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DESIGN AND FABRICATION OF A LOW COST BALLAST SYSTEM FOR DISTANT CONTROLLED SUBMARINE

Mehedi Hasan Tusar[1,*], Md. Kamrul Hasan[2], M. A. B. Sikder[3], N. B. Chowdhury[4] and M. H. Fakir[5]

[1-4]Department of Mechanical Engineering, CUET, Chittagong-4349, Bangladesh
[5]Department of Electrical & Electronic Engineering, CUET, Chittagong-4349, Bangladesh
[1,*]meheditusar95@gmail.com, [2]kamrul05cuet@gmail.com, [3]emon.spiderman@gmail.com,
[4]nahin.me@gmail.com, [5]likhon116@gmail.com

Abstract- *Unmanned underwater vehicles (UUV) have received worldwide attention being an increasing interest for a broad variety of potential applications. This growing interest has prompted different efforts to design and develop unmanned underwater vehicles using powerful embedded controllers, vast arrays of sensors, and advanced robotic systems. This paper introduces a low cost automated piston ballast tank developed for UUV (submarines) which is more reliable, safe and easy to operate than conventional tanks. It can draw accurate amount of water needed by submarine with its electronic system and easy to maintain. No need to be worried about pollute as what it sucked also is discharged. The compression of air inside the hull for ballast tank loading increases the hull strength. It also has screw self-locking mechanism which holds exact position for piston.*

Keywords: Piston Ballast Tank, PWM, Spindle Nut Bearing, Soft O-ring, Screw Self-locking Mechanism

1. INTRODUCTION

Unmanned underwater vehicles (UUV) have received worldwide attention as a potential force multiplier in today's battle-space. Comparing the operation of UUVs from surface platforms, submarines have a clear advantage as their movements are far less likely to be detected. UUVs provide the opportunity for navies to operate in a covert way within areas where normal manned submarines or other military assets may not be free to operate. Submarines are not constrained by sea state and wave motions to the same degree as surface ships [1]. The UUV technology needs to become accessible for more customers in order to speed up its adoption as ocean explorers. Decreasing the cost of commercial UUVs is one of the most important objectives for the next couple of decades. [2]. A low cost automated piston ballast tank is introduced for UUV (submarines).

The ballast tank is a compartment within a boat, ship, submarine or floating structure that holds water for its stability. It is an essential part for all ship and static diving submarines. A good ballast system will not only cause a boat to submerge and surface on command, but will do so reliably [3]. There are two diving methods for UUV- Static diving and dynamic diving. Many model submarines use the dynamic method while static diving is used by all military submarines. When UUV floats it is positively buoyant. In dynamic diving, buoyancy is kept positive. Downward force is created by hydroplanes to submerge it by keeping UUV in motion. So, while UUV rests there is no downward motion and it floats. Static diving submarines use ballast tanks to make it neutrally buoyant from positively buoyant.

Militaries across the world are increasingly turning to unmanned systems to augment their manned capabilities [4]. Military submarines use compressed air ballast system which need compressor, compressed air tank etc. which is not suitable for remote controlled submarines. Therefore, it is necessary to design and develop a ballast system giving better performance, costs lower and easy to make for small submarines. An automated piston ballast tank is developed that provides reliable results with small limitations.

1.2 relative density

Relative density is the ratio of density of substance to the density of water at 4˚c as shown in Eq. (1). So three types of relative density is possible. It may be less than one, equal to one or greater than one.

$$R{\cdot}D{\cdot} = \frac{\rho s}{\rho w} \text{ at } 4^{\circ}\text{C} \qquad (1)$$

1.3 Buoyancy

Buoyancy is the phenomenon for which a body experiences the upward force when it is partially or completely immersed in liquid.

Buoyant force F_b, are given by Eq. (2).

$$F_b = PA$$
$$\Rightarrow F_b = Ah\rho g$$
$$\Rightarrow F_b = \rho g v \qquad (2)$$

1.4 Relation between R.D. & Buoyancy

There are three cases:

1. Whenever a body's relative density is greater than 1 then the gravitational force acting downward will be greater than the buoyant force acting upward. So the body will sink.
2. Whenever the body's relative density is lower than one, buoyant force will be greater and cause the body to float.
3. When a body's relative density is equal to one, buoyant force will equal to gravitational force so the body neither sink nor floats. This is the ideal model for a submarine as a neutrally buoyant item takes the least amount of force to keep it submerged in a position or to be moved in any direction in a fluid.

So, we have to design a ballast tank such that when it is fully loaded it makes the submarine neutrally buoyant and when not the submarine is positively buoyant.

1.5 Screw Self Locking Mechanism

Large frictional forces cause screws self- locking which means applying torque to the shaft will cause it to turn, but no amount of axial load force against the shaft will cause it to turn back. This is suitable for driving piston as axial load force is developed by water pressure, where reciprocal driving of piston may cause the piston to move backwards on large applied force.

1.6 PWM

PWM or pulse width modulation is broadly used to control the speed of dc motor .By varying the duty cycle we can control the average voltage for any cycle and thus control the speed.

2. RELATED WORK

In large submarines ballast tanks are filled by venting the air inside from the ballast tank out so, let water enter the tank and emptied by blowing compressed air into them. But for model submarines, this system is difficult and it also has heavy weight. So many alternative method can be used which is described below [5] as shown in Figs. 1-5.

2.1 Flexible ballast tank

The flexible ballast tank consists of a rubber balloon placed inside a rigid tank. To flood the tank the valve is opened and water is pumped into the tank. The valve is closed to prevent water getting out once the tank is loaded.

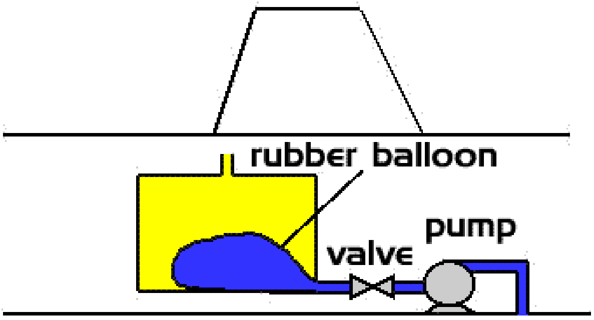

Fig.1: Flexible Ballast Tank [5]

2.2 Vented ballast tank

It is as same as flexible ballast tank but when it is flooded air is released through the vent.

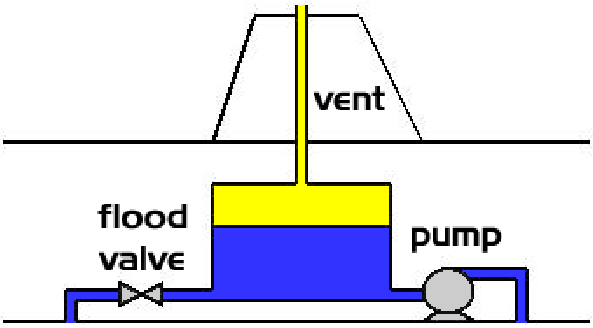

Fig.2: Vented Ballast Tank [5]

2.3 Pressure ballast tank

It is a ballast tank consists of sealed ballast tank capable of withstanding high pressure. It is loaded by a pump .But as the air is trapped inside the ballast tank air is compressed so ballast tank can never be fully loaded.

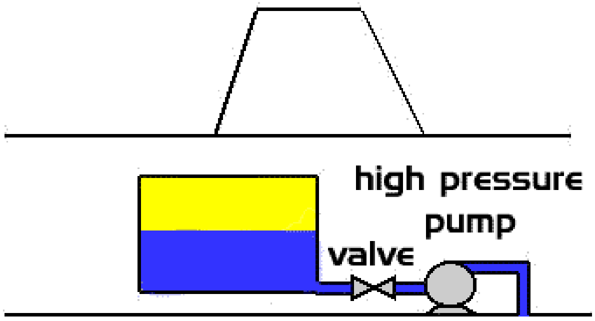

Fig.3: Pressure Ballast Tank [5]

2.4 Piston ballast tank

The piston ballast tank consists of a cylinder and a movable piston. Piston can be moved with a threaded shaft, spindle nut bearing, and a motor. Piston is sealed with two soft O-ring. As ballast tank's loading unloading effect the center of gravity two piston tanks of same size placed in equal distance from center of gravity can overcome this problem.

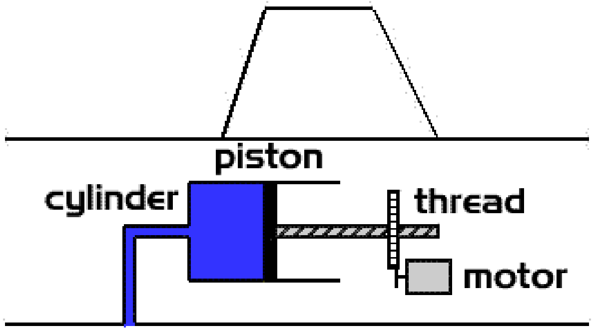

Fig.4: Piston Ballast Tank [5]

2.5 Compressed air ballast tank

This is the identical one that is used in real submarine. For flooding the tank vent valve is opened through which air is released .Water gets in by a hole under the ballast tank .To empty the tank compressed air is released to the tank by opening compressed air release valve.

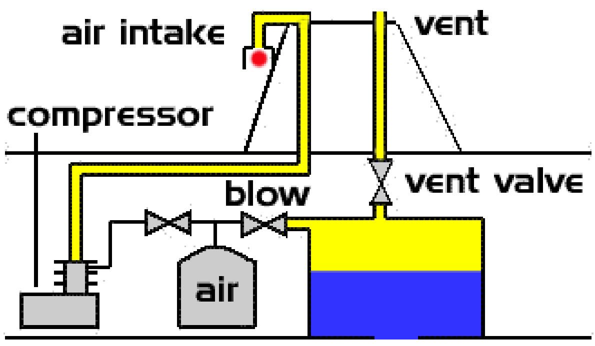

Fig.5: Compressed Air Ballast Tank [5]

2.6 Comparison of Different Types of Ballast Tank

As vent pipe always have to be above water level it cannot be used to give boat neutral buoyancy. Many of this ballast tanks uses valve which makes controlling difficult. Flexible ballast tank does not give accurate buoyancy as it can never be fully loaded and require a high pressure pump .Compressed air system is good but it is heavy and need a compressor which makes design complex. Besides piston ballast tank neither have this problem and upgradation makes it more reliable.

3. DESIGN AND CONSTRUCTION

The solidworks design of piston ballast system is shown in Fig. 6. The ballast system is divided into two sub systems.

i) Mechanical Subsystem
ii) Electrical Subsystem

3.1 Mechanical subsystem:

- Cylinder
- end cap
- Spindle nut bearing
- piston
- Soft o ring
- Threaded shaft
- Spur gears
- 12V Gear motor

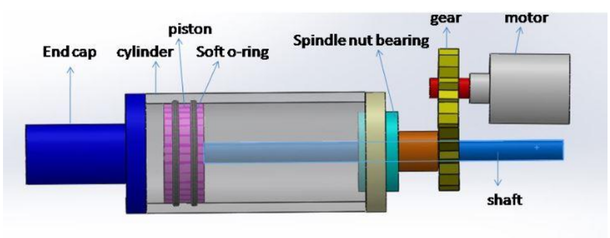

Fig.6: Solid Works Design of PBT

3.1.1 Spindle nut bearing

A spindle nut is machined from a round piece of steel which have an internal thread similar to the threaded shaft. Then the spindle nut is pressed into nearly same diameter bearing. It is spindle nut bearing.

3.1.2 O-ring

An O-Ring is a torus shaped seal typically used to prevent the passing of air or fluid. 2-3 mm thick soft O-ring is used for this project. Because it tend to flow better into these voids and imperfections of the cylinder which is a pathway for fluid to escape. About 10%-15% and 15%-30% o-ring thickness compression are needed for piston and end caps respectively [6].

3.2 Electrical system

Figure 7 shows the circuit diagram of the system. The electrical system contains:

- Arduino
- Water Sensor
- Motor driver(L298N)
- RF receiver & transmitter
- Temperature sensor

3.2.1 Arduino

Arduino is a popular developing board based on AVR microcontroller. Arduino has its own developing environment which is written in C++ and JAVA. In this project, arduinomega(2560) is used.

3.2.2 Motor driver

L298N is a medium range motor driver IC which can provide a output current of about 4A and can operate upto 46V.

3.2.3 RF receiver & transmitter

RF receiver& transmitter is frequently used device for RC application. It operates in between 3 KHz to 300 GHz and has different channel for communication. In this project, 75 MHz 6 channel RF is used.

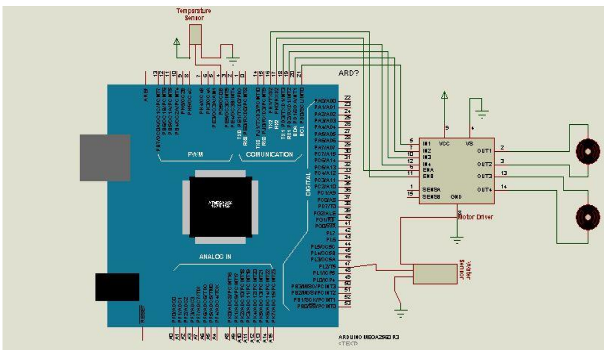

Fig.7: Circuit Diagram

3.3 Materials

Cylinder can be made from aluminum, PVC, steel or transparent plastic. Transparent plastic is better. End caps and piston is made of nylon, threaded shaft from mild steel. Low weight materials are preferred for ballast tank construction so it is easy to design submarine for its neutral buoyancy and additional features can be added for this reduction in weight.

3.4 Working Mechanism

The constructed piston ballast tank is shown in Fig. 8.

By receiving command, gear motor drives the gear connected to the spindle nut. This gear provides high torque to the spindle nut which causes linear motion to the threaded shaft. The threaded shaft is jointed with the piston. Depending on the motors direction of rotation piston makes the Ballast tank loaded or emptied.

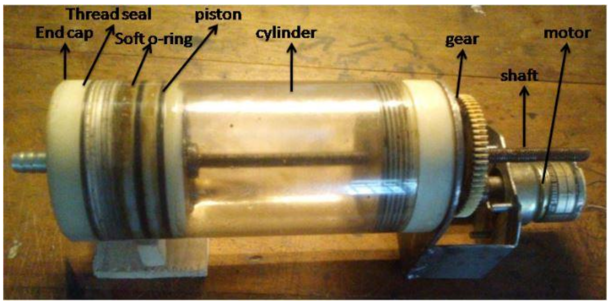

Fig.8: Developed Piston Ballast Tank

3.5 Operational Safety

If a ballast tank fails or leaks, submarine will sink. A decisive advantage of this technology is its highly reliable performance. The discharge pressure is more than sufficient for its operational depth. When emptying or loading, piston reaches end caps. Further movement of piston may break threads or gear teeth. But the sensor power off the motor when piston reaches end caps. If the rack and pinion mechanism is used to move the piston, it may slip from its position and support roller need to used which consumes more power. But using screw self-locking mechanism by using threaded shaft enables it to hold any position. Besides, if any of two ballast tank leaks the water sensor will detect it and submarine will float.

3.6 Special Features

If Submarine's average density equals water's density neutral buoyancy is achieved. As water's density changes with temperature, therefore, manual weight loading unloading is required to match submarine's density with water. But in this design, piston's position can be controlled by controlling motor and thus ballast loading unloading, which makes it automated.

4. DATA ANALYSIS AND CALCULATION

Table 1 shows flow rate for different PWM values of motor driver at 12V. As PWM value decreases power developed by the motor decreases. So it takes more time in ballast loading unloading with decrease in PWM. Figure 9 is the graphical representation of it. Below 200 PWM value of motor driver, motor cannot develop enough power to overcome the frictional forces. So, 255 PWM value is used as it is the largest value for 8 bit output of microcontroller.

The density of water varies with temperature as shown in table 2 [7]. Water density after 40^0 c does not vary so much. So we considered ballast loading for 0^0 c to 40^0 c.

Table1: PWM value & flow rate

PWM	255	240	230	220	210	200
TIME (S)	58	65	73	83	95	106
Linear movement (mm)	1.47	1.31	1.16	1.02	0.89	0.8
Flow rate (cm^3/s)	5.53	4.93	4.36	3.84	3.35	3.01

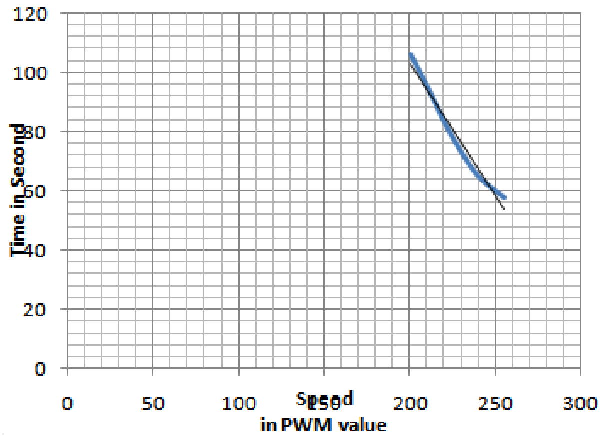

Fig.9: PWM value .Vs. BT loading time

Table 2: Temperature vs. Relative density of water [7]

S.I no	Temper ature (˚c)	Relative Density	S.I no	Tempe rature	Relative density
1	4	1.000000	21	24	0.997326
2	5	0.999992	22	25	0.997074
3	6	0.999968	23	26	0.996813
4	7	0.999930	24	27	0.996542
5	8	0.999976	25	28	0.996262
6	9	0.999809	26	29	0.995974
7	10	0.999728	27	30	0.995676
8	11	0.999633	28	31	0.995369
9	12	0.999525	29	32	0.995054
10	13	0.999404	30	33	0.994731
11	14	0.999271	31	34	0.994399
12	15	0.999127	32	35	0.994059
13	16	0.998970	33	36	0.993712
14	17	0.998802	34	37	0.993357
15	18	0.998623	35	38	0.992994
16	19	0.998433	36	39	0.992623
17	20	0.998232	37	40	0.992246
18	21	0.998021	38	41	0.99186
19	22	0.997799	39	42	0.99147
20	23	0.997567	40	43	0.99107

4.1 Calculation

For example 15000cm^3 submarine need 15000 gm mass for neutral buoyancy at 4˚C. If its dead weight is 14360 gm, then each of the two ballast tanks should be of 320 gm capacity.

Here, the ballast tank capacity is 320 cm^3. Total amount of ballast water is 640gm. Then, Total mass of submarine will be 15000gm.

Neutral buoyancy is achieved at 4˚C. At 40˚C, water density is 0.992; therefore, mass of 15000 cm^3 water is 14880 gm. To obtain neutral buoyancy, the submarine needs total ballast water of 520 gm.Therefore, ballast load in each tank is 260 gm.

For, 255 PWM value, it took 58 second to load $320cm^3$ ballast. The mass flow rate is 5.486 gm/s. Therefore, the time required to load 260 gm ballast is 47.4s. So we have to power the motors for 47.4s.

Thus we can control the accurate neutral buoyancy for different temperatures. As the size of UUV increases, significance of temperature related to ballast laoding increases. Accurately neutrally buoyant UUV needs the least amount of force to drive it.

5. CONCLUSION

This design contains a lot of features at low cost with simple structure. As the demand of unmanned under water vehicles (UUVs) are increasing for various types of operation such as search & rescue, underwater observation, marine research, underwater mining, underwater geological survey and military operations, it will serve a great contribution. But it has some limitations as it consumes large space while piston moves, that space would have used for other purposes. Its ballast loading capacity is small compared to its consumed volume. So, maximum portion of the submarine is submerged according to design even when it floats which increases the drag. It doesn't make that sense for remote control submarines as it is not our major concern. It requires no maintenance, but lubrication after a long time which makes it perfect.

6. REFERENCES

[1] Tim Hardy, and Gavin Barlow, "Unmanned Underwater Vehicle (UUV) deployment and retrieval considerations for submarines", *UUV Deployment and Retrieval Options for Submarines*, INEC 2008, Hamburg, Germany.

[2] A. G. G. Badillo, and I. F. C. Ceron, "Development of Autonomous Underwater Vehicles; A brief overview". [http://www.idt.mdh.se/kurser/ct3340/ht10/FinalPapers/14-Garcia_Castro.pdf]

[3] http://www.subcommittee.com/rcss-ballastsystems.html

[4] http://www.naval-technology.com/features/feature-new-era-underwater-drones-unmanned-systems/

[5] http://www.heiszwolf.com/subs/tech/tech01.html

[6] Piston ballast tank by Von Lothar Mentz. [http://www.rc-submarines.net/uploads/3/6/3/4/3634806/piston_tanks.pdf]

[7] http://www.engineeringcivil.com/relative-density-of-water.html

6. NOMENCLATURE

Symbol	Meaning	Unit
UUV	Unmanned Underwater Vehicle	-
PBT	Piston Ballast Tank	-
BT	Ballast Tank	-
PWM	Pulse Width Modulation	-
R.D.	Relative density	-
F_b	Buoyant force	N
ρ_s	Density of subject	Kg/m^3
ρ_w	Density of water	Kg/m^3
P	pressure	N/m^2
A	Area	m^2
h	Height of the submerged volume	m
ρ	Density	Kg/m^3
g	Gravitational acceleration	ms^{-2}
v	Submerged volume	m^3
RF	Radio frequency	Hz