Submersible Human Powered Research Cycle
(SHARC)

Ocean Projects Tech 797

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May 1994

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Abstract

The Submersible HumAn-Powered Research Cycle (SHARC) project is a two-semester undergraduate ocean research project to design and build a training and test platform for underwater work. The project covers the entire development cycle from a concept to a preliminary list of design criteria to a complete design and eventually to a fully functional test system. The SHARC system is used with a SCUBA diver to measure heart-rate, the RPM applied by the diver and the air consumed during the test. All measured data is sent to a personal computer for display, analysis and data recording.

The SHARC system includes two test modules: a classic rotary drive module and a newly developed linear module. Modularity is incorporated into the design to permit rapid exchange of drive modules during underwater testing. The design also incorporates flexibility for various sized divers and for various orientations of the diver using the device.

The application of the SHARC system is to test, evaluate and train prospective crew members for the International Human Powered Submarine Races. The system also provides a test facility to support future human powered submarine designs. In addition, SHARC provides a platform that could be adopted to other underwater ergonomic research programs.

Mission & Objective

The primary purpose of the Submersible Human-Powered Research Cycle (**SHARC**) is to provide a platform to quantify the performance of humans engaged in underwater work, such as that involved in propelling a submersible. By comparing output power, heart rate and air consumption, the overall performance of the peddler can be obtained. The second objective of the SHARC is to provide a system that can quantitatively test and evaluate the effectiveness of various human orientations on performance. Various angles and elevations are of interest in determining the optimum human position. A design objective of SHARC is the incorporation of modularity to permit evaluation of various propulsion modes. For this project two different modes were to be evaluated: a conventional rotary drive system, which is currently the popular mode of propulsion in human-powered vehicles, and a linear drive system.

A third purpose of the SHARC is to train individuals for future human-powered submarine competitions. By designing and building a versatile test and training platform, future design teams will be able to use the SHARC platform in the design and testing of new drive systems. More importantly, SHARC will be beneficial for training and selecting individuals to be propulsors for future human-powered competitions.

Design Requirements & Constraints

General Requirements:

To effectively design a system that will fulfill all of the mission goals, certain general requirements must be met. These design constraints are derived from the objectives of the project, and are listed below.

- Lightweight (200 - 400 lbs)
- Moderate size (width < 3 ft. Length < 10 ft.)
- Modularity (assembled by 2 people)
- Ease of transportation (no special transportation needed)

The weight of the entire system is limited to less than 400 pounds in order to facilitate handling by two people when assembled. The width of the system is limited to three feet to make it possible for the SHARC to be carried through a single or double door. The length constraint is based on the length of an average truck expected to be used for transportation. Modular design is an important feature that allows testing to be conducted by two people. Assembly and disassembly with only two people keeps the complexity of the process simple. With the size constraints the entire system will be easily transported in an average size truck.

Test Environment:

One of the most important constraints on the design is the testing environment, which is the indoor pool. Designing a system that will work properly underwater requires that several condition be met, including the following:

- Pool is not effected by system. (i.e. non-polluting system)
- All critical systems must be waterproof at design depth.
- Safety of test subject.
- Mechanical systems work in a liquid medium.

There are two driving concerns in keeping the pool unaffected by the presence of the SHARC. The first is that there can be no oil-based lubricants that will contaminate the water. The second factor is that the chlorinated water is very corrosive, therefore any material chosen must not breakdown while in contact with chlorine and water.

To insure that the sensor and electronics subsystems work underwater they must be waterproofed. This requires that either the system chosen is manufactured for this condition or that the design accounts for it.

Testing humans with this system requires a safe test environment for the subject. Therefore, only DC power will be used for all the equipment on the SHARC. The actual interface between the individual and the system must be comfortable. In any emergency the test subject must be able to get in and out of the test system quickly and safely. This means that the design must be keep simple to facilitate emergency egress. The area where the test subject is positioned must not have any obstructions that may interfere with the SCUBA equipment. The safety and the ease of use is one of the foremost design considerations for the system.

The mechanical systems are also constrained by working underwater. Lubrication of all moving parts must be done with food-grade lubricants or none at all. The shape of moving parts must be as streamlined as possible, to reduce hydrodynamic drag during operation. Assembly of separate systems underwater must be made as simple as possible. Simplicity of the entire system is a major focus which will increase the reliability and the safety of the system as a whole.

Test Platform:

The requirements and constraints of the testing process are of a nature that require the SHARC system be as versatile and simple as possible. The test setup and procedure are dependent on the type of test and the dimensions of the test subject. Therefore these constraints focus on the adjustability of the platform bench to fit the various subjects and different test setups. Adjustability must be provided as follows:

- Adjustable for stroke length.
- Adjustable bench height.
- Several declining angles.
- Incremental test loads.

With an adjustable stroke length the test platform is capable of testing short and tall individuals. The adjustable bench height is also an adjustment for different heights and leg lengths. Declining angles are needed to determine the angle at which maximum performance is achieved. To have a wide range of data, test loads must also have a wide range. The test loads must also be known to determine the determine the power output for each test run. Making the mechanical system as simple as possible will decrease the error in setting up the test. Simplicity will also increase the reliability and repeatability of each test that is run.

The accuracy of each test is determined by the accuracy the each sensor. The ability to store and later analyze the test data is also a critical portion of each test. The following data required to be accurately collected and stored:

- Heart-Rate values during test
- Revolutions per minute during test
- Air consumed during test
- All data from test sent to poolside computer
- System calibration data

Heart-Rate is critical to determine the level that the test subject is performing at. The R.P.M.s will be used to calculate the power output of the individual. The air consumed during the test will also be a factor that will determine the level of performance of the test subject. To analyze and evaluate the test, all the data must be gathered and stored in a poolside computer. To ensure that the data is accurate a calibration system must be employed. From these design requirements and constraints several potential designs evolved. These designs are in subsequent sections on specific subsystems.

A block diagram showing all of the major elements of the SHARC system is provided in Figure 2.1. A drawing of the SHARC assembly with a rotary drive system, is given in figure 2.2. Figure 2.3 also shows the side view of the linear drive system.

ToTal System Diagram

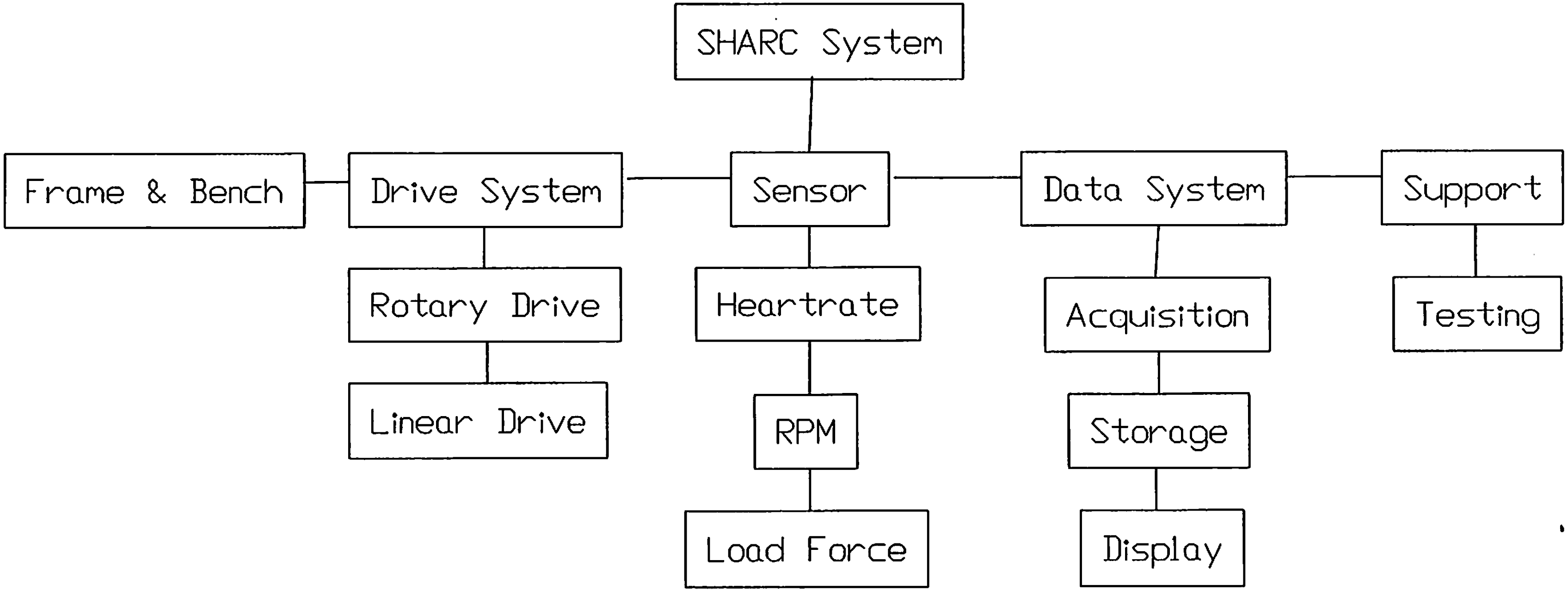
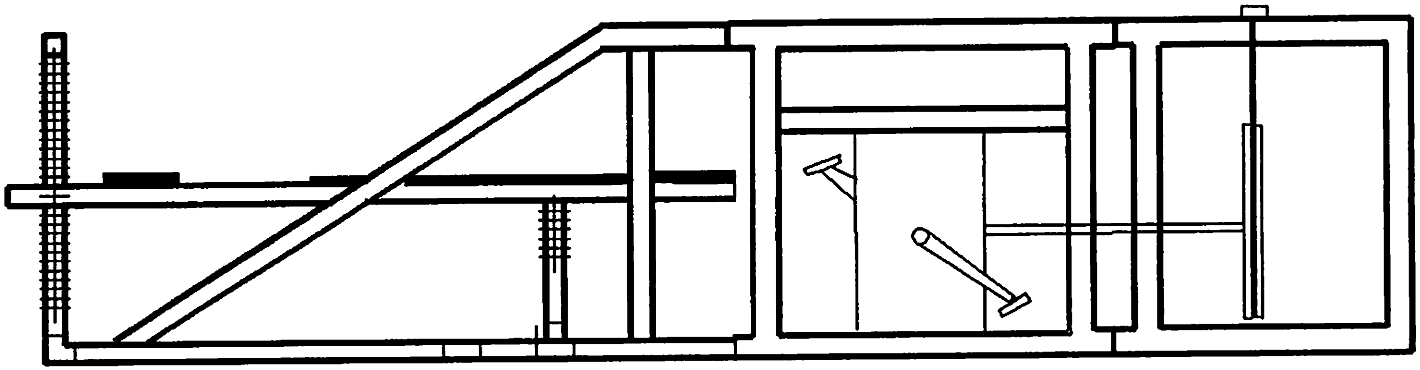
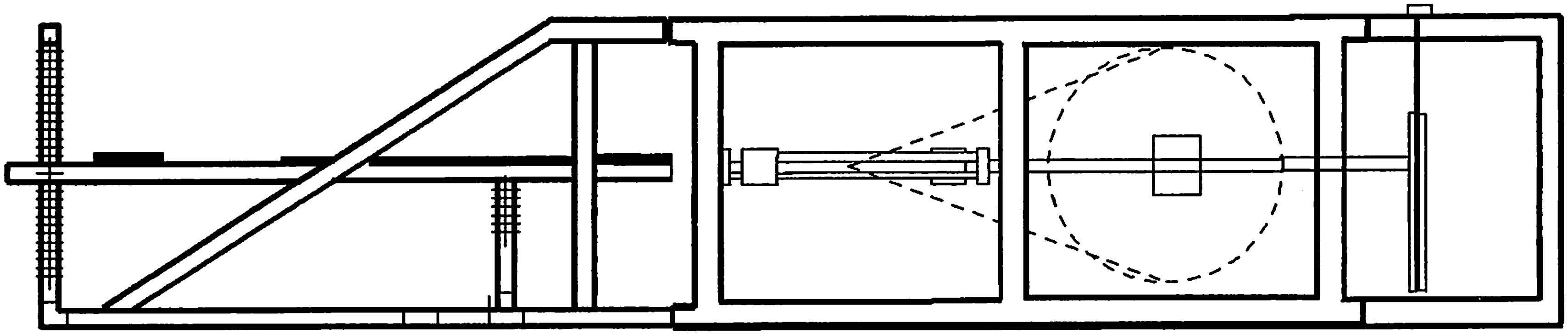


Figure 2.1



SHARC PROJECT

Figure 2.2	Desc: Overall with rotary drive	Date 4/29/94



SHARC PROJECT

Figure 2.3 | Desc: Overall with Linear Drive | Date 4/29/94

Bench Structure System

Functional Requirements

The bench support structure is designed to allow the diver to rest comfortably in the supine position at various angles of inclination while operating the drive systems. The bench support structure also includes a visual display of sensor output.

Design Requirements

Adequate strength to support up to a 300 lb scuba diver

Adjustable configuration:

a) for divers height between five and six and a half feet

b) for length of divers legs

c) for angle of inclination of bench support

Incorporate mountings for sensor displays

Provide modularity for easy attachment to and removal from drive systems.

Relatively light weight such that the structure can be transported by two persons.

Incorporate ballast platforms to anchor structure securely to pool floor.

Provide ability to keep scuba diver in supine position during operation.

System Design Considerations

When considering how strong to make our bench structure we assumed that the maximum weight that a scuba diver would weigh would be 300 lbs. With this weight limit we were able to look at different ways of supporting this weight. Since our bench structure will be used by divers of various heights the bench support structure must be adjustable to accommodate this. The bench support structure must be adjustable for angles of inclination of the bench support to allow for testing of various diver configurations. The bench structure must also provide a mounting for a display box which holds the sensor outputs. This display box enables the diver to observe RPM's and heart-rate while pedaling.

Modularity of the bench support structure is required in order to easily attach the structure to either a rotary drive or linear drive system. Testing of both drive systems should be done with minimal effort to exchange one for the other. In order to make this structure practical for application, it must be light enough

Incorporate ballast platforms to anchor structure securely to pool floor.

Provide ability to keep scuba diver in supine position during operation.

System Design Considerations

When considering how strong to make our bench structure we assumed that the maximum weight that a scuba diver would weigh would be 300 lbs. With this weight limit we were able to look at different ways of supporting this weight. Since our bench structure will be used by divers of various heights the bench support structure must be adjustable to accommodate this. The bench support structure must be adjustable for angles of inclination of the bench support to allow for testing of various diver configurations. The bench structure must also provide a mounting for a display box which holds the sensor outputs. This display box enables the diver to observe RPM's and heart-rate while pedaling.

Modularity of the bench support structure is required in order to easily attach the structure to either a rotary drive or linear drive system. Testing of both drive systems should be done with minimal effort to exchange one for the other. In order to make this structure practical for application, it must be light enough for two people to carry it to and from the pool area. The bench support structure must also have ballast platforms so that the ballast will properly anchor the bench support structure to the pool floor such that there will be no movement of the structure when the diver is operating in it.

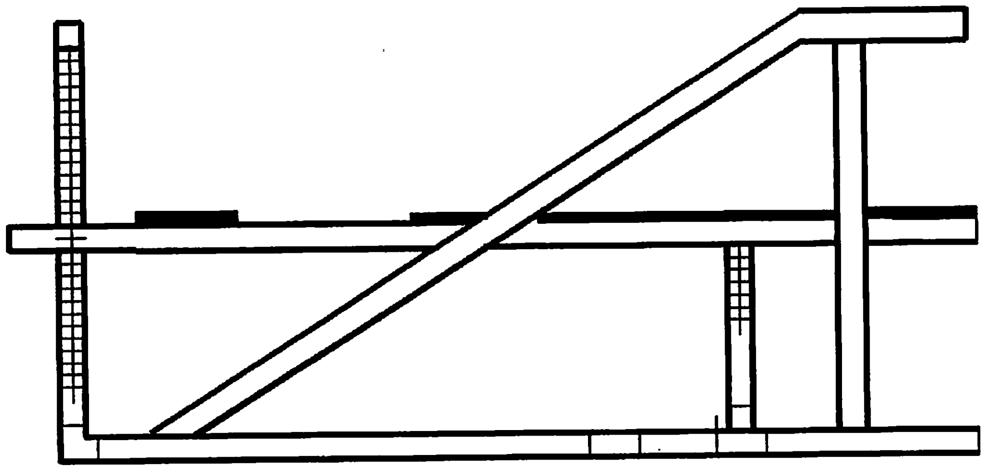
Design Alternatives

One of the material options considered was making the bench structure using steel. Steel would provide adequate strength to support a 300 lb scuba diver, but also results in several draw backs, including weight. Steel would make our structure much too heavy for handling by two persons. Steel would also corrode in the pool environment.

Aluminum was also considered, but was rejected based on price. Another alternative was the use of a simple flat platform, but this would not provide the modularity desired.

System Description:

The design selected incorporates adjustability and modularity. It is made from PVC piping, which met strength requirements and is easy to work with. The design uses schedule 80 PVC tubing and a flat plate of PVC that allows the scuba divers to rest on their stomachs while lying face down. The front upright posts have holes drilled in them with a pin that connects the end of the diver support structure to the front posts. This allows for vertical adjustment of the support structure. At the ends of the bench structure are long tube extenders which allow for adjustments of various leg lengths of the scuba divers. The scuba divers oxygen tank will be placed under the bench structure this will be done as well as using lead weights to keep the bench structure from moving during operation. Drawings of the bench system, giving a side view and a top view, are provided in Figures 3.1 and 3.2.

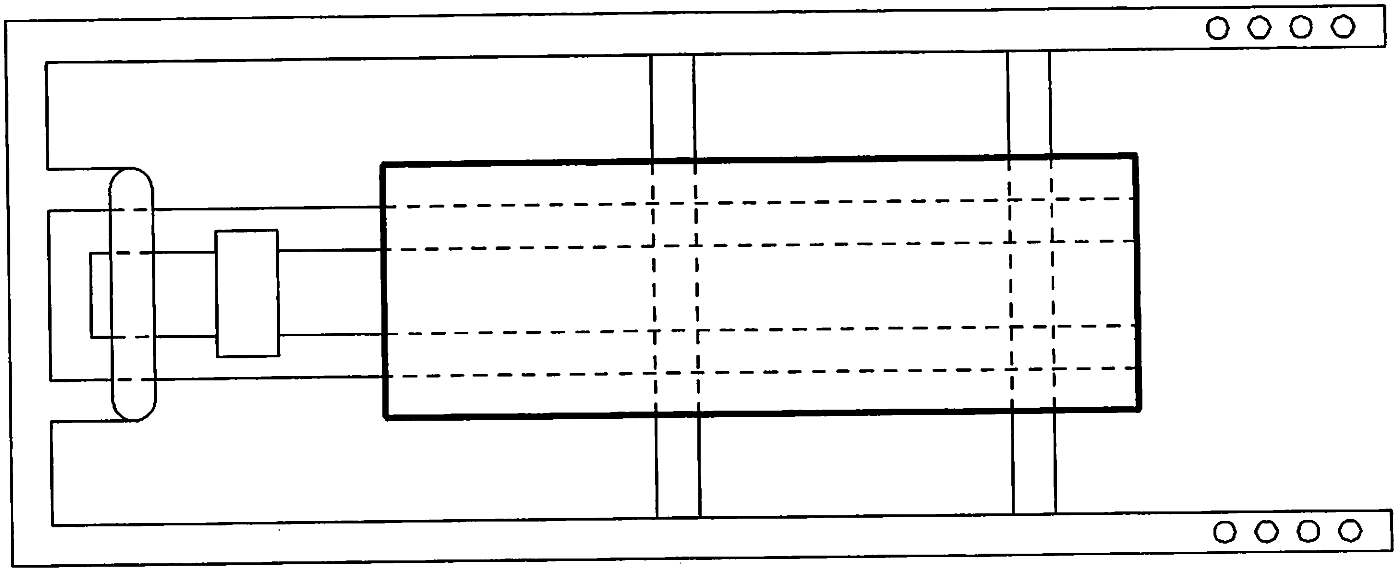


SHARC PROJECT

Figure 3.1

Desc: Bench (Side View)

Date 4/29/94



SHARC PROJECT

Figure 3.2

Desc: Bench (Top View)

Date 4/29/94

Linear Drive System

Functional Requirements:

The system converts the linear pedaling motion of the scuba diver into a rotational motion of the output shaft.

Design Requirements

Must be able to convert linear motion into rotational motion.

Must be corrosion resistant to water

Must be lubrication free to prevent contamination of the pool.

Must be modular or interchangeable with rotary drive system.

Must be light weight

Design Alternatives

Three design alternatives were considered for the linear drive system. One of the first designs considered was a power screw. It works on the principle of pushing a rachet pin through a descending spiral notch way which would cause the shaft to rotate while the pedal moves vertically. This concept had many flaws, and presented operational problems relative to how the pedals would return to the top position after they were pushed to the bottom. It would also require two spiral notched shafts which would some how have to be connected to one main shaft. The design was considered to be too complicated.

Another concept that was evaluated was a rack and pinion drive system. With this concept the rack connects to the pedal while the pinion rotates as the pedals are pushed down. This concept presented a design problem with respect to connecting the two pinions and returning the pedals to their top position.

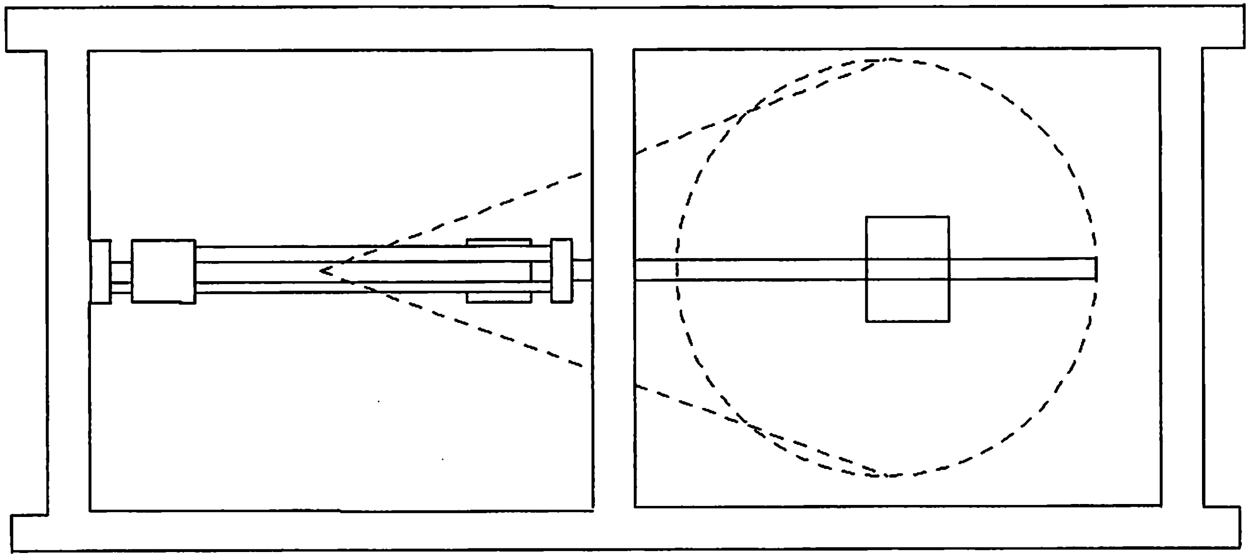
System Description:

The design selected is a crank type of system. This system consists of a piston crank type configuration in which pedals push connecting rods which rotate the crank arm much like a piston does in the engine of an automobile. The crank is connected to a bevel gear box in which an output shaft is driven. This slider crank proved to be the most effective linear drive. Figures 3.3 and 3.4 show the linear drive system.

Design Analyses

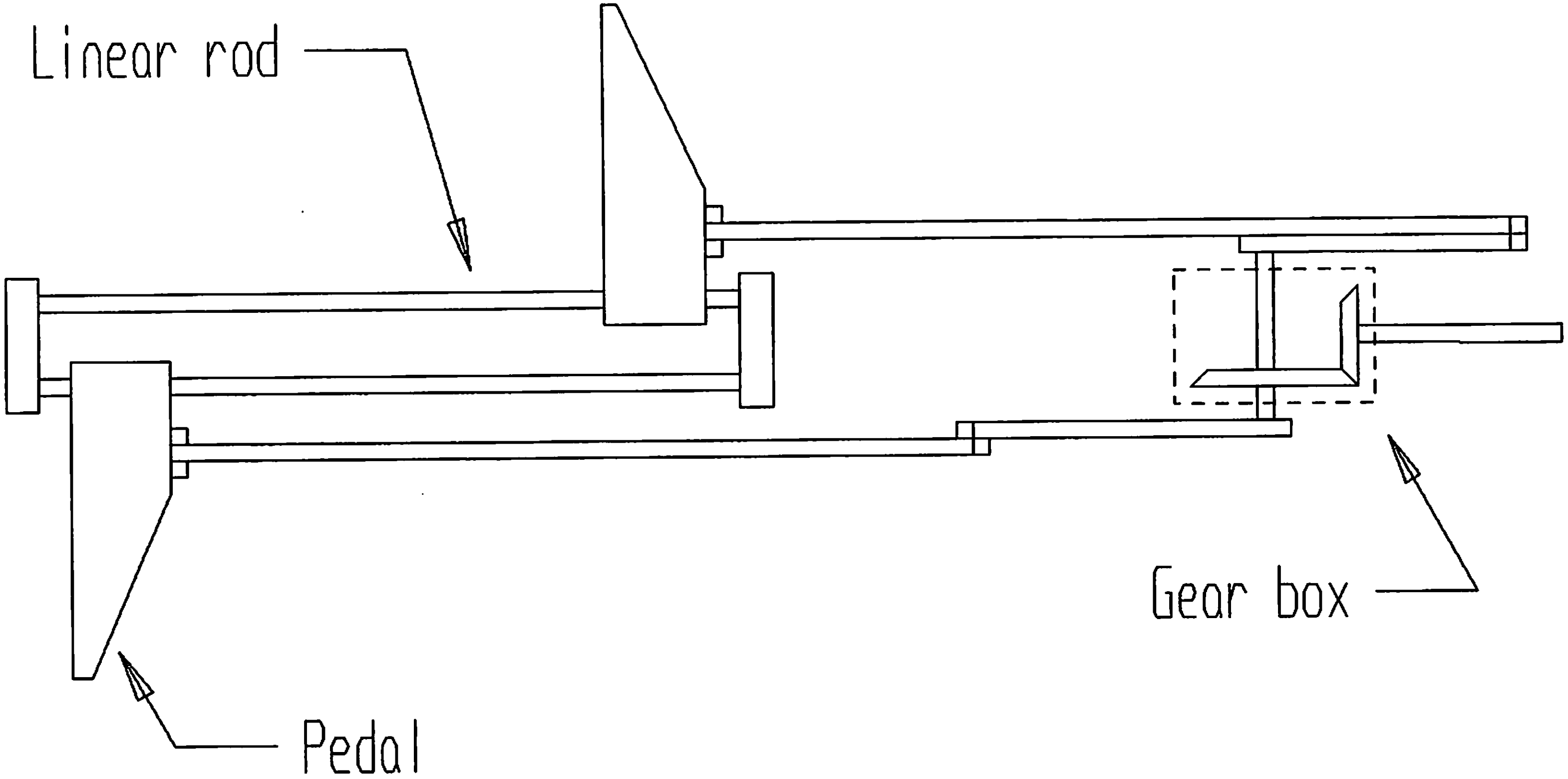
Analyses of the stress, deflection, and buckling of the linear drive system are provided below. Stress analyses for the linear stainless steel rods, connecting rods, and shaft arms were accomplished using the following relationships:

$$\delta = My / I$$



SHARC PROJECT

Figure 3.3	Desc: Linear Motion (Side View)	Date 4/29/94



SHARC PROJECT

Figure 3.4 | Desc: Linear Drive System | Date 4/29/94

Design Analyses

Analyses of the stress, deflection, and buckling of the linear drive system are provided below. Stress analyses for the linear stainless steel rods, connecting rods, and shaft arms were accomplished using the following relationships:

$$\delta = My / I$$

where M is the moment applied, y is distance to neutral axis, and I is moment of inertia given by:

$$I = bh^3 / 12$$

where b is the base and h is the height of the cross-sectional area.

Deflection analyses for the linear stainless steel rods were accomplished using the following equation:

$$\delta = FL^3 / 192 E I$$

where F is the force applied, L is the length of the rod, E is Young's modulus, and I is the moment of inertia given by:

$$I = \pi d^4 / 64$$

where d is the rod diameter. Buckling analyses for the linear stainless steel rods and connecting rods were conducted using the following relationship:

$$P = \pi^2 EI / L^2$$

where E is Young's modulus, L is length of the rods, and I is the inertia.

Rotary Drive System

Functional Requirements:

The rotary drive system transfers rotary pedal motion into rotational shaft motion.

Design Requirements

Must be able to effectively transfer bicycle crank motion onto rotational energy.

Must be light weight

Must be lubrication free to prevent contamination of the pool.

Must be easily attachable to bench support structure and load cell

Must be corrosion resistant to water

System Design Considerations:

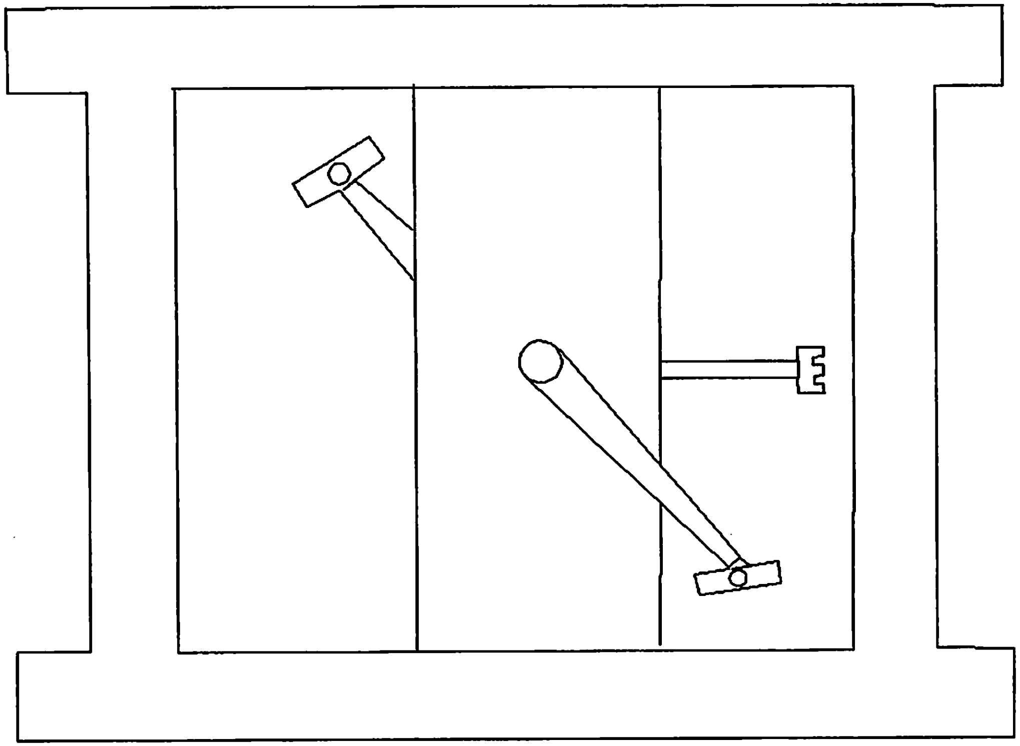
The rotary drive system must be able to efficiently transfer a bicycle crank motion into a rotational shaft. This rotational shaft will couple with the input shaft of our load cell. The rotary drive system must be light enough for two people to carry the rotary drive must also be lubrication free since we will be using it in the pool. The rotary drive system must be easily attachable to our bench structure and load cell. This is done so that the rotary drive can be quickly interchanged with our linear drive system.

Design Alternatives:

One of the original concepts considered for the rotary drive was a bicycle type configuration with a crank connected to a flywheel using minibike chain. This design proved to be lacking in modularity since the chain would have to be disconnected every time the drive system was changed. Another design considered was one using a belt, but this has the disadvantage of a possible slip factor which could occur in water. The belt design also lacked modularity.

System Description

The rotary drive design selected was one adapted from the human powered submarine SPUDS[3]. It is made from stainless steel and aluminum and it requires no lubrication. It consists of a bicycle crank attached to a set of helical gears that are connected to an output shaft. The rotary drive is mounted onto a square PVC exo-structure, which attaches to the bench support structure as well as the load cell. Figure 3.5 shows a side view of the SHARC rotary drive system.



SHARC PROJECT

Figure 3.5

Desc: Rotary drive (side view)

Date 4/29/94

Load Cell System

Functional Requirements:

The load cell provides a means for adjusting load placed on the scuba diver and a means for determining the output power generated by the scuba diver.

Design Requirements:

Must be light weight

Must be easily attachable to rotary drive and linear drive.

Must be corrosion resistant to water.

Must be lubrication free to prevent contamination of the pool.

Design Alternatives

Among the concepts considered was the use of spoked flywheels which are chain driven, such as that used for exercise bike. It was determined that this system would not provide the required modularity. A system using clutch plates was also considered as a means of applying load to the flywheel. This concept was rejected due to complexity.

System Description:

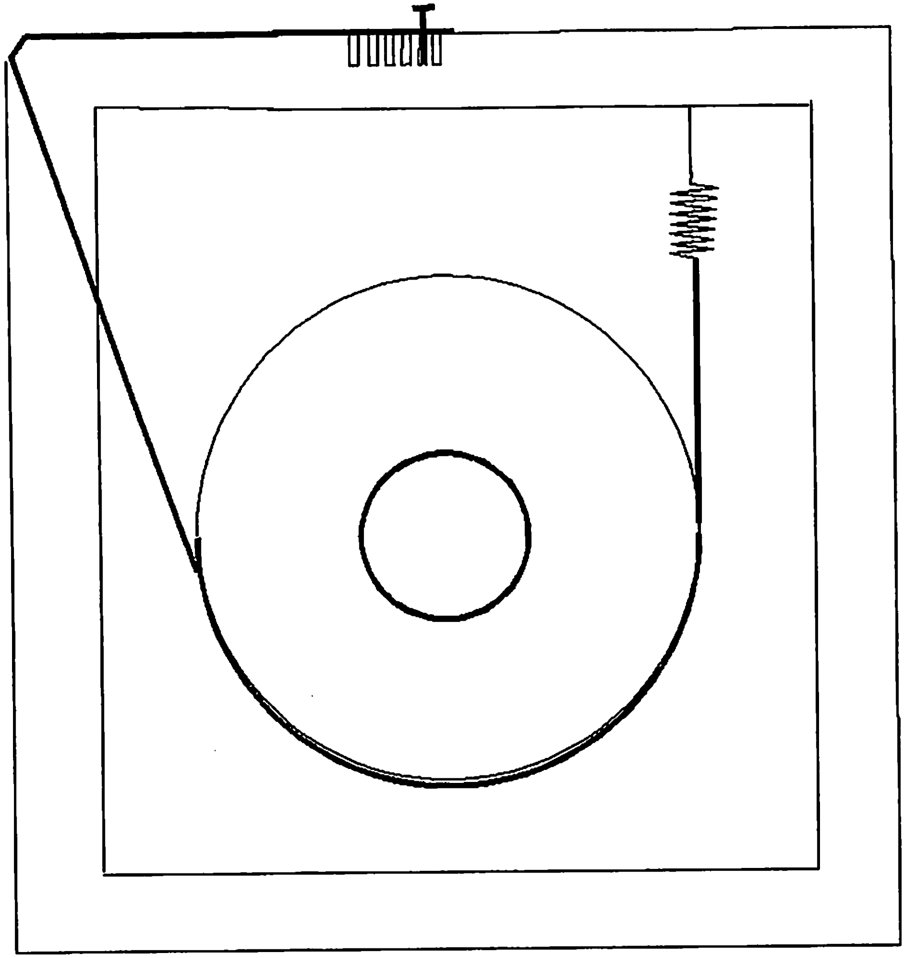
The system selected consists of a flywheel with an input shaft attached. This flywheel has an adjustable tension belt with a spring of known K constant. The belt is stretched a certain distance and a force is put on the flywheel. With the known force applied to the flywheel, the scuba divers output power can easily be calculated. This is done by taking the known force and multiplying it by the radius of the flywheel, then multiplying that torque by the speed(RPM) of the flywheel. A diagram of the load cell assembly is given in Figure 3.6.

To calibrate the load cell in water the following calibration equations were used:

$$T_1 / T_2 = e^{\mu beta}$$

First we set T_1 and T_2 which are tensions in the belt. We know Beta which is the degrees of belt in contact with the flywheel. Then we solve for Mu, the coefficient of friction. We then take T_1 and T_2 and solve for the moment M using the equation:

$$M = (T_1 - T_2)\, r$$



SHARC PROJECT

Figure 3.6

Desc: Load cell (front view)

Date 4/29/94

where r is the radius of the flywheel. The output power is then calculated by the equation:

$$\text{Power} = M(\text{RPM})$$

Where RPM is in radians per second.

One way of computing friction due to the water is by setting our flywheel into the water with a drill and a given arm length. This arm length is attached to a post nearby with a spring of a known spring constant K.

When the drill is running it will cause the arm to pull away from the post. The pulling force can be determined by measuring the displacement of the spring. The equation below allows us to determine the viscous torque:

$$T_{\text{viscous}} = T_{\text{spring}} d$$

where d is the length of the arm on the drill. Power loss to viscosity is given by:

$$\text{POWER} = T_{\text{viscous}}\ \text{RPM}$$

where the RPM is in radians per second.

Material Selection

The application and environment have dramatic effects on materials used in different devices. In a harsh chlorinated pool, the utmost care must be taken to be sure the exposed surfaces are corrosion resistant. One of the crucial elements of the SHARC project is selecting the correct materials for each module. Separately, each module is dissected and the materials chosen are analyzed.

The main structure in each module is made out of schedule 80 polyvinyl chloride (PVC). Actually PVC is the optimum choice for this application. The polymer structure is completely corrosion resistant in a chlorinated pool environment. Its specific gravity being 1.3 makes it light enough to carry around, but it still is negatively buoyant. It is extremely easy to work with, a hacksaw cuts pipe lengths nicely. Connections are just as easy, gluing time is in the range of seconds, after properly primed. With a tensile strength of 6 ksi, a 1 1/2" diameter PVC pipe is more than adequate to support the necessary loads.

The best feature of these tubes is that they slide neatly into one another. A 1 1/2" diameter pipe fits snugly inside a 2" diameter pipe. The connection is so close, it is used for variable lengths. After many hours with the best salesmen in the plumbing business, this lucky property was found. The only drawback of this substance is the availability. Most plumbing warehouses carry limited schedule 80 stock and few fittings. When a large amount of fittings is necessary, (78 tee's for SHARC) the actual manufacturer must be called.

PVC is the main component in the bench assembly. In addition to the pipe frame, a flat sheet of PVC is used as a rest for the diver. Coating the end of this is a 1/4" sheet of neoprene padding. This cushions the jarring motions of the working diver. Also attached to the bench, is an environmental box housing our delicate electronics. Easily fuzed with acetone to a water-tight seal, plexiglass provides ideal transparent protection against the pool water. Connected to the bench is the one of the two drive systems.

The rotary drive was taken directly from the previous year's human powered submarine project, which was successfully used in nearly the same environment. Since the environmental and mechanical constraints are identical, a material evaluation was not considered to be necessary. The only other parts in the SHARC system are the connections from the drive mechanism to the PVC frame. Stainless steel U-bolts and aluminum plates are utilized, both of which are highly corrosion resistant and provide the necessary strength.

The interchangeable module for the rotary drive is the linear drive. When this drive was designed, once again the utmost care was taken to provide a quality device that would stand the physical constraints. The pedals are machined blocks of solid aluminum. Four 3/4" shafts made of 305 stainless steel provide a resilient bearing surface. This steel is strong enough to prevent 1/32" deflection when a 200 pound force is dynamically applied to the pedal. Aluminum is also used in the connecting rods and arms. These members are not bearing surfaces so the mechanical constraints are not as rigid. Regardless, a tensile strength of 10 ksi is more than adequate for this application. Aluminum is the preferred metal due to its specific gravity three times less than 305 stainless.

Stainless steel is also used in the hose clamps on the load cell. These tight clamps fasten a nylon band brake around the fly wheel on the load cell. This plastic cable is built to withstand rubbing and stopping for years to come. The flywheel itself is a 10.5 inch solid aluminum disk fastened on a stainless steel shaft. The shaft runs through bearings attached to the PVC frame by aluminum plates.

Down to the last bolt, great care was taken when parts were ordered. All parts must meet the mechanical loads as well as being highly corrosion resistant. In terms of material selection, the SHARC project has chosen the optimum materials for each application.

Sensors

Functional Requirements:

To accurately determine the optimum configuration, sensors are used to measure air pressure, spring displacement, angular velocity, and pulse rate. Different configurations can be evaluated using these sensed quantities.

Design Requirements:

Must be able to work under 20 feet of water.

Provide accurate and consistent results

All data must be stored in a poolside computer

Design Alternatives:

Many designs were considered in the evaluation of sensor systems. First an inexpensive Vetta cyclocomputer was purchased and evaluated. This compact system features a wireless ECG chest strap for heart-rate measurement and a magnetic pickup for velocity measurement. Due to compact size, it has limited capabilities and could not connect to a computer. It still is useful as a backup and calibration for the main sensor system. Next angular velocity sensors were analyzed. A Keyence EN014-npn magnetic velocity sensor was evaluated. In this sensor the distance between the moving and stationary heads is only three millimeters. The difficulty in maintaining this clearance resulted in eliminating this sensor from consideration. A Truck Uprox Stubby proximity sensor was also evaluated. This sensor required that a hole be drilled in the moving flywheel, and the sensor itself was not waterproof. Because of these unreasonable constraints, the Stubby system was eliminated. In terms of data acquision, a Keithly Metrabyte CTM-05 card was considered. This card would have fit our application nicely, but the estimated cost of $565 would not fit into the SHARC budget. An Acculex DP-680 display was also evaluated. This display would have shown the desired data, but it would not provide a display in terms of revolutions per minute. An industrial quality pulse monitor that meets our design requirements costs approximately $1000. This high quality product does not fit into the SHARC budget. In response, the SHARC team designed its own sensor. All the equipment that was seriously considered are of high quality, but some of the physical constraints were not met. Many more devices were not even considered.

Selected Design:

Spring displacement and air pressure are determined without the use of electronics. Manually, the spring is stretched to a preset displacement. A sleeve of PVC is slid across the top of the load cell to a series of preset holes that displace the spring. This displacement is entered into the poolside computer (PC), and the force on the loadcell is calculated through the previously discussed calibration procedure.

Air pressure is determined simply by viewing the pressure gauge on the SCUBA tank under the bench. The "before and after" test pressures are entered into the software on the PC. The total air volume consumed is calculated using the following equation:

$$P_1 / P_2 = (V_1 / V_2)^n$$

Where P_1 , P_2 and V_1, V_2 are the respective before and after pressures and volumes. The exponent n is equal to 1 for constant temperature. After some manipulation, the equation can be expressed as follows:

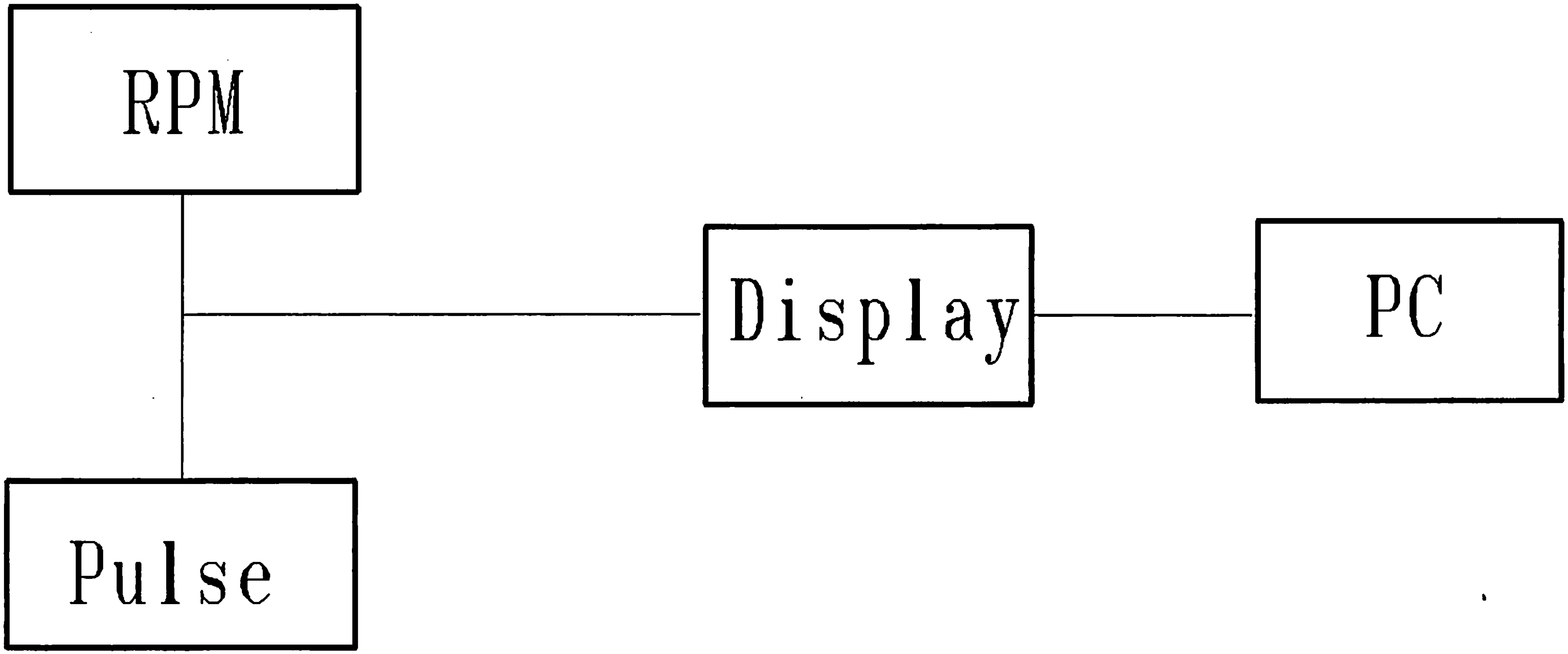
$$V_{consumed} = V_{air} \; (P_1 - P_2) / 14.7$$

The pressures are expressed in pounds per square inch, and V_{air} consumed will have the same units as V_{tank}. Usually a tank volume of 122 cubic inches will be used, but this equation is applicable for any size tank.

Angular velocity is determined through the use of an optical velocity sensor and electronic counter. An Allen Bradley retroflective 42GRU-9000-QD optical sensor (Appendix C) sends a beam of light onto the black, spinning loadcell. This beam is broken by ten reflectors on the rotating disk. The light is captured by the receiving lens and sent through a logic unit where the analog signal is changed to a five volt digital pulse.

The rpm signal is then split sending it to a display and the PC (Figure 4.1). An Acculex DP-680-RM (Appendix C) digital display counts and displays the reading to the operator. This display is placed in a waterproof box directly on the bench. The other half of the signal is sent to a Keithly Metrabyte DAS-8 data acquisition card. This computer board is snugly fit into an expansion slot on the PC. Running SHARC software, the program computes the frequency of the digital pulses. This along with the frozen time is appended to a data file. Figure 4.2 provides a block diagram of sensors and instrumentation.

Finding the blood pulse rate of the diver is quite a different matter. A Tennari ear clip is attached to the earlobe of the diver. This clip contains an infrared light emitting diode (LED) and a receiving infrared photodiode. The LED sends a constant infrared light source across the earlobe. As blood gushes through tiny arterioles in the flesh, the signal is blocked. The photodiode resistance changes with a change in infrared intensity. A small circuit board (Figure 4.3) equipped with a Wheatstone Bridge picks up the minute, noisy signal.



Simplified Signal Diagram

Figure 4.1

Sensors and Instrumentation Block Diagram

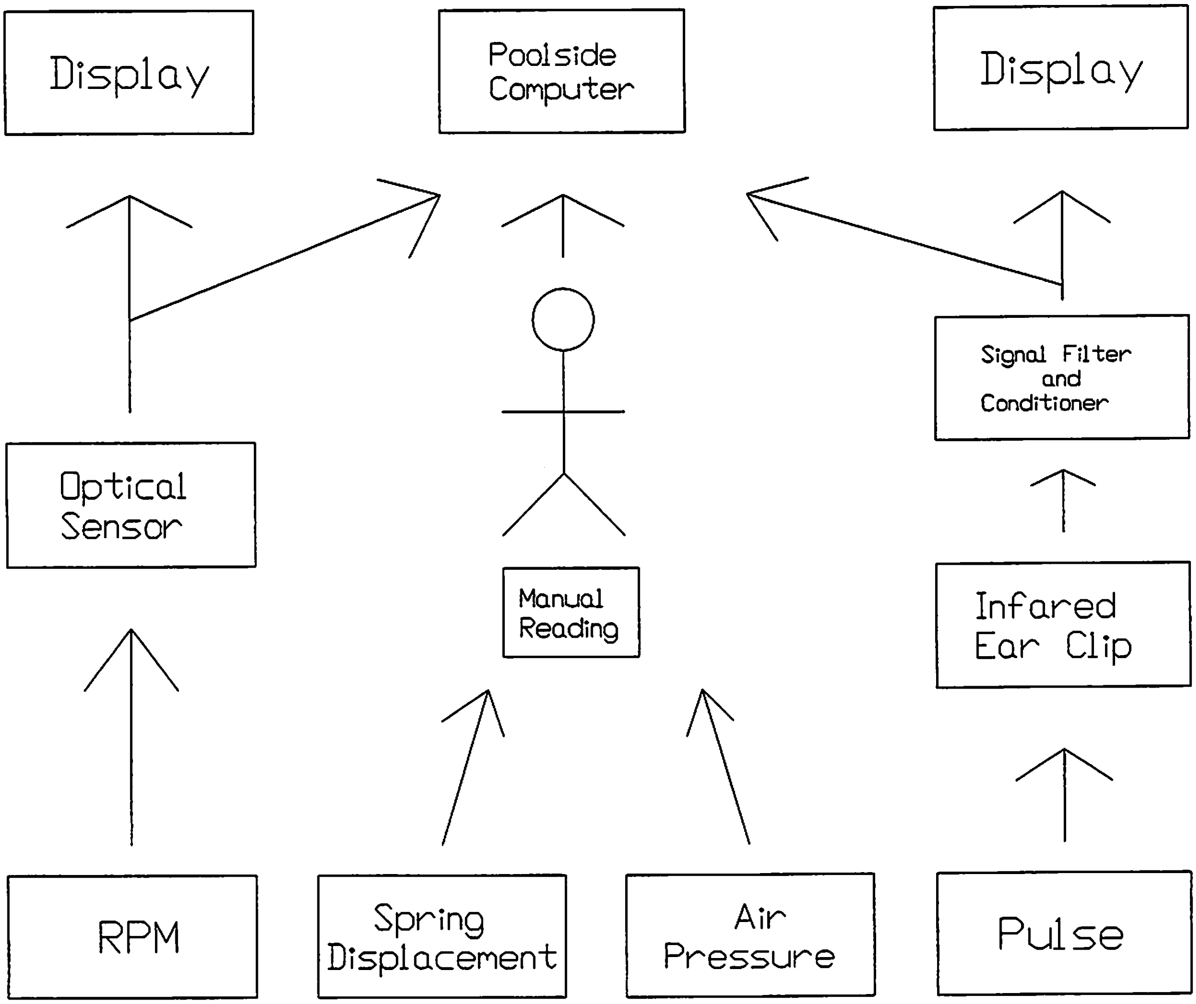


figure 4.2

Pulse Monitor

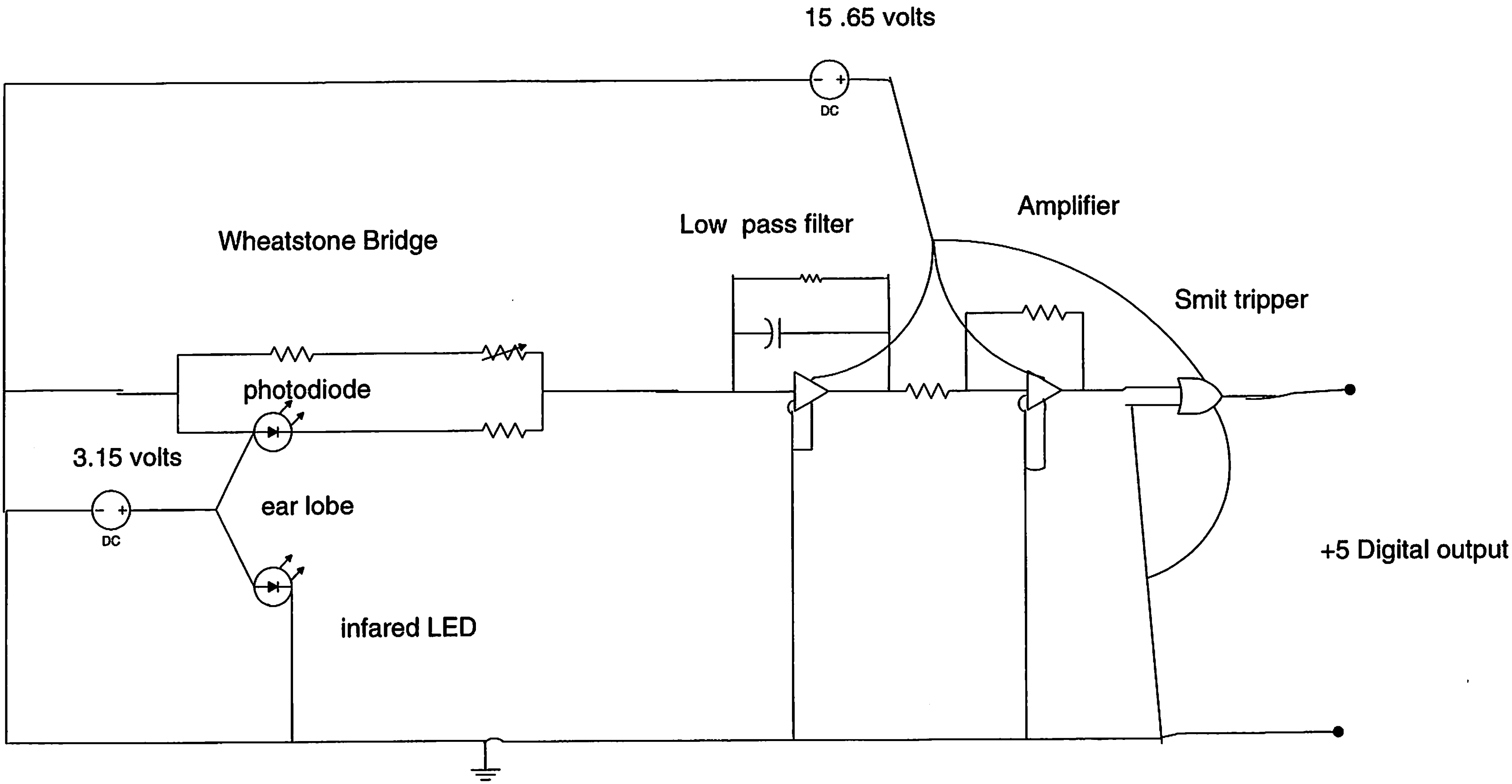


Figure 4.3

Because pulse rate is inconsistent person to person and pulse to pulse, the messy analog signal must be conditioned before it enters the counters. First, the signal enters a low pass filter, where the noise is removed. This was constructed through the use of an operational amplifier cutting out the frequency at 200 beatsper minute. The signal is then amplified from a few millivolts to approximately five volts. Finally, the signal is sent through a common Smit tripper which cuts out the rest of the roughness and sends a crisp, five volt, digital, square wave. This is called a transistor to transistor logic (TTL) signal.

This signal is then split and sent to components similar to the angular velocity measurements. It is sent to a parallel DP-680-RM in the environmental box. Another digital input in the DAS-8 reads the signal as well.

When the testing is complete the test configuration is noted and appended to a test file. On this file will be the information that was performed on the diver. The diver's name, date, time of day, and other operator's comments will be added to the existing information. Output power, cadence, and pulse can be imported and graphed through Labtech Notebook or Quattro-pro. All of the recorded information can then be analyzed to determine optimum parameters.

Test Procedure

Once all of the design and assembly was completed tests were run to determine which system was more efficient. These results are still being evaluated and are not included in this report. The most important aspect of the testing program is to develop a reliable and repeatable test procedure. This was accomplished and demonstrated through our design the setup and process to test is very simple. All the data is sent to a computer that is poolside. Once there it can be analyzed and test performance can be determined. Critical data from each test subject must be gathered to have a basis for comparison. To provide a valid basis for comparison, every test must have a common baseline, such as length of test and force applied. A basic algorithm for testing a human using the SHARC system would apply the following sequence:

1. Assemble either the rotary drive or the linear drive.
2. Set force on flywheel and record value.
3. Determine time for test and record.
4. Determine at what Heart-Rate the subject should work at.
5. Turn on computer and run setup.
6. Load software for data acquisition.

7. Record air pressure before test.

8. Begin peddling.

9. End peddling.

10. Record value of air pressure.

11. End of test.

Conclusions

The SHARC project was successful in achieving its primary goal, to build, design, and evaluate a training and test platform for SCUBA divers. The most important portion of the this project was to design a modular, flexible and, most importantly, functional system. Throughout the project the SHARC project team has gone through the normal iterative design process to come up with a modular, rugged, and functional system. These iterations and design considerations are discussed in the report. From this year long practical engineering experience, the SHARC project team has applied the hands-on side of engineering. In this particular project the SHARC team had to design a system that would function effectively in water, similar to many other ocean related projects. An additional challenge for this project was the need to integrate both electronics and mechanical systems into the design. This need, along with the need to design electronic systems to withstand an underwater environment, made the project much more difficult than originally anticipated. These difficulties provided the basis for a hands-on learning experience in applying concepts from classroom context to a research and development process that resulted in a successful prototype system.

Appendix A
Project Schedule

	Sept		Oct		Nov		Dec		Jan		Feb		Mar		Apr		May	
Research	■	■	■															
System Design		■	■	■														
Design			■	■	■													
Material Order						■	■	■	■									
Hardware As.										■	■	■	■	■				
Develop Software										■	■	■						
Test Hardware												■	■	■	■			
Test Software												■	■	■				
Test System														■	■	■		
Demonstration														■	■	■	■	
Obtain Data															■	■	■	■
Analysis & Sol.															■	■	■	■

SHARC PROJECT TIME SCHEDULE
Figure 6.1

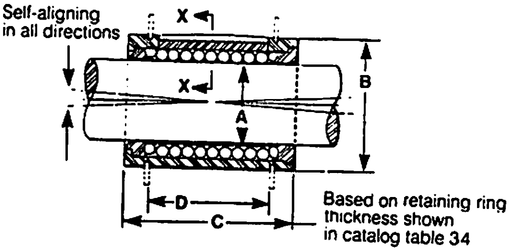
Appendix B
Project Cost Data

BUDGET-SHARC

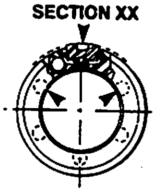
Description	Estimated Total Cost	Expected Donation	Tech 797 Costs
Structure			
1. PVC	400	400	500
Monitoring Systems			
1. Personal Computer	1000	1000	0
2. Cables, Connectors, etc.	100	0	100
3. Sensor Equipment	500	250	350
Life Support Systems			
1. Scuba tanks	800	800	0
2. Hoses	200	200	0
3. Regulators	1200	1200	0
4. Emergency systems	300	300	0
5. Misc. hardware	50	0	150
Anchoring			
1. Lead weights	50	50	0
Miscellaneous			
1. Telephone	100	0	100
2. Printing	200	0	200
3. Travel	100	0	100
TOTALS	5000	4200	1500

Appendix C
Manufacturers' Data on Components

Super Ball Bushing bearing engineering specifications.



Based on retaining ring thickness shown in catalog table 34



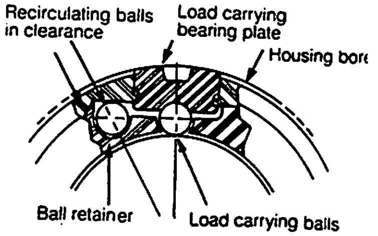


Table 1—Super Ball Bushing bearings—dimensions and load ratings.

SUPER Ball Bushing Bearing Number	Working* Bore Diameter A		Housing Bore Diameter B	Housing Bore Recommended Tolerances Fixed Dia. Housing	Housing Bore Recommended Tolerances Adjustable Dia. Housing (Before Adjustment)	Length C		Distance Between Retaining Rings D		Maximum Shaft Dia. (Thomson 60 Case Class L)	Ball Diameter	No. of Ball Circuits	Bearing Weight
	Inches	Tol. + .0000 to	Inches	Tol.-.0000 to	Tol.-.0000 to	Inches	Tol. +.000 to	Inches	Tol.	Inches	Inches		lbs
SUPER-3	.1875	−.0005	.3750	+.0005	+.001	.562	−.015	—	—	.1870	3/64"	4	.0032
SUPER-4	.2500	−.0005	.5000	+.0005	+.001	.750	−.015	.437	±.010	.2495	1/16"	4	.01
SUPER-6	.3750	−.0005	.6250	+.0005	+.001	.875	−.015	.625**	±.010	.3745	1/16"	4	.02
SUPER-8	.5000	−.0005	.8750	+.0005	+.001	1.250	−.020	.940**	±.015	.4995	3/32"	4	.04
SUPER-10	.6250	−.0005	1.1250	+.0005	+.001	1.500	−.020	1.000	±.015	.6245	1/8"	5	.10
SUPER-12	.7500	−.0005	1.2500	+.0005	+.001	1.625	−.020	1.160**	±.015	.7495	1/8"	6	.14
SUPER-16	1.0000	−.0005	1.5625	+.0005	+.001	2.250	−.020	1.750**	±.015	.9995	5/32"	6	.25
SUPER-20	1.2500	−.0006	2.0000	+.0008	+.001	2.625	−.025	1.875	±.020	1.2495	3/16"	6	.45
SUPER-24	1.5000	−.0006	2.3750	+.0010	+.001	3.000	−.030	2.250	±.020	1.4994	7/32"	6	.85
SUPER-32	2.0000	−.0008	3.0000	+.0010	+.001	4.000	−.040	3.000	±.030	1.9994	1/4"	6	1.45

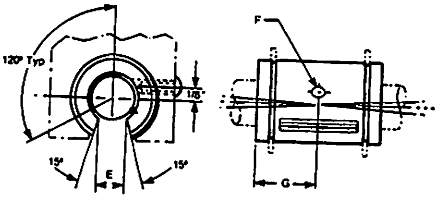
Table 2—Open Type Super Ball Bushing bearings—dimensions and load ratings.

For
sup

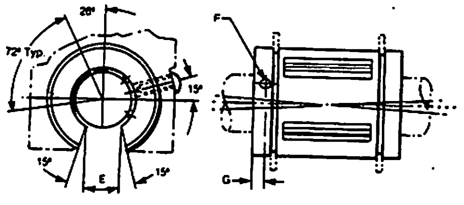
SUPER Ball Bushing Bearing Number	Working* Bore Diameter A		Housing Bore B	Housing Bore Recommend. Tol. Fixed Dia. Housing	Housing Bore Recommend. Tol. Adj. Dia. Housing (Before Adjust.)	Length C		Distance Between Retaining Rings D		Min. Slot Width E	Retention Hole Dia. F	Retention Hole Loc. G	Max. Shaft Dia. (Thomson 60 Case Class L)	Ball Diameter	No. of Ball Circuits	Beari Weig
	Inches	Tol. + .0000 to	Inches	Tol. −.0000 to	Tol. −.0000 to	Inches	Tol. +.000 to	Inches	Tol.	Inches	Inches	Inches	Inches	Inches		Lbs.
SUPER-8-OPN	.5000	−.0005	.8750	+.0005	+.001	1.250	−.020	.940**	±.015	5/16"	.136	5/8"	.4995	3/32"	3	.03
SUPER-10-OPN	.6250	−.0005	1.1250	+.0005	+.001	1.500	−.020	1.000	±.015	3/8"	.105	1/8"	.6245	1/8"	4	.08
SUPER-12-OPN	.7500	−.0005	1.2500	+.0005	+.001	1.625	−.020	1.160**	±.015	7/16"	.136	1/8"	.7495	1/8"	5	.12
SUPER-16-OPN	1.0000	−.0005	1.5625	+.0005	+.001	2.250	−.020	1.750**	±.015	9/16"	.136	1/8"	.9995	5/32"	5	.21
SUPER-20-OPN	1.2500	−.0006	2.0000	+.0008	+.001	2.625	−.025	1.875	±.020	5/8"	.201	3/16"	1.2495	3/16"	5	.38
SUPER-24-OPN	1.5000	−.0006	2.3750	+.0010	+.001	3.000	−.030	2.250	±.020	3/4"	.201	3/16"	1.4994	7/32"	5	.71
SUPER-32-OPN	2.0000	−.0008	3.0000	+.0010	+.001	4.000	−.040	3.000	±.030	1"	.265	5/16"	1.9994	1/4"	5	1.20

*When installed in nominal housing bore, Column B, before adjustment. Any deviation from nominal housing bore diameter will change the working bore diameter A an equal amount.
**This dimension is slightly greater than on other types of Thomson Ball Bushing bearings.
†Based on shaft hardness of Rockwell 60 C and with a travel life of 2 million inches.
Note: Load rating is reduced up to 50% when load is applied to OPEN half of Ball Bushing bearing!
††If higher load capacity is needed, use XR Ball Bushing bearing

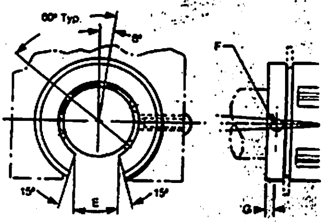
Normally it is not practical to a
position OPN-Type Ball Bushin
maximum capacity because of
which restrict circumferential r
factory for special recommend
needed. Please include applic



SUPER-8-OPN



SUPER-10-OPN



SUPER-12-OPN thru SUPER-

Note: Bearings may be retained in housing by use of pin or screw engaging retention hole "F". Hole positioning varies with size!

Super Ball Bushing bearing installation data. See pages 20 through 22.

Lubrication recommendation, see page 37. For materials and maximum recommended operating temperature, see page 49.

INSTALLATION INSTRUCTIONS PHOTOSWITCH®
RETROREFLECTIVE CONTROL BULLETIN 42GRU–9000

IMPORTANT: SAVE THESE INSTRUCTIONS FOR FUTURE USE. FOR ADDITIONAL INFORMATION REFER TO PUBLICATION 42GR–2.0

BULLETIN NUMBER	OUTPUTS ENERGIZED	POWER CONSUMPTION	VOLTAGE SUPPLY	OUTPUT CHARACTERISTICS			RESPONSE TIME	OPERATING DISTANCE		
				TYPE	RATING	LEAKAGE		3" (76MM) REFLECTOR	1.25" (32MM) REFLECTOR	.625" (16MM) REFLECTOR
42GRU–9000	Cable	4VA MAX	10–40VDC	NPN/PNP	250mA	1µA	2ms	1:1 Margin 1"–30' (2.54cm–9.15m)	1:1 Margin 1"–12' (2.54cm–3.65m)	1:1 Margin 1"–10' (2.54cm–3m)
42GRU–9000–QD	Connector									
42GRU–9001	Cable		10–55VDC		2A/132VAC		15ms			
42GRU–9001–QD	Connector		20–40VAC		1A/264VAC					
42GRU–9002	Cable		65–264VDC 60–264 VAC,	SPDT EM Relay	1A/150VDC		15ms			
42GRU–9002–QD	Connector		50/60Hz					2:1 Margin	2:1 Margin	2:1 Margin
42GRU–9003	Cable		45–264VDC 40–264 VAC,	Solid State Isolated NO	300mA	1mA @ 264V	2ms	1"–24'	1"–10'	1"–8'
42GRU–9003–QD	Connector		50/60Hz			AC/DC		(2.54cm–7.3m)	(2.54cm–3m)	(2.54cm–2.4m)

SPECIFICATIONS

Indiacators:

Yellow .... Power On

Green .... Output Energized

Red

Steady on .... 2.5X Margin

Flashing .... Short Circuit/Overload

Turn On Pulse Protection .... Yes

Field of View .... 1.5°

Transmitting LED .... Visible Red 660nm

Reverse Polarity Protection .... Yes

Short Circuit Protection .... Controls with solid state output only

⚠ **CAUTION: Model 9003 Maximum inrush current should not exceed 2 Amps.**

Overload Protection .... DC models only (9000)

Ambient Temperature Range –29°F to +158°F (–34°C to +70°C)

Relative Humidity 5–95%

Lens Material .... Plastic

Approvals Pending .... UL / CSA

Operating Environment: NEMA 3, 4X, 6P, 12, 13, and IP67 (IEC529) rated housing. Housing material is high-impact, chemically resistant Valox.®

Cable Models:

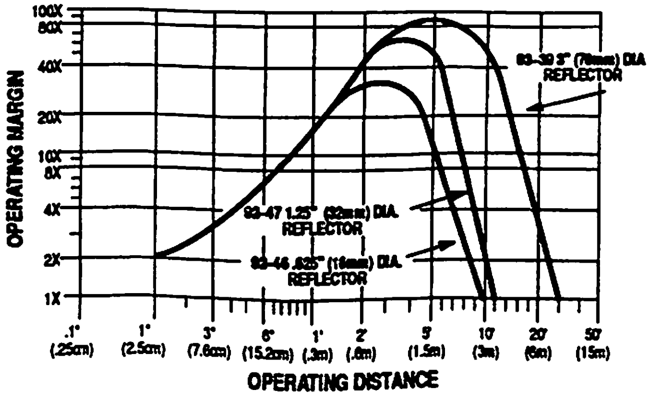
9000, 9003 .... 4 conductor PVC jacketed cable 6.5ft. (2m)

9001, 9002 .... 5 conductor PVC jacketed cable 6.5ft. (2m)

OPERATING DISTANCE SELECTION

The maximum operating distance is based on installing the control in a relatively clean environment. Normal industrial environment actually ranges from moderately *dusty* to extremely *dirty*. Greater operating margin may be required which can be obtained by reducing the operating distance of the control.

TYPICAL RESPONSE CURVE



ACCESSORIES

PART NUMBER	DESCRIPTION
REFLECTOR	
92–39	3" (78mm)
92–47	1.25" (32mm)
92–46	.625" (16mm)
OPTIONAL BRACKET	
60–2421	Universal Mounting Assembly
OPTIONAL MATING CABLES	
42GRU–9000–QD	
60–2365–1	2 M (6.56') 4 Pin Micro–style PVC 300V
60–2365–2	4 M (13.1') 4 Pin Micro–style PVC 300V
60–2365–3	5 M (16.4') 4 Pin Micro–style PVC 300V
42GRU–9001–QD and 42GRU–9002–QD	
60–2423–1	6' (1.82m) 5 Pin Mini–style STO 600V
60–2423–2	12' (3.65m) 5 Pin Mini–style STO 600V
60–2423–3	20' (6.09m)) 5 Pin Mini–style STO 600V
42GRU–9003–QD	
60–2424–1	6' (1.82m) 4 Pin Mini–style STO 600V
60–2424–2	12' (3.65m) 4 Pin Mini–style STO 600V
60–2424–3	20' (6.09m) 4 Pin Mini–style STO 600V

ALIGNMENT

When power is applied to the control, the yellow (Power On) indicator will turn *On*. Visually sight the control at the reflector until the green (Output Energized) indicator turns *On* when the control is set for light energized, or turns *Off* when the control is set for dark energized. Continue to align the control vertically and horizontally until the red (2.5X margin) indicator turns *On*.

Diagnostics

Yellow *On* indicates power on.

Green *On* indicates power is energized.

Red *On* indicates 2.5X Margin.

Red *Flashing* indicates short circuit or overload. (Solid State models only.

To Reset Control:

AC/DC Models – Remove cause of short and cycle turn power to the control *Off*. Then *On*.

DC Models – Remove cause of the short or overload and the control will reset automatically.

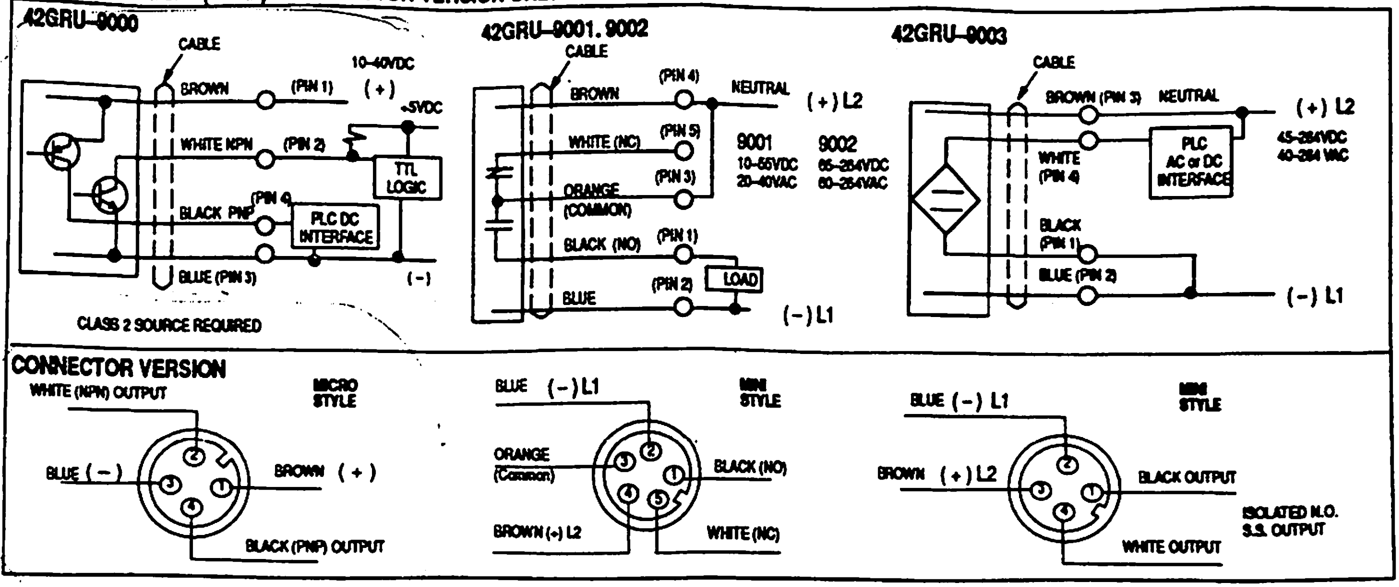
INSTALLATION

The control must be securely mounted on a firm, stable surface or support. A mounting which is subject to excessive vibration or shifting may cause intermittent operation.

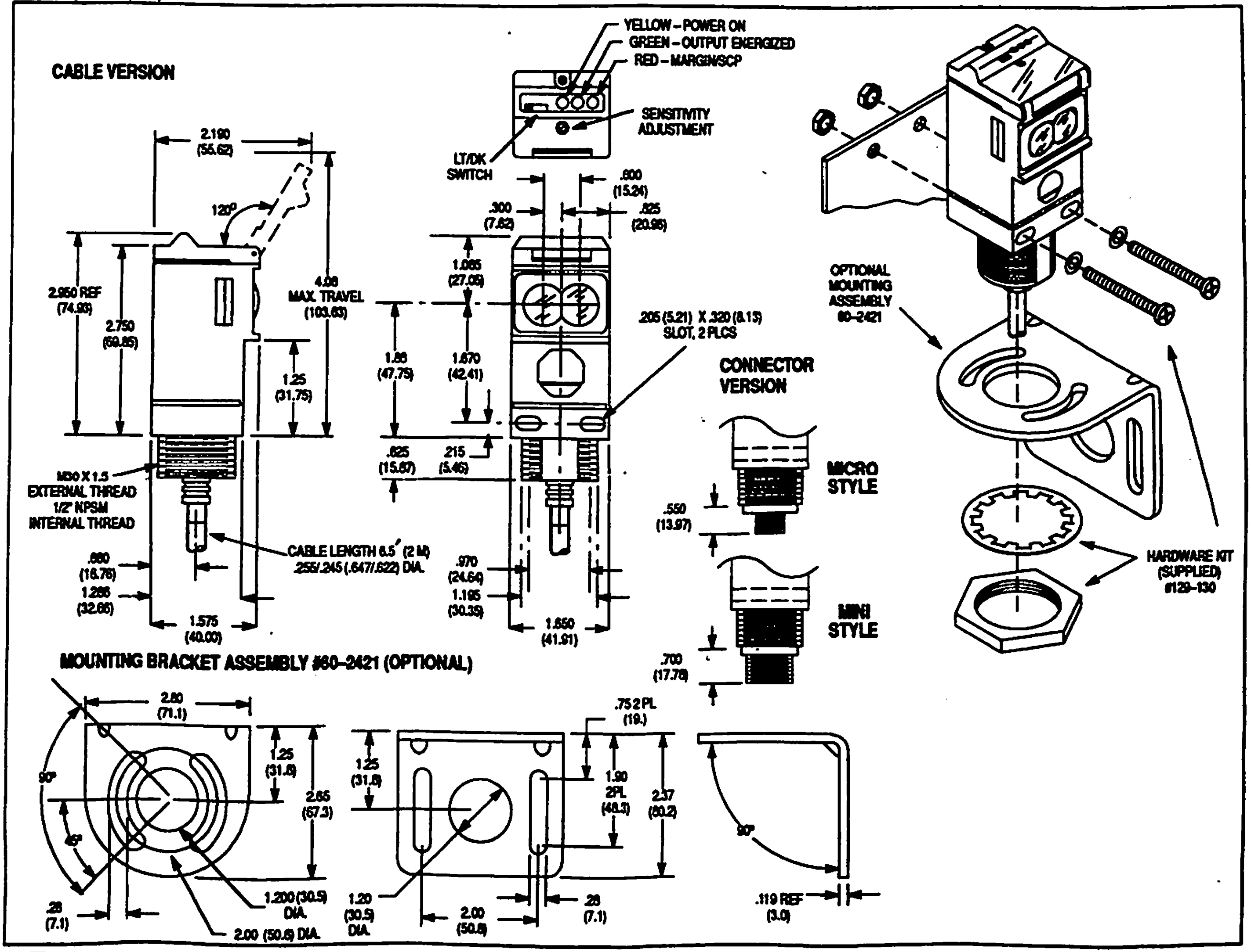
WIRING

All external wiring should conform to the National Electric Code and applicable local codes. See wiring diagrams for external connections.

WIRING DIAGRAMS (PIN #) = CONNECTOR VERSION ONLY



DIMENSIONS ( ) = MM BETWEEN BRACKETS



, an input

EF = 0.1V

)od metal

.istance of
\ practical

ITS

urrent to a
:d to calcu-

= 0.1V
ʔs = 0.2V
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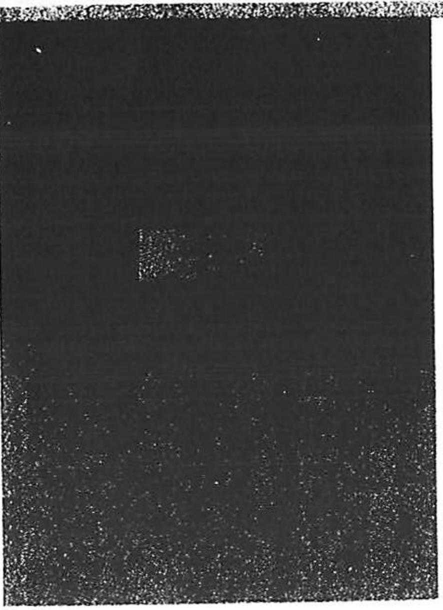
DP-680 SERIES

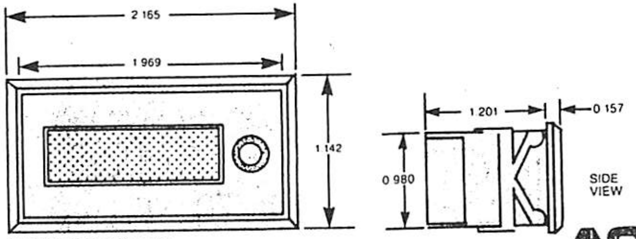
Ratemeter/Tachometer/ Elapsed Timers



The DP-680 Series consists of four sub-miniature, LCD counters, timers, totalizers, ratemeters, & tachometers.

The **DP-680** is an 8-digit, battery powered (replaceable lithium battery included), 10 KHz totalizer with direct inputs from any TTL/DTL, CMOS or 5 VDC compatible signals. An optional 5-220 VAC module is also available (18 Hz, max) as is a termination strip for easy signal input. This makes the DP-680 perfect for all magnetic and/or optical pickups. Totalizing applications to 10 KHz are easily attainable with direct readout on the large, enhanced contrast LCD display.

The **DP-680RM** is a 5-digit, 3 mode, 50 KHz ratemeter, 60,000 RPM tachometer, and 50 Hz (contact closure) monitor with a very wide range of primary operating power (8–30 VDC) including 9, 12, and 24 VDC battery power. Its high degree of versatility combined with the NEMA 4 rated front bezel makes the DP-680RM ideal for portable/mobile, automotive, marine and/or aircraft applications.



PANEL CUTOUT: 2 00 × 1 00"

Note: The diagram shown here is for DP-680 and DP-690RM only. The DP-680TI and DP-680HMS mechanical drawings are different. Cutout dimensions for the DP-680TI and the 680HMS are: 0.89 in x 1.77 in (22mm x 45 mm)

DP-680

- Lithium Battery Included
- NO Signal Conditioning Required!
- Direct Input for TTL/CMOS & +5 VDC Signals
- Optional 5-220 VAC Signal Input Capability
- Very High Speed Operation (10 KHz, max)
- NEMA 1 rated Front Bezel
- Wide Operating Temperature Ranges
- Includes Bezel and Termination Harness

DP-680TI

- Battery Included
- Elapsed Time for Hrs/100ths
- Remote and Front Panel Reset Capability
- Wide Operating Temperature Range
- Includes Bezel and Termination Hardware

DP-680RM

- Frequency to 50 KHz; RPM to 60,000
- NEMA 4 Rated Front Bezel
- Direct Input for TTL/CMOS & +5 VDC Signals
- Simple 5 pin Operation
- Micro-Size (1.97"×0.98")
- 5 Digit Enhanced Contrast LCD Display
- Wide Primary Power Range (8–30 VDC)

As with the DP-680, the DP-680RM requires NO front end signal conditioning and is fully compatible with all TTL/DTL, CMOS and +5 VDC signals. It is ideally suited for use with all optical and magnetic pickups. A simple pin strapping arrangement allows the DP-680RM to be configured for operation at a max input speed of either 50 KHz or 60,000 RPM.

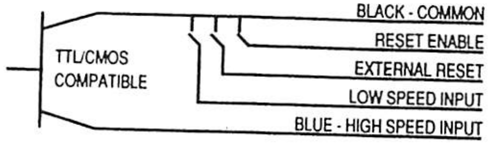
DP-680 HMS (Hours, Minutes, Seconds)

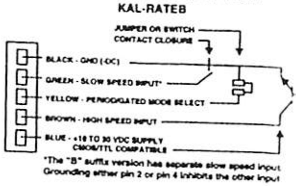
- 6 Digit LCD
- Counting Range (4 selectable)

H—Hour and 1/10 hour 99999.9
HMS—Hours, Minutes, Seconds 99.59.59
M—Minutes and 1/10 minute 99999.9
S—Seconds and 1/10 second 99999.9

- Remote and Front Panel Reset Capability
- Timebase Accuracy ±50ppm Crystal Controlled
- Front Panel Rated NEMA 4
- Battery Included

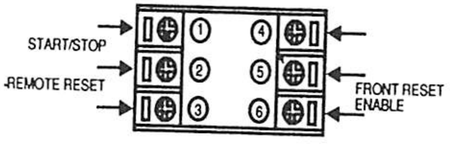
ACCULEX
440 MYLES STANDISH BLVD.
TAUNTON, MA 02780
(508) 880-3880
FAX: (508) 880-0179



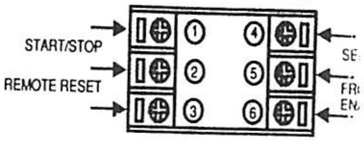


"The "B" suffix version has separate slow speed input. Grounding either pin 2 or pin 4 inhibits the other input

DP-680TI



DP-680 HMS



DP-680

Type	Totalize
Rate	0-10 KHz
Signal	TTL/CMOS, +5 VDC (24 VDC, Max)
RESET	Local or Remote
Inputs	50 Hz (Contacts) 12 mSec Pulse Width 10 KHz (Electronic) 50 uSec Pulse Width
Accuracy	± 1 digit
Rating	NEMA 1
Display	8 Digit, LCD
Height	0.315" (Numerals)
Power	Battery (5 Years)
Connector	Supplied

DP-680RM

Type	Ratemeter /Tachometer
Rate	50 KHz or 60,000 RPM
Signal	TTL/DTL, CMOS, +5 VDC (24 VDC max)
Inputs	FREQ: 50,000 Hz RPM: 60,000 RPM SLOW: 50 HZ 50 uSec Pulse Width
Accuracy	± 1 digit
Rating	NEMA 4
Display	5 Digit, LCD
Height	0.315" (Numerals)
Power	8-30 VDC Required
Connector	Supplied

DP-680 HMS

Type	Elapsed Timei
Rate	Hrs/Mns Scs
RESET	Local or Remc
Inputs	Contact Closu
Rating	NEMA 4
Display	6 Digit
Height	0.315" (Nume
Power	Battery (3 Yea
Connector	Supplied

ORDERING GUIDE

MODEL	DESCRIPTION	PRICE
DP-680	8 Digit Counter	$48
DP-680RM	Ratemeter	$75
DP-680TI	Hr/100ths	$60
DP-680 HMS	Hr/Min/Sec	$60
VIM-680	Voltage Input Module for 680 only	$17
STO-680	Signal Termination Option	$15
PWR-12	12 VDC (250mA) Power Supply	$51

SPECIFICATI

Dimensions..... (DP-680/680 RM)	L 2.95 in (7 W 1.36 in (H 1.14 in (:
Dimensions ..... (680-TI/HMS)	L 1.89 in (4 D 1.81 in (4 H .95 in (24
Oper. Temp	-10 to +50
Store Temp	-20 to +60
Humidity	80% RH
Weight	1.7 oz

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440 MYLES STANDISH B
TAUNTON, MA 0278
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Acknowledgements

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Dr. Andrej Rosinski
Dr. Tom Miller
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