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The hazard risk in electrostatic precipitator using hirarc and fault tree analysis method in the steel industry

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Abstract

This steel industry has 3 production processes: Ironmaking, Steelmaking, and Rolling. One of the hazardous facilities is the electrostatic precipitator that separates dust and gas from the steelmaking process. This research aims to identify hazards, assess risks, and provide risk control recommendations to minimize workplace accidents at the Electrostatic Precipitator facility. HIRARC is the process of identifying potential hazards in every activity within the company, followed by a risk assessment of those hazards. FTA is an analysis tool that graphically translates the combination of errors that cause system failures. The methods used in this research are HIRARC (Hazard Identification, Risk Assessment, and Risk Control) and FTA (Fault Tree Analysis). The results of the hazard identification conducted show that there are 25 hazards, with 3 risks falling into the extreme category. The conclusion of this study is to provide risk control recommendations for 3 hazards categorized as extreme through the installation of safety signs, monitoring of work permits, and providing regular training to workers.

Keywords: fault tree analysis, hazard identification, occupational health and safety, risk assessment and risk control

1. Introduction

The Occupational safety and health factors are critical in every industry, so workplace safety will be the main focus for every employee to avoid work accidents. Industrial accidents are incidents that occur in the workplace, particularly in industrial environments (Yusril et al., 2021). Industrial accidents are generally caused by two main factors: unsafe actions and unsafe conditions. Unsafe acts are activities that deviate from understood safety standards and endanger an individual or a group of people. These acts may be intentional or unintentional, and they may result from a lack of attention, lack of knowledge or training, negligence, or disregard for safety procedures (Nur et al., 2024).The magnitude of a hazard risk depends on the type of industry, technology, and methods used, as well as the risk control efforts implemented, thereby preventing workplace accidents. Unsafe condition is a work environment that is not good or a condition of work equipment that is dangerous. The consequences of an unsafe condition can lead to potential hazards (Basri & Pirmah, 2023).

This company is one of the integrated steel mills located in the city of Cilegon. This steel company has three production processes: Ironmaking, Steelmaking, and Rolling. Steelmaking is the production process with the highest risk. This process consists of three areas: Converter, Gas Cleaning, and Secref. The main facility in this area is the electrostatic precipitator (ESP), which captures and separates dust and gas resulting from the production process in the converter area. The ESP is one of the facilities with high risk because there are many hazards such as the risk of gas poisoning, exposure to toxic dust, explosion risk, noise area risk, and the danger of working in confined spaces.

Based on the report from the safety keeper steelmaking, in 2022 there were 40 findings (23 unsafe action findings and 17 unsafe condition findings) of near-miss cases in the gas cleaning area during repairs or maintenance. The types of unsafe conditions that cause near misses include failure or non-compliance in using personal protective equipment (PPE), incorrect working positions, lack of understanding of standard operating procedures (SOP), using inappropriate or damaged tools, and worker negligence. The types of unsafe conditions that lead to near misses include corrosion on tools or facilities, inadequate lighting, toxic facilities or areas, and radiation. The following can be seen in Figure 1.

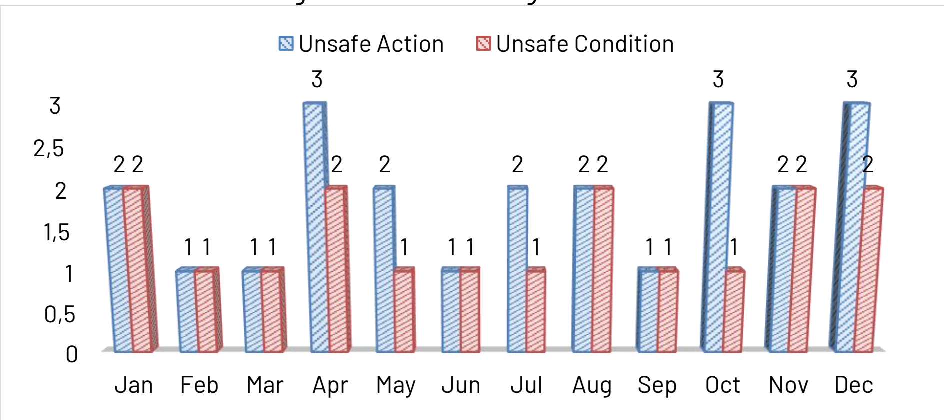

Figure 1. Near-miss report at the ESP facility

Based on image 1, it is clear that the workers still lack awareness regarding the importance of OHS in the company because there are findings of unsafe actions. Unsafe actions are a source of workplace accidents and can indirectly reduce company productivity, as they can disrupt the smooth flow of production.

HIRARC (Hazard Identification, Risk Assessment and Risk Control) is a document that contains the identification of hazards, risk assessment, and control of those risks in order to reduce the occurrence of occupational safety and health disturbances (Kristianti et al., 2023). The Hazard Identification, Risk Assessment, and Risk Control (HIRARC) process is important to ensure a safe and healthy workplace, as well as to comply with applicable occupational safety and health regulations (Islah et al., 2024). Fault Tree Analysis (FTA) is Fault Tree Analysis (FTA) is a technique for classifying instrumental relationships that lead to specific failure modes (Nurwulan & Veronica, 2020). FTA is used to analyze the highest risk levels obtained from hazard identification and risk assessment, to identify the basic events that are the root causes of an incident. The validity test is a test used to determine and examine the accuracy of a measuring instrument to be used as a measure of something that should be measured (Rosita et al., 2021). This research conducts a validity test to ensure whether the prioritized types of risks for control are valid or not through the distribution of questionnaires to workers. Then, the data from the questionnaire will be processed using the Statistical Program for Social Science (SPSS) software.

According to Albar et al., 2022, who conducted research at PT. Perkebunan Nusantara IV Kebun Adolina using the Hazard Identification and Risk Assessment (HIRA) method, it was found that there are 29 potential hazards, namely 8 high-risk and 21 medium-risk. (medium risk). According to (Bastuti, 2020), who conducted research at PT. Prima Alloy Steel Universal using the Hazard Identification Risk Assessment and Determining Control (HIRAC) and Job Safety Analysis (JSA) methods, the results showed that there are 2 work activities with extreme risk potential, 4 work activities with high risk, 3 work activities with moderate risk, and 4 work activities with low risk. Unlike previous research, the novelty of this research is focused on minimizing workplace accidents at Electrostatic Precipitator (ESP) facilities using the Hazard Identification, Risk Assessment and Risk Control (HIRARC) method. Fault Tree Analysis (FTA) used to analyze the highest risk levels obtained from hazard identification and risk assessment, to identify the basic events that are the root causes of an incident. Validity testing used to ensure whether the prioritized types of risks for control are valid or not through the distribution of questionnaires to workers.

This research aims to identify hazard risks present in the Electrostatic Precipitator (ESP) facility, conduct a hazard risk assessment in the Electrostatic Precipitator (ESP) facility, and provide suggestions for improving hazard risk control in the Electrostatic Precipitator (ESP) facility. This research can serve as a reference for comparative studies in the same field and is useful for developing knowledge related to workplace accidents. This research is also beneficial as input and reference for controlling and managing hazard risks in the workplace to minimize the risk of workplace accidents in the company.

2. Methodology

This research uses the Hazard Identification, Risk Assessment and Risk Control (HIRARC), Fault Tree Analysis, and Validity Testing methods. This research uses primary and secondary data (Sugiyono, 2017). Primary data consists of :

a. Observation

Observation involves directly observing the company's production area to understand the condition of the production area.

b. Questionnaire

The distribution of the questionnaire is conducted to identify the hazards identified at the electrostatic precipitator facility (ESP). This research uses the probability sampling technique to determine the number of samples to be observed. According to Sugiono (2019:129), probability sampling is a sampling technique that provides an equal opportunity for each element or member of the population to be selected as a sample. The distribution of the questionnaire was conducted among 30 respondents working at the electrostatic precipitator facility (ESP).

c. Brainstorming

This research conducted a brainstorming session with the production manager to obtain more information regarding the hazards present in the electrostatic precipitator facility.

This research requires secondary data, as follows:

a. Literature review

The literature review is conducted to gather information and theories on Hazard Identification, Risk Assessment and Risk Control (HIRARC), Fault Tree Analysis (FTA), and Validity Testing.

b. Work Accident Data

The electrostatic precipitator (ESP) facility's work accident data from 2022 serves as supporting data for this study.

3. Result and Discussion

Based This section presents the results and discussion of research consisting of the Hazard Identification Risk Assessment and Risk Control (HIRARC) and Fault Tree Analysis (FTA) will also be conducted to validate the identified and analyzed hazards by both methods.

Hazard Identification Risk Assessment and Risk Control (HIRARC)

At this stage, the researchers identify hazards and assess the risks of potential hazards present in the Electrostatic Precipitator facility (ESP).

a. Hazard Identification

Hazard risk identification is carried out through field observation during the maintenance of the Electrostatic Precipitator (ESP) facility. The following can be seen in Table 1.

Table 1. Hazard identification in ESP facilities

No	Activities	Potential Hazard	Hazard Risk
1	Replacement of roller bearing scrapper	Exposure to toxic gas Hazard of confined space Hazard of high temperature area Hazard in dark areas Hazard of being squeezed	worker poisoned by gas workers are experiencing a lack of oxygen The workers are experiencing dehydration. worker slipped Worker squeezed in roller bearing
2	Repair Slopping Conveyor	Hazard of Rotating/Moving Objects Hazard of being squeezed Hazard of dusty areas	The worker got caught in the conveyor. Worker squeezed in Slopping conveyor Workers are experiencing shortness of breath and eye irritation.
3	Replacement of Sprocket Scrapper	Hazard of being squeezed Hazard of confined space Exposure to toxic gas Hazard in dark areas Hazard of Rotating/Moving Objects	Worker squeezed in Sprocket workers are experiencing a lack of oxygen worker poisoned by gas worker slipped The worker got caught in the sprocket
4	Replacement of *Safety Valve*	Hazard of working at heights Hazard of being squeezed	The worker fell from a height. Worker squeezed in *Safety Valve*
5	Repair Rapping Hammer	Hazard of Rotating/Moving Objects Hazard of being hit Hazard in dark areas	The worker got caught in the rapping hammer Worker of being hit by rapping hammer worker slipped
6	Repair & Cleaning Grease Line	Hazard of confined space Flammable Material Hazard in dark areas	workers are experiencing a lack of oxygen A fire broke out. worker slipped
7	Repair Cylinder Double Pendulum	Hazard of Rotating/Moving Objects Hazard of being squeezed Hazard of dusty areas Exposure to toxic gas	The worker got caught in the cylinder Worker squeezed in cylinder Workers are experiencing shortness of breath and eye irritation. worker poisoned by gas

b. Risk Assessment

Risk assessment is carried out through field observation during the maintenance of the Electrostatic Precipitator (ESP) facility. The following can be seen in Table 2.

Table 2. Risk assessment in ESP facilities

No	Activities	Potential Hazard	Hazard Risk	Kode	L	S	LxS	Level
1	Replacement of roller bearing scrapper	Exposure to toxic gas	worker poisoned by gas	RB1	1	4	4	High
		Hazard of confined space	workers are experiencing a lack of oxygen	RB2	2	4	8	High
		Hazard of high temperature area	The workers are experiencing dehydration.	RB3	2	3	6	Mode rate
		Hazard in dark areas	worker slipped	RB4	1	2	2	Low
		Hazard of being squeezed	Worker squeezed in roller bearing	RB5	2	4	8	High

2	Repair Slopping Conveyor	Hazard of Rotating/Moving Objects	The worker got caught in the conveyor.	SC1	1	4	4	High
		Hazard of being squeezed	Worker squeezed in Slopping conveyor	SC2	3	4	12	Extreme
		Hazard of dusty areas	Workers are experiencing shortness of breath and eye irritation.	SC3	2	3	6	Moderate
3	Pergantian Sprocket Scrapper	Hazard of being squeezed	Worker squeezed in Sprocket	SS1	2	4	8	High
		Hazard of confined space	workers are experiencing a lack of oxygen	SS2	2	4	8	High
		Exposure to toxic gas	worker poisoned by gas	SS3	2	4	8	High
		Hazard in dark areas	worker slipped	SS4	2	2	4	Low
		Hazard of Rotating/Moving Objects	The worker got caught in the sprocket	SS5	2	4	8	High
4	Pergantian Safety Valve	Hazard of working at heights	The worker fell from a height.	SV1	2	4	8	High
		Hazard of being squeezed	Worker squeezed in Safety Valve	SV2	2	4	8	High
5	Repair Rapping Hammer	Hazard of Rotating/Moving Objects	The worker got caught in the rapping hammer	RH1	2	4	8	High
		Hazard of being hit	Worker of being hit by rapping hammer	RH2	3	4	12	Extreme
		Hazard in dark areas	worker slipped	RH3	1	2	2	Low
6	Repair & Cleaning Grease Line	Hazard of confined space	workers are experiencing a lack of oxygen	GL1	2	4	8	High
		Flammable Material	A fire broke out.	GL2	2	4	8	High
		Hazard in dark areas	worker slipped	GL3	3	3	9	High
7	Repair Cylinder Double Pendulum	Hazard of Rotating/Moving Objects	The worker got caught in the cylinder	DB1	1	3	3	Moderate
		Hazard of being squeezed	Worker squeezed in cylinder	DB2	3	4	12	Extreme
		Hazard of dusty areas	Workers are experiencing shortness of breath and eye irritation.	DB3	1	3	3	Moderate
		Exposure to toxic gas	worker poisoned by gas	DB4	1	4	4	High

Remark :
L = Likehood
S = Saverity
RB = Replacement of Roller Bearing
SC = Repair Slopping Conveyor
SS = Replacement of Sprocket Scrapper
DB = Replacement of Cylinder Double Pendulum
RH = Replacement of Rapping Hammer
GL = Repair and Cleaning Grease Line
SV = Replacement of Safety Valve

Diagram Fault Tree Analysis (FTA)

Analysis using the FTA diagram is important because the FTA method can identify the occurrence of a failure in the system by illustrating alternative events while considering the cause and effect of an event in a structured block diagram. Analysis using the FTA diagram will focus on work activities that have a risk level categorized as extreme. The following can be seen in Table 3.

Table 3. Extreme risk category

No	Activities	Potential Hazard	Hazard Risk	Kode	L	S	LxS	Level
1	Repair Slopping Conveyor	Hazard of being squeezed	Worker squeezed in Slopping conveyor	SC2	3	4	12	Extreme
2	Repair Rapping Hammer	Hazard of being hit	Worker of being hit by rapping hammer	RH2	3	4	12	Extreme
3	Repair Cylinder Double Pendulum	Hazard of being squeezed	Worker squeezed in cylinder	DB2	3	4	12	Extreme

Based on the table above, it is known that there are 3 hazards categorized as extreme.

a. Worker squeezed in Slopping conveyor

The following is an FTA diagram regarding the analysis of the causes of the risk of workers getting caught in the slopping conveyor hazard. The following can be seen in Figure 2.

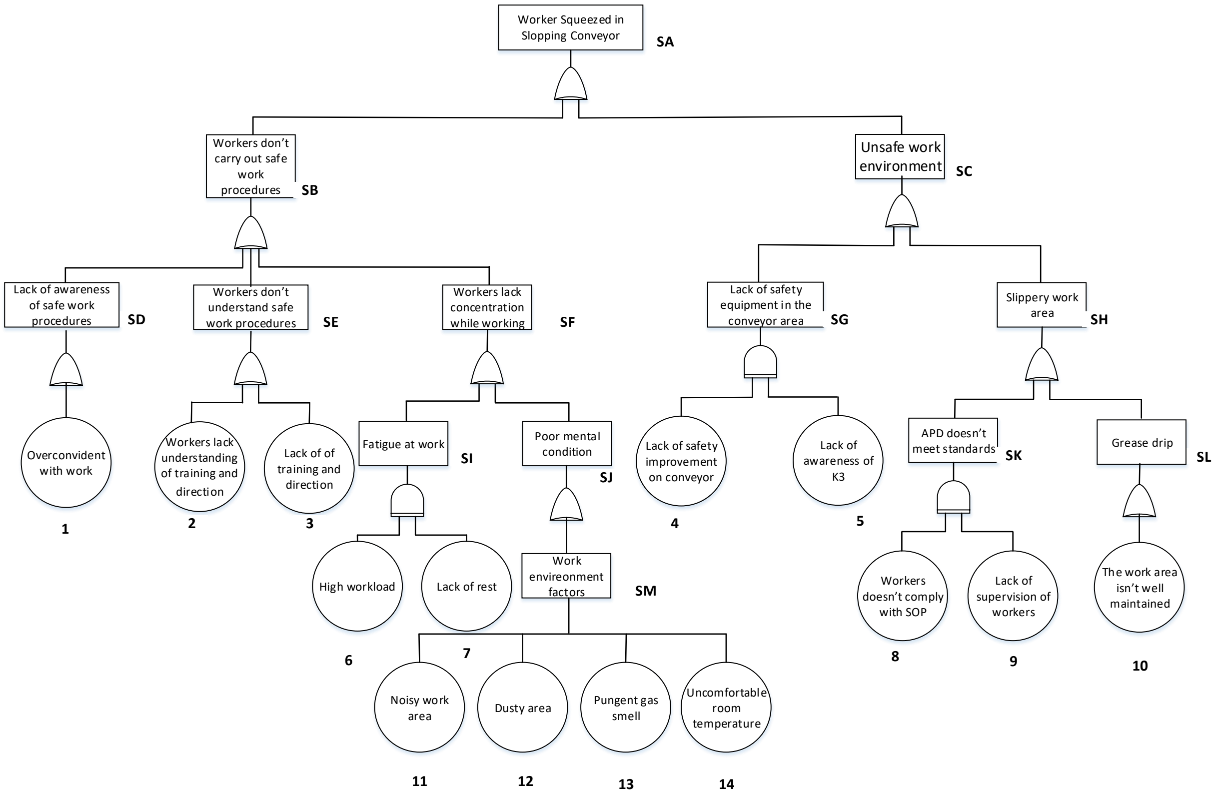

Figure 2. FTA diagram of worker squeezed in slopping conveyor

The following is Table 4 of the minimal cut set calculation using the Mocus method from the FTA diagram of the worker trapped in the slopping conveyor. The following can be seen in Table 4.

Table 4. Calculation of minimal cut set for workers trapped in slopping conveyor

SA (*OR gates*)	SB (*OR gates*)	SD (*OR gates*)	SE (*OR gates*)	SF (*OR gates*)	SI (*OR gates*)	SJ (*OR gates*)
SB	SD	1	1	1	1	1
SC	SE	SE	2	2	2	2
	SF	SF	3	3	3	3
	SC	SC	SF	SI	6	6
			SC	SJ	7	7
				SC	SJ	SM
					SC	SC

SM *(OR gates)*	SC *(OR gates)*	SG *(AND gates)*	SH *(OR gates)*	SK *(AND gates)*	SL *(OR gates)*
1	1	1	1	1	1
2	2	2	2	2	2
3	3	3	3	3	3
6	6	6	6	6	6
7	7	7	7	7	7
11	11	11	11	11	11
12	12	12	12	12	12
13	13	13	13	13	13
14	14	14	14	14	14
SC	SG	4,5	4,5	4,5	4,5
	SH	SH	SK	8,9	8,9
			SL	SL	10

Table 5. Minimal cut set results for workers trapped in slopping conveyor

Minimal *Cut Set*		
1	7	14
2	11	4,5
3	12	8,9
6	13	10

Based on Table 5. the results of the minimal cut set calculation using the MOCUS method show 12 minimal cut sets where all basic events connected by "OR" and "AND" gates have the potential to cause the top event to occur. Here are the details of the minimal cut set calculation results:

1. Basic event number 1 is overconfidence in the work being done.
2. Basic event number 2 is workers not understanding instructions and training materials.
3. Basic event number 3 is lack of training and guidance.
4. Basic event number 6 is high workload.
5. Basic event number 7 is lack of rest.
6. Basic event number 11 is noise in the work area.
7. Basic event number 12 is dusty area.
8. Basic event number 13 is presence of gas/strong odor.
9. Basic event number 14 is uncomfortable room temperature.
10. Basic event numbers 4 and 5 are lack of safety improvements for the conveyor and lack of K3 awareness from the PIC.
11. Basic event numbers 8 and 9 are workers not following SOP and lack of supervision over workers.
12. Basic event number 10 is poor maintenance of the work area.

b. Worker of being hit by rapping hammer

The following is an FTA diagram regarding the analysis of the causes of the risk of worker of being hit by rapping hammer hazard. The following can be seen in Figure 3.

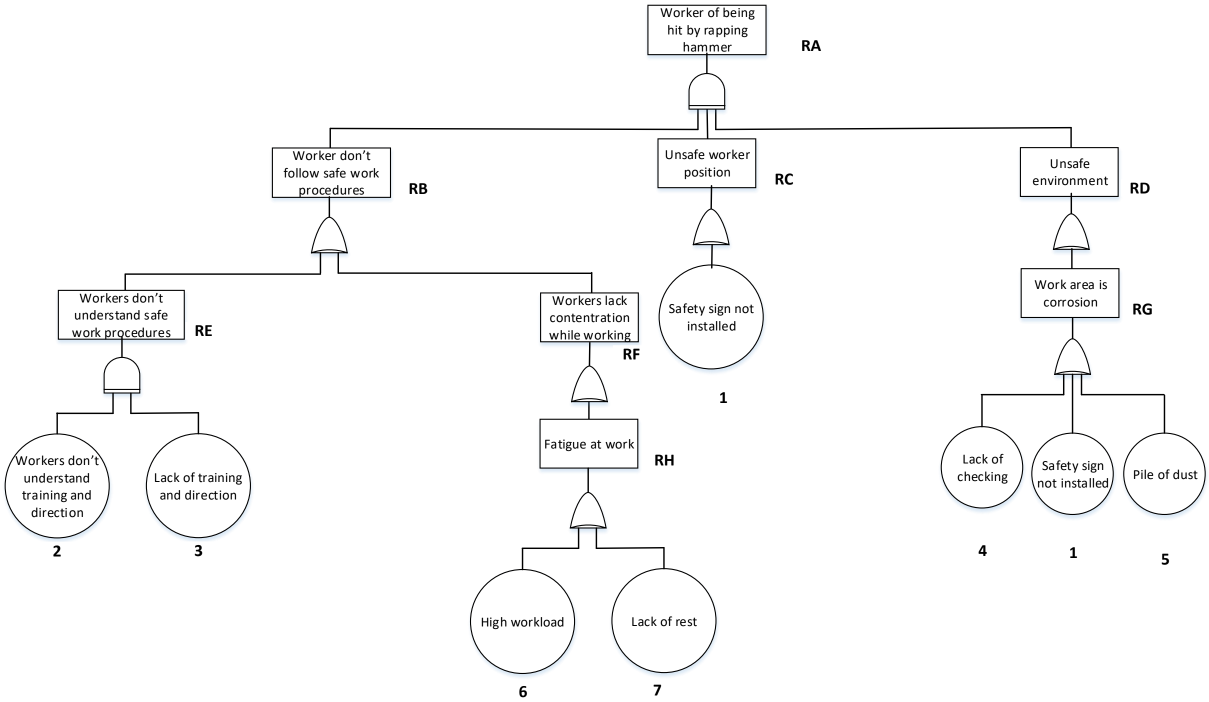

Figure 3. FTA diagram of Worker of being hit by rapping hammer

The following is Table 6 of the minimal cut set calculation using the Mocus method from the FTA diagram of the worker of being hit by rapping hammer. The following can be seen in Table 6 and Table 7.

Table 6. Calculation of minimal cut set for worker of being hit by rapping hammer

RA (*AND gates*)	RB (*OR gates*)	RE (*OR gates*)	RC (*OR gates*)
RB,RC,RD	RE,RC,RD	2,RC,RD	2,1,RD
	RF,RC,RD	3,RC,RD	3,1,RD
		RF,RC,RD	RF,1,RD
RD (*OR gates*)	RG (*OR gates*)	RF (*OR gates*)	RH (*OR gates*)
2,1,RG	2,1,4	2,1,4	2,1,4
3,1,RG	2,1,1	2,1,1	2,1,1
RF,1,RG	2,1,5	2,1,5	2,1,5
	3,1,4	3,1,4	3,1,4
	3,1,1	3,1,1	3,1,1
	3,1,5	3,1,5	3,1,5
	RF,1,4	RH,1,4	6,1,4
	RF,1,1	RH,1,1	7,1,4
	RF,1,5	RH,1,5	6,1,1
			7,1,1
			6,1,5
			7,1,5

Table 7. Minimal cut set results for worker of being hit by rapping hammer

	Minimal *Cut Set*	
2,1,4	3,1,1	6,1,1
2,1,1	3,1,5	7,1,1
2,1,5	6,1,4	6,1,5
3,1,4	7,1,4	7,1,5

Based on above, there are 12 combinations of basic events that cause the occurrence of the top event, where basic event number 1 (absence of safety sign) appears in all combinations, followed by basic event number 4 (lack of inspection) and number 5 (dust accumulation) with 4 occurrences each from the total of 12 combinations that appear.

3. Worker squeezed in cylinder

The following is an FTA diagram regarding the analysis of the causes of the risk of worker squeezed in cylinder hazard. The following can be seen in Figure 4.

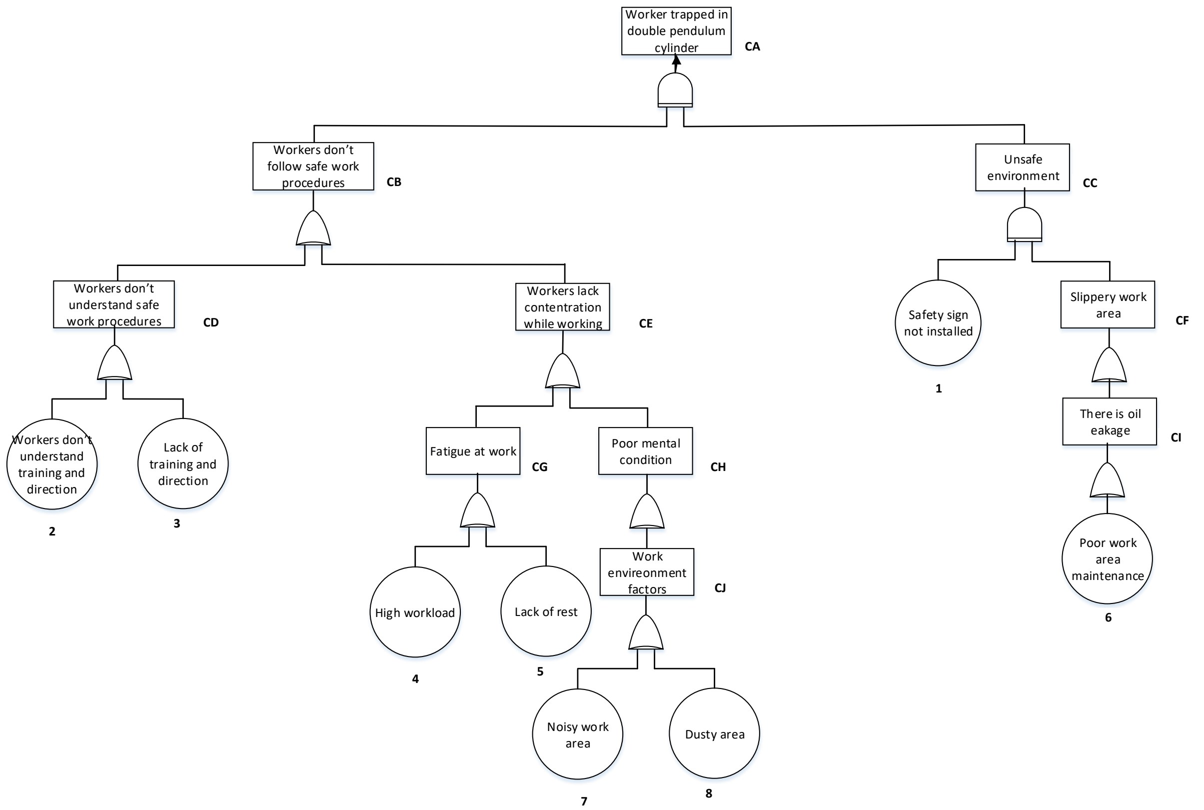

Figure 4. FTA diagram of worker squeezed in cylinder

The following is Table 8 of the minimal cut set calculation using the Mocus method from the FTA diagram of the worker of being hit by rapping hammer. The following can be seen in Table 8 and Table 9.

Table 8. Calculation of minimal cut set for worker squeezed in cylinder

CA *(AND gates)*	CB *(OR gates)*	CD *(OR gates)*	CC *(AND gates)*	CF *(OR gates)*
CB,CC	CD,CC	2,CC	2,1,CF	2,1,CI
	CE,CC	3,CC	3,1,CF	3,1,CI
		CE,CC	CE,1,CF	CE,1,CI

CI *(OR gates)*	CE *(OR gates)*	CG *(OR gates)*	CH *(OR gates)*	CJ *(OR gates)*
2,1,6	2,1,6	2,1,6	2,1,6	2,1,6
3,1,6	3,1,6	3,1,6	3,1,6	3,1,6
CE,1,6	CG,1,6	4,1,6	4,1,6	4,1,6
	CH,1,6	5,1,6	5,1,6	5,1,6
		CH,1,6	CJ,1,6	7,1,6
				8,1,6

Table 9. Minimal cut set results for worker squeezed in cylinder

Minimal *Cut Set*		
2,1,6	4,1,6	7,1,6
3,1,6	5,1,6	8,1,6

Based on Table 9 above, there are 6 combinations of basic events that lead to the occurrence of the top event, where basic event number 1 (absence of safety sign) and number 6 (poor maintenance of the work area) appear in all combinations.

Validity Test

This research conducted a random distribution of questionnaires to 30 respondents directly related to the electrostatic precipitator (ESP) facility. The questionnaire consists of 25 statements derived from the risk hazard identification results at the electrostatic precipitator facility (ESP). The results of the questionnaire distribution show 750 statements with details: 327 statements strongly agree, 284 statements agree, 105 statements are neutral, 31 statements disagree, and 3 statements strongly disagree with the identified hazard risks in the electrostatic precipitator facility. (ESP). After the data from the questionnaire assessment has been successfully obtained, the researcher then conducts validity and reliability tests on the questionnaire to ensure the presented data is accurate. Based on the validity test results using SPSS software, it was found that each item is considered valid because the r-count value > r-table. The statements in the research data questionnaire are considered reliable or consistent because they have a Cronbach's alpha value of 0.967.

Risk Control

Risk control in this study uses the Hierarchy of Control approach based on the fault tree analysis diagram that has been created. This risk control aims to minimize or reduce the level of danger that may occur. Based on the hierarchy of control, risk management can be carried out through elimination, substitution, engineering control, administrative control, and personal protective equipment.

a. Risk Control of Worker squeezed in Slopping conveyor

Risk control for workers getting caught in a slopping conveyor according to the Hierarchy of Control, there are 3 types of risk control recommendations, namely Engineering control, Administrative control, and Personal Protective Equipment (APD). Risk control recommendations through engineering control can be implemented by installing signs/safety signs in the work area. Risk control recommendations through Administrative control include monitoring work (by checking the completeness of work permits such as SOPs, etc.), conducting regular evaluations or updates of SOPs to align with the working environment conditions, making it a preventive step against workplace accidents, and providing regular training and supervision to workers so they understand the importance of occupational health and safety (K3). Recommendations for risk control using personal protective equipment are the last resort in risk management. The appropriate personal protective equipment to reduce the risk of being pinched by a slopping conveyor is gloves to protect the hands and safety shoes to protect the feet.

b. Risk Control of Worker of being hit by rapping hammer

Risk control for the risk of workers being struck by a rapping hammer according to the Hierarchy of Control includes two types of risk control recommendations engineering control and administrative control. Risk control recommendations through engineering control include installing signs/safety signs in the work area and locking out energy sources during repairs or replacements. Risk control recommendations through Administrative control can be implemented by creating a checklist before work or providing a short SOP training regarding the tasks to be performed, as well as checking the completeness of work permits (permit to work).

c. Risk Control of Worker squeezed in cylinder

Risk control for workers getting caught in cylinders according to the hierarchy of control includes 2 types of risk control recommendations, namely engineering control and administrative control. Risk control recommendations through engineering control include locking the cylinder during maintenance or replacement. The goal is to prevent machine errors during repairs, ensuring the cylinder does not move while work is in progress, and installing signs/safety signs in the work area. Risk control for administrative control can be carried out by providing training on the hazards present in the work area, as well as supervising the completeness of work permits such as permits to work, SOPs, and conducting short training before work.

4. Result and Discussion

Based on the research that has been conducted, the researchers can draw the following conclusions: The results of the hazard risk identification at the Electrostatic Precipitator (ESP) facility using the hazard identification, risk assessment, and risk control (HIRARC) method indicate that there are 5 hazard risks in the roller bearing scrapper replacement activity, 3 hazard risks in the slopping conveyor repair activity, 5 hazard risks in the sprocket scrapper replacement activity, 2 hazard risks in the safety valve replacement activity, 3 hazard risks in the rapping hammer repair activity, 3 hazard risks in the grease line repair & cleaning activity, and 4 hazard risks in the double pendulum cylinder repair activity. The results of the risk assessment on the Electrostatic Precipitator (ESP) facility show that there are 3 Low risks, 4 Moderate risks, and 15 High risks, and 3 risks categorized as Extreme. The hazards categorized as Extreme are workers being pinched by the slopping conveyor during slopping conveyor repair activities with a score of 12, workers being struck by the rapping hammer during rapping hammer repair activities with a score of 12, and workers being pinched by the cylinder during double pendulum cylinder repair activities with a score of 12. Based on the FTA diagram analysis, several risk control recommendations were obtained. Recommendations for controlling the risk of workers being caught in a slopping conveyor include installing safety signs, supervising work permits, and evaluating SOPs to ensure they are suitable for the ever-changing environmental conditions, as well as providing regular and periodic training. Recommendations for controlling the risk of workers being struck by a rapping hammer include safety signs and locking the energy source on the rapping hammer, creating a checklist before work, or providing short SOP training on the tasks to be performed, as well as checking the completeness of work permits (permit to work). Recommendations for controlling the risk of workers being caught in a cylinder include locking the cylinder during repair or replacement, installing safety signs, providing training on the hazards present in the work area, and supervising the completeness of work permits such as permit to work.

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