Risk assessment

Collaborative Robot Safety System

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# 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-effector, payload, fixtures, working environment, etc. 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 procedure as displayed in Figure 1. This figure can be found in ISO 13849-1.

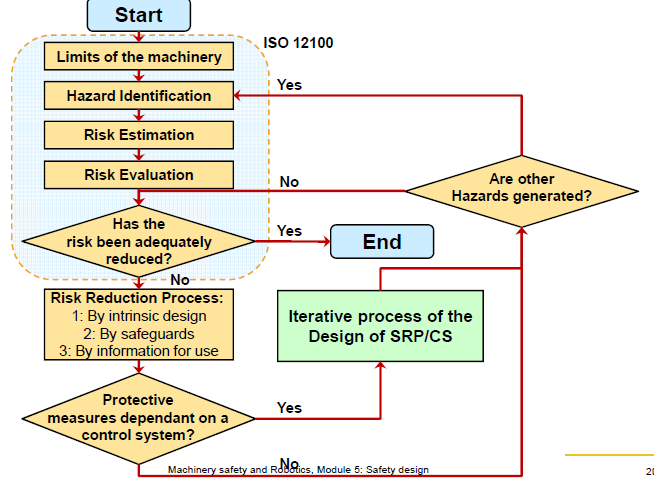


Figure Procedure for taking safety measures

# Basic machine description

## 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 diverse 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 cmwith a mass varying between 100 kg and 3000 kg.



Figure 3 Auger with nuts and bolts

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

## 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.

# 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 |

# Hazards

## 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-effector, payload, fixtures, working environment, etc. are not considered, because these topics are out of scope for the safety system that is being developed in this project.

## 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.

Table 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.

Risk = Severity x Exposure time x Probability (1)

Table 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 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 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 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 |  |

## Risk analysis

All hazards and classifications can be found in Table 6.

Table 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 | 6 | Risk (S x E x P) | | 90 |
| 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 | | | |
| 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 | | | |
| 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 | | | | |
|  |  |  |  |  |
| 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 | | | | |