A Two Axis Sensor Positioning System to Be Mounted On the Front of an AUV

by

Devin Neal

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Submitted to the Department of Mechanical Engineering
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Mechanical Engineering

Abstract

The XAUV is an experimental autonomous underwater vehicle (AUV) intended to be used as a platform to test new cutting edge sensors and mapping algorithms associated with them, as well as control algorithms for the ultimate goal of inspecting naval ship hulls. Current ship hull inspection techniques require divers to inspect by hand. Often the waters are opaque beyond the level that would allow visual inspection to be sufficient, so a tactile inspection is required. This process is slow and dangerous to the inspectors. AUVs with appropriate sensors and algorithms offer the promise of an alternative technique.

It is important that the AUV is capable of directing appropriate sensors in the desired directions prescribed by specific mapping algorithms. This could be accomplished by rigidly attaching the sensors to the body of the AUV. However, manipulating the sensors with respect to the AUV may offer substantial benefits. With two degrees of freedom within the positioning system, the rest of the XAUV will be constructed to be capable of both hovering and traveling at a peak speed of about 5 m/s while still scanning the target area. It will also open up possibilities in developing new algorithms that utilize scanning off of the normal of the target surface.

This document details the design, construction, and preliminary testing of the multi-axis XAUV positioning system. The design has shown through theory and construction that it will provide a stiff, reliable sensor positioning system that does not affect the dynamic motions of the vehicle regardless of sensor postion and acts as a protective housing for the delicate blazed sonar array.

Thesis Supervisor: John Leonard
Title: Associate Professor of Mechanical and Ocean Engineering

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Introduction

The XAUV, depicted in Figure 1, is an experimental autonomous underwater vehicle (AUV) intended to be used as a platform to test new cutting edge sensors and mapping algorithms associated with them, as well as control algorithms for the ultimate goal of inspecting naval ship hulls.

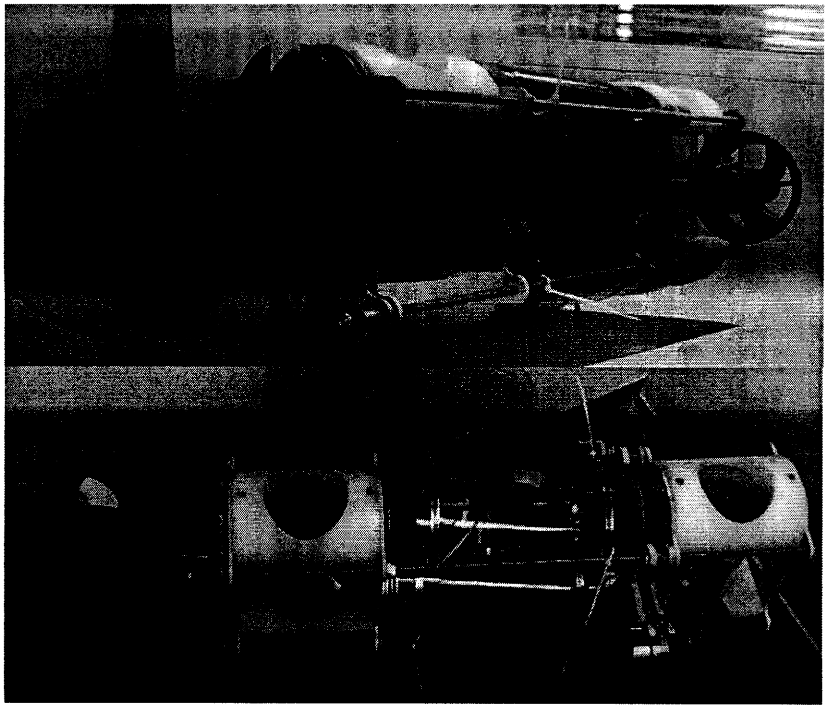

Figure 1: XAUV, a small scale sensor and algorithm testbed.

Current ship hull inspection techniques require divers to inspect by hand. The need for inspections is a function of the cost of major naval ships and the risk of enemies or terrorists placing explosives. Ships often stay at a port for extended periods of time, providing ample opportunity for an opposing force to place explosives. Watchmen are only so effective on the surface and placing guards underwater puts individuals at risk and would cost a significant amount. The next best thing to preventing explosives from being placed is to prevent them from detonating once placed. Without the use of AUVs, divers must carry out this task by hand. Often the waters are opaque beyond the level that would allow visual inspection to be sufficient, so tactile inspection is required. This process is slow and dangerous to the inspectors. AUVs with appropriate sensors and algorithms offer the promise of an alternative technique.

Research has been conducted on AUVs for decades with significant contributions toward the particular goal of handling explosives since 1998 [1]. In 1998 the Explosive Ordnance Disposal Robotic Work Package (EODRWP) Program was completed with the development of Deep Ocean Engineering HVS4 Remotely Operated Vehicle (ROV) as a platform for testing advances in technologies that support teleautonomous ordinance detection. The purpose of the EODRWP program was to demonstrate technologies relevant to unmanned vehicles. Though there were notable drawbacks, including significant drag resulting from a tether, this ROV was successful in demonstrating the potential of these technologies and led to the development of an

AUV called Cetus. Cetus was an attempt to overcome the drag-related shortcomings of the ROV by eliminating the tether and adopting a more hydrodynamic shape [1]. The "teardrop" shape of Cetus can be seen in Figure 2.

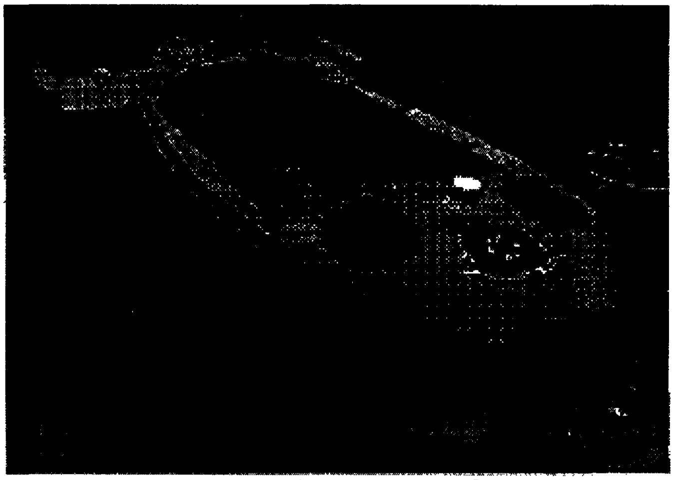

Figure 2: The Cetus UUV [1].

One of the most prominent AUVs designed to be used in mine-related missions is the Remote Environmental Measuring Unit(s) (REMUS). It has proven capable in shallow waters ranging from 3-30 meters in depth. Also of great importance, Naval Fleet Battle Experiments sponsored by Office of Naval Research have shown that members of the fleet are capable of programming, operating and maintaining the AUV. It has a hydrodynamic tube shape with front mounted sensors and is incapable of hovering. To achieve a primarily vertical area of coverage, it must change its altitude during flight as the sensors do not position independent of the AUV [2].

As with mine-related work, the Office of Naval Research is interested in utilizing AUVs for ship hull inspection. Previous research and design conducted by researchers at the Massachusetts Institute of Technology and Bluefin Robotics resulted in the Hovering Autonomous Underwater Vehicle (HAUV), a vehicle that successfully accomplished certain tasks required for ship hull inspection. The goal of the HAUV, as with the XAUV, is to assist in ship hull inspection primarily for "Anti-Terrorism and Force Protection missions" [3]. The XAUV is intended to be the next generation of ship hull inspecting AUVs.

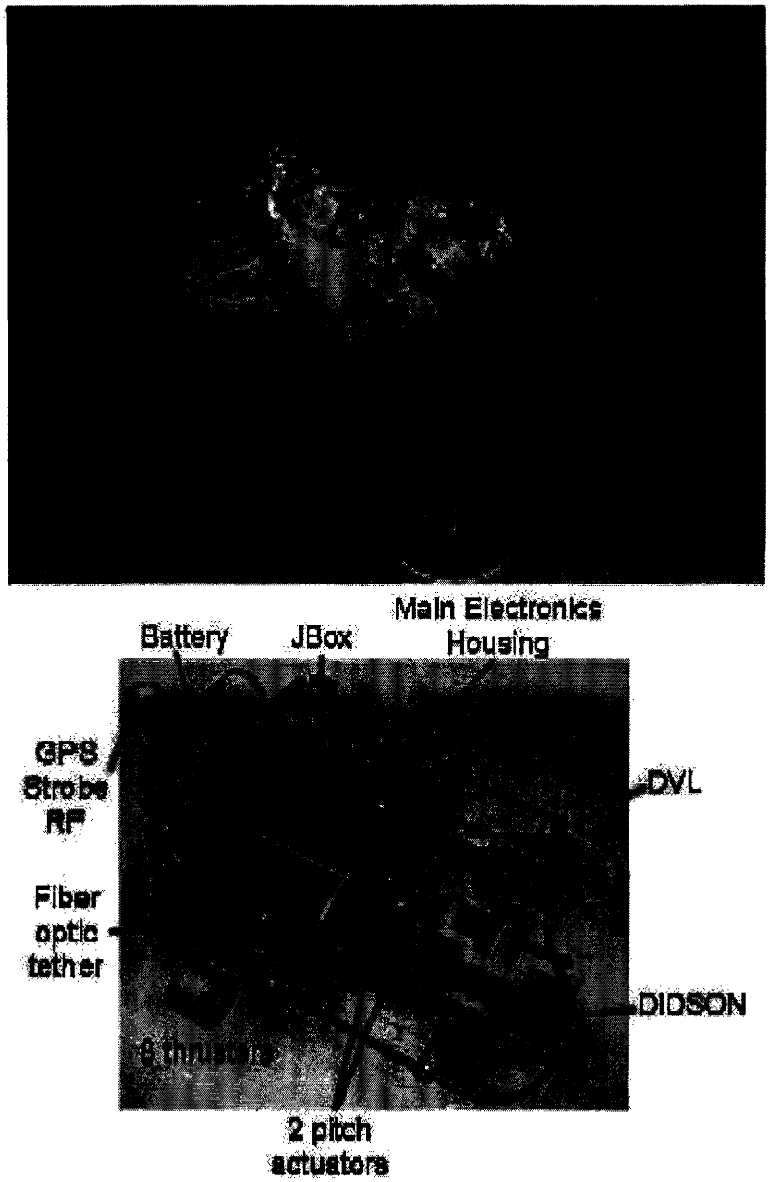

Figure 3: HAUV (with and without floatation foam) [1].

It is important that the XAUV is capable of directing appropriate sensors in the desired directions prescribed by specific mapping algorithms. The ROV developed by the EODRWP program had no independent degree of freedom between the sensors and the main body of the vehicle and had to rely on body orientation [1]. The HAUV directed its sensors by keeping the vehicle facing the surface of the hull and controlling the tilt of the primary sensor, thus allowing for an additional degree of freedom in positioning the sensors without requiring reorientation of the entire body of the vehicle [3]. An alternative approach that the XAUV will use will add an additional degree of freedom to the sensors with respect to the main body of the vehicle. This will allow the XAUV a broader range of orientations with respect to the hull under inspection while maintaining the desired sensor orientations relative to the hull.

Another desired functional requirement is to give the positioning system appropriate geometry such that the dynamics are fully controllable at greater speeds, regardless of sensor orientation. The ROV developed by the EODRWP program had a significant drawback in that the vehicle would dive uncontrollably at speeds greater than 1.5 meters per second due to hydrodynamic effects and geometry [1]. A potential drawback of the HAUV, with reference to the images in Figure 3, is that having the sensors positioned as they are will greatly affect the dynamics of the vehicle at greater velocities. It is desirable that the XAUV not have this same instability issue and that it not destabilize due to changes in sensor positions. The REMUS is quite capable of achieving highs speeds while maintaining control stability [2]. Like the REMUS, the XAUV will position its sensors symmetrically in front of the main body of the vehicle thus affording a more straightforward design of stable hydrodynamic shape. Additionally, the sensors will be encased in a faring such that the position of the sensors will not affect the geometry of the XAUV.

A final functional requirement is structural resilience and protection of the sensors. The HAUV and the ROV developed by the EODRWP program both utilized crash frames for this purpose [1, 2]. The impact protection of the XAUV will utilize the same structure used to decouple sensor position from XAUV hydrodynamics.

The sonar unit that must be protected is the Pro ViewerE P900E-20 by BlueView Technologies depicted in Figure 4. The base unit is priced at $19,500. It is compact and light weight (4.1 pounds), and low power (10 watts), with a resolution of up to 10 frames per second [4].

Figure 4: P900E-20 Underwater Imaging Sonar System [4]

The P900E-20 is a blazed acoustic array. Blazed arrays are capable of providing quality images from a small-sized, low-powered unit because they utilize a single hardware channel to form multiple independent beams. The multi-beam images are possible because the angular information of each beam can be mapped into the frequency domain [5].

This positioning system will make a novel contribution to the field of AUVs by granting the sensors two degrees of freedom with respect to the rest of the vehicle while not hindering the vessels dynamic performance regardless of sensor position. The two angles of servo control will make it easier for the XAUV to either hover in front of the target or fly by the target at a more rapid pace. The two axes of control may even lead to a breakthrough in mapping performance and/or enable faster surveys of a ship's hull.

Design Criteria

To be considered successful, the positioning system must meet specific criteria. The range of movement should create a solid angle of an entire hemisphere. There must be enough power and torque to position the system in a reasonable amount of time. Therefore, either axis should be capable of rotating 90 degrees in roughly 0.5 seconds. The additional weight from the positioning system should be as small as possible. Ten pounds is reasonable for the entire system including the blazed array and a camera. Finally, the system must be capable of withstanding an impact at the maximum potential speed of the XAUV, which is approximately 5 meters per second.

Mechanical Design

To provide a method of manipulating sensors with respect to the body of the XAUV, a two axis front-mounted positioning system has been chosen. Both axes are servo controlled. One axis rotates the front sensor mount around the main axis of the XAUV body. This will be referred to as roll control. The other axis pitches the sensors up and down along the main axis of the XAUV. This will be referred to as pitch control.

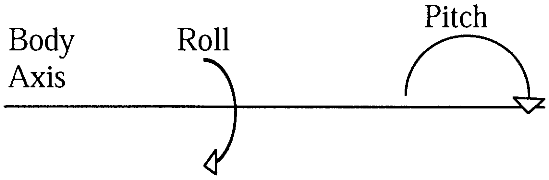

Figure 5: Diagram of roll and pitch axes of rotation with respect to main axis of XAUV body. The roll axis of rotation is along the body axis. The pitch axis is normal to the body axis (out of the page).

To cover all possible directional positions, the roll axis covers an approximate 360 degree range and the pitch axis covers an approximate 180 degree range. The mechanical design of the entire front sensor positioning system can be divided into the design of the roll control and pitch control.

Roll Control Design

The roll axis of rotation rotates the sensors and pitch rotation hardware with respect to the rest of the XAUV. This is accomplished by a short chain of mechanical components. A waterproof servo actuator, housed within the main body of the XAUV, is coupled to a shaft that goes through a plate located on the front-most part of the main body. A spur gear is on this shaft on the other side of the front plate. This spur gear meshes with another spur gear on another shaft that goes through the main plate. This second shaft rotates the rest of the front mounted positioning system.

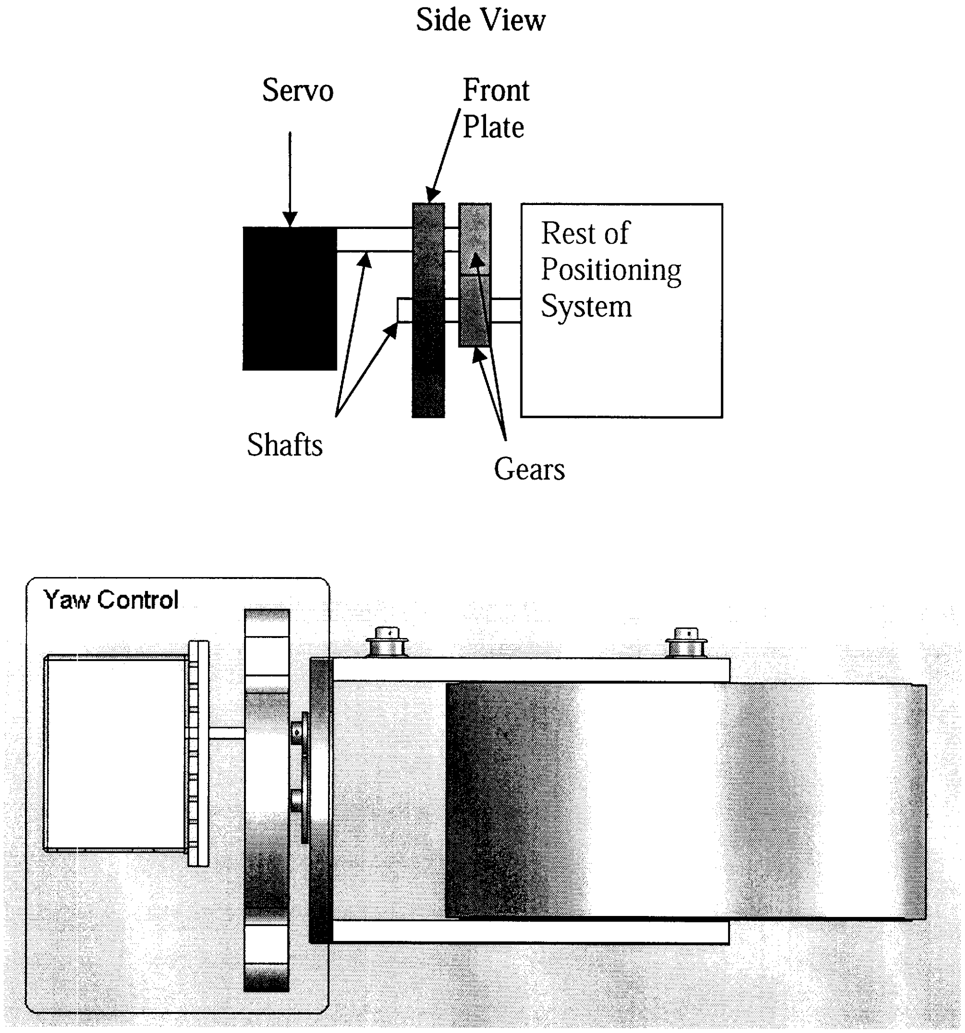

Figure 6: Schematic and solid model of roll control mechanism.

The face plate provides a rigid interface between the main body of the XAUV and the positioning system. The servo is within the body of the XAUV as to require less inertia to move in controlling the roll position. The two spur gears provide an opportunity to adjust the torque and range of motion of the roll axis.

The location of the second shaft, which is responsible for rotating the rest of the positioning system, is in the center of the front plate. The stiffness of this shaft is an issue that must be addressed particularly if it were to withstand any off-axis torques. A gear and the rest of the positioning system are held cantilevered in the face plate. To alleviate the stress held by this shaft and ensure consistent meshing of the gears, an additional ring-shaped bearing surface will extend from the front plate to support the outer edges of the rest of the positioning system.

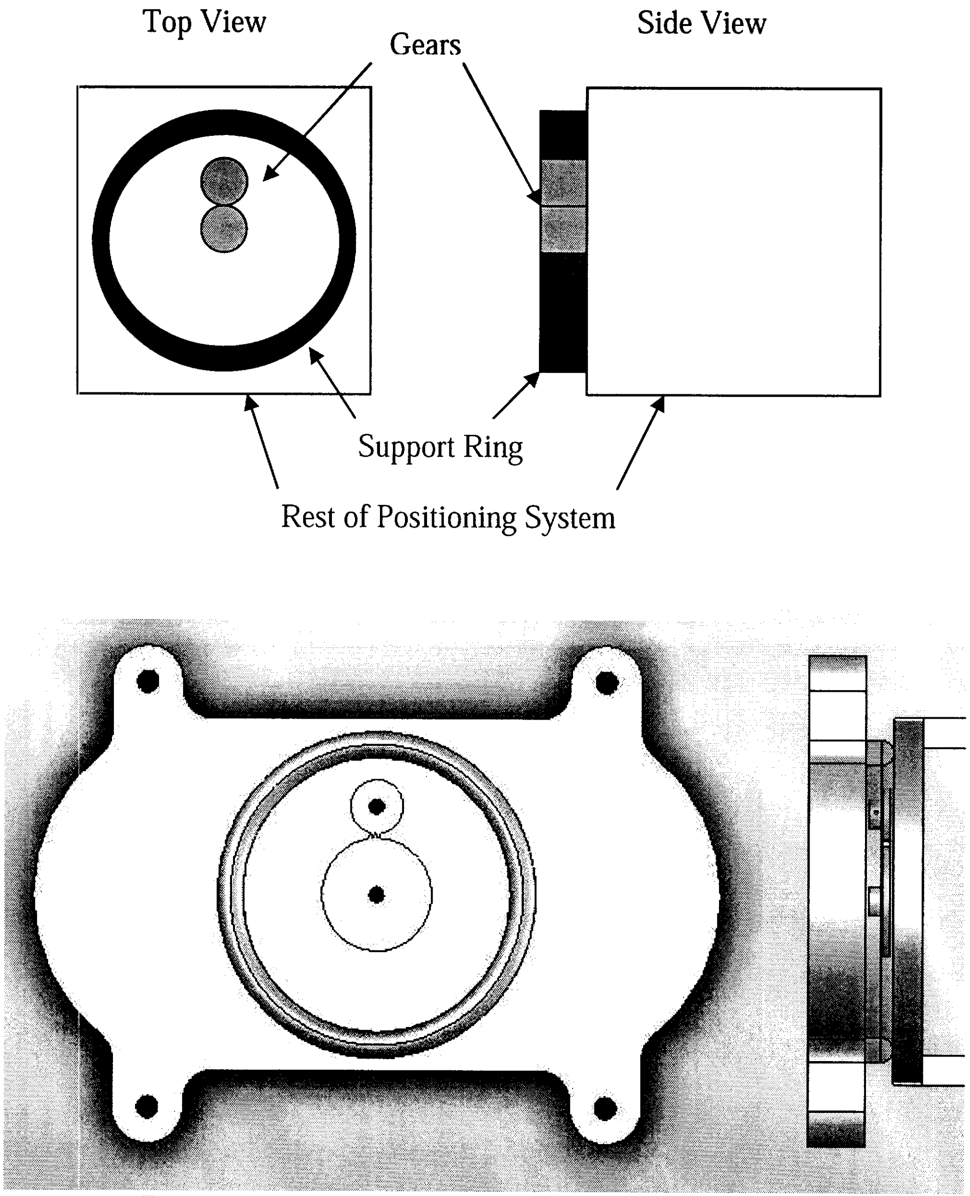

Figure 7: Diagram and solid model of roll axis support ring.

The ring that extends from the front plate will support any undesirable off-axis torques experienced by the shaft supporting the rest of the positioning system while providing a low friction bearing surface on which it can rotate.

Pitch Control Design

The rest of the positioning system is dedicated to adjusting the pitch of the sensors and their enclosure. This motion is again accomplished through a short chain of mechanical components. Two standoffs support the sensors and their enclosure. There is a waterproof servo that lies near the base of the two standoffs. The servo is coupled to a shaft that goes through one of these standoffs near the base of the standoff. On the other side of this standoff, attached to this shaft, is a timing belt pulley. Directly above this shaft is another shaft that goes through the same standoff. On this second shaft is another timing belt pulley coupled to the first timing belt pulley via a timing belt. The other side of this second shaft is rigidly coupled to the sensor enclosure. Finally, the opposite side of the sensor enclosure is supported by the other standoff.

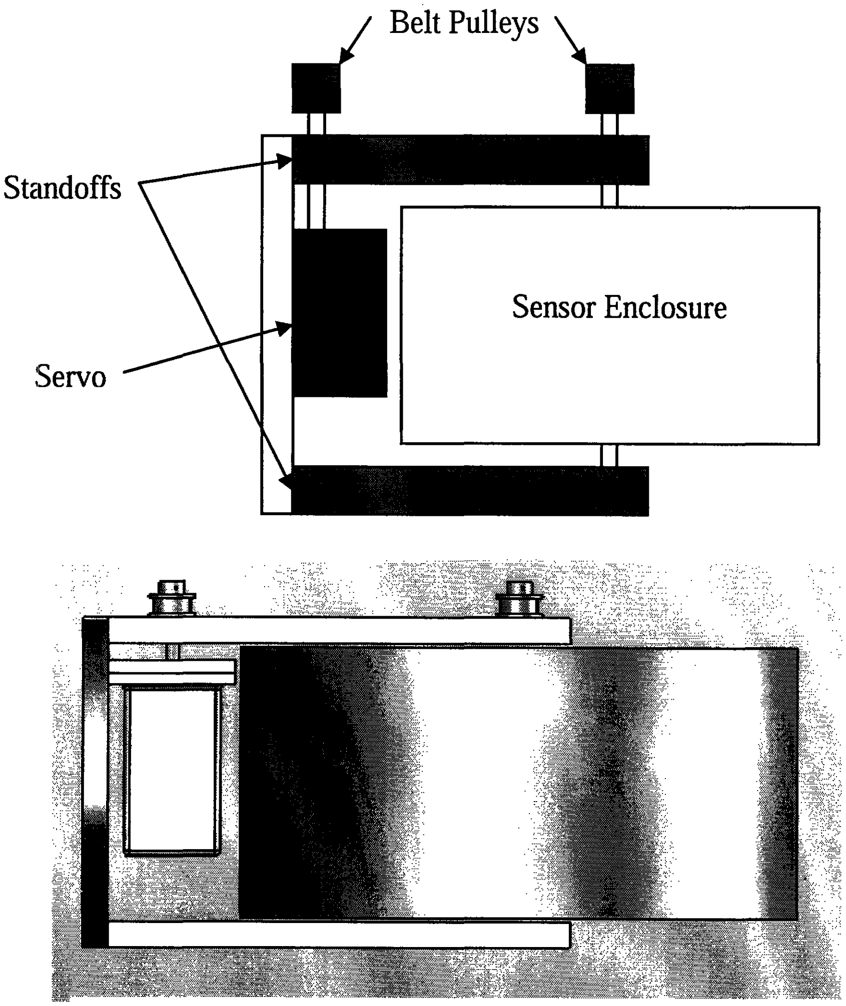

Figure 8: Diagram and solid model of pitch control system.

The belt pulleys are located outside of the standoffs for three reasons. The first is to utilize the width of the standoff to couple the servo to the lower pulley shaft allowing for less bending stress of the servo output shaft. Second, this design is intended to prevent a localized cantilever scenario with the top pulley and sensor enclosure on the same side of the standoff. With the top pulley and sensor enclosure on opposite sides of the standoff, the off-axis torques of the top shaft are minimized. The third reason is to save space. If the pulleys were between the standoffs, the base supporting the standoffs would need to be larger and the sensor enclosure would no longer be located in the center of the base. It is desirable to have the sensor enclosure located centrally to simplify or eliminate geometric corrections and errors in positioning algorithms.

A timing belt was selected over gears because the distance between the servo shaft and sensor housing shaft is far too great for a set of two gears to be selected, and using a train of gears would add excess cost and complexity. A timing belt is used rather than a flat belt because the system needs to be precise and shouldn't allow for slipping or inconsistencies.

The servo could have been placed within the sensor housing, and could have rotated along with the sensors to save space by making the standoffs shorter; however, there were numerous drawbacks to such a design. The sensor housing would likely need to be larger to fit the servo and the servo would add the inertia it is driving. A rigid gear attached to one of the standoffs would have to be precisely made, preferably with gears, such that the servo within the housing could rotate the housing from within.

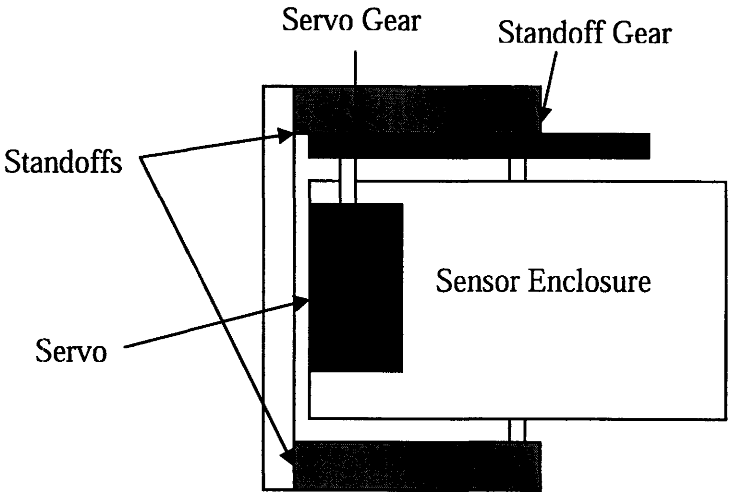

Figure 9: Diagram of pitch control system with servo inside sensor enclosure.

Furthermore, the servo would have to be located far from the center of the enclosure in order to save any space. If it were near the middle, the enclosure would have to be larger to fit the sensors away from the center. With the servo far from the center, the standoff gear would have to be much larger than the servo gear, and that would decrease the range of pitch motion due to the limits of the servo motion.

Sensor Housing

The sensors need proper housing for two reasons. One is to protect the sensors from potential collisions. The second is to reduce the effects of sensor orientation on the movement of the XAUV. The solution to these problems is to enclose the sensors in a cylinder with its axis perpendicular to the main body axis.

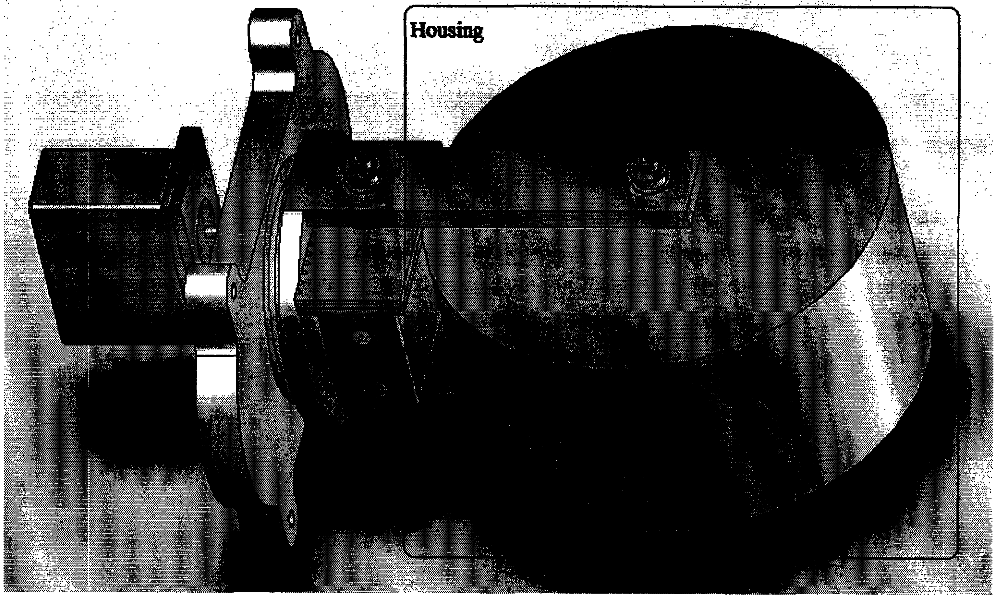

Figure 10: Solid model of cylindrical housing.

This eliminates any effects of the pitch position on the movement of the vehicle and provides a buffer/crush zone to protect against collisions.

Another goal of the enclosure was to make it as compact as possible. Therefore the geometry was selected such that the maximum possible dimensions of the sensors to be enclosed would just fit within. The enclosure will house two main instruments, a camera and a sonar unit. The overall width of the enclosure was selected as to allow for a nominal clearance space, C, between the sensors, each other and the top and bottom of the cylinder.

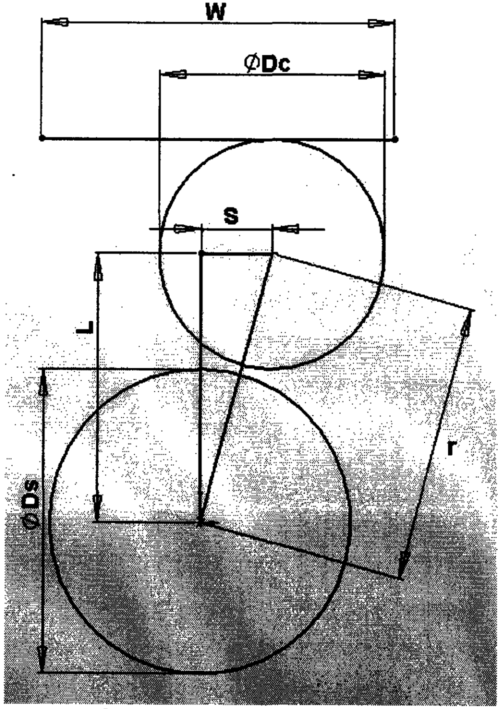

Figure 11: Diagram of relevant dimensions to calculate housing width.

Referring to Figure 11, the radial distance between the centers of the camera and sonar, L, was set equal to the sum of the radii of the sonar and camera. The total distance between the centers of the camera and sonar is equal to the sum of the radii plus a specified clearance, C. Calculating the axial distance between the centers of the sonar and camera, S, is then straightforward because L, S, and r make up a right triangle. The total width of the housing, W, is then simply the sum of the radii, 2 times the nominal clearance value for each side, and the axial offset value S. In terms of the known values, the diameters of the sonar and camera, Ds and Dc respectively, and the clearance value, C, the total width W is,

$$W=\sqrt{\left(\frac{Ds+Dc}{2}+C\right)^2-\left(\frac{Ds+Dc}{2}\right)^2}+\frac{Ds+Dc}{2}+2C. \qquad (1)$$

The next step is to calculate the radius of the housing. This radius was found such that the maximum possible length of the camera and sonar would just touch the edge of the housing cylinder. To accomplish this, the center of the circle had to be offset a distance h from, referring to Figure 12, where the bottom of the camera's circular edge met the top of the sonar's circular edge.

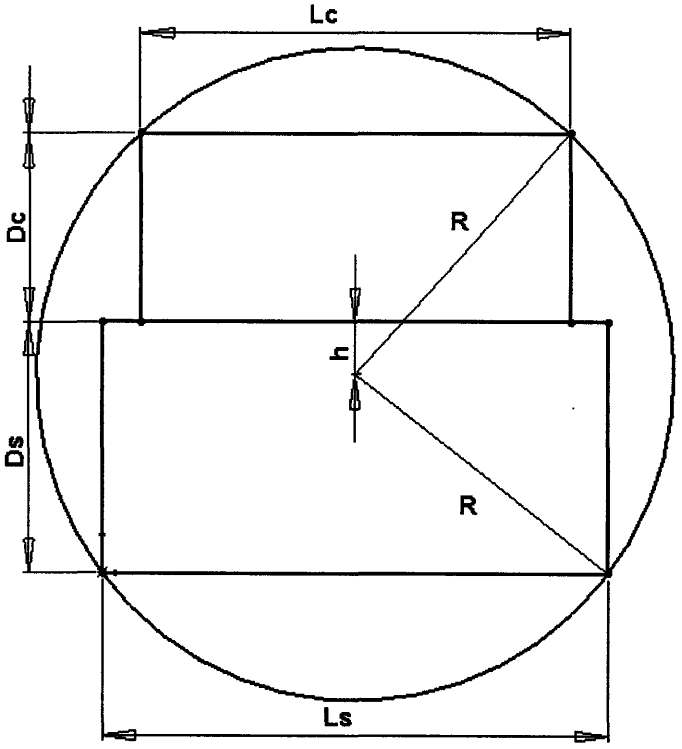

Figure 12: Diagram of relevant dimensions to calculate housing radius.

Referring to Figure 12, the radius of the housing, R, in terms of the diameters of the camera and sonar, Dc and Ds respectively, the lengths of the camera and sonar, Lc and Ls respectively, and the offset value h is found to be,

$$R=\sqrt{(Lc/2)^2+(Dc+Ds/2-h)^2}=\sqrt{(Da/2+h)^2+(Lc/2)^2}\,, \qquad (2)$$

where h is easily solved for numerically and can be used to find R.

The housing rigidly holds the sensors via a half-inch plate of material in the center of the housing. The cylindrical shape if formed by attaching two circular plates on each side of the center plate. Rather than fastening the circular plate with screws or bolts, a comb-like structure is utilized whereby the edges of the center plate have multiple protrusions that fit into slightly smaller corresponding holes in the circular plates. The undersized holes elastically hold the circular plates to the center plate.

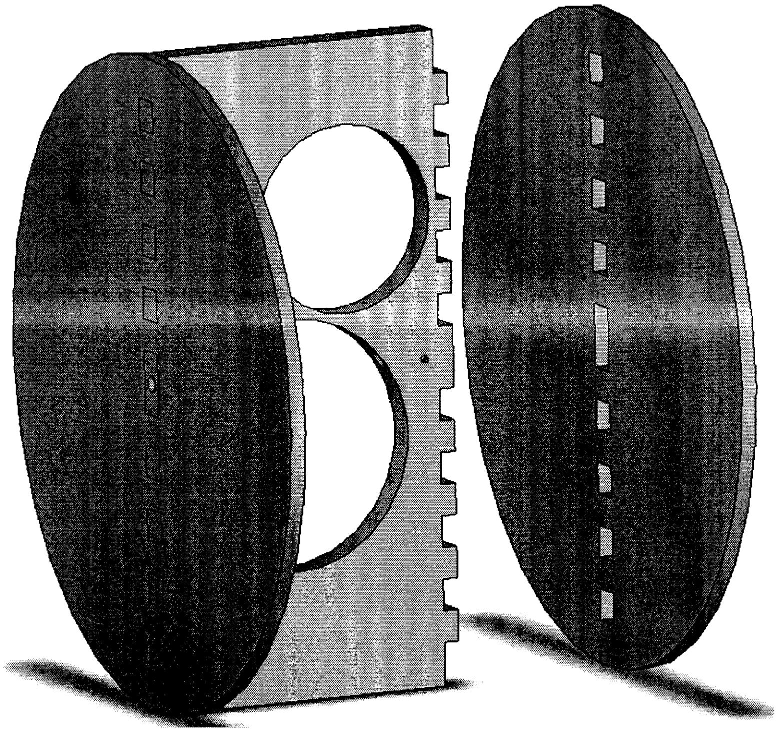

Figure 13: Solid model of comb-like press fit fastening method of housing plates.

This method is preferred for two main reasons: it does not add the additional weight of fasteners and it saves space. Additional width between the standoffs would be required if the heads of the fasteners were not countersunk to avoid collisions with the standoffs. If they were countersunk instead, the circular plates would need to be as thick as the amount required to hold the plates together plus the thickness of the heads of the fasteners to be countersunk. The drawback of this design is the potential difficulty with machining. However, if plastic is used, the machining is actually easier with the use of a laser cutter as no additional holes need to be drilled or tapped precisely.

MATERIAL SELECTION

The material selected for the structure of the positioning system was plastic over metal. Plastic is preferable over metal for the following reasons: plastic is lighter, easier to machine, provides smoother bearing surfaces, is less expensive, and more compliant (for impact absorption). Ultra High Molecular Weight (UHMW) Polyethylene was selected as the main structural material for its high impact strength and shock absorbing properties as well as its reasonably low coefficient of friction [2]. The circular plates of the sensor housing and the front plate of the XAUV are made of ABS, as it is harder and easier to precisely machine. The front plate must be rigid and hard as it is the main connection between the positioning system and the rest of the XAUV. The circular housing plates need to be precisely machined and hard enough to keep their shape, as it is their circular shape that decreases the effect of sensor orientation on the dynamics of the XAUV.

RESULTS

Torque Transmission

At the beginning of this project, a motion of 90 degrees in about 0.5 seconds was the target. If we assume maximum acceleration for the first half of the motion and maximum deceleration for the second half, we have a constant acceleration for half of the required time. Integrating twice over just half the time, t, yields the following expression for required torque, tau, in terms of inertia, I, and the desired values of the angle traveled, theta, and time allowed,t,

$$\ddot{\theta} = \tau / I \Rightarrow \theta / 2 = \tau / I \cdot (t/2)^2 \Rightarrow \tau = \frac{2\theta \cdot I}{t}. \qquad (3)$$

The inertia of a rod the length and mass of the blazed array around its center of mass is given by,

$$I = 1/12 \cdot M \cdot L^2 = 6.4e-3[kg-m^2]. \qquad (4)$$

Of the two axes that move in the positioning system, the roll axis handles the most inertia. An estimation from a CAD program puts this inertia at about 2.8e-2 kg-m^2. Using these values and equation 3, the required torque at the axis is 0.43 N-m. If we include a factor of two for friction and the additional force it takes to displace water, and another factor of two for a 2:1 gear ratio, the required torque out of the servo is about 2 N-m. The servos chosen for this system are Hobbico CS-80 2BB Giant Scale Servos capable of 2.47 N-m of torque at the voltage the XAUV will be running at. This design requires torques well below the values the servos are capable of producing even with a significant safety factor.

Mass Calculation

The total volume of material within the positioning system, not including the servos or sensors is approximately 134.25 cubic inches according to the solid model. The densities of UHMW and ABS are 0.034 and 0.038 pounds per cubic inch respectively. Thus the mass of plastic and smaller components is about 5.1 pounds. The blazed array adds another 4.1 pounds. If we estimate the servos and camera to be 1-2 pounds, the total weight is within a pound of the 10 pound criterion originally set.

Impact Test

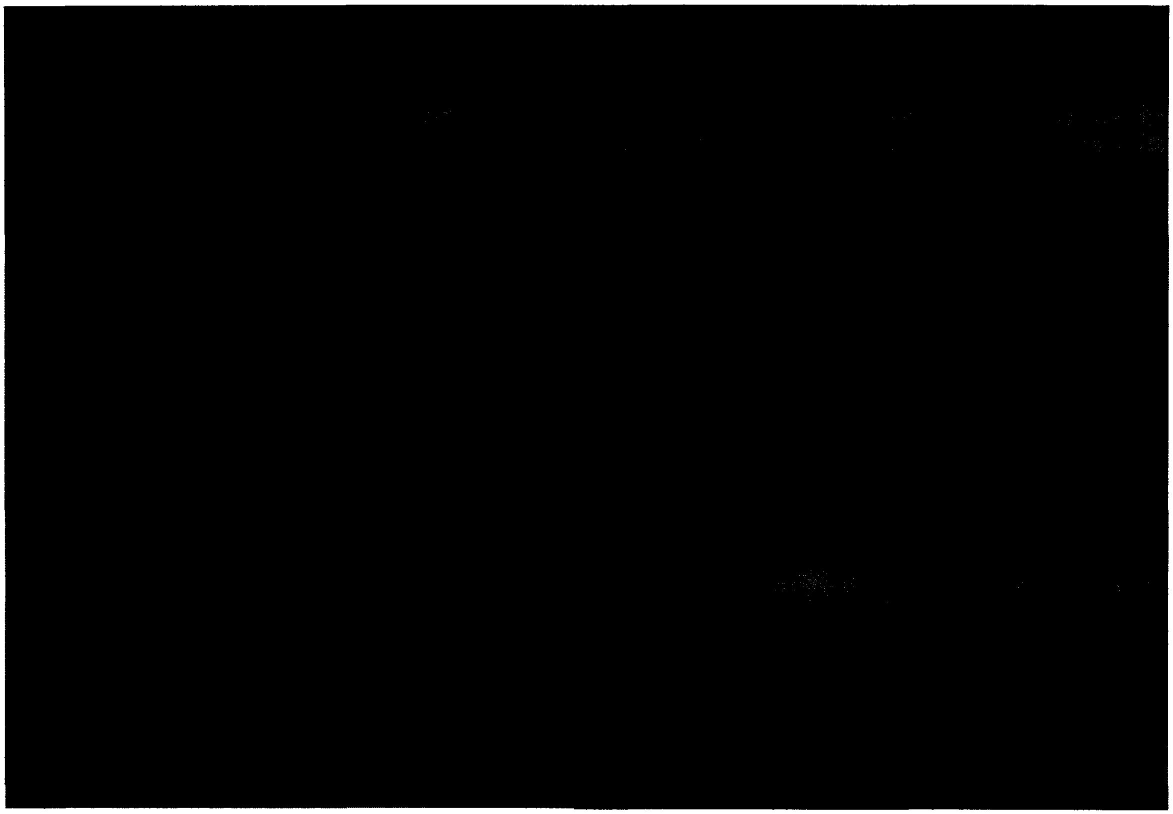

Figure 14: Before (left) and after (right) impact test.

The original criterion was that the positioning system would be capable of withstanding an impact at 5 m/s. To test the effect of an impact at this speed, the system was dropped from a height such that the impact velocity was 5 m/s. Using fundamental physical energy principles, the height was found to be,

$$mgh = \frac{1}{2}mv^2 \rightarrow h = \frac{v^2}{2g}, \qquad (4)$$

where the resulting value of h is about 1.2 meters. Thanks in part to the fantastic impact strength of the plastic selected, there were no noticeable effects from the fall on the system as can be seen in Figure 14.

CONCLUSIONS AND RECOMMENDATIONS

The design is robust with respect to power and torque requirements, as well as impact resistance, while not burdening the XAUV with excessive weight. However, there is still room for improvement. It is better to over-design than under-design when the sensor costs 300 times as much as the positioning system. However, if performance appears to be suffering due to weight-related issues, and it becomes apparent that the sensor does not need as much protection, rebuilding the positioning system with thinner sheets of tougher plastic may decrease the weight and inertia by about 30 percent.

That being said, the system is ready for use and all indicators suggest it will perform its tasks well. It has the potential to help greatly advance the field of ship hull inspection by increasing the speed of inspection and providing a test bed with greater possibilities for next generation algorithms.

ACKNOWLEDGMENTS

I would like to thank the following people for their great assistance in this project:

- Professor John Leonard, for his supervision and encouragement.
- Daniel Walker, for his guidance and willingness to address all of my questions.

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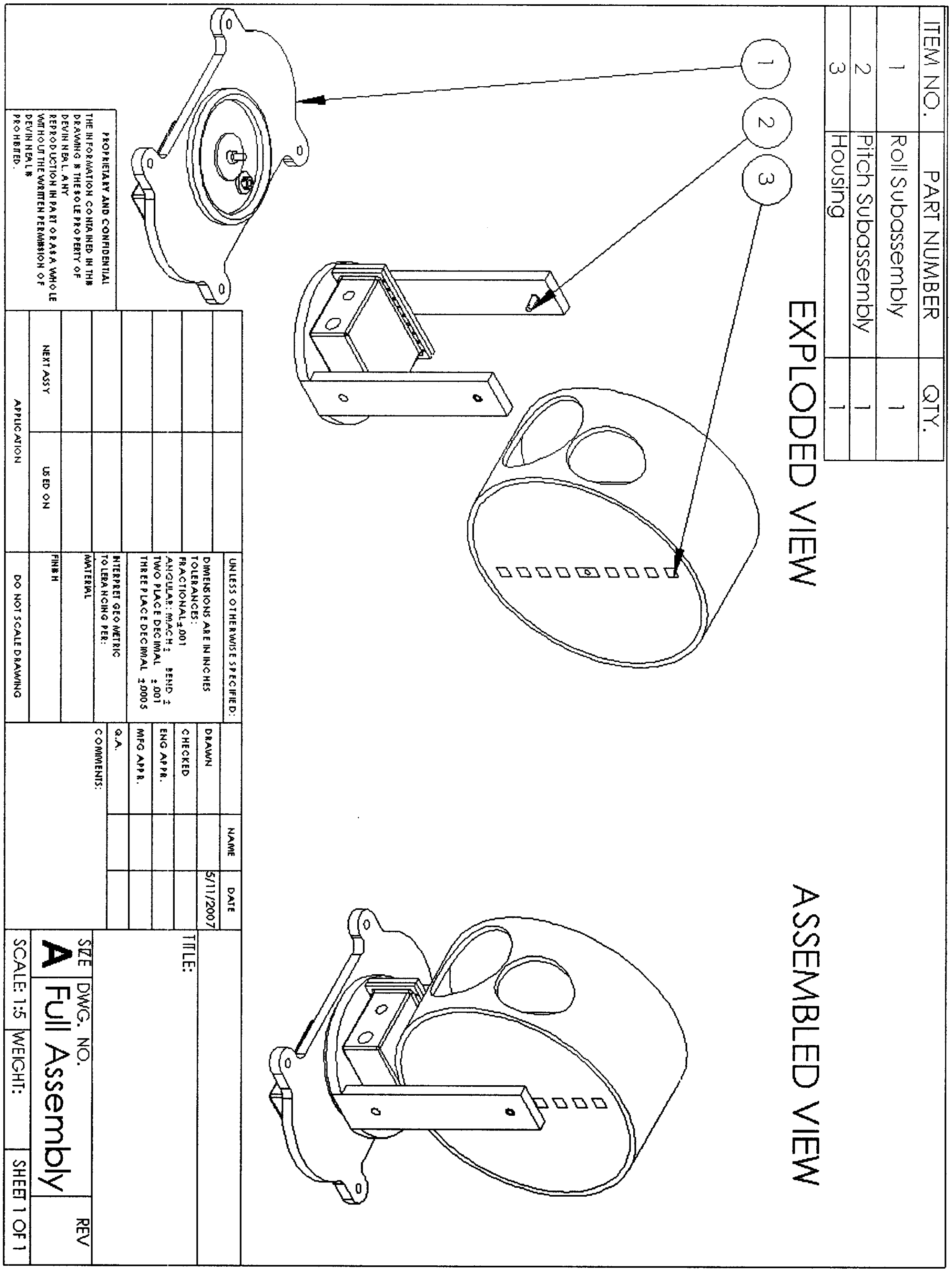
DRAWINGS

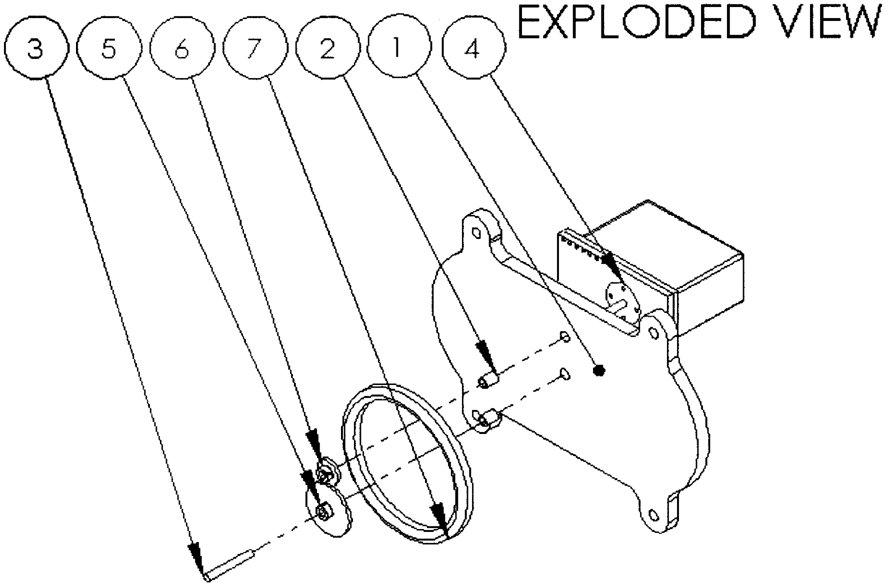
Full Assembly



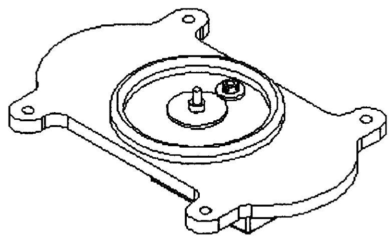
ITEM NO.	PART NUMBER	QTY.
1	Roll Subassembly	1
2	Pitch Subassembly	1
3	Housing	1

Subassemblies

ITEM NO.	PART NUMBER	QTY.
1	Nose Mount	1
2	Sleeve Bearing	2
3	Gear Shaft	1
4	Servo	1
5	2inGear	1
6	1inGear	1
7	Lift	1



EXPLODED VIEW



ASSEMBLED VIEW

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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± .001
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ± .001
THREE PLACE DECIMAL ± .005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		5/11/2007
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

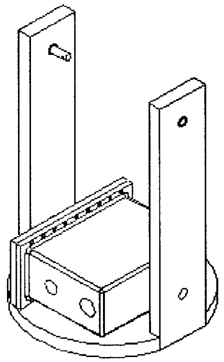
COMMENTS:

TITLE:

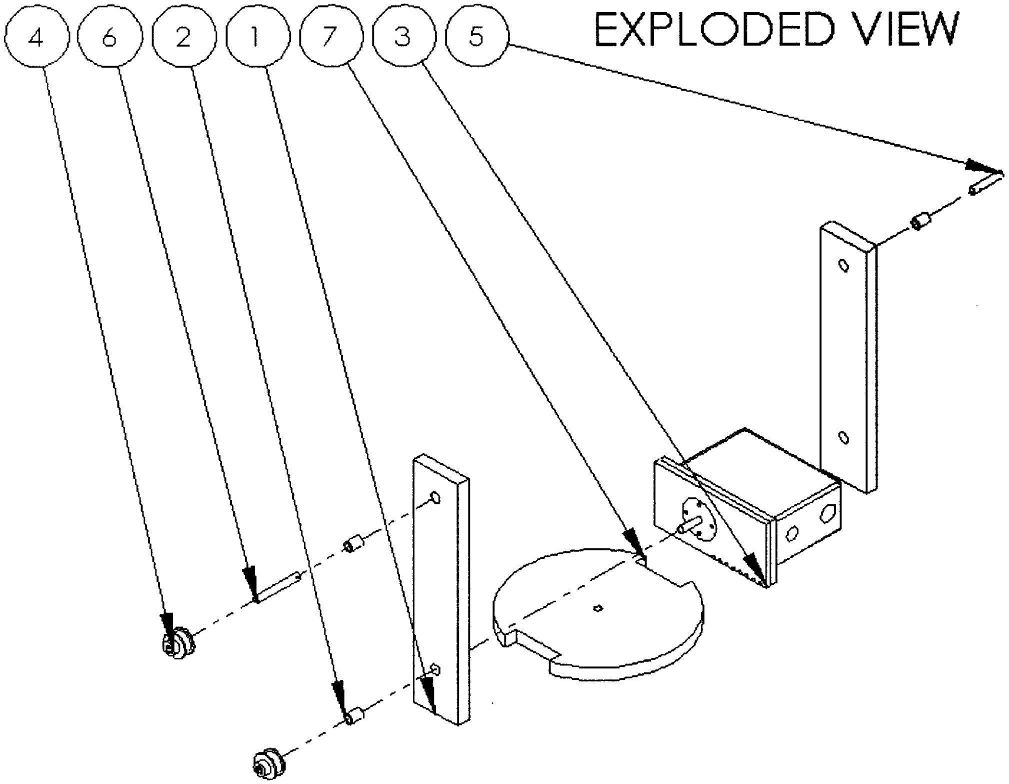
SIZE A
DWG. NO. Roll Subassembly
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1

ITEM NO.	PART NUMBER	QTY.
1	yoke support	2
2	Sleeve Bearing	3
3	Servo	1
4	Timing Pulley	2
5	ShortShaft	1
6	PulleyShaft	1
7	blazedarray yoke plate	1

ASSEMBLED VIEW



EXPLODED VIEW



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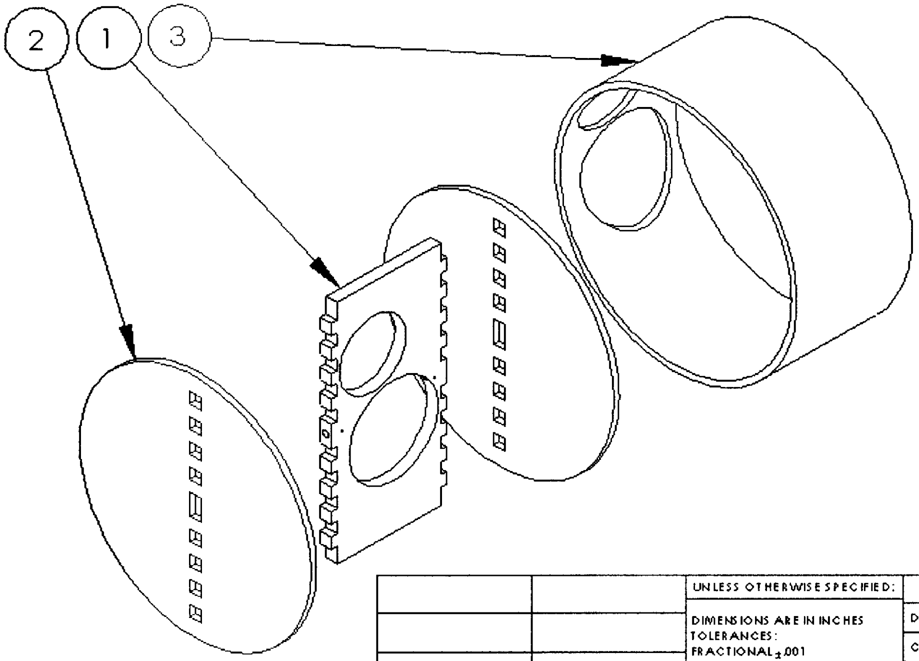
				NAME	DATE
		UNLESS OTHERWISE SPECIFIED:	DRAWN		5/11/2007
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±.001 ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±.001 THREE PLACE DECIMAL ±.0005	CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

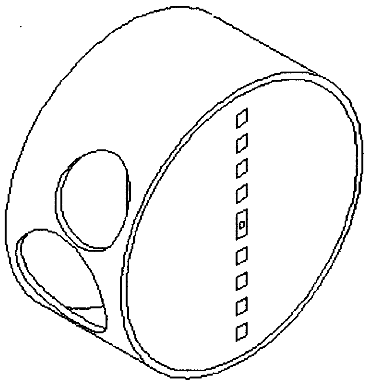
SIZE A
DWG. NO.
Pitch Subassembly
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1

ITEM NO.	PART NUMBER	QTY.
1	Blazed Array Combo Mount Plate	1
2	Blazed Array Combo Mount Side	2
3	HousingCylinder	1

EXPLODED VIEW



ASSEMBLED VIEW



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APPLICATION

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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.001
THREE PLACE DECIMAL ±.0005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

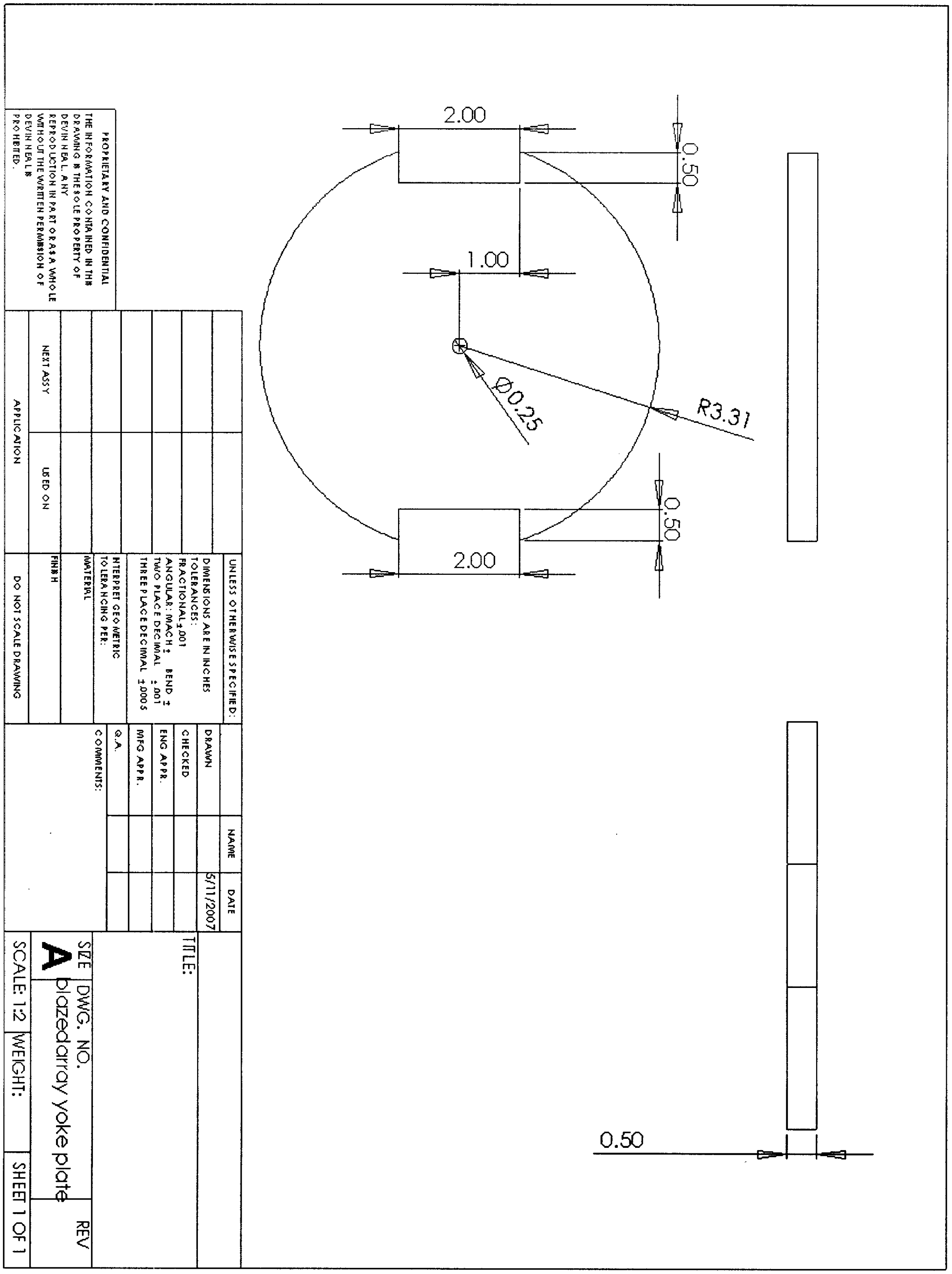
	NAME	DATE
DRAWN		5/11/2007
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

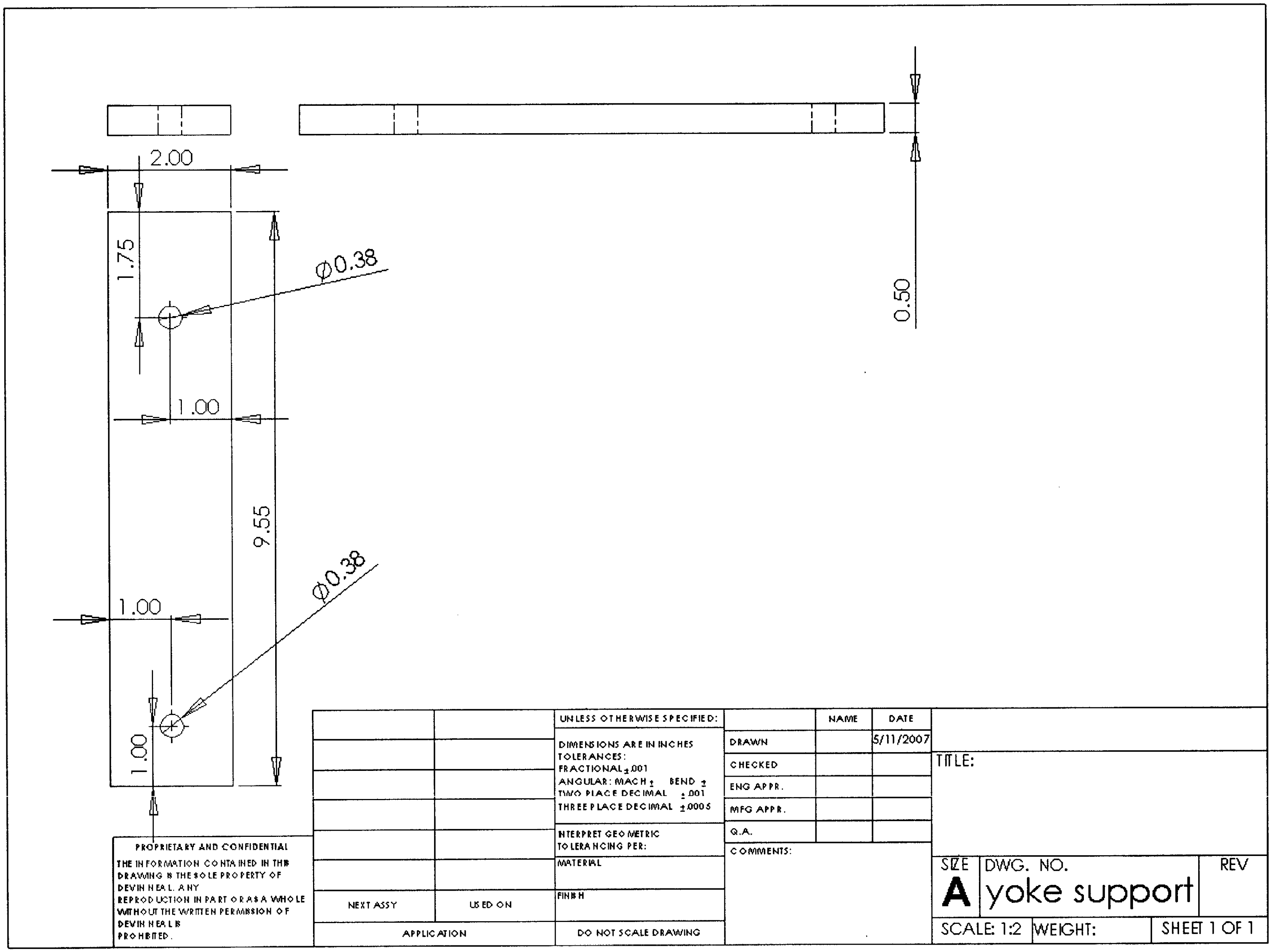
COMMENTS:

TITLE:

SIZE A
DWG. NO. Housing
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1

Plastic Parts




2.00
1.75
Ø0.38
1.00
9.55
Ø0.38
1.00
1.00
0.50
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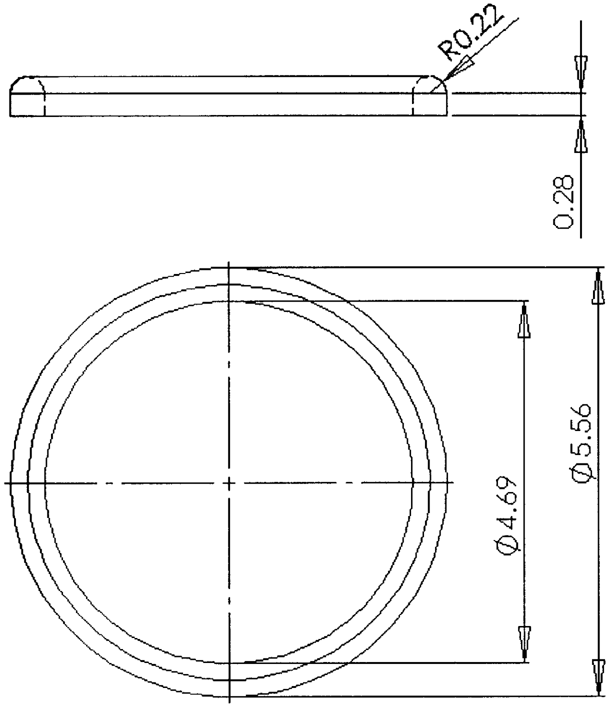
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±.001
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.001
THREE PLACE DECIMAL ±.0005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
5/11/2007
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
A
DWG. NO.
yoke support
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1



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APPLICATION	

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TOLERANCES:
FRACTIONAL ±.001
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.001
THREE PLACE DECIMAL ±.0005

INTERPRET GEOMETRIC
TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

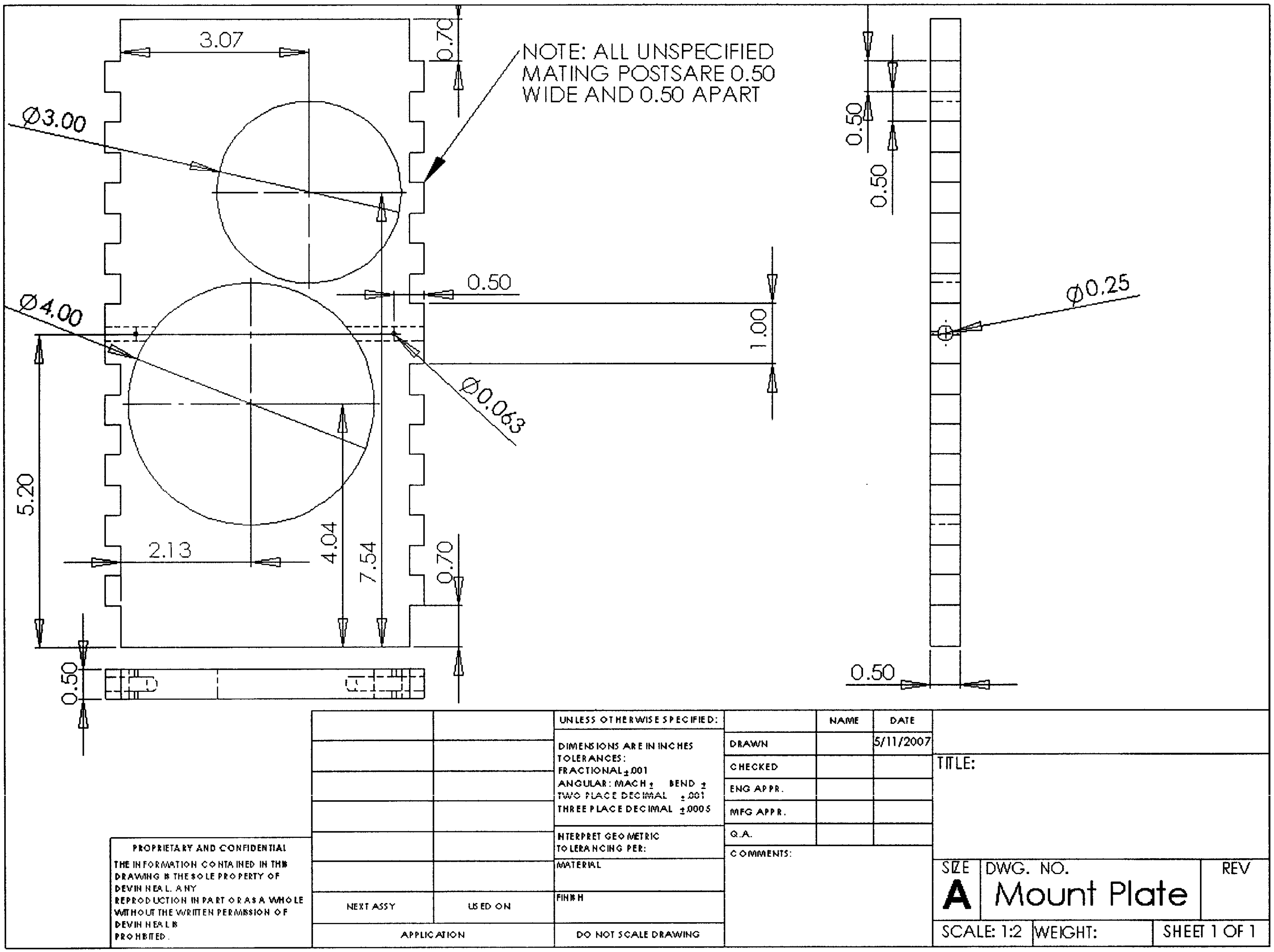
	NAME	DATE
DRAWN		5/11/2007
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
A	Lift	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±.001
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±.001
THREE PLACE DECIMAL ±.0005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
APPLICATION	

	NAME	DATE
DRAWN		5/11/2007
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
A	Mount Plate	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

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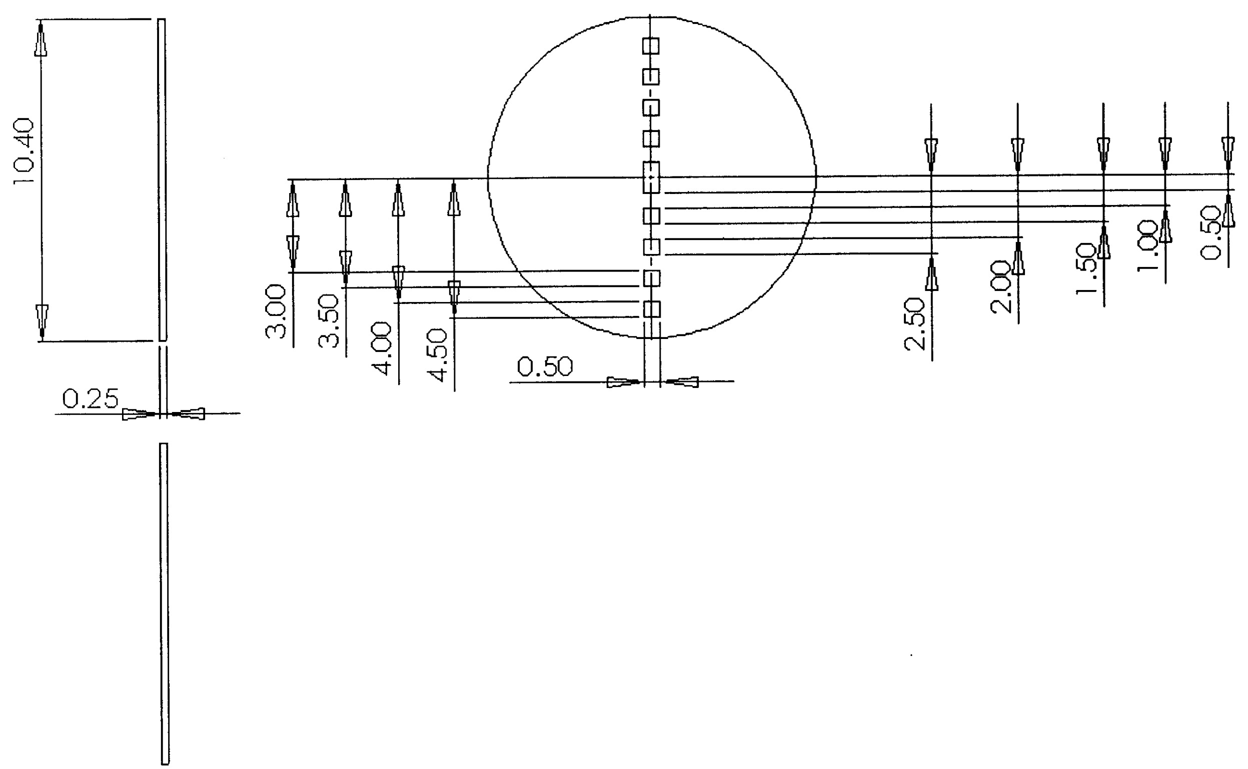

NEXT ASSY	USED ON
APPLICATION	

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TWO PLACE DECIMAL ±.001
THREE PLACE DECIMAL ±.0005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

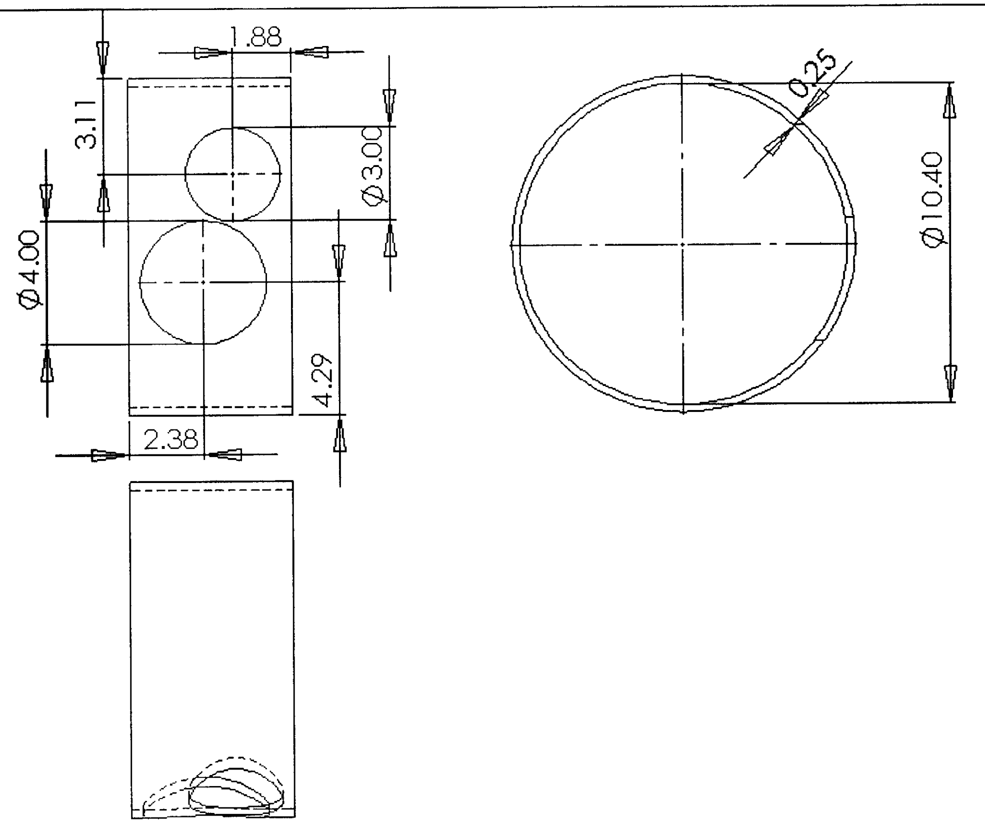
	NAME	DATE
DRAWN		5/11/2007
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
A	Housing Side	

SCALE: 1:5 WEIGHT: SHEET 1 OF 1



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INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		5/11/2007
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE A
DWG. NO. HousingCylinder
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1