Project Report
For
Nutrient Injection System Specialists (NISS)

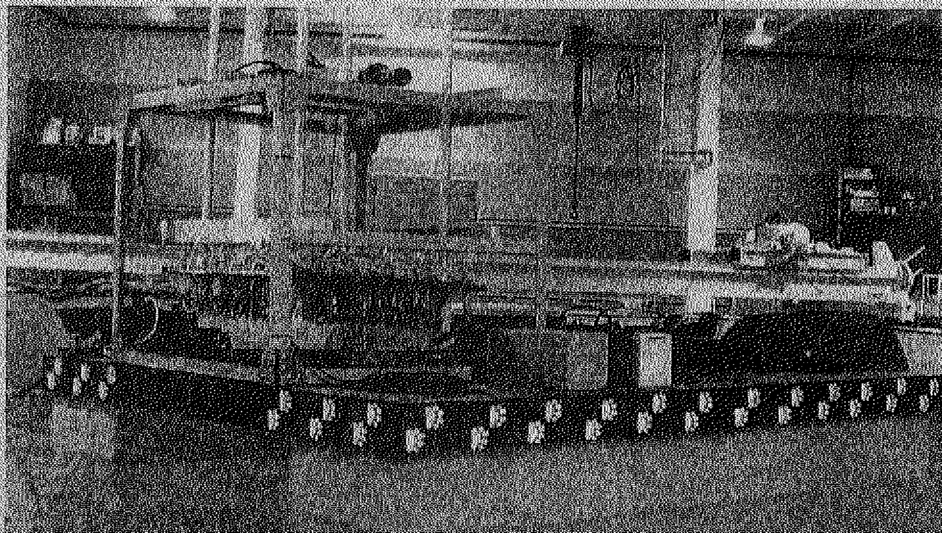

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Of all the estuarine and coastal environments, salt marshes are the most ecologically sensitive areas impacted by oil spills. Remediation of oil-contaminated marshes is difficult with the cutting and burning of marsh grass, sediment removal and replanting, or natural attenuation being common current practices. Enhanced bioremediation has emerged as one of the most effective and inexpensive methods of decontaminating groundwater and soils. These techniques have been recently applied in the contaminated marsh in the Fore River Creek in Portland, ME as part of current and past Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) projects. It has been shown that the practice of introducing nitrate amendments to the marsh substantially increases the rate of hydrocarbon degradation in the sediments by as much as 50%. The initial technique used to introduce the nitrate in the past CICEET research consisted of horizontal wells, which were time consuming to install and provided only minimal marsh coverage. The present technology involves a prototype "injection system" mounted on a prototype "low impact barge" to operate at high tide in the salt marsh. The injection system utilizes pneumatic powered syringes in conjunction with a hoisting mechanism to raise and lower the grid of syringes to the marsh surface below the water line. The pneumatic and mechanical systems are controlled through the use of a Programmable Logic Controller (PLC), which allows the injection system to be automated. The prototype injection system was built at a cost of $1900 and is ready for testing in the marsh environment.

1. INTRODUCTION

1.1 Background

In 1996, the oil tanker Julie N struck the Memorial Bridge in Portland Harbor, Maine spilling 180,000 gallons of No. 2 and 4 fuel oil. Unfortunately, an onshore wind in conjunction with the incoming tide, forced the oil into the Fore River Creek marsh. Since the marsh environment has a high density of Spartina Alternfura, the oil that moved in during the flood cycle was trapped by the marsh grass when the ebb occurred. The natural depletion of the oil from the marsh environment does occur however through the processes of photo- and bio-degradation. Photo-degradation is the decomposition of hydrocarbons by exposure to sunlight while, bio-degradation is the decomposition of hydrocarbons by the biomass in the sediment. These processes often take several years to return the marsh to its original condition.

In June 1998, a project was initiated through funding from the National Oceanic and Atmospheric Administration (NOAA) to investigate the use of enhanced bioremediation techniques for use in the Fore River Creek salt marsh (Gilbert, 2000; Kinner et al., 2002). Results showed that the microbes increased biodegradation on hydrocarbons with the introduction of an amendment solution into the sediment by as much as 50% (Hildebrand, 2001). Originally, the solution was introduced to the sediment through a series of horizontal wells and manifolds. Since these wells were composed of low density, semi-rigid plastic tubing, they floated to the surface of the marsh over time. A second technique of using syringes and needles to inject the nutrient solution into the marsh was then employed. However, this technique proved to be tedious because it required several people to complete during a low tidal period. It was then speculated that a device could be constructed that would automate the injection process. This technique would be the ideal way to deliver the amendment solution to the microbes.

To address these technological issues, two undergraduate mechanical engineering design teams were formed as part of the TECH 797 Ocean Projects (senior design) course to develop an injection vessel to enhance the bioremediation of oil-contaminated salt marshes. The design teams were separated into two groups named The Clean Cat and Nutrient Injection System Specialists (NISS). These two teams were established to collaborate in order to achieve the common goal of developing a system to illustrate that automated injection of amendments is possible for the bioremediation of hydrocarbons in a marsh environment. The goal of this report is to describe the conceptual design, prototype construction (which includes physical testing), maintenance, and future suggestions for the NISS project.

2. CONCEPTUAL DESIGN

2.1 Design Criteria

In general, based on the experiences of the NOAA project principle investigators, it was believed that a floating barge operating at high tide with an injection unit mounted on board would be the most effective way to deliver amendments with minimal damage to the marsh environment. It would also be useful for the floating platform to be approximately the size of a standard piece of plywood so it could be easily loaded into a large pickup truck. In addition, the vessel, injection system, and auxiliary components could be modular to meet this same design constraint. The propulsion system would be designed to minimize any damage done to the marsh environment (see Clean Cat project report).

Through a series of discussions with project personnel, specific criteria for the injection system were established including: injection time, spacing, and volume. The required time for the injection cycle is 15 minutes, as determined from previous injections performed in the marsh. These injection experiments showed that the syringe and needle apparatus must be left in the marsh sediment for at least 15 minutes to allow the amendment solution enough time to dissipate into the soil. The syringe and needle arrangements were spaced so that injections occurred every six inches. This gave the required 50 mL of amendment solution per syringe to the subsurface marsh environment. The needle used for the injection of the solution could not exceed the size of a 15 gauge needle, which allows the marsh substrate to conceal the hole made by the needle after withdrawal.

2.2 Initial Conceptual Design

In the initial conceptual design phase, the injection system was broken into four subgroups: a frame to support a lifting and lowering device, a mechanism to mount syringes to a grid and sense the marsh soil surface, modifications needed to use standard medical syringes, and a control system to operate the apparatus.

Initially, the needle grid was designed to be driven by a jackscrew assembly. The intent was to attach the center of the grid to this jackscrew. The needle grid would be guided to the marsh soil surface by vertical tracks composed of Schedule 40 PVC piping from the floating platform (Figure 2.1). The entire jackscrew assembly would be mounted to a frame that would be secured to the deck.

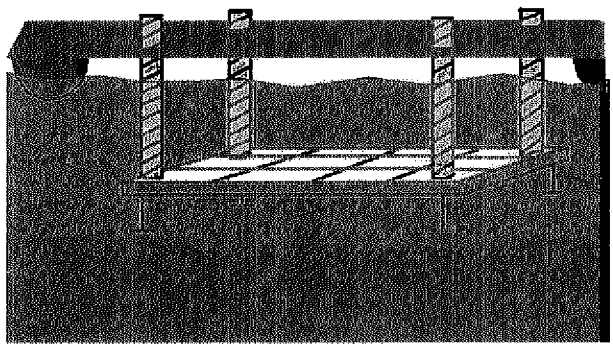


Figure 2.1 - Original needle grid attachment to platform (jackscrew not shown).

The material chosen for the grid was a reinforced fiberglass (Figure 2.2) commonly used for catwalks in industrial applications. This grid material also allows the syringes to be placed and rigidly fixed at the specified spacing of six-inches apart.

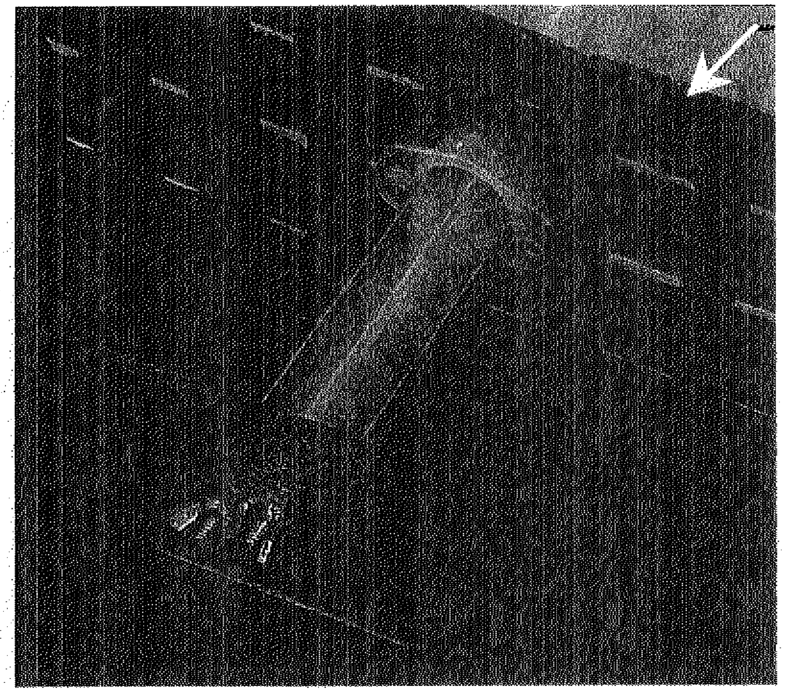


Figure 2.2 - Catwalk grid (indicated by white arrow) and needle placement.

This material is extremely lightweight, non-corrosive, easy to modify (i.e. cut and shape), and is available for no charge. Schedule 40 PVC pipes, in conjunction with a series of waterproof limit switches were proposed to sense the sediment surface of the marsh.

Medical syringes each having a volume of 60 mL with a luer lock tip were considered in the conceptual design phase. This tip allows the needle to be locked in place. A secondary grid attached to the plungers at one end and a jackscrew assembly at the other would actuate the plungers. A check valve placed between the syringe barrel and the needle, in addition to a second check valve between the syringe barrel and solution source, would allow the syringes to be refilled by actuating the plungers.

The control system would be composed of a programmable logic controller (PLC), a digital user interface, and associated control devices for the mechanical and electrical systems. All the systems would use 12 Volts DC to reduce the need for generators, inverters, and/or rectifiers. The PLC and the associated components would be housed in a weatherproof cabinet. The electrical components associated with the jackscrews would also have weatherproof connections to prevent contact with the corrosive seawater.

2.3 Conceptual Design Iterations

Some of these initial designs remained constant, while others changed drastically during the project. Different parts of the four subsystems were modified to help improve many aspects of the injection system. These included construction, repair logistics, durability, and cost.

One subsystem design that had to be reconsidered was the jackscrew system. The smallest linear jackscrew system found had an actuating force of two tons and a drive motor requirement of 240 Volts AC. This is not compatible with the requirements for the floating platform (i.e. space and weight limitations). The cost of the unit was also too high ($1500). Therefore, a cable driven system that incorporates a DC drive clutch winch was considered. Using this mechanism, the needle grid would have to be weighted so that it could drive the needles 4-6 inches into the marsh soil. An advantage of a drive clutch winch is that it produces steady control. After the fifteen-minute injection cycle, the winch would then pull the needle grid out of the sediment. The needle grid could still be guided to the marsh soil surface by a set of tracks connected to the corners of the needle grid called stanchions.

Four end posts would be placed at the corners of the grid, so that the controller would know when the grid has reached the top of the marsh sediments (Figure 2.3). Switches would be placed on the bottoms of the posts to tell the controller when to stop the drive system. However, four waterproof limit switches cost $920, which was well beyond the budget for this project. Snap acting switches were also considered, but they are only spray proof, not submersible.

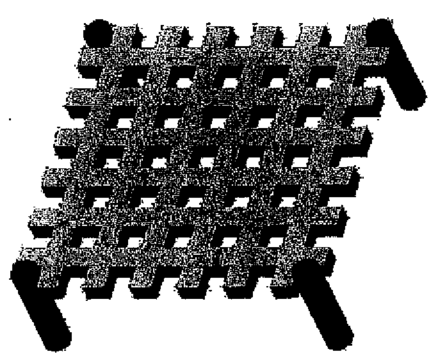


Figure 2.3 - Needle grid material with end posts.

Originally, it was contemplated that the linear actuated jackscrew system would be the best way to drive the rigid platform and syringe plungers. However, this would require all of the syringes to be fixed. If a syringe encountered an obstruction the needle could be damaged. To avoid the problem, each syringe must move independently to minimize damage to the needles and the marsh. Therefore the plungers would have to actuate in a different manner. This lead to another design change that involved the use of pneumatic syringes. These are typically utilized in the adhesive industry. This would allow the syringe barrels to move independently from one another and still be actuated (Figure 2.4).

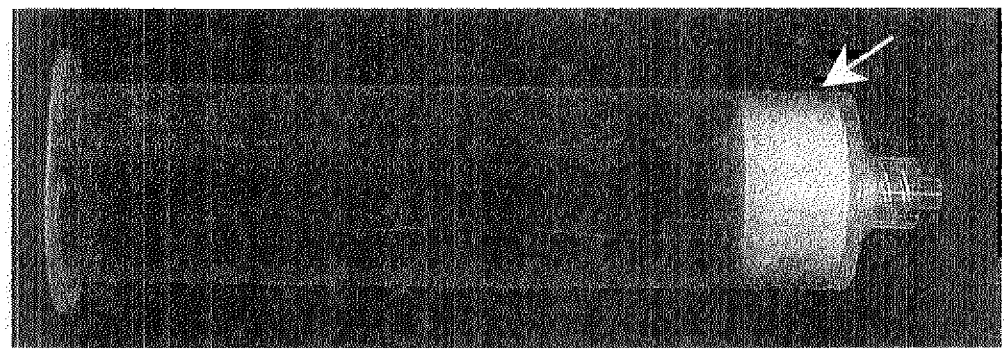


Figure 2.4 - Pneumatic syringe with luer lock hub shown with plastic floating plunger (indicated by the arrow as shown).

These syringes are readily available from most warehouse suppliers (costing approximately $1.00 per syringe). However, the largest available capacity is 30 mL. After conferring with project personnel, it was decided that the amendment solution could be concentrated so that only 30 mL would be needed per injection. The pneumatic syringes would still have to be modified to accommodate the check valves. These check valves placed in-line with the needles would allow liquid to flow out of the needles, but prevent it from being drawn back in once dispensed. The second check valve would be placed at the bottom of the syringe barrels to allow liquid from the solution supply to be drawn into the barrel but prevent the liquid from being forced back into the reservoir (Figure 2.5).

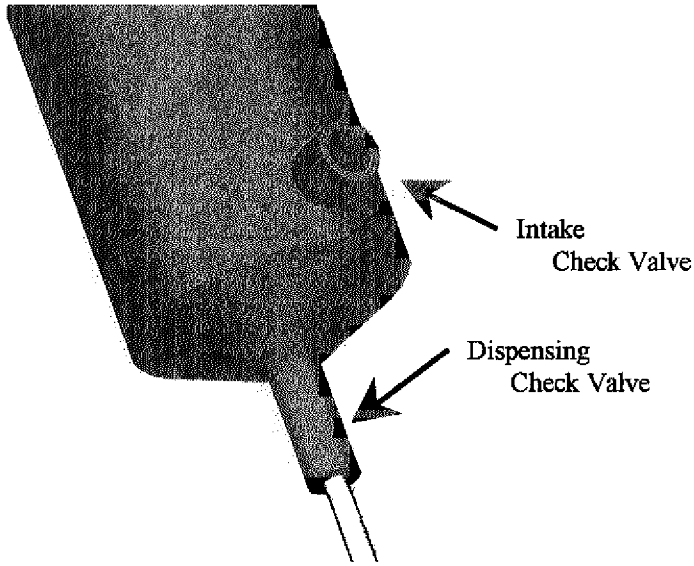


Figure 2.5 - Check valve placements on the syringe.

The use of pneumatic syringes created an additional issue of how to connect the large open end of the barrel to an air supply hose. A company that supplies these syringe barrels also supplies a receiver head that addresses this matter. However, these receiver heads cost $9 each. In an effort to keep costs down, it was found that threaded PVC bushings (available at a local hardware store) fit the inner diameters of the syringe barrels (Figure 2.6) and were much cheaper at $0.85 each.

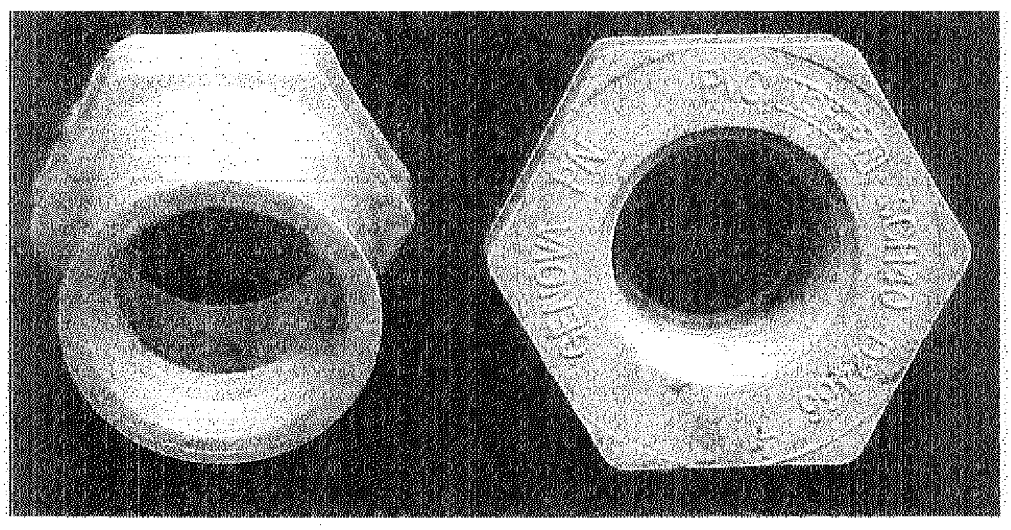


Figure 2.6 - Threaded PVC reducing bushing.

These PVC bushings could be cemented into the syringes and hose barbs could be threaded into the bushing to accept the airline. Compressed air supplied to the syringes would force the solution through the needle while a vacuum supplied through the same configuration would pull the plunger up to draw liquid into the syringe from the reservoir.

To resolve the aforementioned design concern of possible damage to the needles due to underwater obstructions, the mounting of the syringes had to be changed. Hence, two linear springs were attached to each of the syringes at the ears (Figure 2.7). Therefore if a needle encountered a hard object in the sediment, the springs would retract preventing the needles from breaking. This would reduce the number of needles that would be needed to be replaced during operation.

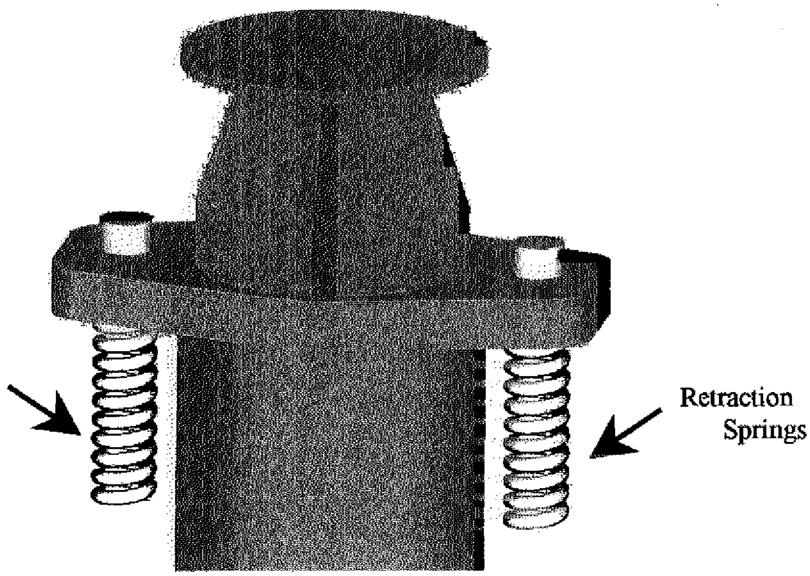


Figure 2.7 - Linear spring attachments.

A PLC, obtained through Automation Direct would be utilized to control the injection system and would be powered with 12 Volts DC (Figure 2.8). It would accept eight DC inputs and send six outputs. It could be driven by a deep cycle marine battery. Relays in conjunction with the PLC would supply the appropriate current to the winch motor at the correct time. The air and vacuum for the pneumatic syringes would be controlled through an electrically actuated valve controlled by the PLC. A digital user interface (Figure 2.9) could be provided if desired, but the controller parameters could be changed through an Ethernet port on the PLC with the use of a laptop computer. The PLC, valves, and electronic components would be housed in a weatherproof box and mounted to the exterior of the apparatus.

Figure 2.8 – PLC Unit

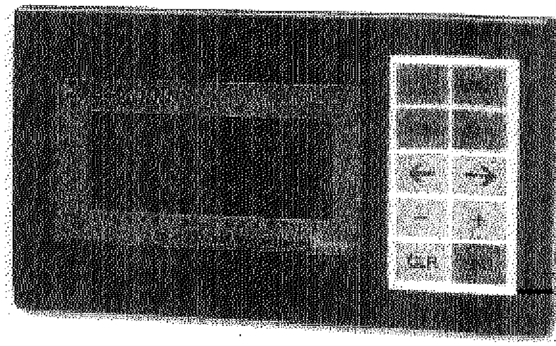


Figure 2.9 - PLC digital user interface.

2.4 Conceptual Design Testing

Model tests must be conducted before committing to any design. This was an especially important concern in the design process because of the project's limited budget. In addition to the budget restrictions for this project, there is also the need to keep all of the advisors informed about the project and be sure that the project is meeting their requirements. Testing models are a good way to accomplish these tasks.

The injection force necessary to push the needles into the marsh soil as well as the force it takes to actuate the plungers to inject the nutrients into the soil was a major concern. These forces affect the sizing of the components for the actuation system for the needle grid and plungers such as spring constants, vacuum, and pressure levels. To determine the force that is required to push the needles into the marsh sediment and the force required to actuate the plungers, theoretical calculations and experiments were performed (see Appendix A for theoretical calculation). An apparatus (Figure 2.10), was developed to experimentally determine these values.

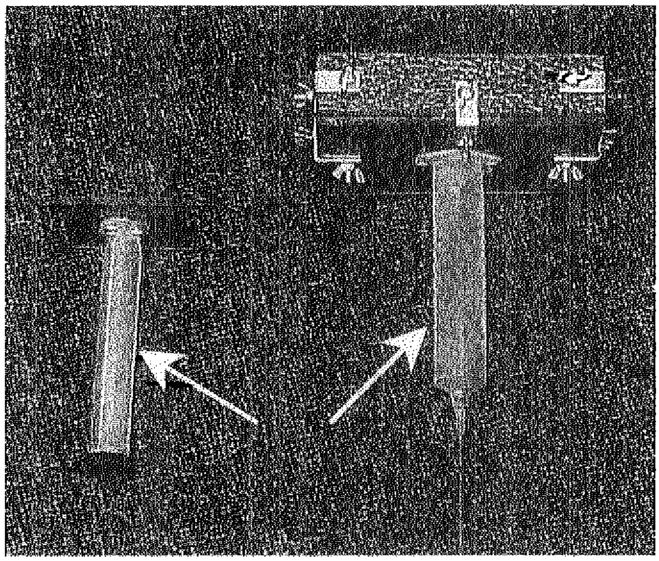


Figure 2.10 - Test apparatus for insertion and injection experiment. The white arrow points to the plunger and the yellow arrow points to the syringe barrel.

Lexan trays were mounted on top of a 50 mL syringe barrel flange and on the end of a plunger flange to hold various weights. The syringe and needle apparatus was then steadied above marsh sediment while weights were added to the tray until the needle reached a depth of six inches into the soil. This process was repeated ten times. Next, the tray attached to the barrel flange was removed, and the syringe was filled with approximately 50 mL of saltwater (Figure 2.11).

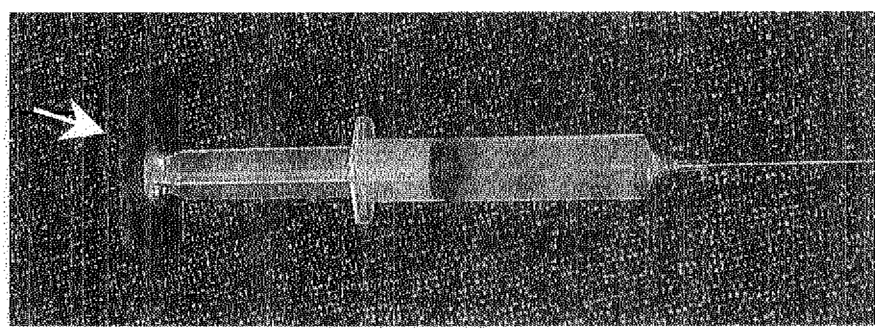


Figure 2.11 - Plunger force test apparatus. White arrow points to the plunger tray.

The needle was then inserted into the marsh soil and weights placed on the plunger tray until the plunger was depressed. This procedure was also repeated ten times. The experiment was run in two additional marsh locations with ten trials conducted in each location.

The results obtained from these experiments were then tabulated (see Appendix B for raw data) and plotted to determine an average force for needle insertion and plunger actuation (Figures 2.12 & 2.13). The large variation in the force exhibited in Figure 2.12 could be attributed to the needle hitting objects below the surface such as plant roots, shellfish, or rocks. In light of this, a statistical approach was taken to obtain the maximum insertion force required. The mean and standard deviation of the data sets were calculated to obtain the required needle insertion force. This force was calculated to be 3.9 N ± 1.57 N. The maximum insertion force for the design considerations was then decided to be the mean plus one standard deviation, which is equal to 5.5 N. The same procedure was used to calculate the plunger activation force. This methodology showed the force required to depress the plunger was 35.5 N ± 0.5 N. Therefore, a value of 36 N was assumed for design considerations.

The force required to bend or buckle the needle must also be calculated to determine if the insertion force is above the buckling force and to size the springs for the dynamic mounting of the syringes to the grid. The buckling theory of a column defines the critical force at which buckling occurs in a column as:

$$P_{cr} := 2.47 \cdot \left(\frac{E \cdot I}{L^2} \right)$$

where: E = Young's Modulus for stainless steel (29 x 10^6 psi)

L = Length of column (Needle length = 6 in)

$$I := \frac{\pi}{64} \cdot \left(OD^4 - ID^4 \right)$$

OD = Outside diameter (0.079 in)

ID = Inside diameter (0.039 in)

The force required to buckle the needle was calculated to be 15.9 N. Based on the results from the buckling calculation and the insertion force data it was determined that the needle would not buckle when inserted into the marsh and also yielded the max working load of the springs to be less than 15.9 N.

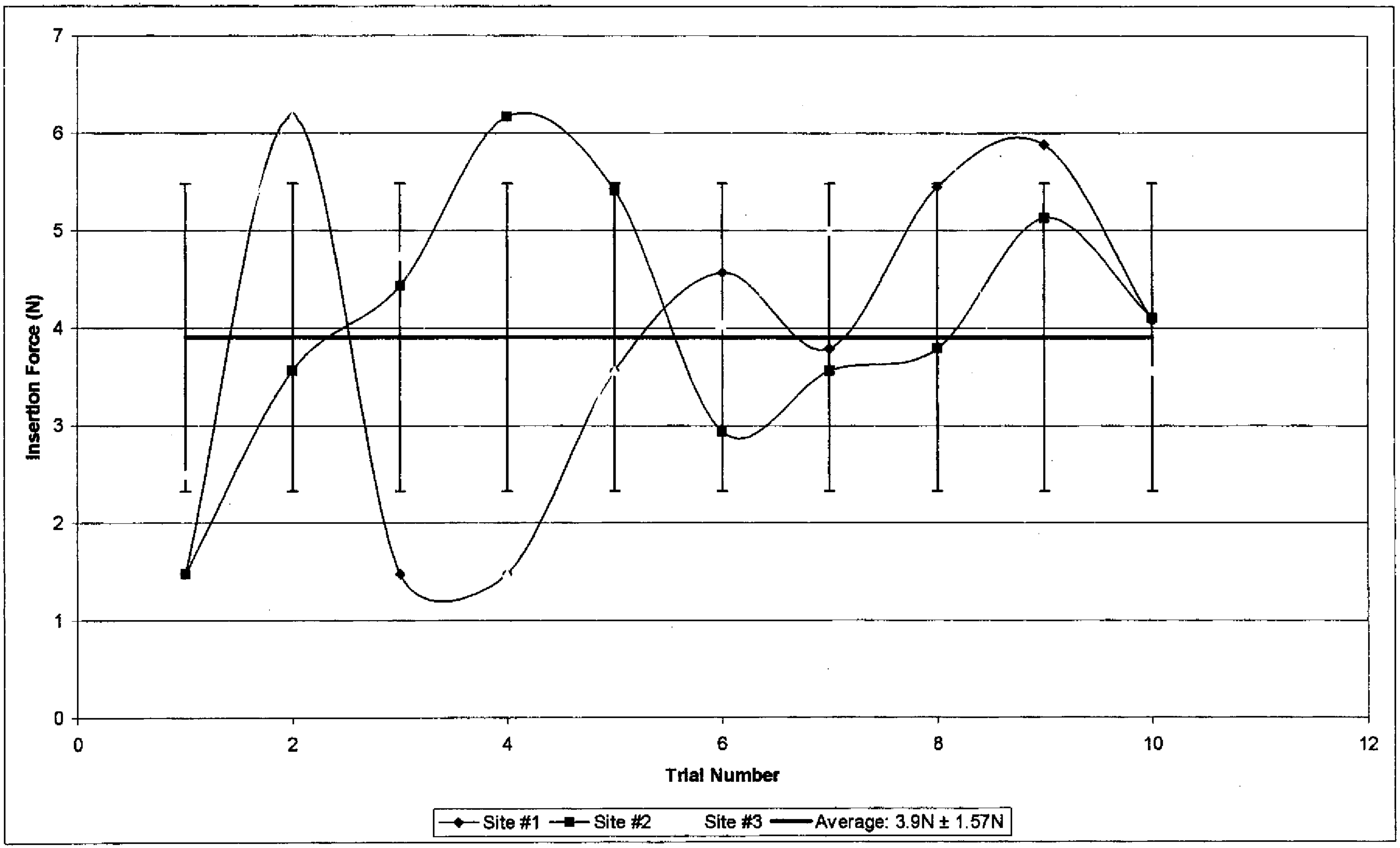


Figure 2.12 - Experimental needle insertion force with average line and one standard deviation error bars.

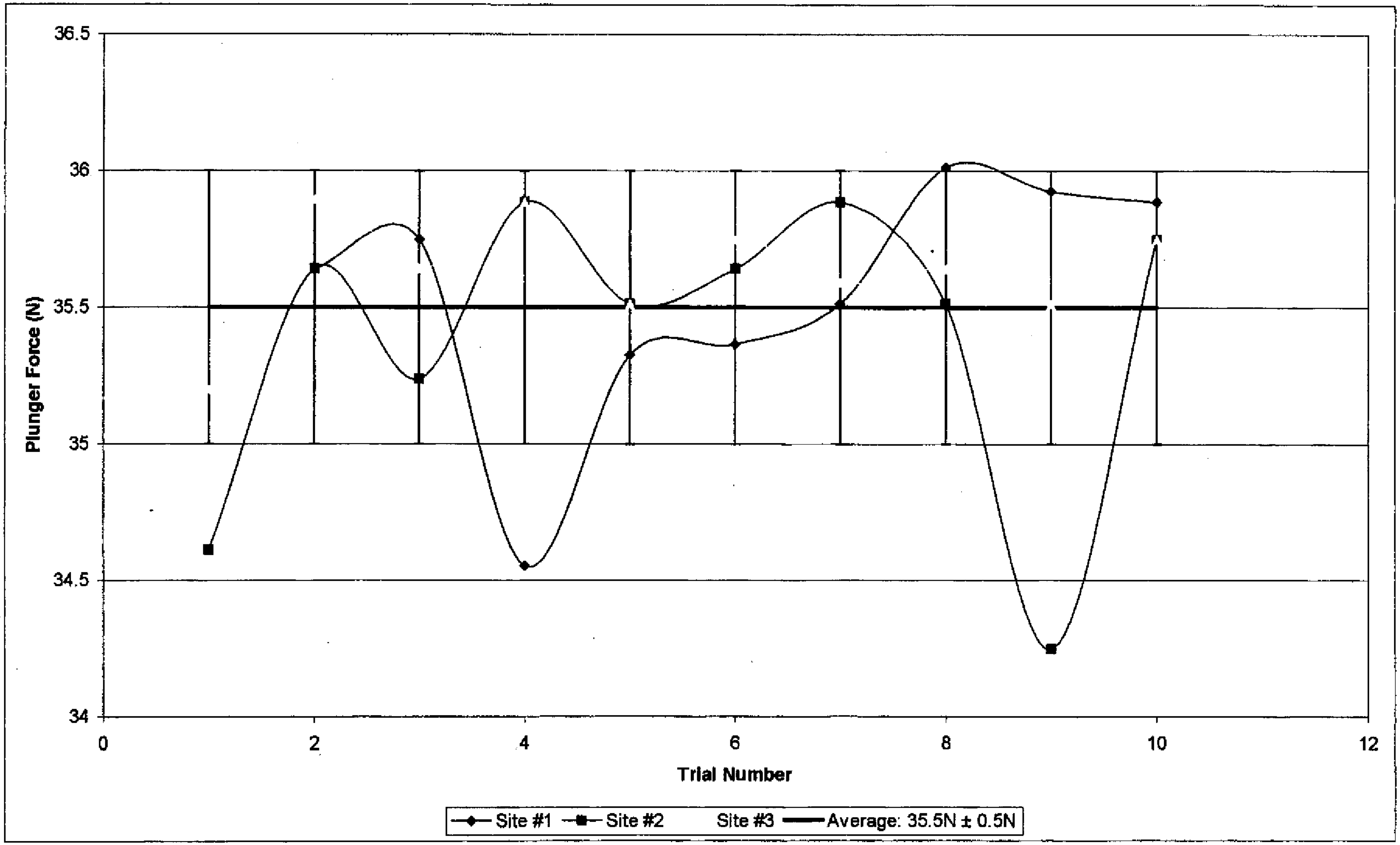


Figure 2.13 - Experimental plunger actuation force with average line and one standard deviation error bars.

The check valves also needed to be tested to determine if they could force the amendment solution to flow in and out of the syringe without letting any marsh water leak in through the needles. The check valves were tested (Figure 2.14) by placing one tube into a water source, while the other was put in a receiving container.

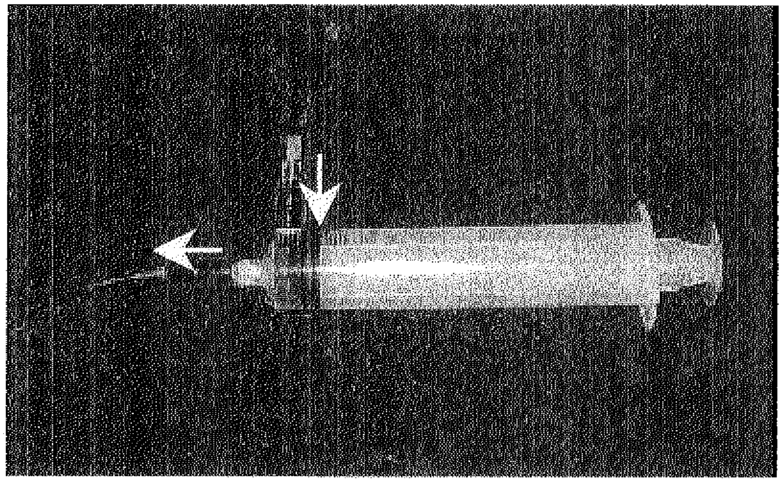


Figure 2.14 - Test apparatus for check valves (arrows indicate the flow directions of solution).

When the plunger on the needle was manually pulled upward, the water flowed into the chamber properly. When the plunger was depressed, the fluid inside the syringe chamber flowed through the needle end tube and into the receiving container. The check valve attached to the side of the syringe did not let any water through the side tube when the plunger was depressed. If the plunger was pulled or depressed too fast the valves tended to show signs of hydro-locking (i.e. blocking fluid flow). These results illustrated the need for industrial strength check valves. A search for better valves was performed along with an improved test setup for this system.

The volume of fluid needed for one tidal cycle was calculated to determine the amendment reservoir size. The tidal cycle in the marsh is semidiurnal, with approximately 6.21 hours between high and low water. Therefore, the total time that a floating platform can operate in the marsh without causing damage is approximately three hours before and after high water. The maximum number of times that an injection cycle can occur is 24. Therefore, the number of needles must be maximized within the dimensional parameters of the floating platform to acquire the maximum amount of marsh area covered in one tidal cycle. It was determined that 36 needles fit into a square grid of 3' by 3' for placement between the pontoons of the floating platform. It was estimated that the system would be able to cover a maximum of 72 square feet in one tidal cycle. The amount of amendment solution that would be used during this time was calculated to be 13.7 gallons. This sets the basic design parameters for the injection system. The supply of amendment solution, electricity and any other material sources were considered to be unlimited for the duration conceptual design process.

Some components of the injection system had not been tested due to the restricted time limits and budget of the project. The PLC and injection actuation testing could not be performed until this equipment had been purchased. However, once these items were available more testing procedures were be put in place to ensure that the system would work properly.

2.5 Final Conceptual Design

Based on the results from theoretical calculations and experiments, modifications were made to the conceptual design. These modifications led to the final conceptual design that was divided into subgroups: needle grid actuator, needle grid arrangement and mounting, syringe modification, and the control system.

The final conceptual design for needle grid actuating device consisted of a clutch winch and guides made of PVC piping. The winch would be mounted onto a tower that would allow for the necessary range of motion. The winch would need to be coated so that the seawater could not affect it. A marine-duty battery would supply the electrical power needed. This was determined to be the most feasible design because the winch is lightweight and durable. An enclosure would also be built to protect the winch from harsh weather.

The final conceptual design for the needle grid system consisted of the initial design of catwalk material for the grid. It is lightweight, non-corrosive, and inexpensive, which makes it the perfect choice for this application. Instead of using four end posts with four switches for the control portion of the grid, a single submersible switch (Figure 2.15) positioned in the center of the needle grid would be used. Implementing a single switch would decrease the price by 75%. It would also make the attachment of the switch much easier. In addition, a small plate would be attached to the contact switch in order to ensure that the switch would be actuated properly, and not sink further into the marsh sediment. The proposed idea for the attachment of the springs to each needle could also be tested along with the other components of the needle grid system.

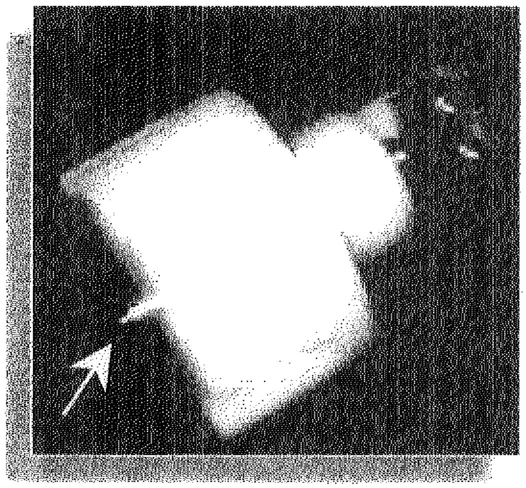


Figure 2.15 - Submersible switch with actuation button as indicated with arrow.

Pneumatic syringes with a volume of 60 mL were found. The syringe barrels would use the threaded PVC bushings, because the previously mentioned receiver heads cost $9 each verses $1 for each of the bushing and hose barb arrangement. Industrial strength check valves used in the medical industry would be used instead of the aquarium check valves to prevent hydraulic locking (Figure 2.16).

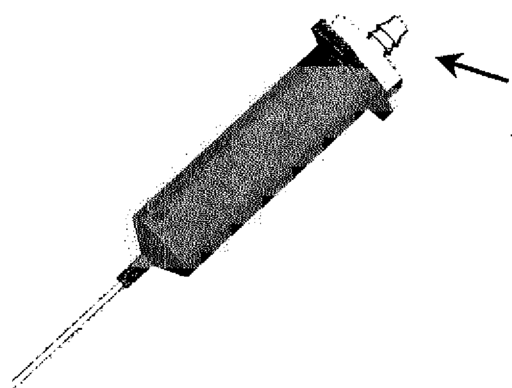


Figure 2.16 - Final conceptual syringe design (arrow points to PVC bushing with hose barb).

The entire system would be controlled through a series of relays, sensors, and valves by a PLC. A set of relays would control the vertical movement of the winch which would be limited by the submersible switch. The compressed air and vacuum supplies for the pneumatic syringes would be controlled through two independent solenoid valves turned on and off by the PLC. The final conceptual controller setup would be enclosed in a weatherproof electrical box.

3. PROTOTYPE CONSTRUCTION

3.1 Initial Construction

The results from further experimentation showed that modifications needed to be made to the final conceptual design. These modifications led to the construction of a prototype that was divided into subgroups: winch and frame system, needle grid arrangement and mounting, syringe modifications, and the control system.

Initially, the stand was constructed of 2" by ¼" steel angle iron and measured 3 cubic feet. The basic construction consisted of two box frames that measured 3' by 3' with 3' supports connecting the top and bottom boxes. Diagonal frame members were added to strengthen the frame to prevent racking (Figure 3.1).

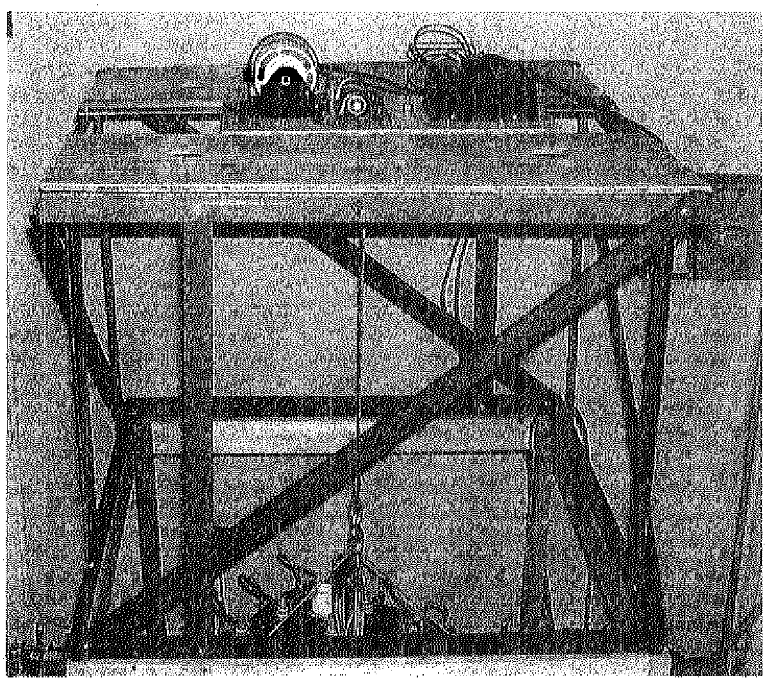


Figure 3.1 - Steel frame.

The frames and supports were bolted together using ¼ - 20 x ¾" hex head bolts. Two additional supports were also added to the top box frame to support the winch motor setup (Figure 3.2). Strips of plywood with 2" diameter holes were attached to the top of box to act as guides for the needle grid stanchions (Figure 3.2).

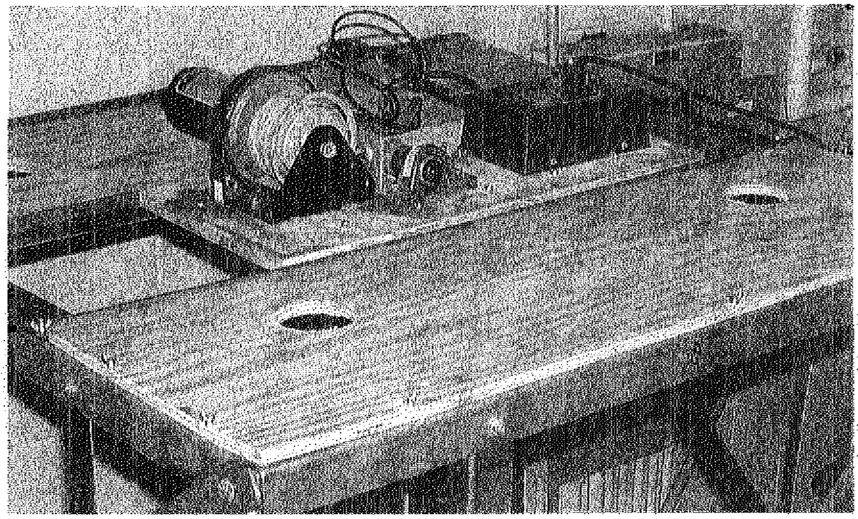


Figure 3.2 - Frame members to support winch setup and stanchion guide holes.

The original winch motor conceptual design was abandoned due to difficulties in the implementation. These complexities included construction of a cable drum and using a belt drive in a marine environment. The next system consisted of a 12 Volt DC direct drive "off the shelf" winch. This winch was easily mounted to the two support members on the frame (Figure 3.3).

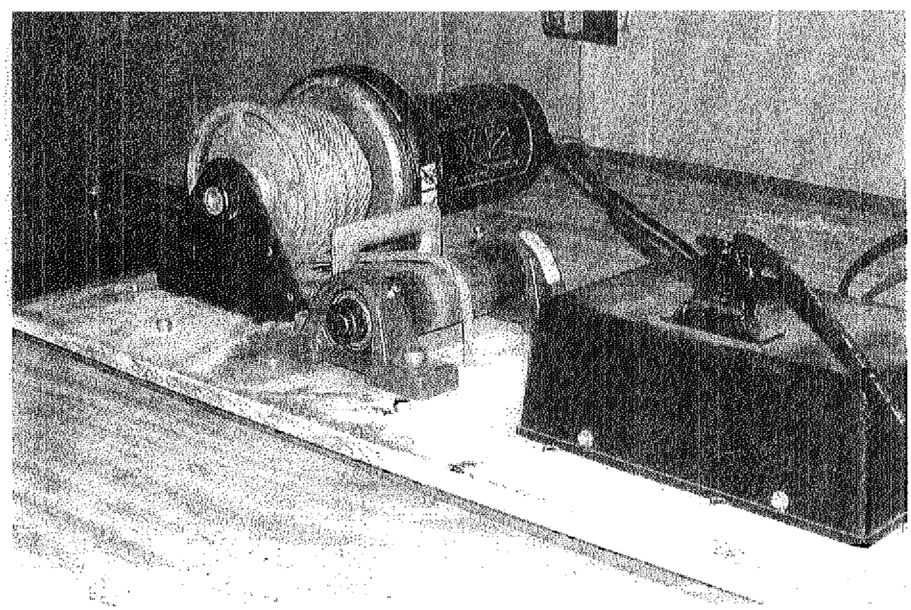


Figure 3.3 - Winch system setup.

The construction of the needle grid became more involved. The fiberglass grid was cut into a 3' x 3' section such that the cuts fell on a whole grid square (Figure 3.4).

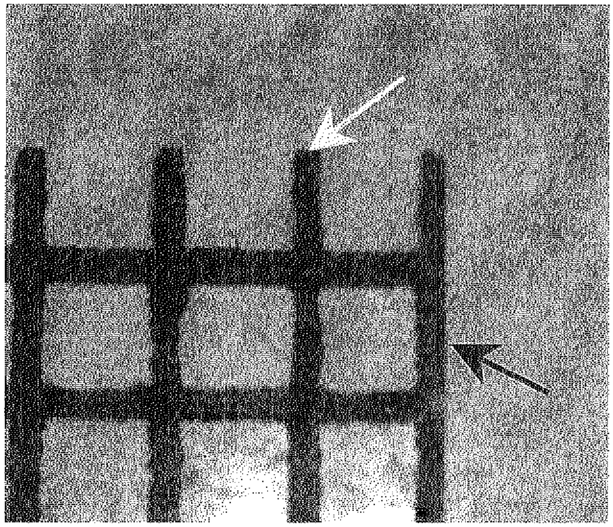


Figure 3.4 - Bad grid cut (white arrow) and a good grid cut (black arrow).

The grid squares in which the needles were inserted were sanded down to prevent the outside of the syringe barrels from abrading. A lifting eye was added to the center of the grid to attach to the lifting winch. Six-inch legs were then added to each corner of the needle grid to ensure the proper needle insertion distance into the marsh sediment (Figure 3.5) as discussed previously. These legs incorporated a female pipe thread so that the stanchions could be removed for transportation (Figure 3.6).

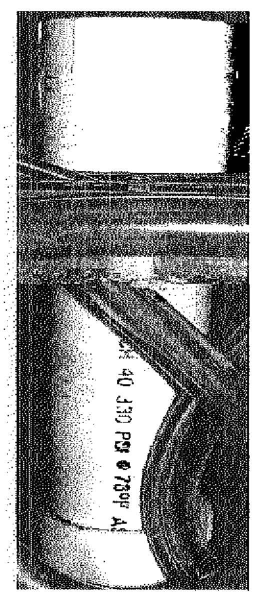


Figure 3.5 - Needle grid legs for proper needle insertion distance.

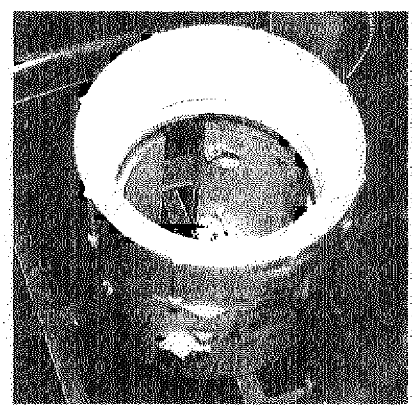


Figure 3.6 - Female NPT for removal of PVC stanchions.

A pneumatic and hydraulic manifold was then added to each side of the needle grid. This consisted of ¼" vacuum tubing and ¼" nylon tube tees (Figure 3.7). The syringe barrels were attached to stainless steel 1 ¾" extension springs, which were attached to the grid with zip ties (Figure 3.8).

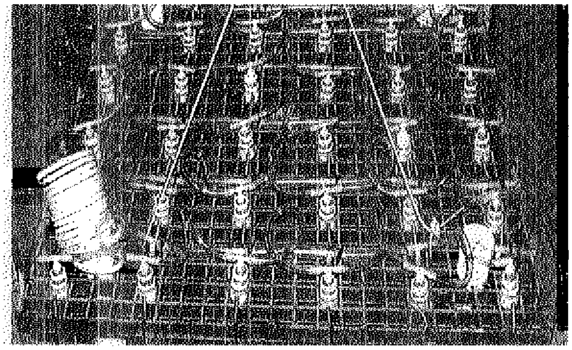


Figure 3.7 - Pneumatic and hydraulic manifolds

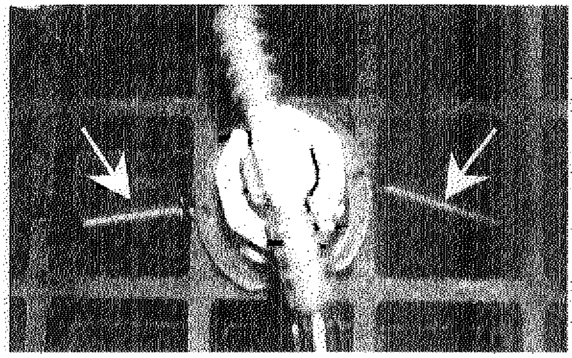


Figure 3.8 - Attachment of springs to grid.

The specified 60 mL syringe barrels had two ¼" holes drilled in the bottom to fit the check valves. Each check valve had to be modified by cutting of one of the barbs so it could fit into the ¼" holes. These modified check valves were then attached to the syringe barrels using epoxy. The stainless steel tubing stock was then cut into 6" lengths and attached to the appropriate check valves using steel putty. This joint was then coated with epoxy to give strength and sealing. At this point plastic wiper plungers were placed inside the syringe barrels. Reducer bushings with dimensions of ¾" x ½" was combined with ½" x ¼" threaded bushings and ¼" x ¼" NPT nylon tube tees to seal off the top of the syringe barrels (Figure 3.9).

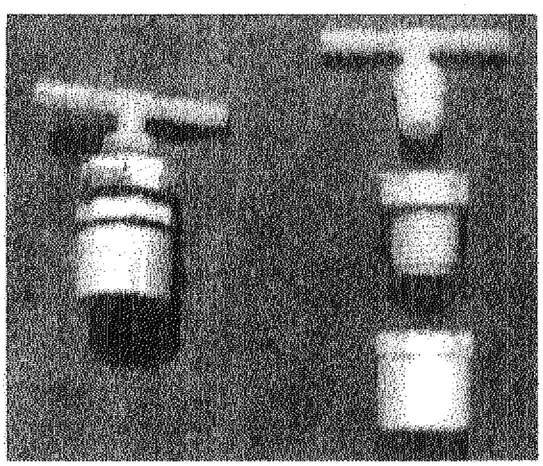


Figure 3.9 - Syringe top assembled (right) and exploded (left) views.

A 1/16" hole was then drilled into each of the syringe barrel ears to accommodate the springs from the needle grid. This completed the construction of the individual syringe setup, which was then inserted into the needle grid. The syringe setups were then connected to the appropriate manifolds and springs (Figure 3.10).

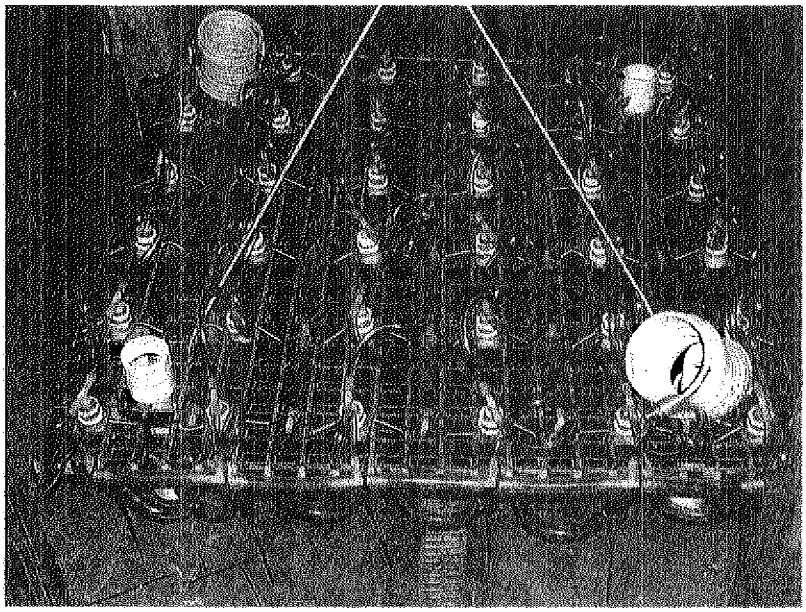


Figure 3.10 - Completed needled grid assembly.

The PLC, relays, solenoid valves, and terminal strips were first mounted to a piece of plywood. Each of the four terminals on the positive terminal strip was connected to the +12V DC post and likewise for the four terminals of the negative terminal strip. The components of the control system were than wired to the PLC (See Appendix C) and the appropriate terminal block to complete the construction of the control system (Figure 3.11).

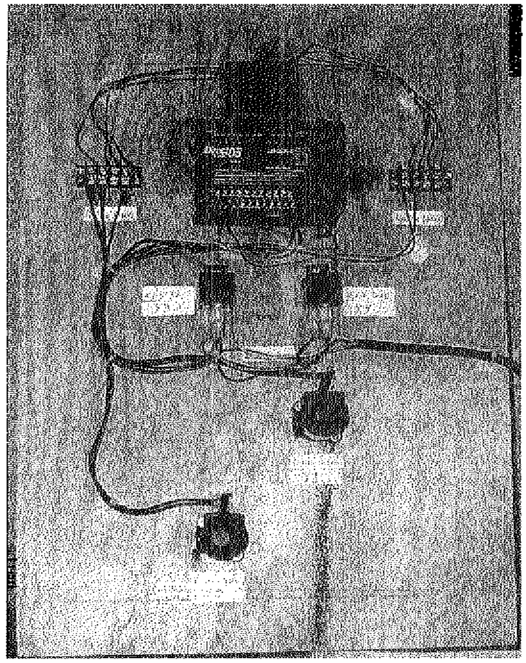


Figure 3.11 - The completed control system assembly.

3.2 Prototype Testing

A series of tests were preformed on the initial prototype. These experiments allowed for the assessment of the syringe setups, winch system, and the dynamic mounting system for the syringes. Tests were performed on pneumatic pressure, hydraulic pressure, winch and stanchions, and dynamic mounting.

The first test preformed was the pressurization of the syringes. The air manifold was pressurized at approximately 20 psi. As expected, the plungers moved to the bottom of the syringe barrels. However, during repeated cycling of the system, it was observed that liquid was leaking through the epoxy holding the fluid supply check valves in the syringes. Fluid was also leaking past the floating plungers. One possible reason for this occurring is that since the plungers are made for adhesive applications, they are designed for more viscous fluids, and therefore clearance tolerances for these syringe barrels do not have to be as tight.

Instead, a vacuum was placed in the pneumatic manifold that actuated the plungers to draw liquid into the syringe barrels. However, once the plungers reached the tops of the syringe barrels they came to rest against the reducing bushings and allowed some solution to be drawn into the pneumatic manifold past the plungers. The leakage was once again due to the fact that the plungers were designed to be used with more viscous fluids. This was a major issue, because as the system was cycled through multiple iterations it was observed that some amendment solution became trapped on top of the plungers and ultimately flowed back into the vacuum pump.

The winch system and stanchions were then tested for their ability to actuate the needle grid in a straight vertical motion. Through the motion sequences it was observed that needle grid had the tendency to twist and tilt. This was not desired because if the needle grid does not retract square through the boat deck it could get stuck. This could cause substantial damage not only to the injection system but also to the boat. The stanchions used to keep the grid aligned consisted of flexible PVC pipe. As the grid was moved vertically, the pipe was not rigid enough to prevent racking. Furthermore, the PVC pipe also had a slight curvature, which compounded the issue.

The final test on the prototype involved lowering the needle grid to the floor to see if the syringes would retract to prevent damage to the needles. The concrete floor simulated potential hard objects in the marsh sediment. This would make it easier to see if the individual springs worked effectively. The results showed that the springs were sized appropriately to prevent bending of the needles.

3.3 Prototype Modifications

As a result of the prototype testing phase, modifications were made to each of the subsystems of the injection mechanism. The modifications addressed the following issues:

- Floating plunger leakage
- Leaking check valve seals
- Racking of needle grid
- Weight of steel frame

The first issue that was addressed was the leakage past the plungers. Most of the commercially available plungers for dispersing water based solutions had a maximum capacity of 35 mL. The only product that was available off the shelf for the 60 mL size syringes had manual rubber plungers. Some test trials were conducted involving a single syringe setup and modified manual rubber plungers. From these trials it was concluded that if the handle extension was cut off just above the rubber plunger it could be used as a pneumatically actuated plunger (Figure 3.12).

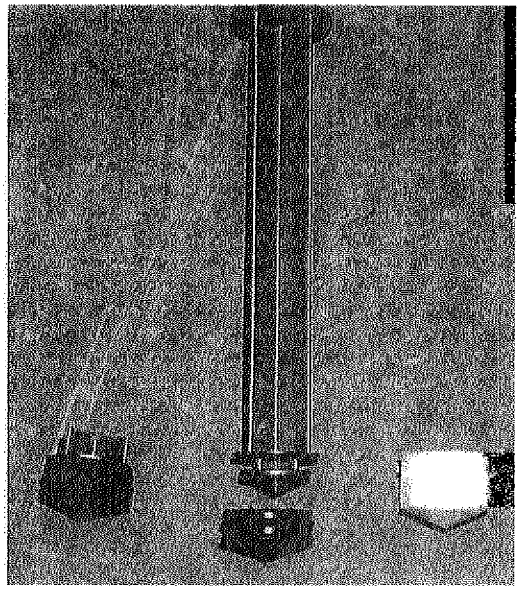


Figure 3.12 - Plastic wiper plunger (right) and modifications to manual rubber plunger (left)

However, these plungers proved to be too big for the syringe barrels causing them to stick during operation. It was found that lubricating the rubber plungers with O-Ring grease enabled them to move smoothly without any leakage.

The next issue dealt with the concern of the leaking check valves. The liquid was not being drawn into the syringe barrels due to these leaky seals between the modified check valves and syringe barrels. At this point all the needles and check valves were removed from the syringe barrels and reattached using a different type of bonding agent called JB-Weld. JB-Weld is composed of an adhesive as well as a metal filler for added strength. This worked exceptionally well to strengthen the joints between the needles and check valves, as well as the joints between the check valves and the syringe barrels. A copper based spray adhesive sealer was then used to coat the JB-Weld.

Changes to the connection between the injection grid and the winch cable were needed to correct the racking of the needle grid. The PVC stanchions caused the grid to tilt. Lifting the grid in the center by a single point meant that the needle grid had to be perfectly balanced in each direction. The correction involved creating a bridle to lift the needle grid up from each of the four corners (Figure 3.13).

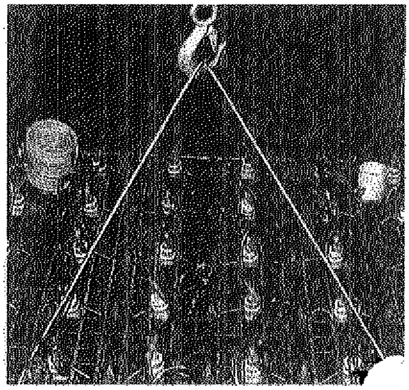


Figure 3.13 - Lifting bridle

The PVC stanchions were also replaced by aluminum pipes. However, the aluminum piping that was purchased had a smaller outside diameter and thinner walls. This meant that the pipes were unable to be threaded and could not be screwed into the legs of the needle grid. The solution was to pin the aluminum pipes into the needle grid legs using ¼" – 20 hex head stainless steel bolts. In addition to replacing the PVC stanchions with aluminum pipes, a second row of guides was added to the frame to complement the guides on the top of the frame (Figure 3.14 and 3.15). This prevented the upper guides from acting as pivot points for the stanchions.

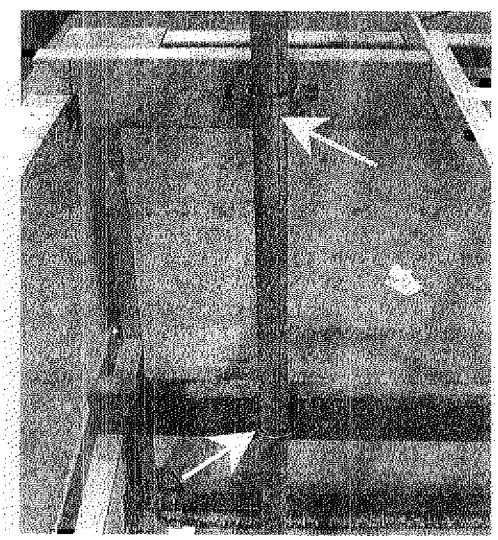


Figure 3.14 - Two rows of stanchion guides to prevent pivoting

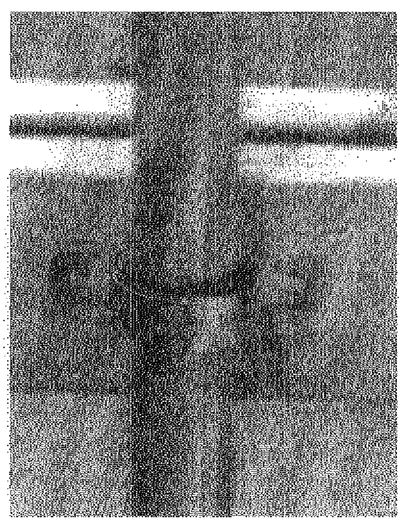


Figure 3.15 - Stanchion guide close-up

The weight and corrosive properties of the steel frame also became an issue, therefore a new frame was constructed from fiberglass angle. The corners of the frame were are together using stainless steel corner brackets and ¼" – 20 Phillips head stainless steel bolts (Figure 3.16). This provided a more rigid structure at approximately half the weight of the previous steel frame. Once the fiberglass frame was built all other system components were transferred.

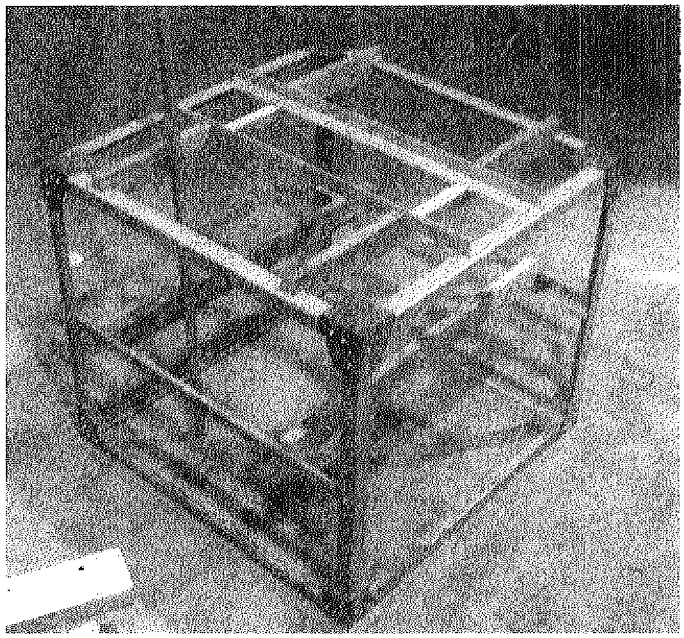


Figure 3.16 - Fiberglass frame with stainless steel corner brackets, stanchion guides, and winch frame

3.4 Current Injection System

Based on the results from further experiments, additional modifications were made to the prototype design. The final drive system consists of a winch (Figure 3.3) that rests on the fiberglass frame (Figure 3.16). The mounting plate for the winch motor rests on the two cross bars on top of the frame and are held in place with bolts. The four aluminum stanchions are guided by four u-clamps that are placed on the wooden 2" x 4" cross members. A splash-proof switch (Figure 3.17) is placed on the underside of one of the lower 2" x 4" cross members.

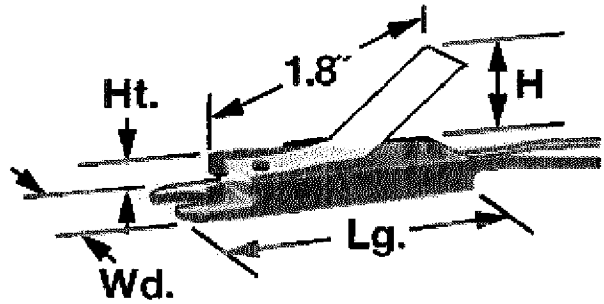


Figure 3.17 - Splash-proof switch

This is actuated by a small metal extension that is placed on one of the stanchions so the winch will stop pulling the grid upward when the switch is hit.

The catwalk material is used for the final injection grid due to its previously mentioned properties. The aluminum stanchions are attached to the threaded PVC guides, which are placed near the four corners of the injection grid. The pneumatic and hydraulic manifolds are set up as previously shown (Figure 3.7). These consist of vacuum tubing and plastic tube tee connectors.

The final syringe and needle design consists of pneumatic syringes with plastic tops (Figure 3.9). Two check valves are attached as described earlier to each syringe to allow the correct flow of amendment solution (Figure 3.18).

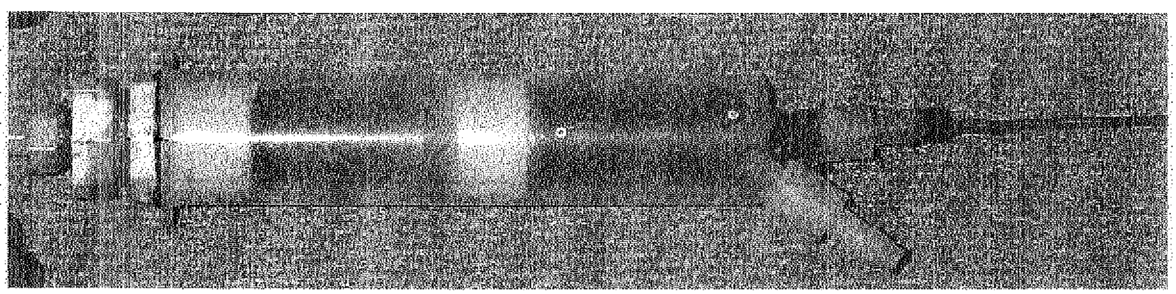


Figure 3.18 - Syringe setup

The check valves are attached to the syringes and needles using JB-Weld, and they are sealed with copper gasket spray. The syringes are attached to linear springs (Figure 3.8), which are attached to the grid with zip ties.

4. MAINTENANCE

Since this injection system is designed for salt marshes, an obvious problem that will most likely occur is salt build-up on the system components. Hence, some maintenance procedures should be implemented in order to ensure proper operation of the system. The following procedures have not been tested due to the time restrictions on this project. Therefore the frequency at which these tasks should be performed is not yet known.

The winch system and frame are extremely susceptible to salt buildup that would come from waves breaking over the side of the vessel during rough weather. Therefore the frame, stanchions, stanchion guides, and winch should all be washed thoroughly on a regular basis.

The injection grid material should be thoroughly washed and scraped regularly to avoid build up near the syringes. All tubes should be frequently flushed with some type of non-abrasive cleaning mixture to prevent clogging. Finally, regular checks for leaks in the tubes and hose barbs should be performed. These could be repaired with either new tubing or adhesive depending on the location and size of the leak(s).

All syringes and needles should be wiped clean of salt and dirt on a regular basis. The plungers should be removed so the inner walls of the syringes can also be cleaned. O-ring grease can be reapplied to the plungers at this time to maintain proper movement and swift injections. Finally, all needles should be flushed with a cleaning solution to prevent any blockage that could occur due to build up on the inner walls.

5. SUGGESTIONS FOR FUTURE PROTOTYPES

As stated earlier, the time restrictions for the completion of this project do not allow for some changes that can be made its design. The following modifications could greatly improve the performance of the system and also make it easier to maintain.

The frame for a future design iteration could be enclosed with a removable case. This would protect the winch motor during operation, and it would also protect the grid when the system is not in use. In addition, a different mounting plate for the winch motor could be implemented. The existing mounting plate is made of a thick slab of aluminum, which can be replaced with a thinner, less dense material such as fiberglass. Finally, stanchions with thicker walls and threaded ends can be used. This would allow for easier attachment and removal from the grid.

A smoother grid material with chamfered or rounded edges might be a better choice to allow the grid to move easily through the water column and avoid hang-ups on underwater obstructions. Also, the plastic grid could be changed to a more rugged material. Weights could be added to the inside of the stanchions to aide in the insertion of the needles into the marsh sediment. Finally, the air and fluid intake lines could be placed somewhere along the top of the grid rather than on the edges. This would prevent tears in the tubing due to sharp underwater objects.

Luer locks with built-in check valves and syringes with built-in fluid intake valves could replace the crudely attached valves that are currently being used. Removable syringe tops could also be constructed to replace the current tops. This would greatly reduce the maintenance time. These items were not purchased due to the project budget restrictions.

6. CONCLUSION

The present prototype for the injection system is ready for field testing. However, there are some unresolved matters that require attention. These issues are mainly related to the current syringe setups and check valve connections. As stated previously, the check valves have been attached to the syringes with JB-Weld. Although this is a strong adhesive, it is not made for sealing applications which has created a leakage problem in the valves. These leaks were discovered after some testing was performed. This test consisted of applying a vacuum and pressurized air with a small AC air pump. A vacuum tube line was used to connect the pump to the pneumatic manifold intake line. Another tube was used to connect the hydraulic manifold line to a large container filled with water to simulate the amendment solution. After repeating cycles of vacuum and pressure to the syringes, it was observed that most of the syringes weren't filling up with fluid as planned. In many syringes, only a small amount of fluid would be taken into the barrel. This is how the leaks in the check valves were discovered. In light of the discovered leaks in the check valves, many solutions have been considered to resolve this matter. The most effective answer at this time would be to use luer lock check valves to attach all the needles. This would eliminate the need for JB-Weld to attach the needles and also make a better seal to avoid leaking. Therefore, another type of bonding agent such as epoxy could be used in this setup to simply add support for the luer lock check valves. Since most of the leakage was observed to be in the needle check valves, it is possible that there would be no need to replace the angled valves once this new setup is implemented. Once these issues are resolved, it is believed that this injection system will be able to operate in virtually any marsh environment.

7. BUDGET

7.1 Purposed Budget

The following is an itemized list of the parts, serial numbers, and their associated prices provided though catalogs and/or price quotes.

Table 7.1 - Pneumatic Needle Subgroup Budget

Quantity	Product #	Description	Company	Unit Price	Total Price
2	460LL - 2PK	60mL Luer Lock Barrel Syringe	Techcon Systems	$27.00	$54.00
2	460L - 9PK	Plastic Wiper Stopper Plunger	Techcon Systems	$29.00	$58.00
9	U-MGPTX-02	2.0mm SS Tubing (15ga) 36 inch section	Small Parts Dot Com	$45.00	$405.00
1	U-211040	Polycarbonate Check Valves Qty 100	Small Parts Dot Com	$175.00	$175.00
100	N/A	Female Bushing Adaptor	Home Depot	$0.20	$20.00
100	N/A	1/4 Hose Barbs	Home Depot	$0.88	$88.00
		Pneumatic Needle Syringe Subgroup Total			**$800.00**

Table 7.2 - Needle Grid Subgroup Budget

Quantity	Product #	Description	Company	Unit Price	Total Price
1	N/A	Need Grid Substrate 3' by 3'	UNH	$0.00	$0.00
1	PAS - 600	Waterproof Switch	Sound ocean	$230.00	$230.00
1	N/A	1-1/2 SCH 40 PVC Pipe	Home Depot	$5.13	$5.13
100	169212	Springs	Home Depot	$1.92	$192.00
10	138677	Electrical Cable	Home Depot	$0.37	$3.70
		Needle Grid Subgroup Total			**$430.83**

Table 7.3 - Needle Grid Actuator Subgroup Budget

Quantity	Product #	Description	Company	Unit Price	Total Price
1	5W660	12V DC Winch	Grainger	$302.00	$302.00
1	6W030	3/16" Vinyl Jacket	Grainger	$45.85	$45.85
4	N/A	1-1/2 SCH 40 PVC Pipe	Home Depot	$5.13	$20.52
		Needle Grid Actuator Subgroup Total			**$368.37**

Table 7.4 - Control System Subgroup Budget

Quantity	Product #	Description	Company	Unit Price	Total Price
1	D0-05DD-D	PLC - 8 inputs / 6 outputs	Automation Direct	$99.00	$99.00
1	DV-1000	User Interface	Automation Direct	$150.00	$150.00
1	BN4121206CH	Waterproof Electrical Box 12 x 12 x 6	Automation Direct	$53.00	$53.00
		Control System Subgroup Total			**$302.00**

Table 7.5 - Total Proposed Budget

Project Total	$1,901.20
Project Contingency	$500.00
Project Grand Total	**$2,401.20**
Amount of Project Covered by UNH Sea Grant	-$1,500.00
Total Cost To Bioremediation CICEET Project	**$901.20**

7.2 Final Project Budget

The following table reflects the money spent to create the prototype.

Table 7.6 - Total Project Budget

Part #	Description	Items / Pkg	Price	Pkg Quantity	Total Price
50415K202	Metric 316 S.S. Tubing 2mm OD, 1mm ID, 1m Lengths	1	$12.63	19	$239.97
5372K634	Nylon Multi-Barbed Tube Fitting, 1/4" Tee Pipe Adapter x 1/4"NPT	10	$5.29	5	$26.45
5372K312	Nylon Multi-Barbed Tube Fitting, 1/4" Elbow Pipe Adapter x 1/4"NPT	10	$4.00	2	$8.00
5372K613	Nylon Multi-Barbed Tube Fitting, 1/4" Tube Tee	10	$5.75	5	$28.75
5372K371	Nylon Multi-Barbed Tube Fitting, 1/4" 90deg Tube Elbow	10	$6.79	2	$13.58
4880K201	PVC Schedule 40, Reducing Hex Bushing, 3/4" x 1/2"	1	$0.44	60	$26.40
4880K343	PVC Schedule 40, Threaded Hex Bushing, 1/2" x 1/4"	1	$1.26	60	$75.60
7876K58	Derlin Direct-Action Solenoid Valve	1	$34.38	2	$68.76
7757K43	Polypropylene Ball-check Valve	1	$2.90	100	$290.00
55525K12	Vacuum PVC Tubing 1/4" ID	1	$0.80	50	$40.00
6763K13	1/4" NPT Brass Pressure Regulator	1	$29.58	1	$29.58
50785K12	1/4" x 1 1/2" Brass Nipple	1	$1.08	2	$2.16
5245K11	1/4" Self-Coiling Airline 12' length	1	$8.95	2	$17.90
94135K8	1 3/4" Extension Spring	6	$6.61	14	$92.54
7389K11	Water-Proof Snap acting Switch, Normally closed	1	$16.32	1	$16.32
D0-05DR-D	PLC w/ 8DC Inputs And 6 Relay outputs	1	$99.00	1	$99.00
D2-DSCBL	PLC Programming Cable	1	$27.00	1	$27.00
460II-1	60cc Luer Lock Barrel	1	$0.38	100	$38.00
460I-9	Pe Air Powered 60cc Piston	1	$0.66	100	$66.00
P80PJ	1 1/2" x 20' Schedule 80 PVC Pipe	4	$16.40	1	$16.40
N/A	1" Aluminum Pipe	4	$85.68	1	$85.68
N/A	Magnum Steel Putty	1	$2.99	2	$5.98
81387	JB Cold Weld	1	$4.49	3	$13.47
18613	5min Epoxy	1	$2.00	3	$6.00
N/A	Copper Gasket spray	1	$4.99	1	$4.99
N/A	24V DC Winch Motor	1	$357.00	1	$357.00
N/A	Misc Ace Hardware Stuff				$149.01
			Grand Total	=	$1,844.54

REFERENCES

Gilbert, J., (2000). *Natural and Nutrient-Enhanced In Situ Bioremediation of Petroleum-Contaminated Salt Marsh Sediments.* Master's Degree Thesis submitted in partial requirement for the Civil Engineering degree program. University of New Hampshire, Durham, NH.

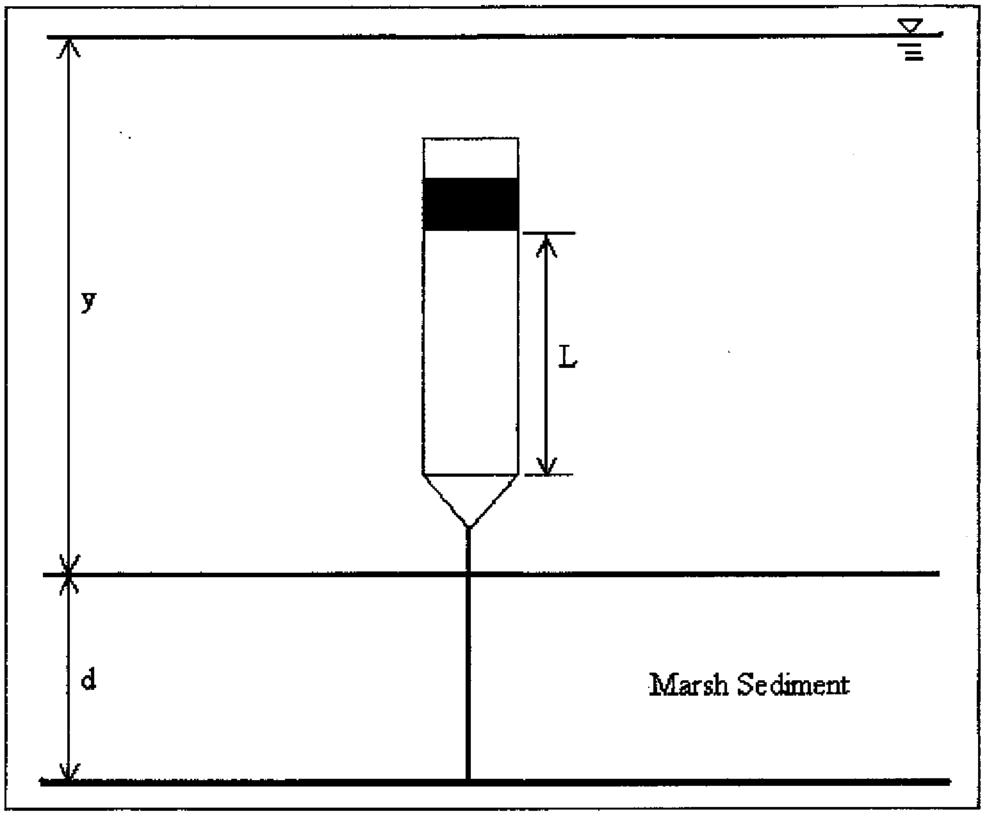
Hildebrand, D., (2001). Natural and Terminal Electron Acceptor-Enhanced In-Situ Bioremediation of Oil Contaminated Salt Marsh Sediments. Master's Degree Thesis submitted in partial requirement for the Civil Engineering degree program. University of New Hampshire, Durham, NH.

Mazzone, M., M. Manning and S. Boduch, (2002). Bioremediation Vessel. Ocean Projects Final Report (TECH 797). University of New Hampshire, Durham NH.

APPENDIX A:

FORCE REQUIRED TO ACTUATE PLUNGER CALCULATIONS

To determine the force necessary to actuate the plungers in the syringe barrels some theoretical calculations needed to be completed. Below is a diagram of the problem:



Given:	$y = 1.524m$	⇒	Water depth
	$d = 0.152m$	⇒	Needle insertion distance into the marsh sediment
	$L = 0.102m$	⇒	Travel distance of the plunger
	$P_d = 0.027m$	⇒	Inside diameter of syringe barrel
	$P_n = 1.9 \times 10^{-5}$	⇒	Inside diameter of needle
	$\rho = 1025\ kg/m^3$	⇒	Density of salt water
Assumptions:	$Q = 2$ cc/s	⇒	Injection rate
	1 Foot of Saltwater = 21.307 Pa		

Start by applying a control volume to the syringe and needle treating it as a nozzle. This allows Bernoulli's equation to be applied:

$$\frac{P_1}{\rho} + \frac{1}{2} \cdot V_1^2 + g \cdot z_1 = \frac{P_2}{\rho} + \frac{1}{2} \cdot V_2^2 + g \cdot z_2$$

where: P_1 = Pressure behind the piston

$V_1 = (Q/P_d)$ ⇒ Velocity of the piston

z_1 = Max height of the piston

$P_2 = 117.19$ Pa ⇒ Pressure at the needle tip

$V_2 = (Q/P_n)$ ⇒ Velocity of liquid exiting the needle tip

z_2 = Min height of the piston

Solving for the pressure behind the piston and multiplying by the area to obtain the force required to depress the plunger:

$$P_1 := P_2 + \left[\frac{1}{2} \cdot \rho \cdot \left(V_2^2 - V_1^2\right)\right] + \rho \cdot g \cdot (z_2 - z_1)$$

$$F := P_1 \cdot \left(\pi \cdot \frac{P_d^2}{4}\right)$$

The force required to depress the plunger is 8.8 N. This differs from the experimental calculations by a magnitude of four. This difference can be attributed to the friction between the plunger and the wall of the syringe barrel. However, most of the difference could be attributed to marsh sediment being forced up inside of the needle causing an initial force greater then the force required to dispense the amendments into the marsh to clear the sediment from the needle.

APPENDIX B:

INSERTION AND PLUNGER FORCE DATA

Experimental Results					
Site #	Trial #	Injector Mass (kg)	Plunger Mass (kg)	Injector Force (N)	Plunger Force (N)
1	1	0.15	1.37	1.4715	13.4397
	2	0.629	3.633	6.17049	35.63973
	3	0.15	3.644	1.4715	35.74764
	4	0.15	3.522	1.4715	34.55082
	5	0.363	3.601	3.56103	35.32581
	6	0.466	3.605	4.57146	35.36505
	7	0.386	3.62	3.78666	35.5122
	8	0.555	3.671	5.44455	36.01251
	9	0.599	3.662	5.87619	35.92422
	10	0.416	3.658	4.08096	35.88498
2	1	0.15	3.528	1.4715	34.60968
	2	0.363	3.633	3.56103	35.63973
	3	0.452	3.592	4.43412	35.23752
	4	0.629	3.658	6.17049	35.88498
	5	0.552	3.62	5.41512	35.5122
	6	0.299	3.633	2.93319	35.63973
	7	0.363	3.658	3.56103	35.88498
	8	0.386	3.62	3.78666	35.5122
	9	0.523	3.491	5.13063	34.24671
	10	0.418	3.644	4.10058	35.74764
3	1	0.254	3.588	2.49174	35.19828
	2	0.629	3.659	6.17049	35.89479
	3	0.483	3.633	4.73823	35.63973
	4	0.15	3.658	1.4715	35.88498
	5	0.363	3.62	3.56103	35.5122
	6	0.411	3.644	4.03191	35.74764
	7	0.51	3.628	5.0031	35.59068
	8	0.629	3.633	6.17049	35.63973
	9	0.15	3.62	1.4715	35.5122
	10	0.363	3.644	3.56103	35.74764

Averages:	3.904707	35.52573103
Standard Deviation:	1.579727198	0.422444013

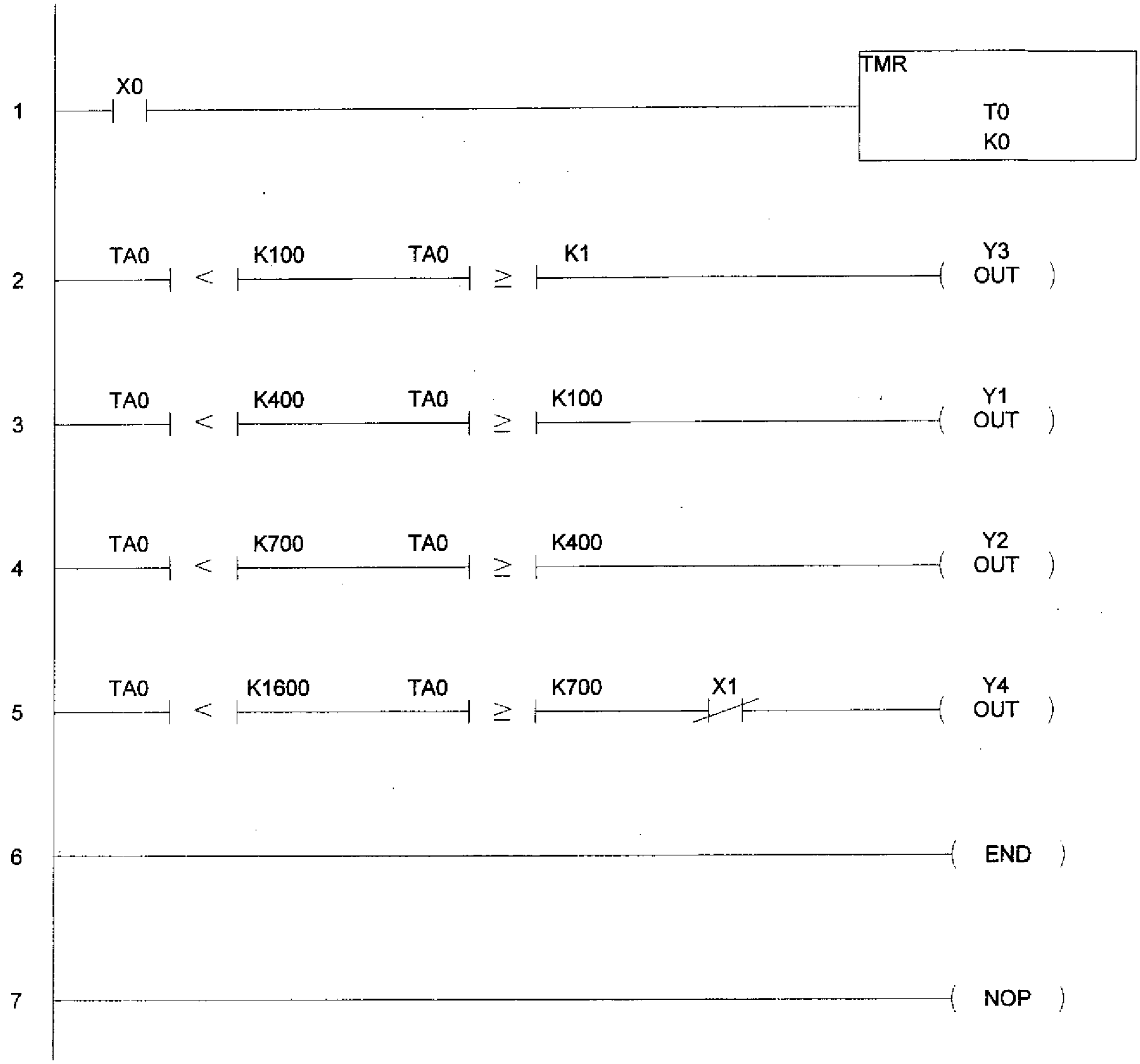
APPENDIX C:

PLC WIRING INFORMATION

The following chart is used to connect the various components of the control system to the PLC:

Channel	**Description**	**Input / Output**	**Terminal Polarity**
C0	Common For X0, X1, X2, X3	Input Power	Positive 12V
C1	Common For X4, X5, X6, X7	Input Power	Not Used
C2	Common For Y0, Y1, Y2	Output Power	Negative 12V
C3	Common For Y3, Y4, Y5	Output Power	Positive 12V
X0	Input signal from Clean Cat	Input Signal	Negative 12V
X1	Input signal from Snap-acting switch	Input Signal	Negative 12V
X2	Not Used	-	Negative 12V
X3	Not Used	-	Negative 12V
X4	Not Used	-	-
X5	Not Used	-	-
X6	Not Used	-	-
X7	Not Used	-	-
Y0	Not Used	-	Positive 12V
Y1	Pressure Valve Actuation	Connect to Negative	Positive 12V
Y2	Vacuum Valve Actuation	Connect to Negative	Positive 12V
Y3	Winch Up Relay	Output Power	Negative 12V
Y4	Winch Down Relay	Output Power	Negative 12V
Y5	Not Used	-	Negative 12V

The following page includes the programming ladders for the PLC.


1
X0
TMR
T0
K0
2
TA0 < K100
TA0 ≥ K1
Y3
OUT
3
TA0 < K400
TA0 ≥ K100
Y1
OUT
4
TA0 < K700
TA0 ≥ K400
Y2
OUT
5
TA0 < K1600
TA0 ≥ K700
X1
Y4
OUT
6
END
7
NOP

Feature and Specifications

The DL05 Micro PLCs contain the CPU, power supply, and I/O all in the same housing. If you examine the CPU Specifications table, you'll see that we included many features found in our modular CPUs.

Reviewing the specs

Make sure these features can satisfy the requirements of your application. Detailed specifications for each version of the DL05 PLC are located later in this section.

System capacity

System capacity is the ability to accommodate a variety of applications. For ladder memory, most boolean instructions require one word. Some other instructions, such as timers, counters, etc. require two or more words. Our V-memory locations are 16-bit words and are useful for data storage, etc.

Performance

Performance is simply the scan time, which is the amount of time required to read the inputs, solve the RLL program and update the outputs.

Instructions and diagnostics

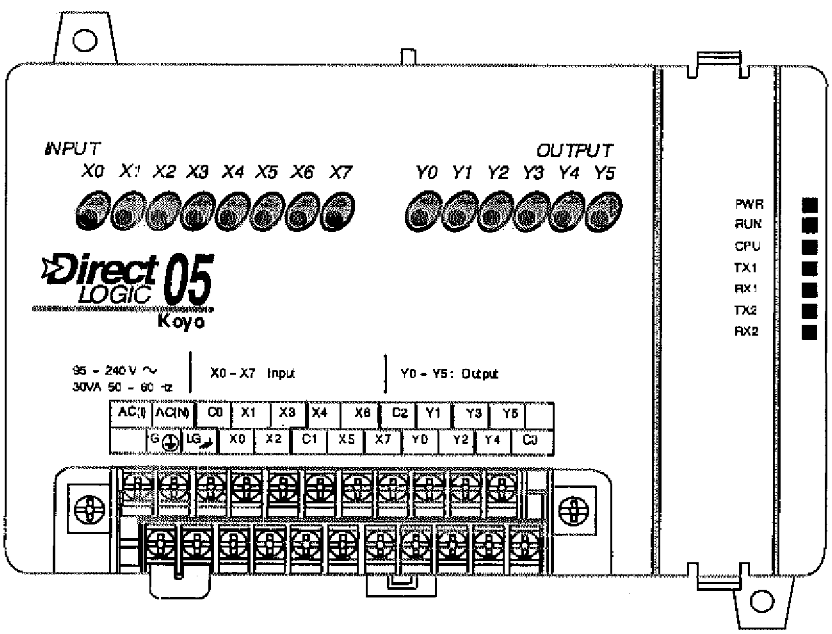
Make sure the unit offers the instructions needed. A complete list of instructions is available at the end of this section.

Communications

The DL05 offers powerful communication features normally found only on more expensive PLCs. Check to see if the available features fulfill your specific needs.

Specialty features

For the DC input and/or DC output versions, we also offer several high-speed I/O features.



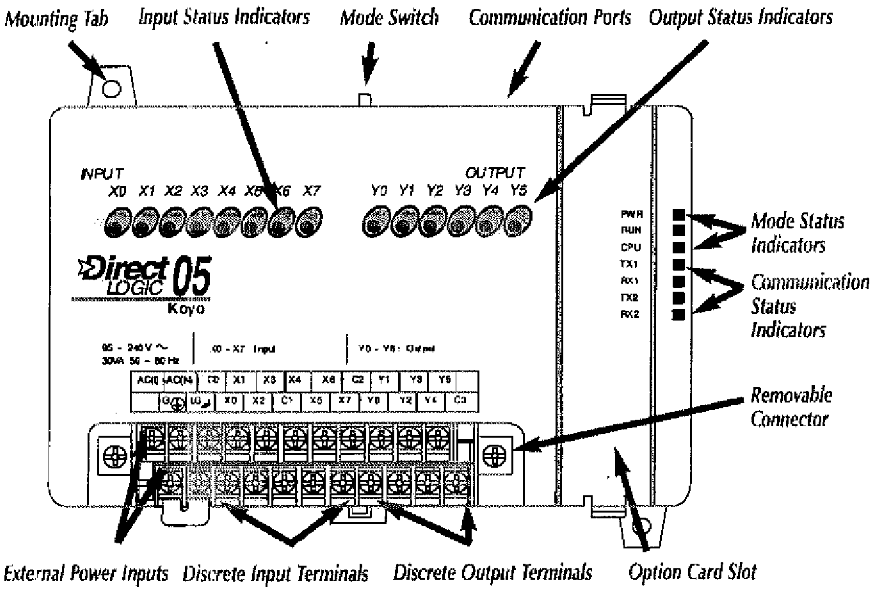
DL05 CPU Specifications	
System capacity	
Total memory available (words)	6K
Ladder memory (words)	2,048
V-memory (words)	4,096
User V	3,968
Non-volatile User V	128
Battery backup	Yes[1]
Total I/O	14
Inputs	8
Outputs	6
I/O expansion	Yes[1]
Performance	
Contact execution (Boolean)	2.0μs
Typical scan (1K Boolean)[2]	2.7-3.2ms.
Instructions and diagnostics	
RLL ladder style	Yes
RLLPLUS/flowchart style (Stages)	Yes/256
Run-time editing	Yes
Scan	Variable/fixed
Instructions	129
Control relays	512
Timers	128
Counters	128
Immediate I/O	Yes
Subroutines	Yes
For/next loops	Yes
Timed interrupt	Yes
Integer math	Yes
Floating-point math	No
PID	Yes[1]
Drum sequencers	Yes
Bit of word	No
ASCII print	Yes
Real-time clock/calendar	Yes[1]
Internal diagnostics	Yes
Password security	Yes
System and user error log	No
Communications	
Built-in ports	Two RS-232C
K-sequence (proprietary protocol)	Yes
DirectNet master/slave	Yes
MODBUS RTU master/slave	Yes
ASCII out	Yes
Baud rate	
Port 1	9,600 baud (fixed)
Port 2	selectable 300-38,400 baud (default 9,600)
Specialty Features	
Filtered inputs	Yes[3]
Interrupt input	Yes[3]
High speed counter	Yes, 5kHz[3]
Pulse output	Yes, 7kHz[3]
Pulse catch input	Yes[3]

1- These features are available with use of certain option cards. Option card specifications are located later in the DL05 section.

2- Our 1K program includes contacts, coils, and scan overhead. If you compare our products to others, make sure you include their scan overhead.

3- Input features only available on units with DC inputs. Output features only available on units with DC outputs.

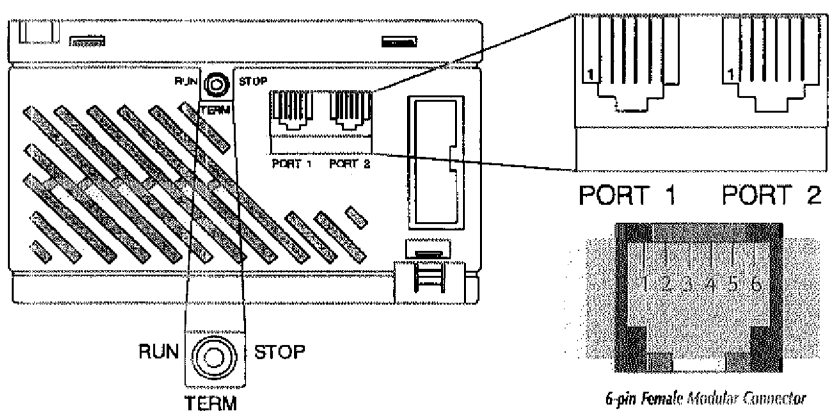
Hardware features diagram



Two communication ports!

Port 1 Pin Descriptions		
1	0V	Power (-) connection (GND)
2	5V	Power (+) connection
3	RXD	Receive data (RS-232C)
4	TXD	Transmit data (RS-232C)
5	5V	Power (+) connection
6	0V	Power (-) connection (GND)

Port 2 Pin Descriptions		
1	0V	Power (-) connection (GND)
2	5V	Power (+) connection
3	RXD	Receive data (RS-232C)
4	TXD	Transmit data (RS-232C)
5	RTS	Request to send
6	0V	Power (-) connection (GND)



6-pin Female Modular Connector

Status Indicators		
Indicator	**Status**	**Meaning**
PWR	ON	Power good
	OFF	Power failure
RUN	ON	CPU is in Run Mode
	OFF	CPU is in Stop or Program Mode
CPU	ON	CPU self diagnostics error
	OFF	CPU self diagnostics good
TX1	ON	Data is being transmitted by the CPU-Port 1
	OFF	No data is being transmitted by the CPU-Port 1
RX1	ON	Data is being received by the CPU-Port 1
	OFF	No data is being received by the CPU-Port 1
TX2	ON	Data is being transmitted by the CPU-Port 2
	OFF	No data is being transmitted by the CPU-Port 2
RX2	ON	Data is being received by the CPU-Port 2
	OFF	No data is being received by the CPU-Port 2

Fixed Flash Memory: The DL05 units offer built-in Flash memory. However, memory cannot be removed or changed like the D2-230 and D2-240 CPU's.

Mode Switch Position	CPU Action
RUN (Run Program)	CPU is forced into the RUN mode if no errors are encountered. No changes are allowed by the programming/monitoring device.
TERM (Terminal)	RUN PROGRAM and the TEST modes are available. Mode and program changes are allowed by the programming/monitoring device.
STOP	CPU is forced into the STOP mode. No changes are allowed by the programming/monitoring device.

DL05 Communication Features

All DL05 units offer two 6-pin, RS-232C ports. Each of these ports can be connected to a hand-held programmer, *Direct*SOFT software, operator interfaces, etc. Port 1 is fixed at 9,600 baud and port 2 has selective baud rates from 300-38,400 baud.

Protocols supported

Each port is capable of communicating with K-sequence, ***Direct***Net, and MODBUS protocols. Port 1 can only be a slave for each of the protocols. Port 2 can serve as a K-sequence slave or a network master or slave for either ***Direct***NET or MODBUS RTU protocols.

An option card is available that will allow you to connect your DL05 to a DeviceNet network. See information on option cards later in this section.

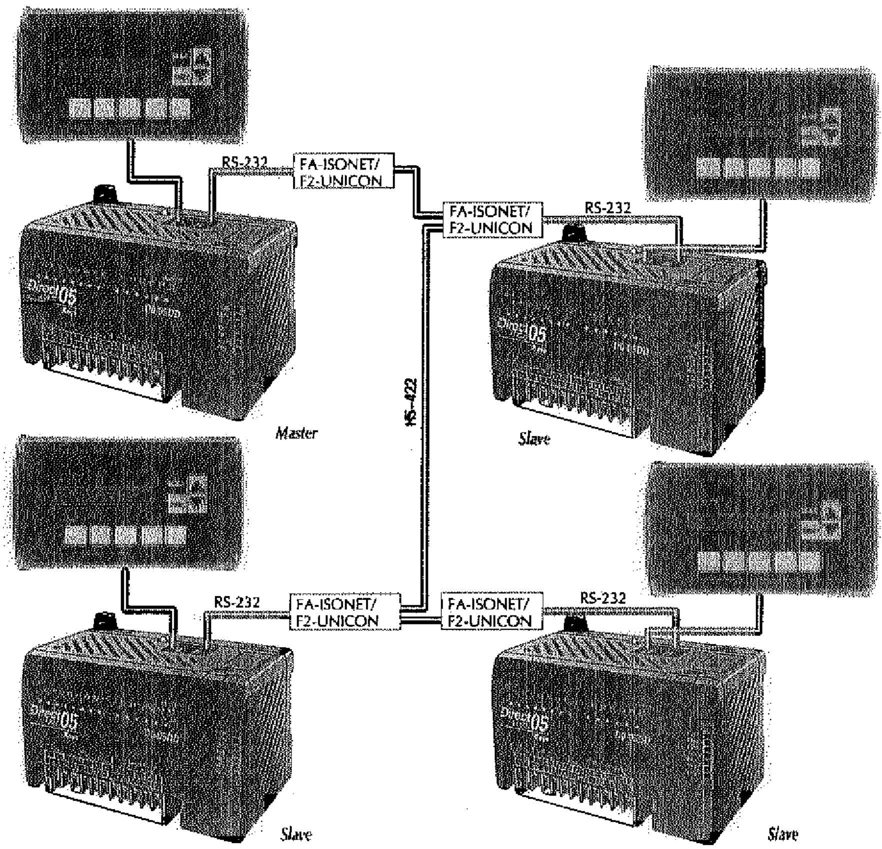
Communication Port 1

Connects to:
HPP, ***Direct***SOFT, operator interfaces, etc.
6-pin, RS-232C
9,600 Baud (fixed)
Parity – odd (fixed)
Station address 1 (fixed)
8 data bits
1 start, 1 stop bit
Asynchronous, Half-duplex, DTE
Protocol: (Auto-Select)
- K sequence (Slave only)
- ***Direct***NET (Slave only)
- MODBUS (Slave only)

Communication Port 2

Connects to:
HPP, ***Direct***SOFT, operator interfaces, etc.
6-pin, RS-232C
Communication speed (baud)
300, 600, 1,200, 2,400, 4,800, 9,600 (default), 19,200, and 38,400
Parity-odd (default), even, none
Station address 1 (default),
1-90 ***Direct***Net/K-sequence,
1-247 MODBUS RTU
8 data bits
1 start, 1 stop bit
Asynchronous, Half-duplex, DTE
Protocol:
- K sequence (Slave only)
- ***Direct***NET (Master/Slave)
- MODBUS (Master/Slave)
- Non-sequence/Print

Networking the DL05



The DL05 product family offers several different combinations of I/O points. Choose the I/O points that are right for your application.

Fixed discrete I/O

All DL05 Micro PLCs have 8 inputs and 6 outputs, regardless of the actual type of points on the unit (DC in/Relay out, DC in/DC out, etc.)

Option card slot

The DL05 has an option card slot that allows you to add a variety of features to your PLC. Detailed specifications for the option cards are available later in this section.

Automatically assigned addresses

The DL05 uses automatic addressing, so for the vast majority of applications, there is no setup required. We use octal addressing for our products, which means there are no 8's or 9's. The 8 input points use addresses X0-X7. The 6 output points use addresses Y0-Y5.

Review the I/O specs and wiring diagrams

The I/O Options Table gives a brief description of the I/O combinations offered for the DL05 PLCs. The I/O specifications discussed in more detail later in this section. Make sure the I/O specifications are within the range required by your application.

I/O Options Table

Part Number	INPUTS			OUTPUTS		
	I/O Type/ Commons	Sink or Source	Voltage Ranges	I/O Type/ Commons	Sink or Source	Voltage/Current Ratings
D0-05AR	AC/2	N/A	90-120VAC	Relay/2	Sink or Source	6-27VDC, 2A 6-240VAC, 2A
D0-05DR	DC/2	Sink or Source	12-24VDC	Relay/2	Sink or Source	6-27VDC, 2A 6-240VAC, 2A
D0-05AD	AC/2	N/A	90-120VAC	DC/1	Sink	6-27VDC, 0.5A (Y0-Y2) 6-27VDC, 1.0A (Y3-Y5)
D0-05DD	DC/2	Sink or Source	12-24VDC	DC/1	Sink	6-27VDC, 0.5A (Y0-Y2) 6-27VDC, 1.0A (Y3-Y5)
D0-05AA	AC/2	N/A	90-120VAC	AC/2	N/A	17-240VAC 47-63Hz 0.5A
D0-05DA	DC/2	Sink or Source	12-24VDC	AC/2	N/A	17-240VAC 47-63Hz 0.5A
D0-05DR-D	DC/2	Sink or Source	12-24VDC	Relay/2	Sink or Source	6-27VDC, 2A 6-240VAC, 2A
D0-05DD-D	DC/2	Sink or Source	12-24VDC	DC/1	Sink	6-27VDC, 0.5A (Y0-Y2) 6-27VDC, 1.0A (Y3-Y5)

Sinking/sourcing

If you are using a DC field device, you should consider whether the device requires a sinking or sourcing configuration on the PLC I/O. For more information on sinking and sourcing concepts, please refer to the appendix section of this catalog.

Sink/Source Inputs — all DC inputs on the DL05 Micro PLCs can be wired in a sinking or sourcing configuration. However, all inputs on a single common must use the same configuration.

Sinking Outputs — all DC outputs on the DL05 Micro PLCs must be wired in a sinking configuration. If a sourcing output is required, consider using a unit with relay outputs.

Special high-speed counting and pulse output features

Selected DL05 units offer special high-speed input features (DC input units) or pulse output features (DC output units). The first three inputs are automatically set up as filtered inputs with a 10 ms filter. By entering a setup code in a special V-memory location, you can choose other features. In some modes of operation, you have a choice as to how you use each point. For example, if you use X0 as an Up Counter, you can choose to use X2 as a reset input for the counter, or as a filtered discrete input. If these features are of interest, you should review the detailed high-speed I/O descriptions found later in this section.

Product Dimensions and Installation

It is important to understand the installation requirements for your DL05 system. This will help ensure that the DL05 products operate within their environmental and electrical limits.

Plan for safety

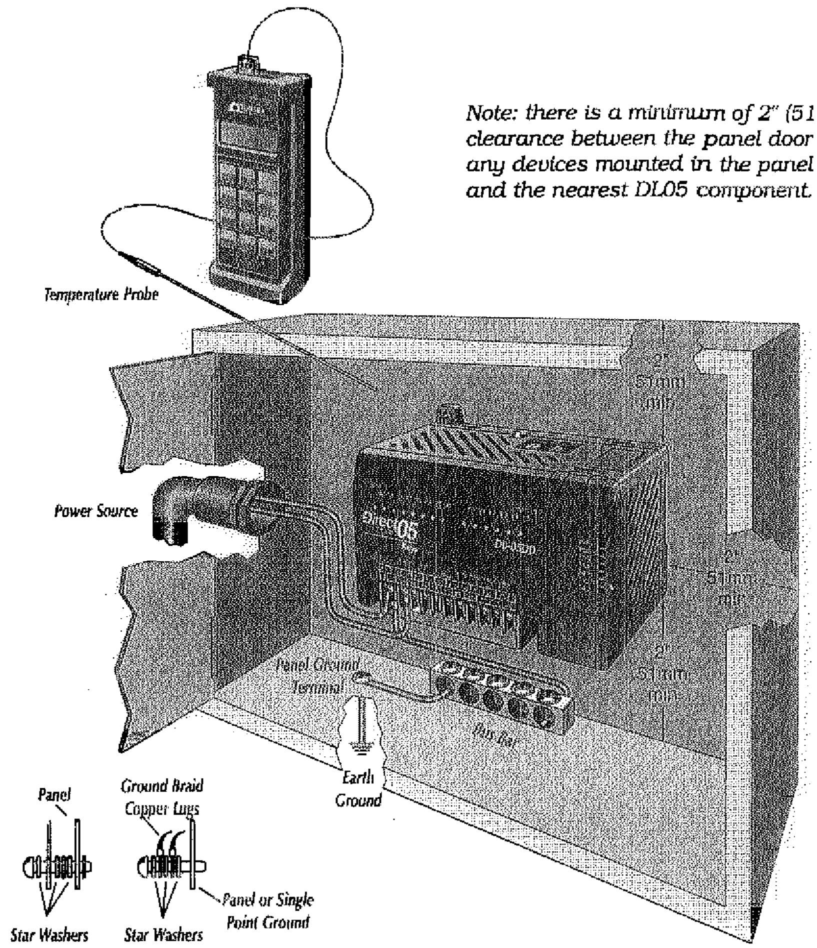
This catalog should never be used as a replacement for the user manual. The user manual, D0-USER-M, contains important safety information that must be followed. The system installation should comply with all appropriate electrical codes and standards.

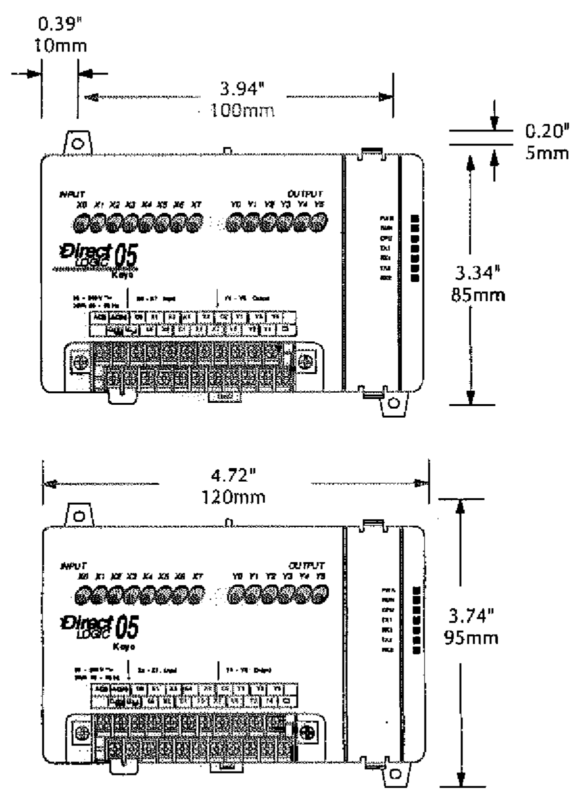
Unit dimensions and mounting orientation

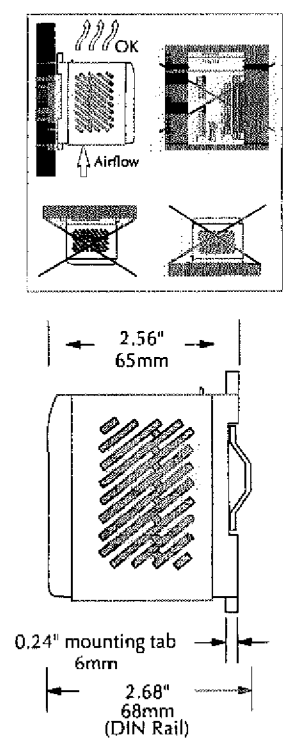
DL05 units must be mounted properly to ensure ample airflow for cooling purposes. It is important to check these dimensions against the conditions required for your application. For example, it is recommended that you leave 2" depth for ease of access and cable clearance; however, your distance may be greater or less. Also, check the installation guidelines for the recommended cabinet clearances.

Environmental Specifications	
Storage temperature	-4° F-158°F (-20°C to 70°C)
Ambient operating temperature	32°F-131°F (0° to 55°C)
Ambient humidity	5 to 95% relative humidity (non-condensing)
Vibration resistance	MIL STD 810C Method 514.2
Shock resistance	MIL STD 810C Method 516.2
Noise immunity	NEMA (ICS3-304)
Atmosphere	No corrosive gases

Note: there is a minimum of 2" (51mm) clearance between the panel door or any devices mounted in the panel door and the nearest DL05 component.







D0-05DD-D wiring diagram and specifications

Power Requirements

Voltage range 12-24VDC
.................................20W max.

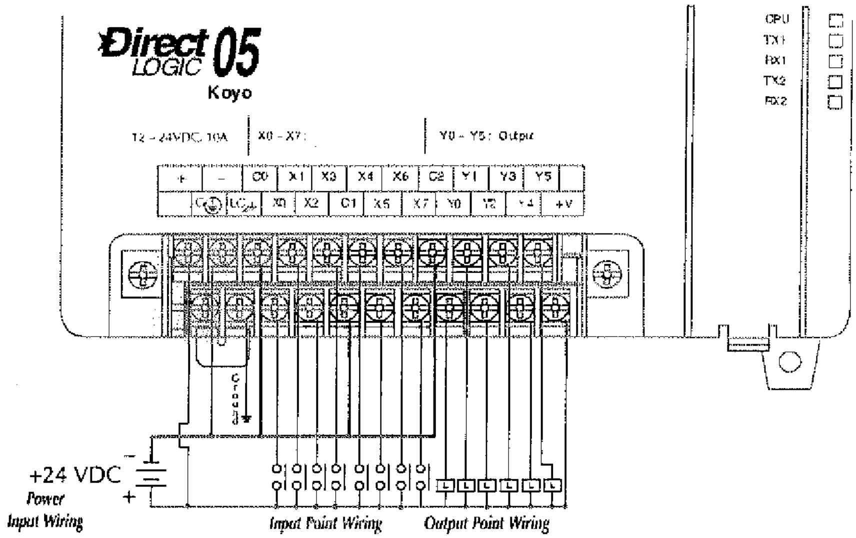
DC Input specifications

Number of input points ....8 (sink/source)
Number of commons ....2 (isolated)
Input voltage range 12-24VDC
Input impedance ....(X0-X2) 1.8K @ 12-24VDC
.....................(X3-X7) 2.8K @ 12-24VDC
ON current/voltage level ....>5mA/>10VDC
OFF current/voltage level ....<0.5mA/<2VDC
Response time X0-X2 X3-X7
OFF to ON ....<100µs <8ms
ON to OFF ....<100µs <8ms
Fuses ....None

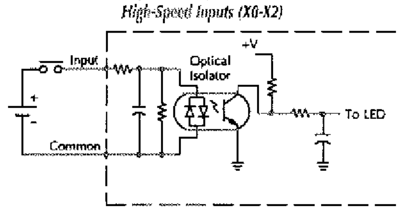
DC Output specifications

Number of output points ....6 (sinking)
Number of commons 1
Output voltage range 6-27VDC
Peak voltage 50VDC
Max.frequency (YC,Y1) 7kHz
ON voltage drop ....0.3VDC @ 1A
Maximum current ....0.5A/point (Y0-Y1)*
...........................1.0A point (Y2-Y5)
Maximum leakage current ....15µA @ 30VDC
Maximum inrush current ....2A for 100ms
OFF to ON response ....<10µs
On to OFF response ....<30µs
External DC power required 20-28VDC
.................................150mA max.
Status indicators ....Logic side
Fuses ....None (external recommended)

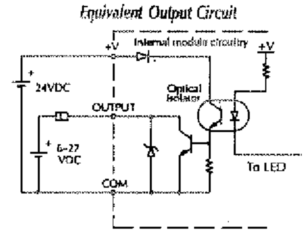
** When output points YO and Y1 are not used in pulse mode, the maximum output current is 1.0A.*



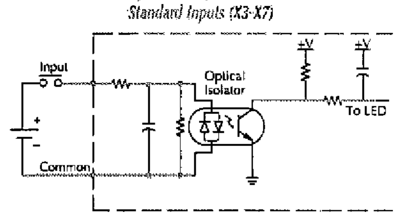
Equivalent Input Circuit, High-Speed Inputs (X0-X2)



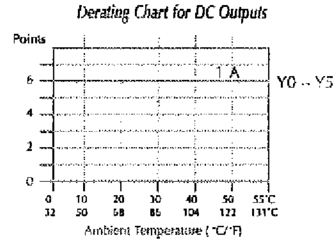
Equivalent Output Circuit



Equivalent Input Circuit, Standard Inputs (X3-X7)

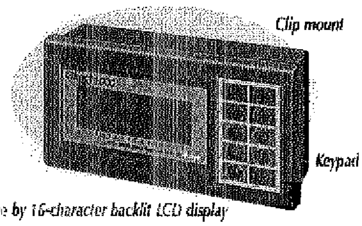


Derating Chart for DC Outputs



Overview

The **Direct**View DV-1000 is an incredibly small, low cost operator interface. The DV-1000 can be directly connected to DL05, DL105, DL205, D3-350 or DL405 CPUs. The DV-1000 is a "ladder logic dependent" terminal which relies entirely on PLC ladder logic to perform its functions. The DV-1000 does not require any configuration software. Instead, setup is performed through special reserved memory locations inside of the CPU. These special memory areas tell the DV-1000 which modes to use, and more importantly, where to get its display data. The following functions can be performed by the DV-1000:



4-line by 16-character backlit LCD display

View memory status: Up to 4 variable addresses can be displayed with their contents on a single screen.

View bit status: Display 32-bits (4 lines of 8) bits or 64-bits (4 lines of 16 bits) on a single screen. Bit data types can include I/O points, control relays, timer/counter and stage bits.

Change values of memory locations: Up to 16 different variable memory values can be changed (32 for DL405). Just move the cursor over the appropriate digit and press the increment (+)/decrement (-) keys.

Units per CPU: Only the DL05, D2-240, D2-250, D3-350, D4-440 and D4-450 CPUs can support two DV-1000s (D4-430 can only if used with a DCM). Both DV-1000s display the same data. Other CPUs can support only one DV-1000.

Display user-defined messages, even with embedded V-memory values: Each line may contain a maximum of four embedded values. Messages are stored in CPU variable memory. Therefore, the number of messages is limited only by available CPU variable memory.

Specifications	
Cable Required	See the cable selection table
Max. Distance	15 feet from the CPU
Connector	Phone jack RJ12
Power Consumption	150mA @ 5VDC max. (supplied by base power supply)
NEMA Rating	None
Agency Approval	UL, CSA, CE
Storage Temp	-4 to 158°F (-20 to 70°C)
Operating Temp	32 to 122°F (0 to 50°C)
Humidity	5-95% (non-condensing)
Vibration Resist	MIL STD 810C Method 514.2
Shock Resist	MIL STD 810C Method 516.2
Noise Immunity	NEMA (ICS3-304)
Atmosphere	No corrosive gases
Manufacturer	Koyo Electronics

Is the DV-1000 right for you?
The DV-1000 is best suited for displaying information and occasionaly changing simple program parameters. To use the DV-1000 you should be very comfortable with ladder logic programming. If you're looking for an operator panel ,you should consider the EZTouch or EZText panels. They are better suited for applications that require operator interaction as a normal part of operation.

Which CPU is best to use with the DV-1000?
The DL05, DL105, D2-240, D2-250, D3-350, D4-440, and D4-450 have ACON instructors that make the DV-1000 easier to work with. The DL105 and D2-230 have only one communication port, which can be a limitation in some cases. The DV-1000 does not work with D3-330 or D3-340 CPUs.

Bit Control: Eight keys on the DV-1000 can be configured to turn bits (Xs, Ys, & Cs) ON when pressed and OFF when released. This is great for debugging a piece of equipment.

Display system-defined error messages and user-defined fault messages even in list format: Scroll through errors and messages. Error logs can even show time and date stamps (D2-240, D2-250, D3-350, D4-440, D4-450 CPUs).

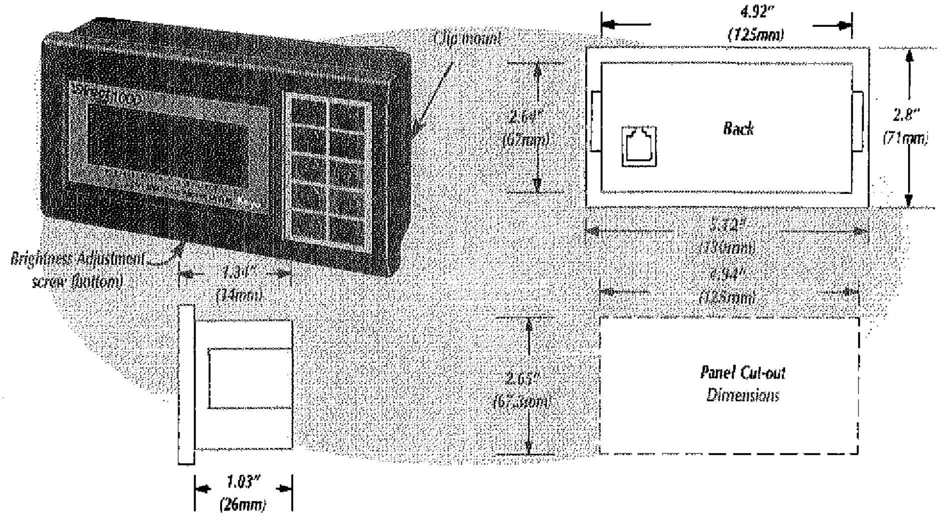
#150

Part Number	Description
DV-1000	*Direct*VIEW 1000 Timer/Counter access unit for *Direct*Logic PLCs
DV-1000CBL	Shielded cable to connect to *Direct*Logic PLCs, (RS-232C)
D4-1000CBL	Shielded cable to connect to 15-pin port on DL405 PLCs (RS232C)
FA-CABKIT	Universal cable kit for all CPUs (RS-232C) and PCs. 4 pre-wired D-sub adapters for plugging together most RS232C ports, 2 cables (RJ11,RJ12)

Dimension and Installation

The DV-1000 is designed to easily snap into a rectangular cutout in a control panel or other surface panel. On each side of the housing there is a retention clip to keep the unit in place after installation. There are no provisions for mounting screws, so if your particular application is subject to high amounts of vibration, this may be a factor in your selection process. The drawing gives the physical dimensions of the DV-1000 housing.

The panel cut-out dimensions are also shown. This size rectangle provides necessary clearance for the body of the unit, but allows the outer housing bezel to cover the edges of the cut-out for a nice finished appearance. The optimum panel thickness for using the retention clips is 1/16" to 1/8".



Cabling requirements

Since the DV-1000 only works with the DL05, DL105, DL205, D3-350 and DL405 CPUs, your cabling choices are fairly simple.

- **DV-1000CBL** — connects to DL05, DL105, DL205, D3-350 and D4-450 phone jack.
- **D4-1000CBL** — connects to all DL405 CPU 15-pin ports.

You can also build your own cable using the Universal Cable Kit (FA-CABKIT); however, this cable is unshielded and is susceptible to electrical noise. It is designed for quick testing situations and not for use in actual applications.

Maximum cable length of 15 feet between the DV-1000 and the PLC is recommended.

The DV-1000 can be connected to a DL205 or DL405 DCM, but you have to build your own cable.