [3, 5]. For example, the emergency stop switch is pressed to stop a failed machinery, and two or more operators approach the machinery for repairs. In this case, there are concerns that even if the emergency stop switch has been designed to satisfy the requirements of the current international safety standards, an accident may be incurred by an operator's failing to conduct proper checks at the start of his operation or by an operator's human errors. To protect himself from an unexpected machinery startup, each of all operators must ensure the OFF status of the emergency stop switch which is keeping the machinery stopped.

The padlockable emergency stop switch presented in this paper is able to accept a padlock when the button is latched, without losing any of the conventional safety features or usability. As shown in Figure 7 (a), the padlockable emergency stop switch has a through hole on the operating button part, and installing a padlock on the through hole prevents the switch from being turned or pulled. In addition, if the number of operators increase beyond the capacity of a padlock, it is possible to attach an auxiliary fitting as shown in Figure 7 (b), to allow all operators to install padlocks.



(a) For One Operator (b) For Two or More Operators

Figure 7. Padlockable Emergency Stop Switch

Figure 8 shows how safety is ensured in the system with a padlockable emergency stop switch, when two or more operators enter the hazardous area.

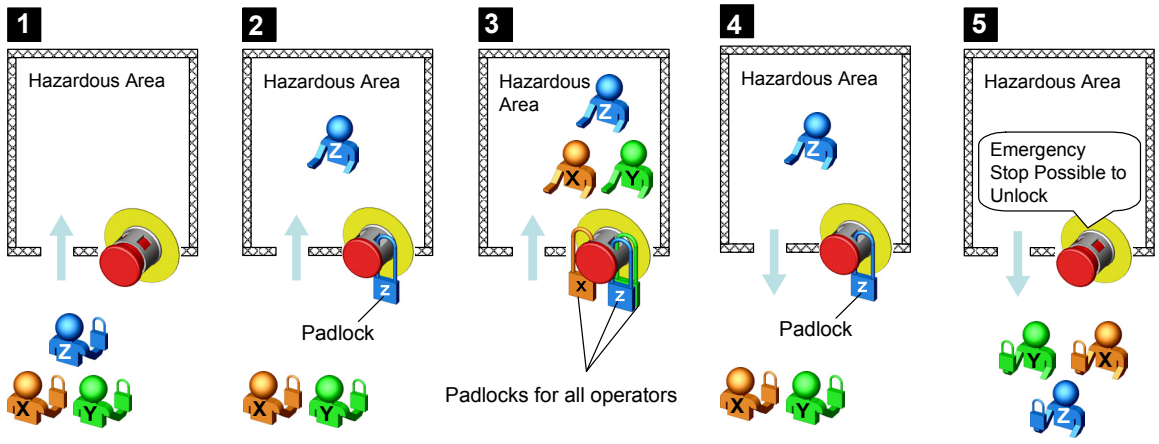


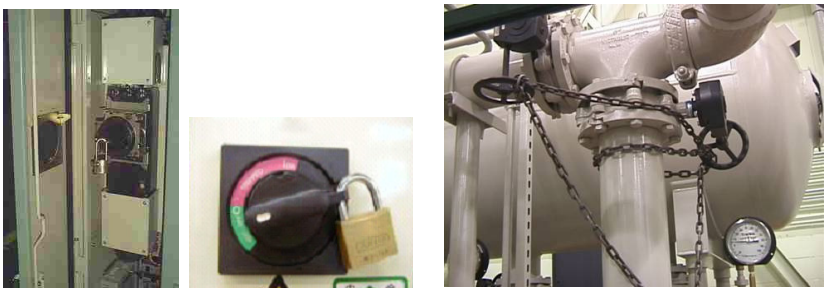
Figure 8. Padlockable Emergency Stop Switch for Two or More Operators

(1) A system malfunctions, and Operators X, Y and Z come to work in the hazardous area. The padlockable emergency stop switch is pressed and the button is latched.
(2) Each of the operators engages his own padlock on the emergency stop switch and enters the hazardous area.
(3) The emergency stop switch locked by the padlocks allows the operators to work safely in the hazardous area.
(4) When their work is finished, Operators X and Y leave the hazardous area, and remove the padlocks they have installed on the emergency stop switch. Operator Z is still in the hazardous area and Operator Z's padlock is still engaged, so the button of the emergency stop switch cannot be unlocked, ensuring his safety. Also, Operators X and Y are able to recognize that Operator Z is still in the hazardous area.
(5) Operator Z leaves the hazardous area and removes the padlock from the emergency stop switch, and finally the button of the emergency stop switch can be unlocked.

Accordingly, until one's own padlock is removed, that is until all padlocks are removed, the machine cannot start and the safety of all operators can be ensured [13].

5. Examples of Padlock Application on other Devices

One method that has been used commonly to ensure the safety of an operator approaching a hazardous area is so-called hostage control, in which the operator enters the hazardous area carrying a key switch or safety plug in order to keep the machine unable to be started [16]. However, as systems grow larger, there will be many situations where two or more operators are required to enter the hazardous area, and since it is difficult to predict the number of operators at the time of designing a system, in most cases the exact



(a) Lockout for Energy Isolating Device (b) Lockout for Hydraulic Valve

Figure 9. Lockout Application Examples

Table 1 Safety Requirements of Lockout by Safety Standards

Standard	Requirement
OSHA Regulations (Standards - 29 CFR)) The control of hazardous energy (lockout/tagout). - 1910.147	1910.147(b) Lockout. The placement of a lockout device on an energy isolating device, in accordance with an established procedure, ensuring that the energy isolating device and the equipment being controlled cannot be operated until the lockout device is removed. Lockout device. A device that utilizes a positive means such as a lock, either key or combination type, to hold an energy isolating device in the safe position and prevent the energizing of a machine or equipment.
ANSI/ASSE Z244.1-2003 Control of Hazardous Energy Lockout/Tagout and Alternative Methods	2.14 lockout/tagout The placement of a lock/tag on the energy isolating device in accordance with an established procedure, indicating that the energy isolating device shall not be operated until removal of the lock/tag in accordance with an established procedure. 2.13 lockout device A positive means such as a lock that secures an energy isolating device in a position that prevents the energizing of a machine, equipment or process.
ISO12100-2:2003 Safety of machinery — Basic concepts, general principles for design — Part 2: Technical principles	5.5 Complementary protective measures 5.5.4 Measures for isolation and energy dissipation Especially with regard to their maintenance and repair, machines shall be equipped with the technical means to achieve the isolation from power supply(ies) and dissipation of stored energy as a result of following actions: b) locking (or otherwise securing) all the isolating units in the isolating position;
IEC60204-1:2005 Safety of machinery – Electrical equipment of machines – Part 1: General requirements	5. Incoming supply conductor terminations and devices for disconnecting and switching off 5.3 Supply disconnecting (isolating) device 5.3.3 Requirements When the supply disconnecting device is one of the types specified in 5.3.2 a) to d) it shall fulfill all of the following requirements: - be provided with a means permitting it to be locked in the OFF (isolated) position (for example by padlocks). When so locked, remote as well as local closing shall be prevented; 5.6 Protection against unauthorized, inadvertent and/or mistaken connection The devices described in 5.4 and 5.5 that are located outside an enclosed electrical operating area shall be equipped with means to secure them in the OFF position (disconnected state), (for example by provisions for padlocking, trapped key interlocking). When so secured, remote as well as local reconnection shall be prevented.

number of key switches or safety plugs required are not provided to the system. Consequently the safety of an operator who must work inside the hazardous area without a key or plug must depend on the care of the person who is responsible for holding the key or plug.

As to the technology to support detection of the presence of an operator in the hazardous area, the usage of laser scanner, mat switch, and most recently the method to employ image processing technology have been introduced. However, the method that has proved effective to ensure the operator's safety from an unexpected machinery startup is what is known as the lockout method shown in Figure 9, used mostly in North America. In this method, all operators install their own padlocks on a power supply breaker, oil pneumatic valve or other energy isolation device [7-8]. Table 1 is a summary of standards applicable to lockout devices. As the table shows, startup prevention using padlocks is required under international safety standards and also by laws, as a simple and highly reliable safety measure. In addition to OSHA and ANSI standard in the US, usage of padlock is required under international safety standards ISO 12100-2 and IEC 60204-1.

6. Conclusion

In this paper, we reported on the analysis of various methods for preventing accidental startup of machinery when operators are working in a hazardous area, and described the effectiveness of a padlockable safety switch and a padlockable emergency stop switch to ensure the safety of operators working in a hazardous area. Engaging a padlock to prevent machinery startup is a complementary protective measure based on operation rules. However, in cases where it is difficult at the design stage to predict the exact number of operators who will work at the same time in a hazardous area, machinery designers will increasingly be required to take the approach of preparing for safety measures available for two or more operators, such as providing startup prevention with padlocks.

We will continue to make preemptive moves in the changes of safety concept, and to make our utmost efforts in pursuing the safety of safety products and technological achievement.

References

[1] ISO12100-1, -2；(2003), Safety of machinery-Basic concepts, general principles for design - Part 1:Basic terminology, methodology - Part 2: Technical principles

[2] IEC 60204-1: (2005), Safety of machinery- Electrical equipment of industrial machines - Part 1:General requirements

[3] ISO13850；(1996), Safety of machinery - Emergency stop - Principles for design

[4] IEC60947-5-1 Ed.3.0；(2003), Low-voltage switchgear and controlgear. Part5-1: Control circuit devices and switching elements - Electromechanical control circuit devices

[5] IEC 60947-5-5 Ed.1.1；(2005) , Low-voltage switchgear and controlgear - Part 5-5: Control circuit devices and switching elements - Electrical emergency stop device with mechanical latching function

[6] ISO14119: (1998), Safety of machinery -- Interlocking devices associated with guards -- Principles for design and selection

[7] Occupational Safety & Health Administration, U.S. Department of Labor, The control of hazardous energy (lockout/tagout). - 1910.147

[8] ANSI/ASSE Z244.1；(2003), Control of Hazardous Energy – Lockout/Tagout And Alternative Methods,

[9] Partial amendments to the Industrial Safety and Health Law (The 108th Law, 2005), November 2, 2005

[10] Guidelines for Risk Assessment, Ministry of Health, Labour, and Industry, March 10, 2006

[11] M. Mukaidono, Machine System Safety Technology in the Age of Globalization, edited by the Society of Safety Technology and Application, The Nikkan Kogyo Shimbun, Ltd. 2000

[12] T. Hidaka, et al., « Development of Safety Switches with Padlocks to Ensure Safety of Operators in Hazardous Areas », presented to the Human Interface Symposium 2006, pp. 785-790

[13] M. Fujimoto, et al., « Development of Emergency Stop Switches used with Padlocks to Ensure Safety of Operators in Hazardous Areas by Preventing Erroneous Resetting », presented to the Human Interface Symposium 2005, pp. 609-612

[14] Y. Kamino, et al., « Coexistence of Human and machine from the Standpoint of Safety », presented to the Human Interface Symposium 1999, pp. 801-806

[15] T. Sakai, « Development of New Emergency Stop Switches which Assures Operator(s Safety at Its Foreseeable Failure », presented to the Human Interface Symposium 2003, pp. 459-462

[16] IDEC Safety Concept Book, 2007. 6th Edition, IDEC CORPORATION, 2007