Risk assessment

Collaborative Robot Safety System

Contents

1 Introduction

This risk assessment is used to develop a safety system for the Collaborative Robot Safety System project as part of the Raak (G)een Moer aan Project. The goal of the project is to develop a modular safety system for robotic arm for collaborative use with humans.

In the selection of the hazards, the additional hazards from application-specific components, such as end-effectors are not considered, because these topics are out of scope for the safety system that is being developed in this project.

The specifications of the robotic arm in the use case of the Collaborative Robot Safety System project are to be determined while writing the first version of this risk assessment. For this project the ABB IRB140 is used.

This document is based on ISO 12100, ISO 10218-1, ISO 10218-2, ISO 13849-1 and ISO TS 15066

Safety measures are taken using the process as displayed in Figure 1. This figure can be found in ISO 13849-1.

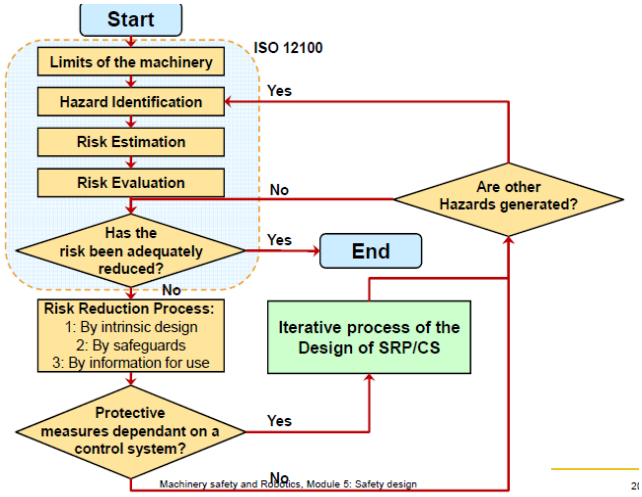


Figure 1 Procedure for taking safety measures

2 Basic machine description

2.1 Intended use

The ABB IRB 140 robot, Figure 2, is an industrial robot. Without an additional safety system, the workspace of the ABB IRB 140 needs to be isolated from humans.

The main task of this robot is to tighten nuts and bolts on an auger (Figure 3) in a shared environment with humans. The ABB IRB 140 is in this case mounted on a stationary frame. This robot operates in an industrial workspace, where multiple tools and objects may enter its workspace. The length of a workpiece (on which an auger needs to be attached) may vary between 60 cm and 600 cm with a mass varying between 100 kg and 3000 kg.

Figure 2 ABB IRB 140 robot. No end-effector is attached

Figure 3 Auger with nuts and bolts

2.2 Machine components

The ABB IRB 140 consists of a base with two links and an end-effector. The end-effector can be taken off the robot and switched with another end-effector for a specific task.

3 Machine specifications

Machine Limits	
Machine Name/Type	ABB IRB 140
Intended Environment	Indoors industrial
Intended Use	Tighten nuts and bolts in a workspace which is shared with humans
Robot mass	98 [kg]
Robot payload	6 [kg]
Max speed	2.5 [m/s]
Machine Dimensions	Radius of 810 [mm]
Machine Environment	Indoors, dry, clean, non-explosive, non-flammable

Operational and Maintenance Information	
Operational Information	
No. of Operators	1
Maintenance Operation	
Maintained by	Operator, Maintenance Technician
Maintenance Frequency	Weekly
Cleaning	Operator
Jamming repair	Operator

Power source	
Main Feed, Elec. Supply:	200–600 V, 50/60 Hz
Pneumatic Supply	Not Applicable
Hydraulic Supply	Not Applicable

4 Hazards

4.1 Hazard identification

Hazards are determined by considering the following sources:

- Annex I of ISO 10218-1
- Annex I of ISO 10218-2
- ISO TS 15066
- Reasonable foreseeable misuse
- Common sense

In the selection of the hazards, the additional hazards from application-specific components, such as end-effectors are not considered, because these topics are out of scope for the safety system that is being developed in this project.

4.2 Risk classification method

Two different risk analysis methods are considered: the Fine & Kinney method and the 14-point risk graph method.

For this risk analysis, the Fine & Kinney method was best suited according to the pros and cons in Table 1. The possibility of avoidance of the hazard is not considered in this risk assessment, because all hazards will be considered unavoidable. To determine performance levels (PL) in a later stage of risk reduction, all hazers will again be considered unavoidable.

Table 1 Methods for risk analysis'

Fine & Kinney		**14-point risk graph**	
Pros	**Cons**	**Pros**	**Cons**
Prioritizing is easy	Outcome varies per assessor	Unambiguous results from different assessors	Prioritizing is difficult
Experience within the team			

The downside of the Fine & Kinney method is a varying outcome per assessor. This issue is tackled by determining risk values in two groups of two team members. Inconsistent results are then discussed with all six team members. Ambiguous results can be clarified using this method.

All hazards are ranked at different risk levels, which consist of grades for severity, exposure time and probability, according to formula 1. For each of these factors, a specific grade is assigned according to a given consequence, duration or chance. The combination of each grade and corresponding consequence is based on values taken from the Fine & Kinney method.
The classification by Fine & Kinney is considered unsatisfying by the project team, because of a lack of options. Additional consequences, time indications and chances are added as suggested and agreed upon by all six team members. Corresponding grades are determined by adding all newly suggested grades and dividing the result by the number of suggestions (i.e. participating team members). The grading process is then repeated to rule out unsatisfying results.

Grading for Severity, Exposure time and Probability can be found respectively in Table 2, Table 3 and Table 4.

$$\text{Risk} = \text{Severity} \times \text{Exposure time} \times \text{Probability} \quad (1)$$

Table 2 Grading severity

Severity (S)	
Grade	**Consequence**
1000	Many fatalities
300	Multiple fatalities
200	One fatality
100	Major permanent injury
37.5	Minor permanent injury/ Major fracture/ Grade 3 burns/ Deep cut

22	Minor fracture/ Grade 2 burns/ Shallow cut
6.25	Absent from work/ Grade 1 burns
1.5	First aid treatment

Table 3 Grading exposure time

Exposure time (E)	
Grade	**Duration**
10	Constant
8	Hourly
6	Daily
3	Monthly
2	Weekly
1	Several times a year
0.5	Very seldom

Table 4 Grading probability

Probability	
Grade	**Chance**
10	Almost surely
6	Quite possible
3	Unusual but possible
1	Possible under certain conditions
0.5	Very unlikely
0.2	Nearly impossible
0.1	Virtually impossible

Finally, the risk is classified according to Table 5. This classification table is a scaled version of the original Fine & Kinney version, in order to match the grading system that is being used in this risk assessment.

Table 5 Risk classification table

Risk classification table		
Very High Risk = Stop	R>5000	
High Risk = Immediate Measures	2000 < R < 5000	
Important Risk = Short-term Measures	500 < R < 2000	
Possible Risk = Long-term Measures	100 < R < 500	
Acceptable Risk = No Measures	R < 100	

4.3 Risk analysis

All hazards and classifications can be found in Table 6.

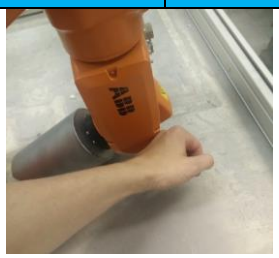
Table 6 Hazards with corresponding risks

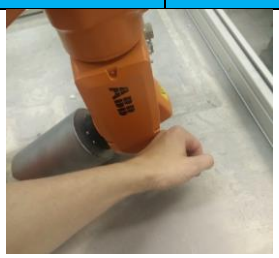
Hazards	Severity	Probability	Exposure	Risk	Risk classification
Mechanical:					
The robot could accidently touch a worker	1.5	10	10	150	
The robot could accidently run into a worker	200	10	10	20000	
Workers limbs could get stuck in the robot	37.5	6	10	2250	
Worker could get crushed between walls or other objects around the robot	200	6	10	12000	
Worker could get pinned between walls or other objects around the robot	1.5	6	10	90	
A worker's hair could get entangled in the robot arm	22	6	10	1320	
A worker's loose clothing could get entangled in the robot arm	22	3	10	660	
A worker's jewelry could get entangled in the robot arm	37.5	1	10	375	
Robot end effector could drop screws	6.25	1	10	62.5	
Sharp objects held by the end effector could cut the worker	200	1	10	2000	
Parts on which the robot arm is working break or fly off and hit worker	100	0.5	10	500	
The robot arm could fall over if not secured properly	200	0.2	10	400	
Human body (in motion) collides with robot(stationary)	6.25	3	10	187.5	
Robot payload collides with human body	200	10	10	20000	
Human body collides with payload	100	3	10	3000	
The payload disconnects from robot and collides with human body	200	1	10	2000	
Electrical hazard:					
Power supply failure due to short circuit	200	0.5	10	1000	
Power supply failure due to voltage overload	200	0.5	10	1000	
End effector cables disconnect from payload/arm	200	1	10	2000	
Noise hazard:					

Noise produced by the robot and effector	100	6	10	6000	
Vibration hazard:					
The robot/table/objects around could vibrate and create discomfort	6.25	3	10	187.5	

Hazards are not specific for the ABB IRB140, they can apply for other brands and types of robotic arms.

As stated in section 4.1: in the selection of the hazards, the additional hazards from application-specific components, such as end-effector, payload, fixtures, working environment, etc. are not considered. All remaining hazards are elaborated below.

Hazard Identification				Hazard No.	1.1
Title	Touch a worker				
Location	Shared workspace				
Target	Human eye				
Activity	Normal operation in shared workspace				
Hazard Type	Mechanical				
Consequence	Impact				
Description	The robot could accidently touch a worker				
References:	ISO 10218-1				
Risk Estimation and Evaluation					
Severity	100	Exposure time	10		
Probability	1	Risk (S x E x P)	1000		
Important risk					
Risk Reduction				Reference	
Cover payload					
Risk Estimation and Evaluation					
Severity	1.5	Exposure time	10		
Probability	1	Risk (S x E x P)	15		
Acceptable risk					

Hazard Identification				Hazard No.	1.2
Title	Run into worker				
Location	Shared workspace				
Target	Head (temple)				
Activity	Normal operation in shared workspace				
Hazard Type	Mechanical				
Consequence	Impact				
Description	The robot could accidently run into a worker				
References:	ISO 10218-1				
Risk Estimation and Evaluation					
Severity	200	Exposure time	10		
Probability	10	Risk (S x E x P)	20000		
Very high risk					
Risk Reduction				Reference	
Add a padding on the robot to reduce impact				ISO TS 15066 [5.5.5.4 b1]	
Risk Estimation and Evaluation					
Severity	37.5	Exposure time	10		
Probability	10	Risk (S x E x P)	3750		
High risk					
Risk Reduction				Reference	
Adapting speed depending on distance to human				ISO 10218-1 [5.6.2]	
Risk Estimation and Evaluation					
Severity	6.25	Exposure time	10		
Probability	3	Risk (S x E x P)	187.5		
Possible risk					

Hazard Identification			Hazard No.	1.3
Title	Limbs get stuck			
Location	Robot mechanical structure with holes			
Target	Limbs, arm			
Activity	Normal operation in shared workspace			
Hazard Type	Mechanical			
Consequence	Crushing, entrapment			
Description	Workers limbs could get stuck in the robot			
References:	ISO 10218-1			
Risk Estimation and Evaluation				
Severity	37.5	Exposure time	10	
Probability	6	Risk (S x E x P)	2250	
High risk				
Risk Reduction			Reference	
Cover the robot so body parts can't get stuck in the robot.			ISO TS 15066 [5.5.5.4 a3]	
Risk Estimation and Evaluation				
Severity	37.5	Exposure time	10	
Probability	0.2	Risk (S x E x P)	75	
Acceptable risk				

Hazard Identification			Hazard No.	1.4
Title	Human crushed			
Location	On a heavy obstacle (e.g. wall or workpiece)			
Target	Head (temple)			
Activity	Normal operation in shared workspace			
Hazard Type	Mechanical			
Consequence	crushing			
Description	Worker could get crushed between the robot and the workbench or workpiece			
References:	ISO 10218-1			

Met opmerkingen [la1]: Between wat?

Risk Estimation and Evaluation			
Severity	200	Exposure time	10
Probability	3	Risk (S x E x P)	6000
Very high risk			

Risk Reduction	Reference
Adapting speed depending on distance to human	ISO 10218-1 [5.6.2]

Risk Estimation and Evaluation			
Severity	200	Exposure time	10
Probability	1	Risk (S x E x P)	2000
High risk			

Risk Reduction	Reference
Measure the force feedback	

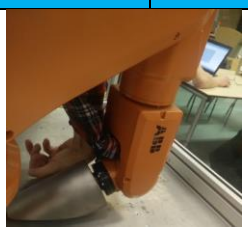
Risk Estimation and Evaluation			
Severity	37.5	Exposure time	10
Probability	1	Risk (S x E x P)	375
Possible risk			

Hazard Identification			Hazard No.	1.5
Title	Human pinned			
Location	On a heavy obstacle (e.g. wall or workpiece)			
Target	Head (temple)			
Activity	Normal operation in shared workspace			
Hazard Type	Mechanical			
Consequence	Trapping			
Description	Worker could get pinned down between the robot and walls or other objects			
References:	ISO 10218-1			

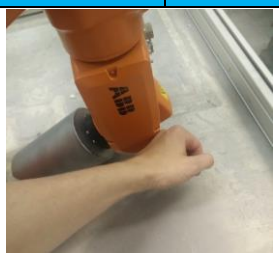
Risk Estimation and Evaluation			
Severity	1.5	Exposure time	10
Probability	1	Risk (S x E x P)	15
Acceptable risk			

Met opmerkingen [la2]: Robot los zetten op wielen onderzoeken. Dan duwt die zichzelf weg

Hazard Identification				Hazard No.	1.6
Title	Human hair entangled				
Location	Shared workspace				
Target	Human hair				
Activity	Normal operation in shared workspace				
Hazard Type	Mechanical				
Consequence	Entanglement, Drawing-in				
Description	A worker's hair could get entangled in the robot arm				
References:	ISO 10218-1				
Risk Estimation and Evaluation					
Severity	22	Exposure time	10		
Probability	6	Risk (S x E x P)	1320		
Important risk					
Risk Reduction				Reference	
Cover the robot so body parts can't get stuck in the robot.				ISO TS 15066 [5.5.5.4 a3]	
Risk Estimation and Evaluation					
Severity	22	Exposure time	10		
Probability	1	Risk (S x E x P)	220		
Possible risk					
Risk Reduction				Reference	
Adapting speed depending on distance to human				ISO 10218-1 [5.6.2]	
Risk Estimation and Evaluation					
Severity	6.25	Exposure time	10		
Probability	1	Risk (S x E x P)	62.5		
Acceptable risk					

Hazard Identification				Hazard No.	1.7
Title	Clothes entangled				
Location	Robot joints				
Target	Clothes (sleeve, hood)				
Activity	Normal operation in shared workspace				
Hazard Type	Mechanical				
Consequence	Entanglement, Drawing-in				
Description	A worker's loose clothing could get entangled in the robot arm				
References:	ISO 10218-1				
Risk Estimation and Evaluation					
Severity	22	Exposure time	10		
Probability	3	Risk (S x E x P)	660		
Important risk					
Risk Reduction				Reference	
Cover the robot so clothing can't get stuck in the robot.				ISO TS 15066 [5.5.5.4 a3]	
Risk Estimation and Evaluation					
Severity	22	Exposure time	10		
Probability	1	Risk (S x E x P)	220		
Possible Risk					
Risk Reduction				Reference	
Adapting speed depending on distance to human				ISO 10218-1 [5.6.2]	
Risk Estimation and Evaluation					
Severity	6.25	Exposure time	10		
Probability	1	Risk (S x E x P)	62.5		
Acceptable risk					

Hazard Identification			Hazard No.	1.8
Title	Jewelry entangled			
Location	Robot joints			
Target	Jewelry(fingers, neck and arms)			
Activity	Normal operation in shared workspace			
Hazard Type	Mechanical			
Consequence	Entanglement, Drawing-in			
Description	A worker's jewellery could get entangled in the robot arm			
References:	ISO 10218-1			
Risk Estimation and Evaluation				
Severity	37.5	Exposure time	10	
Probability	1	Risk (S x E x P)	375	
Possible risk				
Risk Reduction			Reference	
Adapting speed depending on distance to human			ISO 10218-1 [5.6.2]	
Risk Estimation and Evaluation				
Severity	6.25	Exposure time	10	
Probability	1	Risk (S x E x P)	62.5	
Acceptable risk				

Hazard Identification			Hazard No.	1.9
Title	Push workpiece			
Location	Shared workspace and surrounding area			
Target	Lower body			
Activity	Normal operation in shared workspace			
Hazard Type	Mechanical			
Consequence	crushing			

Description	The robot could push a heavy workpiece, which makes it fall on workers around the workspace of the robot.			
References:	ISO 10218-1			
Risk Estimation and Evaluation				
Severity	100	Exposure time		10
Probability	6	Risk (S x E x P)		6000
Very high risk				
Risk Reduction			Reference	
Adapting speed depending on distance to workpiece			ISO 10218-1 [5.6.2]	
Risk Estimation and Evaluation				
Severity	100	Exposure time		10
Probability	0.5	Risk (S x E x P)		500
Important risk				
Risk Reduction			Reference	
Use force feedback				
Risk Estimation and Evaluation				
Severity	100	Exposure time		10
Probability	0.1	Risk (S x E x P)		10
Acceptable risk				