ENT SENIOR DESIGN PROJECT REPORT

Robot Safety Interlocks For ABB

IRB 140 Robot

Submitted to

Professor Cooney

Engineering Technology Department

by

Jacob Mitchell, Joe Grissom, Timothy Robinson

April 6, 2022

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Revision History

Version	Date	Revised by	Description
1.0	6 April 2022	Jacob M. Joe G. Timothy R.	Initial version
2.0	17 April 2022	Jacob M. Joe G. Timothy R	Revised Updated Schematics
3.0	5/2/2022	Jacob M. Joe G. Timothy R	Complete

EXECUTIVE SUMMARY

The Robot Interlocks Capstone project serves its purpose in protecting those in the room of the ABB robot. The entire system was designed by the Robot Interlocks Team of 2021-2022, and built by Campus Facility Services. The students in charge of the project are Joe Grissom, Jacob Mitchell, and Timothy Robinson. The Academic Advisor and supervisor of the project was Professor Elaine Cooney. The project function is to halt robot operation once the door interlock loses contact with its actuator, enclosure gate being opened, or once the area scanners detect obstruction of any kind within the robot enclosure. All documentation used by the team has been referenced within this document. Since this project will continue to be an ongoing project in the future, it is highly recommended to read through this document before going forward with robot operations.

1. INTRODUCTION

The Department of Engineering Technology of IUPUI received an ABB robot through donation a few years ago. This prompted a steady plan to do a capstone project on the robot starting with implementing safety. Our group is made up of Electrical and Computer Engineering Technology majors with experience in industrial controls and hardware. We decided that for complete safety to be the end goal, the project would be a copy of what one would see in a normal industrial setting. The robot enclosure, located in room ET222 in the ET building, is equipped with a safety door interlock, two area scanners, a light stack and more safety equipment to ensure no injury or equipment damage occurs while the robot is operating. The safety aspect is the first step to the capstone project, the robot itself is NOT powered on and requires the next generation to take over.

a. Scope

The current process system for the safety of the ABB robot consists of the hardware that comes with the initial design from the manufacturer. The model for this robot is a IRB 140 which include safety options such as collision detection, full path retraction, an emergency stop button located on the controller for the robot, and a safety lamp. This robot is also in compliance with EN ISO safety standards, European standards, UL, ANSI, and other standards. These are the current safety standards as well as hardware that are included in the current safety process.

The new process is meant to build off of what is already included in the previous process to improve the safety system further to protect not only the users, but the robot as well. The new process involves adding in hardware such as the door interlock system which will automatically halt the robot if the gate is opened while the robot is currently operating, using a physical barrier to separate the robot from the user, using a safety relay to include safety parameters such as restricting the range of movement, safety manual thoroughly describing properly handling of the robot and finally physical signs indicating potential dangers from the robot. The objective of the new process is to activate acting as its own emergency stop button to ensure that even if the user does not stop the robot our program additions will do it automatically.

b. Marketing Requirements

The customer requirements are that the robot has a thoroughly designed safety system by researching industry safety standards, meeting with members of industry that know current safety standards, design and acquire hardware for the safety system, design and program safety programs for the robot, designate robot installation location, and design a safety manual for a wide variety of users to understand. These items should then give an end-user a feeling of safety when using the robot because no matter how much they know of how the system fully functions they will not be in harm's way when using the robot.

2. SPECIFICATION REQUIREMENTS

Functional Specification

3. HIGH LEVEL DESIGN

The safety system is designed so that it will have multiple layers of protection and if one of those systems fail the other systems will make up for it. The safety system uses both physical barriers for protection along with a variety of technologies for keeping people safe. The robot has been mounted on the floor in room ET 222 and it has been surrounded by a machine fencing to enclose the robot with a single gate entrance. The technology implemented in this system are two area scanners, one door interlock, one light tree, one estop, and three safety relays.

The area scanners are located inside the enclosure on opposite sides of the robot causing the robot to shut down if anyone enters the enclosure. The door interlock is located on the gate and requires an actuator to be removed before entering the enclosure which will halt the robot if it is running. The estop button when pressed will halt robot progress until it set back to normal. The safety relays are meant to check problems in the system if something causes the safety system to activate. The light tree has two colors and a buzzer with green meaning if everything is working normally while the red light along with the buzzer will go off if any of the safety systems are broken. These systems all work coherently to create a system that will protect everyone and make it safe for the robot to be powered on.

Below is the link to the high level documentation with more details. Diagrams, schematics, and other relative documentation can be found in the appendices section of this report.

https://drive.google.com/drive/folders/1bocHjHCY6UC0WSAkWSuzavs9a74sIRbY?usp=sharing

4. LOW LEVEL DESIGN

The safety system is designed so that it will have multiple layers of protection and if one of those systems fail the other systems will make up for it working in series. The safety system uses both physical barriers for protection along with a variety of technologies for keeping people safe. The robot has been mounted on the floor in room ET 222 and it has been surrounded by machine fencing acquired from Uline to enclose the robot with a single gate entrance. Located on the outside of the fence are also safety signs including a safety sign on who to call in case of an emergency, an additional who to call sign is located inside the enclosure. Inside the enclosure are three layers of tape with two being anti-slip tape to avoid falling in the enclosure to avoid injury and reflective tape indicating the safe zone for being outside of the robots calculated reach.

Moving on to the technology that is implemented into the robot there are two Keyence area scanners, one Rockwell door interlock, two Rockwell safety relays, one Siemens safety relay, and one light tree. The door interlock is located on the gate with the actuator connected to the gate. The actuator must be removed from the door interlock to enter the enclosure and will also break the circuit to cause power to be lost to the robot and make the light tree go red with the buzzer. The area scanners are located on opposite sides inside the enclosure to cover the whole enclosure ensuring no blind spots are possible. The area scanner uses lidar technology in order to locate movements inside the robot that break the safe area that was designed using a free software program to designate the detection zones. The area scanners will cause the power to halt from the robot while anyone remains inside the enclosure causing the light to go red as well cause the buzzer to go off. They will remain in this state until everyone has left the enclosure, once this is doen the area scanners as well as light tree will return to a normal state. The estop button when pressed will halt robot progress until it set back to normal. Finally the safety relays are all connected to the technology in order to monitor the systems to ensure normal operation. If one of these safety systems are set off it will cause the safety relays to activate which have built in redundancy to check the errors on the systems cutting power to the robot until systems are returned to normal operation. We were also tasked with finding a transformer to step up the power supply to the controller, which is documented in the appendicies.

Below is the link to the low level documentation with more details. Diagrams, schematics, and other relative documentation can be found in the appendices section of this report.

https://drive.google.com/drive/folders/1bocHjHCY6UC0WSAkWSuzavs9a74sIRbY?usp=sharing

5. TEST METHODOLOGY & TEST RESULTS

All hardware equipment that was bought and delivered was appropriately tested before being mounted into place. The first piece of equipment that was tested was the power supply, normal wiring configuration and standard power through the supply made the test results successful. After the power supply was powered on, the remaining equipment was gathered and tested individually. The door interlock, both area scanners, PLC, power supply for PLC, safety relays, and stack light all work as expected and are compatible with the obtained software. The area scanner software is called "SZ configurator" and is best worked on as it is monitoring its designated area. We used normal relays in place of the safety relays for testing and demonstration purposes. The documentation for the demonstration wiring and setup will be provided in the appendices.

6. CONCLUSIONS

The Robot Safety Interlocks final project was demonstrated to IAB members, professors, and fellow students and alike. All were able to walk in and interact in the enclosure as the robot simulation would be halted. The project works as intended and will continue to function for years to come, with proper maintenance on equipment along the way. The Robot Interlocks Capstone project serves its purpose in protecting those in the room of the ABB robot. The entire system was designed by the Robot Interlocks Team of 2021-2022, and built by Campus Facility Services. The students in charge of the project are Joe Grissom, Jacob Mitchell, and Timothy Robinson. The Academic Advisor and supervisor of the project was Professor Elaine Cooney. The project function is to halt robot operation once the door interlock loses contact with its actuator, enclosure gate being opened, or once the area scanners detect obstruction of any kind within the robot enclosure. The Robot Safety Interlocks team has high hopes on the future of the robot project and wishes the new generation of students its best wishes.

RECOMMENDATIONS

- Please call Joe Grissom at 317-361-0576 or email jegrissom0115@gmail.com for safety concerns and advice on the enclosure.
- Contact Rich Collins at rcollins@kirbyrisk.com or call 317-631-2326 and explain the need for the 3-phase step-up transformer 240V to 480V (Part # **HT85F6AS)** for the Robot controller.
- After coming to a decision on what the robot's tasks will be, discuss if the controller should be inside or outside the enclosure with the transformer.
- For any need to have something mounted in the room, go to https://cfs.iupui.edu/forms/work-request.html and put in 1295400 as the work order or contact Tiffany Llewan if the account number has changed.
- Discuss the need for a power switch to the safety enclosure, so the need to unplug it directly does not hinder any progress made on the project.
- For Area Scanner maintenance assistance, contact Keyence customer service at 1 (888) 539-3623
- For Door Interlock and Safety Relay maintenance assistance, contact Kirby Risk customer service at 877-641-0929.
- For Siemens Safety Relay maintenance assistance, contact Siemens customer service at 1 (800) 743-6367.
- If access to any of the files fails to open, please contact Joe Grissom or your project advisor.

- Please look through the Controller and Robot datasheet before planning the project, inspect the physical controller and robot for accurate part numbers.

INDIVIDUAL ASSESSMENT

The project functions as intended with standard relays but does not work with the safety relays. The entire project should revolve around protecting the robot from damage and protecting people from the robot. The entire project is still in the demonstration phase but works as the ultimate goal of the project. The Robot Interlocks Team highly suggests that the safety relay issue should be brought up to the future senior students who will oversee the project for the year. As said in the recommendations, Joe Grissom will be available to assist with the project going forward and offer advice, recommendations, and even history of the project. The next team is also welcome to make any changes to the safety side of robot enclosure to obtain their goal.

NOTES

- To change the software of the area scanners, SZ-Configurator is free from the keyence website. The needed usb cable is required to begin programming.
- The professors should come to an agreement on what the robot will do and what task it will take, it is up to the Senior Capstone Students to design and plan the project.
- The reset buttons for the safety relays still need to be mounted onto to the junction box, this will be left to the next group in determining where the would fit best once power has been applied to the robot.
- The current system will be left in demonstration mode for the next group to understand how the system works.

REFERENCES

Datasheets-
https://drive.google.com/drive/folders/1qft3MlyJjpVBqVgDJeq34RRrWsuYBl9x?usp=sharing

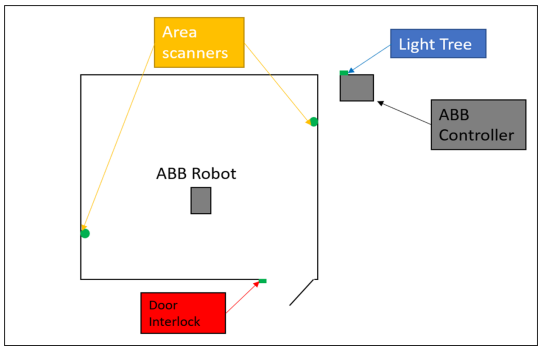
Appendixes

FINAL PROJECT SPECIFICATION (SIGNED)

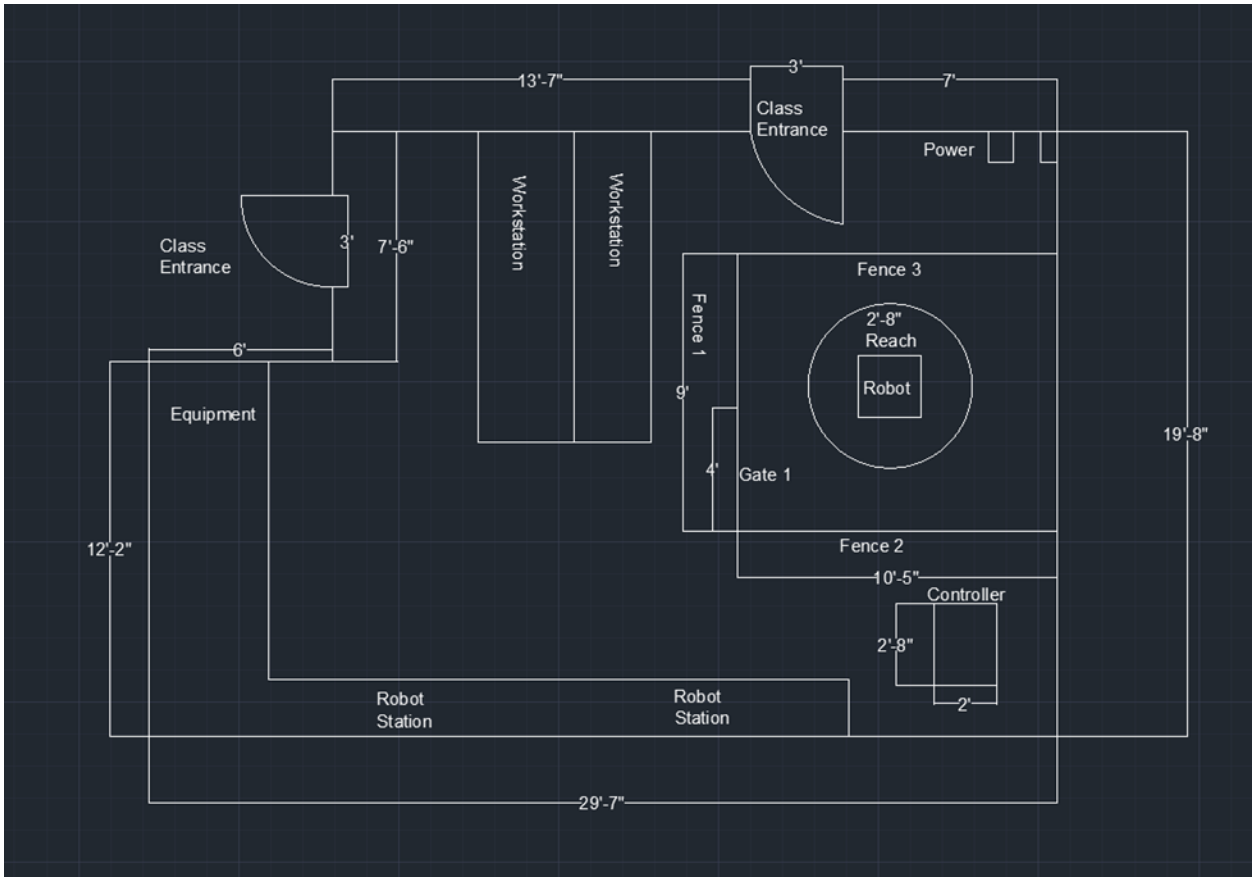
https://docs.google.com/document/d/1FizXry0oXxFGn0_RuG70yiBocnZlc1p5Y6SVvS5XLIc/edit?usp=sharing

- **FINAL PROJECT DESIGN**
  - **MECHANICAL FAB AND ASSEMBLY DRAWINGS WITH DIMENSIONS**

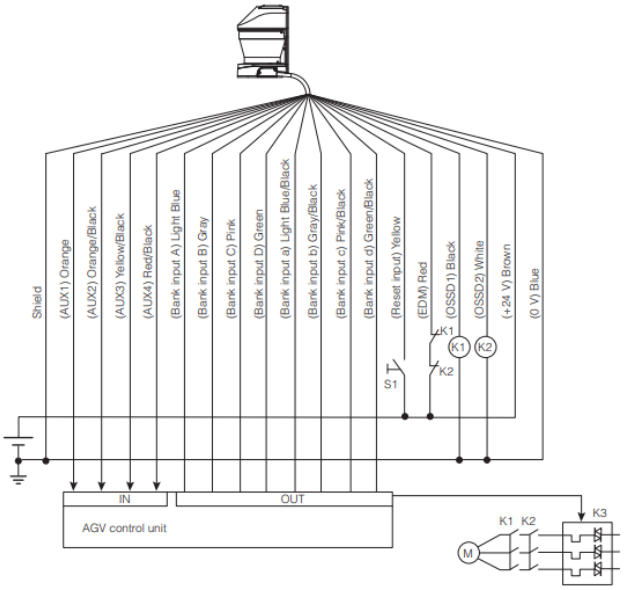
Area Layout



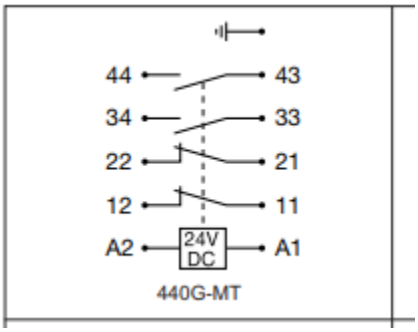
Fence Layout



Area Scanner I/O Assignment

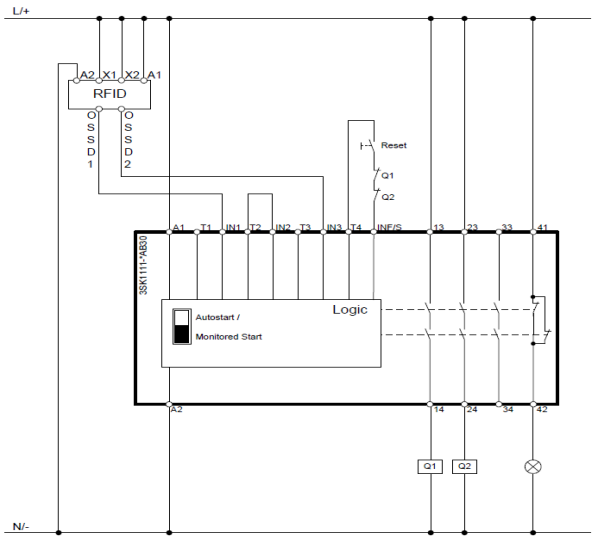


Door Interlock I/O Assignment

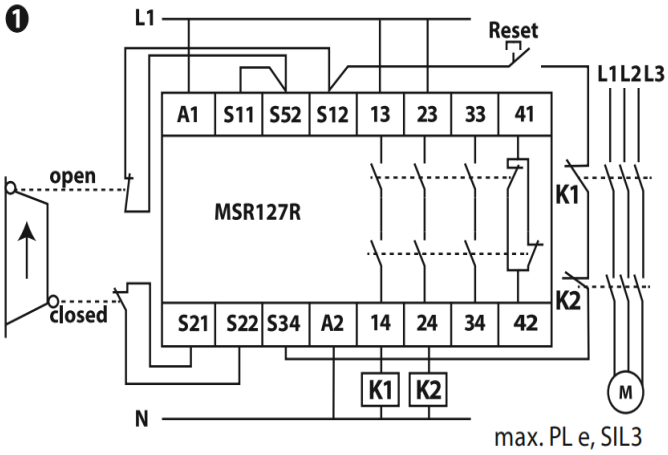


- **ELECTRICAL SCHEMATICS**

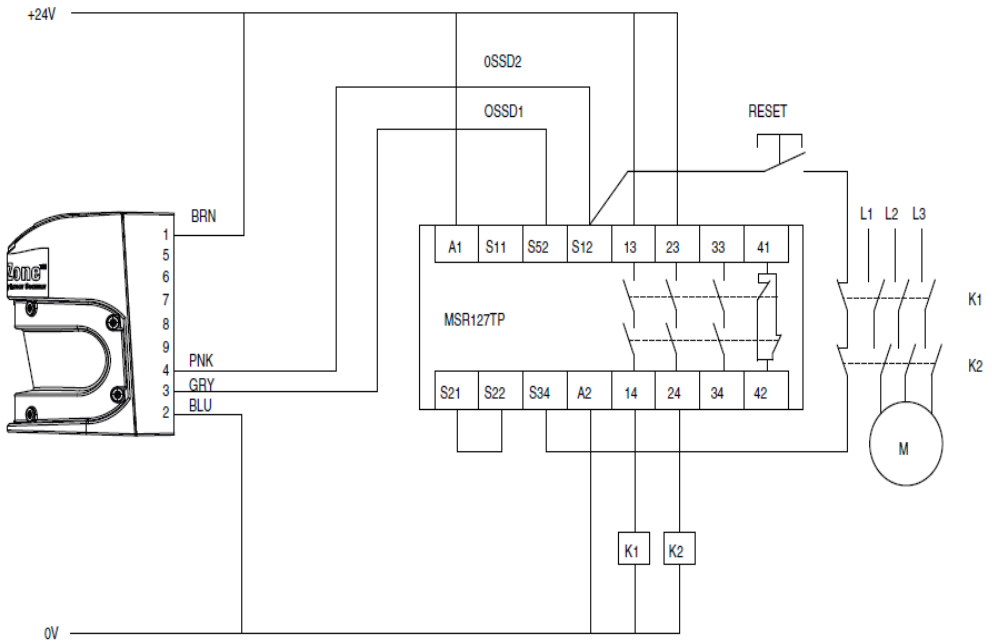
Area Scanner/Siemens Safety Relay



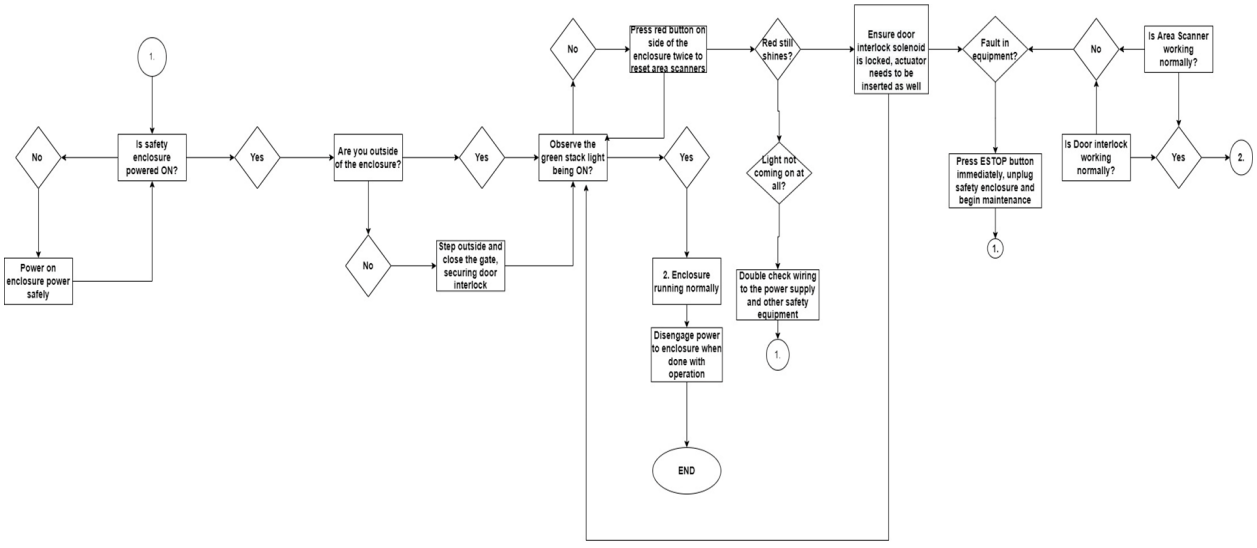
Door Interlock/ Allen Bradley Safety Relay



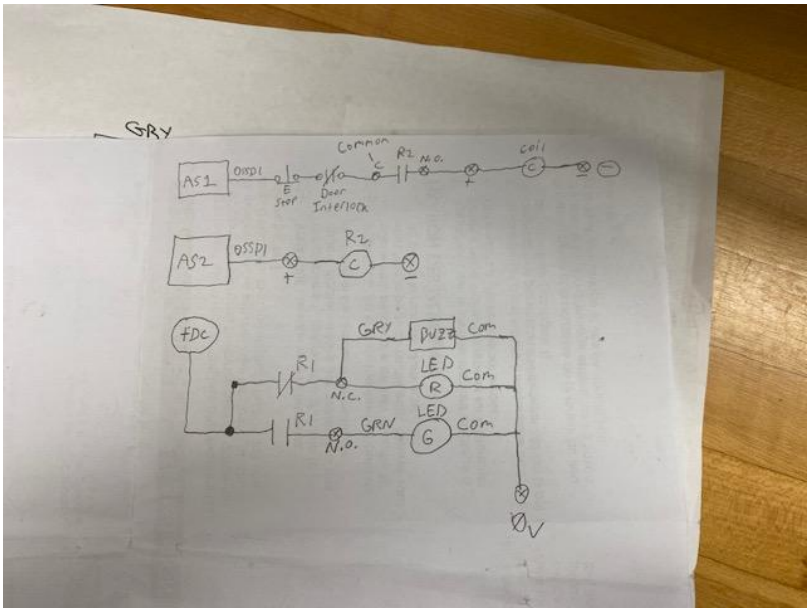
Area Scanner/Allen Bradley Safety Relay



Hardware Block Diagram



Demonstration/Testing Wiring Diagram



- **DESIGN CALCULATIONS**

Transformer recommendation: 3 phase Step up Transformer 6kVA (HT85F6AS)

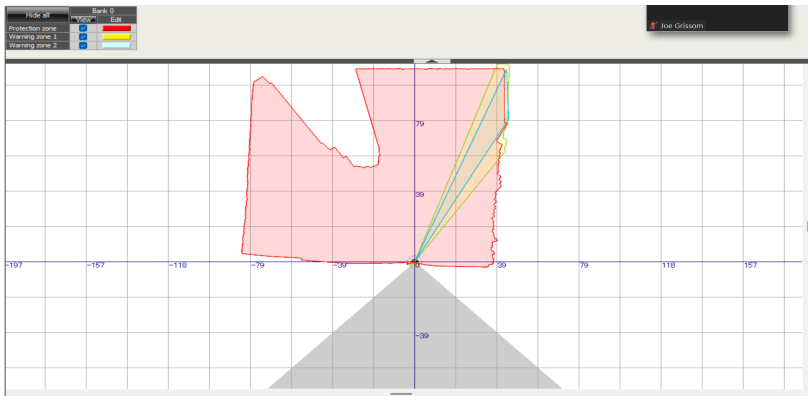
Primary: 220V

Secondary: 480V

Please contact Rich Collins: 317-631-2326 or rcollins@kirbyrisk.com

Or call Kirby Risk customer service and ask for the customized transformer

- **SOFTWARE CODE/ALGORITHMS/FLOWCHARTS**



10 Timothy Robinson

20 Joe Grissom

30 Jacob Mitchell

40 “When powered on area scanner, stack light, and reset button safety features will activate.”

50 “Area scanner will have a specified area safety zone.”

60 “If someone enters Area scanner safety zone robot will halt program.”

70 “Tape will be used on the ground to help show safety zone area being created by the Area Sca

80 “Reset button to reset robot program at any point when not running.”

90 “Three color light stack to specify different stages of how active the robot is.”

100 “Green light to indicate that the robot is running and is experiencing no issues.”

120 “Red light to indicate that the robot is halted due to a breach in the safety devices.”

130 “Area Scanner will have a minimum of three ft safety radius for safety to hardware and users.”

140 “Robot can not be reactivated until safety violation corrected with no obstructions in safety zone.

150 “Reset button will have to be pressed on a red light safety violation before robot can run again.

- **FINAL TEST PLAN**

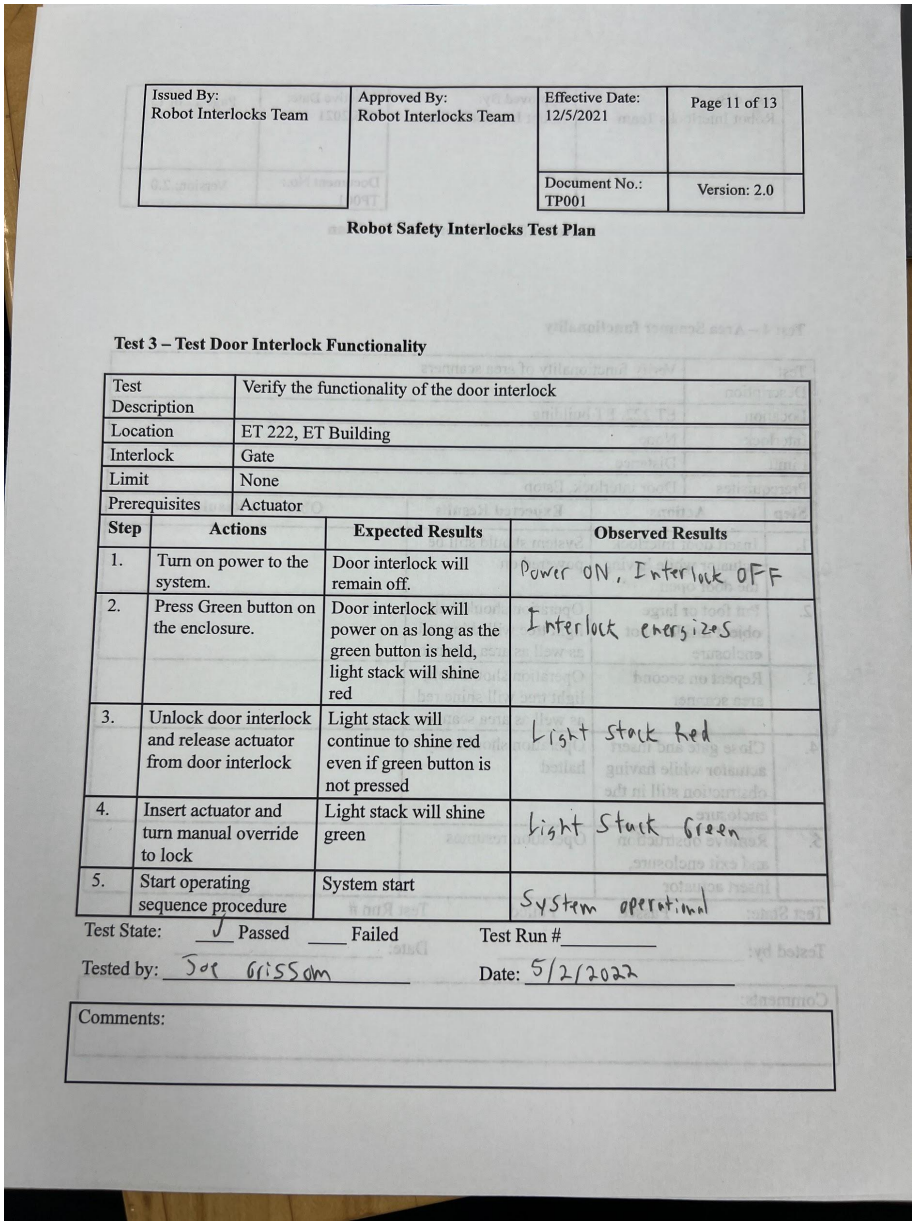
  - **TEST SPECIFICATION**

The area scanner will detect any obstruction or movement around the robot to ensure that no person(s) or objects come into vicinity with the robot while operation is underway. The light tree will signal the current status of the robot, it has 2 colors. Red signifies that operation is halted and green indicates that the robot is operating. A standard E-Stop button is present to stop the robot from an error or emergency that the safety devices could not detect. Finally, a Safety relay will operate with the E-stop button and other devices to fail safely.

- **TEST REPORT**

[Test Plan]

- **LOW LEVEL TEST RESULTS AS NECESSARY**



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		Document No.: TP001	Version: 2.0

Robot Safety Interlocks Test Plan

Test 3 – Test Door Interlock Functionality

Test Description	Verify the functionality of the door interlock
Location	ET 222, ET Building
Interlock	Gate
Limit	None
Prerequisites	Actuator

Step	Actions	Expected Results	Observed Results
1.	Turn on power to the system.	Door interlock will remain off.	Power ON, Interlock OFF
2.	Press Green button on the enclosure.	Door interlock will power on as long as the green button is held, light stack will shine red	Interlock energizes
3.	Unlock door interlock and release actuator from door interlock	Light stack will continue to shine red even if green button is not pressed	Light stack Red
4.	Insert actuator and turn manual override to lock	Light stack will shine green	Light Stack Green
5.	Start operating sequence procedure	System start	System operational

Test State: ✓ Passed ___ Failed Test Run #_____

Tested by: Joe Grissom Date: 5/2/2022

Comments:

Issued By: Robot Interlocks Team	Approved By: Robot Interlocks Team	Effective Date: 12/5/2021	Page 3 of 13
		Document No.: TP001	Version: 2.0

Robot Safety Interlocks Test Plan

Test Pre-Execution Approval

Step	Action	Initial / Date
1.	Obtain Operators Approval and Signature To Perform Procedure	JG 5-2
2.	Ensure All Safe Work Permits and Lockout/Tag Out Procedures Are Followed	JG 5-2
3.	Ensure All Personnel Are Notified of Testing	JG 5-2

Your signature attests that you have reviewed the listed test cases and the test cases are adequate to prove the safe operating condition of the process.

Test Approved By:

Signature Date: 5/2/2022

Joe Grissom
Printed Name

Tester Acknowledgement of Test Plan
Your signature indicates that you have read and understood the Testing protocols.

Tester's Printed name: Joe Grissom Date: 5/2/2022

Tester's Printed name: _____ Date: _____

Tester's Printed name: _____ Date: _____

Issued By: Robot Interlocks Team	Approved By: Robot Interlocks Team	Effective Date: 12/5/2021	Page 9 of 13
		Document No.: TP001	Version: 2.0

Robot Safety Interlocks Test Plan

Test 1 – System Power Checks

Test Description	Verify System Power
Location	ET 222, ET building
Interlock	None
Limit	None

Step	Actions	Expected Results	Observed Results
1.	Plug in the safety enclosure.	Verify System power.	Power comes on Light stuck Red
2.	Safety relay Initialization sequence starts.	Verify system Initializes.	Relays ON
3.	All other equipment will power on	Circuit powered.	Equipment recieves power
4.	Reset all system alarms	System alarms cleared	No Alarms
5.	Unplug safety system power.	Verify enclosure power shuts down safety relay, and all safety equipment power is lost.	Power OFF
6.	Restore System Power.	Power is Restored	Power restored

Test State: ✓ Passed ____ Failed Test Run # 1

Tested by: Joe Grissom Date: 5/2/2022

Comments:

Issued By: Robot Interlocks Team	Approved By: Robot Interlocks Team	Effective Date: 12/5/2021	Page 12 of 13
		Document No.: TP001	Version: 2.0

Robot Safety Interlocks Test Plan

Test 4 – Area Scanner functionality

Test Description	Verify functionality of area scanners
Location	ET 222, ET building
Interlock	None
Limit	Distance
Prerequisites	Door interlock, Estop

Step	Actions	Expected Results	Observed Results
1.	Insert door interlock actuator while having the door open	System should still be powered on	Light stack - Green
2.	Put foot or large object inside robot enclosure	Operation should halt, light tree will shine red as well as area scanner	Light stack and Area Scanner screen - Red
3.	Repeat on second area scanner	Operation should halt, light tree will shine red as well as area scanner	Same results
4.	Close gate and insert actuator while having obstruction still in the enclosure	Operation should stay halted	Same results
5.	Remove obstruction and exit enclosure, insert actuator	Operation resumes	Light stack - Green

Test State: ✓ Passed ___ Failed Test Run # 1

Tested by: Joe Grissom Date: 5/2/2022

Comments:

- **TROUBLESHOOTING & DESIGN IMPROVEMENTS**

  To improve safety of the entire enclosure, the robot interlocks team spent a lot of hours and called every resource available to get the safety relays to communicate with the safety equipment. The resources that were given were followed completely but did not work as intended. For demonstration purposes, the safety enclosure is connected and linked with normal relays. Safety is still applied to the system, if one of the equipment fails while operation is underway then the entire system will not function until the issue is resolved. To improve safety and overall design on the project, wiring exposure is kept to as much of a minimum as possible.

- **FINAL PROJECT PLAN -**

  - **GANTT CHART**

    https://drive.google.com/drive/folders/1fdMW65RqHUvfMwryt6tfSn50MAUjzwK5?usp=sharing

  - **BUDGET/EXPENDITURES/BILL OF MATERIALS (INCLUDES PARTS LIST WITH DESCRIPTION, QUANTITY, MANUFACTURER, MODEL NUMBER, SUPPLIER & STOCK NUMBER, COST)**

    Budget:$9,000

    Total Expenditures: $5,226.84

    Bill of Materials :
    https://drive.google.com/drive/folders/1bocHjHCY6UC0WSAkWSuzavs9a74slRbY?usp=sharing

- **PRESENTATION SLIDES (MIDTERM, FINAL TECHNICAL, FINAL IAB)**

https://drive.google.com/drive/folders/1sZV9t-6ziouRRl7YbNYJaZXM-SnsXlwq?usp=sharing

- **POSTER MASTER**

https://drive.google.com/drive/folders/1SxCE9rl73XwRn6cM4DlJPtxzBDcQsRL4?usp=sharing

- **WEEKLY PROGRESS REPORTS**

https://drive.google.com/drive/folders/1JcAyE-XqW2b0cMSsMar5df4Wi5J1Br6O?usp=sharing