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Sand Bed Turnover Monitor Design Report

Team Aqua Tech

Amanda McGrath, Shannon Mitchell, Mark Raebel, Jacob Meulink, Yogesh Bhattarai

PO Box 440902
Moscow, Idaho 83844-0902
(208) 885-6579
aquatech@uidaho.edu
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Remy Newcombe
Blue Water Technologies
10450 North Airport Drive
Hayden, Idaho 83835-9742

Dear Dr. Newcombe:

Enclosed is a final report detailing the design process, fabrication, and validation of the sand bed turnover monitor. In this report Aqua Tech has explained a summary of progress throughout the first semester and the selection, production, and testing of the recommended design. The designed monitor will allow Blue Water Technologies to track the rate of sand movement inside the filter bed. This will allow detection of bridging at an early stage. A prototype has been created and Aqua Tech has validated that the twister shape is a viable design. A similar report will be delivered to Dr. Steve Beyerlein for the University of Idaho's Capstone Senior Design Course, and Dr. Phil Druker in the University of Idaho's English Department.

This report contains the design for a sand bed turnover monitor. It also includes the test results which show that the monitor is an effective solution to an industrial problem. This report explains why the sand bed turnover monitor solves Blue Water Technologies' problem with early detection of filter bridging.

If there are any concerns or questions with the information presented in this report, please contact us through the e-mail address provided. Thank you for your support on this project.

Sincerely,

Team Aqua Tech

Enclosure: Final Design Report

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1. Executive Summary

Blue Water Technologies has been selling Centra-flo filtration systems for many years. These filters can stop working correctly when the filter media, sand, becomes packed-up which creates a void inside the filter. This creates insufficient sand circulation and water filtration, which is not only harmful to the filter but also dangerous to the environment as it is releasing unfiltered water to environmental streams and water ways.

Due to this problem, Blue Water Technologies asked the University of Idaho's Capstone Senior Design team Aqua Tech to design a solution. After two semesters of design, fabrication, and testing, Aqua Tech has developed a solution to the given problem. This solution includes a lightweight twisted shape suspended in the sand bed. As the sand moves downward through its normal circulation, the force of the sand rotates the device. Attached to the shape is a long solid PVC shaft that connects the device shape to the top mounting bracket. The mounting device consists of a top support structure on the filter with a sealed ball bearing and encoder. The bearing provides support for the weight of the device while still allowing the shaft to rotate. The rotational data is collected using a digital encoder and analyzed using a PLC.

To validate this design, Aqua Tech tested the solution in an acrylic filter model. Multiple shapes were compared and tested against the optimal shape to confirm that the recommended shape was in fact optimal. All successful shapes took between nine and ten minutes to do a quarter of a rotation inside the filter model. The optimal shape fell within this time frame and the prototype was produced using the 3D printer, which allows for this shape to be reproduced.

2. Introduction

2.1 Background

Blue Water Technologies is a company committed to the treatment of wastewater. One of Blue Water's solutions to wastewater filtration is the Centra-flo filter. These filters work by continuously circulating the filter media, sand. The functionality and simplicity are illustrated in Figure 1.

Sand in the tank (3) is driven down to the bottom of the tank by gravity, where it is then lifted to the top of the tank with the patented air lift design (5). At the top, the sand is separated from waste particles with another patented design of Blue Water Technologies called a wash box (9). Wash box discharge (2) exits the tank while the sand is treated with chemicals and dropped back into the filter. Water enters the tank (7) and is piped to the bottom of the sand. As the water is forced up through the media, the pollutants attach to the sand and the clean water leaves the tank (1), cleaned sufficiently to pass EPA standards. Other parts to the filter include the drain (4), a sight gauge (8) to calculate total head loss in filter, and a splash guard (10) to contain the sand.

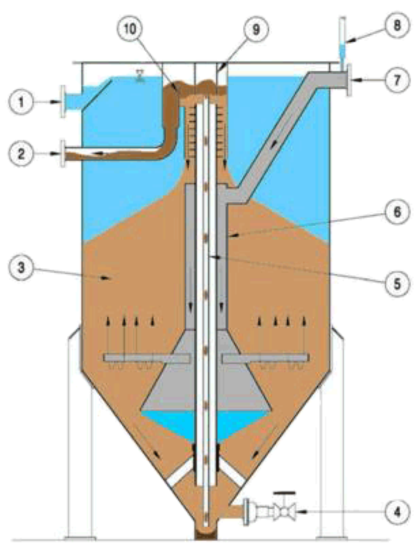


Figure 1. Centra-flo Filter (www.centra-flo.com).

2.2 Acrylic Filter Model

To demonstrate this type of filter to future customers, a prototype was constructed. The prototype is made of acrylic so that the filtration process can be visualized. The acrylic prototype has all the features of the full scale filters, but at a fraction of the size. This model has been valuable to Team Aqua Tech. First, it helped the team to understand the filter design process and limitations to the project and second it provided a device to perform preliminary testing for further project learning. The model was also the instrument of the project's final product evaluation.

Figure 2. Miniature working model of a Centra-flo filter.

2.3 Problem Definition

The sand flow in the Centra-flo gravity sand filtration system needs to be monitored when a large number of systems are in use. This type of tertiary filtration is common both in municipal and industrial operations. Currently the sand flow is monitored manually on a scheduled basis. Proper movement of the sand bed within the filters is imperative to the proper function of the filter. If the filter is not functioning properly, the sand in the filter may clump up, this is known as bridging. Bridging will cause the sand flow to become uneven or even stagnant. This causes inefficient water filtration and further problems getting the system back to optimal operating condition. Currently, the only way to monitor sand bed turnover rate is to place PVC "sticks" in the sand and watch to see how quickly they descend with the sand.

2.4 Morphological Chart

After the preliminary design review, Team Aqua Tech and Blue Water Technologies agreed on a preliminary design. The design features are described below in the morphological chart, shown below in Figure 3. Due to the successful test results over the course of the first semester, a general corkscrew shape was selected as the shape of the design. To ensure there is enough support to hold the device steady, a caster mounting design was chosen. As for the data acquisition system, a digital optical encoder in conjunction with a PLC was selected to measure, analyze, and display the rotational rate. These choices were agreed on by both Aqua Tech and Blue Water Technologies. This ensured that both the team and the company were anticipating the same solution.

Functions	Option1	Option2	Option3	Option4
Material	PVC	Fiberglass	Acrylic	Hard Plastic
Proto Shape	Corkscrew	Auger	Realer Upper	
Mounting	Caster	2 Bearings	Linear Motion	
Detection method	Rotational	Linear		
Transducers	Potentiometer	Linear Position Sensor	Digital Optical Encoder	
Data Conversion	PLC/ Microcontroller	DAQ Cube	Encoder Interface	
Display	Computer	LCD at Filter	LED (green/red)	PLC Display
Software	Matlab/Simulink	Labview	Encoder Software	PLC Software
Power	Battery	Wall Outlet	Computer	

Figure 3. Morphological chart. Highlighted in red are the design features that were selected at the Preliminary Design Review.

2.5 Specifications

A specification table shown below in Table 1 shows the acceptable performance of the device needed to monitor sand bed turnover. The four main general requirements are the physical properties, durability, manufacturing of prototype, and output of results.

General Requirements	Specific Requirements	Acceptable Performance
Physical Properties of Prototype		
Small	Fits in a quadrant	h=1-6", Dia ≤ 6 inches
Weight of device	Can be mounted on top rails or central airlift	≤ 10 lbs
Does not interfere	Avoids effects from wash box and air lift	12"-24" below the surface of the sand slurry
Doesn't effect sand bed turnover	Does not change rate of sand movement	Different devices do not read different rates (keep all variables constant except the size/shape of the monitoring device. Use PVC with marks as a control)
Doesn't contaminate the clean water	No oil/grease, metal	No visible leaches to filter water
Powered by common power source	Prototype device can be run off of common power source	Powered by wall outlet, battery, or computer
Life and Replacement of Prototype		
Easily maintained & replaced	No permanent installation	Can be replaced without replacing filter
Durable	waterproof can be submerged into water/sand slurry Does not corrode or become abraised form the sand	Made from a material that does not absorb water, after testing no marks or abrasions deeper than 1/8"
Manufacturing/Creating Prototype		
Low cost	Material/Part cost, assembly cost, travel	<$3000
Output/Results of Prototype		
Measures the sand movement	Rate in in/min	Measure range capability: 0"-3" per
Electronic data output	Data output to PC	Rate displays on a computer
Consistent results	Must display dependable and consistent results	95% Consistent (within accuracy)
Accurate Results	Must display results that are	± 5 % error
Easy to acquire Results	Must be able to read from a remote location	Access reading on display at desired location
Alerts /Alarm	Should have alert system (sound, flashing light)so as to notify if something is wrong	Alarm that alerts the proper person within 5 seconds of dropping below critical rate

Table 1. These specifications are for the prototype created by Aqua Tech during the first semester.

3. Design Solution

Over the course of two semesters of rigorous design and testing, Aqua Tech is recommending the design solution shown below in Figure 4. The sand bed turnover monitor shown in the solid model is only designed to monitor two quadrants. Two of these devices could be used to measure all four quadrants of one filter.

Figure 4. Design solution for two quadrants.

The design solution consists of a 3D Printer shape connected to a shaft. The mounting consist of steel flat bar with two welded horizontal flat bar pieces to form double storied mounting. The shaft is secured to the mounting using a sealed ball bearing and the encoder. The sealed ball bearing is located on the bottom flat bar of the mounting device. The encoder is located on the top of the mounting bars. This allows both the encoder and bearing to rotate as the shaft rotates. The rotating signal form the optical encoder is sent to the PLC for processing. Ladder logic was used to program the PLC and its display screen was used to display the rotation rate of the encoder in two quadrants. Any difference in rotation between the two quadrants for a time period of three minutes alarms the PLC and displays “Check Filter” on the LCD screen.

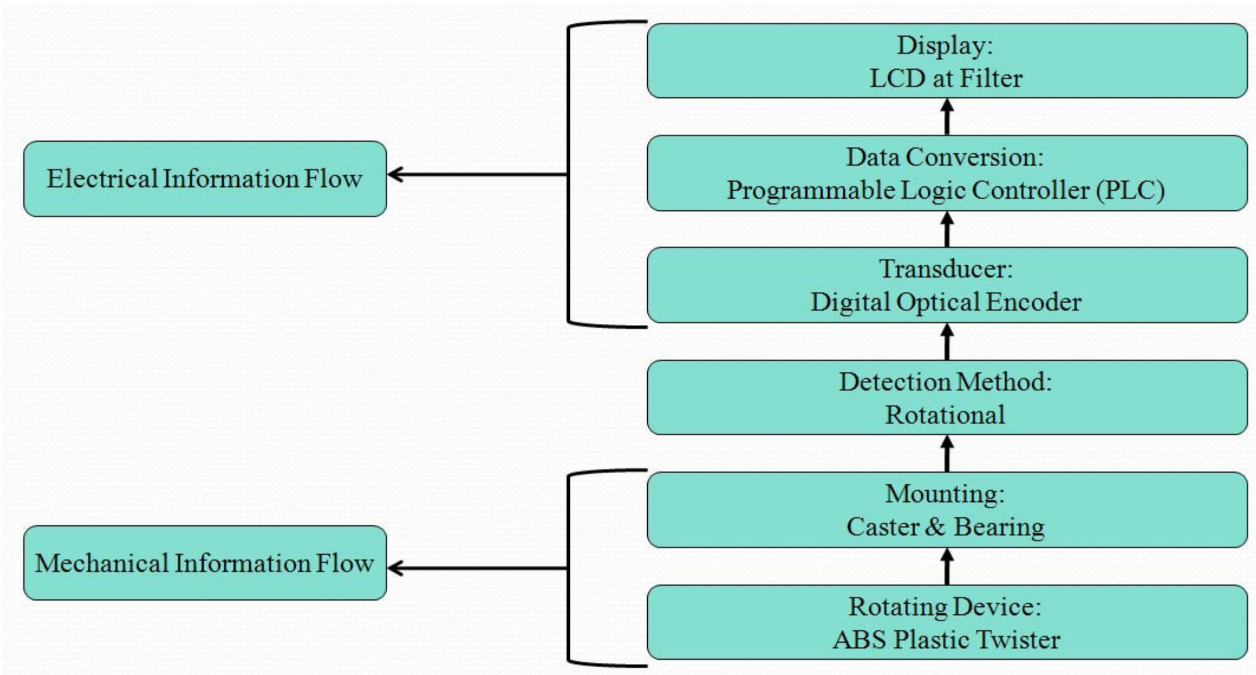


Figure 5. Flow Chart of Design Solution.

3.1 Shape

Over the course of last semester, Aqua Tech experimented with several shape designs in the acrylic model. Through this testing, Aqua Tech was able to determine an optimal shape to develop in more detail throughout the second semester. The focus of the detailed shape design and fabrication was the twisted acrylic design from the first semester, named the Twister. This twisted shape is a rectangular extrusion on a helix. Initial testing of the design was through heating and twisting thin pieces of acrylic. Preliminary testing proved that this was a viable design shape, and multiple variations were modeled using SolidWorks. This allowed the team to test the effects of different details of the design and the computer model created a reproducible design.

After the designs were finalized, models were created using the 3D printer on campus. The 3D printer was the best option for creating these prototypes because it was the least expensive option for Aqua Tech's low volume production and it was readily available. Multiple variations of the model were tested, and through this testing, Aqua Tech was able to observe the effects of different design details, such as amount of twist, model width and thickness. The optimal design was chosen through this testing process.

Figure 6. The Twister is the optimal shape that Aqua Tech is recommending to Blue Water Technologies.

The optimal design is built on a two by one-half inch rectangle. It has one-half revolution (180°) and then tapers from the rectangle to a circular shape, as shown in Figure 6. The overall height is ten inches. A drawing package is provided in Appendix A.

The twister has a hollow PVC pipe mounted to the top cylinder. The hollow shaft is three feet long and has a coupling that reduces the outside diameter from 0.84" to 0.5" at the top of the shaft. The roller bearing is mounted on the hollow shaft before the coupling. After the coupling, the 0.5" outer diameter shaft is only one inch long. The 0.5" shaft then fits into the encoder.

3.2 Mounting

By the end of last semester, Aqua Tech had narrowed the scope of mounting options to focus on the caster design. Throughout the process of the detailed design, an idea that incorporated both the caster and double bearing designs was created. The final method for mounting the sand bed turnover monitors is shown below in Figure 7.

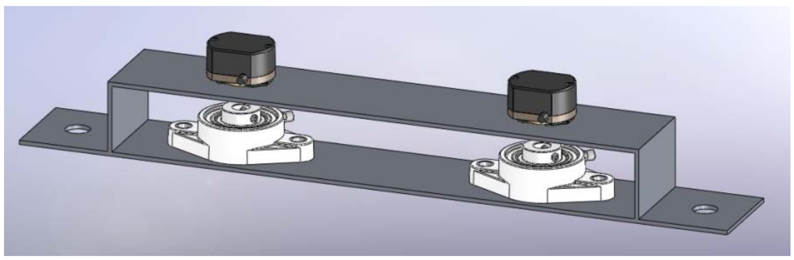


Figure 7. The mounting system is mounted on top of the acrylic model. The bearings are shown in white. The encoders are black and bronze.

The mounting design is created out of two 3” wide stainless steel flat bars. There are two smaller 1 inch by 3 inch flat bars welded to each of the larger bars to add 4 inch of space between them. This creates one surface for the encoder to sit on and act as the caster while the other surface holds a bearing to add extra weight support.

This device is then placed on the top lip of the acrylic model filter. The edges of the bottom flat bar are bolted to the holes on the pre-existing on the filter model lip. Using these bolt holes allows the device to be mounted without modification of the current filter design.

3.3 Mechanical to Electrical Interfacing

The data acquisition system (DAQ) uses two encoders for the data collection. The encoders being used in this design are the Encoder Products Company’s Accu-coder Model 260. Specifically, the model number is 260-N-R-10-L-1270-Q-OC-1-S-NF-2-N. The specifications of the encoder are located in Appendix B. The encoder that was chosen uses a 5-pin M12 connector type. There is a DC power input, DC power ground, cable shield, and two outputs, A and B. The 24V DC power supply of the PLC is connected to the encoders' power inputs, the cable shield is connected to ground, and outputs A and B are connected to the PLC inputs. In this design, the output signal B is not used, but is still connected to the PLC. A diagram of the wiring method used is located in Appendix C.

These particular encoders have 1270 different steps. Each step is 0.00124 inches apart as shown in the Mathcad Appendix D. Therefore, each time the encoder rotates 31.4 µm, signal A will output a high signal into the PLC input.

Figure 8. Encoder used in final design.

3.4 Data Analysis with the PLC

Blue Water Technologies provided Aqua Tech with a PLC from Automation Direct with model number, D0-06DD2. Along with the PLC, Blue Water Technologies also provided the DirectSoft 5 software for programming of the PLC. DirectSoft 5 uses ladder logic to program the PLC. Standard RFF instruction, a type of ladder logic, was used to calculate the rotational rate of the encoders. Appendix E shows the program that Aqua Tech created for the PLC.

As the PLC input transitions from a high to low signal along with the encoder, a counter within the PLC counts each transition. This counts the amount of steps that the encoder passes within the allowed time period. Simultaneously, a timer begins and is reset at 40 seconds. The counter is set to reset to zero when the timer reaches 40 seconds. The counter then continues to count from zero. Since the timer counts in increments of 0.1 seconds, the timer value is divided by 10 to display in units of seconds.

When the timer reaches 30 seconds, the counter is loaded into the accumulator and multiplied by 124. This allows the rate to be displayed without using two memory locations. When a number is divided the remainder is output to the accumulator stack. The DivAppendix shows this in Appendix F. Multiplying the counter by 124 shifts the accumulator left three positions, and thus allowing the rotational rate to be displayed using a single memory address. The resulting number from this multiplication is then divided by the timer in terms of seconds, and outputted to a memory address. A partial flow chart of the program is shown below in Figure 9. A complete flow chart is shown in Appendix G.

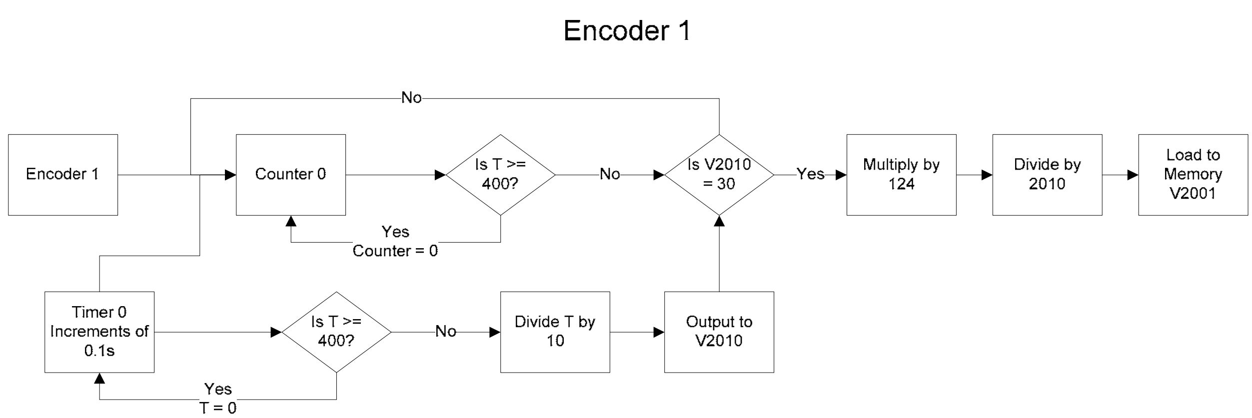


Figure 9. PLC program for single encoder.

Next, the two rates obtained from the two encoders are compared against each other within the program of the PLC. When one rate is larger than another, a counter is activated. When the counter reaches six, the message, “Check Filter” is sent to the LCD. In order for the counter to reach six, the rates must be unequal for six cycles in a row. Since the rates are obtained every 30 seconds, this requires the device rates to be imbalanced for three minutes in order for a “Check

Filter" message to display on the LCD. Below is a table that shows the memory addresses used by the PLC program.

Memory Locations	
Functions	**Memory Address**
Counter 0	V1000
Counter 1	V1001
Counter 2	V1002
Counter 3	V1003
Timer 0	V0000
Timer 0 Conversion	V2010
Encoder 1 Rate	V2001
Encoder 2 Rate	V2002

Table 2. Memory addresses of device functions in the PLC.

3.5 *Display Methods*

The PLC has an external display that is used to display the rotational rate found by the PLC and encoders. The LCD has a data monitor menu that will allow the operator to monitor any memory address located in the PLC. The program has conveniently placed any information that could be helpful in troubleshooting problems in concurrent memory addresses so that problems can be easily accessed.

4. Product Evaluation

4.1 Specification Evaluation

Comparing the actual performance of the sand bed turnover monitor to the specifications outlined at the beginning of the project, the majority of the acceptable performance categories were met. Below is a breakdown of each category and each specification is marked with a "yes" or "no" if the design met or failed to meet the acceptable performance.

Physical Properties

Acceptable Performance	*Meets Performance*	*Actual Measurement*
h=1-6", Dia ≤ 6 inches	Yes	h=1-6", Dia ≤ 6 inches
≤ 10 lbs	Yes	≤ 10 lbs
12"-24" below the surface of the sand slurry	Yes	6"-18"
4 devices	No	2 devices
Not sand attractant or waste attractant	Yes	Hard-durable plastic
No visible leaches to filter water	Yes	N/A
Prototype device can be run off of common power source	Yes	220 V

Life and Replacement

Acceptable Performance	*Meets Performance*	*Actual Measurement*
Can be replaced without replacing filter	Yes	
Made from a material that does not absorb water, after testing no marks or abrasions deeper than 1/8"	Yes	

Manufacturing

Acceptable Performance	*Meets Performance*	*Actual Measurement*
<$1000	No	

Output

Acceptable Performance	*Meets Performance*	*Actual Measurement*
Measure range capability: 0"-3" per minute	Yes	0"-1" per minute
PLC receives data output (avoid PLC Series 300)	Yes	PLC receives data output
95% Consistent (within accuracy)	Yes	
± 5 % error	Yes	
Access reading on display at desired location	Yes	Displayed at the filter
Alarm that alerts the proper person within 5 seconds of dropping below critical rate	No	Radial monitor rate only

Table 3. Specification evaluation against recommended prototype.

Thus, in three specifications, the design failed to meet the acceptable performance. However, in 13 specifications, the designed met the acceptable performance. With a major portion of design successes, the sand bed turnover monitor design project was a success. An acceptable design was fabricated and can be implemented in the large scale Centra-flo filters with little design alterations. Some of these alterations are discussed in the "Further Recommendations" section.

4.2 DFMEA Evaluation

Risk analysis was performed on the sand bed turnover monitor design by using DFMEA evaluation. DFMEA stands for Design Failure Mode and Effect Analysis. It is a process that helps identify design risks and highlights the most risky design features.

Potential failure modes were identified which are: 3D printer material, 3D printer part, mounting system, shaft, bearing, encoder, and PLC. Then, possible effects of the each of these potential failure modes were identified and rated on the severity of the potential effect. Next, likely causes of the effect were identified and rated on an occurrence level. Design controls were identified to state ways to bypass the potential failure mode; a detection rating was also identified. Finally, the "RPN" number, a product of all the three ratings, was calculated in order that each potential failure mode be properly weighted based on the three ratings.

The main purpose of the DFMEA evaluation was to highlight the most risky potential failure modes. The highest rated possible failure modes were the PLC, bearing/shaft connection, and 3D printer material. All other potential failure modes had minimal risk. See Appendix H for the DFMEA evaluation.

4.3 Performance Testing

The preliminary method used to test the monitor shape was to secure the shape to a long durable plastic rod (1/2 inch diameter.). A sealed bearing was then secured to the rod using set screws or was press fit to the rod, depending on the bearing. The monitor was then placed into the sand bed and allowed to submerge until the sealed bearing was the correct height to be secured to a flat steel bar with vise grips which was laid across the top of the filter. Markers were used on the rotating shaft and bearing to measure the 1/4 turns. A stop watch was used to time the rotation. Once the encoder was available for testing, it was attached to the top of the rod with set-screws and then the encoder was attached to the PLC which displayed counts every 30 seconds.

The method used to calibrate the radial shaft rotation to linear sand flow rate was to use a multiplier to convert the encoder counts to a sand bed turnover rate. The team decided to perform multiple linear tests with a PVC stick to experimentally obtain such a multiplier.

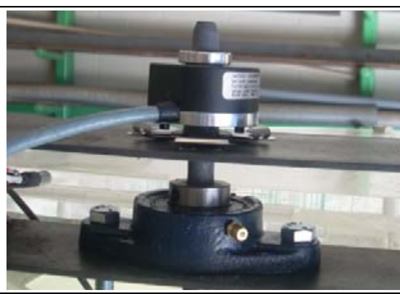
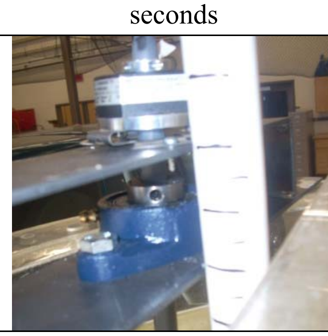
	
1. Secure device shape on long shaft	2. Secure bearing to mounting device
	
3. Attach encoder to shaft on mounting device	4. Sample rotational rate on PLC every 30 seconds
	
5. Time ¼ rotations	6. Calibration method

Table 4. Step by step pictures of testing methodology.

	
1. Acrylic Twister – 180° (left) 5. Red Paint Stir (right)	2. Acrylic Twister – 360° shallow pitch
	
3. Acrylic Twister – 360° steep pitch	4. Acrylic Twister – 90°
	
6. 3D printer corkscrew	7. 3D printer twister

Table 5. Pictures of devices tested in the acrylic model. Numbers for devices correspond to Table 6.

Description of shape tested	Results
1. Acrylic Twister – 180°	10 minutes 30 seconds for a ¼ turn
1. Acrylic Twister – 180° - with encoder	12 minutes 30 seconds for a ¼ turn
2. Acrylic Twister – 360° shallow pitch	14 minutes for a ¼ turn
3. Acrylic Twister – 360° steep pitch	9 minutes 45 seconds for a ¼ turn
4. Acrylic Twister – 90°	18 minutes for a ¼ turn
5. Red Paint Stirrer	9 minutes 40 seconds for a ¼ turn
6. 3D printer corkscrew	Plastic layers sheared - failed
7. 3D printer twister	9 minutes 30 seconds for a ¼ turn
½ inch PVC tube	0.237 inches/minute

Table 6. Testing results obtained for multiple devices. Numbers for devices correspond to Table 5.

- The twister and paint stirrer have comparable results.
- The 180° and 360° steep pitch twisters have comparable results.
- The 3D printer design must be above a certain thickness.
- The linear rate at which all testing occurred was 0.237 inches/minute and an average count was 24 counts/30 seconds.
- The rotational rate must be multiplied by 0.00246875 to obtain the sand bed turnover rate.

The environment that testing was performed in was a constant and unvarying sand slurry at a constant air-lift speed. Further testing needs to be performed by varying the air-lift speed to confirm that the radial monitor of the monitoring device varies linearly with the sand bed rate. At this point, the radial rotating monitor is assumed to be turning linearly with sand bed turnover.

The result of the PVC stick calibration resulted in an average rate of 0.237 inches per minute for the sand bed turnover rate. For this calibration, the red paint stirrer was attached to the encoder which displayed a range of 21 to 25 counts per 30 seconds on the PLC LCD screen. Calculations were made such that the radial and linear rates were compared and it was verified that they were not equal. Thus, the importance of the multiplier for calibration is essential. In conclusion, the radial rotating monitor gives an imitation rate that varies linearly with sand bed turnover, but to obtain the true sand bed turnover rate, each monitor must be calibrated. Each monitor must be calibrated because each variance will divert the radial monitor from the actual sand rate such as bearing resistance and encoder resistance. If all these parameters are kept the same for the four filter monitors, then an actual differential in quadrants is still obtained.

The calibration number calculated for the monitor calibrated is an average of nine trials of one to two inch linear drop depth. Then, the linear drop depth was timed to obtain a linear sand bed turnover rate. The average count was 24 counts per 30 seconds, thus the multiplier (if the rotation follows the sand rate turnover linearly) is 0.00246875 (inches/count).

Calibration calculation:

$$\frac{Rl}{2} = k * Rr \qquad (1)$$

Where, Rl is the linear sand flow rate, Rr is the rotational sand flow rate, and k is the multiplier constant that converts the rotational sand flow rate into the linear sand flow rate. The linear sand rate is divided by two because the encoder counts are each 30 seconds, so the linear sand rate for 30 seconds would be half of what it is from the inches per minute rate.

4.4 Economic Analysis

In order for Blue Water Technologies to implement a monitoring device in each quadrant, the devices will need to be mass produced. Aqua Tech asked ProtoMold for a quote on plastic injection molding. A summary of the cost is shown below in Table 7. For the initial 100 Twister pieces it will cost approximately $13,000. For every 500 devices afterward, it will cost just over

$4,000. A more detailed cost breakdown and design suggestions from ProtoMold are provided in Appendix I.

	Initial Setup	Additional Production
Tooling/Setup Cost	$12,645	$750
Prototypes (ea)	$6.92	$6.92
Total Initial Cost	For 100 Devices: $13,337	For 500 Devices: $4,210

Table 7. Cost of plastic injection molding of recommended twister. Quote from ProtoMold.

Along with the cost of plastic injection molding, creating the rest of the monitoring device has additional costs. It is recommended that Blue Water charge an estimated ten dollars per injection molded device to make up the setup and tooling costs.

In some of Blue Water Technologies Centra-flo filters, a PLC is already required for proper operation. With the monitoring device that Aqua Tech has created, a PLC will need to be included with every filter. Shown below in Table 8 is an implementation cost analysis. This analysis shows the cost for filters that already have a PLC as well as filter models that will need to add a PLC.

Each Quadrant	Cost
Injection Mold	$10
Encoder	$250
Bearing	$9
Mounting	$17
Total per Filter (without PLC)	$1,110
PLC	$199
Total per Filter (with PLC)	$1,309

Table 8. Implementation cost for entire filter. Cost analysis shown both with and without a PLC, which is already included in some filters.

Overall, the cost benefit to Blue Water Technologies has been positive. It has provided a monitoring device that meets all requirements originally is an improvement to acquire a monitoring device that meets all requirements of Blue Water Technologies.

5. Conclusions and Recommendations

The project proved to be overall very effective and Aqua Tech was able to measure the sand flow rate with a fair amount of precision. After two semesters of vigorous design and testing Aqua Tech found that a twisted plastic piece attached to an encoder and PLC via a sealed ball bearing worked most effectively. The design calculations were based on the acrylic water tank that Blue Water Technologies provided on the first visit to Hayden, Idaho. Therefore, in order to implement the design solution in an industrial filter some design modification will be necessary. It is estimated that the total cost for the device in all four quadrants would be approximately $1100. Aqua Tech found that successful designs gave consistent results. It is recommend that Blue Water work with future senior design teams or senior lab teams to conduct further testing on a multiplier before this design is implemented into an industrial system. This would give an observer direct measurement regarding sand flow rate. Aqua Tech also recommends that Blue Water work with future senior design teams to find an alternate electrical component to measure the sand flow rate. This could significantly reduce the overall cost of the design since approximately 90% of the cost was spent on the encoders.

Lastly, Aqua Tech would like to thank Blue Water Technologies for providing the budget and all other supporting information without which the project would not have been possible. Aqua Tech would also like to thank the professors and friends at University of Idaho who helped during the course of design and made this project a success.

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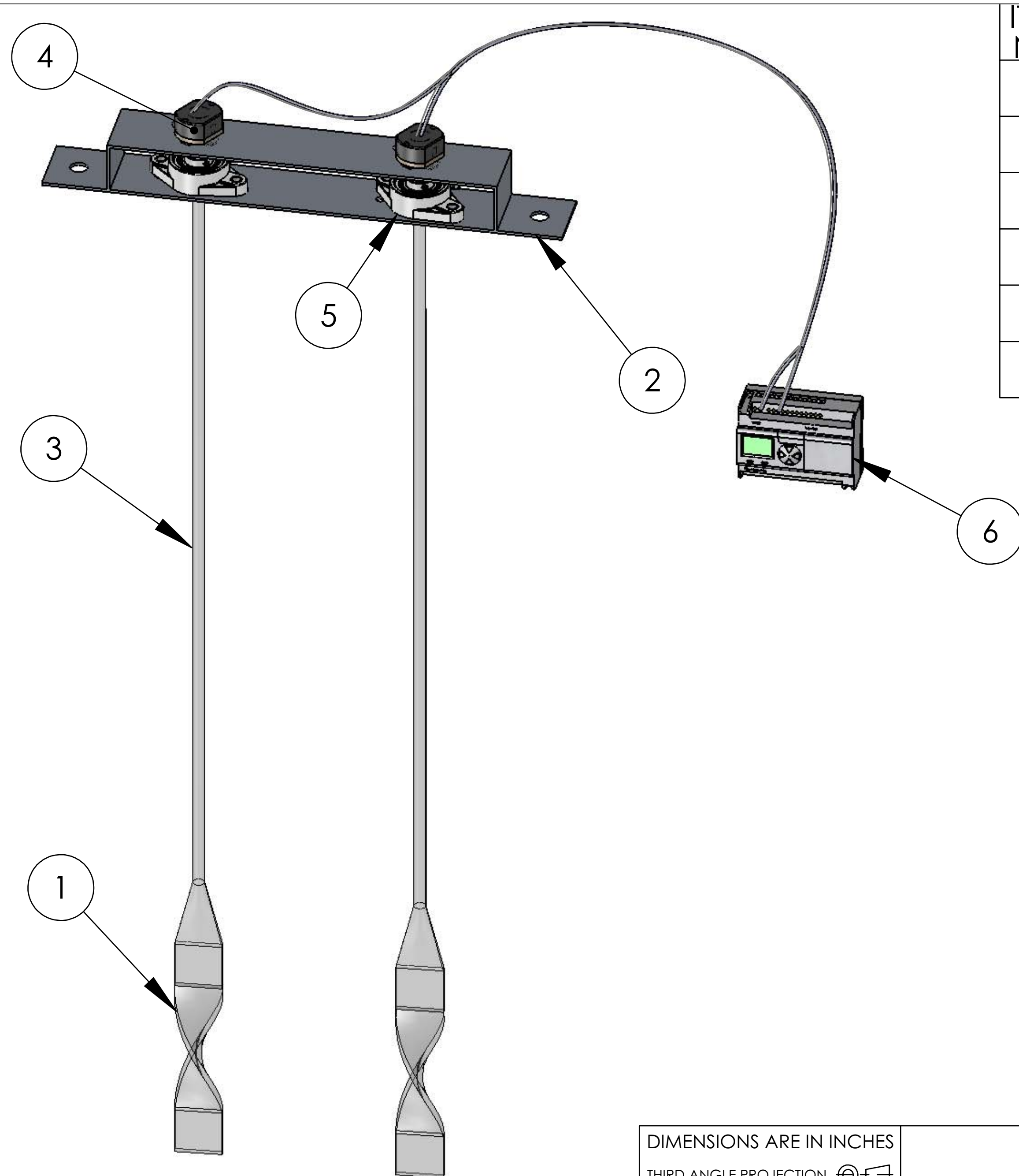
9. VXB Ball Bearings. Retrieved March 15, 2009, from Ball Bearings Website: http://www.vxb.com/Merchant2/merchant.mvc?

Appendix A. Drawing Package



ITEM NO.	DESCRIPTION	QTY.
1	Twister Shape	2
2	Mounting Bracket	1
3	Shaft	2
4	Encoder	2
5	Sealed Ball Bearing	2
6	PLC	1

DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

Material: See Part Drawings

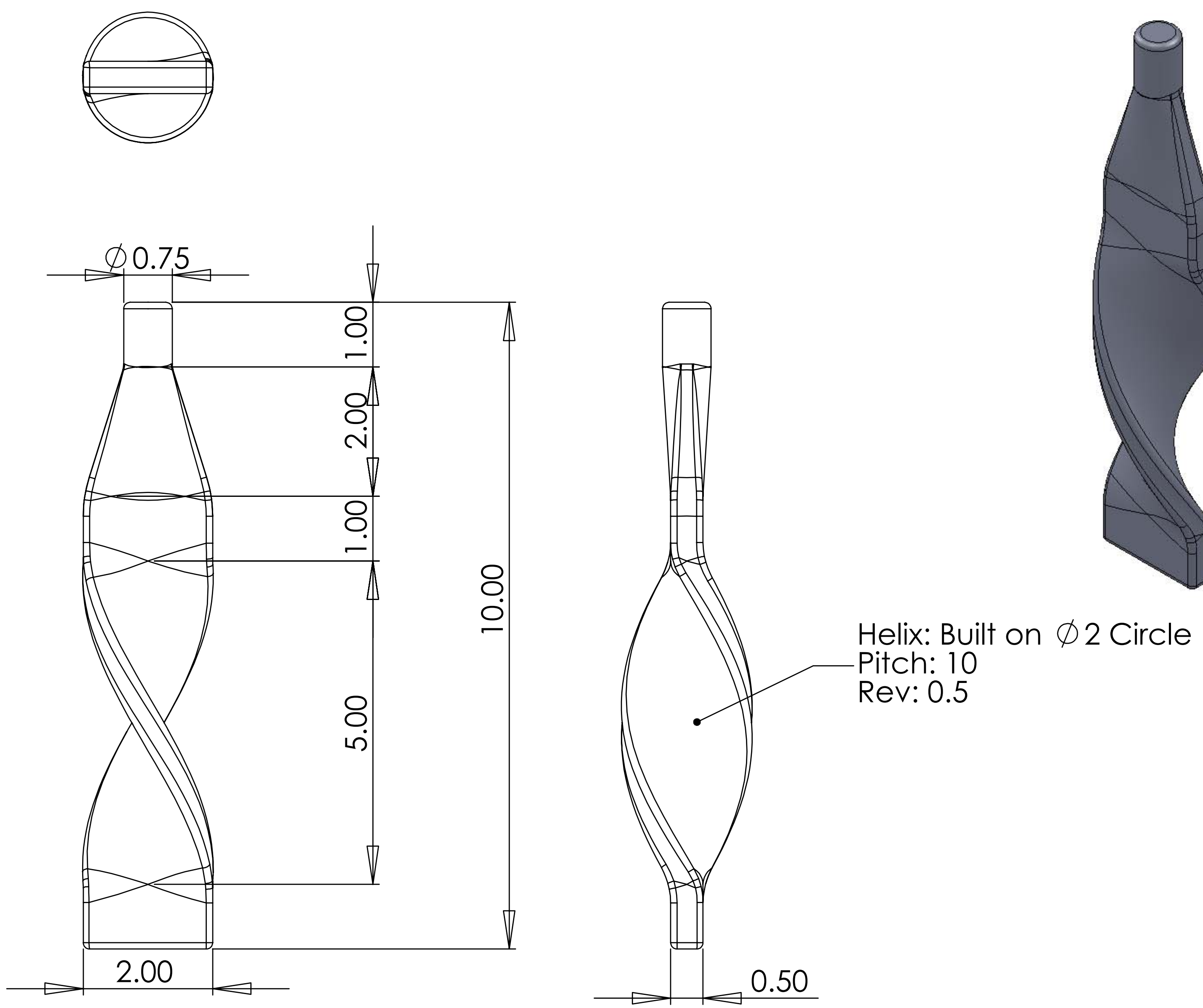
DEFAULT TOLERANCES:

LINEAR:
X. ± .25
X.X ± .1
X.XX ± .01
X.XXX ± .002

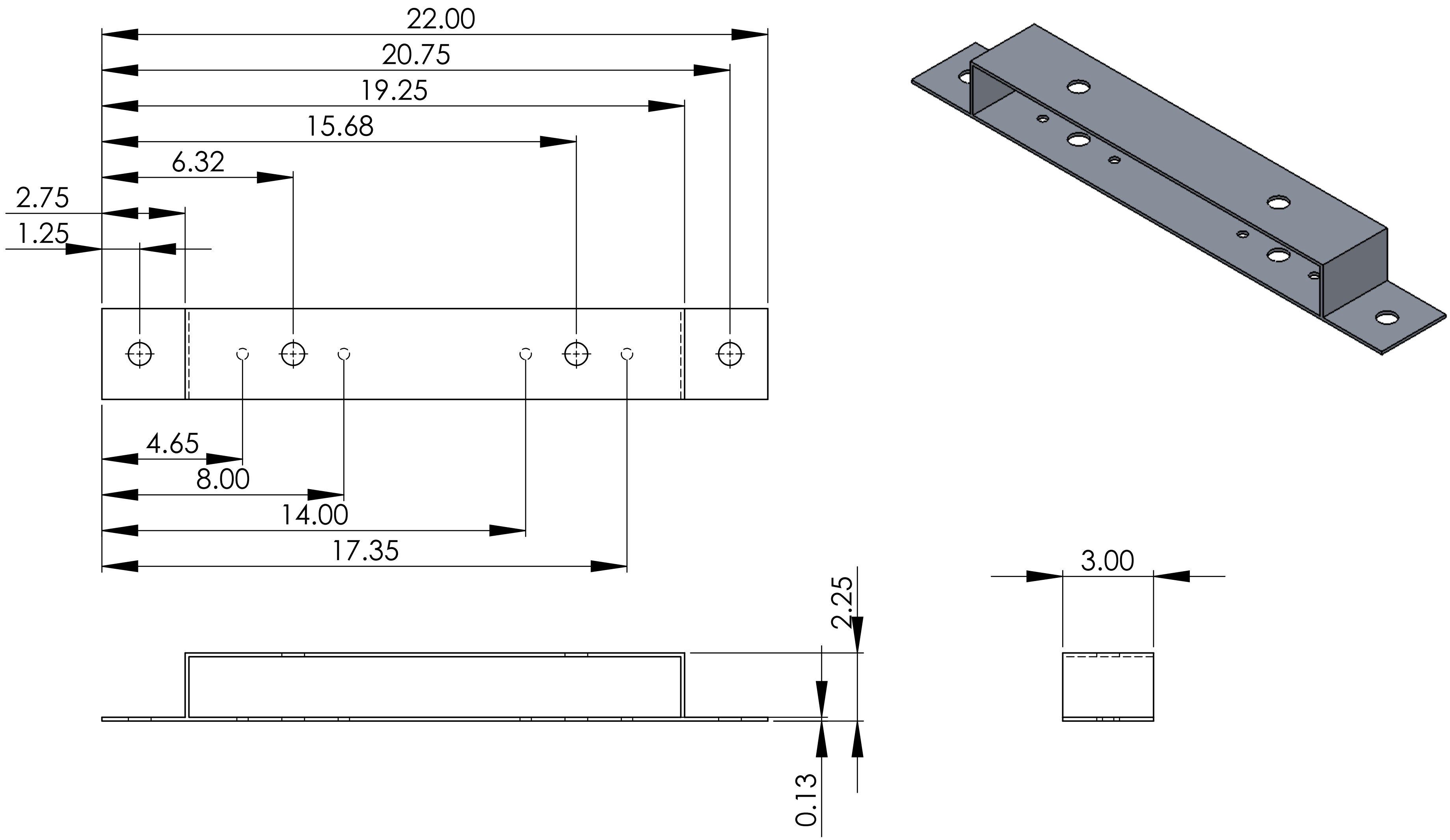
ANGULAR:
X. ± 2
X.X ± 1
X.XX ± 0 30'

DESCRIPTION: Finished Assembled Prototype
CHECKED BY:
DATE:
DRAWN BY: Amanda McGrath
DATE: 4/30/2009
FILE NAME: Finished Assembly
CAD Application SolidWorks

Aqua Tech
UNIVERSITY OF IDAHO
ME DEPARTMENT
Part : Finished Assem.
QTY:
Scale: 1:7
SHEET 1 OF 4



DIMENSIONS ARE IN INCHES THIRD ANGLE PROJECTION	Material: ABS Plastic		Aqua Tech
DEFAULT TOLERANCES: LINEAR: X. ±.25 X.X ±.1 X.XX ±.01 X.XXX ±.002 ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'	DESCRIPTION:		UNIVERSITY OF IDAHO ME DEPARTMENT
	CHECKED BY:	DATE:	
	DRAWN BY: Amanda McGrath	4/16/2009 DATE:	Part : Twister Design / QTY:
	FILE NAME: Twister-1	CAD Application SolidWorks	Scale: 1:2.5 / SHEET 2 OF 4



DIMENSIONS ARE IN INCHES

THIRD ANGLE PROJECTION

Material: 1/8" Steel Flat Bar

Aqua Tech

UNIVERSITY OF IDAHO
ME DEPARTMENT

DEFAULT TOLERANCES:

LINEAR:	ANGULAR:
X. ±.25	X. ± 2
X.X ±.1	X.X ± 1
X.XX ±.01	X.XX ± 0 30'
X.XXX ±.002	

DESCRIPTION: Mounting Bracket

CHECKED BY: DATE:

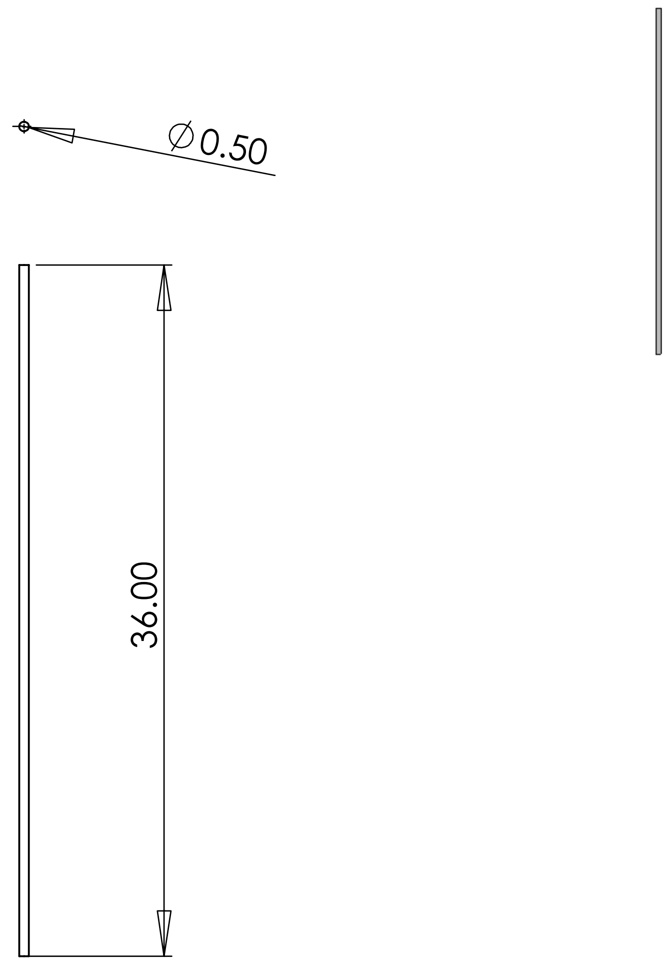
DRAWN BY: Amanda McGrath DATE: 4/26/2009

FILE NAME: Mounting Bracket

CAD Application SolidWorks

Part : Mounting Bracket QTY:

Scale: 1:5 SHEET 3 OF 4



DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION
Material: PVC

DEFAULT TOLERANCES:

LINEAR:	ANGULAR:
X. ±.25	X. ± 2
X.X ±.1	X.X ± 1
X.XX ±.01	X.XX ± 0 30'
X.XXX ±.002	

DESCRIPTION: Shaft
CHECKED BY: DATE:
DRAWN BY: Amanda McGrath DATE: 5/8/2009
FILE NAME: Shaft
CAD Application **SolidWorks**

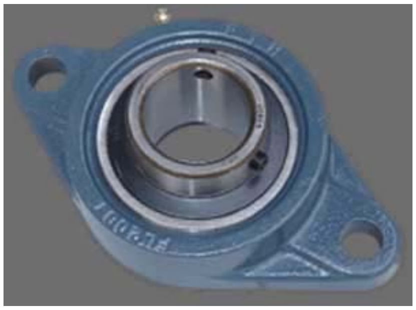
Aqua Tech

UNIVERSITY OF IDAHO
ME DEPARTMENT

Part #: Shaft | QTY:
Scale: 1:10 | SHEET 4 OF 4

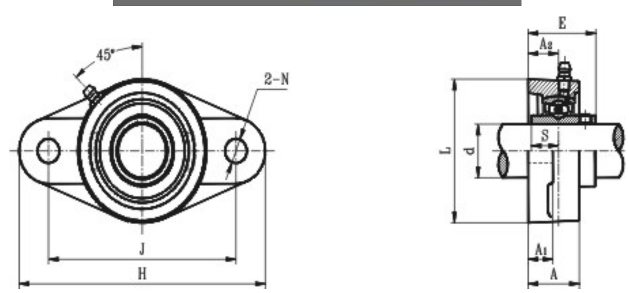
Appendix B. Product Data Sheets

1/2" Mounted Bearing UCFL201-8 + 2 Bolts Flanged Cast Housing



Quantity in Basket: *None*
Part Number: **Kit7328**
Our Low Price: **$9.95**
Shipping Weight: **1.20** pounds

Quantity: 1 add to basket



Unit No	Shaft Dia d (in.)	(mm)	Dimensions(mm) H	L	L	A2	A1	A	E	N	S	A4	Bolt Size	Bearing No.	Housing No.	Mass(kg)	N
UCFL201-8	1/2		113	90	60	15	11	25.5	33.3	11.5	12.7	37.5	M10	UC201-8	FL204	0.51	

VXB Bearings Home > 1/2" inner diameter = 0.500 inch
1/2" Mounted Bearing UCFL201-8 + 2 Bolts Flanged Cast Housing

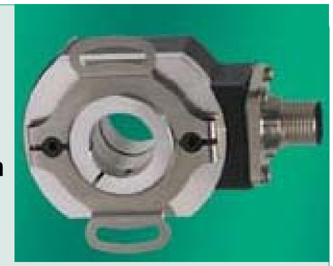
ENCODER PRODUCTS COMPANY

Model 260

New M12 Body Mount!

Features

- Low Profile 1.19"
- Up to 12 Pole Commutation
- Thru-Bore and Hollow Bore (Blind) Styles
- Simple, Innovative Flexible Mounting System
- Incorporates Opto-ASIC Technology
- CE marking available



The Model 260's larger bore (up to 0.625") and low profile make it the perfect solution for many machine and motor applications. Available in two distinct formats - a Hollow Bore and a complete Thru-Bore - the Model 260 uses EPC's pioneering Opto-ASIC design. The Model 260 uses EPC's innovative anti-backlash mounting system, allowing simple, reliable, and precise encoder attachment. Unlike traditional kit or modular encoder designs, it's integral bearing set provides stable and consistent operation without concerns for axial or radial shaft runout. For brushless servo motor applications, the Model 260 can be specified with three 120° electrical phase tracks to provide up to 12 pole commutation feedback. The optional extended temperature capability allows servo motors to operate at higher power outputs and duty cycles.

Common Applications

Brushless Servo Motor Commutation, Robotics, Motor-Mounted Feedback, Assembly Machines, Digital Plotters, High Power Motors

Model 260 Ordering Guide

Blue type indicates price adder options. Not all configuration combinations may be available. Contact Customer Service for details.

260 - N - T - 01 - S - 0256 - Q - OC - 1 - S - SF - 1 - N

MODEL
- 260 Ultra Versatile Commutated Thru-Bore

COMMUTATION[2]
- N No Commutation
- C4 4 Pole
- C6 6 Pole
- C8 8 Pole
- C10 10 Pole
- C12 12 Pole

HOUSING STYLE
- B Hollow Bore (Blind)
- T Front Clamp Thru-Bore
- R Rear Clamp Thru-Bore

BORE SIZE[1]
- 01 1/4", 0.250"
- 02 3/8", 0.375"
- 10 1/2", 0.500"
- 11 5/8", 0.625"
- 06 5 mm
- 04 6 mm
- 14 8 mm
- 05 10 mm
- 09 11 mm
- 12 12 mm
- 13 14 mm
- 15 15 mm

OPERATING TEMPERATURE[3]
- L -40° to 70° C
- S 0° to 70° C
- H 0° to 100° C
- V 0° to 120° C

CYCLES PER REVOLUTION
1-10,000
See *CPR Options* below
Price adder >1999

NUMBER OF CHANNELS[4]

Channel A Leads B
- Q Quadrature A & B
- R Quadrature A & B with Index

Channel B Leads A
- K Reverse Quadrature A & B
- D Reverse Quadrature A & B with Index

See http://www.encoder.com/literature/index-phasing.pdf for additional options, and waveforms.

OUTPUT TYPE
- OC Open Collector
- PP Push-Pull
- HV Line Driver

MAXIMUM FREQUENCY
- 1 Standard
- 2 Extended

See Specifications For Explanation

CONNECTOR TYPE
- S 18" Cable[5]
- J00 18" Cable with 5-pin M12[7]
- K00 18" Cable with 8-pin M12[7]
- SMJ 5-pin Body Mount M12[7]
- SMK 8-pin Body Mount M12[7]

MOUNTING
- SD 1.575" (40 mm) BC Flex Mount
- SF 1.811" (46 mm) BC Flex Mount
- XF 2.250" BC 3-point Flex Mount
- NF 2.375" BC 3-point Flex Mount
- FA Flex Arm
- FB Flex Arm

SEALING
- 1 IP50 for Thru-Bore
- 2 IP64 for Thru-Bore
- 3 IP64 for Hollow Bore
- 4 IP50 for Hollow Bore

CERTIFICATION
- N None
- CE CE Marked[6]

For specification assistance call Customer Service at 1-800-366-5412

Model 260 CPR Options

0001 thru 0189*	0200	0250	0254	0256	0300	
0360	0400*	0500	0512	0600	0720	0800
0840	1000	1024	1200	1220	1250	1270
1500	1800*	2000	2048	2500	2540	3000
3600*	4096	5000	6000	8192	7200*	10,000

*Contact Customer service for availability

Contact Customer Service for other disk resolutions; not all disk resolutions available with every commutation option.

NOTES:
1. Contact Customer Service for additional options not shown.
2. Not available in all configurations. Contact Customer Service for availability.
3. 5 to16 VDC supply only for H option; 5 VDC supply only for V option. Contact Customer Service for availability and additional information.
4. Contact Customer Service for non-standard index gating options.
5. For non-standard cable lengths add a forward slash (/) plus cable length expressed in feet. Example: S/6 = 6 feet of cable. Frequency above 300 kHz standard cable lengths only.
6. Please refer to **Technical Bulletin TB100: *When to Choose the CE Option*** at www.encoder.com.
7. Not available with commutation or extreme temperature (V) option. 5-pin not available with Line Driver (HV) output. Additional cable lengths available. Please consult Customer Service.

Model 260

Model 260 Specifications

Electrical

- Input Voltage............4.75 to 28 VDC for temperatures up to 70° C
  5 to 16 VDC for 0° to 100° C operating temperature
  5 VDC for 0° to 120° C operating temperature
- Input Current............100 mA max with no output load
- Output Format..........Incremental- Two square waves in quadrature with channel A leading B for clockwise shaft rotation, as viewed from the mounting face.
  See *Waveform Diagrams.*
- Output Types............Open Collector- 20 mA max per channel
  Push-Pull- 20 mA max per channel
  Line Driver- 20 mA max per channel (Meets RS 422 at 5 VDC supply)
- Index........................Once per revolution gated to channel A. See *Waveform Diagrams.*
- Max. Frequency........Standard Frequency Response is
  200 kHz for CPR 1 to 2540
  500 kHz for CPR 2541 to 5000
  1 MHz for CPR 5001 to 10,000
  Extended Frequency Response (optional) is 300 kHz for CPR 2000, 2048, 2500, and 2540
- Noise Immunity.........Tested to BS EN61000-6-2; BS EN50081-2; BS EN61000-4-2; BS EN61000-4-3; BS EN61000-4-6, BS EN55011
- Symmetry ....180° (±18°) electrical
- Quad. Phasing..........90° (±22.5°) electrical
- Min. Edge Sep..........67.5° electrical
- Accuracy..................Within 0.01° mechanical from one cycle to any other cycle, or 0.6 arc minutes.
- Commutation ....Up to 12-pole. Contact Customer Service for availability.
- Comm. Accuracy......1° mechanical

Mechanical

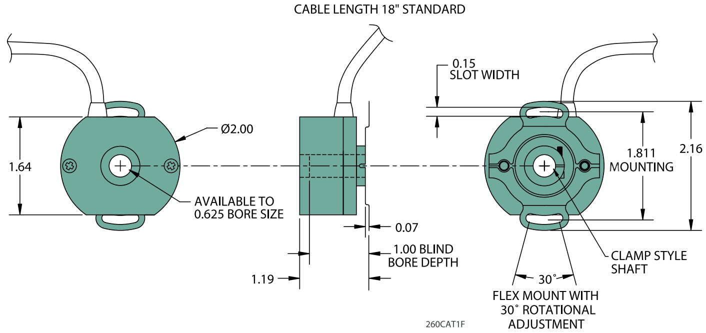
- Max Shaft Speed......7500 RPM. Higher shaft speeds may be achievable, contact Customer Service.
  Note: For extreme temperature operation, de-rate temperature by 5° C for every 1000 RPM above 3000 RPM
- Bore Size..................0.250" through 0.625"
  5 mm through 15 mm
- Bore Tolerance ....-0.0000" / +0.0006"
- User Shaft Tolerances
  - Radial Runout......0.007" max
  - Axial Endplay........±0.030" max
- Starting Torque ....IP50 Thru-Bore: 0.50 oz-in
  IP50 Hollow Bore: 0.30 oz-in
  IP64 Thru-Bore: 2.50 oz-in
  IP64 Hollow Bore: 2.0 oz-in
  Note: Add 3.0 oz-in for -40° C operation
- Moment of Inertia .....3.9×10^{-4} oz-in-sec^2
- Max Acceleration......1×10^5 rad/sec^2
- Electrical Conn ....18" cable (foil and braid shield, 24 AWG conductors non-commutated, 28 AWG commutated), 5- or 8-pin M12 (12 mm) in-line connector with 18" cable (foil and braid shield)
- Housing.....................Black non-corrosive finish
- Mounting...................Slotted Flex Mount standard, additional flex mount options available (see Ordering Guide)
- Weight.......................3.5 oz typical

Environmental

- Operating Temp........0° to 70° C for standard models
  -40° to 70° C for low temperature option
  0° to 100°C for high temperature option
  0° to 120° C for extreme temperature option
- Storage Temp...........-40° to +100° C
- Humidity....................98% RH non-condensing
- Vibration....................10 g @ 58 to 500 Hz
- Shock........................50 g @ 11 ms duration
- Sealing......................IP50; IP64 available

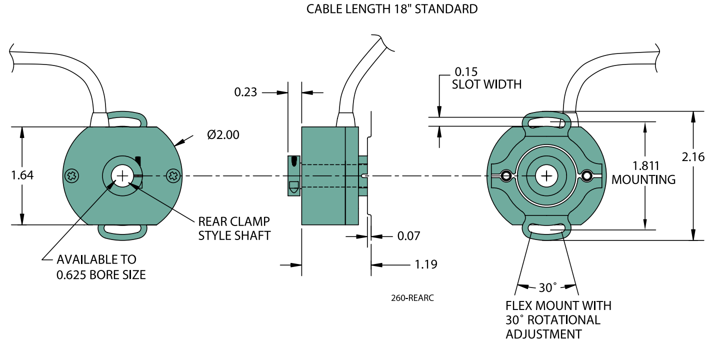
Model 260 With Front Shaft Clamp (T)

With 1.811" (46 mm) BC Slotted Flex (SF)

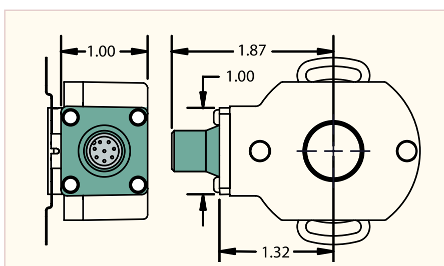


Model 260 Rear Clamp (R)

With 1.811" (46 mm) BC Slotted Flex (SF)



Body Mount M12 (SMJ, SMK)

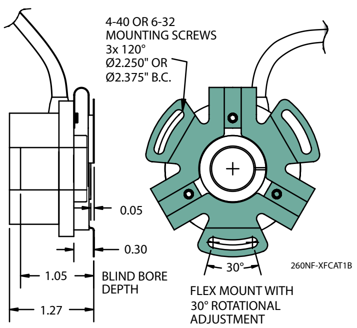


All dimensions are in inches with a tolerance of ±0.005" or ±0.01" unless otherwise specified

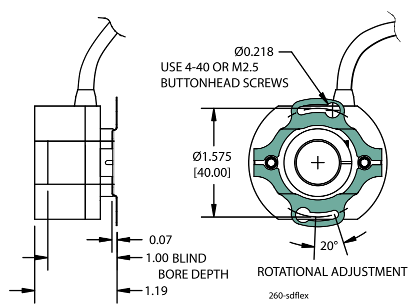
Model 260

ENCODER PRODUCTS COMPANY

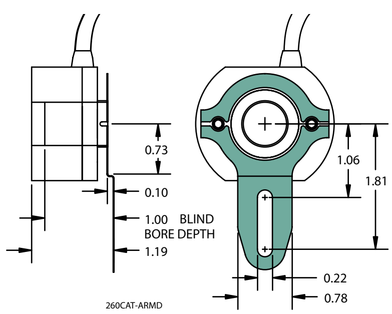
Three Point Flex Mount (XF, NF)



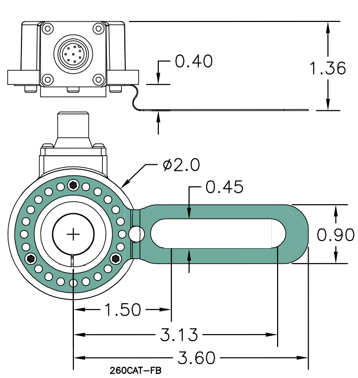
1.575" (40 mm) BC Flex Mount (SD)



Flex Arm (FA)

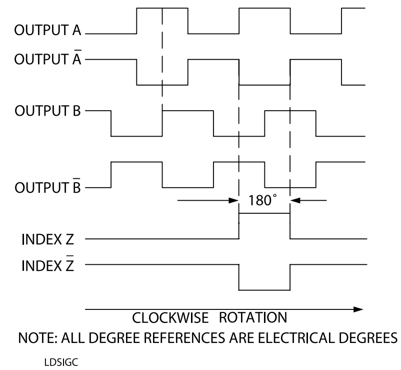


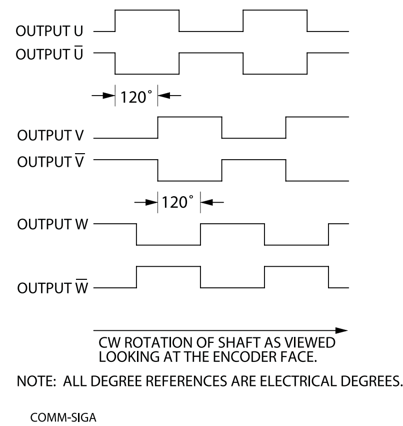
Flex Arm (FB)



All dimensions are in inches with a tolerance of ±0.005" or ±0.01" unless otherwise specified

Waveform Diagrams





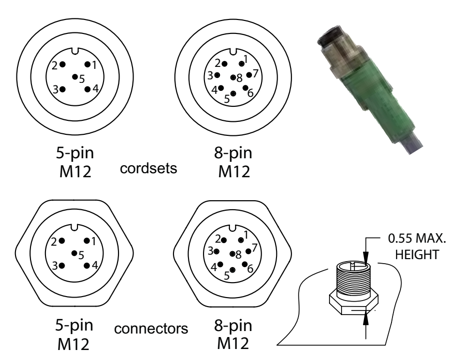
Wiring Table

Function	Cable Wire Color	5-pin M12**	8-pin M12**
Com	Black	3	7
+VDC	White	1	2
A	Brown	4	1
A'	Yellow	--	3
B	Red	2	4
B'	Green	--	5
Z	Orange	5	6
Z'	Blue	--	8
U	Violet	--	--
U'	Gray	--	--
V	Pink	--	--
V'	Tan	--	--
W	Red/Green	--	--
W'	Red/Yellow	--	--
Shield	Bare *	--	--

* CE Option: Cable shield (bare wire) is connected to internal case

**Non-CE Option: Cable shield is connected to M12 connector body. CE Option: Cable shield and M12 connector body is connected to internal case.

Connector Pin-Outs



DL06 I/O Specifications

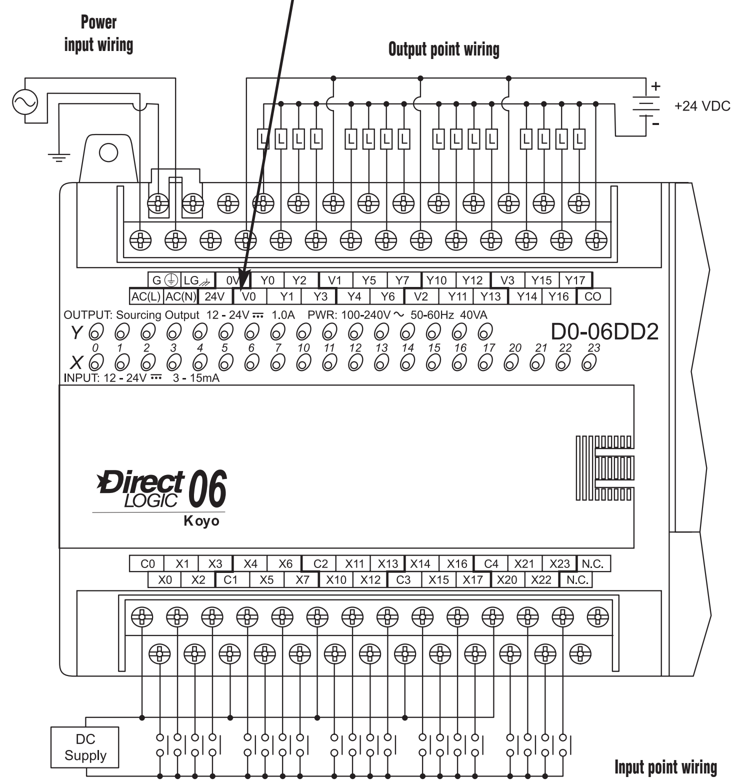
D0-06DD2 <--->

Wiring diagram and specifications

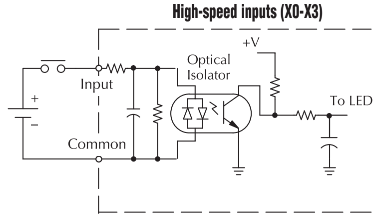
D0-06DD2 Specifications			
AC Power Supply Specifications	*Voltage Range*	95-240VAC (30VA)	
DC Input Specifications	*Number of Input Pts.*	20 (sink/source)	
	Number of Commons	5 (isolated)	
	Input Voltage Range	12-24VDC	
	Input Impedance	(X0-X3) 1.8K @ 12-24VDC (X4-X23) 2.8K @ 12-24VDC	
	On Current/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

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

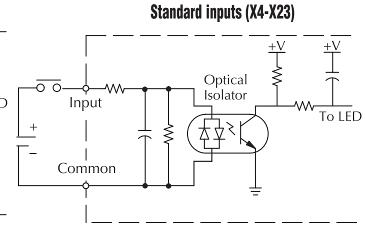
Note: Refer to page 2–29, Power Budgeting, for Auxillary 24VDC current available.



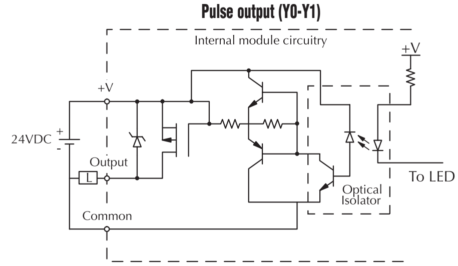
Equivalent input circuit, High-speed inputs (X0-X3)



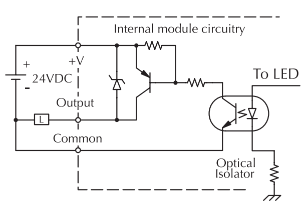
Equivalent input circuit, Standard inputs (X4-X23)



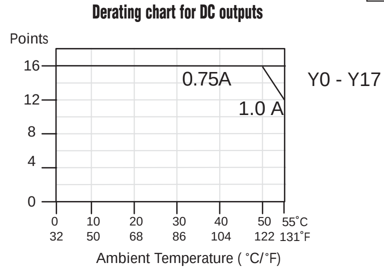
Equivalent output circuit Pulse output (Y0-Y1)



Equivalent output circuit Standard output (Y2-Y17)



Derating chart for DC outputs



Features at a Glance

The DL05 and DL06 micro PLCs are complete self-contained systems. The CPU, power supply, and I/O are all included inside the same housing. Option modules are available to expand the capability of each PLC family for more demanding applications. The standard features of these PLCs are extraordinary and compare favorably with larger and more expensive PLCs.

The specification tables to the right are meant for quick reference only. Detailed specifications and wiring information for each model of the DL05 and DL06 PLCs begin on page 2–33.

Program capacity

Most boolean ladder instructions require a single word of program memory. Other instructions, such as timers, counters, etc., require two or more words. Data is stored in V-memory in 16-bit registers.

Performance

The performance characteristics shown in the tables represent the amount of time required to read the inputs, solve the Relay Ladder Logic program and update the outputs.

Instructions

A complete list of instructions is available at the end of this section.

Communications

The DL05 and DL06 offer powerful communication features normally found only on more expensive PLCs.

Special features

The DC input and DC output PLCs offer high-speed counting or pulse output. Option module slots allow for discrete I/O expansion, analog I/O, or additional communication options.

DL05 CPU Specifications

System capacity

Total memory available (words)	6K
Ladder memory (words)	2,048
V-memory (words)	4,096
User V-memory	3,968
Non-volatile user V-memory	128
Battery backup	Yes[1]
Total built-in I/O	14
Inputs	8
Outputs	6
I/O expansion	Yes[1]

Performance

Contact execution (Boolean)	0.7μs
Typical scan (1K Boolean)[2]	1.5-3ms.

Instructions and diagnostics

RLL ladder style	Yes
RLLPLUS/flowchart style (Stages)	Yes/256
Run-time editing	Yes
Scan	Variable/fixed
Number of Instructions	133
Types of Instructions:	
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
Drum sequencers	Yes
Bit of word	Yes
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
Protocols supported:	
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 modules. Option module specifications are located later in this 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 and output features only available on units with DC outputs.

DL06 CPU Specifications

System capacity

Total memory available (words)	14.8K
Ladder memory (words)	7680
V-memory (words)	7616
User V-memory	7488
Non-volatile user V-memory	128
Built-in battery backup (D2-BAT-1)	Yes
Total I/O	36
Inputs	20
Outputs	16
I/O expansion	Yes1

Performance

Contact execution (Boolean)	0.6μs
Typical scan (1K Boolean)2	1-2ms.

Instructions and diagnostics

RLL ladder style	Yes
RLLPLUS/flowchart style (Stages)	Yes/1024
Run-time editing	Yes
Scan	Variable/fixed
Number of Instructions	229
Types of Instructions:	
Control relays	1024
Timers	256
Counters	128
Immediate I/O	Yes
Subroutines	Yes
For/next loops	Yes
Table functions	Yes
Timed interrupt	Yes
Integer math	Yes
Trigonometric functions	Yes
Floating-point math	Yes
PID	Yes
Drum sequencers	Yes
Bit of word	Yes
Number type conversion	Yes
ASCII in, out, print	Yes
LCD instruction	Yes
Real-time clock/calendar	Yes
Internal diagnostics	Yes
Password security	Yes
System and user error log	No

Communications

Built-in ports:	One RS-232C
	One multi-function RS232C/RS422/RS485

NOTE: RS485 is for MODBUS RTU only.

Protocols supported:	
K-sequence (proprietary protocol)	Yes
DirectNet master/slave	Yes
Modbus RTU master/slave	Yes
ASCII in/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, 7kHz[3]
Pulse output	Yes, 10kHz[3]
Pulse catch input	Yes[3]

1- These features are available with use of certain option module. Option module specifications are located later in this section.

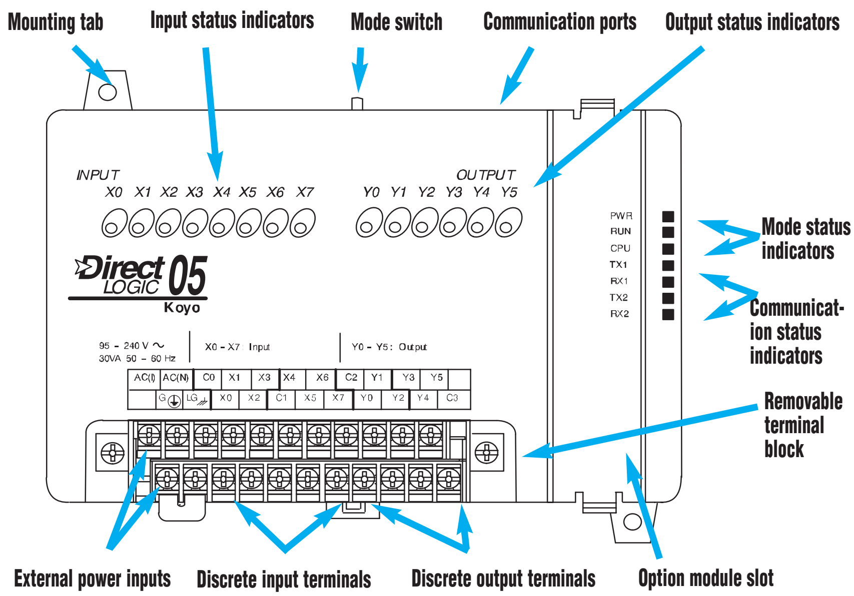
2- Our 1K program includes contacts, coils, and scan overhead. If you compare our products to others, make sure you include their scan overhead.

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

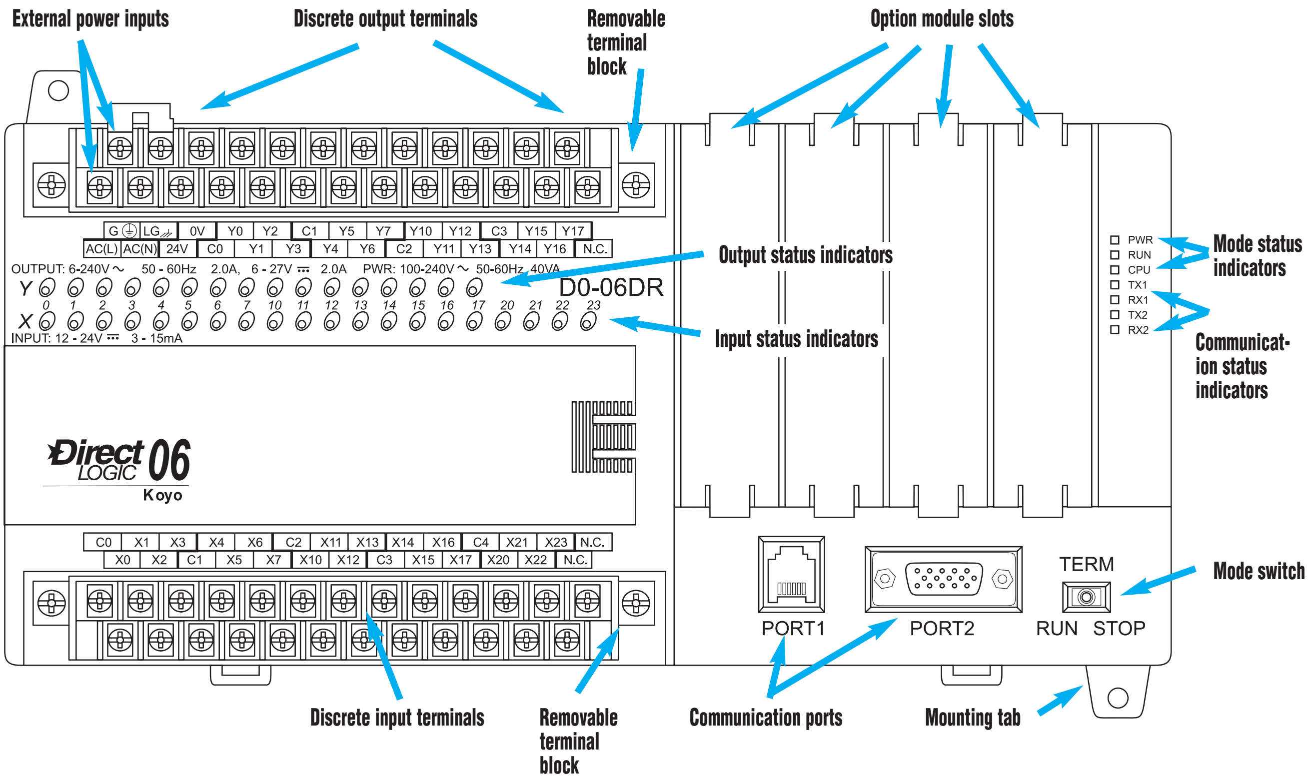
Features at a Glance

*Direct*SOFT software

The DL05 and DL06 PLCs use the same familiar *Direct*SOFT programming software that our larger PLCs use. A FREE version of *Direct*SOFT gives you all the great features of the full version, but with a 100-word PLC program download limitation. For programs larger than 100 words, the full package is required. The FREE PC-DS100 software may be sufficient to program the DL05 and DL06. If you are programming with a full package version prior to v5.0, you will need v2.4 or later for the DL05 PLCs and v4.0 or later for the DL06. We always recommend the latest version for the most robust features. See the Software section in this catalog for a complete description of *Direct*SOFT including features, part numbers of programming packages and upgrades.



Hardware features diagrams



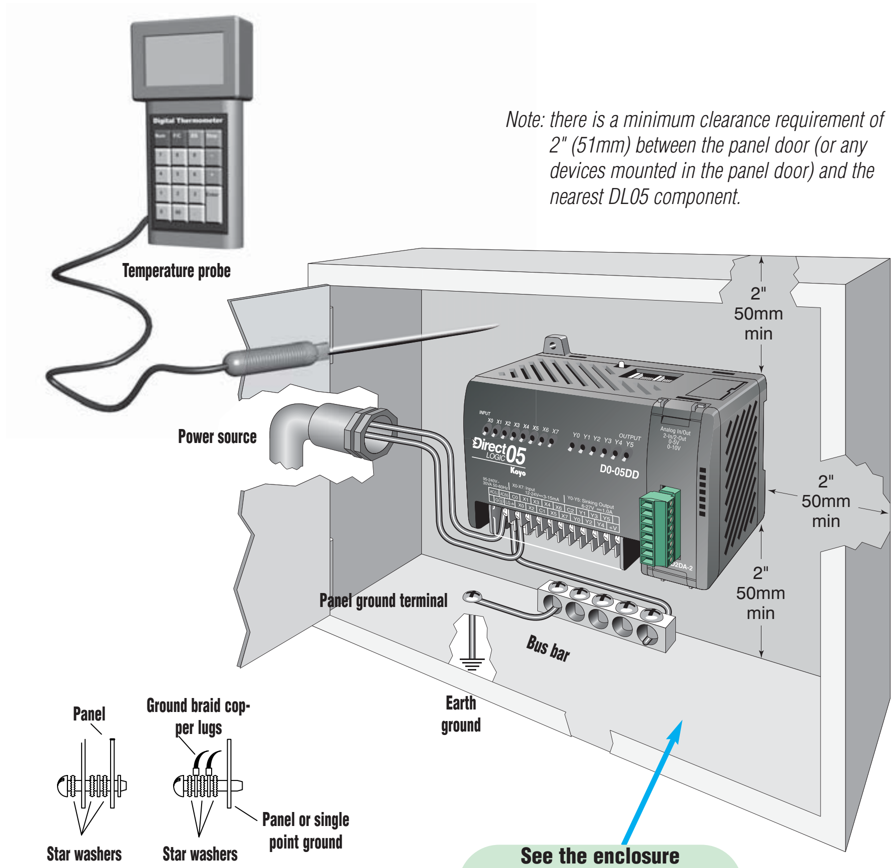
Product Dimensions and Installation

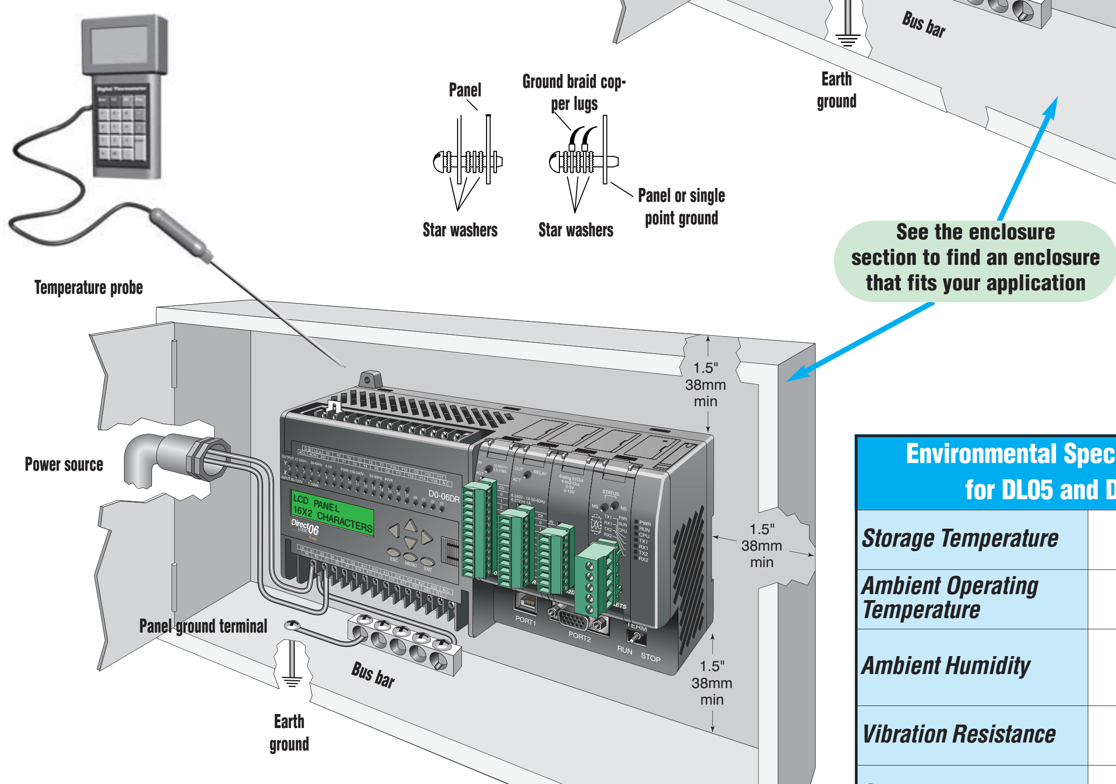
It is important to understand the installation requirements for your DL05 or DL06 system. Your knowledge of these requirements will help ensure that your system operates within its environmental and electrical limits.

Plan for safety

This catalog should never be used as a replacement for the user manual. You can purchase, download free, or view online the user manuals for these products. The D0-USER-M is the publication for the DL05 PLCs, and the D0-06USER-M is the publication for the DL06 PLCs. The D0-OPTIONS-M is the user manual for the option modules. These user manuals contain important safety information that must be followed. The system installation should comply with all appropriate electrical codes and standards.

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





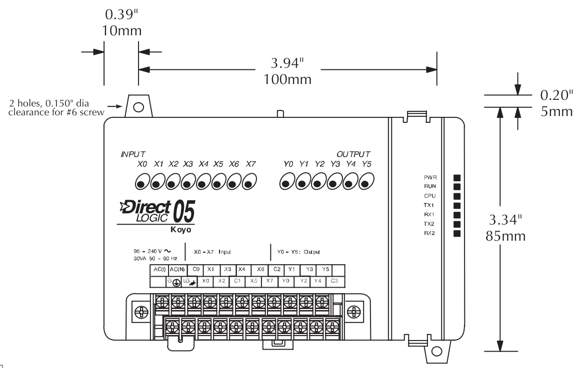
Note: There is a minimum clearance requirement of 1.5" (38mm) between the panel door (or any devices mounted in the panel door) and the nearest DL06 component.

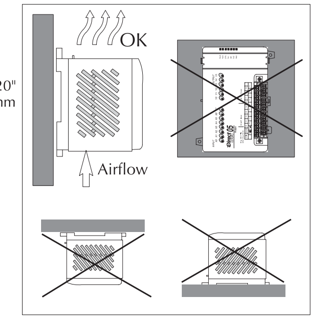
Environmental Specifications for DL05 and DL06	
Storage Temperature	-4º F-158ºF (-20ºC to 70ºC)
Ambient Operating Temperature	32ºF-131ºF (0º to 55ºC)
Ambient Humidity	5 to 95% relative humidity (non-condensing)
Vibration Resistance	MIL STD 810C Method 514.2
Shock Resistance	MIL STD 810C Method 516.2
Noise Immunity	NEMA (ICS3-304)
Atmosphere	No corrosive gases

Product Dimensions and Installation

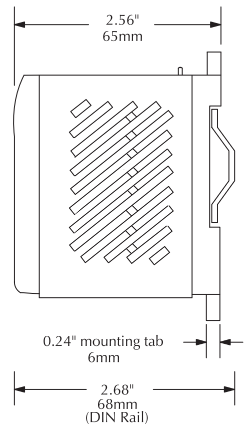
Unit dimensions and mounting orientation

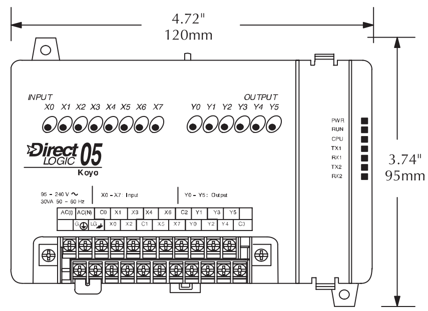
DL05 and DL06 PLCs must be mounted properly to ensure ample airflow for cooling purposes. It is important to follow the unit orientation requirements and to verify that the PLC's dimensions are compatible with your application. Notice particularly the grounding requirements and the recommended cabinet clearances.

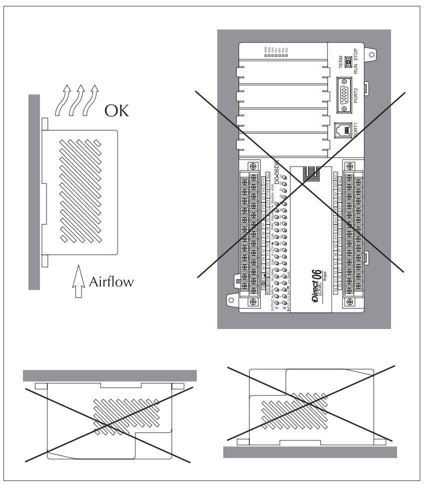




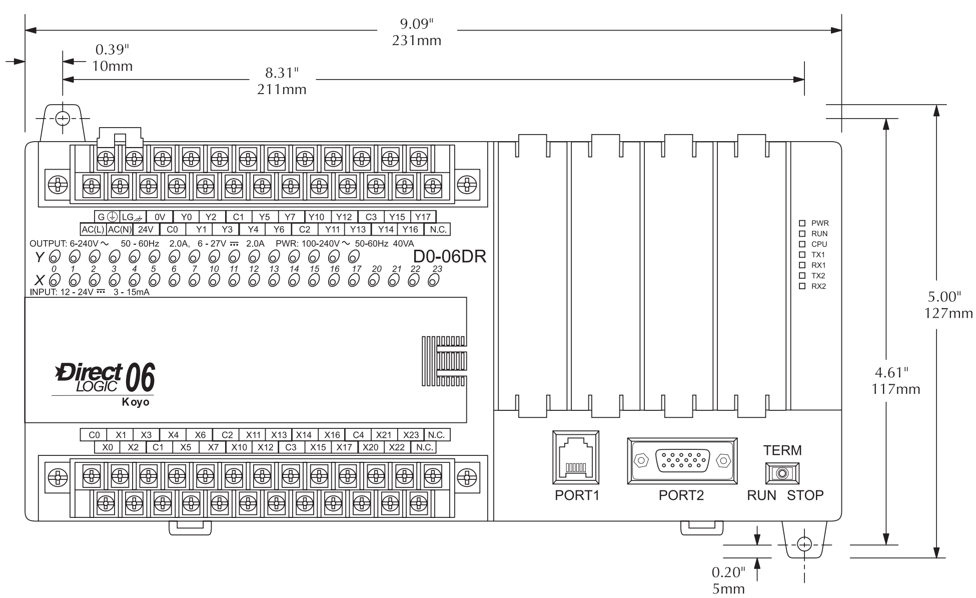
Mounting orientation

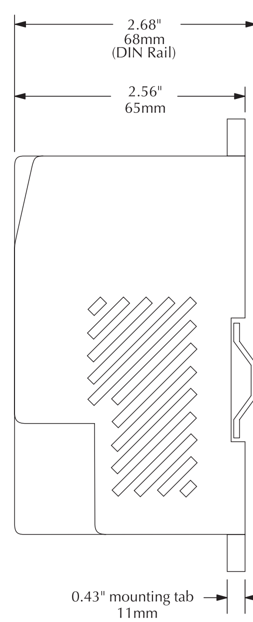






Mounting orientation





PLC Overview
DL05/06 PLC
DL105 PLC
DL205 PLC
DL305 PLC
DL405 PLC
Field I/O
Software
C-more HMIs
Other HMI
AC Drives
Motors
Steppers/ Servos
Motor Controls
Proximity Sensors
Photo Sensors
Limit Switches
Encoders
Current Sensors
Pushbuttons/ Lights
Process
Relays/ Timers
Comm.
TB's & Wiring
Power
Circuit Protection
Enclosures
Appendix
Part Index

Choosing the I/O Type

DL06 Base Unit I/O Table

Part Number	Inputs: I/O Type/ Commons	Inputs: Sink or source	Inputs: Voltage Ranges	Outputs: I/O Type/ Commons	Outputs: Sink or Source	Outputs: Voltage/Current Ratings	Price
D0-06AA	AC/5	N/A	90-120VAC	AC/4	N/A	17-240VAC, 0.5A 50/60 Hz	<--->
D0-06AR	AC/5	N/A	90-120VAC	Relay/4	N/A	6-27VDC, 2A 6-240VAC, 2A	<--->
D0-06DA	DC/5	Sink or source	12-24VDC	AC/4	N/A	17-240VAC, 0.5A 50/60Hz	<--->
D0-06DD1	DC/5	Sink or source	12-24VDC	DC/4	Sink	6-27VDC, 0.5A (Y0-Y1) 6-27VDC, 1.0A (Y2-Y17)*	<--->
D0-06DD2	DC/5	Sink or source	12-24VDC	DC/4	Source	12-24VDC, 0.5A (Y0-Y1) 12-24VDC, 1.0A (Y2-Y17)	<--->
D0-06DR	DC/5	Sink or source	12-24VDC	Relay/4	N/A	6-27VDC, 2A 6-240VAC, 2A	<--->
D0-06DD1-D	DC/5	Sink or source	12-24VDC	DC/4	Sink	6-27VDC, 0.5A (Y0-Y1) 6-27VDC, 1.0A (Y2-Y17)*	<--->
D0-06DD2-D	DC/5	Sink or source	12-24VDC	DC/4	Source	12-24VDC, 0.5A (Y0-Y1) 12-24VDC, 1.0A (Y2-Y17)	<--->
D0-06DR-D	DC/5	Sink or source	12-24VDC	Relay/4	N/A	6-27VDC, 2A 6-240VAC, 2A	<--->

*** These outputs must be derated to 0.6A for EN61131-2 compliance.**

Discrete I/O Option Moduless

Part Number	Inputs: I/O Type/ Number/ Commons	Inputs: Sink or source	Inputs: Voltage Ranges	Outputs: I/O Type/ Number/ Commons	Outputs: Sink or Source	Outputs: Voltage/Current Ratings	Price
D0-07CDR	DC/4/1	Sink or source	12-24VDC	Relay/3/1	N/A	6-27VDC, 1A 6-240VAC, 1A	<--->
D0-08CDD1	DC/4/2	Sink or source	12-24VDC	DC/4/2	Sink	6-27VDC, 0.3A	<--->
D0-08TR	N/A	N/A	N/A	Relay/8/2	N/A	6-27VDC, 1A 6-240VAC, 1A	<--->
D0-10ND3	DC/10/2	Sink or source	12-24VDC	N/A	N/A	N/A	<--->
D0-10ND3F	DC/10/2	Sink or source	12-24VDC	N/A	N/A	N/A	<--->
D0-10TD1	N/A	N/A	N/A	DC/10/2	Sink	6-27VDC, 0.3A	<--->
D0-10TD2	N/A	N/A	N/A	DC/10/2	Source	12-24VDC, 0.3A	<--->
D0-16ND3	DC/16/4	Sink or source	20-28VDC	N/A	N/A	N/A	<--->
D0-16TD1	N/A	N/A	N/A	DC/16/2	Sink	6-27VDC, 0.1A	<--->
D0-16TD2	N/A	N/A	N/A	DC/16/2	Source	12-24VDC, 0.1A	<--->
F0-04TRS	N/A	N/A	N/A	Relay/4/4	N/A	5-30VDC, 3A 5-125VAC, 3A	<--->
F0-08NA-1	AC/8/2	N/A	80-132VAC 90-150VDC	N/A	N/A	N/A	<--->
F0-08SIM	8-pt. Input simulator						<--->

Communications and Specialty Option Modules

Part Number	Description	Price
H0-ECOM	Ethernet Communications Module 10 Mbit	<--->
H0-ECOM100	Ethernet Communications Module 10/100 Mbit	<--->
D0-DEVNETS	DeviceNET Slave Module	<--->
H0-CTRIO	High Speed Counter I/O Module	<--->
H0-PSCM	Profibus Slave Communications Module	<--->
D0-DCM	Serial Communications Module	<--->
F0-CP128	ASCII CoProcessor Module	<--->

Analog I/O

By using option modules, you can add analog inputs or outputs to your DL05 or DL06 PLC. The table below shows the input and output types at a glance. Detailed specifications are provided later in this section.

Analog I/O Option Modules

Part Number	Inputs: No.	Inputs: Input Type	Outputs: No.	Outputs: Output Type	Price
F0-04AD-1	4	0-20mA or 4-20mA	0	N/A	<--->
F0-04AD-2	4	0-5VDC or 0-10VDC	0	N/A	<--->
F0-08ADH-1	8	0-20mA	0	N/A	<--->
F0-08ADH-2	8	0-5VDC or 0-10VDC	0	N/A	<--->
F0-04DAH-1	0	N/A	4	4-20mA	<--->
F0-08DAH-1	0	N/A	8	4-20mA	<--->
F0-04DAH-2	0	N/A	4	0-10VDC	<--->
F0-08DAH-2	0	N/A	8	0-10VDC	<--->
F0-4AD2DA-1	4	0-20mA or 4-20mA	2	0-20mA or 4-20mA	<--->
F0-2AD2DA-2	2	0-5VDC or 0-10VDC	2	0-5VDC or 0-10VDC	<--->
F0-4AD2DA-2	4	0-5VDC or 0-10VDC	2	0-5VDC or 0-10VDC	<--->
F0-04RTD	4	RTD	0	N/A	<--->
F0-04THM*	4	Thermo-couple / Voltage	0	N/A	<--->

*** See module specifications page for thermocouple types and voltage input ranges supported**

Power budgeting

No power budgeting is necessary for the DL05. The built-in power supply is sufficient for powering the base unit, any of the option modules, the hand-held programmer, and even a DV1000 operator interface.

Power budgeting is necessary for the DL06. With four option module slots and an optional LCD display, it is necessary to verify that sufficient power is available for all optional devices. Power budgeting is described in detail on page 2-29 and in the DL06 User Manual.

Appendix C. Wiring Diagrams

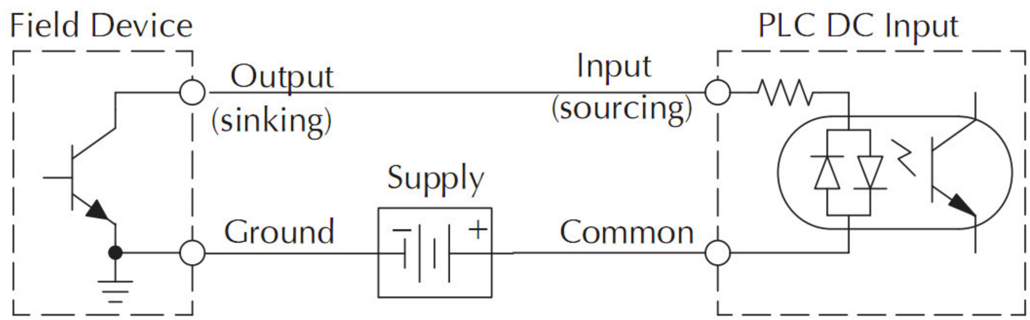


Figure 1: Encoder to PLC Diagram

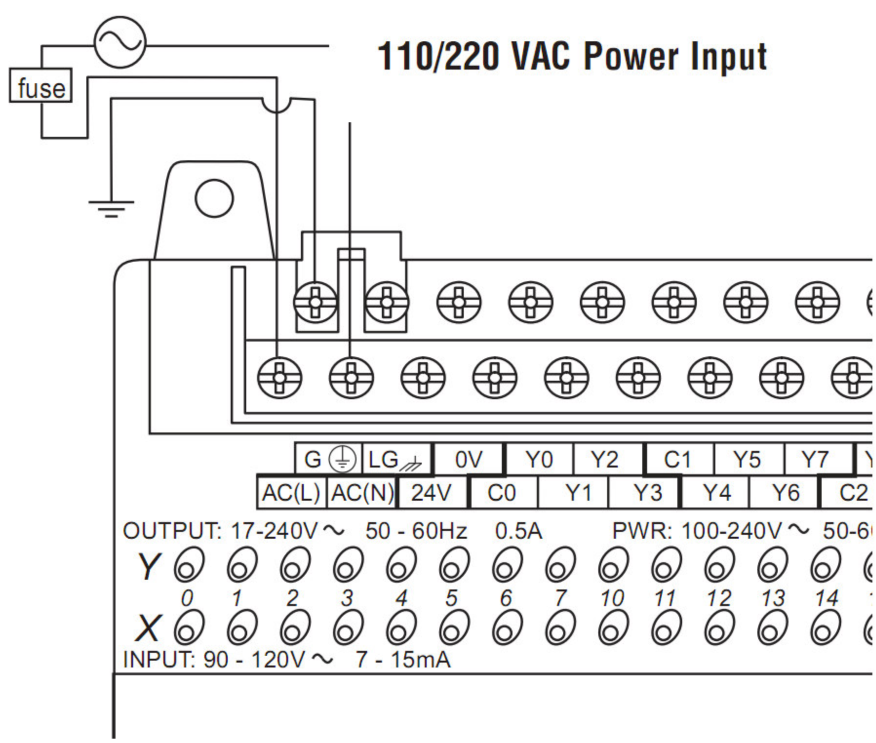


Figure 2: Input Power to PLC Diagram

Appendix D. Mathcad

Distance in between encoder steps:

$d := 0.5in$

$C := \pi \cdot d$

$steps := 1270$

$d_{pstep} := \frac{C}{steps}$ $\qquad d_{pstep} = 1.237 \times 10^{-3} \cdot in$

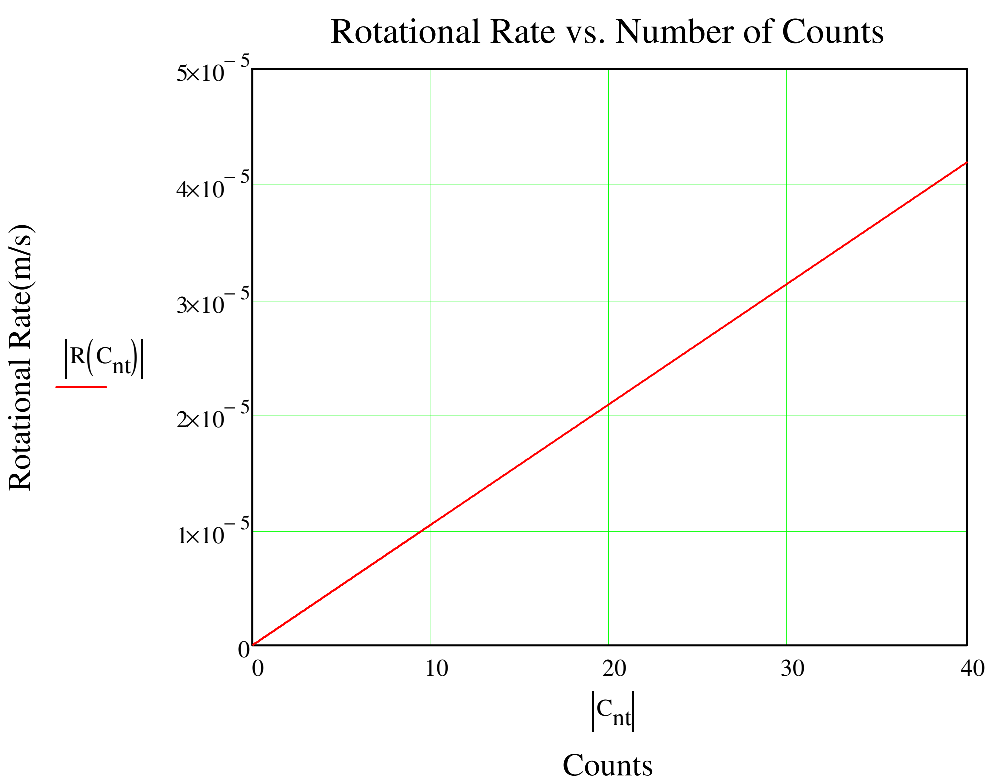
Multiplying Constant

$D := d_{pstep} \cdot 10 \cdot 10^{5}$ $\qquad D = 1.237 \times 10^{3}\, in$

Calculating the rate of the encoder:

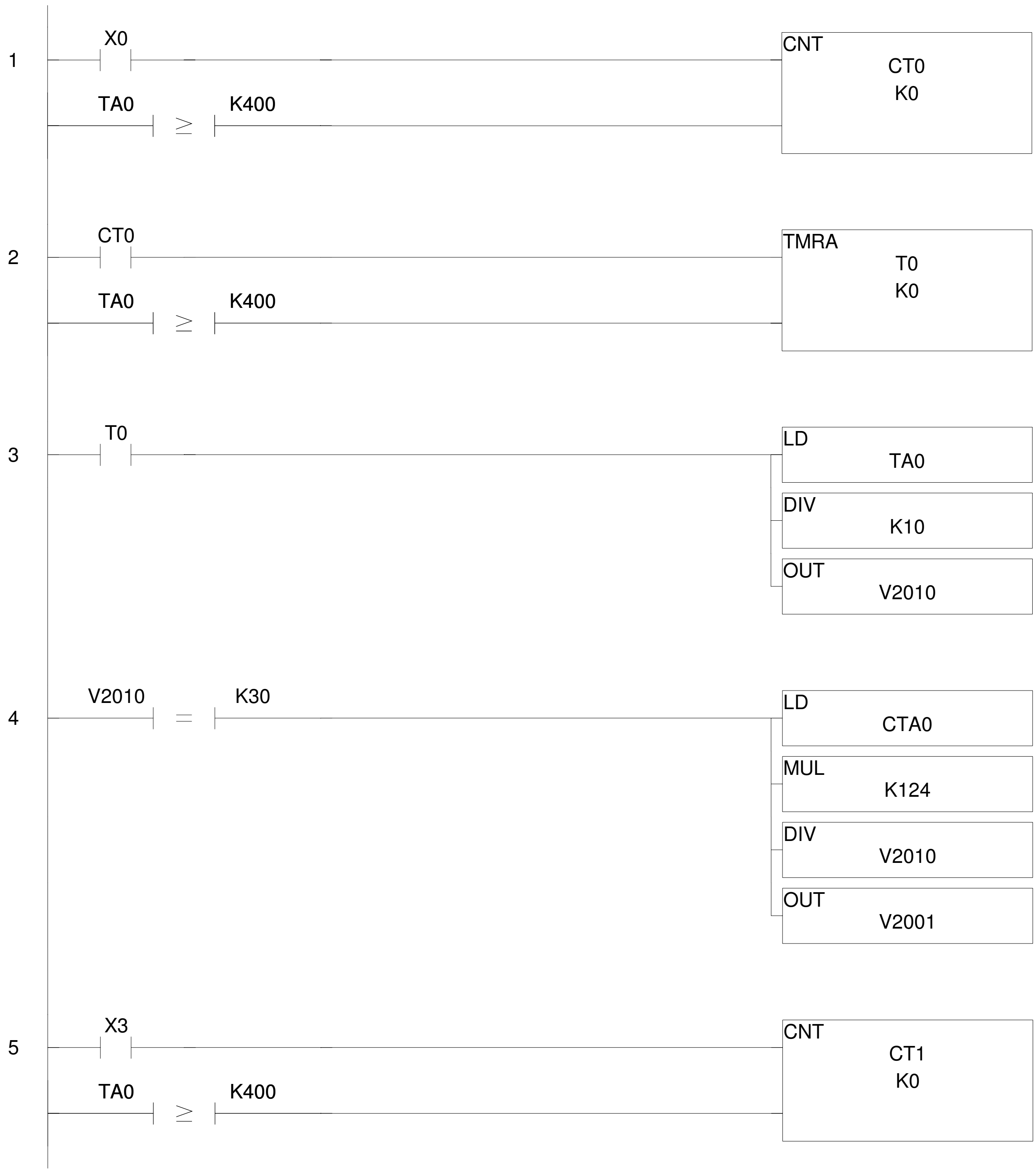
$t := 30s$

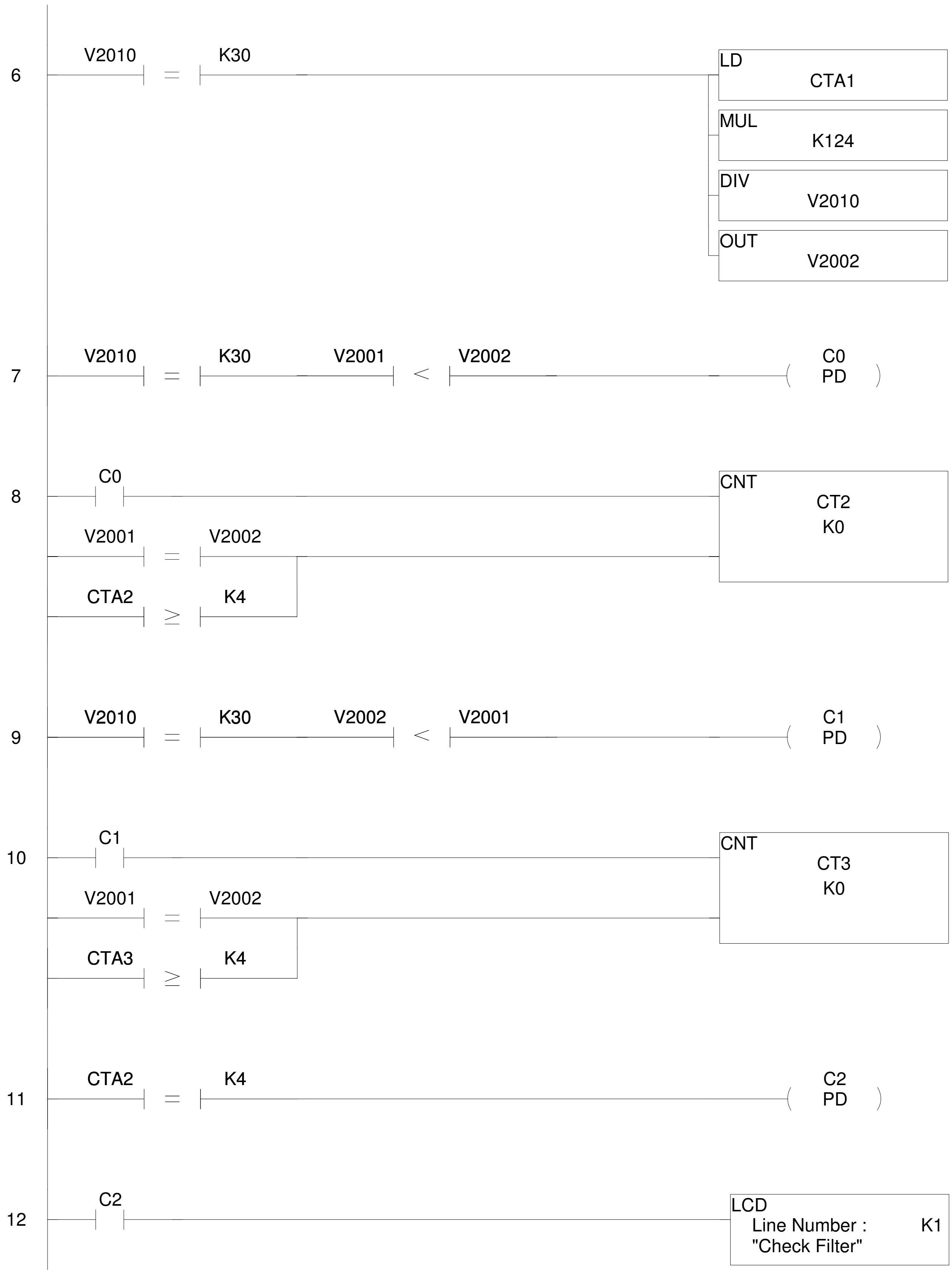
$R(C_{nt}) := \frac{C_{nt} \cdot d_{pstep}}{t}$

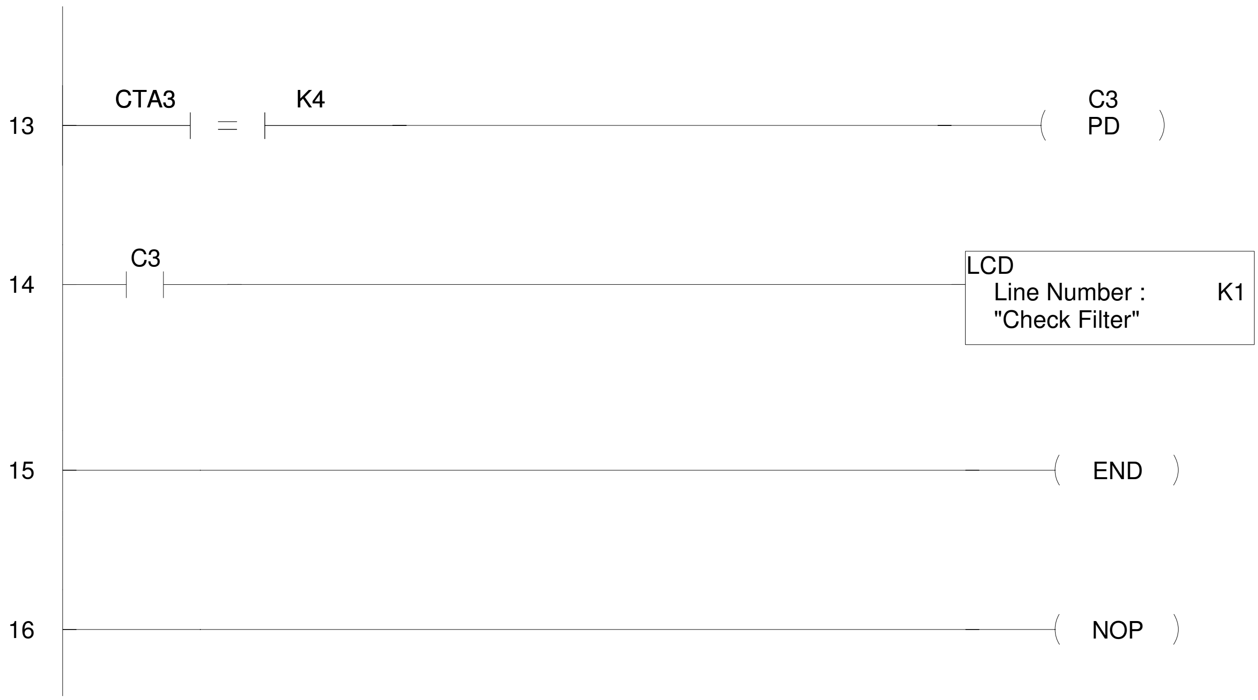


Appendix E. Ladder View Logic

Path: c:\directsoft5\projects\final.prj
Save Date: 05/07/09 15:56:59
Creation Date: 04/29/09 15:26:26
PLC Type: 06
Class ID: DirectLogic 06 Series


1
X0
TA0 ≥ K400
CNT CT0 K0
2
CT0
TA0 ≥ K400
TMRA T0 K0
3
T0
LD TA0
DIV K10
OUT V2010
4
V2010 = K30
LD CTA0
MUL K124
DIV V2010
OUT V2001
5
X3
TA0 ≥ K400
CNT CT1 K0


6
V2010 = K30
LD CTA1
MUL K124
DIV V2010
OUT V2002
7
V2010 = K30 V2001 < V2002
C0 PD
8
C0
V2001 = V2002
CTA2 ≥ K4
CNT CT2 K0
9
V2010 = K30 V2002 < V2001
C1 PD
10
C1
V2001 = V2002
CTA3 ≥ K4
CNT CT3 K0
11
CTA2 = K4
C2 PD
12
C2
LCD
Line Number : K1
"Check Filter"


13
CTA3
=
K4
C3
PD
14
C3
LCD
Line Number : K1
"Check Filter"
15
END
16
NOP

Appendix F. DivAppendix

Divide (DIV)

DS5	Used
HPP	Used

Divide is a 16 bit instruction that divides the BCD value in the accumulator by a BCD value (Aaaa), which is either a V-memory location or a 4-digit (max.) constant. The first part of the quotient resides in the accumulator and the remainder resides in the first stack location.

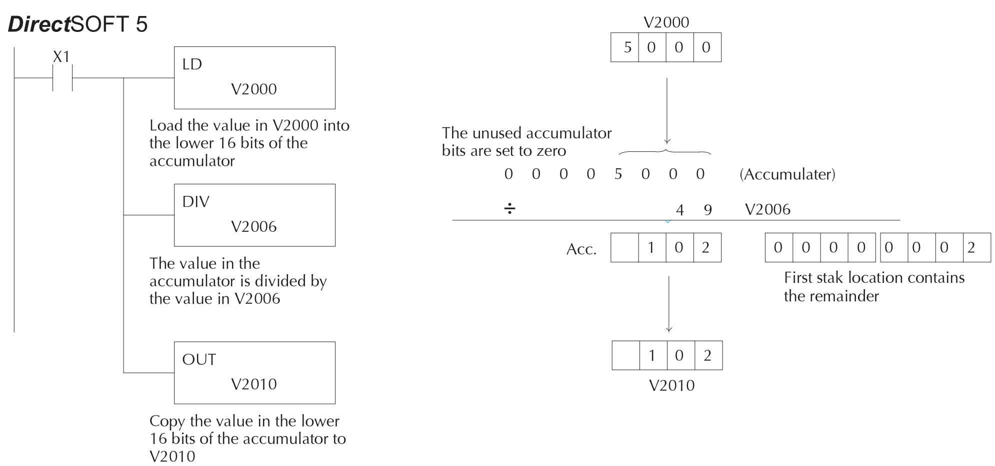
DIV A aaa

Operand Data Type	DL06 Range
. . . . A	aaa
V-memory V	See memory map
Pointer . . . . P	See memory map
Constant . . . . K	0–9999

Discrete Bit Flags	Description
SP53	On when the value of the operand is larger than the accumulator can work with.
SP63	On when the result of the instruction causes the value in the accumulator to be zero.
SP70	On anytime the value in the accumulator is negative.
SP75	On when a BCD instruction is executed and a NON–BCD number was encountered.

NOTE: Status flags are valid only until another instruction uses the same flag.

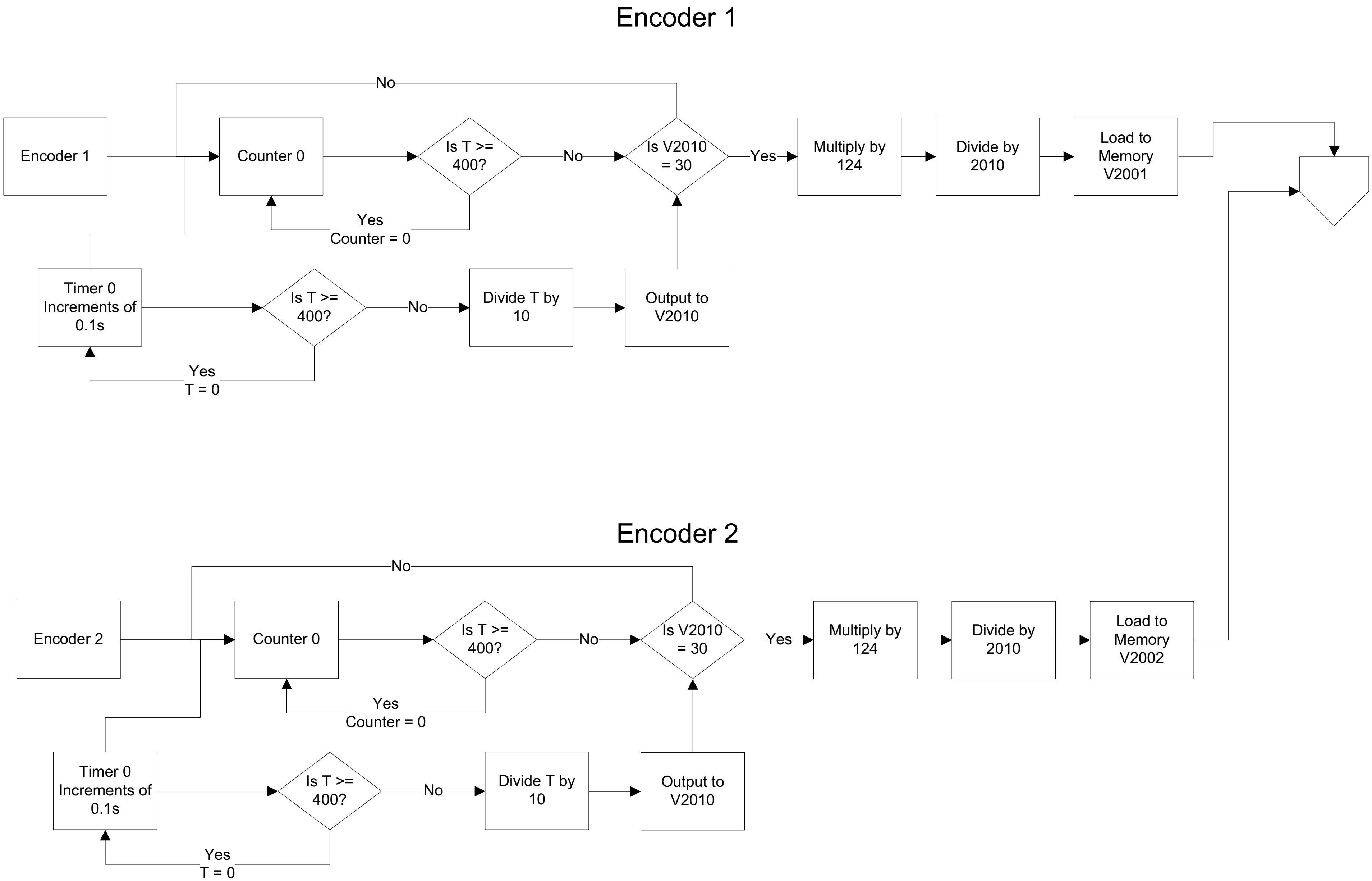
In the following example, when X1 is on, the value in V2000 will be loaded into the accumulator using the Load instruction. The value in the accumulator will be divided by the value in V2006 using the Divide instruction. The value in the accumulator is copied to V2010 using the Out instruction.

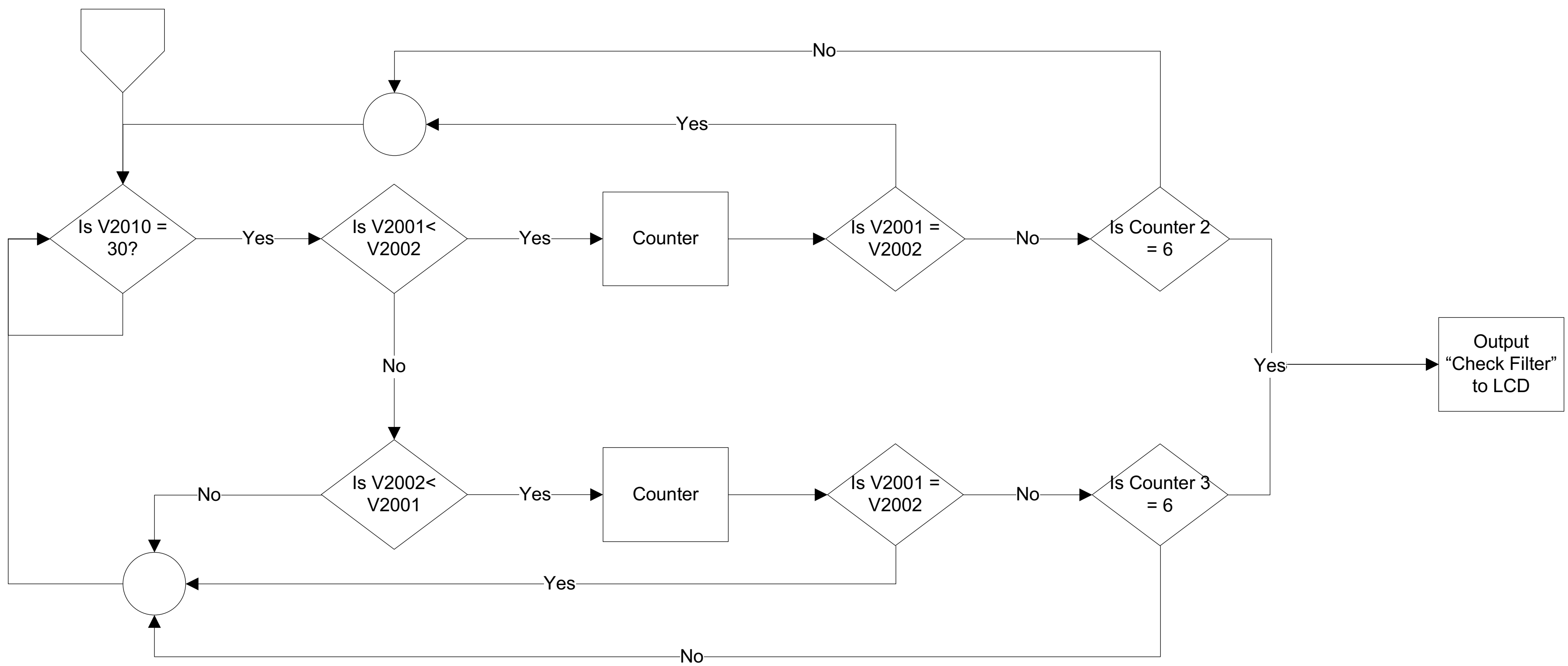


Handheld Programmer Keystrokes

$ STR	→	B 1	ENT						
SHFT	L ANDST	D 3	→	C 2	A 0	A 0	A 0	ENT	
SHFT	D 3	I 8	V AND	→	C 2	A 0	A 0	G 6	ENT
GX OUT	→	SHFT	V AND	C 2	A 0	B 1	A 0	ENT	

Appendix G. Flow Chart of the PLC Program


Encoder 1
No
Encoder 1
Counter 0
Is T >= 400?
No
Is V2010 = 30
Yes
Multiply by 124
Divide by 2010
Load to Memory V2001
Yes
Counter = 0
Timer 0 Increments of 0.1s
Is T >= 400?
No
Divide T by 10
Output to V2010
Yes
T = 0
Encoder 2
No
Encoder 2
Counter 0
Is T >= 400?
No
Is V2010 = 30
Yes
Multiply by 124
Divide by 2010
Load to Memory V2002
Yes
Counter = 0
Timer 0 Increments of 0.1s
Is T >= 400?
No
Divide T by 10
Output to V2010
Yes
T = 0


Is V2010 = 30?
Yes
No
Is V2001< V2002
Yes
Counter
Is V2001 = V2002
Yes
No
Is Counter 2 = 6
No
Yes
Output “Check Filter” to LCD
Is V2002< V2001
Yes
No
Counter
Is V2001 = V2002
Yes
No
Is Counter 3 = 6
No

Appendix H. DFMEA

DESIGN FAILURE MODE AND EFFECT ANALYSIS (DFMEA)

Project Sand Bed Turnover Monitor
Year 2008-2009
Team Members: Amanda, Shannon, Jake, Yogesh, Mark

Revision Date
Revision Number

ITEM AND FUNCTION	POTENTIAL FAILURE MODE(S)	POTENTIAL EFFECT(S) OF FAILURE	SEV	POTENTIAL CAUSE(S) OF FAILURE	OCCUR	CURRENT DESIGN CONTROLS	DETECT	RPN	RECOMMENDED ACTIONS
3D Printer Material	Piece may break	Could affect entire filter operation	5	Part designed too thin/narrow	1	Ensure all pieces are thicker than 1/8"	5	25	Choose a shape that is well supported and avoids thin pieces
	Layers may separate	Could affect entire filter operation	5	Sand abrasion against part (over extended period of time)	1	Change material (plastic injection). To detect failure, reading may stop or slow without bridging	4	20	Recommend to Blue Water to use plastic injection molding to have one solid piece instead of layers.
	Too "springy" to spin	No reading/Filter functions fine	3	Part designed too thin/narrow	1	Ensure all pieces are thicker than 1/8"	1	3	choose a shape that is well supported and avoids thin pieces
				Not enough support in design	1	Add support bars in weak areas	1	3	choose a shape that is well supported and avoids thin pieces
3D Printer Part	May not rotate because the body is too circular	No reading	4	Part is designed too circular	1		1	4	Choose a kind of rectangular shape that will build up pressure from the sand

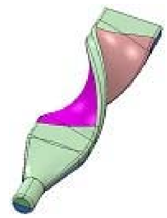
Mounting System	Could prevent the bearing from free spinning	No reading/Filter functions fine	3	Outer race not fully supported Inner race not allowed free movement	1 1	Mount outer race in multiple locations (tack weld in 4+ spots) Do not add any additional friction/restrictions to inner race	1 1	3 3	Mount outer race in enough locations to keep it secure ensure that it is well supported by top brace Ensure that inner race is not touching top support (adding friction) and that it is free to rotate
Shaft	Bends out of place	No readings; broken pieces	4	Non-rigid shaft	2	Different materials or shape	2	16	Test and observe different shafts and research alternatives
Bearing and shaft	Shaft slides around the press fit bearing	Create unsteady-state conditions for the encoder	3	Un-secure fit	3	Add a metal rod through the shaft that can be welded to the bearing to prevent up-down, side-side movement of shaft	3	27	Research different ways to secure the shaft to the bearing
Bearing	May not spin, or may hardly spin	Could affect the reading process	3	Does not give actual sand motion rate	1	Keep away from dirt and water	2	6	Choose correst type of bearing, and be careful while banging on bearing
Encoder	Encoder fails	No data	5	Weather/ moisture wears the components	3	Design an encoder casing that enables the encoder to perform consistently under all weather conditions	1	15	Research an appropriate design to keep the encoder in a steady-state (is this necessary?)
Encoder	Encoder Output Fails	No Data Collection	5	Too much load	1	Weight of shape	1	5	

Encoder	May not give correct results	Affect the reading	3	The frequency of reading is too high or too low for plc to detect	1	Ensure that we choose the right type of encoder	1	3	Select right kind of encoder
			3	Vibrational effect may dampen the reading	1	Take the encoder as high as possible from the sand	2	6	Choose high frequency encoder
PLC	Program Fails	No Data Collection	5	Poor Coding	3	Frequent Testing	4	60	Test Frequently
	Power Cord Fails	No Data Collection	5	Shorted Wires	2	Organization of Wires	1	10	Organize Wires
	LCD Fails	No Data Collection	5	Unfused input/output	3	Fuse Inputs/Outputs	1	15	Fuse Inputs/Outputs
	DC Power Supply Fails	No Data Collection	5	Unfused input/output	3	Fuse Inputs/Outputs	1	15	Fuse Inputs/Outputs
	PLC Fails	No Data Collection	5	Unfused input/output	3	Fuse Inputs/Outputs	1	15	Fuse Inputs/Outputs
				Dropped		Carefulness			Be Careful

Figure X: Design Failure Mode and Effect Analysis (DFMEA), Mode of analyzing potential failure modes of the sand bed turnover monitor, which also provides recommended actions.

Appendix I. Injection Mold Quote from ProtoMold

PROTOQUOTE



ProtoQuote prepared for:
University of Idaho
Quote Number: **104928** Quote Date: **4/27/2009**
Part Name/Number: **Twister (rev 1)**
Extents: **2.021 in x 10 in x 2.021 in**

Thank you for the opportunity to quote your parts. *We look forward to working with you on this project. Should you have any questions, please do not hesitate to contact us at (763) 479-3680.*

1 Enter Specifications

Changes below will reflect automatically in your price:

Cavities:	1 cavity
A (green) side finish:	PM-F1 (Low-cosmetic - most toolmarks removed)
B (blue) side finish:	PM-F0 (Non-cosmetic - finish to Protomold discretion)
Sample Quantity:	100
Delivery:	Sample parts ship in 15 business days (standard delivery)
Material:*	ABS, Black (Lustran 433-904000)*

*The highlighted materials are preferred for their availability and/or cost.

Your Price

Tooling cost:	$12,645
Parts@ $6.92:	$692
TotalUSD:	$13,337

3 Continue

View notes | E-mail

2 Review Issues

VIEW IN 3D

ORDERS UP TO 100,000 PARTS

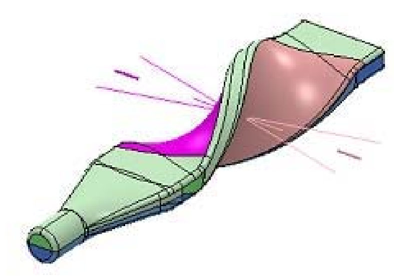
Piece price quotation (in USD) for future/additional orders based on the following material: ABS, Black (Lustran 433-904000)

Enter lot size 500 Go

Price/part:	$6.92
Quantity:	500
Setup charge:	$750
Total USD:	**$4,210**

Required Changes (0) **Moldability Advisory (4)** **Other Info (1)**

The following illustrations indicate general information about how your part will be molded and areas in which the molded part will differ from the geometry of the CAD model due to the milling process used in mold manufacture.



1. Solid arrows and faces with corresponding colors indicate undercut features that will be formed by using side pull cores.

Notes

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- A-side shown in green. B-side (ejection side) shown in blue.
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Upload a new model for a quote

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Without limiting the generality of the foregoing, Seller assumes no responsibility or liability for the selection of any materials for the goods that are the subject of this transaction. The buyer is solely responsible for ensuring that materials selected for goods to be manufactured by Seller meet any regulatory requirements or specifications including but not limited to Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive) together with any national legislation implementing such Directive, ISO, FDA, UL, CSA, CE, TUV, FCC, NSF, and USP. Any statements made by Seller personnel or specifications provided by Seller regarding materials should be verified by the buyer with the manufacturer of that material.

LIMITATION OF DAMAGES. IN NO EVENT SHALL SELLER BE LIABLE FOR ANY INCIDENTAL, CONSEQUENTIAL OR PUNITIVE DAMAGES OF ANY KIND, WHETHER FOR BREACH OF ANY WARRANTY, FOR BREACH OR REPUDIATION OF ANY OTHER TERM OR CONDITION, FOR NEGLIGENCE, ON THE BASIS OF STRICT LIABILITY, OR OTHERWISE.

Indemnification. The buyer shall defend, indemnify and hold harmless Seller (and its employees, representatives and agents) from and against all claims, liabilities, losses, damages, penalties, fines and sanctions of any kind (including, without limitation, interest, attorneys' fees and expenses, customs duties, fines, taxes, penalties or any other governmental sanctions of any kind) (i) resulting from or arising out of any breach of any representation, warranty or covenant of the buyer or its affiliates hereunder; (ii) if the buyer has supplied Seller with drawings, designs or other specifications for the goods or services, arising out of any assertion that any goods manufactured by Seller (or the act of manufacturing such goods) according to those drawings, designs or other specifications infringe or misappropriate any patent, copyright, trade secret or other proprietary right; (iii) otherwise arising out of or related to this transaction; or It is specifically understood that the buyer shall indemnify and defend Seller and hold Seller harmless from claims that Seller was itself negligent or otherwise at fault. If any action, suit or proceeding is commenced, or any claim, demand or assessment asserted against Seller (or its employees, representatives or agents) which may result in liability with respect to which a party seeks indemnification, then the party shall notify the buyer promptly and the buyer shall have the right at its own expense to assume the entire control of the defense, compromise or settlement. Upon the buyer's request and at the buyer's expense, Seller shall cooperate fully in such defense and make available to the buyer all relevant information under its control.

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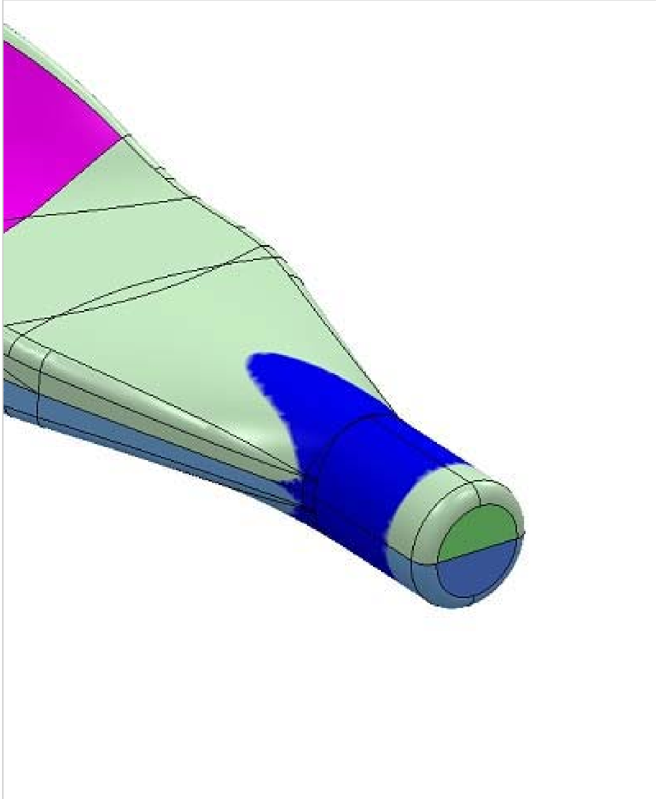
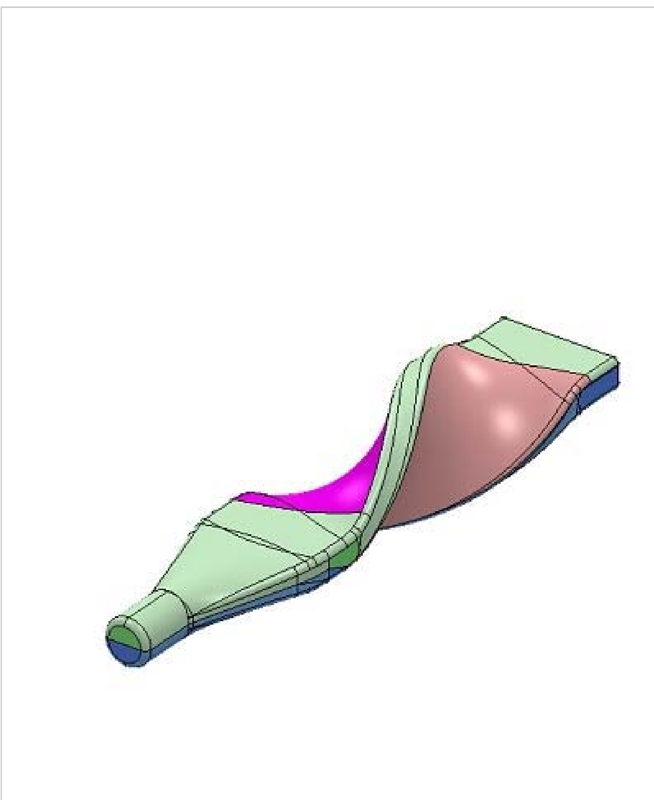
March 25, 2009

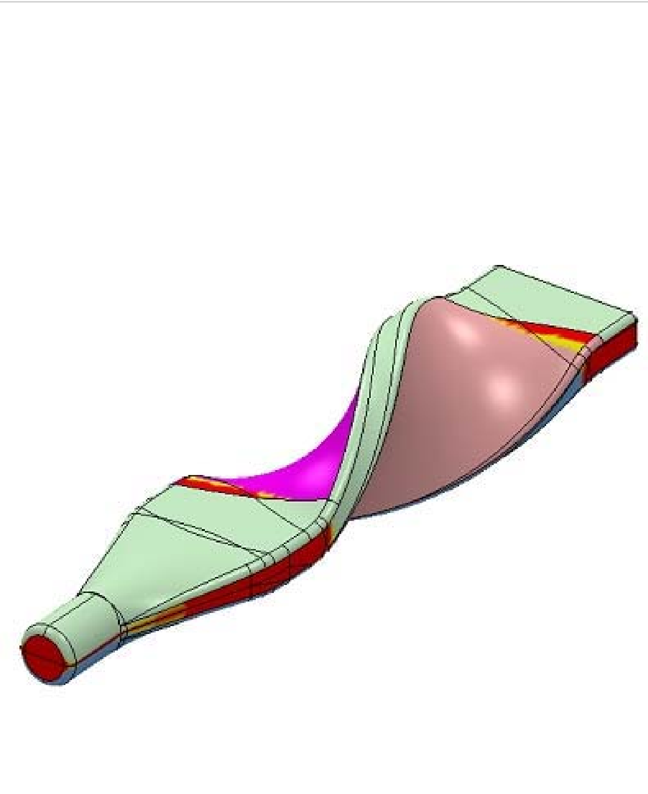
Refresh data.



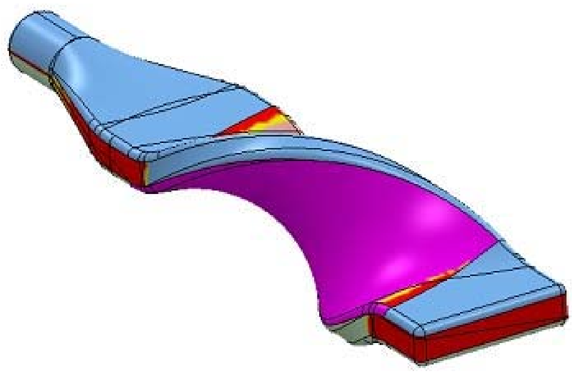
1. Dark blue color coding indicates areas where part thickness is significantly greater than nominal. Sink marks are possible in these areas.



2. This part is thick. Sink marks, internal voids, excessive shrink and warp are possible. You can expect better parts if you redesign your part to thin it out.



3. If you require a textured finish on your part: PM-T1 (light bead blast texture) requires at least 3 degrees of draft, and PM-T2 (medium bead blast texture) requires at least 5 degrees of draft. Faces colored red have a draft of less than 3 degrees, and faces colored yellow have a draft of 3-5 degrees. Additional draft will need to be added to these faces in order to accommodate your texture choice.



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