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Control system design for a C-130 Ro-Ro sensor deployment platform

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CONTROL SYSTEM DESIGN FOR A C-130 RO-RO SENSOR DEPLOYMENT PLATFORM

by

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Abstract

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A WVU team of engineers designed and built a palletized system that will be used to deploy surveillance sensors from a C-130 cargo airplane. There will be two pallets, one that will house the Operator Station and one that will carry a mechanical arm with a Sensor Pod, where the sensors will reside. This pallet will be placed on the C-130 rear door, which will be opened while in flight. The mechanical arm is designed to rotate the Sensor Pod underneath the door so the sensors can observe the ground.

Computer/Electrical engineers were asked to design the control circuit for the Sensor Pallet, providing the user with a user interface to control deployment of the mechanical arm and Sensor Pod. The mechanical arm should also be deployable in an automated process, controlled by a computerized system. They were also responsible for designing the circuit to provide power to the system, interfacing with the power generated on the C-130 cargo airplane.

The thesis "Control System Design for a C-130 Ro-Ro Sensor Deployment Platform" details the power distribution circuit design, the control circuit design and the design of the automated process program.

Dedication

I would like to dedicate my thesis to the Commander in Chief of this great nation, George W. Bush, and all the brave men and women that are fighting for freedom and the war against terror in Afghanistan and Iraq. They are fighting to make this world a better, safer place to live for all mankind. They are fighting to make sure that we stay free, just as our founding fathers fought for our freedom more than 200 years ago. They are fighting to bring democracy to those that are suffering in countries less fortunate than our own. And as a result, some of our nation's finest have paid the ultimate sacrifice. Let us keep our President and our courageous troops in our prayers and in our hearts.

Acknowledgements

First, I would like to thank my family, who has supported me throughout my nineteen years of formal education. My mother Judith, my father Dennis, and my brother Nathan have helped me through twelve years of school and six years of college here at West Virginia University. I also need to thank my grandparents, Warren and Madge Albin and Erman and Norma Hayes, for their continued support of their grandson. I also need to thank my friends, Jason and Tiffany Lysne and Brian and Laura Hetzer, for being there for me through the years. I would, of course, also like to thank a person near and dear to me, Stacy Migdol, for having so much patience with me and listening to all of my problems while I have worked diligently to complete my research and thesis. She certainly amazes and inspires me; her perseverance never overwhelmed by what life hands her.

This publication would not have been possible without the dedicated efforts of many individuals. In the spirit of multiple-agency collaboration, I would like to acknowledge contributions made by Bruce Corso, Program Manager for the DoD-CNTPO, and Maj. Michael Thomas, Technical Projects Manager for the NGB-CD. Sincere thanks also go to Col. James Hoyer, Col. Frye and all members of the WV-NG and ANG who provided guidance for the planning and development of this technology. Finally, the author would like to express gratitude to all the WVU participants for their timeless efforts that have insured the success of this program.

Also, I must thank my committee members, Dr. Roy S. Nutter, Dr. James E. Smith, and Dr. Powsiri Klinkhachorn, for helping and supporting me through this research process. I especially need to thank Dr. Nutter and Dr. Smith for giving me the opportunity to work on a project as interesting and far-reaching as Project Oculus. I have learned so much working on this project in the past year; the experience was more valuable than any I have received in the classroom. I have thoroughly enjoyed the experience.

I would be remiss not to thank the rest of the members of the Project Oculus team. You guys are the best engineers I know, and I am a better engineer and a better person for having worked with you. Thank you for being great coworkers and friends.

And finally, I need to thank my Lord God and give Him praise. I hope that I may glorify His name through my work and my life. To God be the glory, great things He hath done.

And last but not least… LET'S GO MOUNTAINEERS!!!!!!

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Chapter 1: Introduction

The people of the United States of America are continuously facing threats to their everyday way of life, including the constant spread of drug use among the American population and the threat of terrorism from groups like al Qaida. The Department of Defense and the National Guard are constantly searching for new ways to combat these dangers. The philosophy employed by these enforcement agencies is that of preventive action; find the terrorists or the fields of marijuana before they crop up on our city streets and before the profits are made to finance terrorism.

For several years now, there has been the need to quickly and economically deploy surveillance sensors such as a **F**orward-**L**ooking **I**nfra**r**ed (FLIR) turret, high-resolution digital cameras, video recording cameras, radar, multispectral imaging, and other sensors. The C-130 cargo airplane is an attractive candidate to deploy these sensors based on the availability of the airplane (there are many C-130's currently in service across the nation) and the large payload of the C-130. The problem becomes where to mount the surveillance sensors on the large, vibrating freight carriers of the skies? Certainly, the people that own the C-130's and perform routine maintenance on them do not want to have to alter or modify the airplane in any way. That means that the sensors can not be attached to the bottom or the wings of the aircraft. This fact leaves only the rear doors of the airplane, which can be opened while in flight, as an area from which the sensors can be quickly and economically deployed. This concept, for a C-130 sensor deployment system built from commercial-off-the-shelf (COTS) components and to be used without modifying the aircraft, became Project Oculus, which was designed and built by the WVU-CIRA team of engineers.

1.1 C-130 Sensor Deployment Systems Study

Deployment of surveillance sensors from a C-130 platform is not a new and novel idea originated by the WVU-CIRA engineers. On the contrary, there are several predecessors for Project Oculus to follow. Other systems have been developed by both National Guard units and by private industry, funded by the federal government.

1.1.1 137th National Guard Airlift Wing Sensor Pallet

One of the first sensor pallet systems developed for the C-130 is the reconnaissance system built by the 137th National Guard Airlift Wing located in Oklahoma City, Oklahoma. This system did not have the same wide-sweeping goals as Project Oculus; this sensor pallet was only designed to deploy a KC-1B mapping camera, a KS-87 framing camera, and a KA-91A panoramic camera [1]. An illustration of this system is shown in Figure 1.1 below.

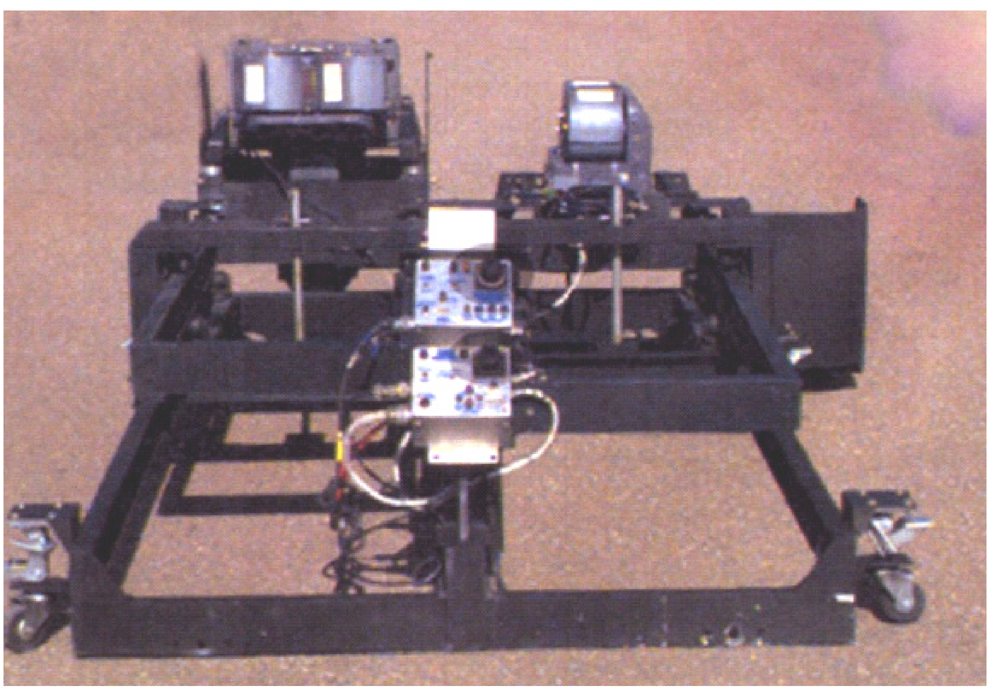


Figure 1.1: 137th National Guard Airlift Wing Sensor Pallet [1]

As seen in the illustration above, the sensors are not mounted on a basic pallet; instead, it is mounted on the rear door of the C-130 by the use of two mounting connections on the cargo door. To deploy the cameras, this system extends two arms out over the edge of the rear door to point the cameras at the ground below. This allows the cameras to view directly below the plane and any ground behind the plane's path. However, the cameras are limited by the rear cargo door and cannot look forward. With the extendable/retractable arms, the operators are able to reload the wet film cameras or even replace the camera entirely. The system is shown in use in Figure 1.2. The 137th Airlift Wing has stopped production of this sensor deployment system and is no longer developing similar systems [1].

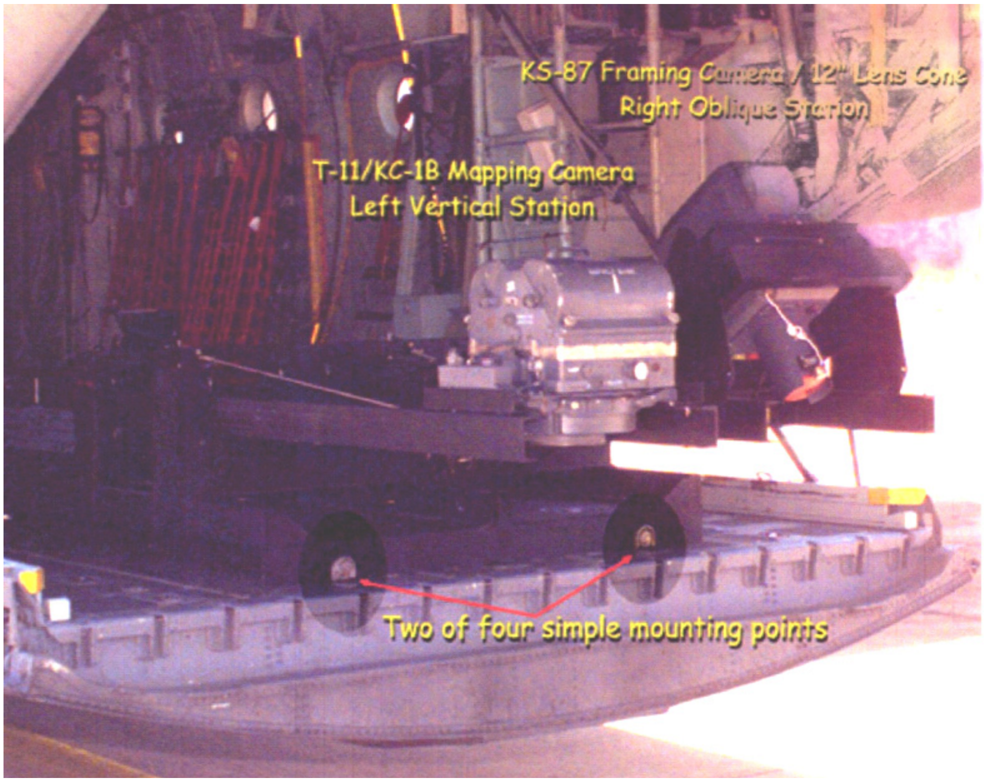


Figure 1.2: 137th National Guard Airlift Wing Sensor Pallet, Shown In Use [1]

1.1.2 146th National Guard Airlift Wing Sensor Pallet

Another sensor deployment system, similar to the system developed by the 137th Airlift Wing, was created by the 146th National Guard Airlift Wing, located in Port Hueneme, California. This pallet also accommodates a KS-87 framing camera and a KS-91 panoramic camera; the system can also deploy a three camera configuration. Instead of the retractable arms that are present in the 137th Airlift Wing's sensor pallet, the 146th Airlift Wing's pallet must be mounted with the cameras already positioned hanging out over the end of the rear cargo door, from which the cameras can film the ground directly underneath the aircraft [1]. This concept limits the components that may fail while in use, but also limits the system's usability.

The 146th Airlift Wing is currently testing a new system that will allow them to deploy Synthetic Aperture Radar (SAR) and infrared sensors. This system will be useable even with the rear cargo door closed, unlike the previous systems discussed. Illustrations of both systems developed by the 146th Airlift Wing are unavailable [1].

1.1.3 152nd National Guard Airlift Wing Sensor Pallet

The 152nd National Guard Airlift Wing, located in Reno, Nevada, has created a sensor pallet systems analogous to the one designed by the 137th Airlift Wing. Commercial surveillance cameras, which could be the KS-87 camera, the KS-91 camera, or the KS-87 long lens camera, are mounted are two retractable arms and extended over the end of the rear cargo door, exactly like the 137th Airlift Wing's sensor pallet [1]. This pallet is illustrated in Figure 1.3 shown below.

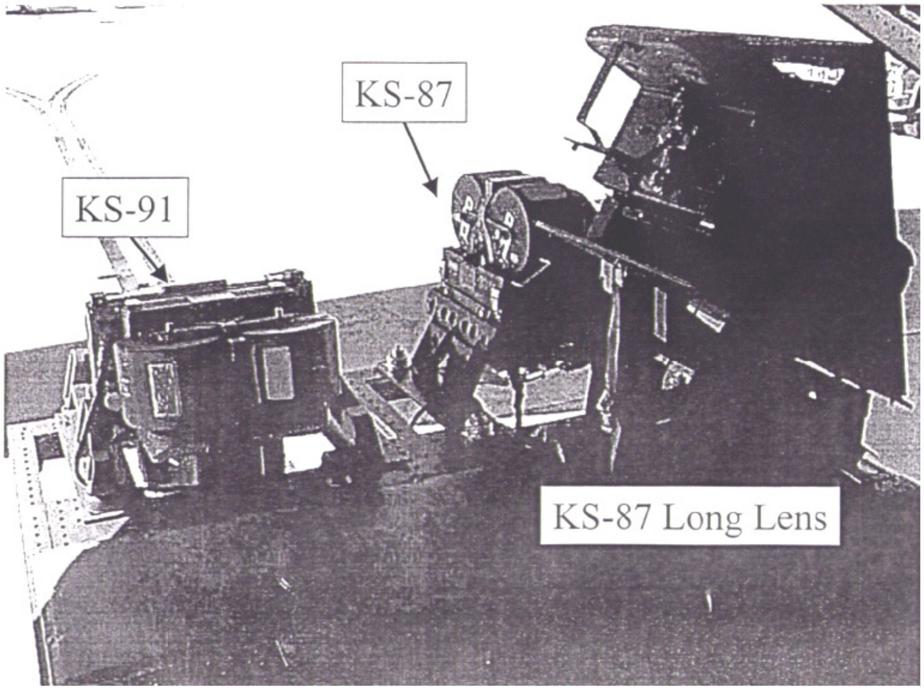


Figure 1.3: 152nd National Guard Airlift Wing Sensor Pallet [1]

However, the 152nd Airlift Wing has expanded the scope of the normal sensor pallet configurations with the development of the SCATHE view system. The SCATHE system provides near real-time data by introducing the use of a gimbaled turret mounted beneath the nose of the airplane, an operator workstation built atop a pallet loaded into the cargo bay, and a communication link from the system to a ground base. The turret encompasses a FLIR unit, a spotter scope, and a laser rangefinder. Ongoing testing to add newer and better sensors to the system is still under way [1]. The system, shown with the palletized workstations, is illustrated in Figure 1.4 below.

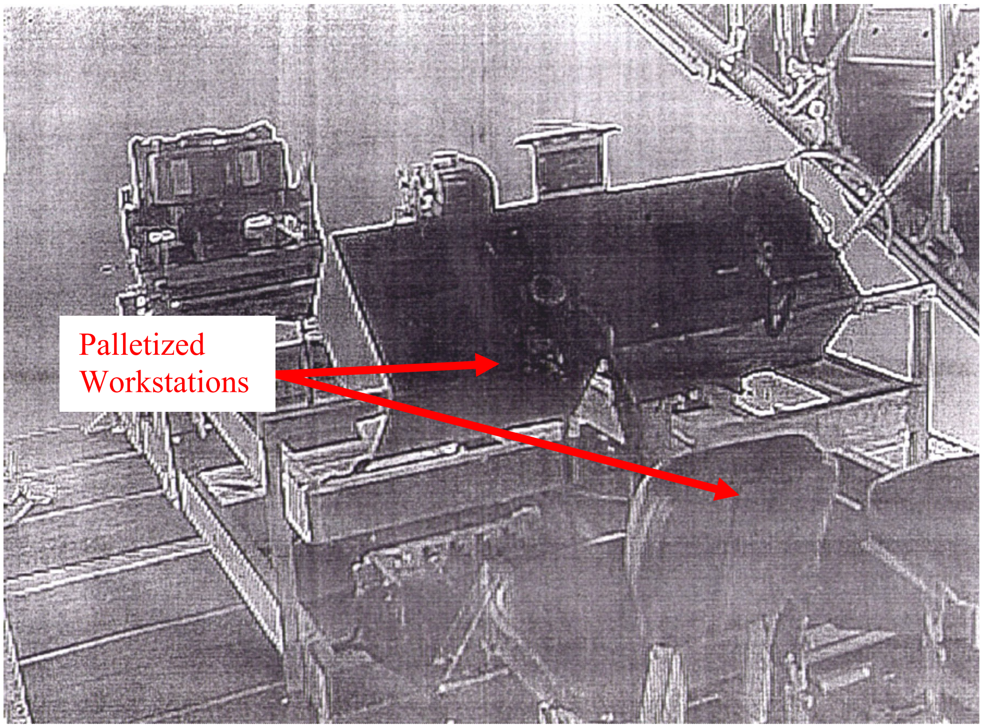


Figure 1.4: 152nd Airlift Wing Sensor Pallet with Palletized Workstations [1]

1.1.4 Hairy Buffalo II

The systems discussed above were all designed to mostly handle only the KS-87 framing camera, the KS-91 panoramic camera, and the KC-1B mapping camera, and due to the mounting position on the rear cargo door, had a limited field of view (FOV) of only the ground directly underneath the plane. These systems were also only equipped with wet-film cameras, which do not provide the operators with real-time data. As can be seen with the 152nd Airlift Wing's sensor pallet, the C-130 sensor deployment system was beginning to evolve to providing near real-time data to the operators, and the FOV of the system was increasing to include more of the ground below. However, attaching the gimbaled turret to the aircraft nose took time; therefore, a sensor deployment system that could position the sensors below the rear cargo door or C-130 fuselage was desired.

The federal government began to fund C-130 sensor deployment projects with the introduction of the “Hairy Buffalo” mission. NAVAIR Inc. followed this system with Hairy Buffalo II. The system includes three operator stations built on an operator pallet, a C4 shelter designed to plug into a C-130 jump door for a fourth operator, and a wing mounted ISR sensor pod based on Lockheed Martin’s SAMSON pod [1, 4]. The system is shown below in Figure 1.5.

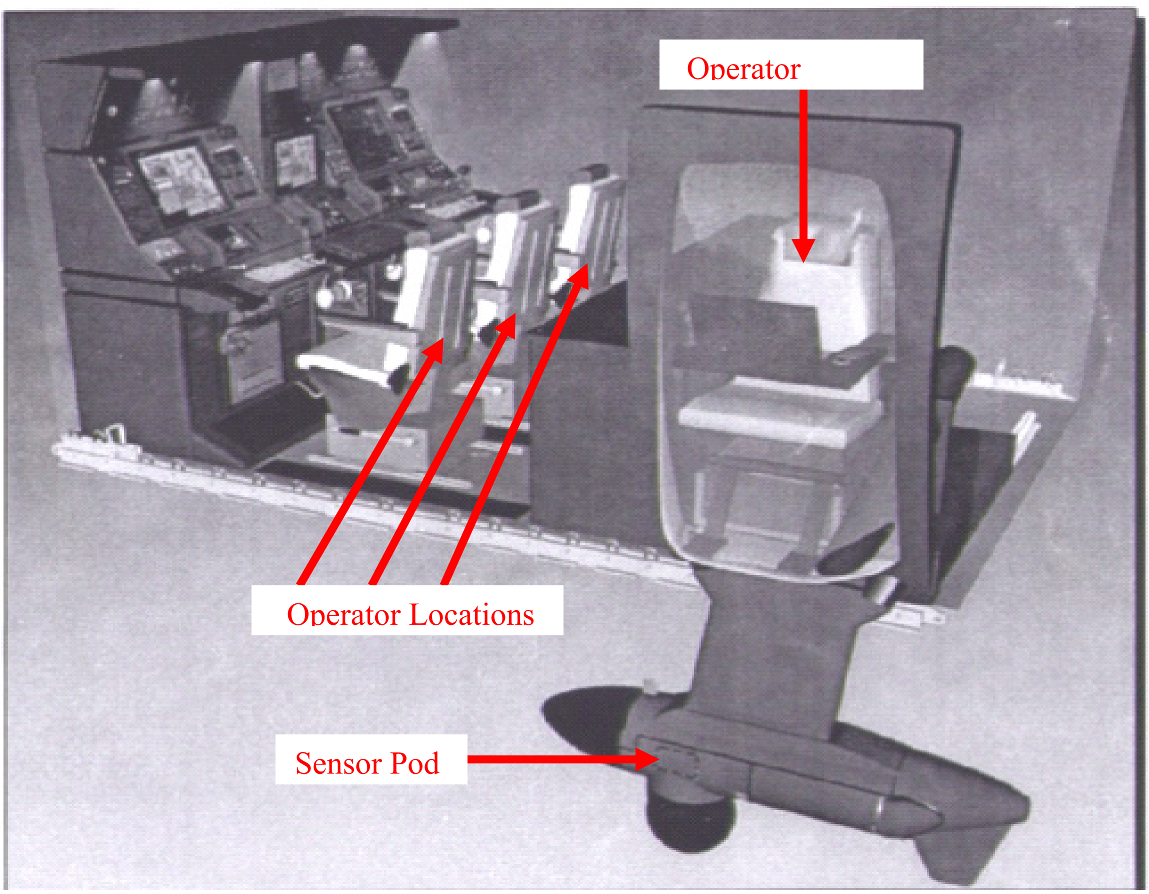


Figure 1.5: Hairy Buffalo II Sensor Pod and Operator Stations [1]

The sensor pod is mounted just below the C-130 jump door and is controlled by the operator seated in the customized AS-6 Door Plug. The sensor pod provides a full 360º of ground coverage beneath the aircraft and can be modified to house any currently available sensor or future sensors, including Star Safire FLIR units, Lynx SAR radar, MODSAR radar, hyperspectral sensors, CA-260 EO digital framing cameras, and VHF/UHF antennas. The door plug itself is equipped with a GPS antenna that will relay exact coordinates of an event to a ground base [1, 4]. The door plug and sensor pod components are illustrated in Figure 1.6.

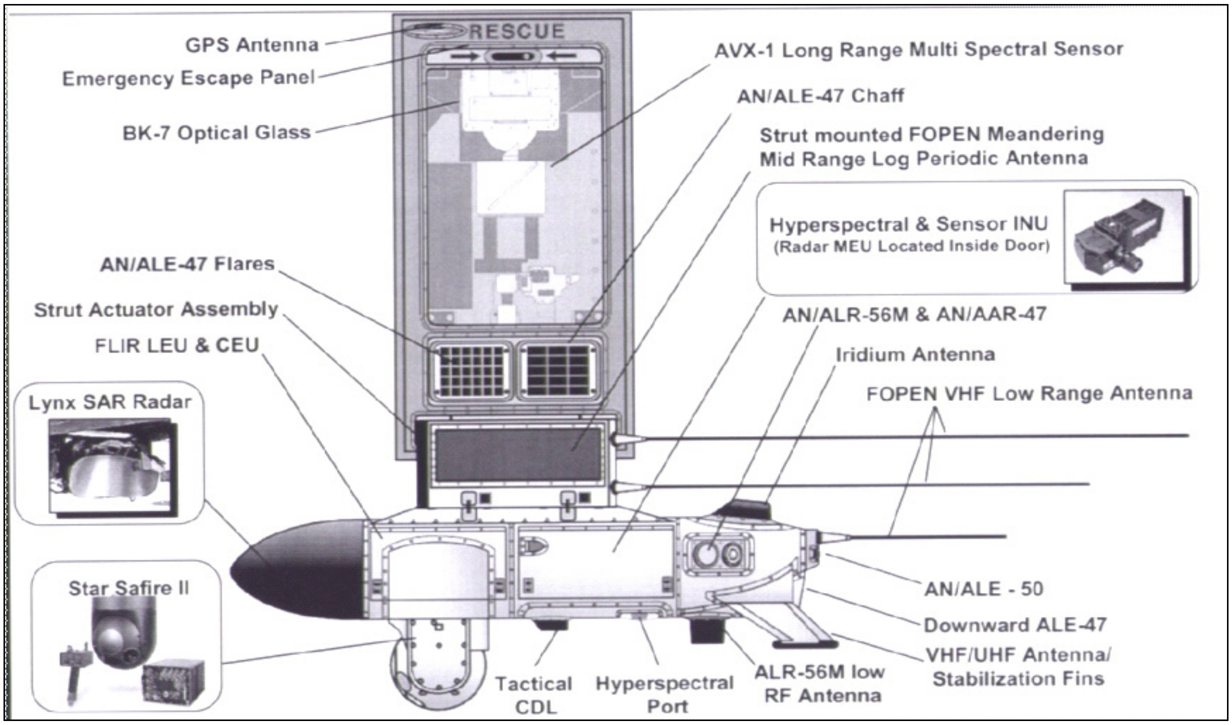


Figure 1.6: Hairy Buffalo II – Sensor Pod and Door Plug Unit [1]

The sensors can see out of the pod through cutouts in the bottom of the pod. The MODSAR radar is mounted in the front fairing to eliminate interference with other sensors. The sensor pod yields 14.7 ft^3 of volume for sensors and can weigh up to 600 lbs. with full sensor payload [1]. A closer view of the sensor pod with included sensors is shown in Figure 1.7 below.

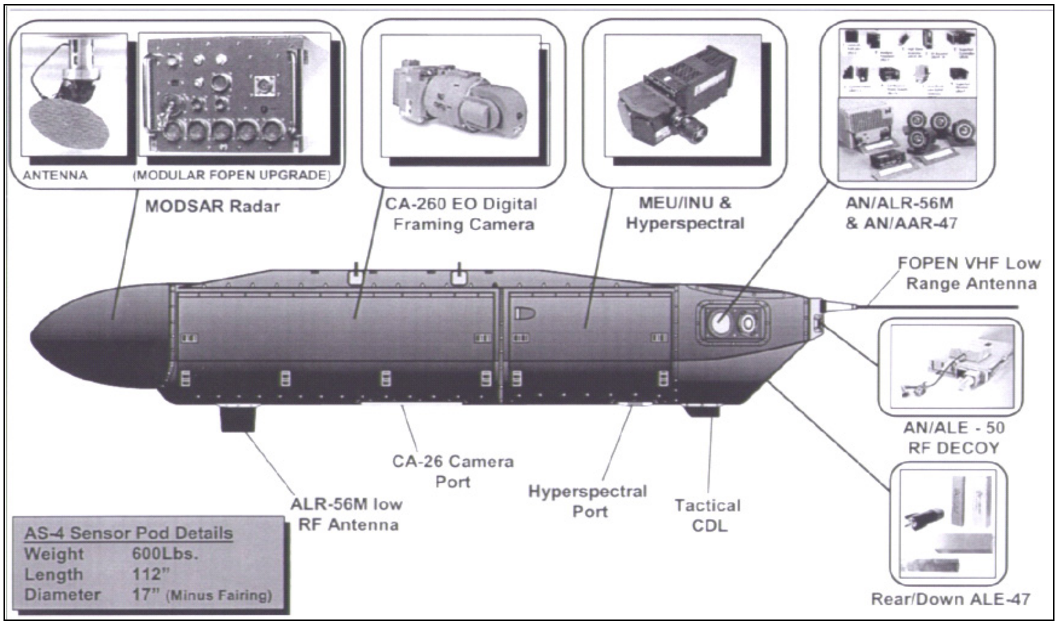


Figure 1.7: Hairy Buffalo II Sensor Pod (Sensor Payload) [1]

The AS-6 Door Plug cannot be installed without the entire removal of the C-130 jump door. Based on the fact that the system requires significant aircraft modification and an extensive amount of time and effort to become operational, the Hairy Buffalo II project and its federal government funding has been terminated [1]. Instead, funding for a system that does not require modifications to the aircraft and can be flown with minimal time and effort has been undertaken at West Virginia University with the emergence of Project Oculus.

1.2 Project Oculus

In the spring of 2003, the WVU-CIRA team of engineers proposed a solution to the sensor deployment problem. The proposal was to create a palletized system, using standard C-130 Gen-X freight pallets used by the military, with the slight modification of adding a ¾" top plate on the pallet, rather than the standard 0.063". One pallet would house sensor interface equipment, computer equipment, and the operators themselves, and is known as the “Operator Station.” The Operator Station is shown in Figure 1.8, showing two of the operator’s seats, two entry doors, three electronic equipment racks, and one side of the input/output power connector and sensor communication panels [3].

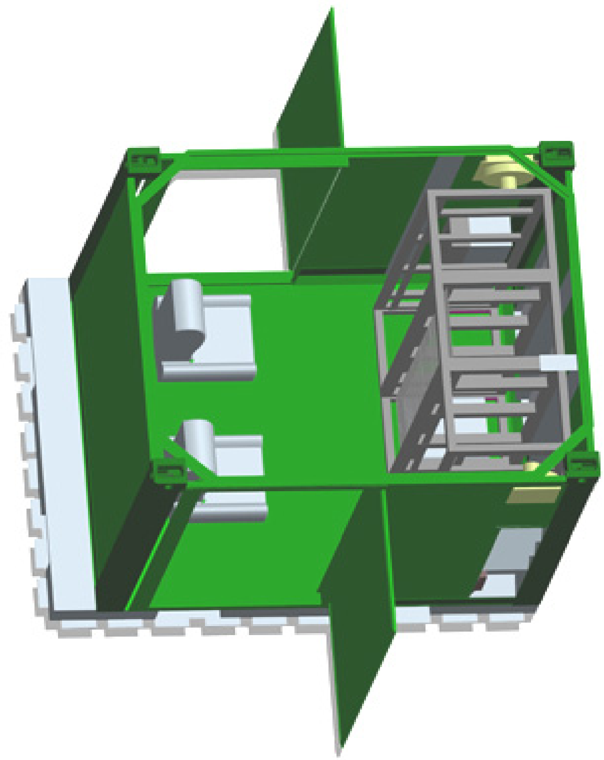


Figure 1.8: Operator Station (Shown Without Rooftop) [5]

The “Sensor Pallet”, as the second pallet is called, would be the platform from which the surveillance sensors would be deployed. The sensors would be mounted into or on the outer edges of a “Sensor Pod”, which would be bolted to the end of four mechanical stabilizing arms that will rotate out the open rear door of the C-130 and position itself against the butt plate on the exterior of the rear ramp. The mechanical arms will be on a shaft that is turned by a gearbox and a 2.0 HP 240 VAC motor. These components are placed on top of a translating plate that is moved by a 1/3 HP 110 VAC motor. The translating plate and all other components will be mounted permanently on the Sensor Pallet [3]. This pallet is shown in Figure 1.9 below.

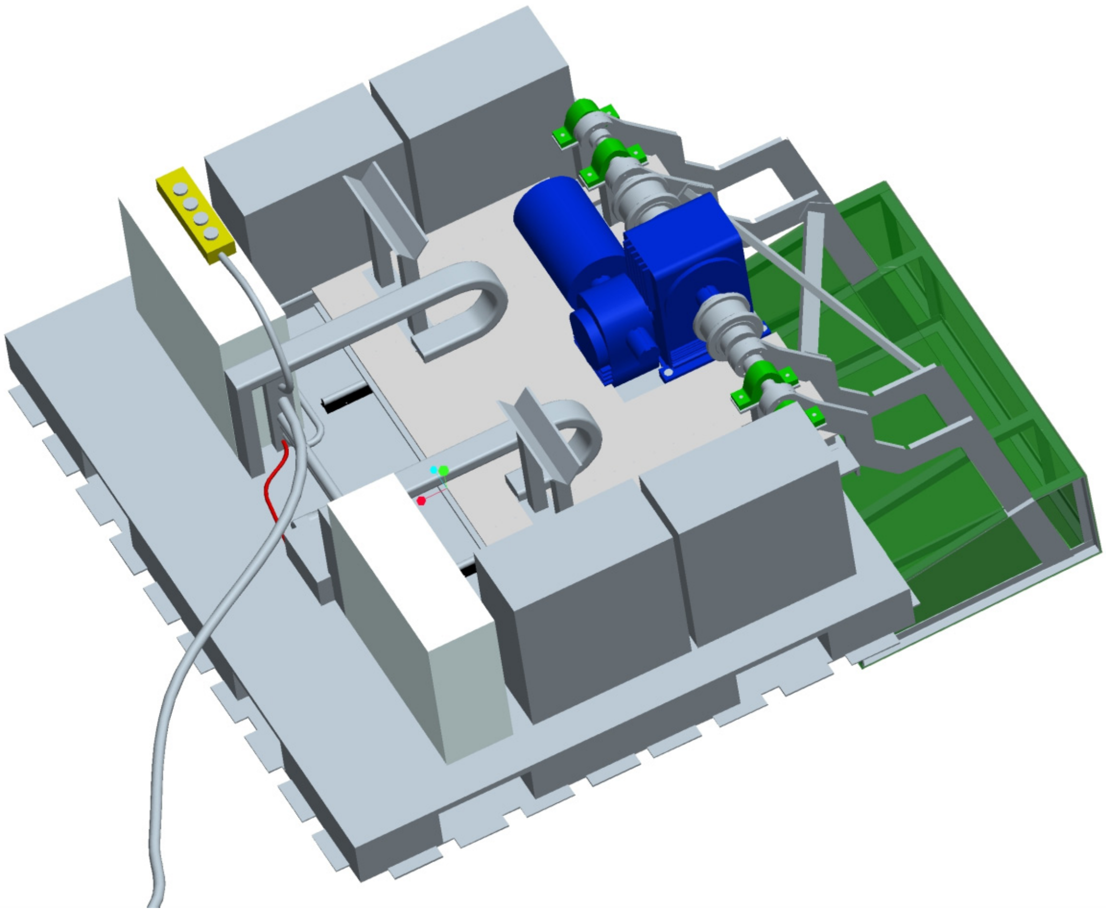


Figure 1.9: The Sensor Pallet Platform (Shown in Deployed Position) [5]

1.3 Project Oculus Deployment Procedure

The deployment procedure of the Sensor Pod from its fully stowed position to its fully extended position is a 3-step process. A profile view of the sensor pallet in its fully stowed position is shown in Figure 1.10 below.

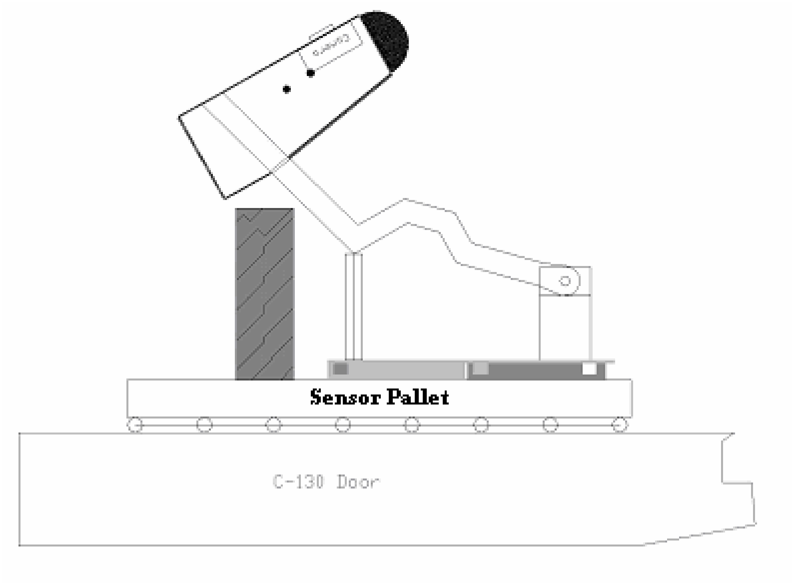


Figure 1.10: Sensor Pallet Completely Stowed [6]

Step 1 of the deployment procedure involves the movement of the translating plate. The translating plate travels 19 inches towards the back of the plane on stainless steel rails attached to the top of the pallet. It is imperative that the translating plate completes the movement so that when the arm is rotated, it does not strike the pallet or the C-130 door. A profile view of a completed Step 1 is shown in Figure 1.11.

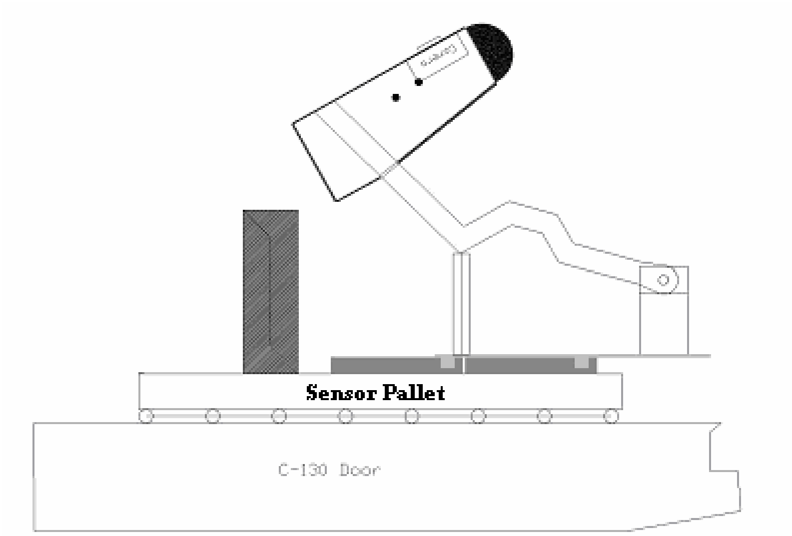


Figure 1.11: Completion of Step 1 -Translating Plate Moved 19" [6]

Step 2 of the deployment procedure involves the rotation of the arm so that the sensor pod is positioned underneath the plane. The arm is rotated 206° from its resting position to its position underneath the C-130 door. A profile view of a completed Step 2 is shown in Figure 1.12.

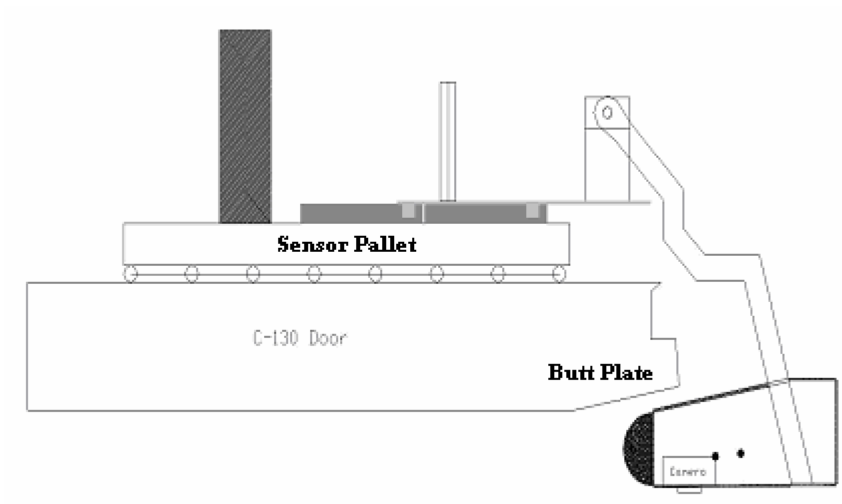


Figure 1.12: Completion of Step 2 - Arm Rotated 206° under C-130 Ramp [6]

The final phase of the deployment procedure, Step 3, again involves movement of the translation plate. Here, the translating plate returns toward the front of the plane until the pod is pulled in tight against the butt plate on the exterior of the ramp. This provides stabilization of the sensor pod, which is important because of the sensitivity of the sensors mounted inside. A constant vibration or movement of the pod could cause pictures to be blurry, noisy signals, and so on. A profile view of a completed Step 3 is shown in Figure 1.13.

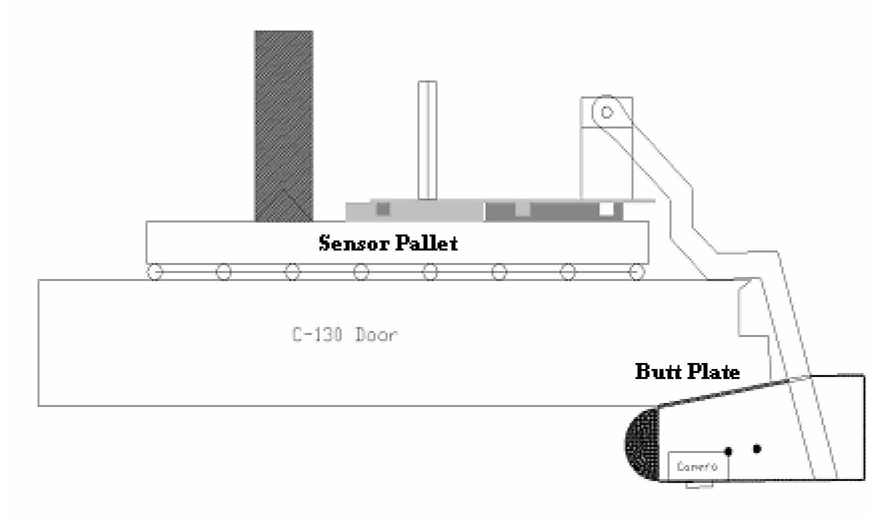


Figure 1.13: Completion of Step 3 - Sensor Pod Pulled Back Against C-130 Ramp Butt Plate [6]

The stowing procedure of the Sensor Pod performs these three steps in the exact opposite order. First, the translating plate moves outward to the fully extended position to give the arm room to rotate. Then, the arm rotates back to its resting position upon the arm supports. Finally, the translating plate travels backward to its fully stowed position, completing the stowing procedures.

1.4 Automatic and Manual Modes

During the design process, it was decided that the deployment and stowing procedures could be done in one of two modes: automatic mode or manual mode. Manual mode should be performed without the use of a computer; it is completely controlled by the system operator. Therefore, the system operator can precisely place the "mechanical arm" and/or translating plate in the exact position that he or she prefers. This could aid in maintenance on the sensor pod or the mechanical arm, or in sensor placement or maintenance inside the pod.

Automatic mode is controlled by a computer; the only user inputs that control automatic mode are a single push of the Extend and Stow buttons. There will also be input from sensors to describe the location of the translating plate and the rotational arm.

Each mode is controlled from a user pendant, which consists of a combination of three pushbuttons and two switches. The pushbuttons are the Emergency Stop button, the Extend button, and the Stow button; the switches are the Automatic/Manual Mode switch and the Translate/Rotate switch. A diagram showing a picture of the pendant with the layout of the pushbuttons and switches is shown in Figure 1.14 below.

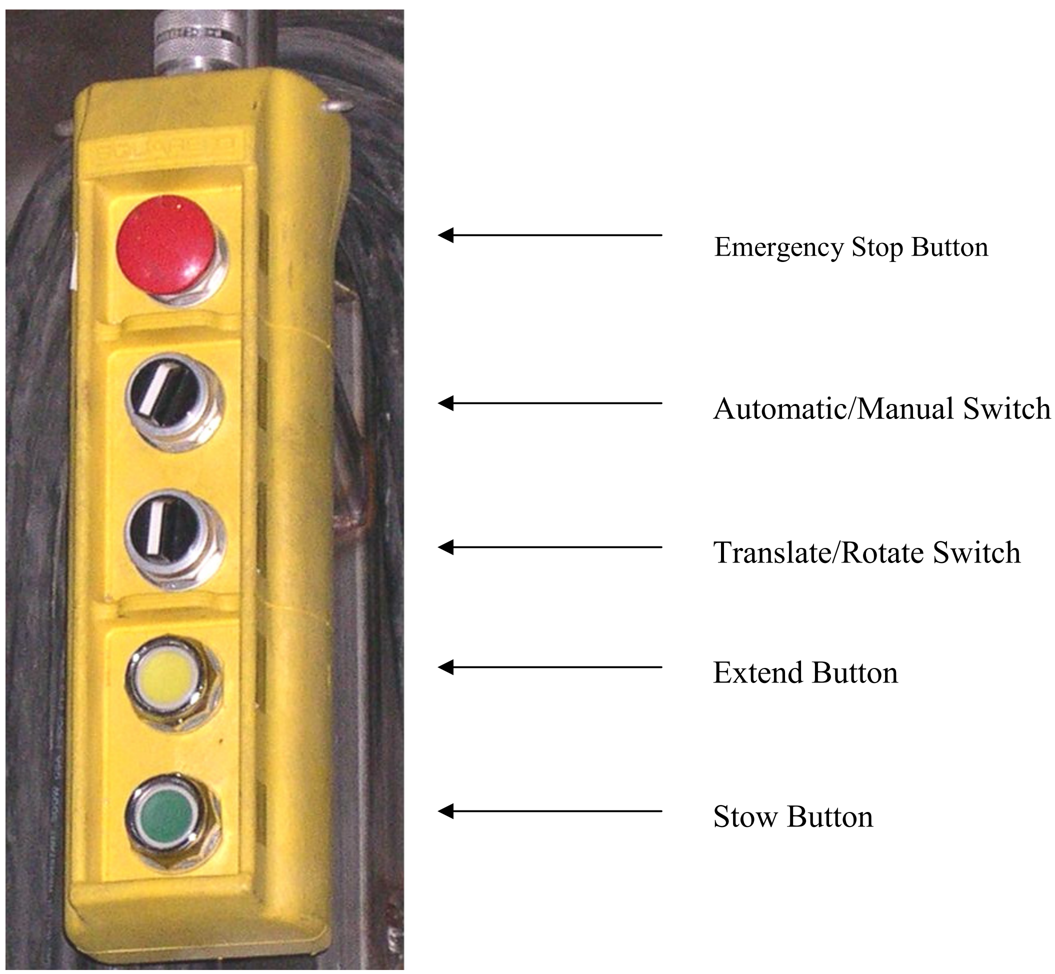


Figure 1.14: Pendant with Pushbutton/Switch Layout

1.5 Statement of the Thesis Project Problem

Project Oculus required electrical design of rotational and translational motors power, interface design, automatic mode control, and sensors for detecting the translating plate and rotational arm positions.

The rest of this document is intended to detail the design of the sensor pallet electrical components and the development of the automatic mode Programmable Logic Controller (PLC) program. The circuit designed to implement the desired functions will be discussed, as well as the hardware chosen to build the circuit. Also, the development of the PLC software will be discussed thoroughly, complete with a tutorial on the use of the PLC programming software and ladder programming in general. All circuit diagrams, component data sheets, and the PLC program are available in the appendices at the end of the document.

Chapter 2: Project Background

For Project Oculus to be a success, the WVU-CIRA electrical engineers had to do some preliminary background work before they could proceed. The first topic of discussion was about how the implementation of the system would take place. Basically, a general overview of what the system would look like must first be discussed.

The second subject that needed to be researched was for a power source for the system once it had been loaded onto the plane. The engineers needed to know the type of power that is generated and where the power outlets were located in the C-130 Ro-Ro cargo area.

Third, a study of the types of proximity sensors that are commercially available for the system must be conducted. When designing and building the control circuit for the Sensor Pallet, the engineers will be using some type of position sensors to sense the position of the sensor head. The various strengths and weaknesses of the different kinds of proximity sensors need to be identified so that the best position sensor for the job is chosen.

The last topic of discussion here will be programming PLC's, most notably, programming with the DirectSoft32© software. In Chapter 4, it will be discussed that the D0-06DD2 PLC available from Automation Direct is chosen to run Automatic mode and that the DirectSoft32© software, designed specifically for programming with the DL06 PLC processor, is the tool that one uses to program this PLC. Before programming the PLC, the engineer had to learn how to use the software; this background discussion will teach the reader how to use the software as well.

2.1 General Overview of Project Oculus

For the WVU-CIRA electrical engineers, there are several issues that must be solved during the design and building process of Project Oculus. Here, a quick overview of the problems and proposed solutions are discussed. The design of these circuits and programs are discussed further in future chapters.

First, the problem of supplying power to the sensor pallet had to be solved. The proposed solution is to use the 28VDC 200Amp power supply connector on the bulkhead of the C-130. The Operator Station would plug into this power source and then with the use of an inverter convert the DC power to split-phase 220VAC 60Hz. Using a power outlet connector on the external panel of the Operator Station, the Sensor Pallet can plug into the power generated in the Operator Station. Using the 220VAC split-phase, the translational motor can be supplied with 110VAC 60Hz and the rotational motor can be supplied with 220VAC 60Hz.

Once the power is available to the motors on the sensor pallet, the question of controlling the motors through manual and automatic modes had to be designed. For the proposed solution, the pendant that was pictured before will be used with the same buttons and switches. The pendant will use a 24VDC signal to engage relays that send the 110VAC 60Hz power to the translational motor or generates 3-phase 220VAC 60Hz power to the rotational motor.

Finally, how will automatic mode be controlled? Automatic mode will be run by a Programmable Logic Controller (PLC). It will respond to inputs from the user (Extend button or Stow button pushed) and sensors that identify the position of the translating plate and the rotational arm. These sensors will take the form of capacitive proximity sensors that will be strategically placed on the pallet and the translating plate. There will also be LED indicators mounted somewhere on the Sensor Pallet with the purpose of communicating the progress of the Sensor Pallet deployment procedure to the user. These LED's can be driven by the PLC or the proximity sensors, or a combination of both. The exact layout of LED's will be discussed in the design.

2.2 C-130 Power Sources

Project Oculus requires an ample amount of power to be functional. For an estimate of the power required by the system, please see Appendix 2 "Project Oculus Power Budget". Where will this power come from once the system has been loaded onto the plane? The WVU-CIRA electrical engineers needed to know this information before they could design the power interface circuit that will reside in the Operator Station.

After making a visit to the Air National Guard base in Charleston, WV, to study a C-130, the engineers were able to gather the information they required. All C-130 airplanes generate both 28VDC and 115/200VAC 400Hz power. Though some of the planes also supply 115/200VAC 60Hz power, the Project Oculus engineering team could not design the system with the assumption that this power supply would be available onboard any given plane used to deploy the system. There are various power outlets available in the cargo bay area, as well. A summary of these power outlets, with voltage and current supplied, connector manufacturer, connector model number, and the calculated power available from that power outlet is shown below in Table 2.1.

Table 2.1: Overview of Power Outlets in C-130 Cargo Bay

Location	Connector Label	Voltage Label	Current Label	AC(Hz)/DC	Connector MFG	Connector Model	Calc Power (Watts)	Wire Size
Jump Door	DC outlet	28V	10A	DC	Hubbel	7526M2	280	10 AWG
	Iron Lung	28V	25A	DC	Amphenol	MS 3102R-24-9S	700	4 AWG
	Galley	115VAC	20A	400Hz	Bendix	MS 3102A-20-4S	2300	12 AWG
Winch Cable (forward bulkhead)	DC outlet	28V	200A	DC	AMFS America	?		
	rectangular	28V	200A	DC	Fleet Service	AN2552-3A	5600	"0" AWG
	(small round)	28V	10A	DC	Hubbel	7526M2	280	10 AWG
	(big round)	115/200VAC	50A	400Hz	Bendix	MS 3102R-22-22S	5750@115	8 AWG
Forward Right Side	DC outlet	28V	10A	DC	Hubbel	7526M2	280	10 AWG
	Iron Lung	28V	25A	DC	Amphenol	MS 3102R-24-9S	700	4 AWG
	Galley	115VAC	20A	400Hz	Bendix	MS 3102A-20-4S	2300	12 AWG
	(giant round)	115VAC	20A	400Hz	Bendix	MS 3102A-18-10S	2300	14 AWG

One power source in this table is significant. At the Winch Cable, located at the forward bulkhead, there is a "rectangular" power outlet, part number AN2552-3A, that supplies 28VDC 200A, for a total amount of power of 5600W. Preliminary calculations suggest that that should be enough power for Project Oculus to function. However, if this power source is used, a rather large and heavy cable (Table 2.1 refers to it as "0" AWG cable, but 2/O AWG cable will be used) will have to be used to connect the Winch Cable power outlet to the Operator Station. This might make the system cumbersome to use, a result that may make potential customers reluctant to use the system.

As an alternative solution, the engineers may be able to use a combination of the 400Hz power supplies that are available. There are two power outlets available at the "forward right side" of the plane, the galley and a round connector, that provide up to 2300W of 400Hz power each. Because these outlets are not as high current as the AN2552-3A, the cables connecting to these outlets would not have to be nearly as thick and heavy. However, this poses a new problem; no computers, monitors, or radios operate on 400Hz power. Therefore, there would have to be some sort of "frequency changer" residing in the Operator Station that could turn the 400Hz power down to 60Hz. Though this sounds easily done, a frequency changer that could perform this operation and meet aircraft specifications would be a rather expensive solution. Thus, the AN2552-3A DC power outlet was chosen as the power source for the system while on the plane. This is discussed further in Chapter 3.

2.3 Proximity Sensors Study

There are several kinds of proximity sensors commercially available: mechanically, inductive, capacitive, photoelectric, and ultrasonic. Before the WVU-CIRA electrical engineers can decide which proximity sensor is right for Project Oculus, a knowledgeable study about each type was conducted. Presented here are the findings of this study.

2.3.1 Inductive Proximity Sensors

Inductive proximity sensors are intended to be non-contact sensors that detect the presence, or lack thereof, of ferrous material. The ideal target for sensing is mild steel, more than 1mm thick, and is at least the same diameter as the sensing face of the device. The four major components of an inductive proximity sensor are (1) a ferrite core with coil, (2) an oscillator, (3) a Schmitt trigger, and (4) an output amplifier [7]. These components are illustrated in Figure 2.1 shown below.

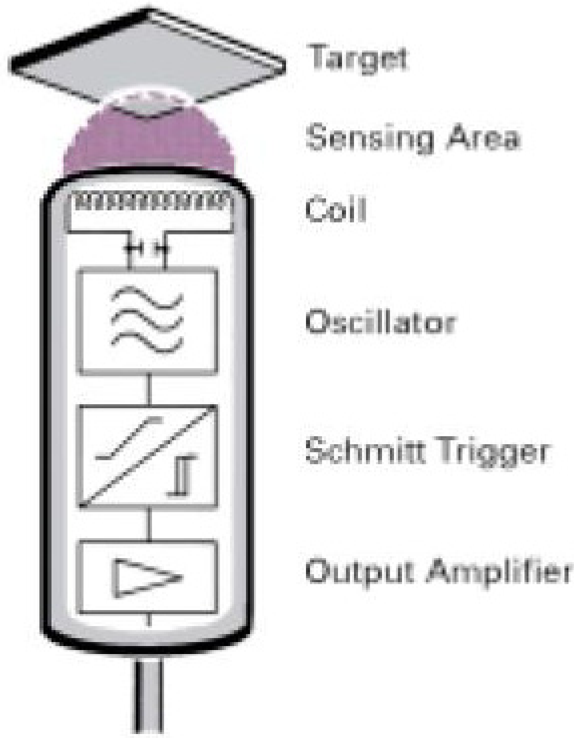


Figure 2.1: Components of an Inductive Proximity Sensor [7]

The inductive proximity sensor works by using a magnetic field. The oscillator creates a symmetrical oscillating magnetic field which radiates out through the coil array and extends out past the sensing face, making up the "sensing area" shown in Figure 2.1. Whenever a magnetic metal is placed in the sensing area, Eddy currents are induced on the face of the metal, hence the name "inductive" proximity sensor. This creates a power loss in the amplitude of the magnetic field produced by the oscillator, which is known as the Eddy Current Killed Oscillator (ECKO) principle. The reduced amplitude in the oscillations is "noticed" by the Schmitt trigger, which then generates and sends an output that the object has been detected [7].

Because of the limitations of magnetic fields, inductive proximity sensors have a very small sensing range from fractions of a millimeter to up to 60mm. The speed of an inductive proximity sensor is rather fast, as well; 10-20Hz for most AC models, and 500-5kHz for DC models. Inductive proximity sensors are also rather rugged in design and nature, and they are equipped to handle any environment [7].

2.3.2 Capacitive Proximity Sensors

Capacitive proximity sensors give the user a few more options than the inductive proximity sensors. By design, capacitive sensors can sense any material and are not limited to detecting ferrous material like the inductive sensors. Capacitive sensors are comprised of (1) two plates (acting as an open capacitor), (2) an oscillator, (3) a Schmitt trigger, and (4) an output amplifier [7]. A diagram of the capacitive proximity sensor is shown in Figure 2.2 below.

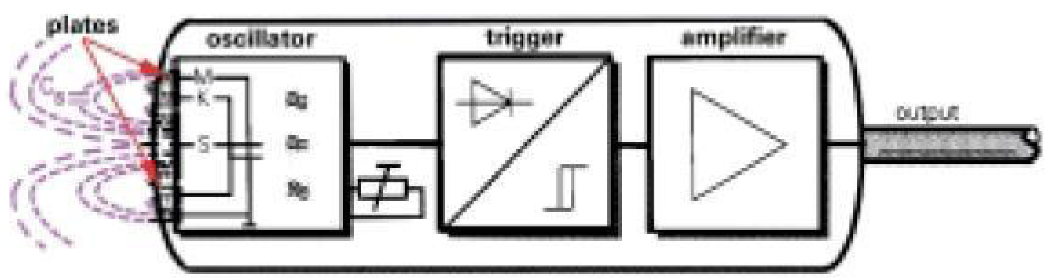


Figure 2.2: Components of a Capacitive Proximity Sensor [7]

The capacitive proximity sensor works by using the properties of the open capacitor. When an object enters the sensing area, the capacitance between the two plates increases and causes the oscillator to increase its oscillations. This is registered by the Schmitt trigger, which generates and sends the detecting output. The capacitive proximity sensor works in a "reverse" way as the inductive proximity sensor; the inductive sensor senses when the oscillations of the oscillator lose amplitude, the capacitive sensor senses when the amplitude of the oscillations of the oscillator increases [7].

This operating principle of the capacitive sensor makes it slightly slower than the inductive sensor, usually ranging from 10-50Hz. Their sensing range is comparable to inductive sensors, ranging anywhere from 3-60mm [7]. They are also ruggedly built and are ideal for any rough environment. Extra care must be taken when mounting these sensors, however; since they sense any material, they could pick up something else in the environment and be falsely triggered.

2.3.3 Photoelectric Proximity Sensors

Photoelectric proximity sensors are the fastest growing field of proximity sensors available. They have one of the greatest sensing distances obtainable, and can detect objects as small as 0.01mm in diameter. Though there are several flavors of the photoelectric sensor, each one has a few basic parts: (1) an emitter, a light source such as an LED or a laser diode, (2) a photodiode or phototransistor receiver to detect this light source, and (3) supporting electronics to amplify the signal relayed from the receiver. The three kinds of photoelectric proximity sensors are Through-Beam sensors, Retro-Reflective sensors, and Diffuse sensors [7].

2.3.3.1 Through-Beam Photoelectric Sensors

Through-Beam sensors separate the light source and the receiver from one another. The light source is beamed to the receiver; detection occurs when an object passes through the beam of light and the receiver fails to receive the beam [7]. Figure 2.3 illustrates the use of a Through-Beam photoelectric sensor.

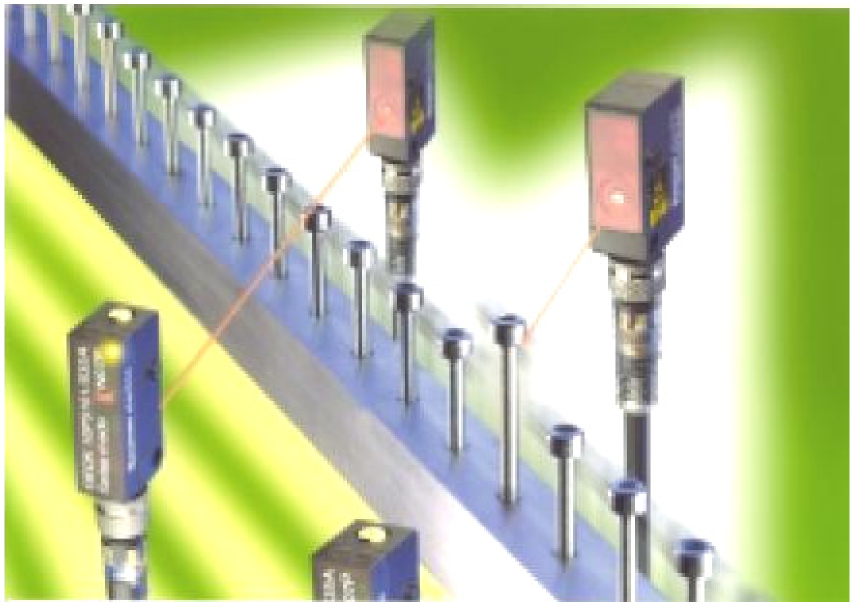


Figure 2.3: Through-Beam Photoelectric Sensors [7]

Depending on the light source, these units can offer detecting distances of up to 60m. Even at these distances, an object 3mm in diameter can be sensed, and at closer ranges, an object only 0.01mm in diameter can be detected. The speed of sensing is generally the same for all light sources, which is 500Hz [7]. These sensors are good for most environments; they can detect objects even with the presence of dirt or other contaminants in the air. However, this type of sensor requires the user to wire up both the transmitter and the receiver; the transmitter must have power to operate, and the receiver generates the output. This could be a drawback on the use of this sensor, depending on the application.

2.3.3.2 Retro-Reflective Photoelectric Sensors

The Retro-Reflective sensor works on the same general concept of the Through-Beam sensor. Instead of mounting the receiver on the other side of the beam of light, however, the receiver and emitter are together in the same housing. The receiver sees the beam of light from a reflector mounted on the other side of the sensing area. Detection occurs when the beam is broken, meaning that the beam is no longer being reflected back to the receiver, causing the receiver to generate a detecting output [7]. Figure 2.4 illustrates the use of a Retro-Reflective photoelectric sensor.

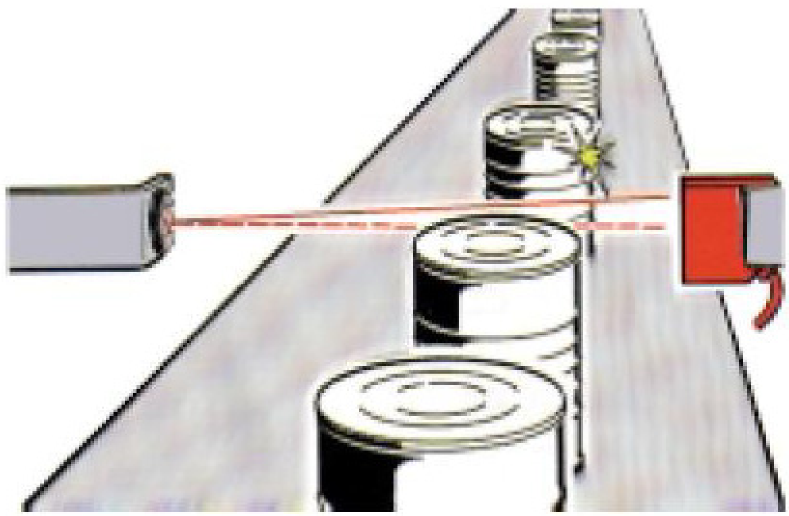


Figure 2.4: Retro-Reflective Photoelectric Sensors [7]

This is done to solve the problem with Through-Beam sensors, where it may be difficult to wire up both the transmitter and receiver; here, they are in the same area and should be easier to get to. Sensing distances for this type of sensor range up to 10m.

2.3.3.3 Diffuse Photoelectric Sensors

Diffuse sensors work on a little bit different concept as the Retro-Reflective sensors. Again, the transmitter and receiver are housed together. Instead of using a reflector for the beam, however, these sensors use the object itself as the reflector. Detection, then, does not occur when the beam is "broken"; rather, detection occurs when an object reflects the beam back to the receiver [7]. Figure 2.5 illustrates the use of a diffuse photoelectric sensor.

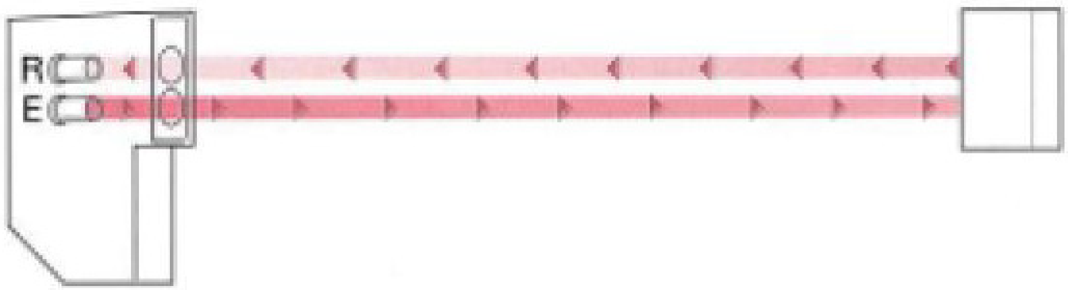


Figure 2.5: Diffuse Photoelectric Sensor [7]

This operating principle means that the diffuse sensor is limited by the object it is meant to detect. If the object does not reflect light, or is oriented in a certain fashion so that it does not reflect the light back to the receiver, the sensor will not work. Also, background objects could reflect the light back to the receiver and cause a false trigger. Therefore, these sensors cannot be used in all environments.

2.3.4 Ultrasonic Proximity Sensors

Ultrasonic sensors employ the use of sound waves instead of light beams to detect objects. Because they use sound waves, they are not limited by the objects color, transparency, or orientation; however, they are subject to the texture of the object. But for the most part, they can detect just about any object. They come in the same flavors as photoelectric sensors: Through-Beam, Retro-Reflective, and Diffuse [7].

Ultrasonic sensors use a special sonic transducer that not only emits a series of sonic pulses but also can receive the reflected sound waves. When the sensor "hears" the reflected pulses, it generates an output of detection. At the same time, this type of sensor can also tell the distance from the sensor to the detected object. This may be important information to know for certain types of applications. Sensing distances for these sensors range up to 2.5m [7].

2.4 DirectSoft32© Programming Tutorial

In Chapter 4, the selection of the D0-06DD2 PLC as the device to control Automatic mode of deployment of the Sensor Pallet is discussed at length. Here, the use of the programming software for that PLC, which is called DirectSoft32©, will be discussed. In this abbreviated tutorial, only the software features needed to program Project Oculus are covered. Subjects covered here are getting started with the software, intro to ladder programming, entering normally open/closed contacts, programming with PLC timers, and setting/resetting PLC memory locations. Whenever appropriate, screenshots will be included for the reader's convenience. For a complete overview of the software and its features, please see the user's manual that accompanied this software.

2.4.1 Introduction to Ladder Programming

Ladder programming is rather different from any other kind of programming. In many ways, ladder programming is easier than programming in one of the popular programming languages such as C, C++, or even Visual Basic. One of the major differences is that when running a program written in any of these languages, the program runs through once, finishes, and does not continue. With PLC ladder programming, the PLC continues to scan the inputs, running through the program over and over again, without the programmer having to include loops of any kind. This is an important feature because PLC users want the program to be running continuously, always checking the inputs and reacting accordingly.

The basic principle of ladder programming is to think of the program as one would think of an electrical circuit. The "power line" runs down the left side of the ladder programming window. To turn on the outputs, which are placed on the right end of each "ladder rung", the contacts or conditions placed on the ladder rung must be true, thereby relaying the power from the "power line" to the output. Therefore, if there are no conditions or contacts placed on the rung, the output will always be true. If any or all of the conditions on the rung are false, the output will not be turned on. Ladder rungs can also be placed in parallel; this way, an output can be turned on with several different combinations of contacts and conditions, just like a parallel electrical circuit.

The DirectSoft32© graphical interface software makes ladder programming rather easy. The next section will teach the reader how to use this programming software.

2.4.2 DirectSoft32© - Getting Started

Upon starting the DirectSoft32© software, the "DSLaunch" window is displayed. Figure 2.6 shows a screenshot of the DSLaunch window.

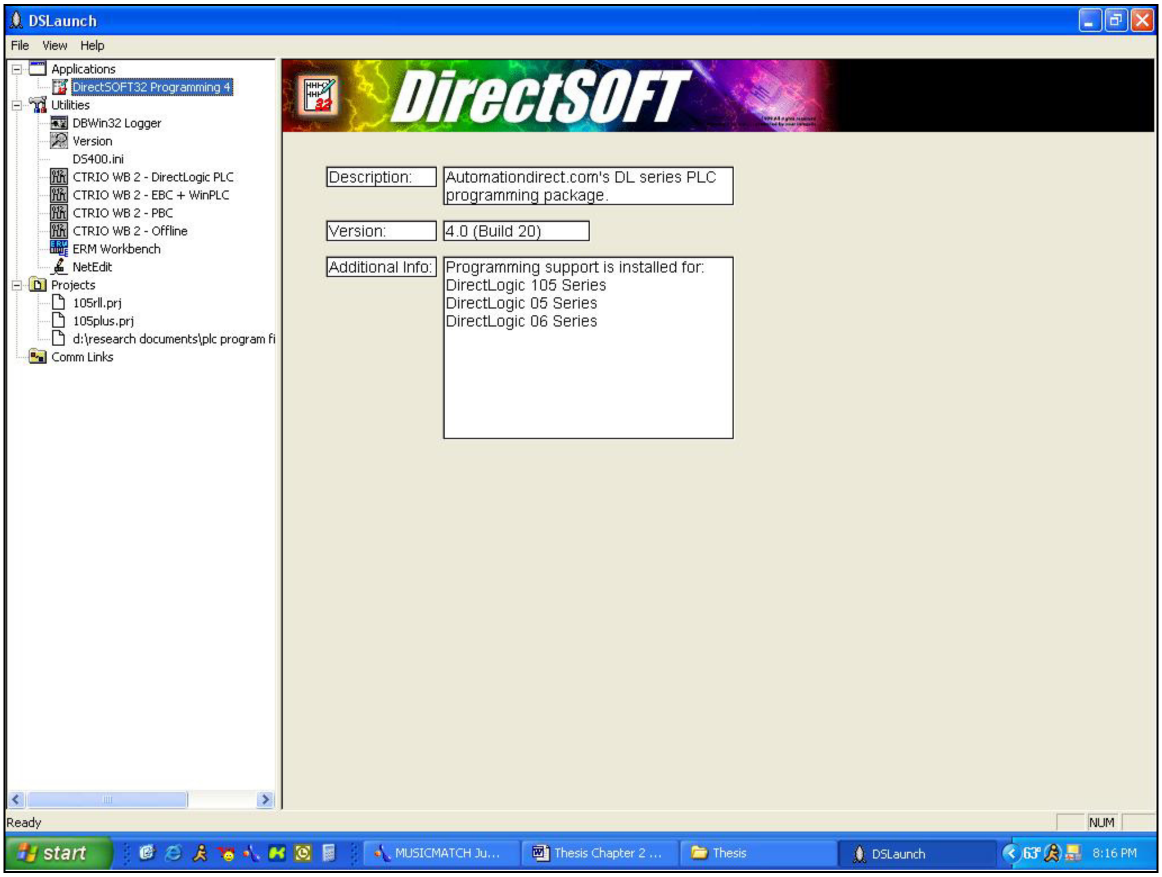


Figure 2.6: Screenshot of the DSLaunch Window

From this window, past projects can be viewed and opened, communication links to available PLC's can be viewed, and the utilities provided by the software can be manipulated. The programming application can be launched from this window by double-clicking "DirectSoft32© Programming 4" located at the top left corner of the screen. After double-clicking this icon, the screenshot shown in Figure 2.7 is displayed.

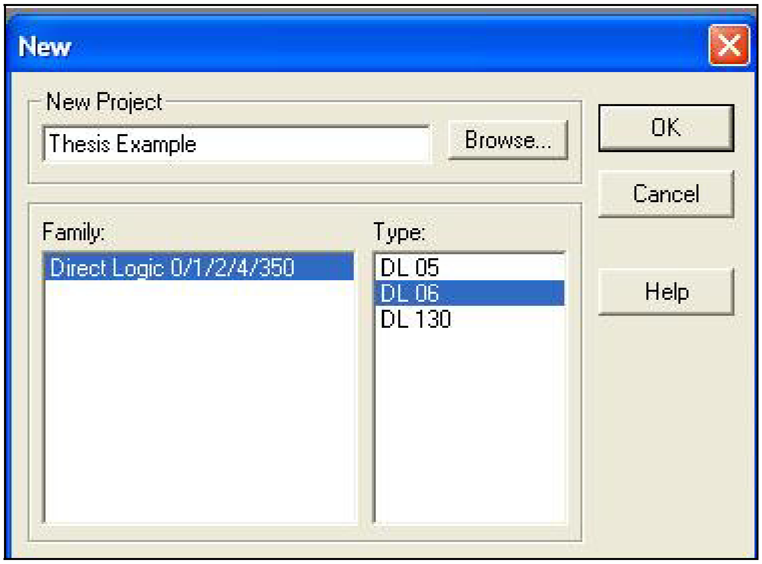


Figure 2.7: Open New Project Screen

This is the New Project screen. In the "New Project" title box, type the new project name; the example here will be called "Thesis Example". The D0-06DD2 PLC has the DL06 processor, so DL06 has to be chosen in "Type" as well. Once this is done, click the "OK" button to see the Ladder View of the new project, which is shown in Figure 2.8.

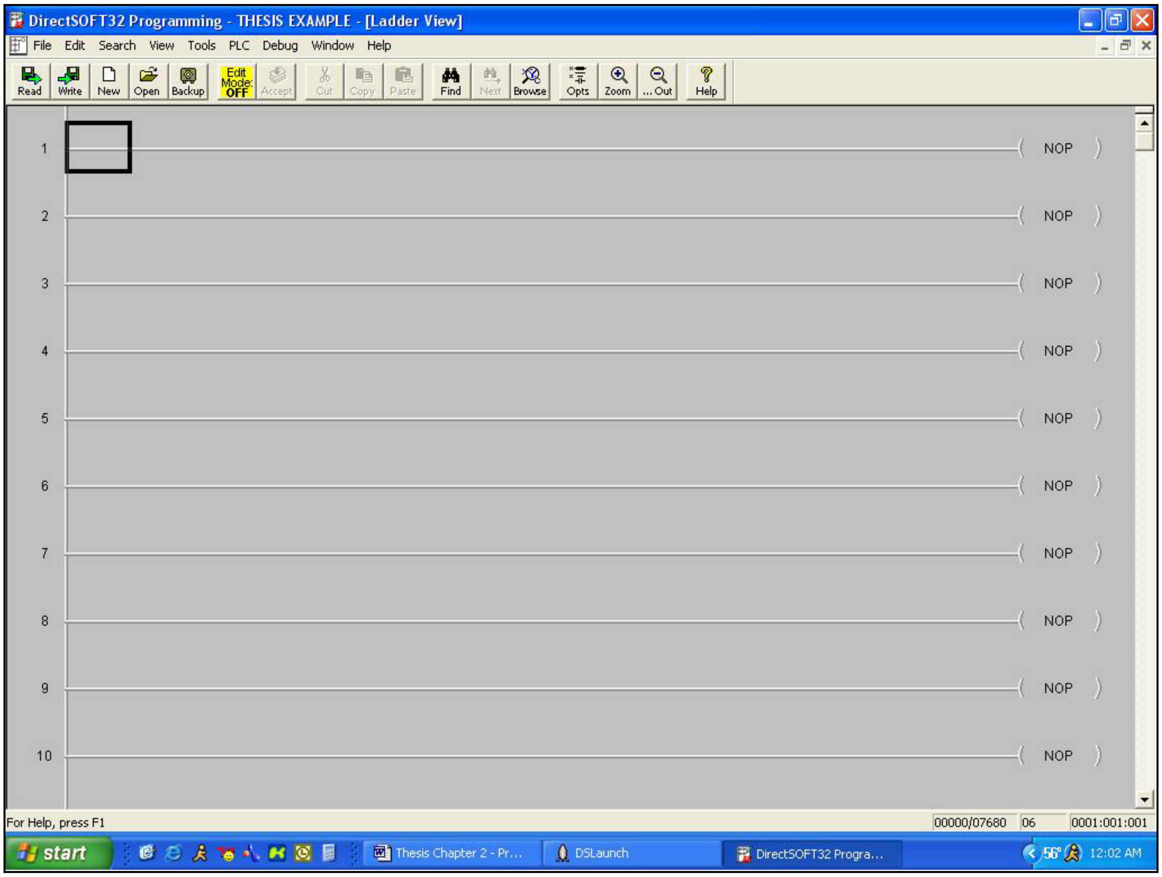


Figure 2.8: Ladder View of Project

Once the user has reached this point, he is ready to edit the new project. To edit the ladder program, the user must first click on the yellow "Edit Mode" button at the top of the screen. When it is yellow, it says "Edit Mode: **OFF**"; after clicking it, the button turns gray and says "Edit Mode: **ON**". When the Edit Mode is on, the user is supplied with a toolbar at the bottom of the screen, showing all the types of contacts that can be added to the program. This toolbar is shown in Figure 2.9 below.

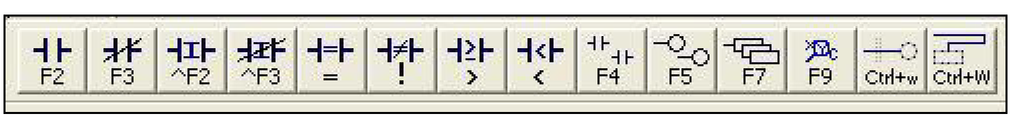


Figure 2.9: Program Editing Toolbar

2.4.3 Entering Contacts/Conditions onto Ladder Rungs

To place a contact or condition on a ladder rung, the Edit Mode must first be turned on. Then, place the cursor on the ladder rung where the contact should be located. Next, identify whether the contact should be a normally open or normally closed contact. If a certain contact input should be "on" to make the output true, use the normally open contact. If the input should be "off", then use the normally closed contact. Once the correct contact has been chosen, the user should click on the corresponding button on the toolbar shown in Figure 2.9. The normally open contact is shown on the far left; the normally closed contact is the next one on the right. Once the correct button is clicked, the contact will appear on the ladder rung where the cursor was placed. At this point, the user should type in the input that should be scanned here; any input from X0-X23 will suffice. An example of each contact being entered is shown in Figure 2.10 below.

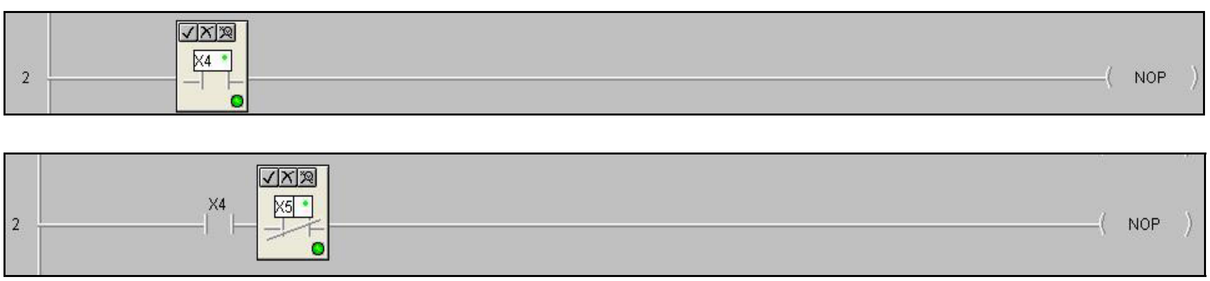


Figure 2.10: Entering Normally Open/Closed Contacts

The same process is used to enter a conditional statement on a ladder rung. The user can make a comparison, such as greater than, less than, equal to, or not equal to, between any two inputs or two memory locations. All the user needs to do is click on the corresponding button on the toolbar; the comparison buttons are the fifth through eighth buttons from the left. Once the button has been clicked, the "comparison contact" will appear where the cursor has been placed. Then the user can type in what inputs or memory locations that he wants to compare. Figure 2.11 shows the addition of a comparison contact.

Figure 2.11: Entering a Comparison Contact

The user will also need to know how to enter parallel ladder rungs. To create a parallel ladder rung, first define the connection point from one ladder rung to the new parallel ladder rung and place the cursor at this point. Then, while holding down the Ctrl button, press the arrow keys to "draw" the rung into the program. The new ladder rung should be drawn until it terminates on the originating ladder rung or on the "power line." A parallel ladder rung is shown in Figure 2.12 below.

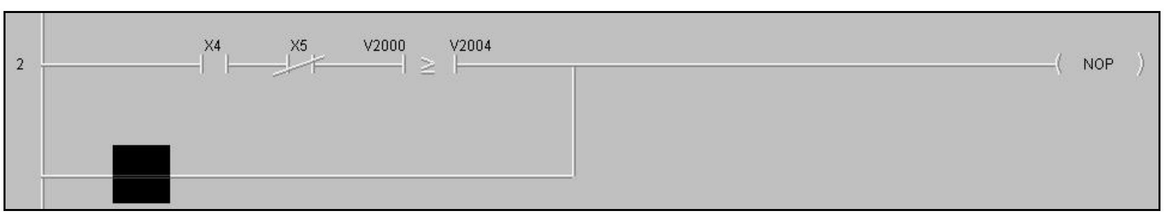


Figure 2.12: Adding a Parallel Ladder Rung

2.4.4 Ladder Rung Outputs

Now the user needs to learn how to set up outputs in a ladder program. The most basic output command, of course, is the "OUT" command. To program any output, first place the cursor on the output point of the ladder rung, normally designated with the letters "NOP" in parentheses. For the out command, just type the word "OUT" and press

Enter. At this point, the software requires the user to type the output point that will be turned on, which can be any output from Y0-Y17. Figure 2.13 shows the adding of an "OUT" command.

Figure 2.13: Adding an OUT Command

Another ladder rung output is writing messages to the LCD screen on the PLC. To begin, again place the cursor on an output point and type the letters "LCD". After pressing Enter, the screen shown in Figure 2.14 appears.

Figure 2.14: Defining an LCD Message

The LCD screen has two lines on which to display text. In this screen, the user can specify the line number on which to place the message. Using "K1" designates the first line; using "K2" designates the second line. Then, the message to be displayed is specified. In the message text box, the message should be typed, surrounded by quotation marks. The message is limited to 17 characters. Once finished filling out this screen, pressing the Enter button will finish adding the command. Figure 2.15 shows a completed LCD command statement.

Figure 2.15: Adding an LCD Command

The next series of outputs deal with setting and resetting memory locations. To set a memory location, first highlight the output point with the cursor and then type "SET" and press Enter. At this point, the user can type in the memory location that he wants to set. Setting memory locations is important for applications like remembering button presses. To reset a memory location, again highlight the output point with the cursor and type "RST" before pressing Enter. Again, the user will be prompted to type in the memory location to reset. Figure 2.16 shows adding both a SET and RST command.

Figure 2.16: Adding SET and RST Commands

The final output to be covered is timers. The D0-06DD2 PLC has 256 separate configurable timers available for use by the programmer. Each of the timers is numbered from T0-T377, based on the octal numbering system employed by the PLC. When the timer is in the output, that timer is set to a certain number of seconds, and the countdown begins immediately. To use the finished timer countdown, a normally open contact for that timer should be present on a ladder rung. To remember that the timer has finished its countdown, this normally open contact input could set a memory location at the output.

To program a timer, highlight the output point and type "TMR" before pressing Enter. The user will then be prompted to identify the timer to use and the number of seconds the timer will be programmed to count down. Time is specified in the following manner: if the user wants to program the timer for 3.0 seconds, he would type in K30 in the time field. This way, the user can specify fractions of a second; if the user wanted the timer to count 5.5 seconds, he would type K55. Figure 2.17 illustrates the adding of a timer to the program.

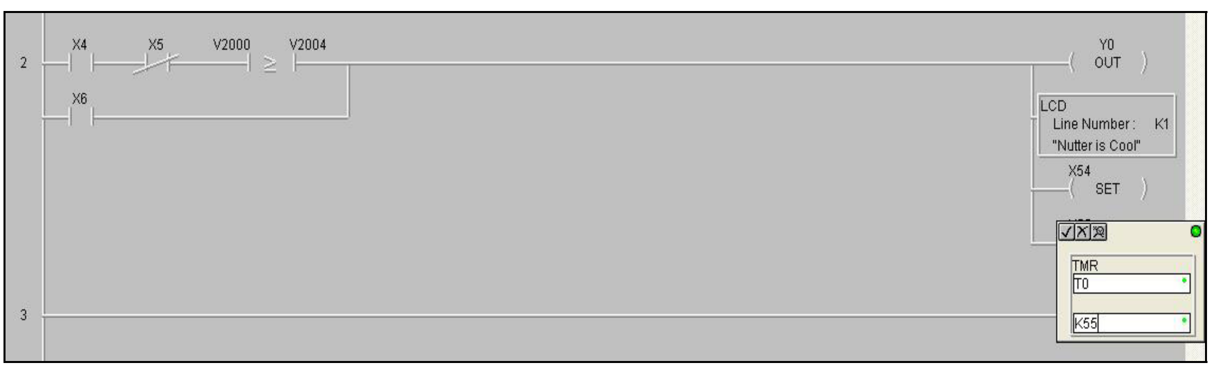


Figure 2.17: Adding a TMR Command

2.4.5 Optional Module Setup

The D0-06DD2 PLC is equipped with four expansion slots for a multitude of optional modules that are designed to accommodate several different inputs and outputs. Two optional modules are used in the implementation of Automatic mode: the F0-04AD-1 analog input board and the D0-08CDD1 digital input/output board. The D0-08CDD1 module is plug-and-play; the D0-06DD2 PLC automatically knows how to use the board for inputs and outputs. However, use of the F0-04AD-1 analog input module requires the programmer to instruct the D0-06DD2 PLC how to deal with the inputs from this module.

There are four instructions used when setting up the F0-04AD-1 module. The first instruction loads a constant that contains the number of channels to scan and the stored input data format requested by the user. This constant can be either K400 or K8400; the upper byte selects the data format (0 = BCD and 8 = Binary) and the number of channels, here set to four for the 4-channel F0-04AD-1 [8].

Next, using the OUT command, this constant is stored in a special V-memory location assigned to expansion slot 1 of the D0-06DD2 PLC, which is the first slot on the left. The value stored in that V-memory location configures the input data coming into that slot. All slots have an assigned V-memory location; the V-memory location corresponding to the expansion slot where the F0-04AD-1 must be used here [8]. V-memory locations for the other slots can be found in Figure 2.18 below.

The third instruction is loading the octal value O2000 for the first V-memory location that will be used to store the incoming data, using the LDA command. By doing this, the incoming data from the 4-channels are designated as such: Channel 1 – V2000, Channel 2 – V2001, Channel 3 – V2002, Channel 4 – V2003. Any unused memory location can be used for this purpose; V2000 is used here in this system [8].

The final instruction outputs this value to a predetermined input pointer corresponding to the chosen expansion slot, using the OUT command. For the first expansion slot, the pointer is V-memory location V701 [8]. Figure 2.18 shown below shows the designated input pointer for each expansion slot.

Analog Input Module DL06 Special V-memory Locations				
Slot No.	1	2	3	4
No. of Channels	V700	V710	V720	V730
Input Pointer	V701	V711	V721	V731

Figure 2.18: Special V-Memory Locations for D0-06DD2 Expansion Slots [8]

In Chapter 4, the CLN-50 current sensor is discussed; this device creates the data that will be input to the F0-04AD-1 analog input module. This data will be compared to a value determined in Chapter 4, which is 10mA. However, the data that is stored in V-memory location V2000 (Channel 1) is in Binary Coded Decimal (BCD) format. Therefore, 10mA needs to be converted to BCD and stored in the PLC memory for use in the program. The following formula converts 10mA to BCD [8].

$$D = (4095/16)\,(A - 4)$$
$$D = (4095/16)\,(10mA - 4)$$
$$D = 255.93*6$$
$$D = 1536$$

To store this value, the constant K1536 is loaded and then stored to V-memory location V2004 using the OUT command [8]. In the Automatic mode program, V-memory locations V2000 and V2004 are compared to determine if the Sensor Pod has pulled up tightly against the butt plate on the C-130 door. These instructions are placed on an unconditional ladder rung at the beginning of the program. They are showed in Figure 2.19 below.

Figure 2.19: F0-04AD-1 Analog Input Module Setup

This concludes the project background section. The next chapter will begin to detail the circuit design that will power up and control Project Oculus.

Chapter 3: Project Oculus Circuit Design

For Project Oculus to function correctly, the WVU-CIRA electrical engineers had several tasks to complete. First, the entire system, both the Operator Station and the Sensor Pallet, needs power in order to operate. As was discussed in the literature review presented in Chapter 2, most C-130 Ro-Ro airplanes only have two types of power available; 28VDC and 400 Hz AC power. There will most likely be a need for DC power to run certain sensors designed to operate on aircraft power, such as the Star Safire FLIR, but what about the computers, monitors, VCRs, and radios in the Operator Station and the motors on the Sensor Pallet? These devices all run off 110/220 VAC 60 Hz power, not 400 Hz AC that is available on the plane. Therefore, the engineers need to design how to bring power into the system and invert it to 110/220 VAC 60 Hz power that these devices can use. The second task to be undertaken by the WVU-CIRA electrical engineers is to design the control circuitry and user interface pendant to control Automatic and Manual modes on the Sensor Pallet. This chapter will discuss both of these tasks in depth, showing the circuit designs and hardware chosen to carry out the design.

3.1 Operator Station Power Distribution Circuit

There are several issues that must be addressed while designing the Operator Station power distribution circuit. First, what power sources are going to be used and how will that power enter the Operator Station? Should there be a fuse on the power input(s) to protect the circuitry and the operators sitting inside the station? Second, how will the 110/220 VAC 60Hz power be generated and supplied to the devices inside the Operator Station? In relation to this problem, will there be circuit breakers to protect the computers and other devices? Third, how will the Sensor Pallet receive the 110/220 VAC 60Hz power that it needs to operate?

While answering these questions, other issues were raised. Should there be any indicators, in the form of LED's, to signify what kind of power is available to the system? Should the user be able to turn the power off and on? Where will these components reside in the Operator Station? All these topics will be resolved in the discussion of the design.

3.1.1 Input Power for Project Oculus

The first question to solve is the source of the input power to the system. Of course, the system needed to receive power on the C-130 Ro-Ro; therefore, one of the two available power sources on the plane had to be utilized. Of the sensors that would be deployed from the Sensor Pallet and the devices that would be placed in the Operator Station, nothing operated from 400Hz AC power. Also, a "frequency changer" that would turn the 400Hz AC power to 60Hz AC power was rather expensive. For these reasons, the electrical engineers decided to make use of the 28VDC 200 Amp power supply available on the plane when the system is in use.

3.1.1.1 28VDC 200 Amp Input Power

As was discussed in Chapter 2, there are several 28VDC power outlets available in the plane; it was decided that the normal plug-in point would be the connector at the bulkhead of the aircraft.

Now that the power source on the aircraft has been chosen, the electrical engineers had to determine the parts needed to connect to the power connector on the plane and plug into the Operator Station. The DC power connector on the Operator Station was chosen to match the connector on the aircraft's bulkhead. The 28VDC 200 Amp connector found there is a standard connector with the part number AN2552-3A. This part was purchased from Aircraft Spruce and mounted on the outside of the Operator Station on the "power-in" panel. The AN2552-3A DC power connector is shown in Figure 3.1 below.

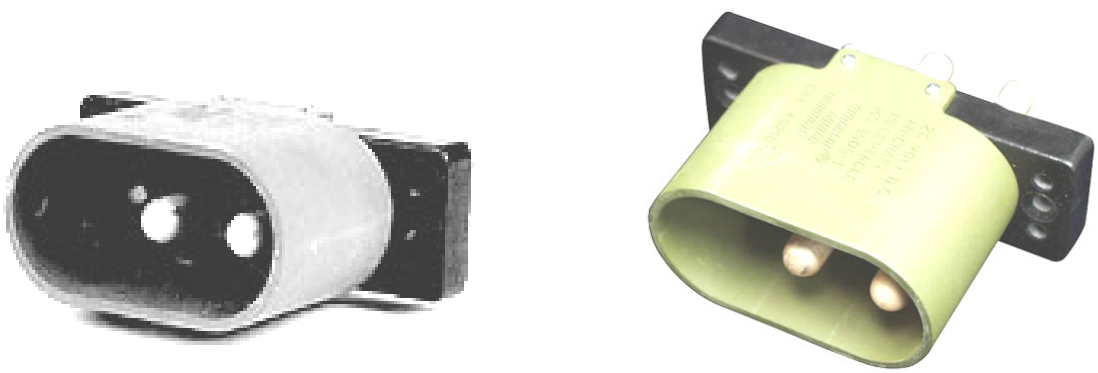


Figure 3.1: AN2552-3A 28VDC 200Amp Connector [9]

The plug that mates with the AN2552-3A is the AN2551 [9]. A cable with this plug connector at each end was constructed to connect the power source plug on the aircraft bulkhead to the Operator Station. The cable was built 60 feet long so that it would have enough slack to go up and over freight stored on the plane and still reach from the bulkhead to the Operator Station no matter where it was located in the freight area. The cable was made from two pieces of 2/O SOOW welding cable, one wire for the positive connection and one for the negative connection.

3.1.1.2 220VAC 30Amp Input Power

The WVU-CIRA electrical engineers realized that there may not always be a 28VDC 200Amp power supply available to the system for power when it is on the ground and not in use. Therefore, the ability to interface to an alternative power source, 220VAC 30Amp single phase, was designed for the system. For safety purposes, the cable carrying current from the power source would have a female plug on the end; therefore, the male connector would be mounted on the Operator Station. The female plug chosen was the HBL430C12W, which is pictured in Figure 3.2 shown below.

Figure 3.2: HBL430C12W 220VAC 30Amp Female Plug Power Connector [10]

This plug was placed on the end of a 60 foot piece of 10/4 SOOW welding cable. The other end that connects to the power source was not part of the finalized design. This is because there are several 220VAC power receptacles that the cable could have to interface with; therefore, there was no plug attached to that end.

The male connector that mates with the HBL430C12W is the HBL430B12W power connector. The HBL430B12W power connector was added to the "power-in" panel on the exterior of the Operator Station. This connector is pictured in Figure 3.3.

Figure 3.3: HBL430B12W 220VAC 30Amp Male Chassis Mount Power Connector [11]

3.1.2 AC Power Inverter

Now that the sources of power have been defined, the electrical engineers had to figure out what to do with it. Recall that most of the components in the Operator Station and the translational motor run off 110VAC 60Hz, and the rotational motor runs off 220VAC 60Hz. Therefore, an inverter is required to take the DC power available and make it 60Hz AC.

3.1.2.1 Vanner TSC24-4500D Inverter Overview

To this effect, the Vanner, Inc. TruSine 4500 Inverter/Charger System model number TSC24-4500D was chosen to perform this task. The TSC24-4500D is pictured in Figure 3.4 shown below, and a drawing of the front panel is shown in Figure 3.5.

Figure 3.4: Vanner Inverter TSC24-4500D [12]

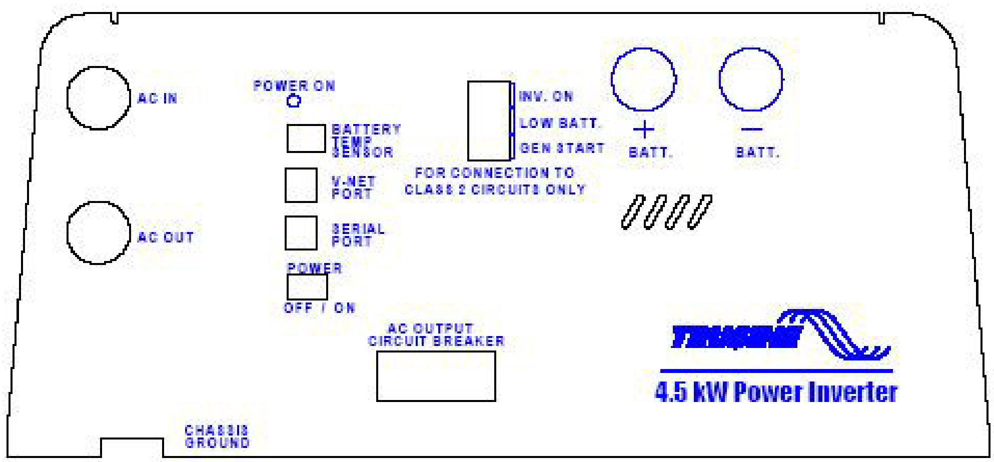


Figure 3.5: Vanner Inverter TSC24-4500D Front Panel [13]

This inverter is designed to take an input of either 21-34 VDC or 120/240 VAC single phase and provide an output of 120/240 VAC 60Hz [13]. In Table 3.1 shown below, several specifications for the TSC24-4500D are shown; for a complete specification sheet, view Appendix 1.

Table 3.1: Specifications for the Vanner TSC24-4500D Inverter [13]

Item	Specification
AC Input	120/240 V ± 10%, 3-wire, 1Ø
DC Input	21-34 VDC No Load: 1.8 Amps Full Power: 210 Amps
AC Output Frequency L1 to Neutral L2 to Neutral L1 to L2	120/240 VAC ± 3% 60Hz ± 0.5% 2250W (18.8 Amps) 2250W (18.8 Amps) 4500W (18.8 Amps)
Inverter Efficiency, @ 4500W	82.5%
Dimensions	17.5"H x 19.0"W x 8.5"D
Weight	83 lbs.
Mount	Wall or Shelf Mounting

3.1.2.2 Inverter Efficiency and Power Budge Study

In Table 3.1, the inverter efficiency at 4500W is shown to be 82.5%. This is an important specification to take into consideration; not all of the power is available to the system for use. The DC power available to the system from the C-130 bulkhead is:

$$P_{DC\text{-}available} = VI$$
$$P_{DC\text{-}available} = 28V * 180A$$
$$P_{DC\text{-}available} = 5040W$$

But this power is limited by the efficiency of the inverter; the power that can be counted on for use by the system is calculated to be:

$$P_{inverter} = P_{available} * \text{Inverter Efficiency}$$
$$P_{inverter} = 5040W * 82.5\%$$
$$P_{inverter} = 4158W$$

Using the TSC24-4500D, only 4158W of AC power is guaranteed for use by the system. Based on this observation, it would be beneficial to conduct a power budget study for Project Oculus. The power budget is shown in Appendix 2.

3.1.2.3 TSR-2 Remote Control for the TSC24-4500D Inverter

The TSC24-4500D is equipped with an optional TSR-2 remote control. The TSR-2 remote contains an alphanumeric LCD display and a functional keypad with up/down, left/right, Menu and ESC functions. Through the remote control, system status messages can be displayed, any faults that occur are reported, system functions can be enabled/disabled, and system set points may be examined and modified. The TSR-2 remote control is pictured in Figure 3.6 below.

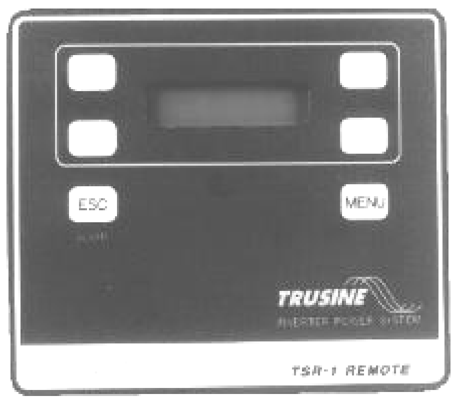


Figure 3.6: TSR-2 Remote Control for the TSC24-4500D Inverter [13]

3.1.3 Operator Station Circuit Design

Now the WVU-CIRA electrical engineers had to design the circuit that brings power to the Vanner TSC24-4500D inverter. Even though the inverter is built to sustain up to a 10,000W surge [13], it is important to protect the electronics inside the Operator Station. Therefore, it was decided to place fuses on both the 28VDC input and the 110/220 VAC 60Hz input. A 200 Amp DC fuse was placed on both the positive and negative line of the DC input, and a 30 Amp fuse was placed on both Line 1 and Line 2 of the AC input.

In addition to fuses on the power input, the electrical engineers also designed a sort of “interlock” between the two inputs. The idea behind this interlock is to keep the inverter from seeing both AC and DC inputs. The interlock was designed using a DC contactor on the DC input circuit and an AC contactor on the AC input circuit. The operator inside the station can choose which power input to use by flipping on/off switches that control each input. The toggle switches that were chosen for the system, part number 23F1895 from Newark Electronics, are shown in Figure 3.7.

Figure 3.7: On/Off Toggle Switch [14]

3.1.3.1 LED Indicators

Also included in the design are LED indicators. Three red LED’s will be installed on the DC input and on each line of the AC input. These LED’s are designed to show the user which power sources are available to the system. In addition, three green LED’s will be installed; one for DC and one for each of the two AC lines. Whenever the user flips on the DC or the AC power input, the green LED’s will turn on to indicate that that power source has been turned on. To ensure that 220VAC 60Hz and 28VDC power is available to the system, more green LED indicators were installed on the output from the TSC24-4500D inverter. The LED’s that were picked for the Operator Station “Power In” and “Power Out” panels are outlined in Table 3.2 shown below.

Table 3.2: Operator Station LED Indicators [11, 12]

	Red DC LED	Green DC LED	Red AC LED	Green AC LED
Voltage	24VDC	24VDC	130VAC	130VAC
Current	17 mA	17 mA	6 mA	6 mA
Size (Diameter)	0.550”	0.550”	0.550”	0.550”
Part Number	95C0354	95C0356	95C0364	95C0365

This circuit design can be studied in Appendix 4 “C-130 Operator Station Power Schematic”.

3.1.3.2 DC Contactor

The DC contactor chosen for the system was the Albright SW190. This contactor is a Double Pole Single Throw (DPST) normally open contactor with a maximum current rating of 200 Amps, which is the current rating of the 28VDC power source. The SW190 is shown in Figure 3.8 below.

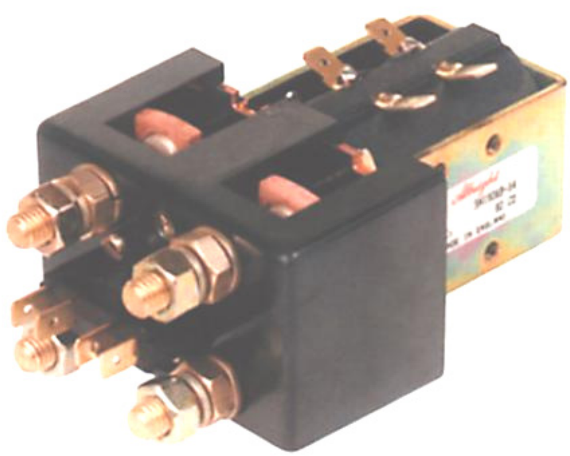


Figure 3.8: Albright SW190 DC Contactor [17]

3.1.3.3 AC Contactor

The AC contactor chosen for the system was the GH15FT-3-00A contactor available from Automation Direct. This is a 120V 60Hz contactor; Line 1 and Line 2 from the AC input have their own contact. The contacts are rated at 32 Amps each [18], which is above the rating of each AC line that is fused at 30 Amps. However, this contactor does not have enough contacts to build the circuit shown in the diagram in Appendix 4. The GH15S11 auxiliary contacts, one normally open and one normally closed, available from Automation Direct, was added to solve this problem. The GH15S11 contact mounts on the side of the GH15FT-3-00A contactor [19]. The GH15FT-3-00A contactor and the GH15S11 auxiliary contact are shown in Figure 3.9 below.

Figure 3.9: GH15FT-3-00A AC Contactor and GH15S11 Auxiliary Contact [14, 15]

3.1.4 110VAC 60Hz Outlet Circuit

The devices mounted in the electronics racks, such as the computers, monitors, VCRs, and radio receivers, all run off 110VAC 60Hz power. They are equipped with standard AC power plugs. Therefore, the Operator Station racks needed to be outfitted with outlet strips. Three outlet strips, measuring 60” in length, were purchased from Wiremold. These outlet strips contain ten AC outlets spaced 6” apart. One outlet strip was mounted behind or near each of the three electronic racks.

To protect the devices in the electronic racks, every two outlets in the outlet strips were put on a 10 Amp circuit breaker. The circuit breakers that were used in the system were Klixon 7274-11-10 aircraft circuit breakers. One of these circuit breakers is pictured in Figure 3.10 shown below, and the components of the circuit breaker are shown in Figure 3.11.

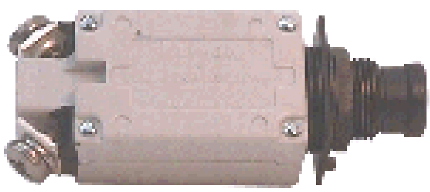


Figure 3.10: Klixon 7274-11 Aircraft Circuit Breaker [20]

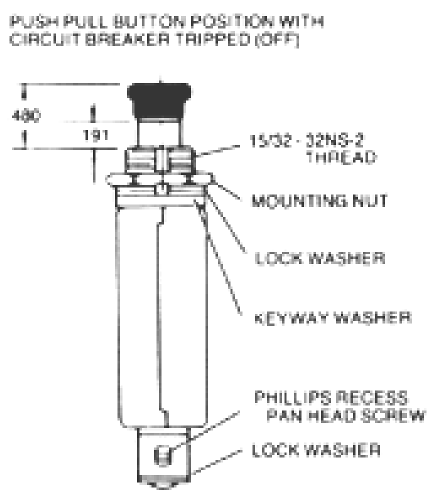


Figure 3.11: Klixon 7274-11 Circuit Breaker Components [20]

These circuit breakers are designed specifically for use on aircraft. Some pertinent specifications for the Klixon 7274-11 are shown in Table 3.3. A full data sheet for the Klixon aircraft circuit breakers can be found in Appendix 3; dimensions of the circuit breakers and other important information can be found there.

Table 3.3: Klixon 7274-11 Aircraft Circuit Breaker Specifications [20]

Item	Specification
Vibration	10 G minimum, 50-500 Hz
Mechanical Shock	35 G
Acceleration	10 G
Weight	33 grams
Max Voltage Drop 10 Amp 20 Amp	 0.28 V 0.25 V
Mil Spec Rating 7274-11-10 7274-11-20	 MS 22073-10 N/A
MIL-C-5809 Qualified	

3.1.5 Operator Station Panel Design

All these components that have been discussed, namely the LED indicators, the toggle switches, the circuit breakers, and the TSR-2 remote control to the inverter, have to be mounted somewhere in the Operator Station for ease of use. The area chosen to mount these components was in the top of the three electronic racks.

First, the TSC24-4500D power inverter was mounted in the top of the center rack. This means that the TSR-2 remote control should be mounted closely to it, as well as the LED indicators attached to the inverter output. A panel was then fashioned to house the TSR-2 inverter remote control and these LED indicators; this panel was mounted in front of the inverter in the top of the center rack.

Second, the "Power In" LED indicators and the on/off toggle switches had to be mounted. Since the input power connectors are on the left hand side input panel, the "Power In" panel was mounted in the top of the left hand rack.

Finally, the aircraft circuit breakers had to be mounted. For the sake of symmetry, and the desire to move the circuit breakers up where operators couldn't kick or bump into the breakers, the circuit breakers were mounted in the top of the right hand rack. A panel with a piano hinge was fashioned to house the circuit breakers; the piano hinge is important so that the operators can get in behind the circuit breakers to check wiring and the like. The rough drawing of the finalized design of these panels is shown in Figure 3.12 below. The figure includes future optional 400Hz input and output power LED indicators.

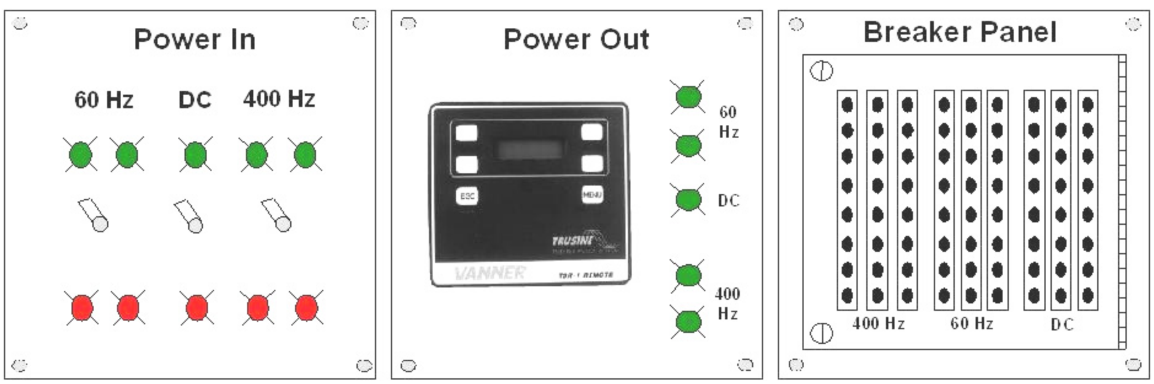


Figure 3.12: Operator Station Panel Design

3.1.6 Power Out to Sensor Pallet

The final part of the Operator Station power circuit design is the power out circuit to the Sensor Pallet. The power that will be sent to the Sensor Pallet is the 120/240VAC 60Hz "split-phase" power generated by the TSC24-4500D inverter. Line 1 and Line 2 of this AC output is run to 20 Amp Klixon aircraft circuit breakers, part number 7274-11-

20. From the circuit breakers, the lines are run to a chassis mount power connector. For safety reason, the female connector HBL430R12W was chosen for the system. The connector was mounted on the "communication panel" that was designed to mount connectors for sensor inputs from the Sensor Pallet to the computers housed inside the Operator Station. The HBL430R12W connector is pictured in Figure 3.13 shown below.

Figure 3.13: HBL430R12W 120/240VAC 60Hz 30Amp Female Chassis Mount Power Connector [21]

The HBL430R12W female chassis connector mates with the HBL430P12W male plug connector. This connector is attached to a 60 foot piece of 10/4 SOOW cable that runs to the Sensor Pallet. The HBL430P12W plug is shown in Figure 3.14 below.

Figure 3.14: HBL430P12W 120/240VAC 60Hz 30Amp Male Plug Power Connector [22]

3.2 Sensor Pallet Control – Hardware and Circuit Design

The Sensor Pallet control circuit needs to accomplish two tasks, running both Automatic and Manual modes. Automatic mode will mostly be covered in both Chapter 4 “Automatic Mode Hardware Design” and Chapter 5 “Automatic Mode Software Design.” But in this section, several components for both modes of the circuit are determined.

The fundamental problem to be solved here is turning on the translation and rotational motors in the correct direction whenever the operator desires to do so. Therefore, a user interface pendant needs to be designed and built; through this pendant, a signal needs to be sent to relay 110VAC 60Hz to the translation motor or power on the 220VAC 60Hz 3-phase rotational motor (engaging each motor in the correct direction depending on the operator’s wishes).

3.2.1 Translation and Rotational Motor Power Sources

The control circuit that is designed has to supply the right power to each motor. As previously stated, the translation motor uses 110VAC 60Hz for power in both clockwise and counterclockwise directions. The rotational motor uses 220VAC 60Hz 3-phase power to operate. However, the power that is generated in the Operator Station and delivered to the Sensor Pallet is 220VAC 60Hz “split-phase”, which means that there are two lines with 110VAC on each. Therefore, a 3-phase power source was found for the rotational motor.

3.2.1.1 Translation Motor Power Source

The translation motor has four wires; a green ground wire, a white neutral wire, a blue wire that turns the motor clockwise, and a red wire that turns the motor counterclockwise. The translation motor also requires a 68 μF starting capacitor; this capacitor is utilized by placing two 136 μF capacitors in series on the red and blue input wires. Since the power coming from the Operator Station is 220VAC split-phase, just one of the lines gives 110VAC 60Hz that can be used to operate the translation motor.

3.2.1.2 Rotation Motor Power Source

The rotation motor is more complicated than the translation motor. A 3-phase power source has been found to operate the motor. The WVU-CIRA electrical engineers decided to use a motor controller for this task; the GS2-22P0 motor controller, available from Automation Direct, was chosen for the system. The GS2-22P0 is pictured in Figure 3.15 below.

Figure 3.15: GS2-22P0 Motor Controller [23]

Specifications for the GS2-22P0 are shown in Table 3.4; more specs are in Appendix 7.

Table 3.4: GS2-22P0 Motor Controller Specifications [24]

Item	Specification
Motor Rating Horsepower Power	 2.0 HP 1.5 kW
Rated Input Voltage	Single/Three Phase: 200/208/220/230/240VAC ± 10% 50/60 Hz ± 5%
Rated Output Voltage	Corresponds to Input Voltage, 3-phase
Rated Input Current	15.7/8.8 A
Rated Output Current	7.0 A
Climate Ambient Operating Temperature (without derating) Humidity	 -10ºC to 50ºC (14ºF to 122ºF) 20% to 90% (no condensation)
Vibration	1G at less than 10Hz; 0.6G at 10-60Hz
Location	Altitude 1,000m or less
Weight	3.7 lb.
Dimensions	151.0mm x 100.0mm x 140.5mm

The GS2-22P0 is a programmable motor controller. Several parameters have to be set through programming. The programs can be accessed by using the "Program" and "Enter" keys on the keypad. Table 3.5 gives an outline of the programs and their correct value.

Table 3.5: GS2-22P0 Motor Controller Programs [25]

Program	Value
P 0.00 Motor Nameplate Voltage	220 V
P 0.02 Motor Base Frequency	60 Hz
P 0.03 Motor Base RPM	1750 RPM
P 0.04 Maximum Motor RPM	1800 RPM
P 1.00 Stop Methods	00 (Ramp to Stop)
P 1.01 Acceleration Time	5.0 seconds
P 1.02 Deceleration Time	0.1 seconds
P 3.00 Source of Operation Command	01 (Operation determined by external control terminals. Keypad STOP is enabled.)
P 3.01 Multi-Function Input Terminals	00 DI1 – FWD/STOP DI2 – REV/STOP

When setting programs P3.00 and P3.01 as outlined in Table 3.5, the digital inputs are wired up as shown in Figure 3.16.

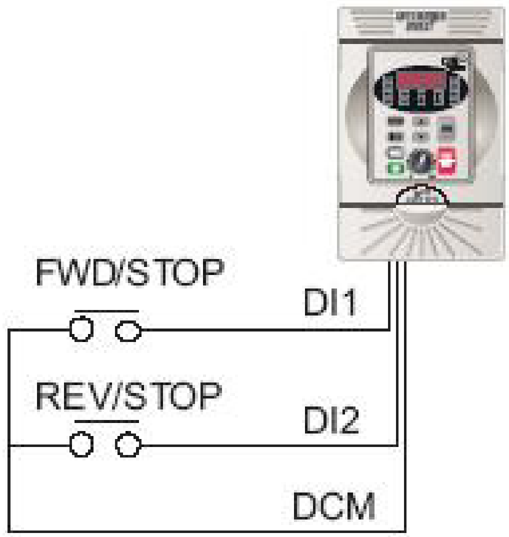


Figure 3.16: GS2-22P0 Motor Controller Wiring Diagram [25]

3.2.2 LED Indicators

The WVU-CIRA engineers decided that a good feature for the system deployment would be LED indicators to show the operator where the system was and what it was doing. A system of eight LED indicators was chosen. There would be three LED's for both translation and rotation, identifying to the user whether the system was in translation/rotation extended, translation/rotation stowed, translation/rotation operate mode. Also, there would be two LED's indicating whether the system was in Automatic or Manual mode. The LED colors are as follows: yellow for translation/rotation extended, green for translation/rotation stowed, and blue for translation/rotation operate. Also, there would be a red LED to indicate the system is in Manual mode and a green LED to indicate the system is in Automatic mode.

How these LED's are turned on vary for different LED's. The Automatic mode and translate/rotate operate LED indicators are turned on by PLC outputs (further discussed in Chapters 4 and 5); the translate/rotate operate LED's will not be functional in manual mode. The Manual mode LED indicator will be turned on whenever the user selects "Manual" with the Automatic/Manual selector switch on the pendant. The extended and stowed LED indicators will be turned on by the various proximity sensors, which are further defined in Chapter 4. The LED's that will be used in the system are outlined in Table 3.6 below.

Table 3.6: Sensor Pallet LED Indicators [16]

	Red DC LED	Green DC LED	Blue DC LED	Yellow DC LED
Voltage	24VDC	24VDC	24VDC	24VDC
Current	17 mA	17 mA	17 mA	17 mA
Size (Diameter)	0.550"	0.550"	0.550"	0.550"
Part Number	95C0354	95C0356	95C0357	95C0355

3.2.3 Operator Pendant

The operator pendant was introduced previously in Chapter 1. The concept is to have a "box" that houses certain buttons and switches to accomplish the task of running the Sensor Pallet. The pendant should have two pushbuttons; one to "extend" the Sensor Pod and one to "stow" the Sensor Pod. Of course, "extending" and "stowing" can occur with both translation and rotation; therefore, there should be a selector switch to determine if the user wants to operate the translation motor or the rotation motor. In addition, there are two modes that the user can deploy the Sensor Pod: Automatic and Manual. Thus, another selector switch should be present to switch between each mode.

Finally, there should be one overriding pushbutton that will stop any motion; to that end, an emergency stop pushbutton should also exist in the operator pendant.

3.2.3.1 Pendant Pushbuttons

The pushbuttons and selector switches chosen for the operator pendant had to be watertight, commercially available, and able to fit inside the chosen pendant enclosure. Square D pushbuttons, selector switches, and the corresponding contact blocks were chosen, since they are equipped with rubber sealing gaskets and fit standard 30mm holes in commercially available pendant enclosures. The emergency stop pushbutton, Grainger part number 2EN49, is pictured in Figure 3.17.

Figure 3.17: Emergency Stop Pushbutton [26]

The selector switch that will be used for both the Automatic/Manual switch and the Translate/Rotate switch, Grainger part number 5B445, is shown in Figure 3.18.

Figure 3.18: Selector Switch [27]

The pushbutton that will be used as both the "Extend" and "Stow" buttons, Grainger part number 5B517, is shown in Figure 3.19. This pushbutton is a "universal" model because it has several colored inserts; it was decided that the "Stow" button would assume the green colored insert (for safety, pod moving back into plane) and the "Extend" button would assume the yellow colored insert (for caution, pod moving out plane door).

Figure 3.19: Extend and Stow Pushbutton [28]

3.2.3.2 Pendant Enclosure

The pendant enclosure chosen for the system had to be watertight, heavy duty, and would accommodate up to five 30mm pushbuttons/switches. The Square D pendant enclosure, Grainger part number 2ER81, was chosen. This enclosure had only four 30mm holes, but had a place at the top of the faceplate where another hole could be drilled out for a fifth pushbutton. This enclosure was also equipped with a watertight sealing rubber grommet around the faceplate. It is made out of heavy duty plastic, and this entire assembly meets NEMA 1, 3, 4, 4X, and 13 standards. This enclosure even had a ¾" NPT conduit hole in the top for the pendant cable to enter [29]. The 2ER81 Square D pendant enclosure is pictured in Figure 3.20 below.

Figure 3.20: Operator Pendant Enclosure [29]

3.2.4 Control Circuit Design

The control circuit diagrams can be found in Appendix 6: "Sensor Pallet Control Circuit Diagrams." There are three general areas to explore: operator pendant circuit, the translation/rotation motor control circuit, and the PLC circuit. All these circuits work together to make Project Oculus a success.

The WVU-CIRA electrical engineers had to decide how to relay the required power, or turn on the motor controller, at the right time. The answer was to use relays; for example, when the user wants the translation motor to operate in the "extend" direction, a certain signal will be sent to energize the "translation extend" relay and supply 110VAC 60Hz to the counterclockwise input wire on the translation motor. With this idea in mind, what "signal" should be supplied? Relays with 24VDC coils were chosen; therefore, a +24VDC power supply was needed to generate the "signal."

3.2.4.1 24VDC Power Supply

The 24VDC power supply chosen for the system is the PS24-075D available from Automation Direct. This power supply is pictured in Figure 3.21 below.

Figure 3.21: PS24-075D 24VDC Power Supply [30]

Important specifications for the PS24-075D are given in Table 3.7 below. Further specifications can be found in Appendix 8.

Table 3.7: PS24-075D 24VDC Power Supply Specifications [31]

Item	Specification
Input Voltage	93-132VAC 187-264VAC
Input Frequency	47-63Hz
Input Current 115VAC 230VAC	 3.0A 1.7A
Efficiency	84%
Output Voltage	24VDC
Output Current (Max.)	3.0A
Output Power	75W

3.2.4.2 Relays

To utilize the circuit "Motor Circuit Diagram" shown in Appendix 6, no fewer than seven relays will be used. To distinguish between each relay, they were given descriptive names which were later abbreviated, as can be seen by the circuit diagram in Appendix 6.

The first relays discussed will be the R-TCCW and the R-TCW relays. These acronyms stand for "**R**elay - **T**ranslation **C**ounter**c**lock**w**ise" and "**R**elay – **T**ranslation **C**lock**w**ise." Whenever these relays are energized by a +24VDC signal, they supply 110VAC 60Hz to the respective input wires on the translation motor. A block diagram illustrating the use of the R-TCW and R-TCCW relays is shown in Figure 3.22.

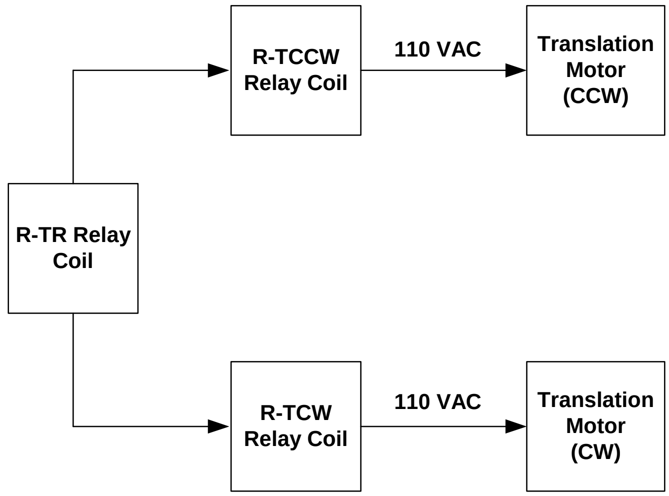


Figure 3.22: Block Diagram of R-TCW and R-TCCW Relays

The second relays discussed will be the R-RF and the R-RR relays. These acronyms stand for "**R**elay – **R**otation **F**orward" and "**R**elay – **R**otation **R**everse." The R-RF relay controls digital input DI1 and the R-RR relay controls digital input DI2 on the GS2-22P0 motor controller. Whenever these relays are energized by a +24VDC signal, they close a circuit that shorts DC common to the digital inputs; refer to Figure 3.16 for wiring. A block diagram illustrating the use of the R-RF and R-RR relays is shown in Figure 3.23.

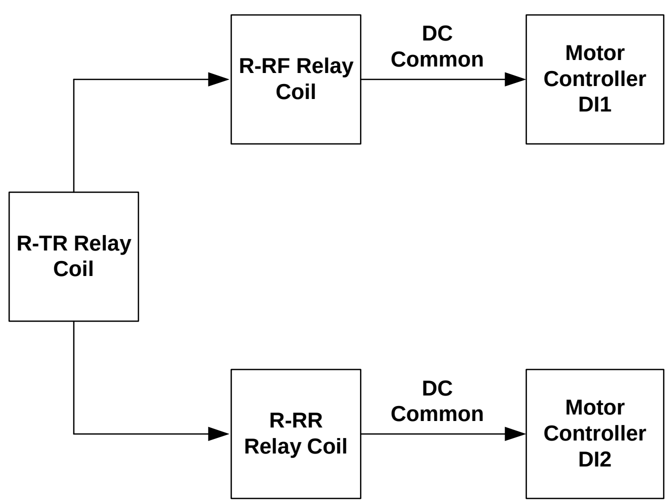


Figure 3.23: Block Diagram of R-RF and R-RR Relays

Next, the R-RB relay will be discussed. This acronym stands for "**R**elay – **R**otation **B**rake." This relay is energized when the digital inputs on the motor controller receive a signal. It then relays 220VAC 60Hz to the brake on the rotation motor, releasing the brake so that the motor can turn. A block diagram illustrating the use of the R-RB relay is shown in Figure 3.24 below.

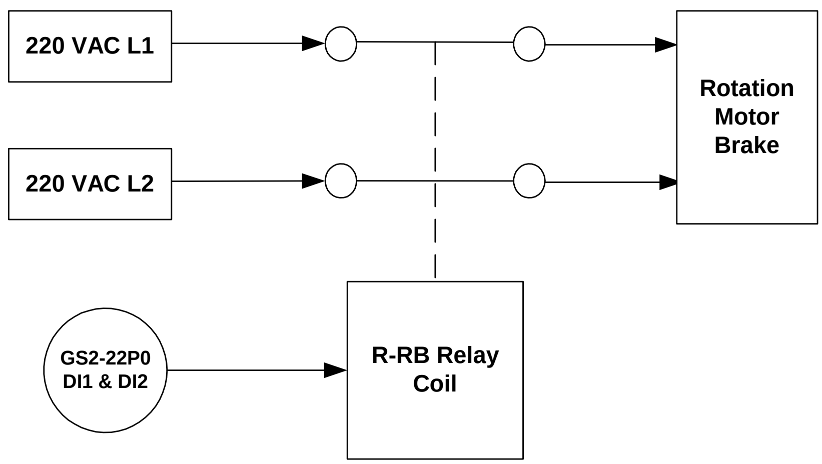


Figure 3.24: Block Diagram of R-RB Relay

To determine whether the translation or rotation relays receive the +24VDC signal from the Extend/Stow buttons on the pendant, the R-TR control relay is implemented. This acronym stands for "**R**elay – **T**ranslation/**R**otation." The energizing signal for this relay comes from the Translate/Rotate selector switch on the pendant. When the relay is not energized, the +24VDC signal is relayed from the Extend/Stow buttons is sent to the translation relays, R-TCW and R-TCCW. When the relay is energized, the +24VDC signal is relayed from the Extend/Stow to the rotation relays, R-RF and R-RR. A block diagram illustrating the use of the R-TR relay is shown below in Figure 3.25.

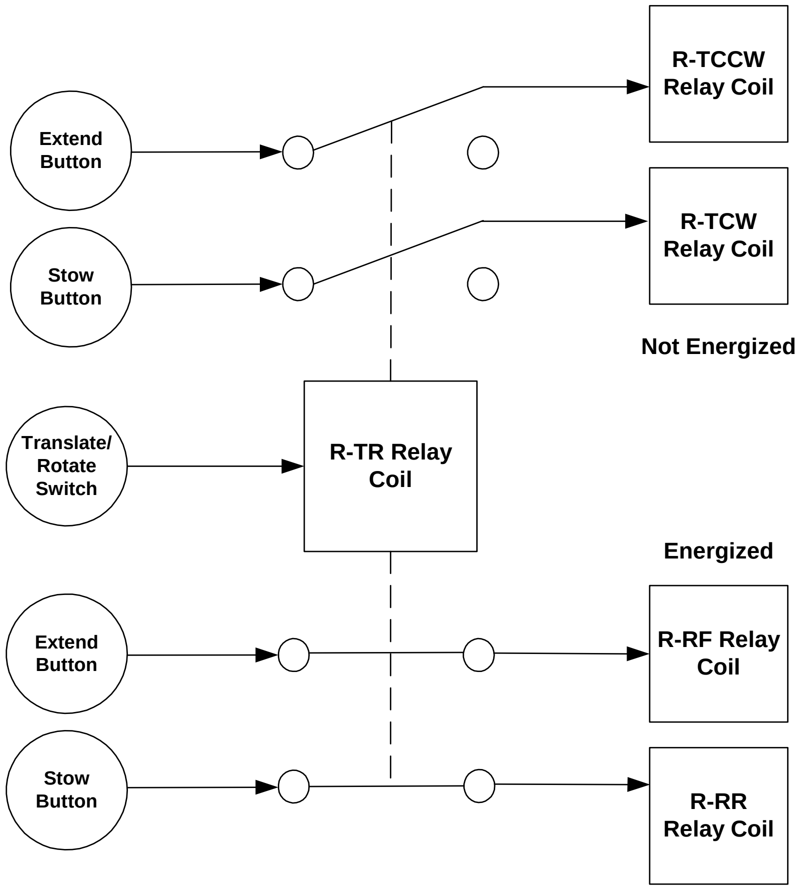


Figure 3.25: Block Diagram of R-TR Relay

The final relay to discuss is the R-PLC relay in the PLC circuit diagram. This acronym stands for "**R**elay – **P**rogrammable **L**ogic **C**ontroller." This relay is energized when the Automatic/Manual selector switch on the pendant is set to "Automatic." When energized, this relay sends 220VAC 60Hz to the PLC to turn it on and run Automatic mode. Automatic mode will be further discussed in Chapters 4 and 5. A block diagram illustrating the use of the R-PLC relay is shown below in Figure 3.26.

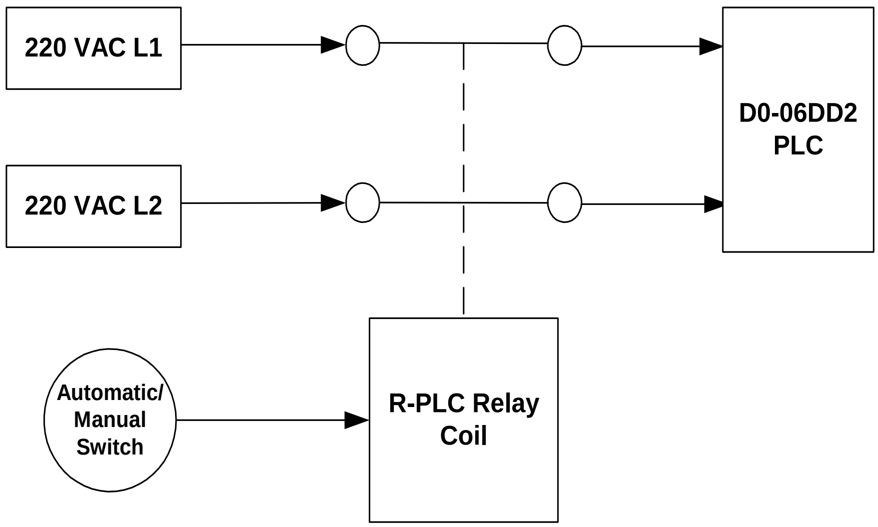


Figure 3.26: Block Diagram of R-PLC Relay

The relay chosen to perform all these tasks was the QL2X1-D24 available from Automation Direct. It is pictured in Figure 3.27 shown below.

Figure 3.27: QL2X1-D24 24VDC Relay [32]

Important specifications for the QL2X1-D24 are given in Table 3.8 below. Further specifications can be found in Appendix 9.

Table 3.8: QL2X1-D24 Relay Specifications [33]

Item	Specification
Contact Specifications	
Contact Rating, Current	10A
Contact Rating, Max. Voltage	250VAC/125VDC
Configuration	2PDT
Coil Specifications	
Coil Voltage	24VDC
Rated Current at 50Hz/60Hz	36.9mA
Coil Resistance	650Ω
Power Consumption	0.9W
Options	LED Indicator, Diode Protection
General Specifications	
Operate Time	25 ms
Release Time	25 ms
Vibration Resistance	10Hz to 55Hz
Shock Resistance	1,000 m/s^2 (approx. 100G)
Ambient Temperature	-25ºC to 70ºC (-13ºF to 158ºF)
Ambient Humidity	45% to 85% Relative Humidity
Weight	35g (1.24 oz.)
Socket Needed	SQL08D

3.2.4.3 Limit Switches

To protect the operator from damaging the translation motor or any other part in the system, two mechanical limit switches were added to the design of the circuit. One limit switch was placed at the stowed position and the other switch was placed at the extended position of the translating plate's path of motion. Whenever the plate translates too far in either direction, the limit switch will be "tripped" and the motion will stop. This is done by putting the limit switches in line with the signal from the R-TR relay to the R-TCW and R-TCCW relays. The "stowed limit switch" is placed in line with the R-TCW relay and the "extended limit switch" is placed in line with the R-TCCW relay.

The limit switch chosen for the system is the ABM6E42Z11 available from Automation Direct. It comes equipped with an aluminum chassis and a stainless steel roller actuator. It also has three cable entry holes that will accommodate ½” NPT conduit [34]. This limit switch is pictured in Figure 3.28 shown below.

Figure 3.28: ABM6E42Z11 Limit Switch [34]

3.2.4.4 Pendant Circuit Design

The pendant has a combination of five pushbuttons and switches and several tasks to accomplish. The Extend and Stow buttons actually have to serve a dual purpose. When the system is in Manual mode, these buttons should relay the +24VDC signal directly to the respective translation relay; when the system is in Automatic mode, these buttons should send the +24VDC signal to the PLC (discussed further in Chapters 4 and 5). These separate functions can be realized by using two different contact blocks (Automatic and Manual) for both the Extend and Stow buttons.

First, the +24VDC signal will be brought into the pendant. Since the Emergency Stop button is supposed to end all motion when pressed, this button is placed on the +24VDC signal line with a normally closed (NC) contact. When the button is pressed, the circuit is opened and the +24VDC signal is not relayed through the other buttons; therefore, none of the relays are energized in the circuit and everything turns off.

From the emergency stop button, the +24VDC signal is run through the Automatic/Manual selector switch. When the switch is on “Automatic”, the +24VDC signal is relayed to three places: (1) the R-PLC relay, (2) the Extend button (Automatic NO contact), and (3) the Stow button (Automatic NO contact). Then, when either the Extend or Stow buttons are pushed, the circuit is closed and the +24VDC signal is relayed to the respective input on the PLC (inputs defined in Chapter 5).

When the switch is on “Manual”, the +24VDC signal is relayed to three places: (1) +24VDC turns the red Manual LED Indicator on, (2) the Translate/Rotate switch, which should only receive power in Manual mode (this switch is inoperable in Automatic mode), and (3) the Extend button (Manual NC contact). When the Extend button is not being pressed, the signal is sent through the NC contact to the Stow button; this ensures that the user cannot send an “extend” and “stow” signal to the system at the same time in manual mode. When the Extend button is pressed, the +24VDC signal is relayed to the R-TCCW relay; when the Stow button is pressed, the +24VDC signal is relayed to the R-TCW relay. This entire process is illustrated in the drawing “C-130 Pendant Schematic” found in Appendix 6.

Chapter 4: Automatic Mode Hardware Design

As discussed previously, a Programmable Logic Controller (PLC) will execute the automatic mode of deployment of the mechanical arm. First, though, the WVU-CIRA engineers had to look at the operation of the mechanical arm and sensor pod itself and recall the deployment steps of the system presented earlier in Chapter 1. First, the translating plate has to travel 19 inches outward, moved by the 110VAC 60Hz translating motor. Second, the mechanical arm has to be rotated 206° to its final position under the C-130 door. Finally, the translating plate has to be moved backward until it presses up firmly against the butt plate on the door, providing stability to the sensor pod and the delicate electrical equipment stored inside. Though the engineers knew the initial translating distance and the rotational angle for every deployment procedure that the arm will undertake, the final distance that the pod must travel back to the butt plate can vary every time, depending on the type of C-130 that the system has been loaded upon and is operating from. This fact had to be taken into consideration; therefore, the use of a proximity sensor to determine the final translating distance back to the butt plate was impossible. Thus, the first task to be undertaken before writing code is to determine the placement of the proximity sensors to identify the position of the translating plate and the rotating arm, and then the second task would be to determine the solution to the problem of identifying when the sensor pod has pulled up tight against the butt plate.

4.1 Proximity Sensor Design

Now that it has been determined that automatic mode will use input from proximity sensors, the specific proximity sensors that will be used in the system needs to be determined. There are several determining factors to deciding on a proximity sensor.

All factors should be considered during the design process. First, the WVU-CIRA engineers reviewed the proximity sensor design criteria, and then finally made a decision as to which proximity sensor to employ in the system.

4.1.1 Proximity Sensor Design Criteria

First, should the sensor be an NPN-type or PNP-type; in other words, should the sensor sink or source current when sensing? This needs to be considered with the specific PLC or computing equipment in mind. The PLC inputs either will sink or source current, so the proximity sensor needs to be picked accordingly.

Second, what kind of sensor should it be? There are a several types of proximity sensors, which were clearly defined and discussed in the literature review in Chapter 2. The most popular are inductive proximity sensors and capacitive proximity sensors. Inductive proximity sensors can only sense magnetic metals, while capacitive sensors can sense just about anything, including everything from non-magnetic metals to a person’s finger.

Third, what should the sensing distance for the respective proximity sensors be? This question can relate back to what kind of sensor should be chosen, since different kinds of proximity sensors have vastly different sensing distances. Sensing distances can vary from a couple of millimeters to several meters in length. Adding complexity to this problem is the fact that the sensor needs to sense moving components; the translating plate and the rotating arm will be moving when the proximity sensor should sense them.

Finally, in what type of environment will the sensor be used? If the environment is electrically noisy, this could render the proximity sensor useless. However, this problem can be corrected with the use of a shielded sensor. Proximity sensors can be built with electrically shielded bodies so that exterior electrical noise cannot interfere with the delicate circuitry found inside the sensor. Also, the cable leading to the sensor can be shielded so that the signal from the sensor cannot be electrically interfered with as well. Considering the electrical environment that the sensor will be used in is extremely important because the noise interference will most likely cause a false positive signal to be generated on the signal line coming from the sensor.

4.1.2 Choosing a Proximity Sensor

All these design criteria were weighed in determining the right proximity sensor for the job. First, should the proximity sensor be NPN or PNP? The WVU-CIRA engineers decided that the PLC chosen would sink current at the inputs, so therefore a PNP proximity sensor, a sensor that sources current when sensing, should be chosen so that the two components interface properly.

Second, what kind of sensor should be chosen? The selection process came down to inductive or capacitive proximity sensors. The metal that the sensor will be sensing is aluminum; the rotating arm is made from aluminum, as well as the manual stops underneath the translating plate that the sensors will be seeing. The WVU-CIRA mechanical engineers chose to use aluminum because it is easier to work with and weighs less than stainless steel while also being corrosion resistant. However, aluminum is not a magnetic metal, which makes the use of an inductive proximity sensor impossible. Therefore, a capacitive proximity sensor will be needed.

Third, what sensing distance is required for the chosen proximity sensor? Since the proximity sensor will have to be picking up moving objects, albeit slow-moving objects, it should have a sensing distance that is far enough away so that it picks up the moving object and delivers the signal to the PLC in time for it to turn off the respective motor before the object collides with the sensor itself and damages it. A study of available sensors finds that a sensing distance of up to 15mm is readily available.

Lastly, should the proximity sensor be built with a shielded body and a shielded cable? The C-130 itself is notorious for being electrically noisy, since it houses power generators and is outfitted with a lot of communications equipment. Also recall the intention of Project Oculus; to deploy sensors such as a FLIR, radar, and an antenna for communication, among various other pieces of equipment. Any of these sensors could cause a critical amount of electrical noise for the proximity sensors. In addition, the power to the rotational and translational motors should be considered. The rotational motor, as mentioned earlier, is a 2.0 HP motor operating from 220VAC 60 Hz 3-phase power that is generated from a PWM inverter. This kind of power has the potential to create a serious amount of electrical noise. With all these possible sources of electrical noise that can cause havoc with the proximity sensor, it was decided that a proximity sensor with a shielded body and cable would be best for the job at hand.

The final design constraints for a proximity sensor are thus: a PNP capacitive proximity sensor with a sensing distance of up to 15mm and comes equipped with a shielded body and cable. One product that meets these requirements is the CT1-AP-1A, a capacitive proximity sensor that encompasses most of these specified criteria and made available by Automation Direct. The CT1-AP-1A is pictured in Figure 4.1 shown below.

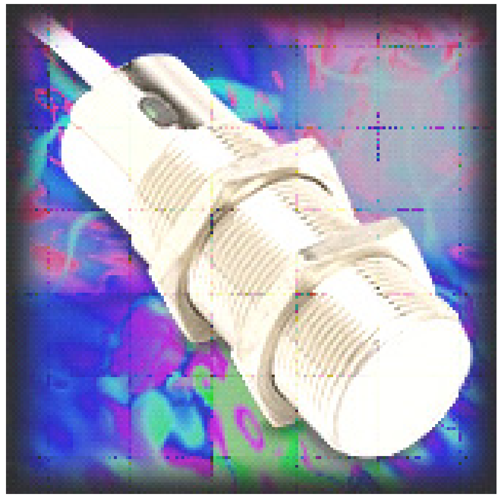


Figure 4.1: CT1-AP-1A Proximity Sensor [35]

The CT1-AP-1A has two status LED’s in its base; a green “Power-On” LED and a red “Sensing” LED. The equivalent circuit for the PNP output is shown in Figure 4.2.

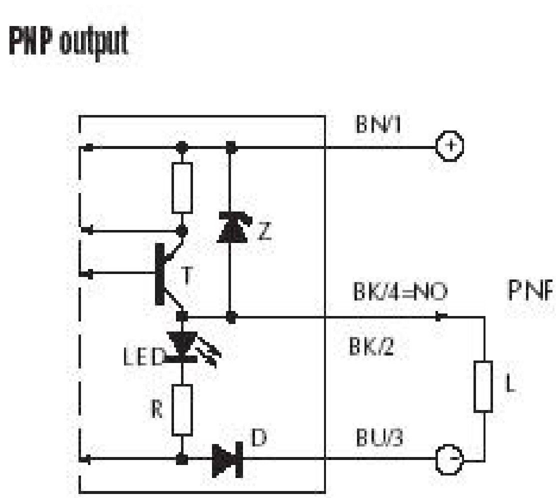


Figure 4.2: CT1-AP-1A Equivalent Output Circuit [36]

Relevant specifications for the CT1-AP-1A are given below in Table 4.1; further specifications can be found on the CT1-AP-1A data sheet supplied from Automation Direct shown in Appendix 11.

Table 4.1: Specifications of the CT1-AP-1A Proximity Sensor [36]

Item	Specification
Size of sensing face	30mm
Power Source	10-30 VDC
Maximum Source Current	200mA
Output Type	PNP
Shielded/Unshielded	Shielded Body, Unshielded 3-Wire Cable
Sensing Distance	Adjustable 2-15mm nominal sensing distance
NO or NC?	Normally Open Output
Type of Sensor?	Capacitive

By examining the specifications of this specific sensor, the reader will notice that the 3-wire cable for the sensor is not shielded. However, this is easily fixed by replacing the supplied cable with a piece of shielded 3-conductor 18 AWG cable. The three wires in the cable are for +24 VDC and DC common, so that the sensor can be powered, and a signal line that will carry current whenever the sensor is sensing an object.

Now that a proximity sensor has been chosen, the engineers must decide where the sensors will be placed. This topic is discussed in the next section.

4.2 Proximity Sensor Placement

To determine the placement of the proximity sensors, the WVU-CIRA engineers first had to establish what positions needed to be sensed. It was decided that it was important to sense the instant when the translating plate or the rotating arm had finished a given movement.

4.2.1 Placement of the Translation Proximity Sensors

The movements that the translating plate would be performing during the extending and stowing procedures would be translating outward a full 19 inches and returning to its "home" position. Therefore, one proximity sensor would be needed at the "home" position and another would be needed at the 19 inch mark. This "home" position sensor was named the "Translation Stow Sensor," or otherwise known as the "T-Stow Sensor," and the sensor placed at the 19-inch mark was named the "Translation Extend Sensor," or otherwise known as the "T-Extend Sensor." It was decided that the proximity sensors would be a normally open circuit until the translating plate reached the sensor, at which time the proximity sensor would sense the plate was there and close the circuit.

4.2.2 Placement of the Rotation Proximity Sensors

The movements that the rotating arm would be performing during the extending and stowing procedures would be rotating outward 206° to its position under the door and rotating back to the arm supports mounted on top of the translating plate. Therefore, one proximity sensor would be mounted on the arm support itself to see when the arm had reached its stowed position, and another would be placed on the front of the translating plate underneath the rotating shaft to sense when the arm had finished rotating 206°. The proximity sensor mounted on the arm support was named the "Rotation Stow Sensor," also known as the "R-Stow Sensor," and the proximity sensor mounted on the front of the translating plate was named the "Rotation Extend Sensor," also known as the "R-Extend Sensor." As before, it was decided that these proximity sensors would be a normally open circuit until the rotating arm reached the sensor, at which time the proximity sensor would sense the arm was there and close the circuit.

In the end, the important positions of the translating plate and the rotating arm should be known with the use of four simple proximity sensors. The placement of these sensors (shown in red) as discussed above is illustrated in Figure 4.3 shown below.

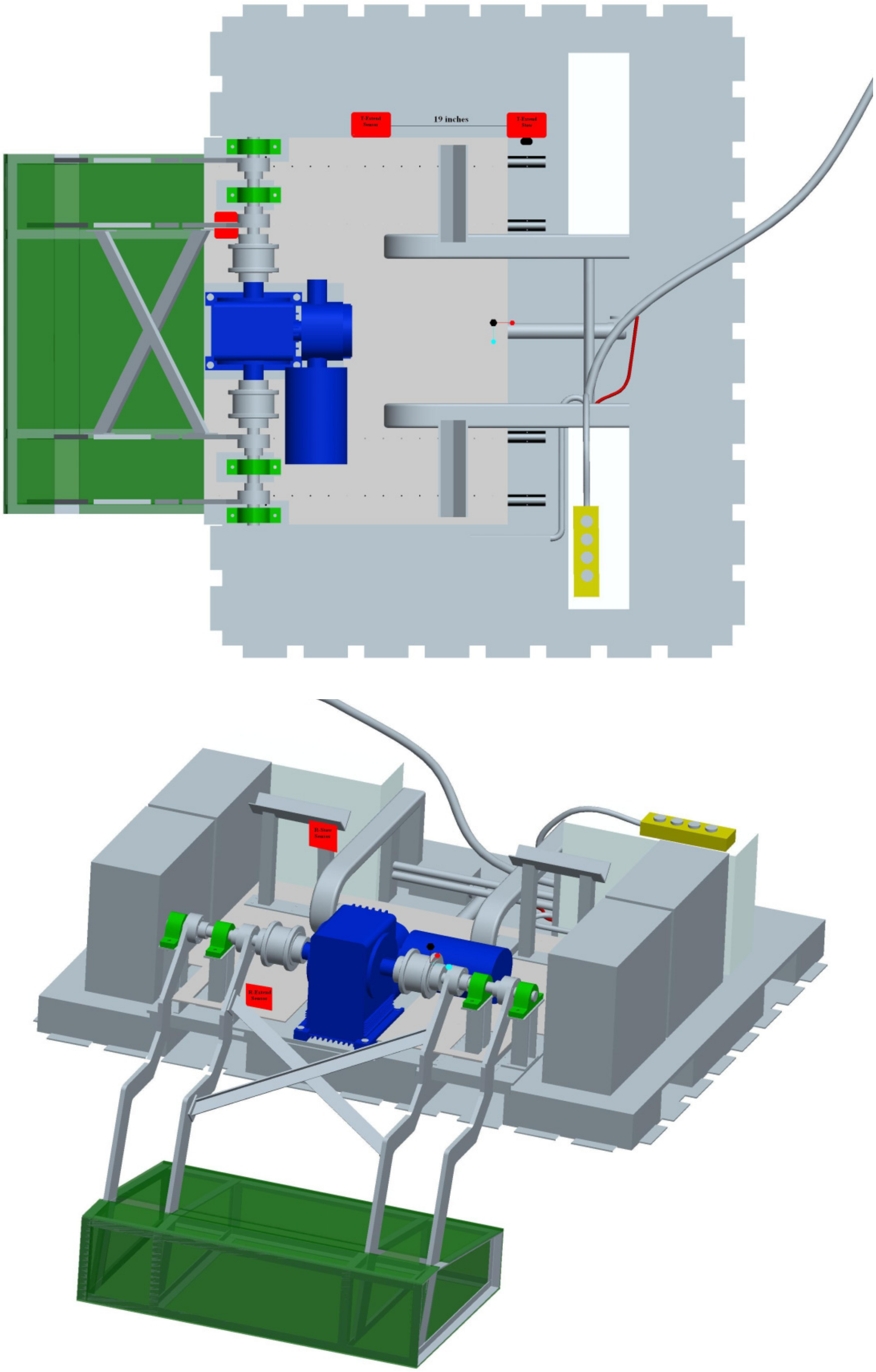


Figure 4.3: Placement of Proximity Sensors on the Sensor Pallet [5]

4.3 Final Deployment Positioning – Current Sensor

The sensor pod is in its fully deployed position when it has finished rotating and pulled back up tight against the butt plate on the C-130 door. But in automatic mode, how will the PLC be told that the sensor pod has finished pulling up against the door? As discussed before, the use of a proximity sensor to perform this operation is impossible.

4.3.1 Solution – Current Sensor

To solve this problem, the WVU-CIRA engineers looked at the conditions surrounding the problem; in other words, what conditions exist when the sensor pod has pulled up against the door that did not exist before it happened? The sensor pod is pulled back against the door by using the 110VAC 60Hz translational motor. Whenever the sensor pod pulls up against the door and cannot be moved any further, this causes the translational motor to "bind up," which results in a current spike to the motor. If the PLC could sense this current spike, then it would know that the sensor pod has reached its fully deployed state and therefore turn off the translation motor. To perform this operation, a current sensor can be used; the PLC should be able to be programmed to search for a specific range of current so it knows when to shut off the translation motor.

A Hall Effect current sensor was chosen to solve this problem. Regardless of the direction the translation motor is turning, the neutral wire to the motor is always carrying current; therefore, the neutral wire to the translation motor can be run through the Hall Effect current sensor to measure the current to the motor.

The Hall Effect current sensor chosen for the system was the CLN-50 from F.W. Bell. This sensor is pictured in Figure 4.4 shown below.

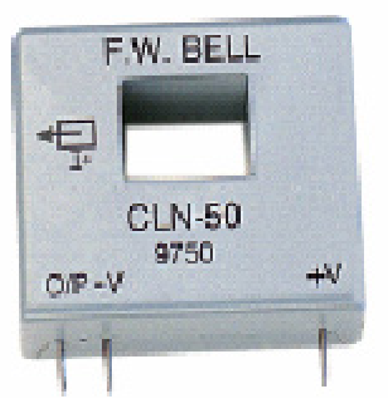


Figure 4.4: CLN-50 Current Sensor [37]

The CLN-50 is a small square device with a square hole in the middle where the current-carrying wire will pass through the sensor. This current sensor has three pins; a pin each for a +V and –V power source, and a third pin for the output O/P. The CLN-50 requires a +/-12 VDC power source. The power source is used as a reference voltage for the O/P; the current sensor can measure positive and negative current. Further specifications for the CLN-50 hall-effect current sensor can be found in Appendix 12, a data sheet provided by F.W. Bell.

4.4 Programmable Logic Controller Design

Now that all the other components for Automatic Mode have been selected, the heart and soul of the system must be chosen: the Programmable Logic Controller. Choosing a PLC for the job depends on several criteria, each of which was considered carefully by the WVU-CIRA engineers.

4.4.1 Programmable Logic Controller Design Criteria

First, what kind of input does the PLC accept? This refers to whether the inputs sink or source current, and whether the inputs are AC or DC. Second, what kind of outputs does the PLC give? Again, this is in reference to whether the outputs sink or source current, and also whether the outputs are AC or DC. Third, does the PLC have the ability to accept different kinds of input? There can be a mixture of AC and DC inputs; this system may need a PLC that has this kind of flexibility in its inputs, whether the inputs come standard on the PLC or can be added through additional optional modules. A final specification that would be appreciated is to choose a PLC that is easy to program. Most commercially available PLCs use ladder logic to create their programs. Ladder logic is an easy way to define the certain outputs that should be turned on when specific inputs are present.

4.4.2 Choosing a Programmable Logic Controller

Now that the design criterion has been established, a choice for a PLC can be made. Based on the selection of the PNP proximity sensors and the design of the pendant circuit discussed in Chapter 3, the PLC inputs must sink current provided from a 24VDC power source. However, there is also a required input from the CLN-50 current sensor discussed in the previous section. The output provided from this sensor is an AC signal; therefore, the PLC chosen must accept analog input or have the ability to add an expansion module to do so.

As for the next requirement, the PLC outputs need to source DC current. This is based on the fact that the outputs need to energize 24VDC relays to run the translation motor, a design that was discussed in Chapter 3, and also must drive 24VDC LED indicators, also discussed in Chapter 3. However, this does not define all needed outputs from the PLC. The PLC needs to be able to run the GS2-22P0 motor controller discussed in Chapter 3. Recall that the digital inputs used to control the motor controller source DC current; therefore, the PLC must be able to have two outputs that can sink current.

Keeping these requirements in mind, the D0-06DD2 PLC available from Automation Direct was chosen for Project Oculus. This unit is a cost effective yet easy to program as the solution to the problem at hand. The D0-06DD2 PLC is pictured in Figure 4.5 shown below.

Figure 4.5: D0-06DD2 Programmable Logic Controller [38]

The D0-06DD2 PLC accepts up to 20 24VDC inputs and provides up to 16 24VDC outputs. The first four inputs (inputs X0-X3) to the unit are high-speed inputs; they are generally not going to be used for this system. The next 16 inputs (inputs X4-X23) are standard inputs [39]. The equivalent circuit for these inputs is shown in Figure 4.6.

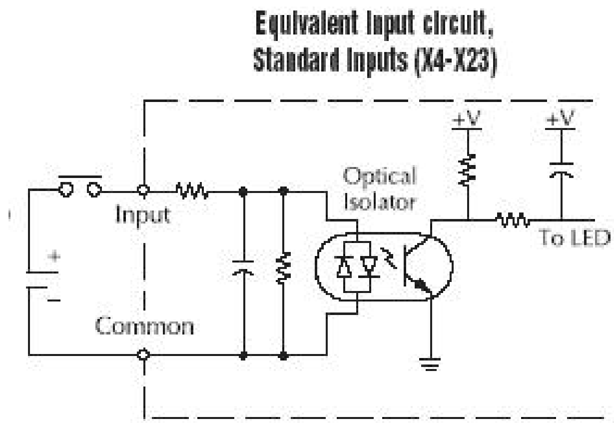


Figure 4.6: Equivalent Input Circuit on the D0-06DD2 PLC [39]

Of the 16 available outputs provided by the D0-06DD2 PLC, the first two outputs (outputs Y0-Y1) are configurable pulse outputs and will not be used in the system. The next 14 outputs (outputs Y2-Y17) are standard and will be used in the system [39]. The equivalent circuit for these standard outputs is shown in Figure 4.7 below.

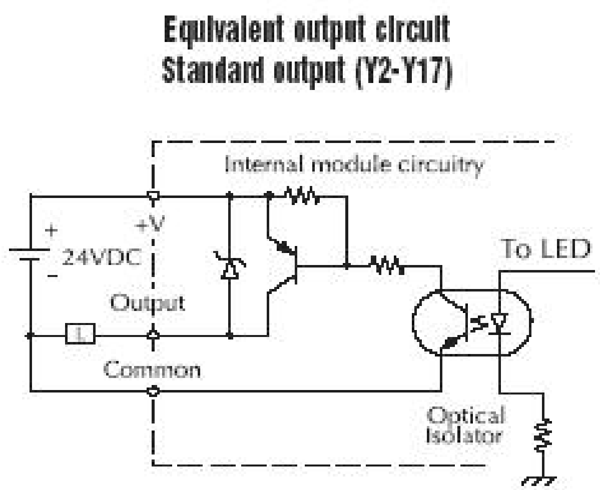


Figure 4.7: Equivalent Output Circuit on the D0-06DD2 PLC [39]

The D0-06DD2 PLC also has four expansion slots for additional optional modules. These expansion slots will be used for optional modules that will handle the

AC input from the current sensor and provide the output needed for the digital inputs to the GS2-22P0 motor controller. These expansion modules will be discussed further in Section 4.4.4 PLC Optional Modules.

Relevant specifications for the D0-06DD2 PLC are given below in Table 4.2; further specifications can be found on the D0-06DD2 PLC data sheet supplied from Automation Direct shown in Appendix 13.

Table 4.2: Specifications of the D0-06DD2 Programmable Logic Controller [39]

Item	Specification
Power Supply	110/220 VAC
Auxiliary DC Power Supply	0.3A 24VDC Power Supply
Communication Ports	• 2 built-in RS232C ports • RS232C/RS422/RS485 secondary port
Inputs	• 20 DC inputs • 12-24 VDC current sinking/sourcing • 5 isolated commons (4 I/Ps per common) • 4 configurable high-speed I/Ps
Outputs	• 16 DC outputs • 12-24 VDC current sourcing • 1.0A per point maximum • 4 non-isolated commons (4 O/Ps per common)
Expansion Slots	4 option slots available
CPU	DL06 CPU
Programming Software	DirectSoft32© Software for the DL06 CPU
DIN Rail Mountable?	Yes

4.4.3 PLC Accessories

Along with the D0-06DD2 PLC, several accessories needed to be added. First, this PLC affords the ability to add an LCD display to the front of the unit. When programming the unit, text can be written to the LCD display to inform the user of which step the PLC is performing at any given time. The LCD display that is available for the

D0-06DD2 PLC is the D0-06LCD, also available from Automation Direct. It can display 16 characters across two rows, for a total display of 32 maximum characters [40]. The D0-06LCD LCD display is pictured in Figure 4.8 shown below.

Figure 4.8: D0-06LCD LCD Display for the D0-06DD2 PLC [40]

The next accessory for the D0-06DD2 PLC that is needed is the programming cable. Once the programmer writes the controlling program on a personal computer, the programming cable is needed to transfer this program to the PLC. The programming cable for the D0-06DD2 is the D2-DSCBL, available from Automation Direct. It is a 12ft. (3.66m) RS232 shielded PC programming cable that is specifically used for DL05, DL06, DL205, D3-350, and D4-450 CPUs. It is equipped with a 9-pin D-shell female connector on one end that connects to the PC, and an RJ12 6P6C connector on the other end that attaches to the D0-06DD2 PLC via Port 1 [41]. This important cable is pictured in Figure 4.9.

Figure 4.9: D2-DSCBL Programming Cable for the D0-06DD2 PLC [41]

Finally, the PLC cannot be programmed without the programming software itself. Of course, there is specific programming software for the particular Version 4.0 DL06 CPU that controls the D0-06DD2 PLC. This programming software is called DirectSoft32©, and it is part number PC-PGM-BRICK, available from Automation Direct. As is the case with most PLCs, this programming software is based on ladder logic. The ladder rungs are illustrated in the software; the inputs that make the rung "true" are placed on the rungs and the resulting output(s) are placed at the end of the rung. The software provides the user with instant programming error-checking, the ability to add element names and documentation, and full printing features. It also manages the connection between the PC and the PLC. DirectSoft32© is compatible with Windows 98/2000/NT 4.0 or later, and all Windows XP versions. There are no UNIX, LINUX, Macintosh, or DOS versions of this product available. The minimum system requirements for running this software are a Pentium/Celeron CPU running at 333MHz clock speed, CD-ROM for loading the software, 32MB of free memory, 11MB free hard drive disk space, at least one unused serial communication port, and a color SVGA monitor [42].

4.4.4 PLC Optional Modules

The D0-06DD2 PLC gives the user the ability to add up to four optional modules; Project Oculus will require the use of two of these expansion slots. The CLN-50 hall-effect current sensor has an analog output that the PLC must be able to receive. However, the standard inputs on the unit are 12-24 VDC inputs. Therefore, an optional module that will enable the D0-06DD2 PLC to accept an analog input must be added. The F0-04AD-1 4-channel analog input module, available from Automation Direct, will be installed in the first expansion slot. This input module has a range of 4-20mA or 0-20mA and a 12 bit resolution. The F0-04AD-1 input module is shown in Figure 4.10.

Figure 4.10: F0-04AD-1 Analog Input Module [43]

All specifications and user manual information about the F0-04AD-1 analog input module supplied from Automation Direct are shown in Appendix 14. It is important that the module is placed in the first expansion slot, the one that is located to the far left of the expansion slots. The reason for this is software based; when writing the program to control the PLC, code is written to configure the F0-04AD-1 analog input module and refer to memory locations associated with the first expansion slot.

For the F0-04AD-1 analog input module to accept the signal from the CLN-50 current sensor, the O/P signal needs to be rectified into a +/- signal. To do this, the O/P signal is ran through a bridge rectifier. The circuit to perform this operation is shown below in Figure 4.11.

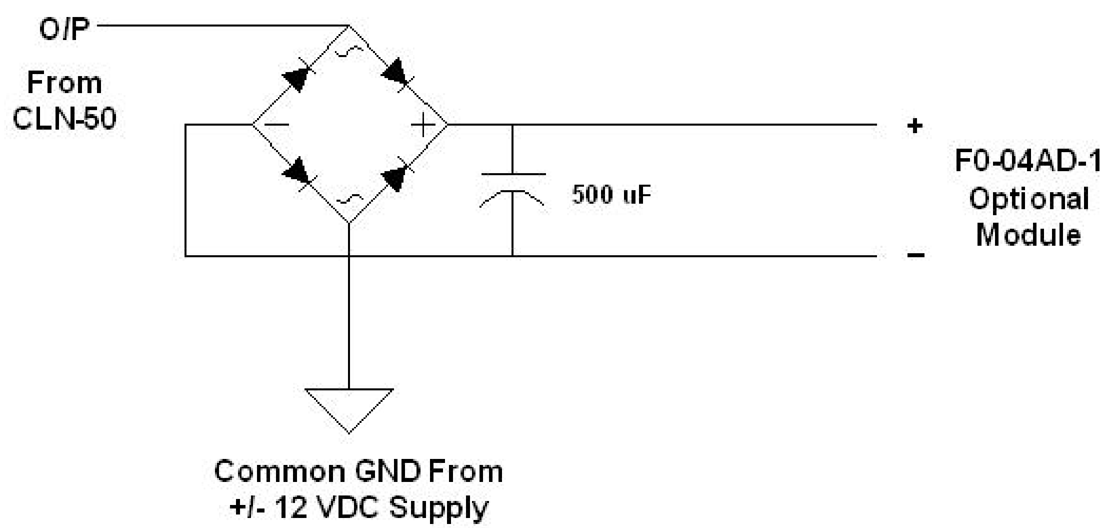


Figure 4.11: Current Sensor to F0-04AD-1 Analog Input Module Circuit

Studying the specifications for the D0-06DD2 PLC, one will find that the outputs source current. The source current here is needed to energize the relays for the translation motor and drive the LED indicators, but this type of output will not operate the digital inputs on the GS2-22P0 motor controller. Therefore, the second optional module that is needed for the system is a digital output module that will sink current rather than source current. The optional module chosen for this operation is the D0-08CDD1 available from Automation Direct. This module is actually a combination of four digital inputs and four digital outputs; however, only the digital outputs are important here. This module is pictured in Figure 4.12 shown below.

Figure 4.12: D0-08CDD1 Digital Output Module [44]

The outputs' operating voltage range is 6-27 VDC, and the maximum output current is 0.3A per point and 1.2A per common [44]. All specifications supplied by Automation Direct for the D0-08CDD1 digital output module are shown in Appendix 15. Also, the equivalent circuit for the digital output is shown in Figure 4.13 below.

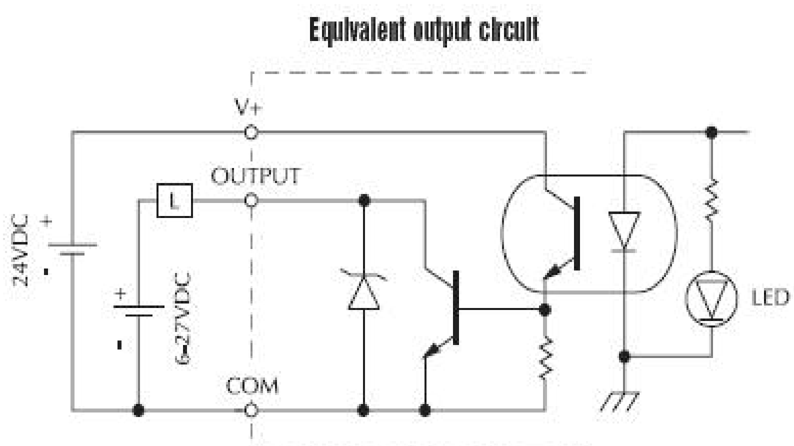


Figure 4.13: Equivalent Output Circuit for the D0-08CDD1 [45]

This concludes the hardware specifications for automatic mode. Now that the hardware has chosen and the placement for proximity sensors has been set, the program to run automatic mode must be designed and written. Chapter 5 will detail the design and coding of the automatic mode ladder program.

Chapter 5: Automatic Mode Software Design

Now that the Programmable Logic Controller (PLC) has been chosen to be the D0-06DD2 available from Automation Direct, the WVU-CIRA computer engineer had to program it to carry out the automatic mode deployment of the sensor arm/pod system. To program the PLC, the engineer needed to use the special programming software designed especially for the DL06 PLC processor, which is the DirectSoft32© programming software that was described in Chapter 2. This chapter will detail the process followed in designing the program and programming the PLC.

First, the inputs to and outputs from the PLC need to be defined. Once the inputs and outputs have been determined, a program must be created that responds to certain groups of inputs and generates the correct corresponding outputs. Finally, certain error states that could occur during operation should be determined and prepared for in the program itself.

5.1 Definition of PLC Inputs and Outputs

The PLC inputs and outputs were first defined and then mapped to input and output points on the PLC itself. The inputs have been basically defined in previous chapters. There are four proximity sensors, defined in Chapter 4 as "T-Stow Sensor", "T-Extend Sensor", "R-Stow Sensor", and "R-Extend Sensor", as well as two operator pushbuttons on the pendant, the Extend and Stow buttons, that need to be inputs accepted by the PLC. These six inputs take the form of 24VDC signals. Also, there is an analog signal generated by the CLN-50 current sensor that the PLC must see as an input. This input is received by the optional F0-04AD-1 analog input module discussed in Chapter 4. For the D0-06DD2 PLC to accept inputs from this optional module, the optional module and the expansion slot that it is mounted in needs to be "configured" in the program itself, which was covered in Chapter 2.

The outputs have changed during the course of the design and now have been finalized at five standard outputs and two outputs from the D0-08CDD1 digital output module. The standard outputs are of course two signals to turn on the R-TCW and R-TCCW relays, an output to turn on the green Automatic Mode LED indicator, and two outputs to turn on the Translation and Rotation Operating LED indicators. The other LED indicators that are present in the system will be driven by their respective proximity sensors.

The two outputs from the D0-08CDD1 digital output module control the digital inputs of the GS2-22P0 motor controller. When using the D0-08CDD1 module, the D0-06DD2 PLC reserves certain output reference names for the four outputs present on the module. D0-08CDD1 module outputs 0-3 directly map to D0-06DD2 PLC outputs Y100-Y103 that can be controlled through the DirectSoft32© programming software. The D0-08CDD1 module does not need to be configured for use in the program like the F0-04AD-1 module; it is strictly plug-and-play.

These inputs and outputs described above were mapped to the D0-06DD2 PLC input/output points, which are illustrated in Figure 5.1 shown below. All the commons on the input side of the PLC, points C0-C4, were tied together to the PS24-075D 24VDC power supply common. The voltage input points on the output side were tied together to the PS24-075D + 24VDC power supply, and the single common point C0 was wired to the PS24-075D power supply common.

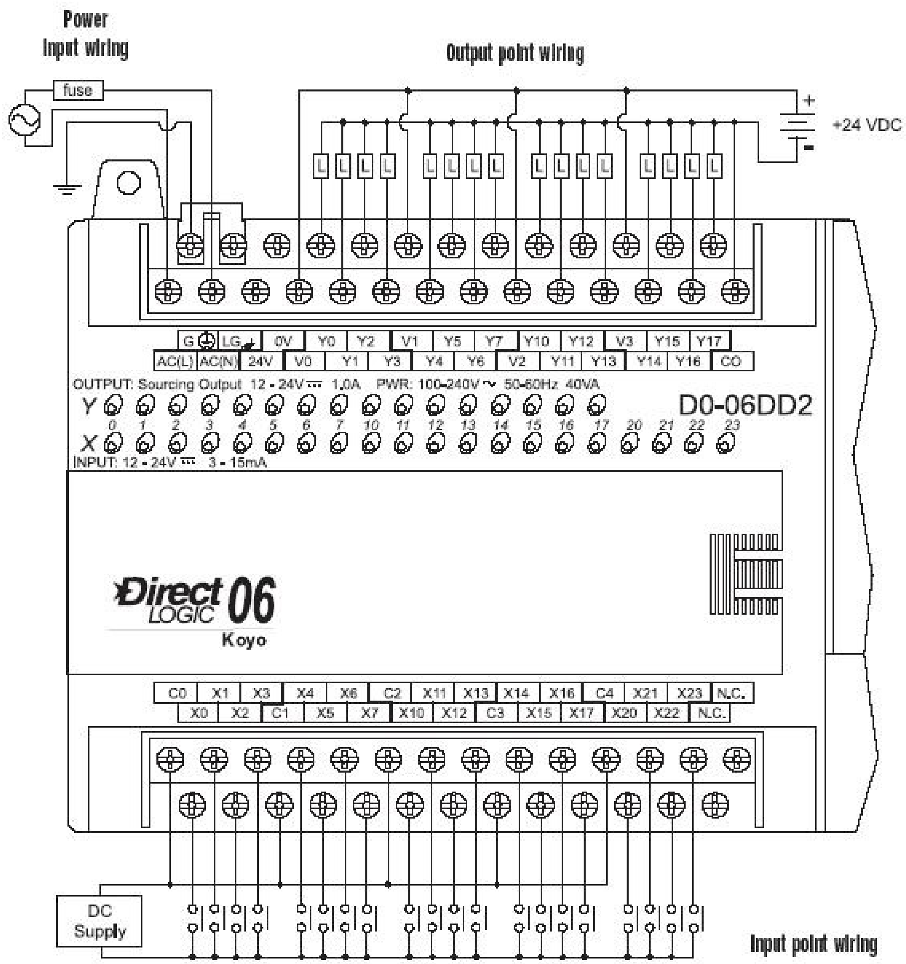


Figure 5.1: D0-06DD2 PLC General Wiring Diagram [39]

This figure provides a general wiring diagram for the D0-06DD2 PLC; for the specific wiring diagram created for the Project Oculus system, please see the drawing "C-130 PLC Circuit Diagram" shown in Appendix 6 "Sensor Pallet Control Circuit Diagrams."

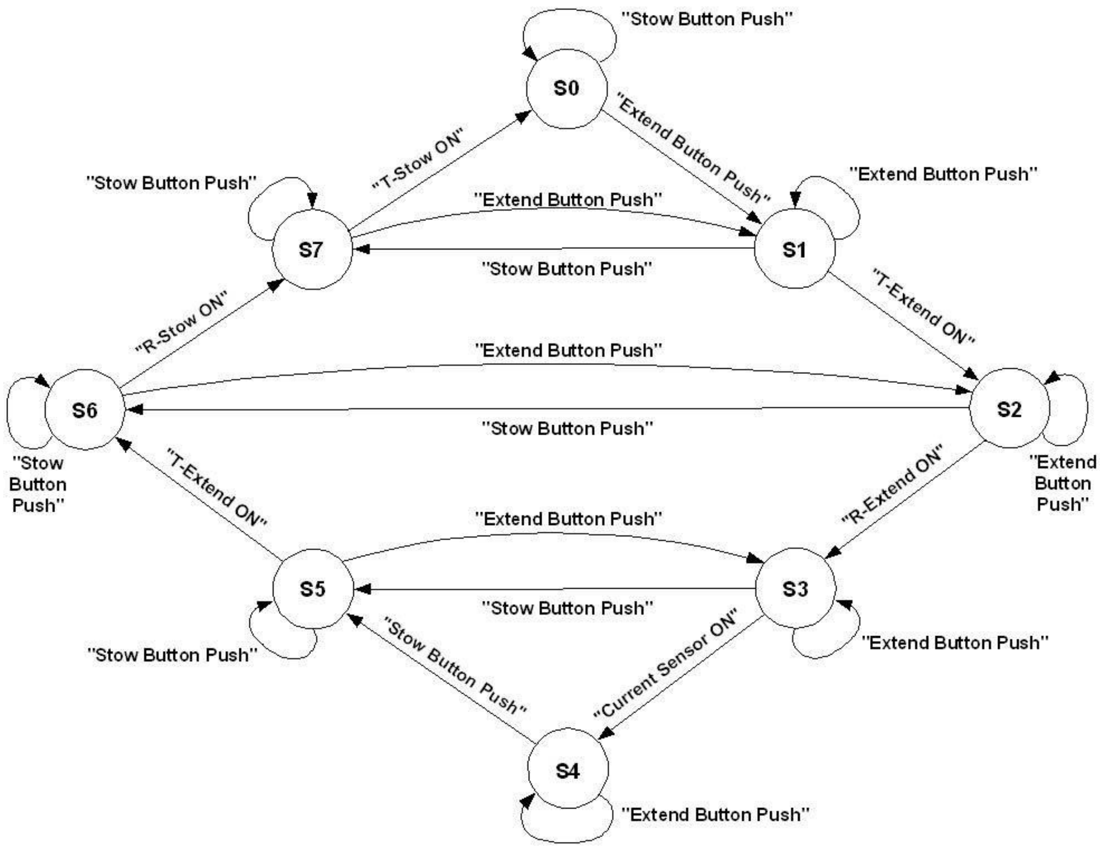
Table 5.1 shown below illustrates the way the inputs and outputs were mapped to the input/output points on the PLC. Inputs X0-X3 were not used because they are high-speed inputs; likewise, outputs Y0-Y1 were not used because they generate pulse outputs. Since outputs Y2-Y3 were in the same bank as Y0-Y1, they were also skipped.

Table 5.1: D0-06DD2 PLC Input/Output Map

Inputs		Outputs	
Input Point	**Status**	**Output Point**	**Status**
X0	Not Used – High Speed Input	Y0	Not Used – Pulse Output
X1	Not Used – High Speed Input	Y1	Not Used – Pulse Output
X2	Not Used – High Speed Input	Y2	Not Used
X3	Not Used – High Speed Input	Y3	Not Used
X4	Extend Button	Y4	Not Used
X5	Stow Button	Y5	Not Used
X6	Rotation Extend Sensor	Y6	Translate Operate LED Indicator
X7	Rotation Stow Sensor	Y7	Not Used
X10	Translation Extend Sensor	Y10	Not Used
X11	Translation Stow Sensor	Y11	Rotate Operate LED Indicator
X12	Not Used	Y12	Not Used
X13	Not Used	Y13	Not Used
X14	Not Used	Y14	Not Used
X15	Not Used	Y15	Not Used
X16	Not Used	Y16	R-TCCW Relay
X17	Not Used	Y17	R-TCW Relay
X20	Not Used	Y100	GS2-22P0 DI2
X21	Not Used	Y101	GS2-22P0 DI1
X22	Not Used	Y102	Not Used
X23	Not Used	Y103	Not Used

5.2 Automatic Mode Program Design

When determining the design of the PLC program that will operate Automatic mode, a state diagram is a good way to illustrate what needs to happen. The state diagram can show all the stages that the system can be in and the inputs that need to be present to cause a change of state. The state diagram is shown in Figure 5.2 below.



S0 ⟶ Fully Stowed
Inputs: T-Stow "ON", R-Stow "ON"
Outputs: NONE

S1 ⟶ Translating Out
Inputs: Extend Button "PUSH", R-Stow "ON", T-Extend "OFF"
Outputs: Translate Motor OUT Relay "ON", T-Operate LED "ON"

S2 ⟶ Finished Translating Out / Rotating Out
Inputs: Extend Button "PUSH", T-Extend "ON", R-Extend "OFF"
Outputs: Rotation Motor Controller Forward "ON", R-Operate LED "ON"

S3 ⟶ Finished Rotating Out / Translating In Against Butt Plate
Inputs: Extend Button "PUSH", R-Extend "ON"
Outputs: Translate Motor IN Relay "ON", T-Operate LED "ON"

S4 ⟶ Finished Translating In / Fully Deployed Arm
Inputs: Current Sensor signal > 10mA
Outputs: NONE

S5 ⟶ Translating Out
Inputs: Stow Button "PUSH", R-Extend "ON", T-Extend "OFF"
Outputs: Translate Motor OUT Relay "ON", T-Operate LED "ON"

S6 ⟶ Finished Translating Out / Rotating In
Inputs: Stow Button "PUSH", T-Extend "ON", R-Stow "OFF"
Outputs: Rotation Motor Controller Reverse "ON", R-Operate LED "ON"

S7 ⟶ Finished Rotating In / Translating In
Inputs: Stow Button "PUSH", R-Stow "OFF", R-Stow "ON"
Outputs: Translate Motor IN Relay "ON", T-Operate LED "ON"

Figure 5.2: PLC Program State Diagram

5.2.1 Discussion of the State Diagram

Recall from Chapter 1 that there are three steps or stages to both of the extending and stowing procedures. When the system is extending, first the translating plate moves outward 19”, then the rotating arm rotates 206º, and finally the translating plate moves backward till the Sensor Pod has fit tightly up against the C-130 door. When the system is stowing, first the translating plate moves outward to its 19” fully extended position, then the rotating arm rotates back to its resting position, and then the translating plate moves backward to its fully stowed position.

The state diagram shown in Figure 5.2 above shows each of these states, as well as the stimuli that must be present to jump from state-to-state. The fully stowed position, where the translating plate and rotating arm are in their initial resting positions, is represented by state S_0. The fully deployed state, where the arm has rotated completely and the Sensor Pod has been pulled back against the butt plate underneath the door, is represented by state S_4.

5.2.1.1 State Diagram - System Deployment Procedure

The three stages of the extending (deployment) procedure are illustrated by states S_1, S_2, and S_3. To leave the stowed state S_0 and enter the deployment procedure at state S_1, the user must press the Extend Button on the operator pendant. This sets the translating plate into motion outward. To do this, the R-TCCW relay must be energized (output Y16 must be turned “ON”). This puts 110VAC on the red wire of the translation motor and turns the motor in the counterclockwise direction, moving the translating plate outward. Also, the Translation Operate LED indicator (output Y6) will be turned on at this time.

Once the plate has moved 19" outward, it reaches the "T-Extend" proximity sensor. When this sensor is tripped, the system moves to state S_2, where the rotating arm rotates 206º to its final position underneath the plane's door. This is done by sending a signal to the GS2-22P0 motor controller digital input DI1, which is done by turning on output Y101. In this stage, the Rotation Operation LED indicator (output Y11) will be turned on as well.

When the rotating arm has completed its motion, it reaches the "R-Extend" proximity sensor. By tripping this sensor, the system is put into state S_3, where the translating plate pulls the Sensor Pod back against the butt plate underneath the C-130 door. To perform this stage, the PLC must energize the R-TCW relay (output Y17). This puts 110VAC on the blue wire to the translation motor and turns the motor in the clockwise direction, moving the translating plate inward. Again, the Translation Operate LED indicator (output Y6) will be turned on at this time.

Once the Sensor Pod makes contact with the butt plate and pulls up tight, the translation motor pulls more and more current, causing a current spike of up to 11A or more. When this happens, the CLN-50 current sensor registers the current spike; the analog output on the O/P pin on the CLN-50 sensor will go over 10mA at this point. The F0-04AD-1 analog input module is continually taking the value from the O/P pin and storing the value in PLC memory location V2000 (directly maps to Channel 1 on the F0-04AD-1 when mounted in expansion slot 1). A comparison is made during each PLC sweep comparing the value stored in V2000 to V2004, which stores the value 10mA in BCD format (1536); at the point that the current spike occurs, the value in V2000 goes over 10mA and the translation motor is shut off. The system is now in state S_4, which is the fully deployed system state.

At any point during this deployment process, the user may be able to push the Extend or Stow buttons on the user pendant. In any of the states S_1-S_4, if the Extend button is pushed, the system should remain in its current state. However, if the Stow button is pressed, the system should stop and jump to a different state to begin the stow procedure. If the system is in state S_1, the system will jump to state S_7; if the system is in state S_2, the system will jump to state S_6; and if the system is in state S_3, the system will jump to state S_5.

5.2.1.2 State Diagram – System Stowing Procedure

The three stages of the stowing (retracting) procedure are illustrated by states S_5, S_6, and S_7. To leave the fully deployed state S_4 and enter the retracting procedure at state S_5, the user must press the Stow Button on the operator pendant. This sets the translating plate into motion outward. To do this, the R-TCCW relay must be energized (output Y16 must be turned "ON"). This puts 110VAC on the red wire of the translation motor and turns the motor in the counterclockwise direction, moving the translating plate outward. Also, the Translation Operate LED indicator (output Y6) will be turned on at this time.

Once the plate has moved outward as far as it will go, it reaches the "T-Extend" proximity sensor. When this sensor is tripped, the system moves to state S_6, where the rotating arm rotates back to its resting position on the arm supports mounted on the translating plate. This is done by sending a signal to the GS2-22P0 motor controller digital input DI2, which is done by turning on output Y100. In this stage, the Rotation Operation LED indicator (output Y11) will be turned on as well.

When the rotating arm has completed its motion, it reaches the "R-Stow" proximity sensor. By tripping this sensor, the system is put into state S_7, where the translating plate translates back to its initial, resting, position. To perform this stage, the PLC must energize the R-TCW relay (output Y17). This puts 110VAC on the blue wire to the translation motor and turns the motor in the clockwise direction, moving the translating plate inward. Again, the Translation Operate LED indicator (output Y6) will be turned on at this time.

When the translating plate reaches its initial stowed position, the "T-Stow" proximity sensor is tripped, and the system has completely returned to its fully stowed state, represented by state S_0. All motors are turned off and the system returns to waiting for any user input in the form of button presses on the pendant.

At any point during this deployment process, the user may be able to push the Extend or Stow buttons on the user pendant. In any of the states S_5-S_7, if the Stow button is pushed, the system should remain in its current state. However, if the Extend button is pressed, the system should stop and jump to a different state to begin the extend procedure. If the system is in state S_5, the system will jump to state S_3; if the system is in state S_6, the system will jump to state S_2; and if the system is in state S_7, the system will jump to state S_1.

5.2.2 PLC Program Specifications

Besides performing the steps illustrated in the State Diagram, there are other specifications that the program should have. The WVU-CIRA engineers decided that there should be a timed delay whenever the system goes from state-to-state. There will also be status messages displayed on the PLC's LCD screen so that the operator will be able to determine the PLC state in case of an error.

5.2.2.1 Timed Delays in the Program

Timed delays are important for safety reasons; if either the Extend or Stow button is pressed with anyone in the way of the system, that person will be able to clear the area before the system is set in motion. Otherwise, the person may be injured by the translating plate or the heavy Sensor Pod. Also, after the system has already been set into motion, there should be a delay from state-to-state to protect the components in the system. Quickly changing outputs and turning on different motors could cause damage to the system components.

Whenever the Extend or Stow button is pressed, there will be a five second delay before any motion takes place, regardless of where the translating plate or rotating arm is positioned at the time. Between states, there will only be a three second delay before the next stage of motion takes place. Programming with timers in the DirectSoft32© software was discussed in Chapter 2. When programming, there was a different timer used for each change of state. The timers that are used in the PLC program are illustrated below in Table 5.2.

Table 5.2: Timers in the PLC Program

PLC Timer	Timer Use
T0	5-sec. Extend Button Timer
T1	5-sec. Stow Button Timer
T2	3-sec. Translating Out to Rotating Out Timer (Extend Process)
T3	3-sec. Rotating Out to Translating Back Timer (Extend Process)
T4	3-sec. Translating Out to Rotating In Timer (Stow Process)
T5	3-sec. Rotating In to Translating Back Timer (Stow Process)

5.2.2.2 LCD Screen Messages

The program utilizes LCD screen messages so that the user will know what state the program is in (or going to be in once the respective timer completes its countdown) and for the purpose of error diagnosis. Writing messages to the LCD screen in the program is detailed in Chapter 2.

Whenever the PLC receives a new input, a new message appears on the LCD screen. The LCD has two lines on which a message can be displayed. The top line should always read “Automatic Mode”; this is an unconditional output to the LCD screen in the program and cannot be changed as long as the program is functioning correctly. The second line will display the state of the program. Table 5.3 shown below outlines the possible LCD messages and what they mean.

Table 5.3: LCD Messages

LCD Message	Meaning
“Fully Stowed”	Translating plate and rotating arm are in their resting positions
“E: Button Push”	Error: Extend and Stow button have been pushed simultaneously, which should not occur
“Extend Button”	Extend Button has been pressed
“Translating Out”	The translating plate is translating outward
“Rotating Out”	The rotating arm is rotating outward
“Translating Back”	The translating plate is translating backward
“Fully Extended”	Current Sensor has been tripped, should mean that the Sensor Pod has been pulled up tightly against the butt plate on the door
“Stow Button”	Stow Button has been pressed
“Rotating In”	The rotating arm is rotating inward

5.2.3 Error States

With every system, errors can occur. The user may input erroneous stimuli, sensors may be accidentally tripped or could fail completely, or any other unforeseen problem could occur. One of the error states that can clearly occur in this system is the user pressing both the Extend and Stow buttons on the pendant simultaneously. At that point, the PLC will be confused as to how to proceed, most likely beginning motion in one direction and then the other. This could somehow cause damage to components as well, jumping from state to state in such a manner.

Therefore, to prevent an occurrence of such a nature from harming components, an error state is introduced to the program. Whenever the PLC receives input from both the Extend and Stow buttons at the same time, all motion is halted and all timers and memory locations are reset. Once a single button is pushed, whether it is the Extend or Stow button, the error state is cleared and normal operation of the system can continue.

Other error states may exist, such as the ones alluded to before where sensors may fail, but the PLC program does not account for these error states. Future work in this area may be needed to be done for the system to become more fully functional.

5.2.4 PLC Memory Locations Used in Program

PLC's are constantly scanning their inputs and reacting accordingly, as well as checking their timers. Their outputs are based on the inputs and timer countdowns that occurred during that "sweep"; therefore, if a button is pressed for a moment and then released, that input is only seen for that moment. Likewise for a timer; when the timer finishes counting down, the PLC only sees that it finished its countdown for a single "sweep". Though this makes the PLC dynamic and allows it to react to a series of inputs without making the programmer write a series of loops, it does cause other programming problems. How might the PLC "remember" that a certain input has occurred? In the PLC program, this is an important question; stages in the program that last for several "sweeps" in a row depend on whether the Extend or Stow button has been pressed or whether a timer has finished its countdown. The answer is to use PLC memory locations to store when a button press has occurred or a timer has finished its countdown. The memory locations used in the programs and what is stored there are shown below in Table 5.4.

Table 5.4: Memory Location Definition

Memory Location	Data Stored
X50	Extend Button Memory
X51	Stow Button Memory
X52	Extend Timer Memory (5-sec.)
X53	Stow Timer Memory (5-sec.)
X54	Current Sensor Comparison Memory (V2000 ≥ V2004)
X55	Extend/Stow Button Press Error Memory
X56	Translating Out to Rotating Out Timer Memory (3-sec.)
X57	Rotating Out to Translating Back Timer Memory (3-sec.)
X60	Translating Out to Rotating In Timer Memory (3-sec.)
X61	Rotating In to Translating Back Timer Memory (3-sec.)

This concludes the description of the PLC program development. To see the PLC program as it was coded, please see Appendix 5. The program is shown there fully commented to ease in reading.

Chapter 6: Project Results

Over the last few months, the electrical design for the Operator Station and the Sensor Pallet, as well as the Automatic mode program, were implemented in the system assembled by the Project Oculus team of engineers. Once everything was assembled, the testing process began.

6.1 Testing the Operator Station Circuit

After the Operator Station had been wired, the system had to be tested. The first test for the system was to power it up using a 28VDC 200A "generator set" that simulated the power supply aboard the C-130. This power source was equipped with an AN2551 female plug to fit into the AN2552-3A male socket on the power input side of the Operator Station. A red LED located inside the operator station in the top left rack indicates that a 28VDC power source is available. Upon the flip of the "ON" switch, the green LED came on to indicate that DC power was powering the system. A look at the TSC24-4500D inverter remote controller showed that the inverter was converting the DC power to 220VAC 60Hz split-phase, indicating that it was working properly. All 30 power outlets (ten outlets on three power outlet strips located on the back of the racks inside the operator station) were tested to ensure that they were supplying 110VAC 60Hz for the devices that would reside in the racks inside the Operator Station. The circuit breakers were also tested to ensure that they would manually open the circuit.

The next test for the Operator Station circuit was to make certain that it could be powered from a standard 220VAC 60Hz power source. A cable equipped with a 220VAC 30Amp plug on one end to fit the 220VAC wall outlet located in the WVU hanger wall, and a HBL430C12W on the other end was plugged into the power input side of the Operator Station. Again, the red LED indicators corresponding to Line 1 and Line 2 of the 220VAC input came on, signifying that 60Hz AC power was directly available for the system. Flipping the switch powered on the system, just as the DC power had before.

The final test for the Operator Station power input circuit was to make sure that the interlocking between the two possible power sources would work. If the DC power source is available and turned on, the interlocking circuit should not allow the user to apply an available 60Hz AC power to the system, and vice versa. To perform this test, both 60Hz AC and DC power sources were connected as in the previous tests. First, the 60Hz AC power source was turned on with the switch, supplying power to the system. Then, the DC power switch was flipped to the "on" position; the system remained powered by the 60Hz AC power, and the green LED indicator showing that the system was powered from DC remained off. Next, the system was powered from the DC power source, and the 60Hz AC power was turned on; the system remained powered from DC and did not allow the 60Hz AC power to be available. Having completed all these tests, the Operator Station power input circuit design was deemed a success.

6.2 Testing the Sensor Pallet Circuit and Program

Next, the electrical engineers had to test the Sensor Pallet to ensure it was in good working order. The Sensor Pallet had three general areas to test: (1) would the sensor pallet electronics power up when its power cord was plugged into the Operator Station, (2) manual mode operation with the operator pendant, and (3) Automatic mode, including all electronics and software associated with Automatic mode.

6.2.1 Testing the Sensor Pallet Power

To test the Sensor Pallet, the jumper cable located on the Sensor Pallet must be connected into the Operator Station power. The HBL430P12W plug on the jumper cable needs to be plugged into the matching HBL430R12W receptacle on the exterior of the Operator Station facing the Sensor Pallet. Then, the power in the Operator Station needs to be turned on to supply power to the Sensor Pallet. Upon doing this, visual inspection of the Sensor Pallet shows that the GS2-22P0 motor controller inside the motor control panel and the 24VDC power supply power are on. The red Manual mode LED indicator located on the motor control panel comes on if the Automatic/Manual switch on the operator pendant is switched to "Manual." Switching the Automatic/Manual switch to "Automatic" turns off the red Manual mode LED indicator and powers on the D0-06DD2 Programmable Logic Controller (PLC). Seeing that all the Sensor Pallet electronics are powering on, this test is successful.

6.2.2 Testing the Sensor Pallet in Manual Mode

Now that the Sensor Pallet is powered, the two different modes of operation of the Sensor Pallet can be tested. First, the engineers will test Manual mode. The testing procedure is illustrated in the flow chart shown in Figure 6.1 below.

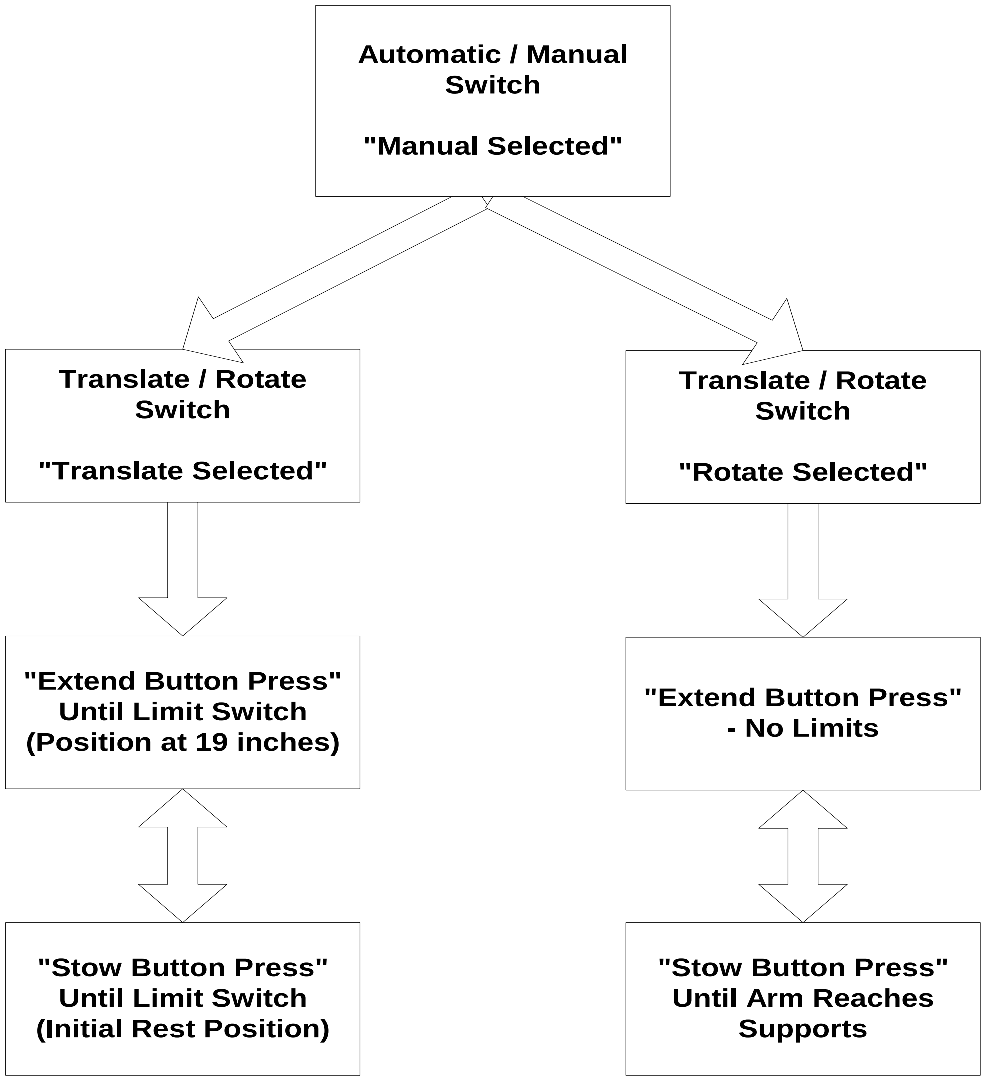


Figure 6.1: Manual Mode Testing Procedure

To run the pallet in Manual mode, the Automatic/Manual switch should be set to "Manual." In manual mode, the operator designates which motor he wants to run by using the Translate/Rotate switch, also on the operator pendant. Flipping this switch to "Translate", the engineers first tested Manual mode for the translation process. When pressing the Extend button, the translating plate moved from its initial resting position to its fully extended position 19" inches outward before the limit switch mounted there was triggered and stopped the translation. Pressing the Stow button moved the translating plate back to its initial resting position; again the process was ended by triggering the other limit switch. All components of that process, which included powering the translation motor, wiring of the buttons and switches, and the use of the limit switches, were deemed a success.

Flipping the Translate/Rotate switch to "Rotate", the engineers may now test Manual mode for the rotation process. For this test to be successful, the GS2-22P0 motor controller digital inputs must be wired correctly and supply sufficient power to the rotation motor. When pressing the Extend button, the rotating arm rotated outward, going as far as the user wants it to go, considering there are no limiting factors on its manual motion as there is on the translational process. Pressing the Stow button moved the rotating arm back to its initial resting position on the supports mounted on the translating plate. All components of this process, which included sending the correct signals to the motor controller, powering on the rotation motor, and the wiring of the buttons and switches, were deemed a success.

6.2.3 Testing the Sensor Pallet in Automatic Mode

To test the Sensor Pallet, the Automatic/Manual switch needs to be on "Automatic" and the D0-06DD2 needs to be set on "Run", which means it is running the program that is stored in the PLC's memory. No motion should occur right away; the system is waiting on input from the user pendant pushbuttons. Also, the Translate/Rotate switch is nonfunctional in Automatic mode.

The engineers tried to test a full cycle of the automated process. Upon pushing the Extend button, the deployment procedure began. The translating plate moved from its initial position to its fully extended position 19" outward, and then the system began to try to rotate the arm out. However, a problem occurred at this point. The PLC was receiving conflicting inputs from the rotation stowed and extended proximity sensors, sending the system into two different states at the same time. Therefore, the system was not functional at that time.

This was the major bug that had to be fixed in the system. The problem was hypothesized to be electrical noise interference generated by the power cord to the rotational motor being picked up by the proximity sensor cables. This noise would cause a false triggering signal on the sensing lines of these sensors. Indeed, the test prototype ran both the power cable to the rotational motor and the proximity sensor cables together through the same conduit.

The first solution to the problem was to run shielded cable to the proximity sensors rather than the unshielded cable that the sensors were purchased with. The shield was grounded to the box housing the electronic equipment, and the shielded cable was run all the way from the sensor to the PLC inputs. But when the test was run again, the same problem still occurred. Though this was a good idea that normally fixes problems such as these, another approach was needed.

After other failed attempts at solving the problem, which included increasing the sourcing current from the proximity sensors, it was decided that physical separation of the cables was required to make the system work. The rotation stowed and rotation extended proximity sensors were moved to the opposite side of the pallet but remained connected with shielded cable. The testing procedure was repeated, again pressing the Extend button to begin the deployment procedure. When the translating plate finished its motion, the rotating arm began rotating with no problem. A full cycle of both the deployment and stowing procedures were completed to ensure that Automatic mode was in full working order. Finally, Automatic mode was deemed a success.

6.3 Project Oculus Tested on the C-130

In February, 2004, the WVU-CIRA team of engineers accompanied the Project Oculus system to the Air National Guard base in Charleston, WV, to load the pallets onto the plane for testing purposes and for a show-and-tell session. The Operator Station was plugged into the plane's 28VDC power source, just as it was designed to do, and was powered up with no problems. The Sensor Pallet was placed on the C-130 rear door, where the mechanical arm was completely deployed using only Manual mode. Automatic mode was not tested at this time; though it had been proven to work, the engineers feared they may damage the plane in some way. The visit and test session in Charleston was a success; Figure 6.2 below shows the Sensor Pallet on the C-130 door.

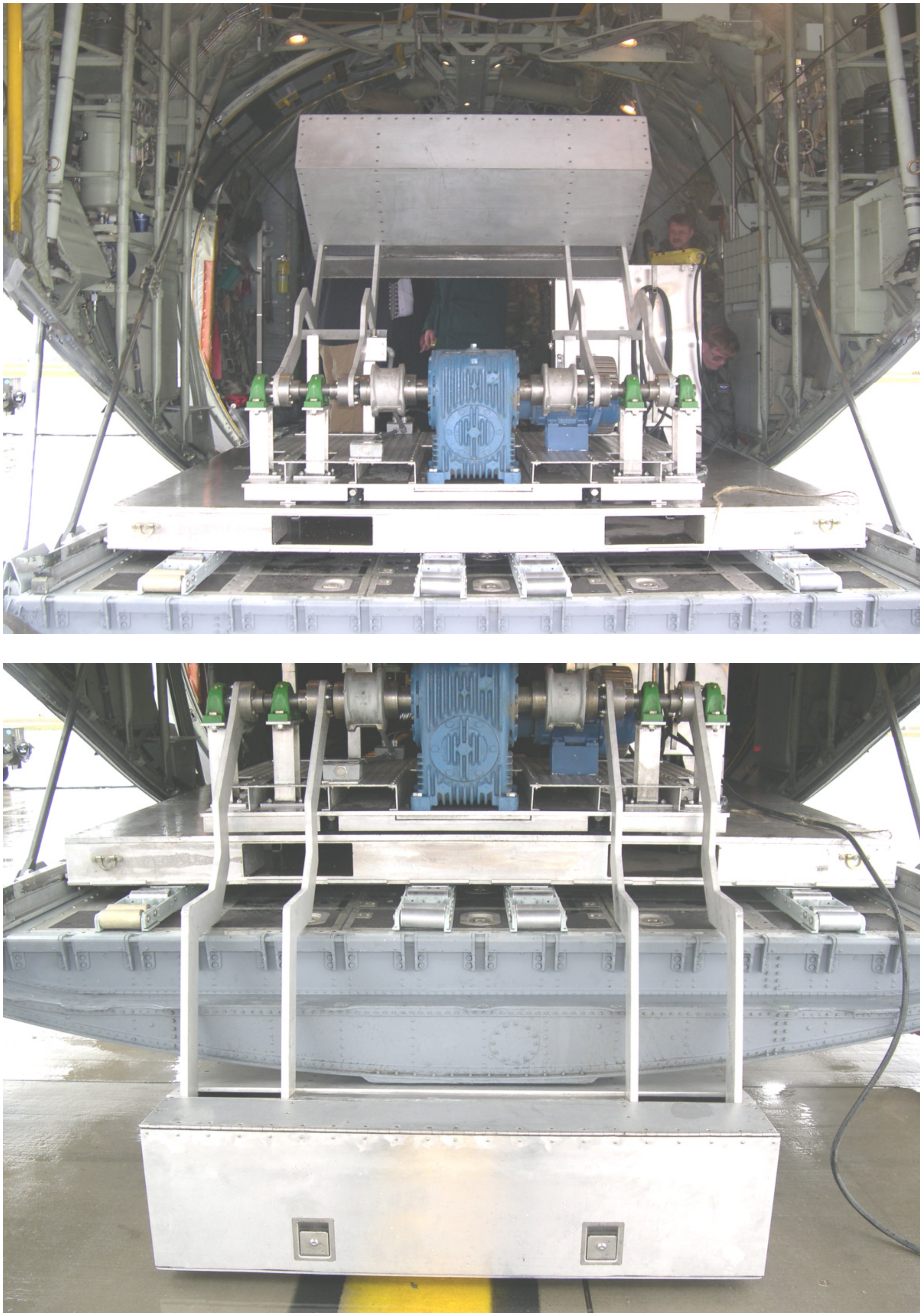


Figure 6.2: Sensor Pallet in Operation on C-130 in Charleston, WV

Chapter 7: Conclusion

First, in these concluding remarks, it must be said that one of the overriding goals of this thesis was to be a complete summary of all the work performed by the electrical engineers on Project Oculus. It should be a fully inclusive manual providing all the design criteria, circuit diagrams, program design, and specifications of the hardware that was put into this project.

7.1 Project Conclusions

This project has been completely designed, built, programmed, and tested. It seems that every aspect of the project has passed all testing configurations. The Operator Station power distribution circuit design is a success; it works, providing all devices with their required power. After working out a few bugs, the Sensor Pallet control circuit, operating in both Automatic and Manual modes, is also in working order.

One main issue of concern, however, in this design is the amount of power that is needed to run all components involved and the sensors that will be deployed in the Sensor Pod on the Sensor Pallet. This study is shown in Appendix 2, which is a Power Budget prepared by team member Jonathan Byrd. The team of electrical engineers perhaps should make decisions on supplemental forms of power for the system.

7.2 Recommendations for Future Work

Because no design is ever finished or completely optimized with every known feature, recommendations for future work are offered here. There are a few areas of the project that can be improved or modified in the future. First, plans for additional power need to be addressed in the near future.

The second area that needs improved is “system protection” in Manual mode. The electrical engineers did install mechanical limit switches to protect system components when the system is running in Manual Translate mode; however, there is no analogous feature for Manual Rotate mode. The operator can extend the mechanical arm as far as he wants to, which could allow the arm to strike and damage the “R-Extend” proximity sensor.

And the final area that needs improved is the Automatic mode ladder program. Through this study, error states had already begun to be defined, but only one error state was really handled in the code itself. Future work on the project could revolve around making the Automatic mode program better by handling more errors, such as defining the process to follow if the proximity sensors should fail. Other unforeseen features could most likely be added to the program as well; the system should stay up-to-date with the future requirements of the system.

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Appendix 1: Vanner TSC24-4500D Inverter Specifications

This appendix contains data sheets and general information regarding the Vanner TSC24-4500D power inverter and the optional TSR remote control [46].

DuraSine TSC

AC Power Inverter/Charger

Your AC solution for display vans, mobile offices, communications backup, sensitive test equipment, traffic signal backup, and more!

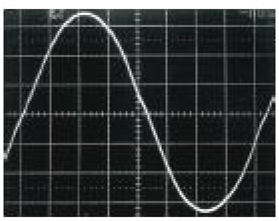
Introduction

The TruSine® 4.5kW system consists of a high-performance 4500 watt sine-wave inverter, four-stage battery charger/conditioner, and an automatic AC transfer switch. The system offers you unparalleled capabilities for the most demanding applications. For example, a high-efficiency, low power sine-wave inverter saves energy by operating when only small AC loads such as battery rechargers are present. Because the test equipment and tools you use may be sensitive to the quality of AC power, we have designed the TruSine® inverter/charger to supply high quality, low Total Harmonic Distortion sine-wave power while also maintaining high operating efficiencies over the power range.

Recognizing that installation configurations and requirements vary, we have designed maximum flexibility into the TruSine® inverter/charger system. We have separated the operator's console/remote control from the inverter enclosure, allowing you to control and monitor the system from wherever you want. Our data communications network allows you to install multiple operator's consoles near the inverter, or at remote locations. Installation is simplified with the consolidation of all wiring on the bottom panel of the unit (the bottom surface on the wall mounted unit). This panel contains an isolated AC wiring compartment, complete with cable clamps for the external AC cables, and a unique DC wiring compartment is provided for the battery cables with two screw-type terminals to accommodate the DC cables.

Underwriters Laboratories Listed

TruSine® models TSC24-4500 and TSC24-4500D are UL and C-UL Listed as a Power Inverter for Land/Recreational Vehicles.



Actual photo of TruSine® waveform at 4500 watts

Power Inverter

Vanner's advanced TruSine® technology inverter design produces a smooth, extremely high quality sinusoidal waveform that has no visible steps. This produces less than 1.75% Total Harmonic Distortion (THD), enabling loads such as motors and electronic equipment to operate more efficiently than with stepped sine-wave or modified sine-wave inverters. Output AC voltage is regulated to +/- 3% and frequency regulation is maintained to within +/- 0.1 Hz. The inverter produces 4500 watts of continuous power and 10,000 watts of surge power, enabling it to run the most demanding loads. In order to meet your installation needs, we offer two AC power configurations:

- TSC24-4500D: 120/240 volt/60 Hz 3-wire "split-phase" input and output
- TSC24-4500: 120 volt/60 Hz single phase input and output

Battery Charger/Conditioner

Battery charging is accomplished efficiently with the TruSine® system's 100 amp (24 volt), four-stage charging sequence. This approach quickly charges the battery bank, then applies a float charge to maintain the charge. For flooded lead acid batteries, the operator may call for an equalize charge cycle through the remote operator's console.

Automatic AC Transfer Switch

The systems' automatic AC transfer switch connects the AC input to both the AC output and to the battery charger when AC output power is present. The transfer will occur after an adjustable time delay which allows for generator stabilization. Upon loss of AC input power, the transfer back to the inverter will occur instantly (within 40 milliseconds) to minimize power interruption to the AC loads.

Operator Controls

When complete function control and monitoring is required, we recommend installing the optional TSR Operator's Console. The TSR allows you to operate the TruSine® inverter system from multiple locations. You can locate a TSR near the inverter and others at remote locations. The TSR remote control panel is a compact but powerful terminal consisting of a backlit LCD display, function keypad and alarm LED indicator. The TSR functions provide system status display, fault monitoring and alarm display, password protected data parameter programming, display of data values, and system operating mode control.

Optional TSR Remote

To simplify operation, a main menu is provided along with an advanced function menu for the more complex functions. The TSR is easily installed with four screws in a panel cutout.

EXPERIENCE THE POWER.

DuraSine TSC

AC Power Inverter/Charger

TruSine 4.5kW Inverter/Charger Specifications Model	TSC24-4500	TSC24-4500D	TSC-4500EX*
Inverter:			
AC Output Voltage	120Vac +/- 3%	120/240Vac +/- 3%	230Vac +/- 3%
Continuous Power at 25C	4500 Watts (37.50 Amps)	4500 Watts (18.75 Amps per Leg)	4500 Watts (18.75 Amps)
Surge Power	10,000 Watts	10,000 Watts	10,000 Watts
Frequency	60 Hz +/- 0.1 Hz	60 Hz +/- 0.1 Hz	50 Hz +/- 0.1 Hz
AC Waveform	Pure Sine-wave	Pure Sine-wave	Pure Sine-wave
Total Harmonic Distortion (THD)	< 1.75%	< 1.75%	< 1.75%
Power Factor Allowed	-0 to 1 to +0	-0 to 1 to +0	-0 to 1 to +0
DC Input			
Nominal	24 Volts	24 Volts	24 Volts
Operating Range	12 to 34 Volts	12 to 34 Volts	12 to 34 Volts
No Load, Inverter On	0.5 Amps (13 Watts)	0.5 Amps (13 Watts)	0.5 Amps (13 Watts)
No Load, Inverter Standby	0.2 Amps (5.2 Watts)	0.2 Amps (5.2 Watts)	0.2 Amps (5.2 Watts)
Full Power	225 Amps	225 Amps	225 Amps
Battery Charger:			
Maximum Charger Power	100 Amps DC	100 Amps DC	100 Amps DC
Input Voltage	120Vac +/- 10%	120/240Vac (4-wire) +/- 10%	230Vac +/- 10%
Input Current Waveform	Sinusoidal	Sinusoidal	Sinusoidal
Input Current Rating	32 Amps	16 Amps per Leg	16 Amps
Input Frequency	60 Hz +/- 12%	60 Hz +/- 12%	50 Hz +/- 12%
AC Transfer Switch:			
Power Rating	30 Amps at 120Vac	30 Amps at 120/240Vac	30 Amps at 230Vac
Transfer Speed	< 40 milliseconds	< 40 milliseconds	< 40 milliseconds
System:			
Operating Ambient Temp.	-40C (40F) to +40C (104F)		
Cooling	Thermostatically controlled exhaust fan		
Mounting	Wall or shelf		
Weight	83 Lbs. (37.7 kg.)		
Dimensions	17.5"H x 19.0"W x 8.5"D		

Vanner's policy is one of continuous improvement. We reserve the right to change specifications without notice.
**Consult factory for availability. 50 Hz model is not UL listed.*

Your authorized Vanner distributor is:

Corporate Office:
Vanner, Inc.
4282 Reynolds Drive
Hilliard, Ohio 43026
Tel: 614-771-2718
Fax: 614-771-4904

800-AC POWER

www.vanner.com
e-mail: pwrsales@vanner.com

Appendix 2: Project Oculus Power Budget

This appendix contains the Project Oculus Power Budget, created as an Excel spreadsheet by C-130 project team member Jonathan Byrd. This budget consists of all components that exist in the system and the power that these components consume. Not all components will be drawing power at the same time; therefore, an "In Use" column was added so that the user may determine the available power when only certain components are being used. The power budget is shown below with all components in use.

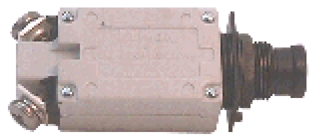
Project Oculus Power Budget	There are 5040 W available as total power,				**Remaining DC power on SP (W)**	
Developed by Jonathan Byrd	4158 W of that can be used as AC power.				-730.4	
Created: March 8, 2004					**Remaining AC power (W)**	
Last Revised: April 12, 2004					-112.67	
					Total Remaining Power (W)	
Power Available:					769.33	
Description:	Max Voltage (V)	Max Current (A)	Efficiency	Total Input Power (W)		
28 Volt DC Input from bulkhead	28	180	N/A	5040		
Wanner inverter DC - AC eff@4500W 82.5%	120	34.65	0.825	4158		
DC power available on sensor pallet	24	3	N/A	72		
SENSOR PALLET						
Power Used:						
Item Description	Quantity	AC or DC	Voltage (V)	Current (A)	Power Used (W)	In Use (1 or 0)
Proximity Sensors	4	DC	28	0.2	22.4	1
Rotational Motor 2HP	1				1492	1
Translational Motor 1/3HP	1				248.67	1
Camera and Sensor	1	DC	28	10.714285	300	1
Flir System	1	DC	28	17.142857	480	1
Cooling Fans	2	AC	110	0.338181818	74.4	1
OPERATOR STATION						
Power Used:						
Item Description	Quantity	AC or DC	Voltage (V)	Current (A)	Power Used (W)	
KVM Switch CS-228	1	AC	120	0.06	7.2	1
Little Lite Rack Mount Light	3	AC	120	0.2	72	1
Communications Reciever IC-R9000L	1	AC	120	0.45	54	1
VCR Sony SV0-1630	1	AC	120	0.133333333	16	1
STC Leicus Dehumidifier	1	AC	120	1.5	180	1
Overhead Florescent Lights	2	AC	120	0.283333333	68	1
Exhaust Fan	2	AC	120	1.4	336	1
Florescent Lighting (behind rack)	2	AC	120	0.333333333	80	1
LCD Flat Panel Monitors	2	AC	120	0.583333333	140	1
Computer Power Supplies	2	AC	120	2.916666667	700	1

Appendix 3: Klixon Aircraft Circuit Breakers, 7274 Series

This appendix consists of specifications and general information for the 7274 series of Klixon aircraft circuit breakers, made by Texas Instruments. Specifically, the Project Oculus system uses Klixon series 7274-11 circuit breakers, with current ratings of 10 Amps and 20 Amps. Circuit breakers used in the system are highlighted where appropriate [20].

7274 Series

Single Phase, Non-Compensated



Features

- Uses Minimum Space
- Light Weight
- Current Rating (½ to 20 Amps)
- MIL-C-5809 Qualified
- High Vibration Resistance

Overview

The Klixon® 7274 series are small, lightweight, low amperage devices that are specifically designed to protect aircraft/aerospace cable and components in airborne vehicles and equipment.

The 7274 series features a trip-free, indicating-type reset button. They are available in standard ratings from ½ to 20 amps.

Options

- Long Pushbuttons
- Auxiliary Switch
- Dust Boot [1]

[1] Part number 14500-1 fits 15/32 bushing
Part number 14500-5 fits 7/16 bushing

Calibration: 1-20 Amps (Typical*)

Temp °C	Min. Ult. Trip	Max. Ult. Trip	Trip Time - Seconds		
			200%	500%	1000%
+25	115%	150%	2 - 20	.16 - 1.2	.046-.80
-55	135%	180%	-	-	-
+71	90%	130%	-	-	-

*The above calibration chart is representative of a standard commercial device. TI offers specific variants with similar performance dependant on military or customer specifications.

Performance

Vibration*.................10 G minimum, 50-500 Hz
Mechanical Shock.....35 G
Acceleration..............10 G
Weight...................... 7274-2 - 28 grams
7274-2-5 - 19.8 grams
7274-4 - 28 grams
7274-11 - 33 grams
7274-11-5 - 24.7 grams
7274-69 - 33 grams
7274-70 - 33 grams

*Other vibration levels available

Interrupting Capacity

½ - 5 amps	Unlimited amps at 28 VDC
7½ - 15 amps	2000 amps at 28 VDC
½ - 1½ amps	Unlimited amps at 120 VAC, 400 Hz
2 - 5 amps	800 amps at 120 VAC, 400 Hz
7½ - 20 amps	500 amps at 120 VAC. 400 Hz

Endurance

2500 cycles	120 VAC. 400 Hz, Inductive
5000 cycles	120 VAC. 400 Hz, Resistive
2500 cycles	30 VDC, Inductive
5000 cycles	30 VDC, Resistive
10,000 cycles	Mechanical, No Load

Amp Rating	Voltage Drop (max)*	Amp Rating	Voltage Drop (max)*
½	2.00	4	0.45
¾	1.45	5	0.35
1	1.10	7 ½	0.30
1½	0.75	10	0.28
2	0.75	15	0.25
2½	0.70	20	0.25
3	0.55		

*Max voltage drop at nominal rated current.

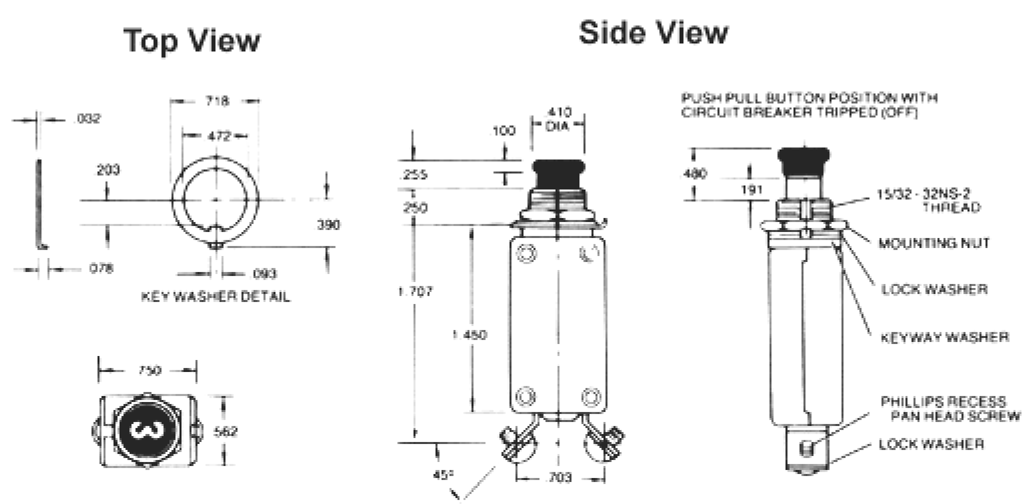
Qualifications

TI Number	MS Number	TI Number	MS Number
7274-2-½	MS 26574-½	7274-4-½	MS 26574-½A
7274-2-¾	MS 26574-¾	7274-4-¾	MS 26574-¾A
7274-2-1	MS 26574-1	7274-4-1	MS 26574-1A
7274-2-1½	MS 26574-1½	7274-4-1½	MS 26574-1½A
7274-2-2	MS 26574-2	7274-4-2	MS 26574-2A
7274-2-2½	MS 26574-2½	7274-4-2½	MS 26574-2½A
7274-2-3	MS 26574-3	7274-4-3	MS 26574-3A
7274-2-4	MS 26574-4	7274-4-4	MS 26574-4A

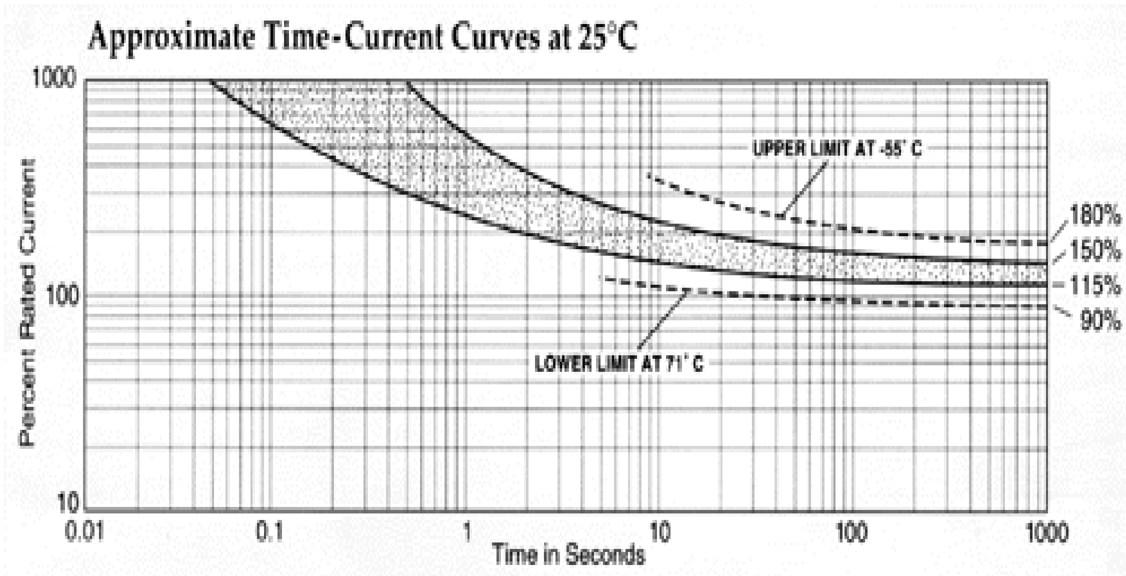
7274-2-5	MS 26574-5	7274-4-5	MS 26574-5A
7274-2-7 ½	MS 26574-7½	7274-4-7 ½	MS 26574-7½A
7274-2-10	MS 26574-10	7274-4-10	MS 26574-10A
7274-2-15	n/a	7274-4-15	n/a
7274-2-20	n/a	7274-4-20	n/a

TI Number	**MS Number**	**TI Number**	**MS Number**	**TI Number**	**MS Number**
7274-11-½	MS 22073-½	7274-69-½	MS 22073-½V	7274-70-½	MS 26574-½L
7274-11-¾	MS 22073-¾	7274-69-¾	MS 22073-¾V	7274-70-¾	MS 26574-¾L
7274-11-1	MS 22073-1	7274-69-1	MS 22073-1V	7274-70-1	MS 26574-1L
7274-11-1½	MS 22073-1½	7274-69-1½	MS 22073-1½V	7274-70-1½	MS 26574-1½L
7274-11-2	MS 22073-2	7274-69-2	MS 22073-2V	7274-70-2	MS 26574-2L
7274-11-2½	MS 22073-2½	7274-69-2½	MS 22073-2½V	7274-70-2½	MS 26574-2½L
7274-11-3	MS 22073-3	7274-69-3	MS 22073-3V	7274-70-3	MS 26574-3L
7274-11-4	MS 22073-4	7274-69-4	MS 22073-4V	7274-70-4	MS 26574-4L
7274-11-5	MS 22073-5	7274-69-5	MS 22073-5V	7274-70-5	MS 26574-5L
7274-11-7 ½	MS 22073-7½	7274-69-7 ½	MS 22073-7½V	7274-70-7 ½	MS 26574-7½L
7274-11-10	MS 22073-10	7274-69-10	MS 22073-10V	7274-70-10	MS 26574-10L
7274-11-15	n/a	7274-69-15	n/a	7274-70-15	n/a
7274-11-20	n/a	7274-69-20	n/a	7274-70-20	n/a

7274-11 and 7274-69



Nominal dimensions provided for reference purposes.

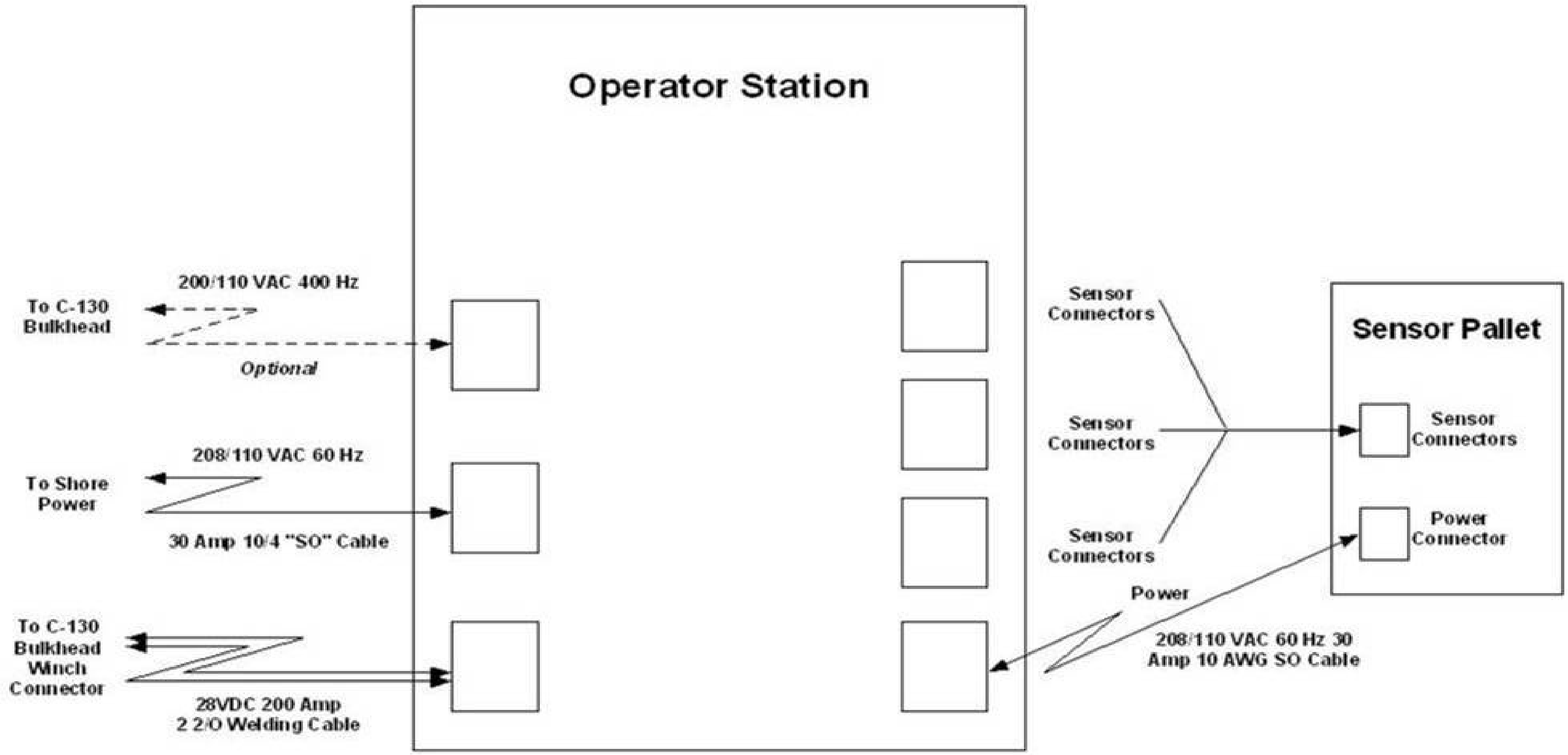

Approximate Time-Current Curves at 25°C
1000
100
10
Percent Rated Current
0.01
0.1
1
10
100
1000
Time in Seconds
UPPER LIMIT AT -55° C
LOWER LIMIT AT 71° C
180%
150%
115%
90%

Appendix 4: Operator Station Circuit Diagrams

This appendix consists of the Operator Station input power circuit diagrams. The diagrams shown are

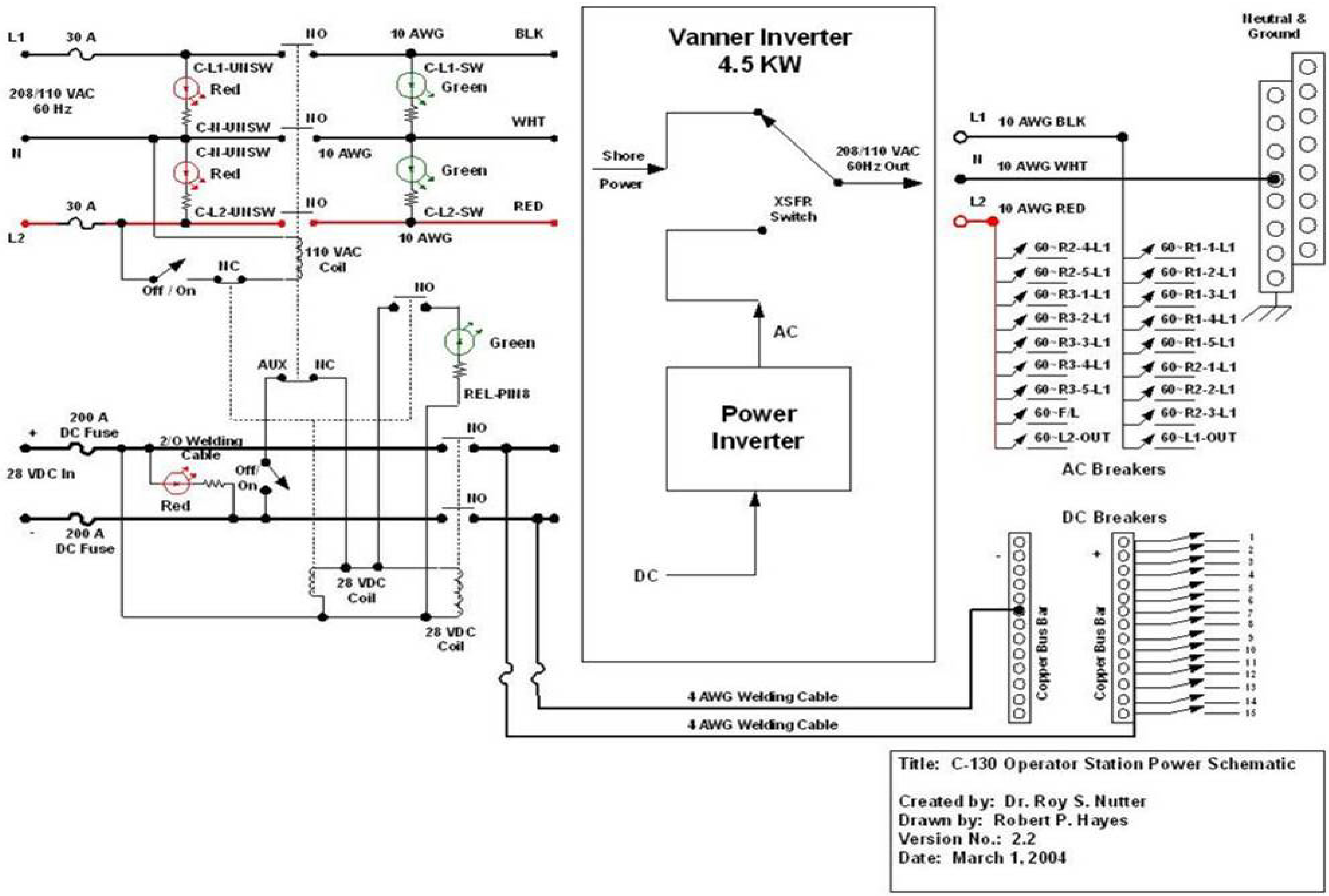
(1) C-130 Operator Station Power In/Out: An illustration of input power available to the system and output power for the Sensor Pallet.
(2) C-130 Operator Station Power Schematic: Circuit diagram for DC and 60Hz AC input power, Vanner inverter, and AC and DC circuit breakers.
(3) C-130 Operator Station Power In Control: Close-up version of the power input control interlocking circuit shown in diagram (2).

The circuits were originally designed by Dr. Roy S. Nutter; these diagrams were drawn by Robert P. Hayes.

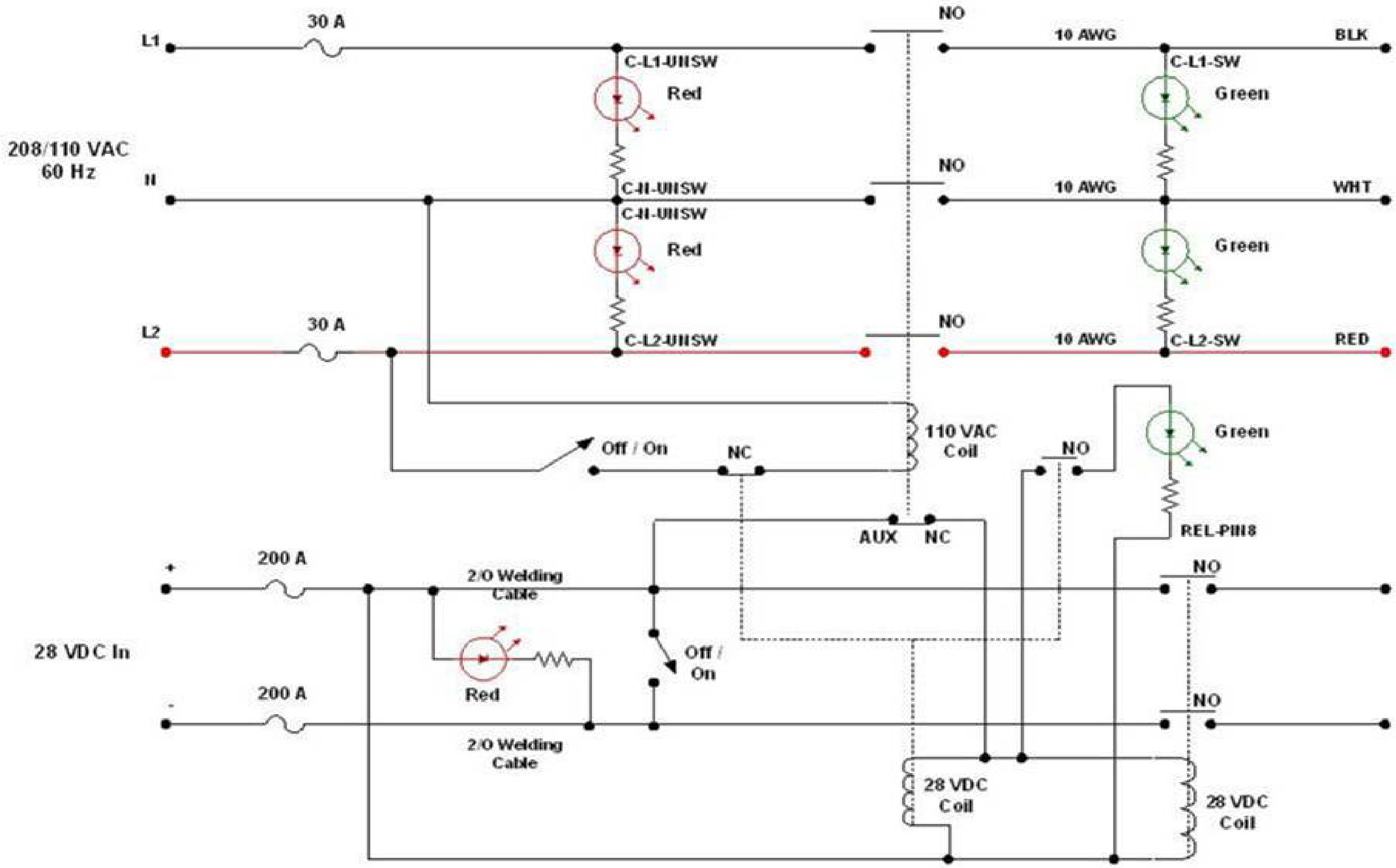


Title: C-130 Operator Station Power In/Out

Created by: Dr. Roy S. Nutter
Drawn by: Robert P. Hayes
Version No.: 1.0
Date: November 10, 2003



L1
30 A
208/110 VAC
60 Hz
N
L2
C-L1-UNSW
Red
C-N-UNSW
C-L2-UNSW
NO
10 AWG
BLK
WHT
RED
C-L1-SW
Green
C-L2-SW
110 VAC
Coil
NC
Off / On
AUX
REL-PIN8
200 A
DC Fuse
2/O Welding
Cable
28 VDC In
Off/
On
28 VDC
Coil
4 AWG Welding Cable
Vanner Inverter
4.5 KW
Shore
Power
208/110 VAC
60Hz Out
XSFR
Switch
AC
Power
Inverter
DC
Neutral &
Ground
10 AWG BLK
10 AWG WHT
10 AWG RED
60~R2-4-L1
60~R2-5-L1
60~R3-1-L1
60~R3-2-L1
60~R3-3-L1
60~R3-4-L1
60~R3-5-L1
60~F/L
60~L2-OUT
60~R1-1-L1
60~R1-2-L1
60~R1-3-L1
60~R1-4-L1
60~R1-5-L1
60~R2-1-L1
60~R2-2-L1
60~R2-3-L1
60~L1-OUT
AC Breakers
DC Breakers
Copper Bus Bar
Title: C-130 Operator Station Power Schematic
Created by: Dr. Roy S. Nutter
Drawn by: Robert P. Hayes
Version No.: 2.2
Date: March 1, 2004

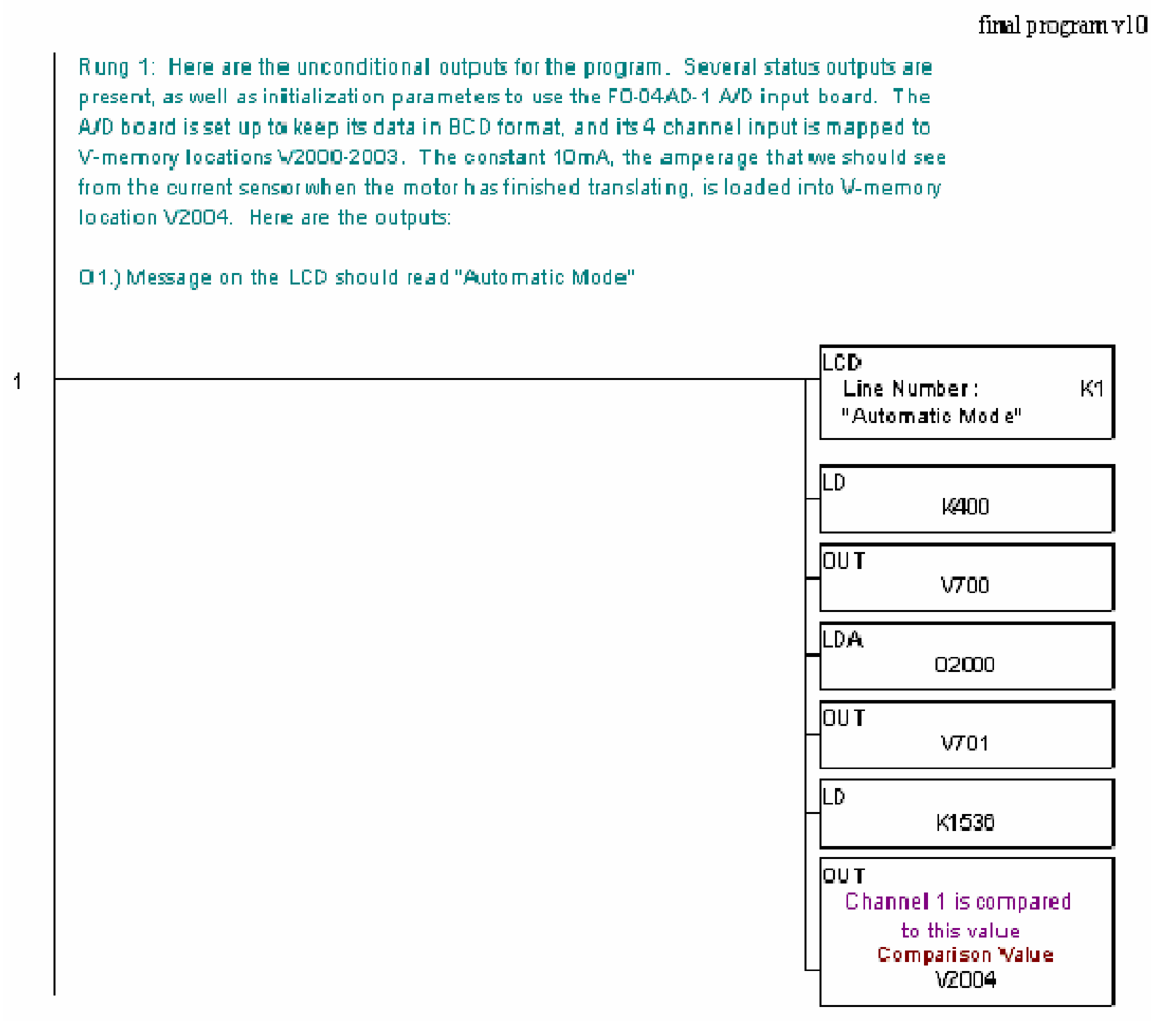


Title: C-130 Operator Station Power In Control

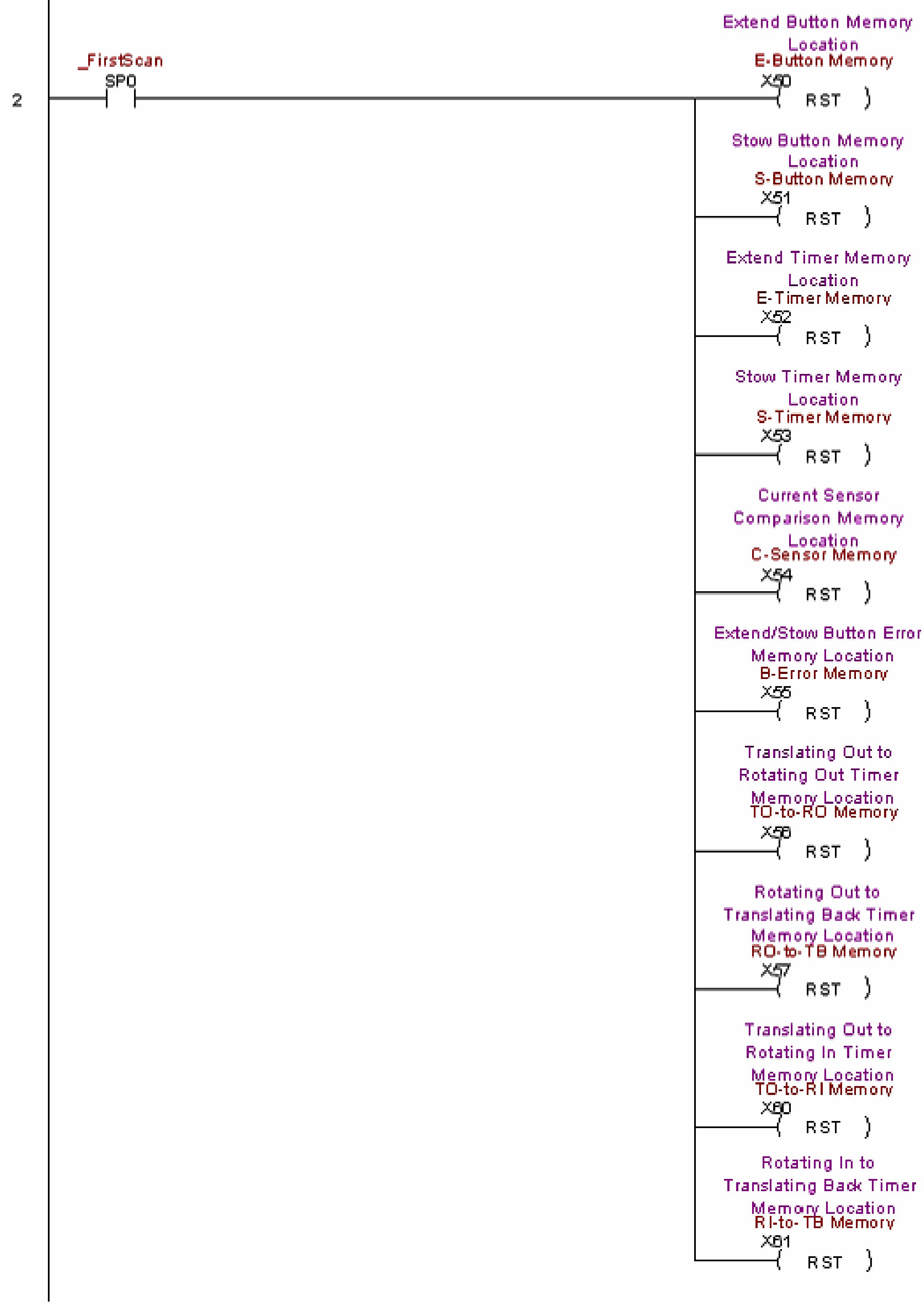
Created by: Dr. Roy S. Nutter
Drawn by: Robert P. Hayes
Version No.: 1.0
Date: November 24, 2003

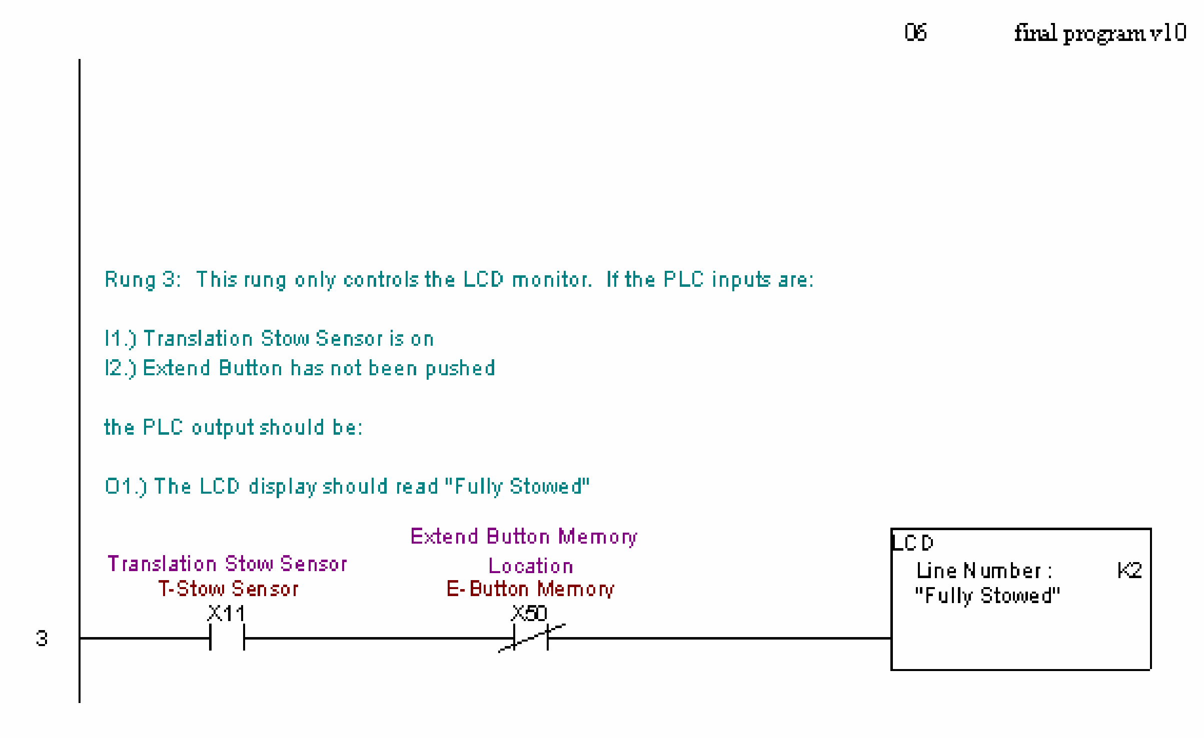
Appendix 5: Automatic Mode Ladder Program

This appendix contains the ladder program written to control the Automatic mode deployment of the Sensor Pallet, written using the DirectSoft32© programming software. Every rung of the program is commented to explain the purpose of each rung. The program was written by Robert P. Hayes.


final program v10
Rung 1: Here are the unconditional outputs for the program. Several status outputs are present, as well as initialization parameters to use the F0-04AD-1 A/D input board. The A/D board is set up to keep its data in BCD format, and its 4 channel input is mapped to V-memory locations V2000-2003. The constant 10mA, the amperage that we should see from the current sensor when the motor has finished translating, is loaded into V-memory location V2004. Here are the outputs:
O1.) Message on the LCD should read "Automatic Mode"
1
LCD
Line Number : K1
"Automatic Mode"
LD
K400
OUT
V700
LDA
O2000
OUT
V701
LD
K1530
OUT
Channel 1 is compared to this value
Comparison Value
V2004

Rung 2: On the first scan through the program, the memory locations used to store button pushes and timers should be cleared. Here, this is done. Memory locations X50, X51, X52, X53, X54, X55, X56, X57, X60, and X61 are cleared.



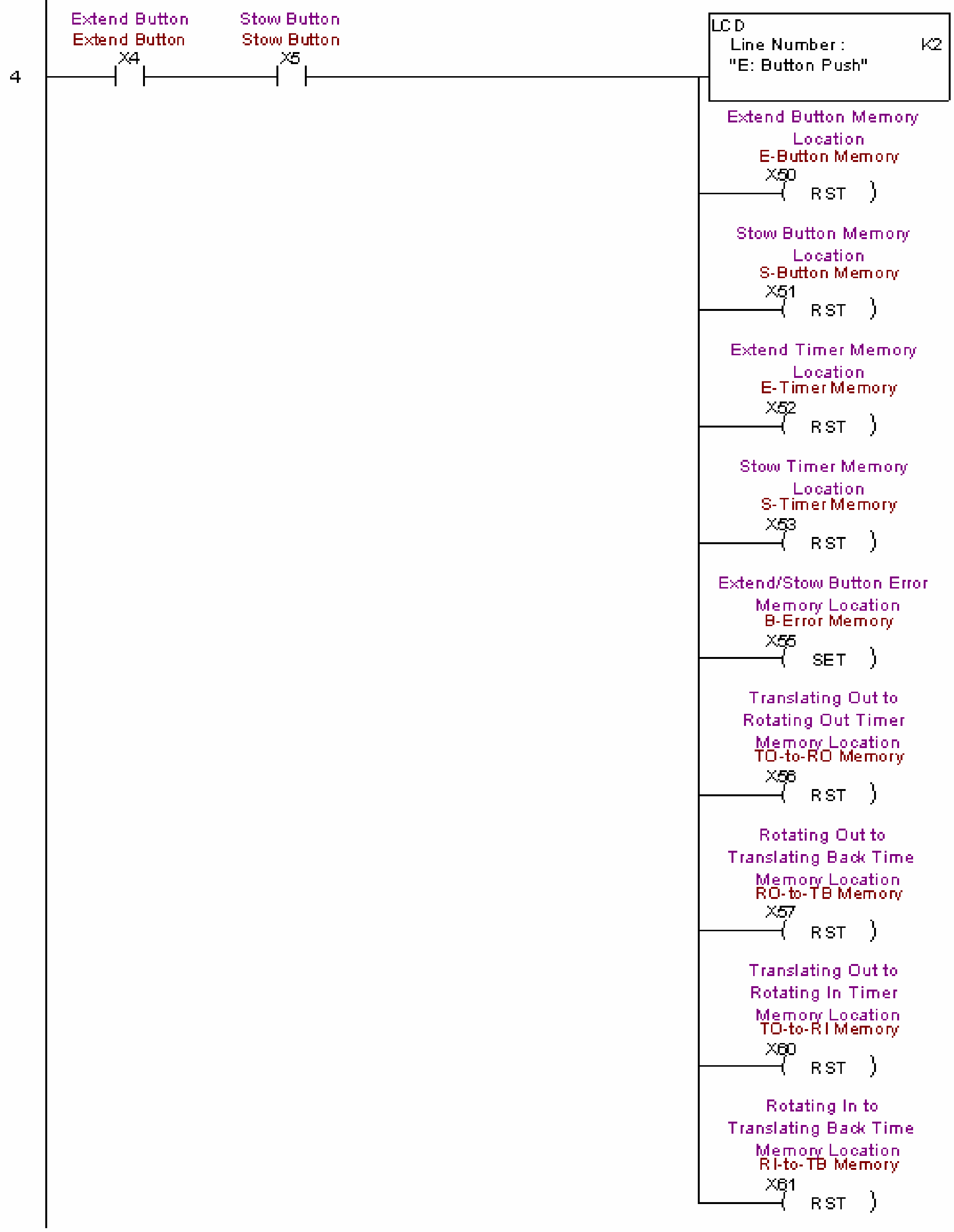

06 final program v10
Rung 3: This rung only controls the LCD monitor. If the PLC inputs are:
I1.) Translation Stow Sensor is on
I2.) Extend Button has not been pushed
the PLC output should be:
O1.) The LCD display should read "Fully Stowed"
Translation Stow Sensor
T-Stow Sensor
X11
Extend Button Memory
Location
E-Button Memory
X50
3
LCD
Line Number : K2
"Fully Stowed"

Rung 4: This is the ladder rung that handles the error state of pushing both the Extend Button and Stow Button at once. If the PLC inputs are:

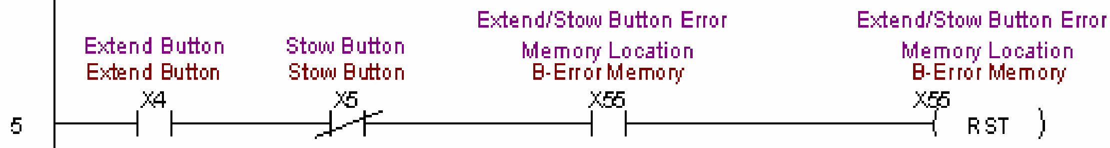
I1.) Extend Button is pushed
I2.) Stow Button is pushed

the PLC outputs are:

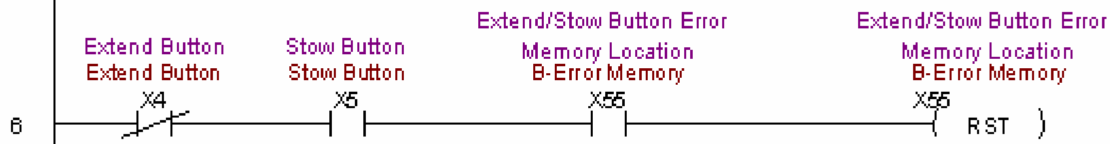
O1.) The LCD display should read "E: Button Push"
O2.) The Extend Button memory location is cleared.
O3.) The Stow Button memory location is cleared.
O4.) The Extend Timer memory location is cleared.
O5.) The Stow Timer memory location is cleared.
O6.) The Extend/Stow Button Error memory location is set.
O7.) The TO-to-RO Timer memory location is cleared.
O8.) The RO-to-TB Timer memory location is cleared.
O9.) The TO-to-RI Timer memory location is cleared.



Rung 5: This is another error handling ladder rung. If the Button Error memory location is set, and only the Extend Button is pushed, the Button Error memory location should be reset.



Rung 6: This is another error handling ladder rung. If the Button Error memory location is set, and only the Stow Button is pushed, the Button Error memory location should be reset.

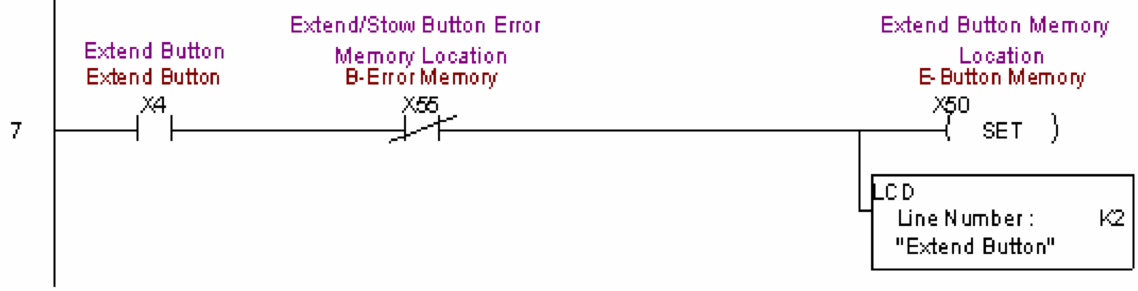


Rung 7: This rung sets the extend process into motion. When the Extend Button is pushed, the Extend Button memory location is set. The PLC inputs are:

I1.) The Extend Button is pushed.
I2.) The Extend/Stow Button Error memory location is not set.

The PLC outputs are:

O1.) The Extend Button memory location is set.
O2.) The LCD display should read "Extend Button".

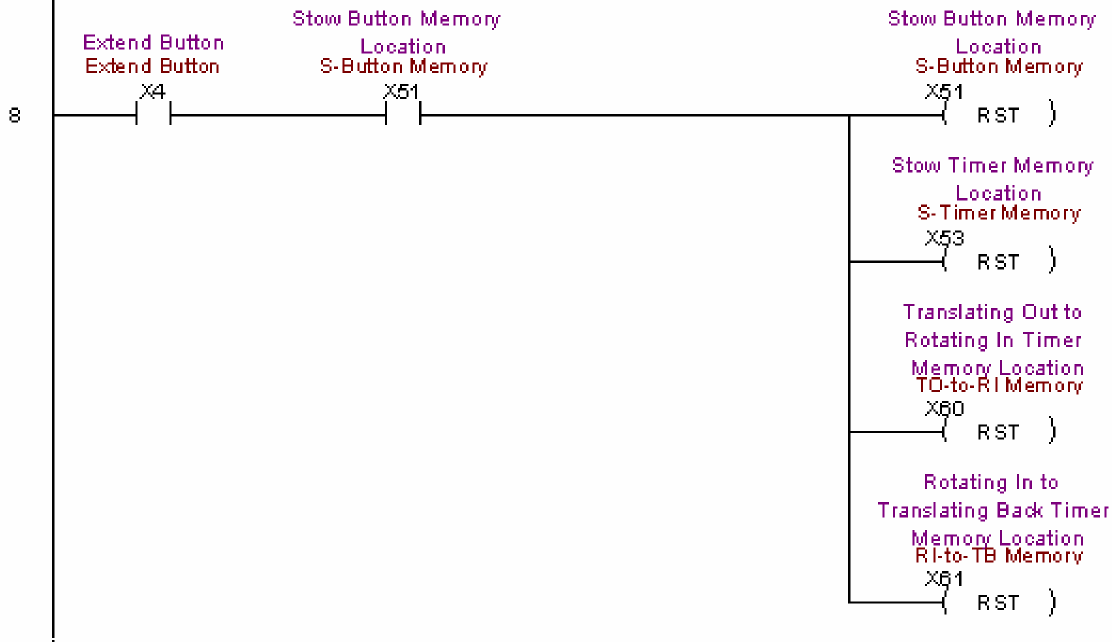


Rung 8: This rung is to handle the memory locations. If the Stow Button memory location is set when the Extend Button is pushed, the memory locations associated with the stow process should be reset. The PLC inputs are:

I1.) The Extend Button is pushed.
I2.) The Stow Button memory location is set.

The PLC outputs are:

O1.) The Stow Button memory location is reset.
O2.) The Stow Timer memory location is reset.
O3.) The TO-to-RI Timer memory location is reset.
O4.) The RI-to-TB Timer memory location is reset.

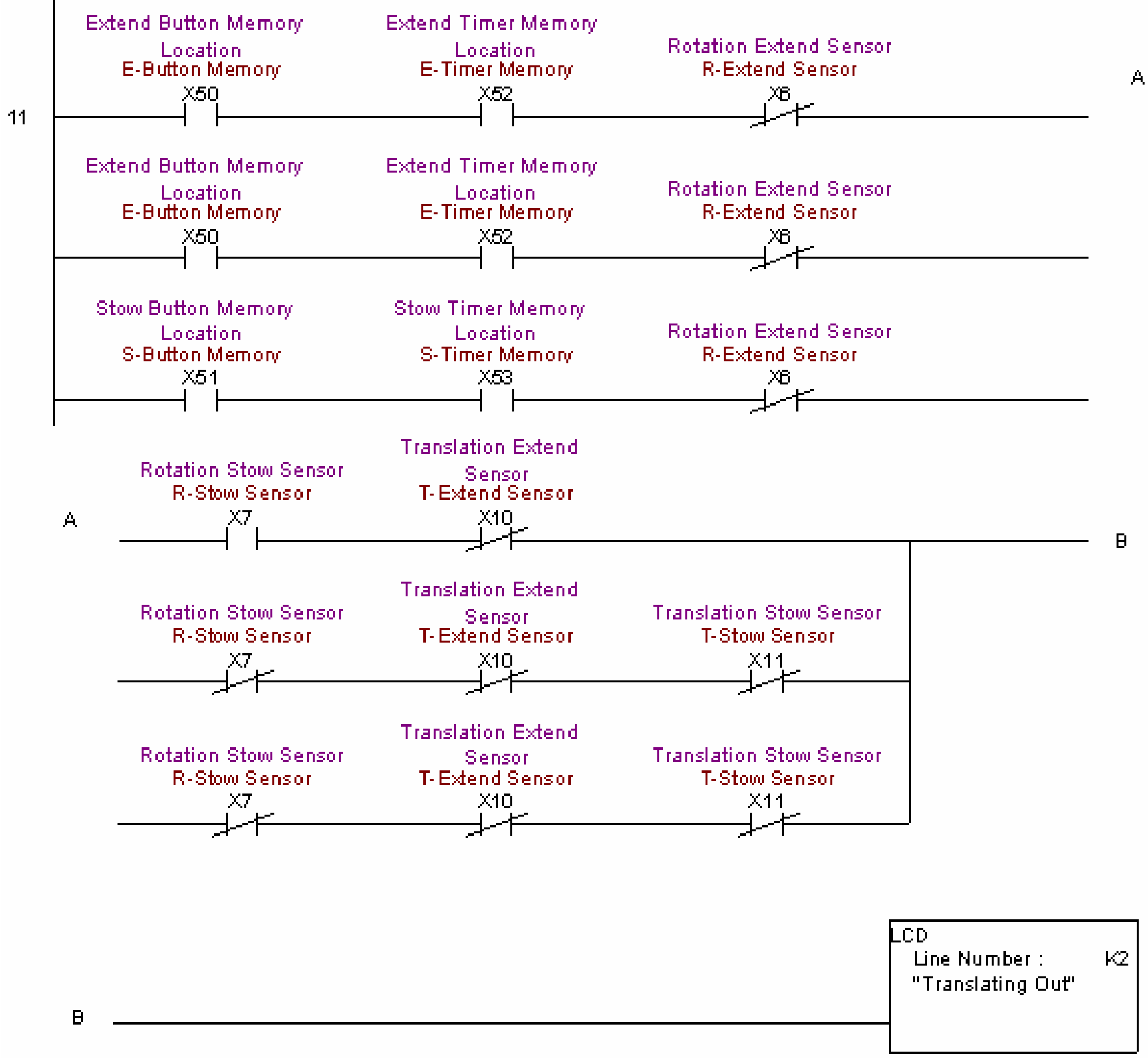


Rung 9: When the Extend Button is pushed, it sets a 5.0 second timer that must finish its countdown before the extend process begins. Here, the Extend Button Timer is set to 5.0 seconds.

Rung 10: The PLC must remember that the Extend Button Timer finished its countdown, so at this rung, when the Extend Button Timer finishes, the Extend Timer memory location is set.

Rung 11: This rung only controls the LCD display. If the PLC inputs are:

I1.) The Extend Button memory location is set.
I2.) The Extend Timer memory location is set.
I3.) The Rotation Extend Sensor is not on.
I4.) The Rotation Stow Sensor is on.
I5.) The Translation Extend Sensor is not on.
-OR-
I1.) The Extend Button memory location is set.
I2.) The Extend Timer memory location is set.
I3-6.) All Sensors are not on.
-OR-
I1.) The Stow Button memory location is set.
I2.) The Stow Button memory location is set.
I3-6.) All Sensors are not on.

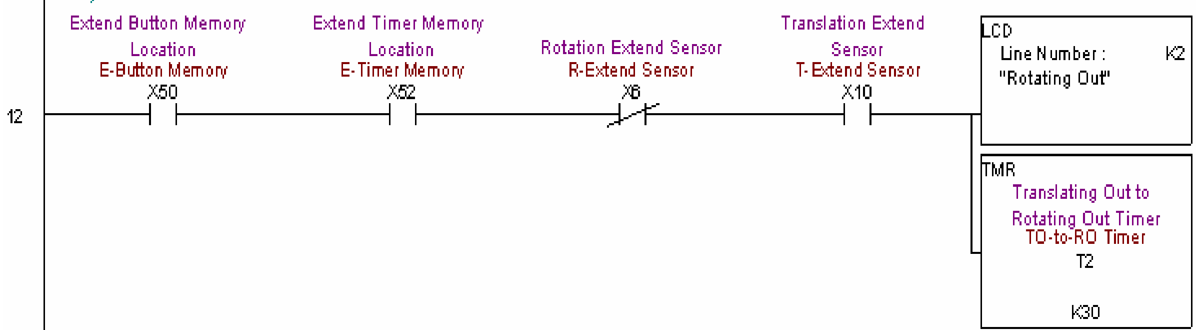


Rung 12: This rung controls the LCD display as well as sets the Translating Out to Rotating Out Timer to 3.0 seconds. If the PLC inputs are:

I1.) The Extend Button memory location is set.
I2.) The Extend Timer memory location is set.
I3.) The Rotation Extend Sensor is not on.
I4.) The Translation Extend Sensor is on.

the PLC outputs are:

O1.) The LCD display should read "Rotating Out".
O2.) The TO-to-RO Timer is set to 3.0 seconds.



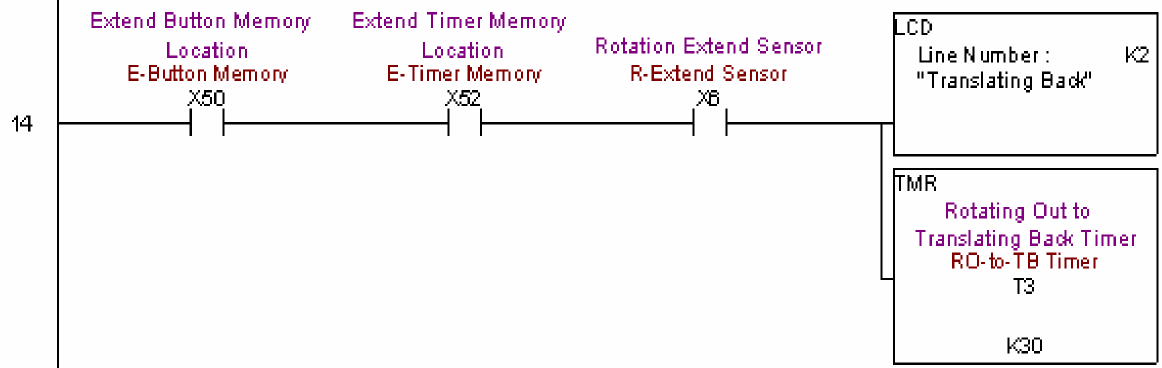
Rung 13: When the TO-to-RO Timer finishes its 3.0 second countdown, the PLC needs to remember that the timer has finished. Here, the TO-to-RO memory location is set when the timer finishes its countdown.

Rung 14: This rung controls the LCD display and sets the Rotating Out to Translating Back Timer to 3.0 seconds. If the PLC inputs are:

I1.) The Extend Button memory location is set.
I2.) The Extend Timer memory location is set.
I3.) The Rotation Extend Sensor is on.

the PLC outputs are:

O1.) The LCD display should read "Translating Back".
O2.) The RO-to-TB Timer is set to 3.0 seconds.



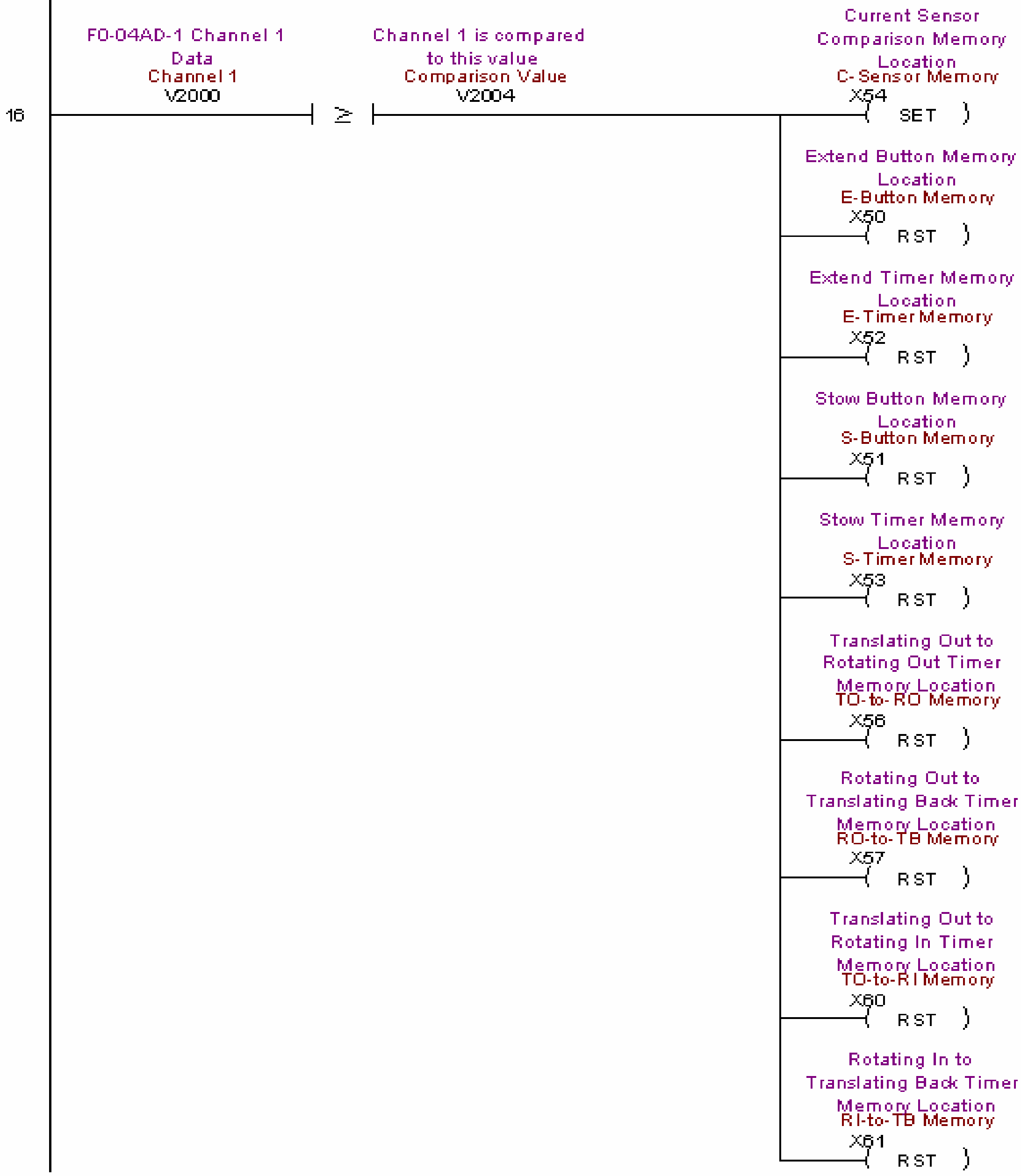
Rung 15: When the RO-to-TB Timer finishes its 3.0 second countdown, the PLC needs to remember that the timer has finished. Here, the RO-to-TB memory location is set when the timer finishes its countdown.

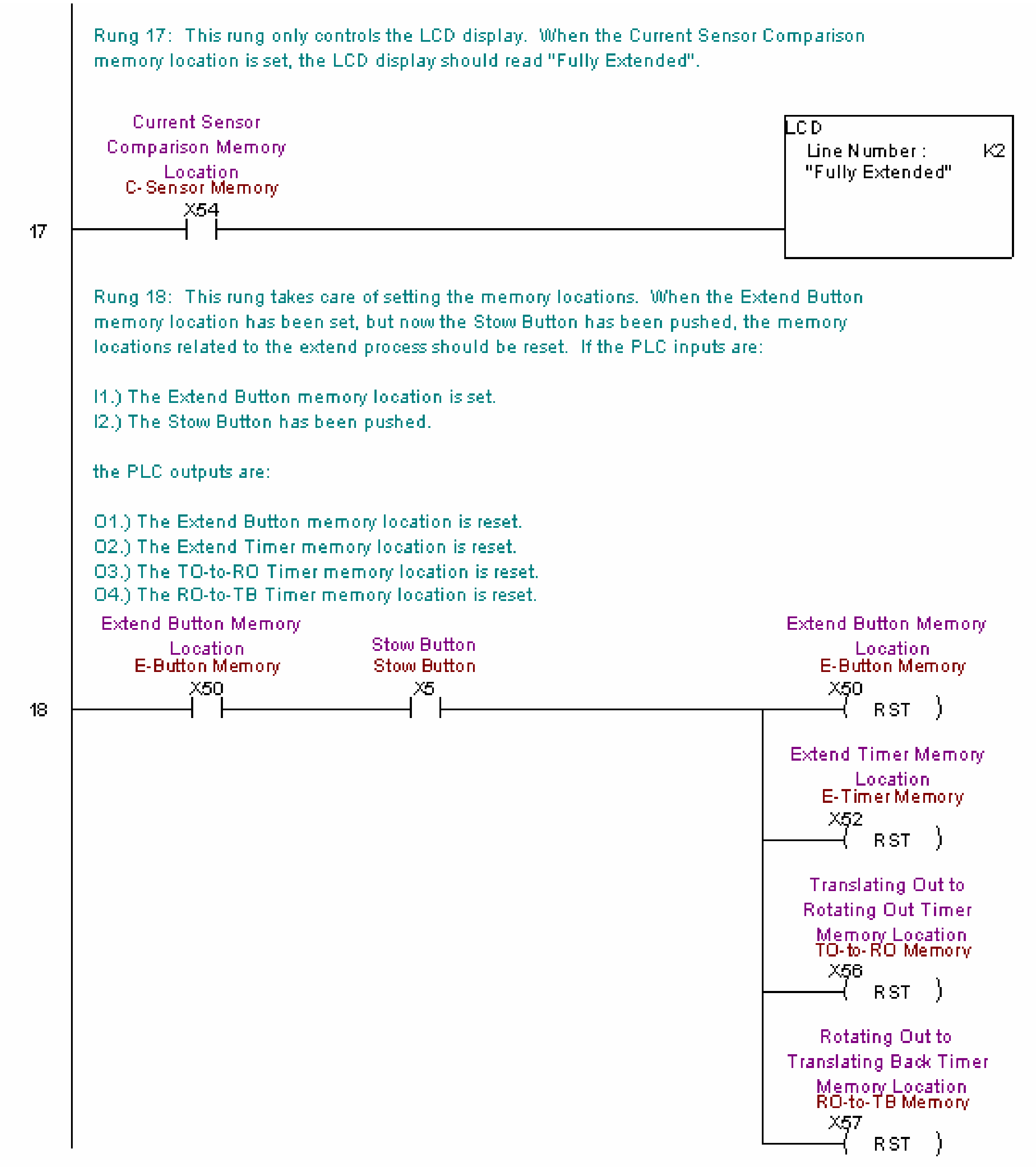
Rung 16: In this stage, the plate finishes translating inward and is in its fully extended position. This is initiated by the plate/arm jamming up against the C-130 door, causing a current spike seen by the current sensor CLN-50 and captured by the F0-04AD-1 A/D input board. When this occurs, the current spike should rise above 10mA, and this is reflected by setting the Current Sensor Comparison memory location. The PLC inputs are:

I1.) Channel 1 of the A/D input board (stored at V2000) is greater than or equal to 10mA (stored in V2004)

The PLC should output:

O1.) The Current Sensor Comparison memory location is set.
O2.) The Extend Button memory location is reset.
O3.) The Extend Timer memory location is reset.
O4.) The Stow Button memory location is reset.
O5.) The Stow Timer memory location is reset.
O6.) The TO-to-RO Timer memory location is reset.
O7.) The RO-to-TB Timer memory location is reset.



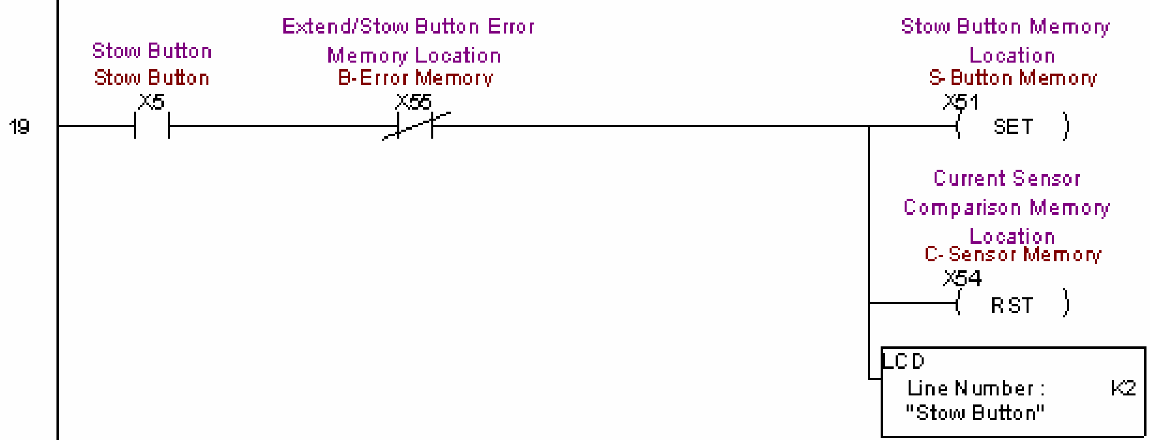

Rung 17: This rung only controls the LCD display. When the Current Sensor Comparison memory location is set, the LCD display should read "Fully Extended".
Current Sensor Comparison Memory Location
C-Sensor Memory
X54
17
LCD
Line Number : K2
"Fully Extended"
Rung 18: This rung takes care of setting the memory locations. When the Extend Button memory location has been set, but now the Stow Button has been pushed, the memory locations related to the extend process should be reset. If the PLC inputs are:
I1.) The Extend Button memory location is set.
I2.) The Stow Button has been pushed.
the PLC outputs are:
O1.) The Extend Button memory location is reset.
O2.) The Extend Timer memory location is reset.
O3.) The TO-to-RO Timer memory location is reset.
O4.) The RO-to-TB Timer memory location is reset.
Extend Button Memory Location
E-Button Memory
X50
Stow Button
Stow Button
X5
18
Extend Button Memory Location
E-Button Memory
X50
RST
Extend Timer Memory Location
E-Timer Memory
X52
RST
Translating Out to Rotating Out Timer Memory Location
TO-to-RO Memory
X56
RST
Rotating Out to Translating Back Timer Memory Location
RO-to-TB Memory
X57
RST

Rung 19: In this rung, the stow process is set into effect. It begins by setting the Stow Button memory location when the Stow Button is pushed. If the PLC inputs are:

I1.) The Stow Button is pushed.
I2.) The Extend/Stow Button Error memory location is not set.

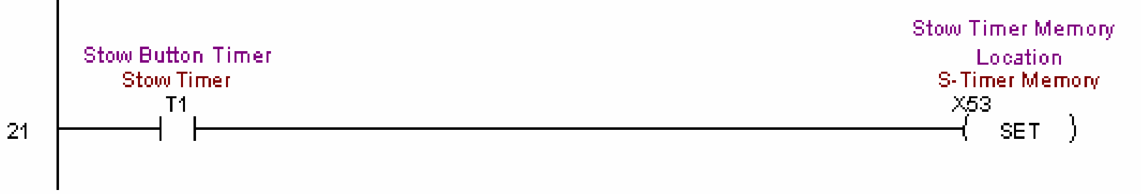
the PLC outputs are:

O1.) The Stow Button memory location is set.
O2.) The Current Sensor Comparison memory location is reset.
O3.) The LCD display should read "Stow Button".



Rung 20: When the Stow Button is pushed, it sets a 5.0 second timer that must finish its countdown before the stow process begins. Here, the Stow Button Timer is set to 5.0 seconds.

Rung 21: The PLC must remember that the Stow Button Timer finished its countdown, so at this rung, when the Stow Button Timer finishes, the Stow Timer memory location is set.

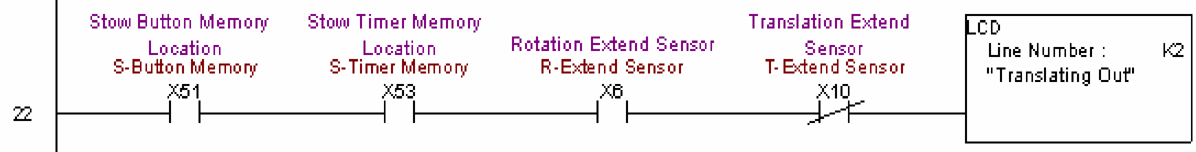


Rung 22: This rung only controls the LCD display. If the PLC inputs are:

I1.) The Stow Button memory location is set.
I2.) The Stow Timer memory location is set.
I3.) The Rotation Extend Sensor is on.
I4.) The Translation Extend Sensor is not on.

the PLC output is;

O1.) The LCD display should read "Translating Out".

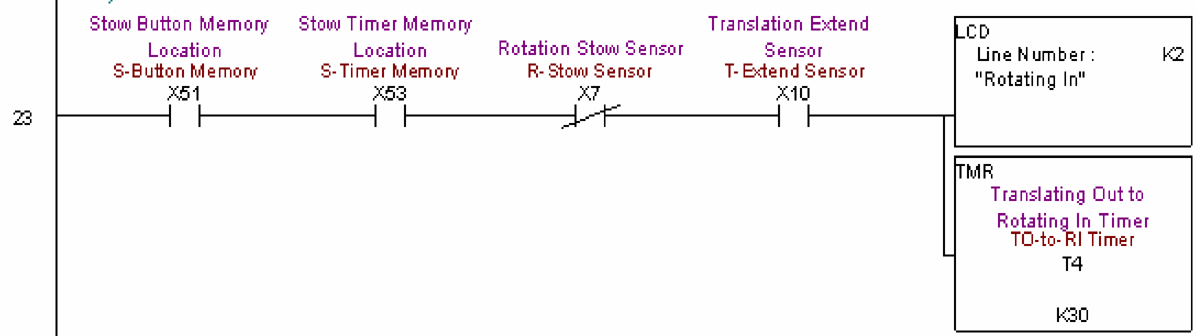


Rung 23: This rung controls the LCD display and sets the Translating Out to Rotating In Timer to 3.0 seconds. If the PLC inputs are:

I1.) The Stow Button memory location is set.
I2.) The Stow Timer memory location is set.
I3.) The Rotation Stow Sensor is not on.
I4.) The Translation Extend Sensor is on.

the PLC outputs are:

O1.) The LCD display should read "Rotating In".
O2.) The TO-to-RI Timer is set to 3.0 seconds.



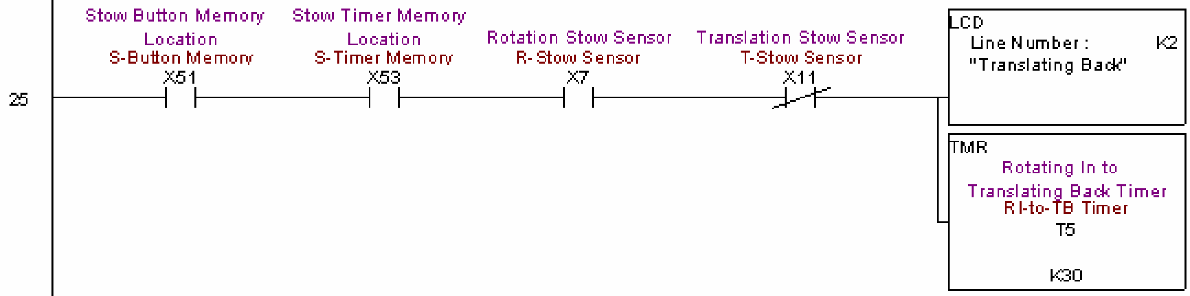
Rung 24: When the TO-to-RI Timer finishes its 3.0 second countdown, the PLC needs to remember that the timer has finished. Here, the TO-to-RI memory location is set when the timer finishes its countdown.

Rung 25: This rung controls the LCD display and sets the Rotating In to Translating Back Timer to 3.0 seconds. If the PLC inputs are:

I1.) The Stow Button memory location is set.
I2.) The Stow Timer memory location is set.
I3.) The Rotation Stow Sensor is on.
I4.) The Translation Stow Sensor is not on.

the PLC outputs are:

O1.) The LCD display should read "Translating Back".
O2.) The RI-to-TB Timer is set to 3.0 seconds.



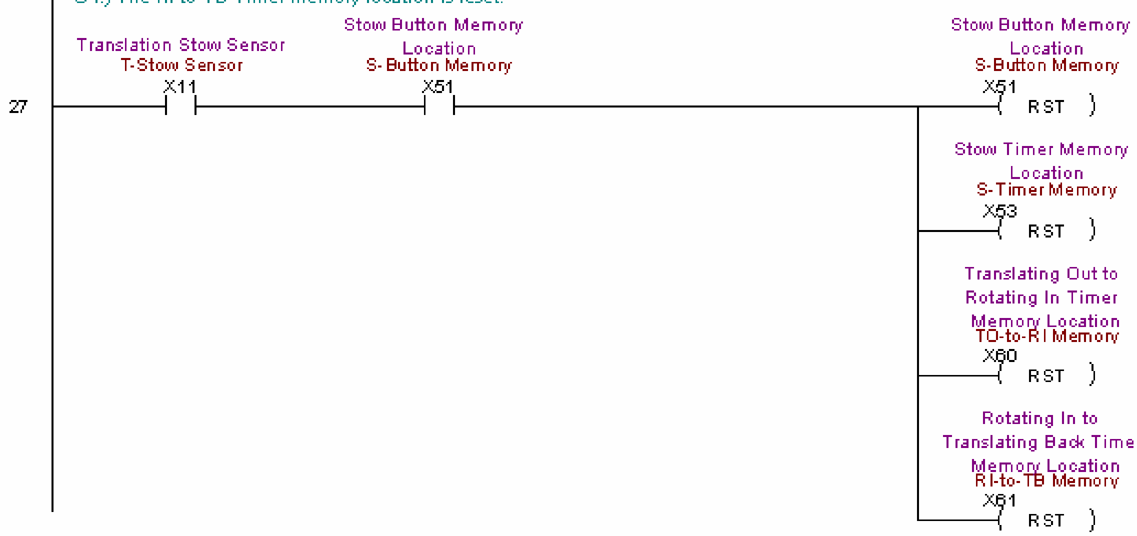
Rung 26: When the RI-to-TB Timer finishes its 3.0 second countdown, the PLC needs to remember that the timer has finished. Here, the RI-to-TB memory location is set when the timer finishes its countdown.

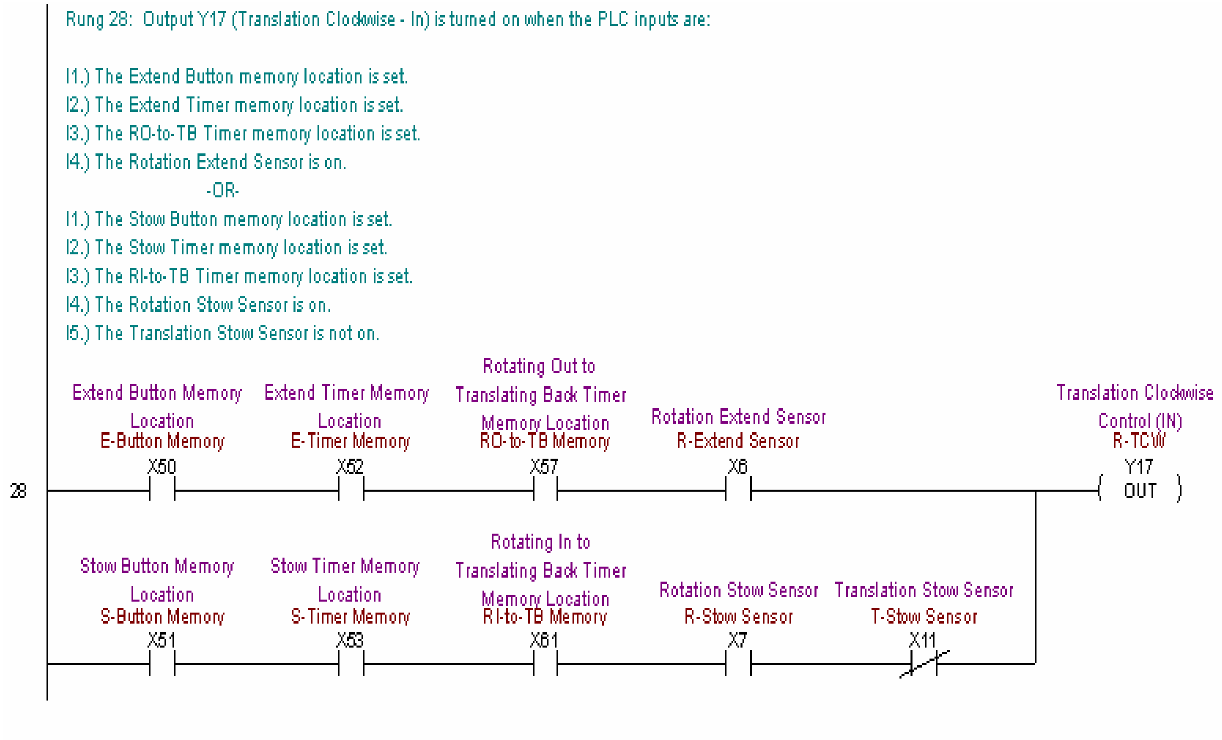
Rung 27: This rung takes care of setting /resetting memory locations. If the Translation Stow Sensor turns on after the Stow Button has been pushed, the memory locations related to the stow process should be reset. If the PLC inputs are:

I1.) The Translation Stow Sensor is on.
I2.) The Stow Button memory location is set.

the PLC outputs are:

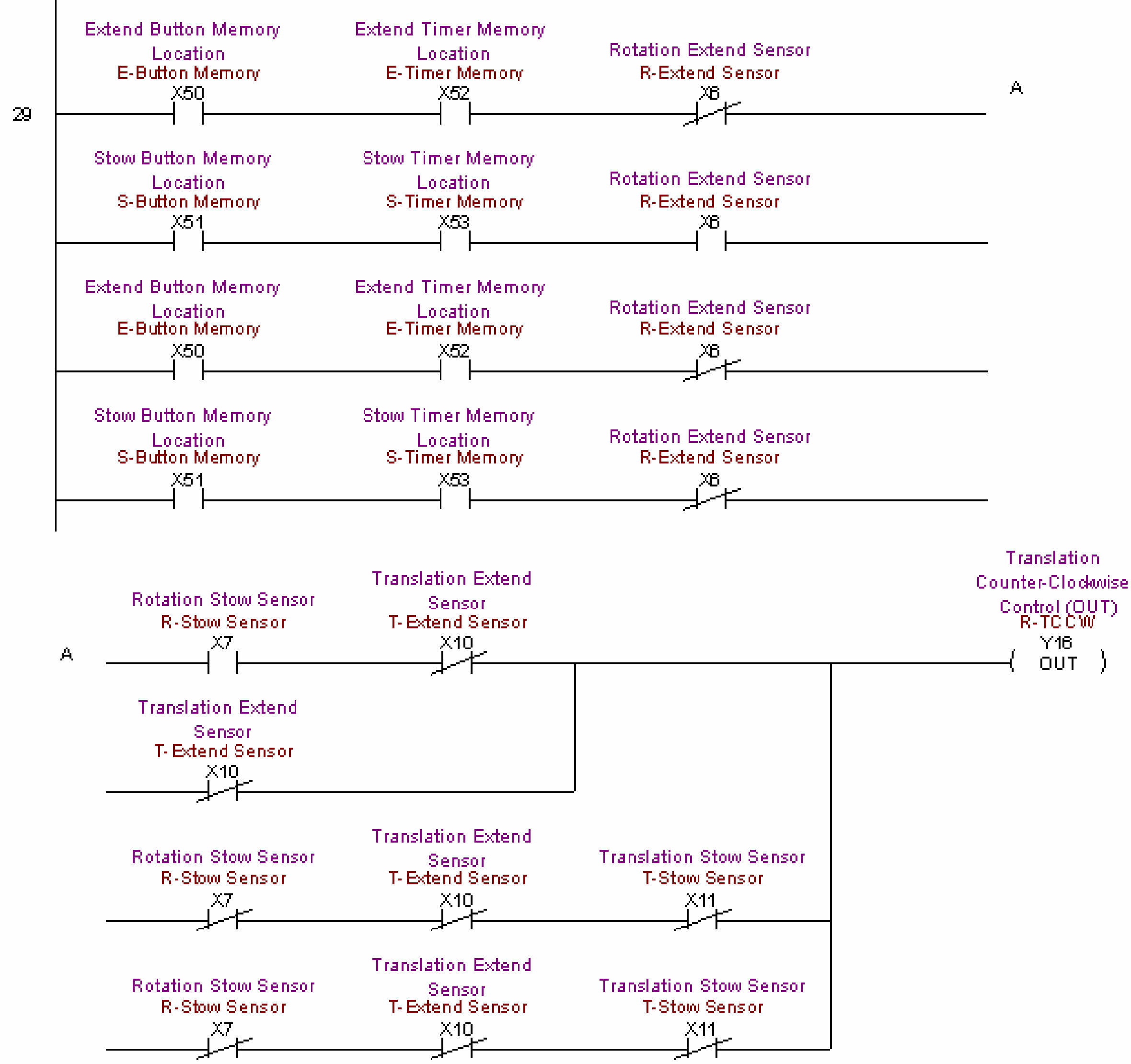
O1.) The Stow Button memory location is reset.
O2.) The Stow Timer memory location is reset.
O3.) The TO-to-RI Timer memory location is reset.
O4.) The RI-to-TB Timer memory location is reset.




Rung 28: Output Y17 (Translation Clockwise - In) is turned on when the PLC inputs are:
I1.) The Extend Button memory location is set.
I2.) The Extend Timer memory location is set.
I3.) The RO-to-TB Timer memory location is set.
I4.) The Rotation Extend Sensor is on.
-OR-
I1.) The Stow Button memory location is set.
I2.) The Stow Timer memory location is set.
I3.) The RI-to-TB Timer memory location is set.
I4.) The Rotation Stow Sensor is on.
I5.) The Translation Stow Sensor is not on.
Extend Button Memory Location
E-Button Memory
X50
Extend Timer Memory Location
E-Timer Memory
X52
Rotating Out to Translating Back Timer Memory Location
RO-to-TB Memory
X57
Rotation Extend Sensor
R-Extend Sensor
X6
Translation Clockwise Control (IN)
R-TCW
Y17
OUT
28
Stow Button Memory Location
S-Button Memory
X51
Stow Timer Memory Location
S-Timer Memory
X53
Rotating In to Translating Back Timer Memory Location
RI-to-TB Memory
X61
Rotation Stow Sensor
R-Stow Sensor
X7
Translation Stow Sensor
T-Stow Sensor
X11

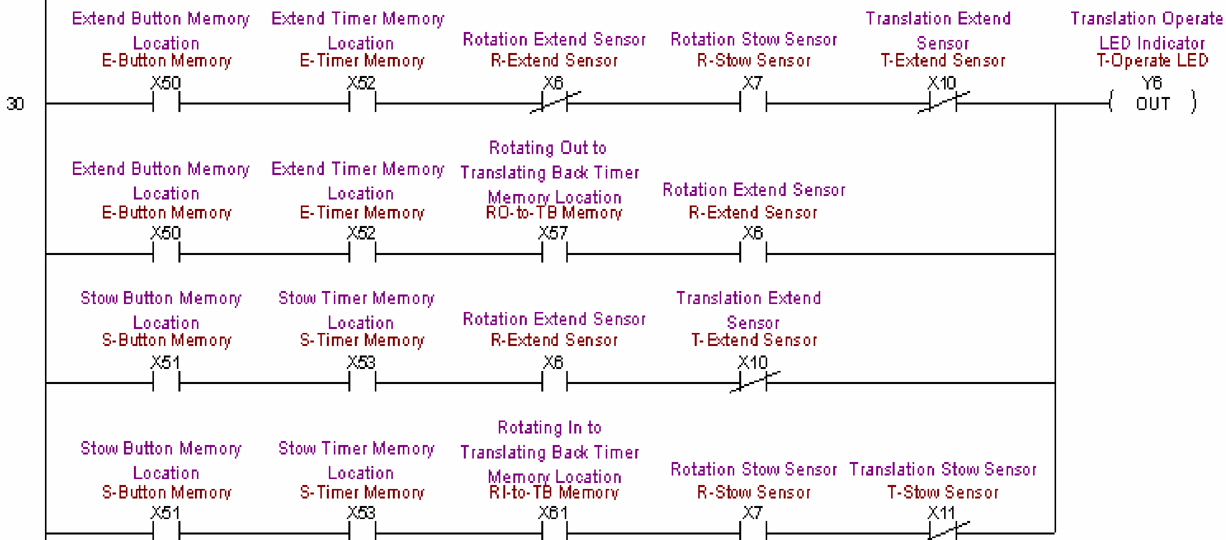
Rung 29: Output Y16 (Translation Counter-Clockwise - Out) is on when PLC inputs are:

I1.) The Extend Button memory location is set.
I2.) The Extend Timer memory location is set.
I3.) The Rotation Extend Sensor is not on.
I4.) The Rotation Stow Sensor is on.
I5.) The Translation Extend Sensor is not on.
-OR-
I1.) The Stow Button memory location is set.
I2.) The Stow Timer memory location is set.
I3.) The Rotation Extend Sensor is on.
I4.) The Translation Extend Sensor is not on.
-OR-
I1.) The Extend Button memory location is set.
I2.) The Extend Timer memory location is set.
I3-6.) All Sensors are not on.
-OR-
I1.) The Stow Button memory location is set.



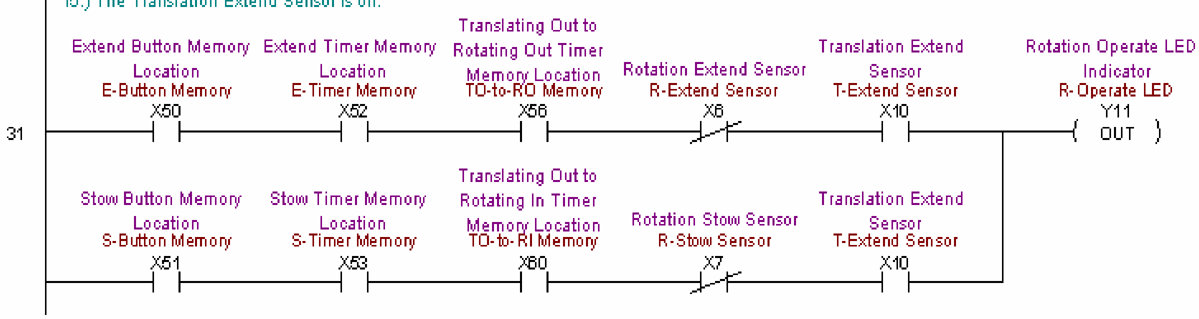
Rung 30: Output Y6 (Translation Operate LED Indicator) is on when the PLC inputs are:

I1-2.) The Extend Button and Extend Timer memory locations are set.
I3.) The Rotation Extend Sensor is not on.
I4.) The Rotation Stow Sensor is on.
I5.) The Translation Extend Sensor is not on.
-OR-
I1-2.) The Extend Button and Extend Timer memory locations are set.
I3.) The RO-to-TB memory location is set.
I4.) The Rotation Extend Sensor is on.
-OR-
I1-2.) The Stow Button and Stow Timer memory locations are set.
I3.) The Rotation Extend Sensor is on.
I4.) The Translation Extend Sensor is not on.
-OR-
I1-2.) The Stow Button and Stow Timer memory locations are set.
I3.) The RI-to-TB memory location is set.
I4.) The Rotation Stow Sensor is on.



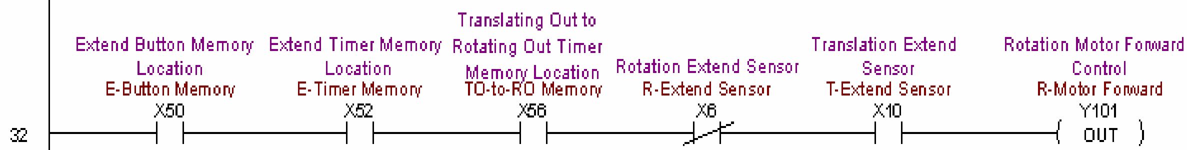
Rung 31: Output Y11 (Rotation Operate LED Indicator) is turned on when the PLC inputs are:

I1.) The Extend Button memory location is set.
I2.) The Extend Timer memory location is set.
I3.) The TO-to-RO Timer memory location is set.
I4.) The Rotation Extend Sensor is not on.
I5.) The Translation Extend Sensor is on.
-OR-
I1.) The Stow Button memory location is set.
I2.) The Stow Timer memory location is set.
I3.) The TO-to-RI memory location is set.
I4.) The Rotation Stow Sensor is not on.
I5.) The Translation Extend Sensor is on.



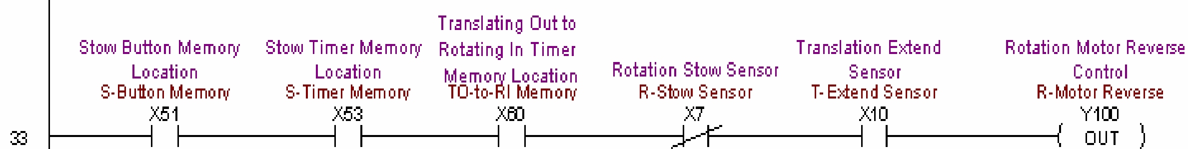
Rung 32: Output Y101 (Rotation Motor Forward Controller) is turned on when the PLC inputs are:

I1.) The Extend Button memory location is set.
I2.) The Extend Timer memory location is set.
I3.) The TO-to-RO Timer memory location is set.
I4.) The Rotation Extend Sensor is not on.
I5.) The Translation Extend Sensor is on.



Rung 33: Output Y100 (Rotation Motor Reverse Controller) is turned on when the PLC inputs are:

I1.) The Stow Button memory location is set.
I2.) The Stow Timer memory location is set.
I3.) The TO-to-RI Timer memory location is set.
I4.) The Rotation Stow Sensor is not on.
I5.) The Translation Extend Sensor is on.



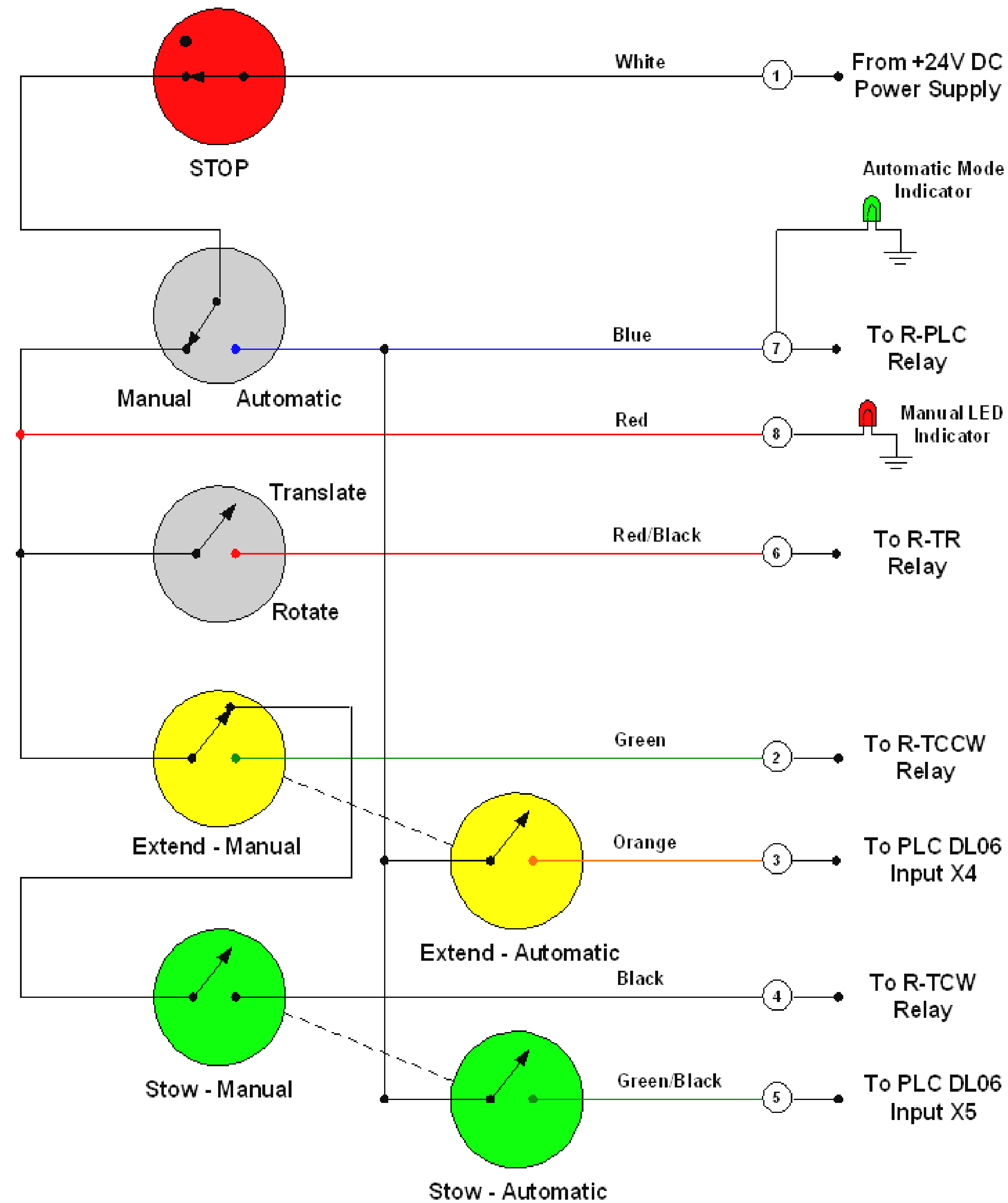
Rung 34: This is the END rung, the end of the program.

Appendix 6: Sensor Pallet Control Circuit Diagrams

This appendix contains the circuit diagrams used to implement Automatic and Manual mode deployment of the Sensor Pallet. The diagrams shown here are:

(1) C-130 Pendant Schematic: Diagram of how the Emergency Stop, Extend, and Stow pushbuttons and Automatic/Manual and Translate/Rotate switches are wired in the operator pendant.
(2) C-130 Motors Circuit Diagram: Control circuit for the translation and rotation motors used on the Sensor Pallet.
(3) C-130 PLC Circuit Diagram: Diagram showing how the Programmable Logic Controller was wired up, including the inputs and outputs, and the proximity sensors.

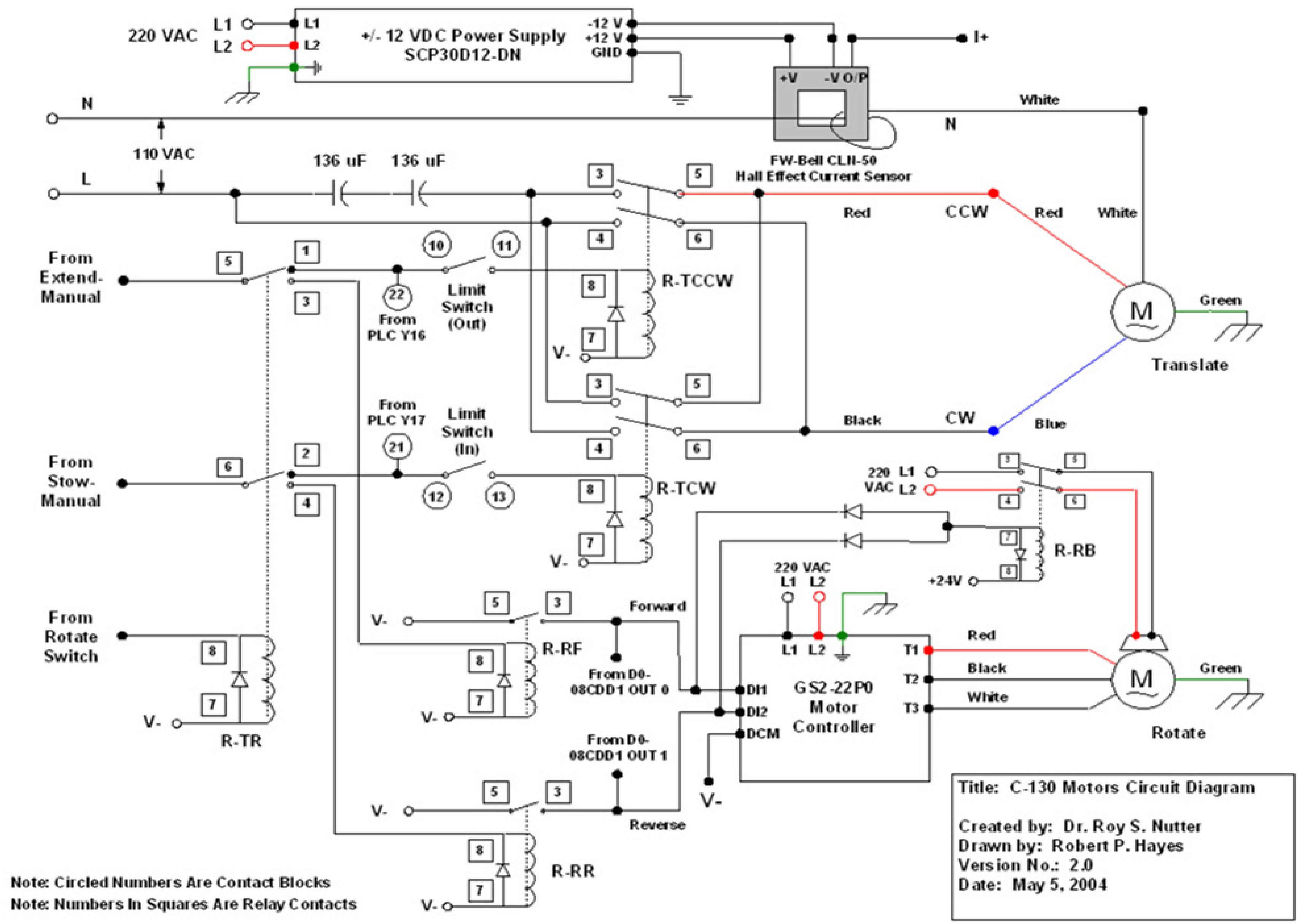
The circuits were originally designed by Dr. Roy S. Nutter; these diagrams were drawn by Robert P. Hayes.

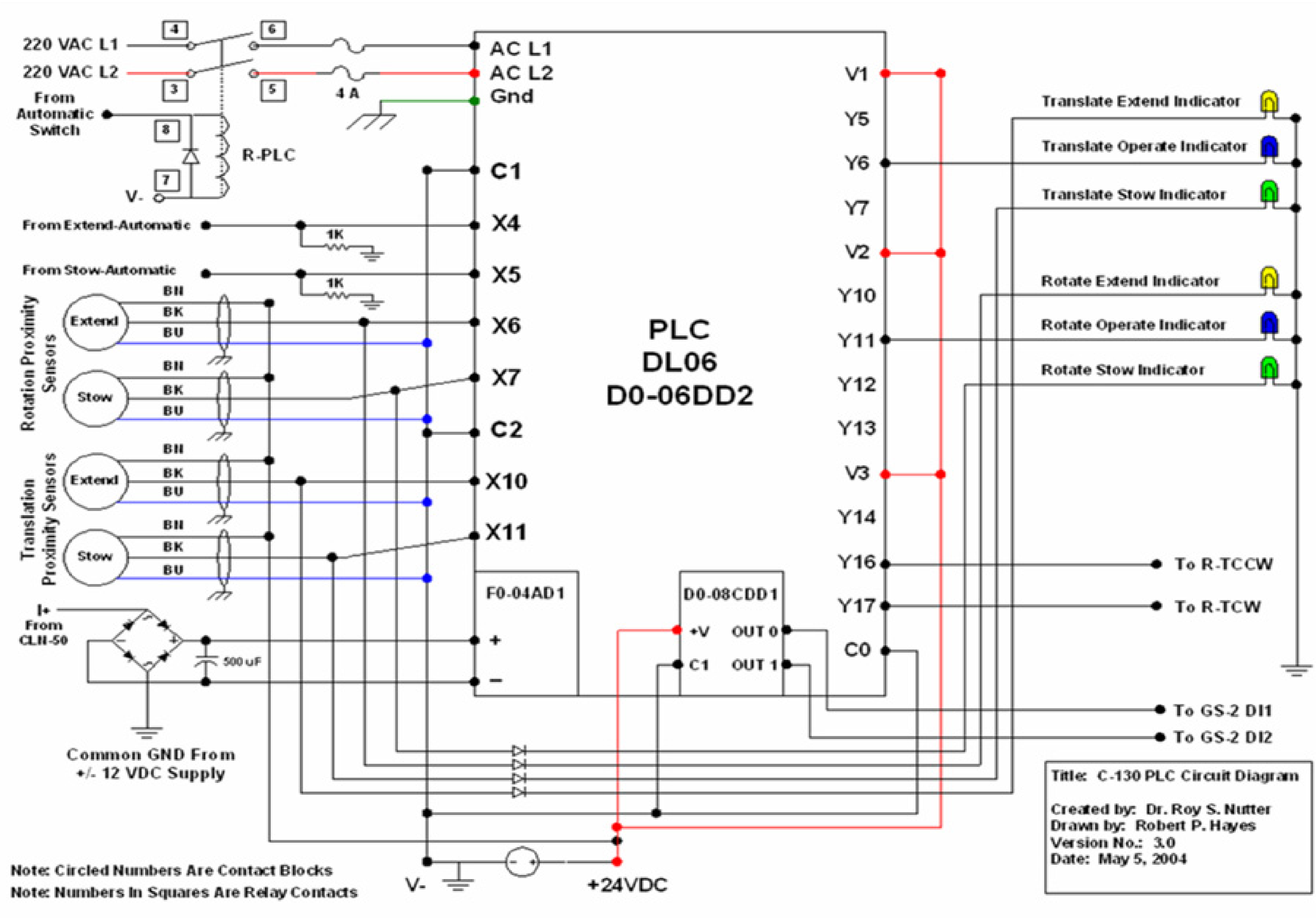


Title: C-130 Pendant Schematic

Created by: Dr. Roy S. Nutter
Drawn by: Robert P. Hayes
Version No.: 1.0
Date: May 5, 2004

Note: Circled Numbers Are Contact Blocks


220 VAC
L1
L2
+/- 12 VDC Power Supply
SCP30D12-DN
-12 V
+12 V
GND
I+
+V
-V O/P
FW-Bell CLN-50
Hall Effect Current Sensor
N
110 VAC
L
136 uF
136 uF
White
Red
CCW
Red
White
Green
Translate
Black
CW
Blue
From Extend-Manual
From PLC Y16
Limit Switch (Out)
R-TCCW
V-
From PLC Y17
Limit Switch (In)
From Stow-Manual
R-TCW
220 VAC
R-RB
+24V
From Rotate Switch
R-TR
Forward
R-RF
From D0-08CDD1 OUT 0
From D0-08CDD1 OUT 1
Reverse
R-RR
GS2-22P0 Motor Controller
DI1
DI2
DCM
T1
T2
T3
Red
Black
White
Green
Rotate
Title: C-130 Motors Circuit Diagram
Created by: Dr. Roy S. Nutter
Drawn by: Robert P. Hayes
Version No.: 2.0
Date: May 5, 2004
Note: Circled Numbers Are Contact Blocks
Note: Numbers In Squares Are Relay Contacts



220 VAC L1
220 VAC L2
From Automatic Switch
R-PLC
V-
4 A
AC L1
AC L2
Gnd
C1
X4
X5
X6
X7
C2
X10
X11
From Extend-Automatic
From Stow-Automatic
1K
1K
Rotation Proximity Sensors
Extend
Stow
Translation Proximity Sensors
Extend
Stow
BN
BK
BU
I+ From CLN-50
500 uF
Common GND From +/- 12 VDC Supply
PLC
DL06
D0-06DD2
F0-04AD1
D0-08CDD1
+V
C1
OUT 0
OUT 1
V1
Y5
Y6
Y7
V2
Y10
Y11
Y12
Y13
V3
Y14
Y16
Y17
C0
Translate Extend Indicator
Translate Operate Indicator
Translate Stow Indicator
Rotate Extend Indicator
Rotate Operate Indicator
Rotate Stow Indicator
To R-TCCW
To R-TCW
To GS-2 DI1
To GS-2 DI2
+24VDC
Note: Circled Numbers Are Contact Blocks
Note: Numbers In Squares Are Relay Contacts
Title: C-130 PLC Circuit Diagram
Created by: Dr. Roy S. Nutter
Drawn by: Robert P. Hayes
Version No.: 3.0
Date: May 5, 2004

Appendix 7: GS2-22P0 Motor Controller Specifications

This appendix contains information for the GS2-22P0 2.0HP motor controller used to operate the rotation motor on the Sensor Pallet. This includes specifications, installation, wiring diagrams, and diagrams for the device. This device and further information is available from Automation Direct [24].

GS2 Series - Introduction

GS2 Series Drives								
Motor Rating	Hp	.5	1	2	3	5	7.5	10
	kW	0.4	0.75	1.5	2.2	3.7	5.5	7.5
Single/Three Phase 200 Volt Class		✓	✓	✓	✓			
Three Phase 200 Volt Class					✓	✓	✓	
Three-Phase 400 Volt Class			✓	✓	✓	✓	✓	✓

Overview

The GS2 series of AC drives offers all of the features of our GS1 drive plus dynamic braking, PID and a removable keypad. The drive can be configured using the built-in digital keypad or with the standard RS-485 serial communications port. The standard keypad allows you to configure the drive, set the speed, start and stop the drive, and monitor specific parameters during operation. Each GS2 features one analog and six programmable digital inputs, and one analog and two programmable relay outputs.

Features

- Simple Volts/Hertz control
- Sinusoidal Pulse Width Modulation (PWM)
- 1-12KHz carrier frequency
- IGBT technology
- 175% starting torque
- 150% rated current for one minute
- Electronic overload protection
- Stall prevention
- Adjustable accel and decel ramps
- S-curve settings for acceleration and deceleration
- Automatic torque compensation
- Automatic slip compensation
- Dynamic braking circuit
- DC braking
- Three skip frequencies
- Trip history
- Programmable jog speed
- Integral PID control
- Removable keypad with speed potentiometer
- Programmable analog input
- Programmable analog output
- Six programmable digital inputs
- Two programmable relay outputs
- RS-232/485 MODBUS communications @38.4K
- Optional Ethernet communications
- UL/CE listed

Accessories

- AC line reactors
- EMI filters
- Braking resistors
- Fuse kits and replacement fuses
- Ethernet interface
- Replacement keypads
- Keypad cables in 1, 3 and 5 meter lengths
- Four and eight port communication boards

Detailed descriptions and specifications for the GS2 accessories are available later in this section.

GS2 series part numbering system

GS2- 4 7P5

- **Applicable Motor Capacity**
  0P5: 0.5HP　1P0: 1.0HP
  2P0: 2.0HP　3P0: 3.0HP
  5P0: 5.0HP　7P5: 7.5HP
  010: 10HP
- **Input Voltage**
  2: 200-240VAC
  4: 380-480VAC
- **Series Name**

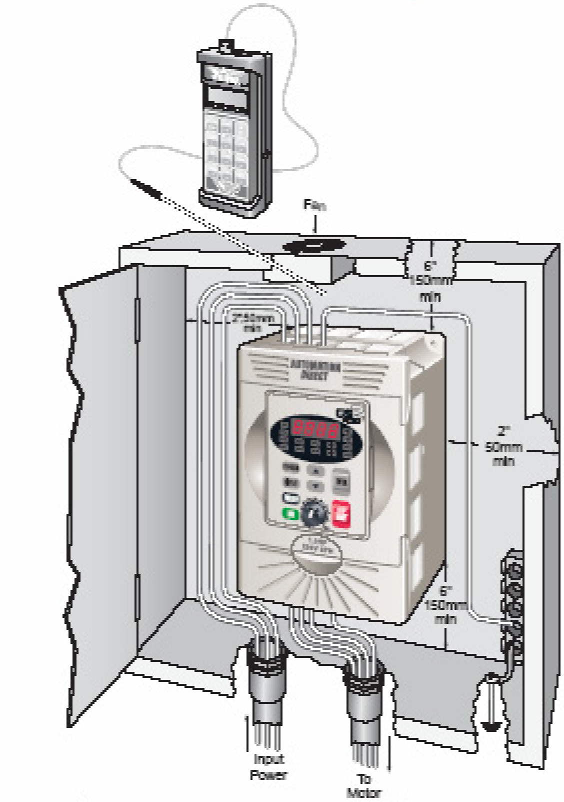
GS2 Series Specifications

200V Class GS2 Series							
Model		GS2-20P5	GS2-21P0	GS2-22P0	GS2-23P0	GS2-25P0	GS2-27P5
Price		$188.00	$209.00	$279.00	$329.00	$364.00	$597.00
Motor Rating	**HP**	1/2HP	1HP	2HP	3HP	5HP	7.5HP
	kW	0.4kW	0.75kW	1.5kW	2.2kW	3.7kW	5.5kW
Rated Output Capacity (200V) kVA		1.0	1.9	2.7	3.8	6.5	9.5
Rated Input Voltage		Single/Three phase : 200/208/220/230/240VAC ±10%, 50/60Hz ±5%				Three phase : 200/208/220/230/240VAC ±10%, 50/60Hz ±5%	
Rated Output Voltage		Corresponds to input voltage					
Rated Input Current (A)		6.3/2.9	11.5/6.3	15.7/8.8	27.0/12.5	19.6	28
Rated Output Current (A)		2.5	5.0	7.0	10	17	25
DC Braking		Frequency 60-0Hz, 0-100% rated current, start time 0.0-5.0 seconds, Stop Time 0.0-25.0 seconds					
Protective Structure		Protected chassis IP20					
Ambient Operating Temperature		-10°C to 50°C (14°F to 122°F) without derating					-10°C to 40°C (14°F to 104°F) without derating
Storage Temperature		-20° to 60°C (-4° to 140°F) during short term transportation period					
Humidity		20 to 90% Humidity (no condensation)					
Vibration		9.8 m/s² (1G) at less than 10 Hz; 5.9 m/s² (0.6G) 10 to 60 Hz					
Location		Altitude 1,000m or less, Keep from corrosive gases liquids or dust					
Watt Loss 100% (I)		34	57	77	111	185	255
Weight: (lb)		3.5	3.6	3.7	8.5	8.5	8.5
Dimensions (HxWxD) (mm)		151.0mm x 100.0mm x 140.5mm				220.0mm x 25.0mm x 189.5mm	
Accessories							
Line Reactor	**Single Phase**	GS-20P5-LR-1PH	GS-21P0-LR-1PH	GS-22P0-LR-1PH	GS-23P0-LR-1PH	N/A	N/A
	Three Phase	GS-20P5-LR-3PH	GS-21P0-LR-3PH	GS-22P0-LR-3PH	GS-23P0-LR-3PH	GS-25P0-LR	GS-27P5-LR
Braking Resistor		GS-20P5-BR	GS-21P0-BR	GS-22P0-BR	GS-23P0-BR	GS-25P0-BR	GS-27P5-BR
EMI Filter		20DRT1W3S			32DRT1W3C	40TDS4W4B	
Fuse Kit	**Single Phase**	GS-20P5-FKIT-1P	GS-21P0-FKIT-1P	GS-22P0-FKIT-1P	GS-23P0-FKIT-1P	N/A	N/A
	Three Phase	GS-20P5-FKIT-3P	GS-21P0-FKIT-3P	GS-22P0-FKIT-3P	GS-23P0-FKIT-3P	GS-20P5-FKIT	GS-27P5-FKIT
Replacement Fuses	**Single Phase**	GS-20P5-FUSE-1P	GS-21P0-FUSE-1P	GS-22P0-FUSE-1P	GS-23P0-FUSE-1P	N/A	N/A
	Three Phase	GS-20P5-FUSE-3P	GS-21P0-FUSE-3P	GS-22P0-FUSE-3P	GS-23P0-FUSE-3P	GS-25P0-FUSE	GS-27P5-FUSE
Spare Keypad, GS2 Series Drive		GS2-KPD					
Keypad Cable, GS2 Series, 1 meter		GS-CBL2-1L					
Keypad Cable, GS2 Series, 3 meter		GS-CBL2-3L					
Keypad Cable, GS2 Series, 5 meter		GS-CBL2-5L					
Ethernet Communications module for GS2 Series Drives (DIN rail mounted)		GS-EDRV					

GS2 Specifications — Installation

Understanding the installation requirements for your GS2 drive will help to ensure that it operates within its environmental and electrical limits.

Note: Never use only this desk reference for installation instructions or operation of equipment.



Environmental Specifications	
Protective Structure [1]	IP20
Ambient Operating Temperature [2]	-10 to 50°C (14°F to 122°F) - 10 to 40°C (14°F to 104°F) for models 7.5HP and higher
Storage Temperature [3]	-20 to 60°C (-4°F to 140°F)
Humidity	To 90% (no condensation)
Vibration [4]	5.9 m/S² (0.6G), 10 to 55 Hz
Location	Altitude 1,000 m or less, indoors (no corrosive gases or dust)

1: Protective structure is based upon EN60529

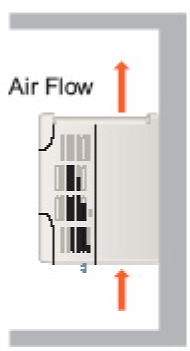
2: The ambient temperature must be in the range of -10° to 40° C. If the range will be up to 50° C, you will need to set the carrier frequency to 2.1 kHz or less and derate the output current to 80% or less. See our Web site for derating curves.

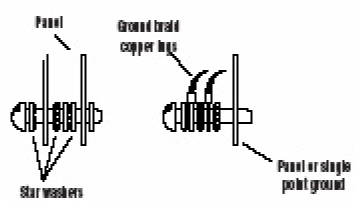
3: The storage temperature refers to the short-term temperature during transport.

4: Conforms to the test method specified in JIS C0911 (1984)

Warning: Maximum ambient temperatures must not exceed 50°C (122°F), or 40°C (104°F) for models 7.5Hp (5.5kW) and higher!

Watt-loss Chart	
GS2 Drive Model	*100% In**
GS2-20P5	34
GS2-21P0	57
GS2-22P0	77
GS2-23P0	111
GS2-25P0	185
GS2-27P5	255
GS2-41P0	73
GS2-42P0	86
GS2-43P0	102
GS2-45P0	170
GS2-47P5	240
GS2-4010	255

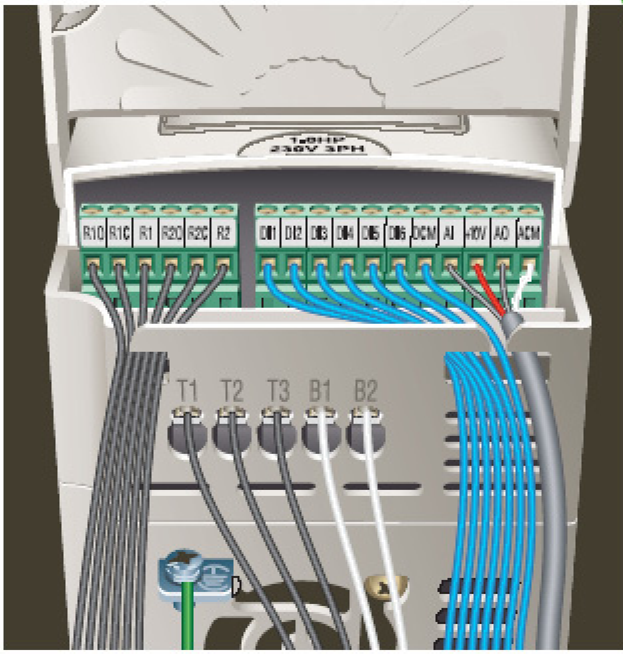


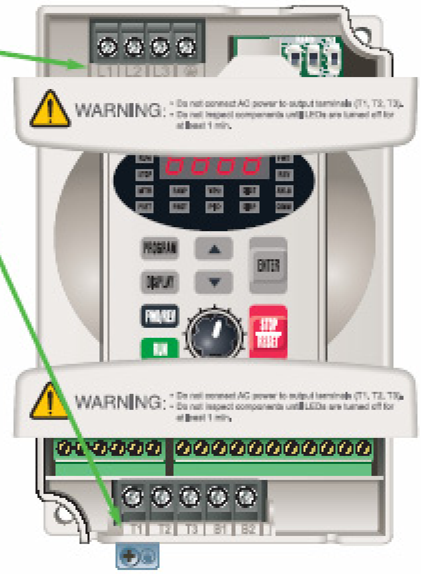


Warning: AC drives generate a large amount of heat which may damage the AC drive. Auxiliary cooling methods are typically required in order not to exceed maximum ambient temperatures.

GS2 SPECIFICATIONS — TERMINALS

Main Circuit Wiring	
Terminal	*Description*
L1, L2, L3	Input power
T1, T2, T3	AC drive output
B1, B2	DB resistor input
⏚	Ground



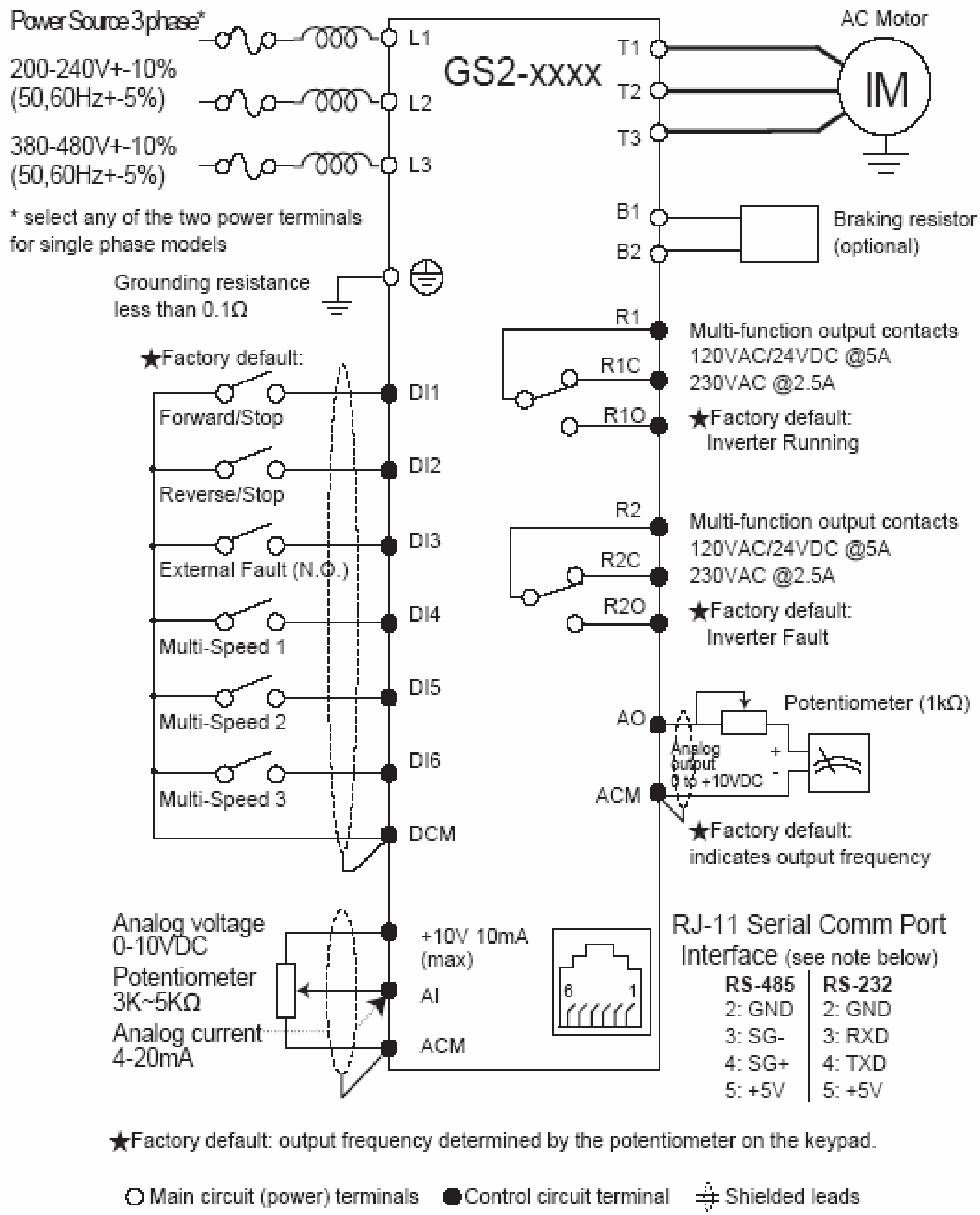


Control Circuit Terminals	
Terminal Symbol	*Description*
R1O	Relay output 1 normally open
R1C	Relay output 1 normally closed
R1	Relay output 1 common
R2O	Relay output 2 normally open
R2C	Relay output 2 normally closed
R2	Relay output 2 common
DI1	Digital input 1
DI2	Digital input 2
DI3	Digital input 3
DI4	Digital input 4
DI5	Digital input 5
DI6	Digital input 6
DCM	Digital common
AI	Analog input
+10V	Internal power supply (DC 10V)
AO	Analog output
ACM	Analog common

***Note:** Use twisted-shielded, twisted-pair or shielded-lead wires for the control signal wiring. It is recommended to run all signal wiring in a separate steel conduit. The shield wire should only be connected at the drive. Do not connect shield wire on both ends.*

GS2 Specifications — Basic Wiring Diagram

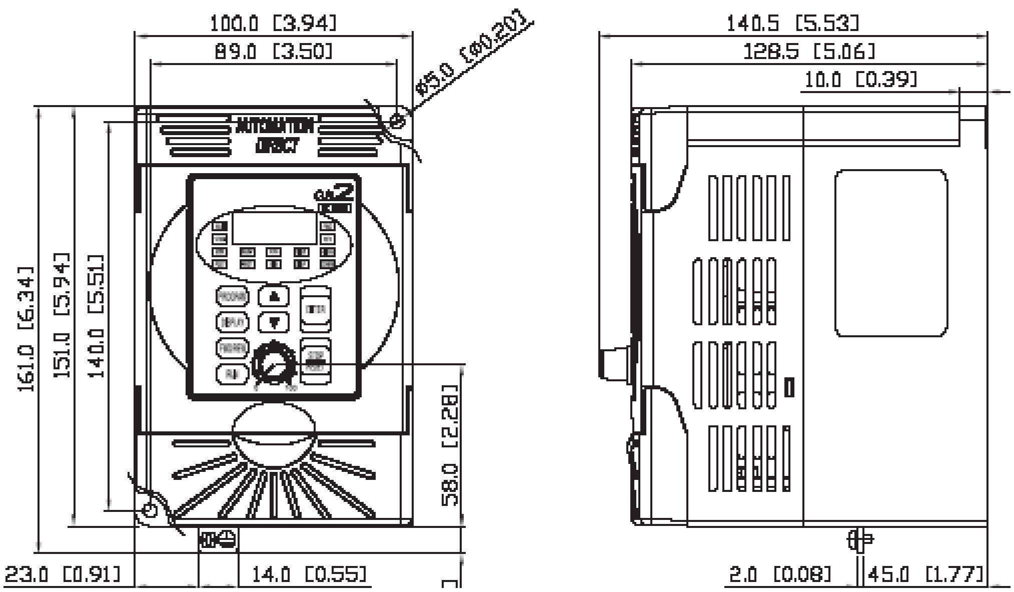
Note: Users MUST connect wiring according to the circuit diagram shown below.



Warning: Do not plug a modem or telephone into the GS2 RJ-11 Serial Comm Port, or permanent damage may result. Terminals 2 and 5 should not be used as a power source for your communication connection.

GS2 Specifications — Dimensions

GS2-20P5, GS2-21P0, GS2-22P0, GS2-23P0, GS2-41P0, GS2-42P0, GS2-43P0



GS2-25P0, GS2-27P5, GS2-45P0, GS2-47P5, GS2-4010

Appendix 8: PS24-075D 24VDC Power Supply Specifications

This appendix contains the specifications and dimensions of the PS24-075D +24VDC power supply used on the Sensor Pallet to power up the proximity sensors and as the operator pendant input signal. This device and further information is available from Automation Direct [31].

PS Series Power Supplies Specifications

PS24-075D

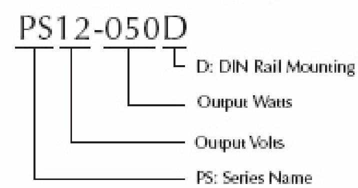
Note: All specifications are valid at nominal input voltage, full load and +25°C after warmup time, unless otherwise stated.

Input Specifications							
Part Number	Input Voltage Range	Input Frequency Range	Input Current (Typical)		Inrush Current (<2mS)		Efficiency (Typ.)
			115VAC	230VAC	115VAC	230VAC	
PS24-075D	93-132VAC 187-264VAC *(switch selectable)*	47-63Hz	1.7A	0.9A	<16.5A	<33A	

Output Specifications									
Part Number	Price	Output Voltage	Output Voltage Adj. Range	Output Current (Max.)	Output Power (Max.)	Output Voltage Regulation*	Hold-Up Time		MTBF (IEC 1709 @ 25°C)
							115VAC	230VAC	
PS24-075D	$80.00	24VDC	24-28VDC	3.0A	75W	1%	25mS	30mS	1,800,000 hours
*Load variation (10-90%)				*Notes: Output current characteristic suitable for battery charging applications. Not recommended for redundancy or parallel operation.*					

General Specifications	
Temperature	Operating (ambient) -25°C to + 70°C max Derating above 50°C 2%/C Storage (non-operating) -25°C to + 85°C max Temperature drift 0.02%/C
Humidity	95% (non-condensing) relative humidity max
Output Regulation	Input variation: ± 0.2% max Load variation: 50W, 75W, 150W models: ± 1% max 300W, 500W, 600W models: ± 0.3% max
Output Voltage Ripple	<50 mV peak-peak (20 MHz bandwidth)
Output Protection	Current limit 110% maximum output rating Voltage limit: 140% Vout nom
Vibration	1gn 20 sweeps each axis
Shock	15gn, 11mS each axis
Enclosure Rating	IP 20
Enclosure Material	Aluminum (chassis) / stainless steel (cover)
Mounting	Snap-on with self-locking spring for 35mm DIN rails
Connection	Removable screw terminals for 22-10 AWG
Agency Approvals	UL/cUL 60950 recognized UL/cUL 508 listed UL/cUL 1604 listed (Class 1, Div 2, groups A,B,C, and D hazardous locations), except PSxx-060 and PS24-500D, which are not UL/cUL1604 listed.
Note: All specifications are valid at nominal input voltage, full load and +25°C after warmup time, unless otherwise stated.	

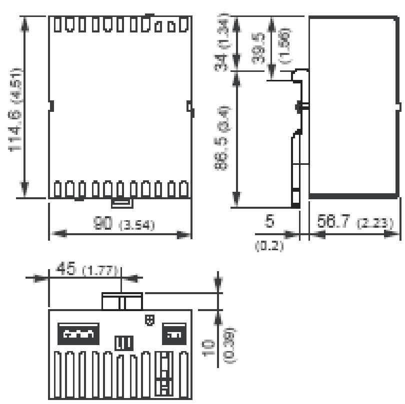
Part numbering system



PS Series Power Supplies Dimensions

Note: All dimensions are in millimeters (inches).

PS12-075D, PS24-075D



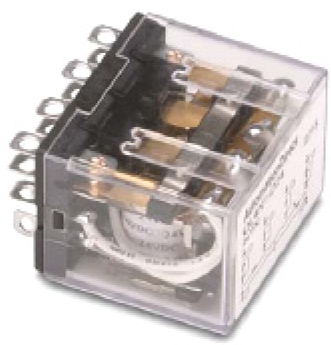
Appendix 9: QL2X1-D24 Series Relays Specifications

This appendix contains information for the QL2X1-D24 relay used in the implementation of the control circuit on the Sensor Pallet. This includes coil and contact specifications, wiring diagrams, derating curves, and dimensions of the device. This component and further information is available from Automation Direct [33].

Electro Mechanical Relay Selection Guide

Specification	QL Series
Coil Voltages	110/120VAC, 220VAC, 24VDC
Configuration	2PDT, 4PDT
Contact Rating	10A
Base Socket	8 or 14 pin spade terminal
Agency Approvals	UL Recognized (#E222847), CE Certified (9667186-9811), CSA Approval pending
Pricing	Starting at $7.00

QL Series Electro Mechanical Relay Selection Guide



QL series relays are general purpose relays designed for a wide range of applications, from power to sequence controls in various factory machines and control panels. They are ideal for electric control panels requiring stable and reliable relays.

Features

- Small package design
- ARC Barrier equipped
- Silver Cadium Oxide contact
- High dielectric strength (1,800 VAC)
- High reliability and long life
- Ultra-high sensitivity with quick response time (25 ms max.)
- High vibration and shock resistance
- LED indicator on all models, so you can easily see if relay is working properly without using a voltmeter
- Diode protection available on 24 VDC models, which protects contacts and electronic components from back EMF
- UL recognized, CE certified, CSA approval pending
- DPDT and 4PDT models

• *Order socket separately*

QL Series Selection Guide								
Part Number	*Price*	*Coil Voltage*	*Configuration*	*Contact Rating*	*Dimensions*	*Relay Socket Part Number*	*Price*	*Dimensions*
QL2X1-D24	$9.00	24VDC	2PDT	10A	Figure 1	*SQL08D*	$3.00	Figure 3

QL Series Electro Mechanical Relay Specifications

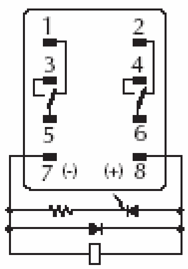
Part Numbers	QL2X1-D24
Contact Specifications	
Current Rating	10A
Contact Type	DPDT
Terminal Type	Spade Plug-In Socket
Rated Max. Resistive Load	10A@110VAC/10A@24VDC
Rated Max. Inductive Load	7.5A@110VAC/ 5A@24VDC
Max. Switching Cap. (Resistive Load)	1,100VA; 240W
Max. Switching Cap. (Inductive Load)	825VA, 120W
Max. Contact Rating	250VAC/ 125VDC
Coil Specifications	
Options	LED Indicator/Diode Protection
Coil Input Voltage	24VDC
Rated Current at 50Hz	36.9mA
Rated Current at 60Hz	36.9mA
Coil Resistance	650Ω
Power Consumption	Approx. 0.9W
Dropout Voltage (% of rated voltage)	Min. 10%
Pick-Up Voltage (Must operate voltage)	Max. 80% of the rated coil voltage
Max. Voltage (Max. continuous voltage)	110% of the rated coil voltage
Min. Operating Voltage	80% of the rated coil voltage

General Specifications	
Service Life	Mechanical: AC: Min. 50 million operations; DC: Min. 100 million operations (at operating frequency of 18,000 operations/hour)
	Electrical: DPDT: Min. 500k operations; 4PDT: Min. 200k operations (at operating frequency of 1,800 operations/hour)
Operate Time	25ms max
Release Time	25ms max
Ambient Temperature	-25° C to 70° C (-13° F to 158° F)
Ambient Humidity	45% RH to 85% RH
Contact Material	Silver Cadium Oxide
Contact Resistance	50mΩ max.
Operating Frequency	Mechanical 18,000 operations/hour, Electrical 1,800 operations/hour
Vibration Resistance	10Hz to 55Hz at double amplitude of 1.0mm
Shock Resistance	1,000m/s² (approx. 100G)
Weight	35g (1.24oz.)
Agency Approvals and Standards	UL Listed (#E150950), CE Certified (9667186-9811), CSA Certified

QL Series Wiring Diagrams and Derating Curves

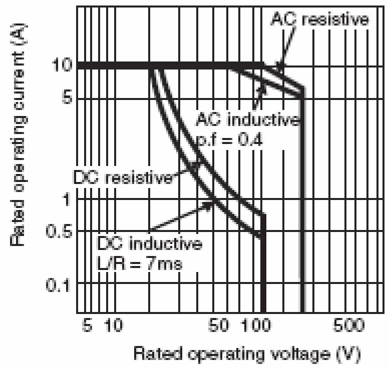
Wiring Diagrams

QL2X1-D24



Derating Curves DPDT

Max. Switching capacity

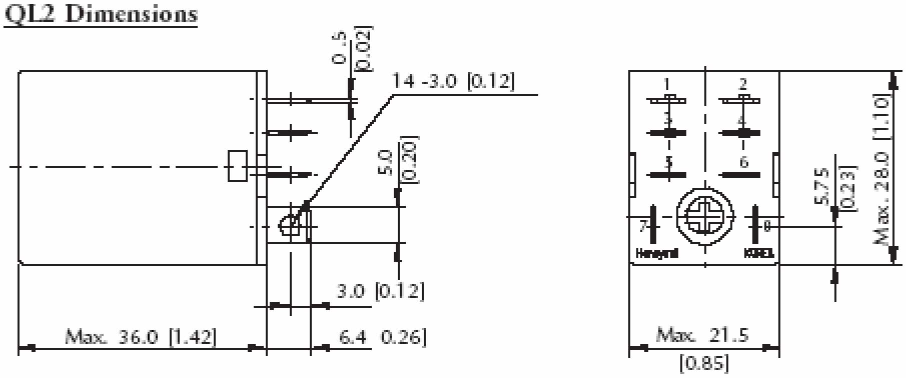


QL DPDT

QL Series Dimensional Drawings

Mounting dimensions (mm/in)

Figure 1
QL2 Dimensions



Appendix 10: ABM6E42Z11 Mechanical Limit Switch Specifications

This appendix contains information for the ABM6E42Z11 mechanical limit switches used in the implementation of the control circuit on the Sensor Pallet. This includes specifications of the switch and the contact blocks and how the actuator may be adjusted for the user's needs. This device and further information is available from Automation Direct [47].

CENTSABLE™ IEC LIMIT SWITCHES

ABM series heavy-duty IEC limit switches

- Featuring a die-cast aluminum body for heavy-duty industrial applications
- Single and multiple conduit openings to save wiring time and money when interconnecting several limit switches
- Conduit openings in 1/2" NPT or PG13.5
- Splined actuator shaft allows very fine adjustment of switch to fit all applications
- Choose from eight different actuators including roller levers and plungers
- Choose from six interchangeable combinations of contact blocks

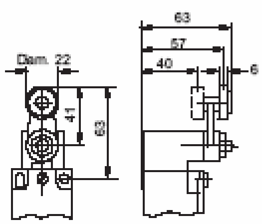
ABM Series					
Part Number	*Price*	*Actuator Type*	*Number of Conduit Openings*	*Conduit Threads*	*Dimensions: Body / Head*
ABM6E42Z11	$34.00	Rotary lever with stainless steel roller (See accessories for optional roller and actuator levers)	Three cable holes	1/2" NPT threads	Figures 2, 8

CENTSABLE™ IEC LIMIT SWITCHES DIMENSIONS

Switch body dimensions

Dimensions are in millimeters. 25.4 mm = 1 inch
For example, 30 mm to inches = 30/25.4 = 1.181 inches.

Fig. 8: Side rotary with roller (ABM, ABP models)



CENTSABLE™ IEC CONTACT BLOCK SPECIFICATIONS

Approvals		
All: CENELEC EN 50041, CEI EN 60947-5-1 Plastic models: UL (508), CSA C22.2 No 14-M91		
Environmental		
Degree of Protection		Plastic models: IP65 according to IEC 529 Aluminum models: IP65 according to IEC 144-CEI70-1
Temperature Range		Plastic models: stocking: -30° to 80°C (-22° to 176° F) working: -25° to 70°C (-13° to 158°F) Aluminum models: stocking: -30° to 80°C (-22° to 176°F) working: -10° to 70°C (14° to 158°F); minimum temperatures assume that the atmosphere is free of moisture, which could cause moving parts to freeze up
Pollution Degree		3
Mechanical Ratings		
Working Positions		All (although some types of actuator, such as a long, heavy spring with the adjustable actuator fully extended, may not work properly if installed in a horizontal position) (Actuators can be rotated in 90° increments)
Mechanical Life		Straight line working heads: 30 million operations, side rotary heads: 25 million operations, multidirectional heads: 10 million operations
Enclosure Material		Plastic models: fiberglass-reinforced plastic-V0 class (UL94); aluminum models: die cast aluminum
Contact Blocks Rating		
Positive Opening*		Yes, all models
Maximum Switching Frequency		Contact blocks: all two cycles per second
Repeat Accuracy		0.01mm on the operating points at 1 million operations
Short-Circuit Protection		Cartridge fuses gl 10A-500V 10.3x38 1 100KA
Contact Resistance		≥ 25 milli ohms
Recommended Minimum Operating Speed		With snap-action contacts: 20 mm per minute** With slow-action contacts: 500 mm per minute***
Rated Insulation Voltage		660V
Terminals Marking		According to CENELEC EN 50013
Wiring Connections		2 x 2.5mm² (AWG14) to 2 x 0.5mm² (AWG18)
Wiring Terminal Type		Captive screw with self-lifting pressure plate
Wiring Terminal Markings		According to CENELEC EN50013
User Protection		Double insulation (plastic models only)
Contact Blocks Performance		
Operation Frequency		3600 ops/h
Working Factor		0.5
Usage Class	***AC15***	24VAC: 10A, 130VAC: 6.5A, 230VAC: 4A, 400VAC: 2.5A
	DC13	24VDC: 1.5A, 110VDC: 0.5A
Tools Needed		
Phillips screwdriver, #1 #2 / Hex wrench, 10mm		

* Positive opening is a snap-action contact block is performed by a rigid mechanism that forces the N.C. contact to open in case the snap action mechanism fails. This would provide protection if, for example, the contacts became "welded" together by excessive current rush. Generally, positive opening is not considered to work properly on switches with actuators that are not a solid design (such as a spring or rubber roller), despite the fact that the contact block itself has positive opening. In order to be considered as having positive opening, a switch must not have flexible components between actuator actioning points and the electrical contact.
** This is the speed at which snap-action contact blocks are tested. There is no minimum operating speed for snap-action contacts because the speed has no influence on the switch action. When using spring actuators, the change-over time may vary from 1 to 3 ms from max. to min. operating speed.
*** Slow-action contacts must not be operated at very low speeds because of the tendency to maintain the arc if contacts are not rapidly separated.

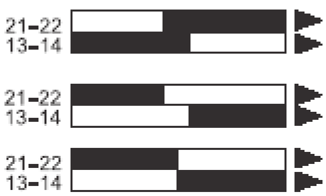
CENTSABLE™ IEC LIMIT SWITCHES BAR CHARTS

Bar charts

Limit switch types

Snap action contact: A contact element in which the contact motion is independent of the speed of the actuator. This feature ensures reliable electrical performance even in applications involving very slow moving actuators.

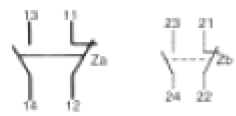
Slow make — slow break contacts: A contact element in which the contact motion is dependent on the actuator speed.



Terminal identification (IEC)

Each terminal is marked with two digits. The first digit indicates the pole (circuit). The second digit indicates the type of contact.

_1-_2 is N.C., _3-_4 is N.O., so 11-12, 21-22 are N.C., while 13-14, 23-24 are N.O.

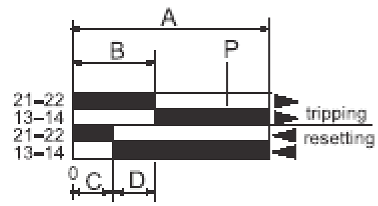


Make-before-break (overlapping) SPDT: the N.O. contact closes before the N.C. contact opens.

Break-before-make (offset) SPDT: the N.C. contact opens before the N.O. contact closes.

Simultaneous make and break SPDT: the N.C. contact opens at the same time as the N.O. contact closes.

Terminal Markings	
European	
Terminal No.	*Type*
11-12	N.C. contact of pole no. 1 [1]
13-14	N.O. contact of pole no. 2 [1]
21-22	N.C. contact of pole no. 2 [2]
13-14	N.O. contact of pole no. 1 [2]
[1] With non-isolated contacts	[2] With isolated contacts



= Contact open

= Contact closed

A = Max. travel of the operator in mm or degrees

B = Tripping travel of the contact

C = Resetting travel of the contact

D = Differential travel (B - C)

P = Point from which positive opening is assured

Appendix 11: CT1-AP-1A Proximity Sensor Specification

This appendix contains information for the CT1-AP-1A capacitive proximity sensors used in the implementation of Automatic mode on the Sensor Pallet. This includes general specifications, dimensions, and a wiring diagram for the device. This component and further information is available from Automation Direct [36].

CT Series M30 Capacitive Proximity Sensors

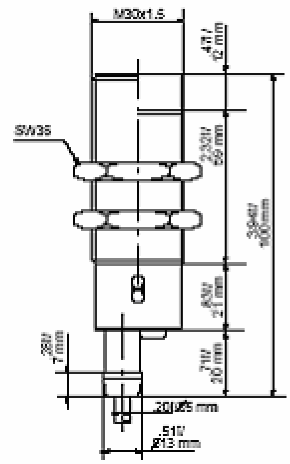
Capacitive proximity sensors: M30 (30mm) – DC

- 6 models available • Sensitivity adjustment with 20-turns trimmer
- Metal housing with axial cable
- Detects metallic and non-metallic objects
- Complete overload protection
- IP65 protection degree
- Double LED status indicators

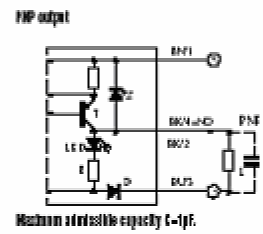
CT Series 30DC Capacitive Prox Sensor Selection Chart						
Part Number	**Price**	**Sensing Range**	**Housing**	**Output State**	**Logic**	**Connection**
CT1-AP-1A	$64.00	2 to 15mm (0.079-0.59in)	Shielded	N.O.	PNP	2m (6.5') axial cable

Specifications		
Type	Shielded	
Operating Distance	2-15mm (0.079-0.59in)	
Differential Travel	2 to 20%	
Repeat Accuracy	10%	
Operating Voltage	10-30VDC	
Ripple	≤10%	
No-load Supply Current	8mA	
Load Current	≤200mA	
Leakage Current	≤10µA	
Voltage Drop	1.8 volts maximum	
Output Type	NPN or PNP / N.O. or N.C. / 3 wire	
Switching Frequency	100Hz	
(tv) Time Delay Before Availability	100ms	
Input Voltage Transient Protection	Yes, only if transient peak does not exceed 30VDC	
Input Power Polarity Reversal Protection	Yes	
Output Power Short-Circuit Protection	Yes (switch autoresets after overload is removed)	
Temperature Range	-25° to +70° C (-13° to 158° F)	
Temperature Drift	20% Sr	
Protection Degree (DIN 40050)	IEC IP65	
LED Indicators	Green (supply, Red (N.O. output energized)	
Housing Material	Nickel-plated brass	
Sensing Face Material	PBT	
Tightening Torque	100Nm (73.7lb./ft.)	
Weight (cable/connector)	280g (19.88oz)	

Dimensions



Wiring diagrams



Appendix 12: CLN-50 Current Sensor Specifications

This appendix contains information about the CLN-50 Hall Effect current sensor used in the implementation circuit of Automatic mode on the Sensor Pallet. Though these data sheets shown here include the CLN-100, only the CLN-50 was used in the system. This device and further information is available from F.W. Bell [37].

Model CLN-50/100 — Closed Loop Hall Effect

Description

Models CLN-50 and CLN-100 are closed loop Hall effect current sensors that accurately measure DC and AC currents and provide electrical isolation between the current carrying conductor and the output of the sensor.

Features

- Noncontact measurement of high current
- Measures DC, AC and impulse currents
- Current sensing up to 400A peak
- Very fast response and high accuracy
- High overload capacity
- PC board mount
- Solid core with aperture

Applications

- Variable speed drives for motors
- Welding Equipment
- Power supply Equipment
- Measure and control system
- Over current protection
- Protection of power semiconductors

Electrical Specifications

	CLN-50		CLN-100	
Nominal current (I_N)	50 A rms		100 A rms	
Measuring range	0 to ±90A		0 to ±150A	
Sense resistor	R. min.	R. max.	R. min.	R. max.
with ±12V at ± 70 A peak	50 ohms	90 ohms	n/a	n/a
at ±100 A peak	n/a	n/a	30 ohms	55 ohms
at ±150 A peak	n/a	n/a	10 ohms	25 ohms
with ±15V at ± 90 A peak	70 ohms	100 ohms	n/a	n/a
at ±100 A peak	n/a	n/a	30 ohms	85 ohms
at ±150 A peak	n/a	n/a	30 ohms	40 ohms
Nominal analog output current	50 mA		100 mA	
Turns ratio	1:1000			
Overall accuracy at 25 C and ±12V	±0.9% of I_N			
Overall accuracy at 25 C and ±15V	±0.5% of I_N			
Supply voltage (Vdc)	±12 to ±15(±5%)			
Dielectric strength (between the current carrying conductor and the output of the sensor)	3 kV rms/50 Hz/1 min.			

Accuracy-Dynamic Performance

Zero current offset at 25°C	±0.2 mA max.
Offset current temperature drift	
between 0°C and +70°C	±0.3 mA typ., ±0.5 mA max.
between -25°C and +85°C	±0.3 mA typ., ±0.8 mA max.
Linearity	better than ±0.1%
Response time	less than 500ns
di/dt accurately followed	better than 100 A/µs
Bandwidth	0 to 150 kHz (-1dB)

General Information

	CLN-50	CLN-100
Operating temperature	-40°C to +85°C	
Storage temperature	-40°C to +90°C	
Current drain (plus output current)	10 mA (at ±15V)	14 mA (at ±15V)
Coil resistance at +70°C	30 ohms	
Package	Flame retardant plastic case	
Weight	18 grams	21 grams
Mounting	Designed to mount on PCB via thru hole connection pins	
Aperture	0.531" x 0.394" (13.5 mm x 10 mm)	
Output reference	To obtain a positive output on the terminal marked "O/P", aperture current must flow in the direction of the arrow (conventional flow)	

Notes:
- The temperature of the current carrying conductor should not exceed 90°C.
- Contact F.W. Bell for other models.
- Due to continuous process improvement, specifications are subject to change without notice

SYPRIS
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F.W. BELL

Rev. date 04/2003

Appendix 13: D0-06DD2 Programmable Logic Controller Specifications

This appendix contains general information about the D0-06DD2 programmable logic controller used in the implementation of Automatic mode on the Sensor Pallet. This includes specifications and wiring diagrams for the device, as well as diagrams of the each input and output available on the device; programming specifications for this PLC is covered elsewhere. This component, accessories, and further information are available from Automation Direct [39].

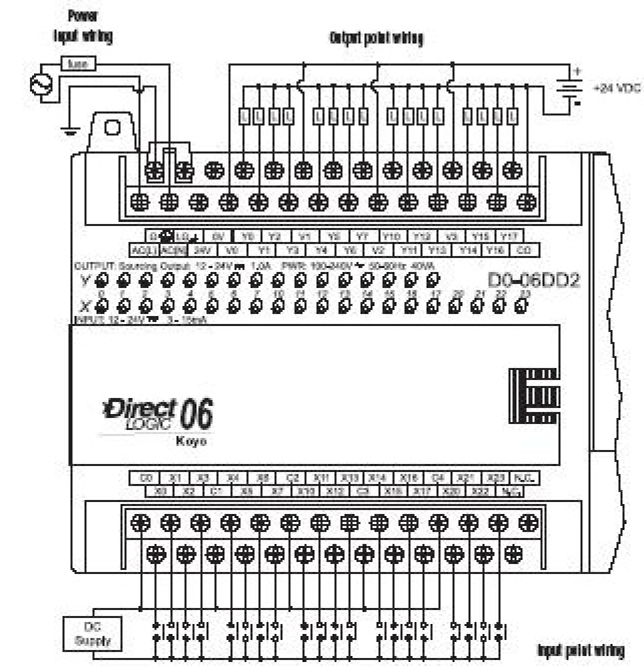
DL06 I/O Specifications

D0-06DD2 $199.00

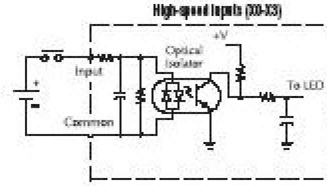
Wiring diagram and specifications

D0-06DD2 Specifications			
AC Power Supply Specifications	***Voltage Range***	95-240VAC (30VA)	
DC Input Specifications	***Number of Input Pts.***	20 (sink/source)	
	Number of Commons	2 (isolated)	
	Input Voltage Range	12-24VDC	
	Input Impedance	(X0-X3) 1.8K @ 12-24VDC (X4-X7) 2.8K @ 12-24VDC	
	On Current/ Voltage Level	>5mA/10VDC	
	OFF Current/ Voltage Level	<0.5mA/<2VDC	
	Response Time	X0-X3	X4-X23
	OFF to ON Response	<100µs	<8ms
	ON to OFF Response	<100µs	<8ms
	Fuses	None	
DC Output Specifications	***Number of Output Points***	16 (sourcing)	
	Number of Commons	4 isolated	
	Output Voltage Range	12-24VDC	
	Peak Voltage	30VDC	
	Max.Frequency (Y0,Y1)	7kHz	
	ON Voltage Drop	0.3VDC @ 1A	
	Maximum Current	0.5A / pt (Y0-Y1)* 1.0A pt (Y2-Y17)	
	Maximum Leakage Current	15µ @ 30VDC	
	Maximum Inrush Current	2A for 100ms	
	OFF to ON Response	<10µs	
	ON to OFF Response	<20µs (Y0-Y1) <0.5ms (Y2-Y17)	
	External DC Power Required	20-28VDC 150mA max.	
	Status Indicators	Logic side	
	Fuses	None (external recommended)	

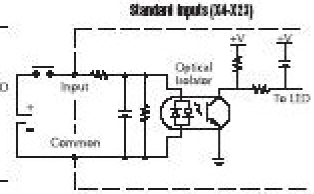
*When Y0-Y1 are not used for pulse outputs, maximum current output is 1.0A.



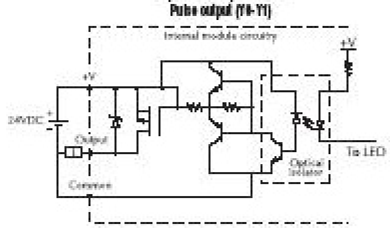
Equivalent input circuit, High-speed inputs (X0-X3)



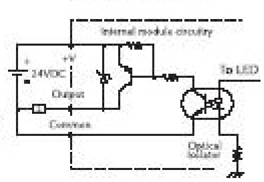
Equivalent input circuit, Standard inputs (X4-X23)



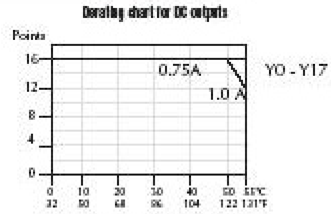
Equivalent output circuit Pulse output (Y0-Y1)



Equivalent output circuit Standard output (Y2-Y17)



Derating chart for DC outputs



Appendix 14: F0-04AD-1 Analog Input Module Specifications

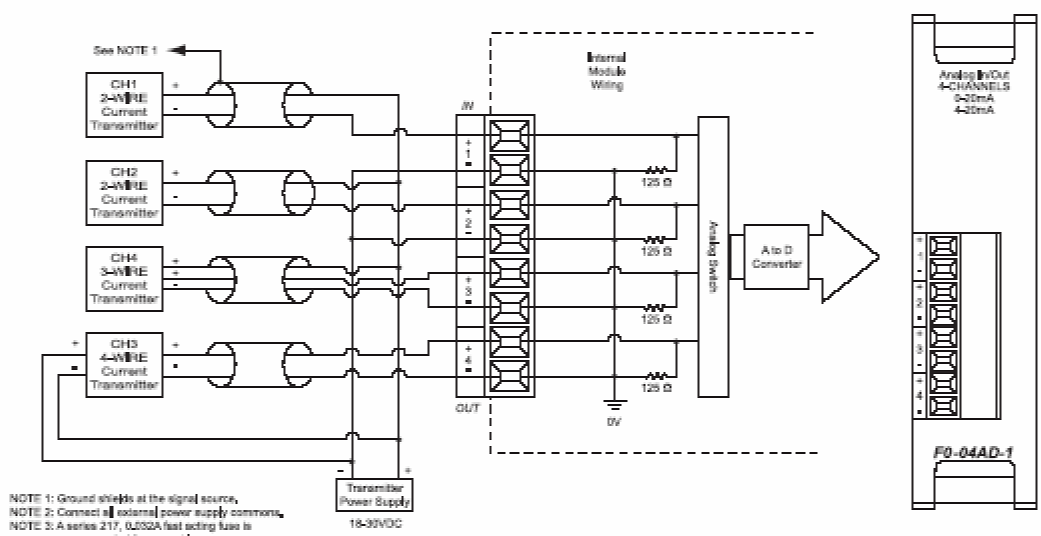
This appendix contains information for the 4-channel F0-04AD-1 analog input module used in conjunction with the D0-06DD2 PLC. This includes input specifications and wiring diagrams for the device. This component and further documentation is available from Automation Direct [48].

DL05/06 Option Modules

F0-04AD-1 $79.00

4-channel analog input module

Input Specifications	
Number of Channels	4, single ended (one common)
Input Range	0 to20mA or 4 to 20mA (jumper selectable)
Resolution	12 bit (1 in 4096)
Step Response	25.0mS (typ.) to 95% of full step change
Crosstalk	1/2 count max (-80db)
Active Low-pass Filtering	-3dB at 40Hz (-12dB per octave)
Input Impedance	125Ω ±0.1%, 1/8 watt
Absolute Max Ratings	-30mA to +30mA, current input
Converter Type	Successive approximation
Linearity Error (end to end)	±2 counts
Input Stability	±1 count*
Full-scale Calibration Error	±10 counts max. @ 20mA*
Offset Calibration Error	±5 counts max. @ 4mA*
Max Inaccuracy	±0.4% at 25°C (77°F) ±0.85% at 0 to 60°C (32 to 140°F)
Accuracy vs. Temperature	±100 ppm/°C typical
Recommended Fuse	0.032A, series 217 fast-acting, current inputs



Appendix 15: D0-08CDD1 Digital Output Module Specifications

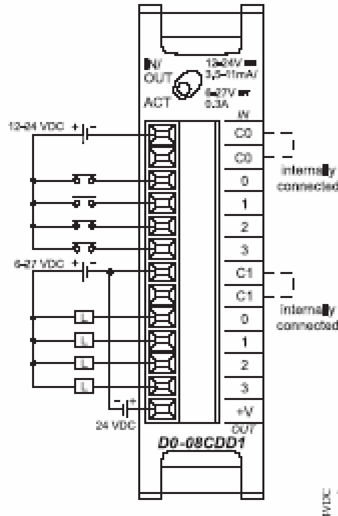
This appendix contains information for the D0-08CDD1 digital input/output module used in conjunction with the D0-06DD2 PLC. Though this specification includes both the input and output specifications, only the outputs were used in the system. This device and further information is available from Automation Direct [45].

DL05/06 I/O Option Modules

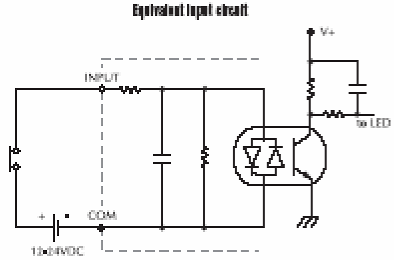
D0-08CDD1 $50.00

4-point DC input and
4-point DC output module

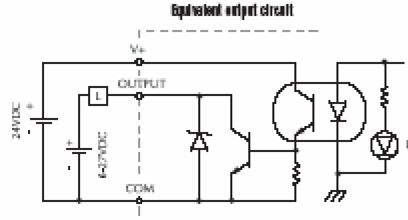
D0-08CDD1 Input Specifications	
Number of Inputs	4 (sink/source)
Input Voltage Range	12-24VDC
Operating Voltage Range	10.8-26.4VDC
Peak Voltage	30.0VDC
Input Current	Typical: 4.0mA @ 12VDC 8.5mA @ 24VDC
Maximum Input Current	11mA @ 26.4VDC
Input Impedance	2.8KΩ @ 12-24VDC
On Voltage Level	> 10.0 VDC
Off Voltage Level	< 2.0 VDC
Minimum ON Current	3.5mA
Maximum OFF Current	0.5mA
Off to On Response	2-8ms, Typ. 4ms
On to Off Response	2-8ms, Typ. 4ms
Commons	2 non-isolated (2 points/common)



Equivalent input circuit

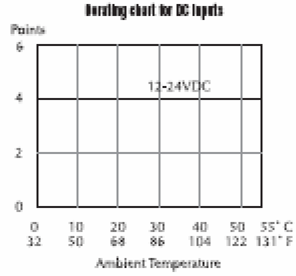


Equivalent output circuit

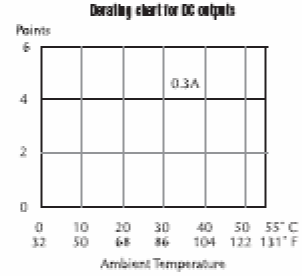


D0-08CDD1 Output Specifications	
Number of Outputs	4 (sinking)
Operating Voltage Range	6-27VDC
Output Voltage Range	5-30VDC
Peak Voltage	50.0VDC
Maximum Output Current	0.3A/point, 1.2A/common
Minimum Output Current	0.5mA
Maximum Leakage Current	1.5μA @ 30.0VDC
On Voltage Drop	0.5VDC @ 0.3A
Maximum Inrush Current	1A for 10ms
Off to On Response	< 10μs
On to Off Response	< 60μs
Status Indicators	Module activity: one green LED
Commons	2 non-isolated (2 points/common)
Fuse	No fuse
Base Power Required (5V)	Max. 200mA (all pts. on)
External DC Power Required (24V)	20-28VDC, max. 80mA (all pts. on)

Derating chart for DC inputs



Derating chart for DC outputs



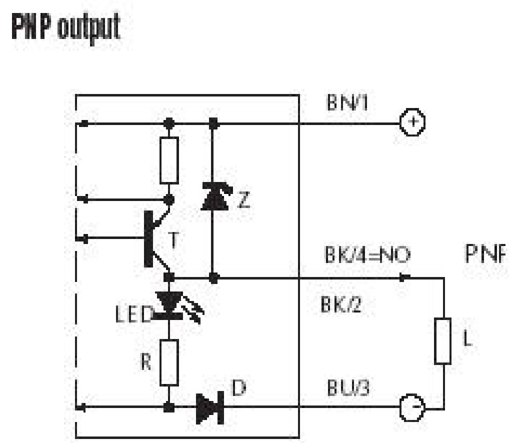
Appendix 16: Quick Troubleshooting Handbook for Project Oculus

This appendix is a quick troubleshooting handbook that can be used as a reference for the electrical engineer working on Project Oculus. It should be used in conjunction with the circuit diagrams presented in appendices 4 and 6. Included here are:

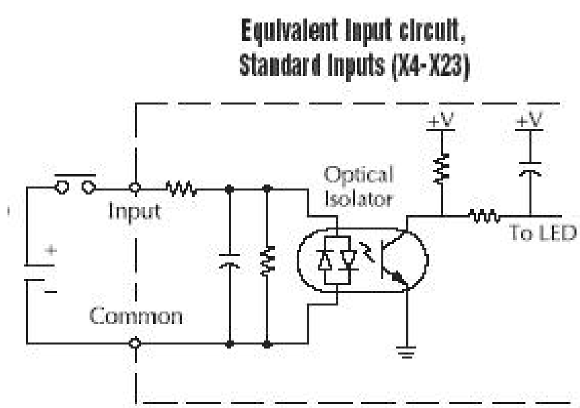
(1) GS2-22P0 Motor Controller Program Table: For Project Oculus to operate correctly, the GS2-22P0 should have these values set for each program listed in the table.
(2) CT1-AP-1A Proximity Sensor Equivalent Output Circuit: Output circuit for the proximity sensors used on the Sensor Pallet.
(3) D0-06DD2 Equivalent Input Circuit: Input circuit for the D0-06DD2 PLC normal inputs. Inputs should be connected as illustrated there.
(4) D0-06DD2 Equivalent Output Circuit: Output circuit for the D0-06DD2 PLC normal outputs. Outputs should be connected as illustrated there.
(5) D0-06DD2 General Wiring Diagram: Illustration showing a general wiring diagram for the D0-06DD2 PLC.
(6) CLN-50 to F0-04AD-1 Analog Input Module Circuit: Diagram of the circuit connecting the CLN-50 current sensor output to the F0-04AD-1 analog input module input.
(7) D0-08CDD1 Equivalent Output Circuit: Output circuit for the D0-08CDD1 input/output module used with the D0-06DD2 PLC. Only the outputs on this module are used, so that is the only circuit shown here. The outputs should be connected as illustrated there.
(8) D0-06DD2 PLC LCD Messages: Table showing the possible LCD messages that will appear on the LCD screen of the D0-06DD2 PLC while in Automatic mode operation and what they mean to the user.
(9) D0-06DD2 PLC Input/Output Map: Table showing all possible inputs and outputs for the D0-06DD2 PLC and where these inputs and outputs are mapped to in the system.

GS2-22P0 Motor Controller Programs

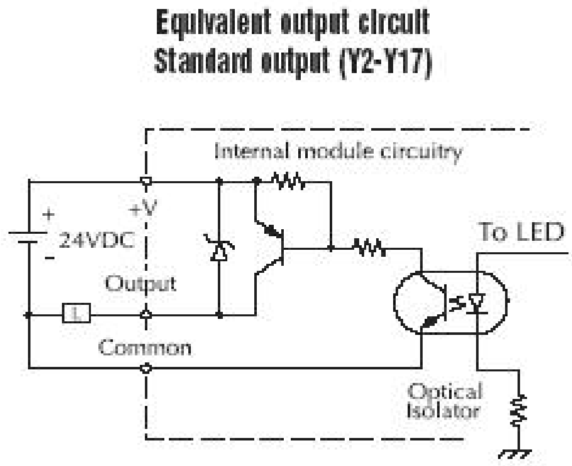
Program	Value
P 0.00 Motor Nameplate Voltage	220 V
P 0.02 Motor Base Frequency	60 Hz
P 0.03 Motor Base RPM	1750 RPM
P 0.04 Maximum Motor RPM	1800 RPM
P 1.00 Stop Methods	00 (Ramp to Stop)
P 1.01 Acceleration Time	5.0 seconds
P 1.02 Deceleration Time	0.1 seconds
P 3.00 Source of Operation Command	01 (Operation determined by external control terminals. Keypad STOP is enabled.)
P 3.01 Multi-Function Input Terminals	00 DI1 – FWD/STOP DI2 – REV/STOP



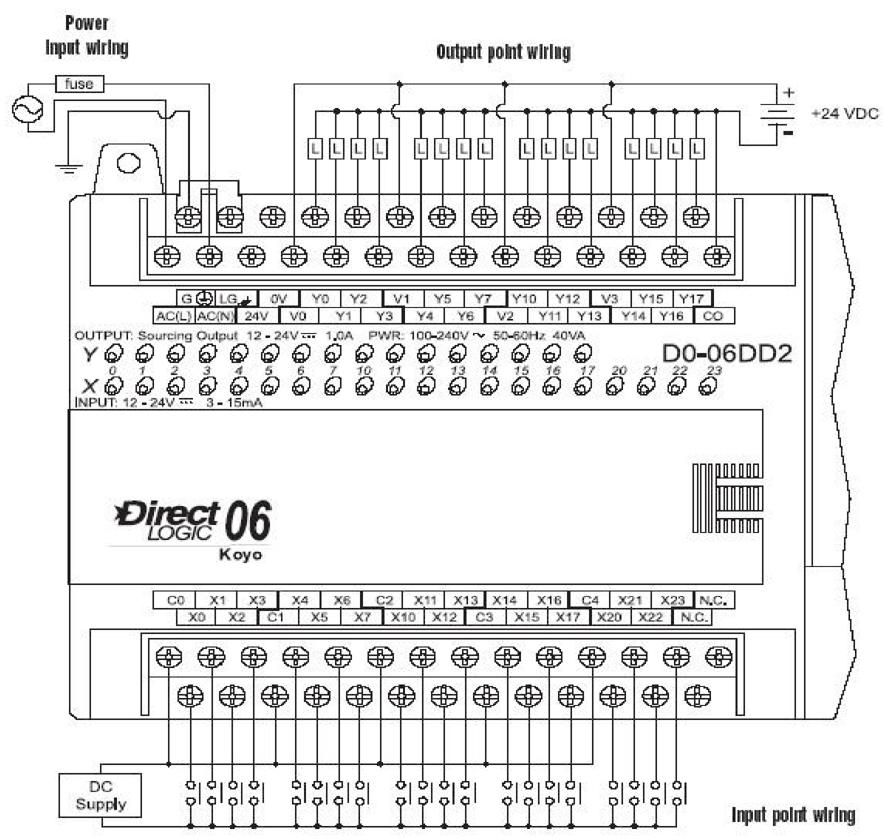
CT1-AP-1A Proximity Sensor Equivalent Output Circuit [36]



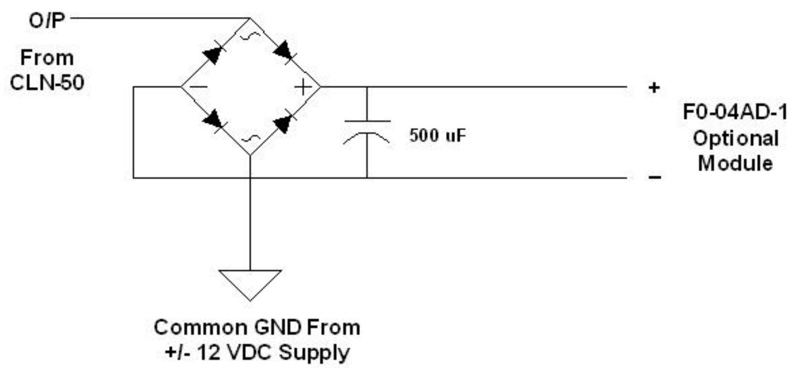
Equivalent Input Circuit on the D0-06DD2 PLC [39]



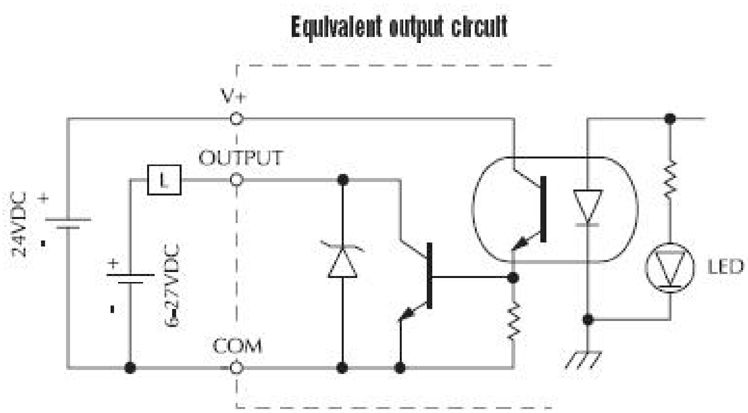
Equivalent Output Circuit on the D0-06DD2 PLC [39]



D0-06DD2 PLC General Wiring Diagram [39]



Current Sensor to F0-04AD-1 Analog Input Module Circuit



Equivalent Output Circuit for the D0-08CDD1 [45]

D0-06DD2 PLC LCD Messages

LCD Message	Meaning
"Fully Stowed"	Translating plate and rotating arm are in their resting positions
"E: Button Push"	Error: Extend and Stow button have been pushed simultaneously, which should not occur
"Extend Button"	Extend Button has been pressed
"Translating Out"	The translating plate is translating outward
"Rotating Out"	The rotating arm is rotating outward
"Translating Back"	The translating plate is translating backward
"Fully Extended"	Current Sensor has been tripped, should mean that the Sensor Pod has been pulled up tightly against the butt plate on the door
"Stow Button"	Stow Button has been pressed
"Rotating In"	The rotating arm is rotating inward

D0-06DD2 PLC Input/Output Map

Inputs		Outputs	
Input Point	**Status**	**Output Point**	**Status**
X0	Not Used – High Speed Input	Y0	Not Used – Pulse Output
X1	Not Used – High Speed Input	Y1	Not Used – Pulse Output
X2	Not Used – High Speed Input	Y2	Not Used
X3	Not Used – High Speed Input	Y3	Not Used
X4	Extend Button	Y4	Not Used
X5	Stow Button	Y5	Not Used
X6	Rotation Extend Sensor	Y6	Translate Operate LED Indicator
X7	Rotation Stow Sensor	Y7	Not Used
X10	Translation Extend Sensor	Y10	Not Used
X11	Translation Stow Sensor	Y11	Rotate Operate LED Indicator
X12	Not Used	Y12	Not Used
X13	Not Used	Y13	Automatic Mode LED Indicator
X14	Not Used	Y14	Not Used
X15	Not Used	Y15	Not Used
X16	Not Used	Y16	R-TCCW Relay
X17	Not Used	Y17	R-TCW Relay
X20	Not Used	Y100	GS2-22P0 DI2
X21	Not Used	Y101	GS2-22P0 DI1
X22	Not Used	Y102	Not Used
X23	Not Used	Y103	Not Used

Curriculum Vitae

Robert P. Hayes

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Keyser, WV 26726

(304) 298-3709
robertwvu@hotmail.com

Objective

To obtain a full-time position in the computer/electrical engineering field, continuing my experience of working on exciting R&D projects that make a difference in society

Education

West Virginia University, Morgantown, WV

Master of Science in Electrical Engineering, emphasis in Digital Systems, Certificate in Computer Forensics

- Thesis: "Control System Design for a C-130 Ro-Ro Sensor Deployment Platform"
- Expected graduation August 2004
- Graduate GPA: 3.78/4.00
- Relevant Courses: Computer/Data Forensics, Information Technology Auditing, Law and Privacy, Fault Tolerant Computing, Information Theory, Computer Systems Architecture, Computer Networking

Bachelor of Science in Computer Engineering, May 2002
Bachelor of Science in Electrical Engineering, May 2002
Computer Science Minor, May 2002

- Undergraduate GPA: 3.77/4.00, Magna Cum Laude
- Relevant Courses: Communication Systems, Biometrics, Fiber Optics, Digital Image Processing

Computer Skills

C, C++, PSpice, Matlab, Ada, Xilinx, Word, Excel, PowerPoint, Access, Visual Basic 6.0, Visio, Internet Explorer
Have built numerous computers, programmed PLC's and PIC chips

Employment History & Projects

Graduate Research Assistant, WVU, Morgantown, WV June 2002 – May 2004

1. Worked on DoD/National Guard funded project called Project Oculus with Dr. Jim Smith and Dr. Roy Nutter
- Palletized system consisting of an operator station and surveillance sensor deployment system onboard C-130
- Designed power distribution for the system
- Circuit design to control sensor pod deployment operation
- Programmed a Programmable Logic Controller (PLC) to control automatic mode of sensor pod deployment

2. Automatic analysis of EEG data to classify the sleep state of a rat with Dr. Stephanie Schuckers
- Wrote the analysis program in Matlab

Stockman, Wal-Mart, LaVale, MD June 1999 - May 2003
- Customer service: helped customers locate desired items and lift heavy merchandise
- Brought shopping carts into the store for customer use

Senior Design Project: Video On Demand (August 2001 – May 2002)
- System allows user to search database of movies on a server and download the movie file via cable modem
- User can play back the movie with functions such as pause, stop, fast-forward, and rewind with remote control
- Designed all user interfaces and MS Access database front ends using Visual Basic 6.0

Professional Associations

Eta Kappa Nu, Inducted April 2000 (Treasurer, August 2000 – May 2002) – Electrical Engineering Honor Society
Golden Key National Honor Society, Inducted April 1999
National Society of Collegiate Scholars, Inducted April 1999
WVU Honors Program (August 1998 – May 2002)

Scholarships/Awards

Presidential Scholarship (August 1998 – May 2002) – Paid full tuition for four years
Edwin C. Jones Scholarship (August 2000 – May 2002) – Awarded from the CSEE department at WVU
The National Dean's List (April 1999)
Valedictorian, Frankfort High School, Ridgeley, WV, Class of 1998

References Available Upon Request