Design of a RC Submersible ROV for Underwater Repairing of Pond Liner

Prof. Sampat Patil[1], Chinmay Dani[2], Vaidehi Kulkarni[3], Ankit Jagtap[4], Sneha Wavare[5]

[1]Assistant Professor, Dept. of Mechanical Engineering, PESMCOE, Pune, Maharashtra, India
[2,3,4,5]B.E. Students, Dept. of Mechanical Engineering, PESMCOE, Pune, Maharashtra, India

---***---

Abstract – *Artificial farm ponds use HDPE sheets/liners for harvesting water in the basin created by excavating a piece of land. Small scratches, holes in this liner cause stored water to drip in the soil beneath. This paper aims at mechanizing the repairing job of such liners for which a prototype is thought of. The prototype includes a Remotely Operated Vehicle (ROV) carrying a sealing mechanism attached with it. Surveying and sealing operation of liners is controlled via a person on the ground. Radio Communication (RC) is used to control the device and configured using suitable cable. This work is proposed by keeping in mind the simplicity and cost effectiveness of the prototype.*

Key Words: ROV, RC, prototype, design, pond-liner, sealing-mechanism, low-cost

1. INTRODUCTION

Agricultural farm ponds in Maharashtra state, India have been growing in numbers under various schemes launched by Govt. of Maharashtra and they are contributing significantly to the production quality and overall growth of farmers. A farm pond is basically a basin created by excavating a piece of land, the size of which is decided according to the need of storing water for protective irrigation in draughts/draught like conditions. A HDPE (High Density Poly Ethylene) sheet/liner of thickness up to 2mm is layered upon the basin for avoiding dripping of water in the soil. This sheet is prone to scratches/holes due to debris in the water.

The liner can be repaired by patching the damaged area or use a sealant for smaller holes but requires skilled labor as well as sometimes pumping the water out of the pond which costs considerable expenses in maintenance. The objective of this project is therefore to build a device that will work underwater for surveying and sealing small damages on the liner and control of such a device will be done manually by an operator on the ground with real-time data telemetry (live feeding the surveying and sealing operation done underwater to the operator).

The device consists of a ROV built by considering certain design parameters and limitations such as costing, operating depth, sealing limited to vertical surfaces i.e. liner on walls of the basin, etc. This ROV is basically an UUV (Unmanned Underwater Vehicle) with control of motions like propulsion, steering and immersion. ROVs have been in the use since many years predominantly for underwater exploration, military applications and industry specific functions [1]. This project extends the concept of exploratory ROV with an added functionality of sealing the pond liners.

The prototype is an ROV made by adapting a cylindrical submarine design with modifications according to the functions required and a sealing mechanism enclosed in a pipe attached with the ROV which is expected to apply sealant on the liner. The paper is divided into following sections:

- Mechanical Design of ROV
- Design of Sealing Mechanism
- Control System
- Impact Analysis of the Vehicle
- Conclusion

2. MECHANICAL DESIGN OF ROV

2.1 Scope of the Project

1) The maximum operating depth of the ROV is considered to be 4m-5m in still water.
2) Hole on the liner to be sealed is limited to 5mm in diameter.
3) Four degrees of freedom will be controlled, namely; Fore/Aft, Rolling, Up/Down, & Yawing.
4) Sealing operation is limited to the liners on the vertical walls of the basin.

2.2 Operating Environmental Conditions

1) Water- Translucent with pH levels in between 6 and 8.
2) Temperature of water- 10°C to 40°C.
3) Working depth of the ROV- 4 to 5 meters (assumed).

2.3 Design of Carrier Vehicle

Various underwater vehicle designs were studied [2] and final design for the prototype was developed. The different designs include; caged structure ROV [3], ROV having cuboidal body [4] and ROV having cylindrical hull [1]. In the caged structure ROV, the entire machine was enclosed inside a framework, onto which the electronic components were housed at the centre inside a cylindrical block for insulation and the propellers were mounted on this structure. This structure permits the components to be constant on the cage without difficulty, but the vehicle designed in this style is not as hydrodynamic as compared to other design alternatives studied, also the structure was too large, which was one of its major disadvantages. In the cuboidal shaped ROV, the electronic components were enclosed right into a cuboidal-shaped structure, and propellers were fixed on it. Compared to the first design alternative, fixing of attachments in this shape was tough; however, it had a remarkable balance due to its cuboidal form. It was compact in size compared to the first design but again, it was less hydrodynamic. The last design alternative was ROV with cylindrical hull; this design was similar to the submarines. In this design, the electronic components can be enclosed within the cylindrical hull. This shape was very hydrodynamic due to its cylindrical nature. It was simple and compact compared to the first design alternative and easy to manufacture with fewer components compared to other designs. Thus, the cylindrical hull ROV was preferred; due to its hydrodynamic nature, compact size and simplicity in the construction.

Various materials were explored for the construction of the prototype. It included aluminum, stainless steel, mild steel 1018, mild steel 1020, and PVC (Polyvinyl Chloride). Taking into account the three main aspects; operating depth, cost required for the material and its availability, PVC material was chosen as it was able to sustain at the required depth with the lowest cost estimation. Also, PVC material was most suitable for the operating environmental conditions considering its chemical and physical properties such as corrosion resistance, stiffness, shock absorption, and neutral chemical behavior [5]. Further, for the fore part of the prototype a transparent dome was required inside which the camera will be installed for the live feedback system. The materials studied for the dome were glass, acrylic and polycarbonate. Considering the three main factors; strength requirement, cost and availability of the material, acrylic material was chosen. Acrylic material has good structural strength and resistance to corrosion [6]. Though polycarbonate was better at strength, the material was costly and it was vice a versa for the glass, hence they were not preferred.

The final prototype of the carrier vehicle was designed as shown (figure 1). The design included; a cylindrical hull to house the electronic modules, a transparent acrylic dome at the fore position for camera installation, the immersion system at the sides of the hull which included two vertical axis propellers and at the aft position propulsion system was designed which included one propeller with rudder system. Also stands were provided for better stability when the vehicle lands on the surface of the basin. Finally, the sealing mechanism was attached to the carrier vehicle at the lower position, as shown in the figure.

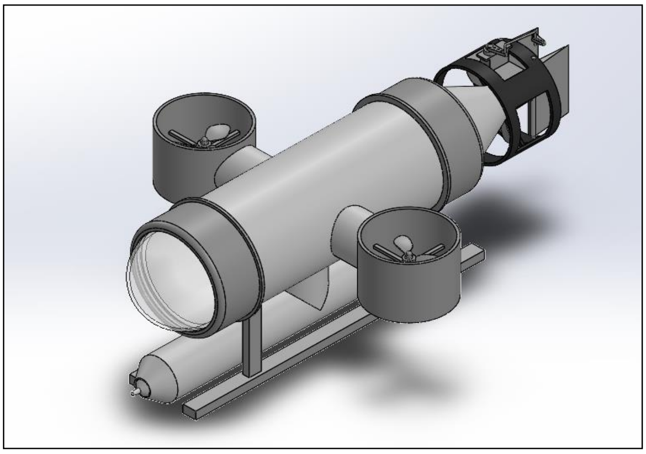

Fig -1: CAD of the Prototype

2.4 Calculation of the Forces

i. The pressure of water changes with varying depth, thus it was important to check the structural sustainability of the vehicle at the required depth. The pressure of water column was calculated using the following formula:

$$Pw = \rho g h$$

Pw: The pressure of the water (Pa)
$Pw = \rho g h$: The density of the water (kg/m^3)
g: Acceleration due to gravity (m/s^2)
h: Maximum operating depth (m)

By taking the depth as 5m, the pressure of water column was obtained as 0.049 MPa. The main part prone to deformation was hull, thus the critical pressure of the hull was calculated for cylindrical shape, and it was obtained as 0.157 MPa. The critical pressure value was greater than the pressure obtained hence it was concluded that the material was sustainable. Thus factor of safety achieved was 3.2, which was adequate for the hull to sustain at that depth.

ii. As discussed in the previous point, two propellers were attached at the sides for immersion purpose (figure 2). The vehicle was made negatively buoyant by making the body heavier than the buoyant force developed. The buoyant force was calculated by the following formula:

$$Fb = \rho g V$$

Fb: The buoyant force (N)
$Pw = \rho g h$: The density of the water (kg/m^3)
g: Acceleration due to gravity (m/s^2)
V: The volume of the water displaced by the vehicle (m^3)

Substituting the value of the volume of the water displaced by the vehicle as 0.005924 m^3, the buoyant force obtained was 58.11 N and the estimated weight of the body was determined as 60.822 N. Thus it was concluded that the total thrust needed by the propellers to lift the body should be more than 60.822 N.

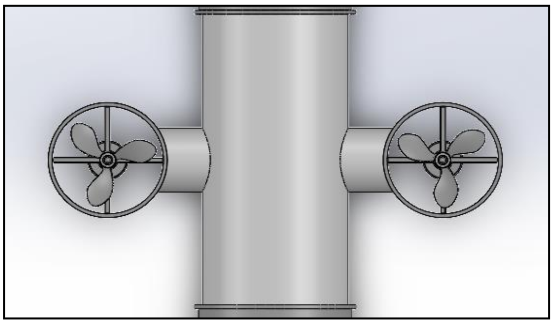

Fig -2: CAD of Immersion system

iii. The propulsion system included one propeller with rudder system (figure 3); the rudders are used for steering the vehicle and are attached to the servo motor, through a push rod, as shown in the figure. When the vehicle travels inside the water, it experiences certain resistance to its motion; this resistance is called as the drag force. The total drag force has two components, drag force acting on the vehicle and the skin friction drag experienced by the vehicle. These forces were calculated using the following formulae,

$$Fd = Cd \times \frac{\rho v^2}{2} \times Af$$

$$Fs = Cf \times \frac{\rho V^2}{2} \times As$$

Fd: Drag force (N)
Fs: Skin friction drag (N)
Cd: Coefficient of drag
Cf: Coefficient of friction
v: The linear velocity of the vehicle (m/s)
Af: Area of frontal portion in contact (m^2)
As: Lateral surface area in contact (skin) (m^2)

Taking the velocity of the vehicle as 1.5 m/s and substituting the values of the frontal and lateral surface areas, the drag force and skin friction force were obtained as 50.58 N and 0.515 N respectively.
Thus the total drag experienced by the vehicle is 51.095 N; hence for the propulsion inside the water the desirable thrust by the propellers should be greater than the total drag obtained.

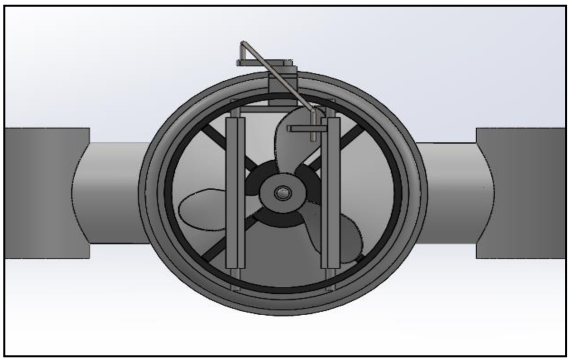

Fig -3: CAD of Propulsion system

3. DESIGN OF SEALING MECHANISM

The mechanism of power screw – mechanical device used to amplify the input force to lift heavy weights – is used as the fundamental operating principle of this sealing mechanism. Gold Label Pond Aquarium Sealer developed by Hutton Aquatic Products [7] is best suitable for sealing of liners without affecting water.

Table -1: List of Components required

Sr. No.	Component	Specification	Qty.
1.	Metric Threaded Bolt	M8*1.25, Plain Carbon Steel	1
2.	Hex Nut	For M8 bolt, PCS	1
3.	Bush	Nylon cylinders with through hole	2
4.	Syringe	Commercial, 50ml	1
5.	PVC pipe	Schedule 40, Size: 1.5'', 1.5ft. long	1
6.	DC Gear Motor	12V, 300RPM, Stalling: 15Nm, 10A	1

In this project, a DC motor is used to spin the bolt and thereby let the hex nut reciprocate in axial direction. The nut is connected to a nylon bush having a drilled hole of size 10mm to allow spinning of bolt without any hindrance. The bush in turn transfers the reciprocating motion to the piston of the syringe which is fixed in the pipe using another nylon bush and eventually pushing the sealant out of the nozzle. To avoid nut spinning with the bolt, the nylon bush is fitted in the pipe such that it offers frictional resistance with the internal surface of PVC pipe enough to avoid the rotation of nut.

The speed of DC motor is controlled via joystick and motor control module incorporated in the control system of device. Entire Assembly of the sealing mechanism is fixed in a PVC pipe and the pipe is attached with the ROV.
The sealant is offered in two colors by the manufacturer and both are used in this project. The syringe will be filled with majority of one color (black) and a small quantity of white such that when the white sealant is seen to be

applied on the liner, the operator should refill the syringe for further job.

3.1 Calculation of Loads to be pushed

1. Water pressure acting on sealant from nozzle opening:
    - At operational depth of 5m, water column plus air column pressure acting on sealant is 0.1522Mpa.
    - Nozzle Diameter: 3mm.
    - Pressure Force = $P_{(Water+Air)}$×Area of nozzle opening = 1.075N.
2. Weight of sealant acts vertically downward thus neglected since sealing mechanism is placed horizontally in the pipe.
3. Boundary layer resistance to flow of sealant offered by syringe body is neglected as flow is considered laminar for the given input velocity of piston travel.

Total Load (W) to be pushed = 1.075N

3.2 Torque requirement – Pushing Load

Using ISO metric thread having thread angle 2θ=60°,
M8*1.25 bolt having single start, pitch = lead (L) = 1.25mm
Nominal Diameter of bolt (d) = 7.78mm
Core Diameter of bolt (d_c) = 7.2mm
Mean Diameter of bolt (d_m) = (d+d_c)/2=7.5mm
Coefficient of Friction between threads (μ) = 0.15
Torque Required (T_p) is calculated [8]
T_p = 1.45N-mm

Max. Torque provided by motor = 15kg-cm = 1471N-mm
Therefore, the motor is sufficient to push the load against all resistances offered by system as well as surroundings.

The high friction between metric threads is the reason why they are not used for power screws for efficiency concerns but in this application the high friction offers an advantage of self-locking of nut and also cost effectiveness of overall design.

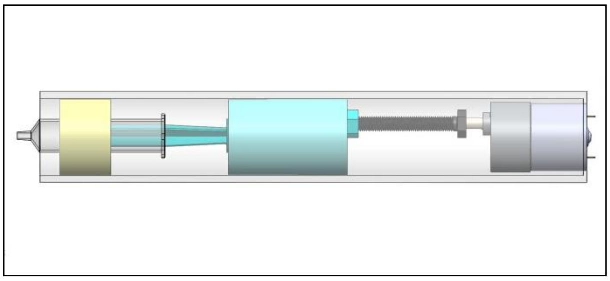

Fig -4: CAD of Sealing Mechanism

4. CONTROL SYSTEM

Electronic components for establishing control over the device were chosen by considering low-cost approach and functionality required at this level of project. Open loop type of control system is established where operator with a remote controller and display unit will control the device underwater. The movement of ROV and actuation of sealing mechanism is achieved via DC motors. Microcontroller coupled with motor control modules and radio communication module is fitted inside the ROV and powered using rechargeable Lithium-Ion batteries.

4.1 Radio Communication

High frequency Radio waves cannot directly penetrate the water from ground and to generate low frequency waves, expensive transducers are required thus the wireless communication is omitted. A coaxial cable is used to transmit radio waves of frequency 2.4GHz generated by NRF24L01+PA+LNA radio module. Two radio modules are required for transmitting and receiving the control signals and both are connected with the cable using SMA (Sub-Miniature type-A) connectors.

4.2 Transmitter Side

The operator has a remote controller having 2-channel joysticks for controlling forward/reverse, immersion/hovering, steering motion control of the ROV. Arduino UNO microcontroller receives the analog input from joysticks and sends this data to Receiver microcontroller via RC for which one NRF module is coupled with the Arduino UNO.

4.3 Receiver Side

Electronic components like microcontroller, motor controllers, NRF module and batteries are mounted on a plate and the plate is inserted in the main hull of the ROV. Further the modules are connected with actuators for getting movement.

Arduino Mega 2560 is used for receiver side since it offers more memory and PWM pins than Arduino UNO. The radio signal sent by operator is received by the NRF module coupled with Arduino Mega which then converts the analog input to digital PWM (Pulse Width Modulation) output for DC motors as well as Servo motor.

4.3 Actuators & Power Supply

Brushed DC motors (qty. 3), speed up to 7500 rpm with operating range (6-12V) out of which one for propulsion and two for immersion/hovering motion control are used. A 12V DC Gear motor is used for sealing mechanism for high torque and low speed requirements. A servo motor is used to control the rudders for steering the ROV.

L298N dual H-bridge motor controller is used for controlling the speed and direction of motors with PWM signals. One module controls 2 motors at a time thus two motor controllers are coupled with microcontroller at the receiver.

18650 Li-ion batteries with 2500mAh capacity each (Qty.4) are used to supply maximum of 14.8V to all the components except Microcontroller which is powered by a 9V battery separately at the receiver side. Considering the fully charged condition of battery and 2C discharge rate [9], 20mins of continuous operation is expected to be achieved without any disturbances related to power supply. Also this time will be the indicator for the operator to take the device out for recharging the batteries.

4.4 Data Telemetry

Scanning the liner and performing the sealing job on the scratches/holes once detected is live fed to the operator on ground as human intervention is needed to detect the damage as well as control the device while repairing it.

A simple Webcam – model: Zebronics Zeb-Ultimate Pro [10] - is fitted in the dome of the ROV and positioned to get a view of nozzle and liner surface. This Webcam offers a 5P lens with 1080P video resolution at 30fps frame rate which is adequate for this project. The webcam is connected to a laptop/Smartphone of the operator via a 10m USB cable.

5. IMPACT ANALYSIS OF THE VEHICLE

The front impact analysis was performed to determine the impact on the vehicle travelling with a velocity of 1.5 m/s and having a collision with the wall of the pond. The figures of the analysis are given below (figure 5 and figure 6). Figure 5 shows the total deformation on the vehicle after the impact.

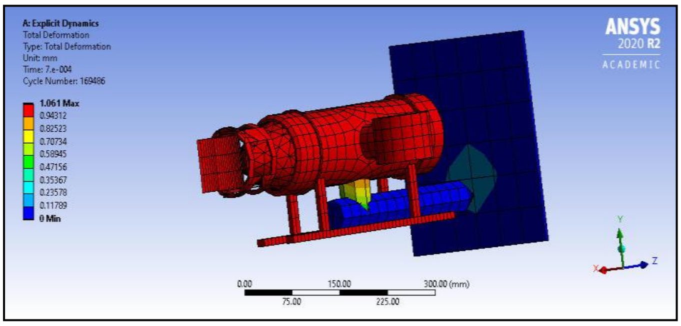

Fig -5: Front Impact Analysis of the Vehicle

It was concluded from the analysis that the main part prone to deformation after the front impact is mid pipe which connects the sealing mechanism to the carrier vehicle. If it gets deformed there is a possibility that the connection might get lost. But the value of the deformation obtained was negligible and there was no other significant deformation in the vehicle.

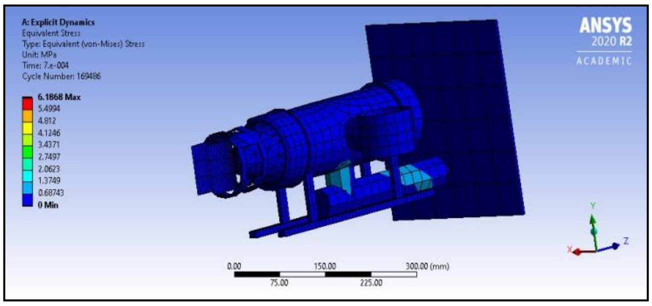

Fig -6: Von Misses Stress Induced on the Vehicle

6. CONCLUSION

The design, development and controlling of the prototype of the machine which is planned to be used for underwater repairing of pond liner was successfully carried out. The first phase of the project involved the design of the carrier vehicle, along with its mathematical modelling. The calculations for the structural sustainability of the vehicle were done, and the immersive and propulsive forces were determined. In the second phase, the sealing mechanism was developed and the calculations for load and torque were carried out. The control system of the vehicle was also developed while keeping in mind the cost limitations. Lastly, the front impact analysis of the vehicle for a velocity of 1.5 m/s was done. It was observe that the vehicle was completely safe with minor deformation.

Thus, a simple and compact system was designed and developed for the underwater repairing of pond liner. This system is cost effective, safe and needs less number of labors as compared to the methods followed till date for the repairing purpose.

REFERENCES

[1] Bharat Kungwani and Noopoor Misal, "Design and Fabrication of A Low Cost Submersible ROV for Survey of Lakes", International Research Journal of Engineering and Technology, vol. 04, issue. Sept. 09, 2017.

[2] Gabriel Martos, Ashley Abreu and Sahivy Gonzalez, "Remotely operated underwater vehicle (ROV)," B. S. Thesis, Florida International University, Sept. 21, 2013.

[3] Oscar Adrian Aguirre-castro, EverardoInzunza-Gonzalez, Enrique Efren Garcia-Guerrero, Esteban Tlela-Cuautle, Oscar Roberto Lopez-Bonilla, Jesus EverardoOlguin-Tiznado and Jose Ricardo Cardenas-Valdez, "Design and construction of an ROV for underwater exploration," Sensors, Dec. 06, 2019.

[4] Avilash Sahoo, Santosha K. Dwivedy and P. S. Robi, 2017. "Design of a Compact ROV for River Exploration," In Proceedings of the Advances in Robotics (AIR '17). Association for Computing Machinery, New York, NY, USA, Article 30, 1–6.DOI:https://doi.org/10.1145/3132446.3134894.

[5] Nigel Jones, "Top 10 Benefits of PVC Pipes", *Australian Vinyls*, January 30, 2015. Citing internet sources URL http://www.thinkpipesthinkpvc.com.au/about-us/late [Accessed Sept. 5, 2020].

[6] J. D. Stachiw, "Acrylic plastic as the structural material for underwater vehicles," Proceedings of the 2004 International Symposium on Underwater Technology (IEEE Cat. No.04EX869), Taipei, Taiwan, 2004, pp. 289-296, doi: 10.1109/UT.2004.1405581.

[7] Hutton Aquatic Products Gold Label Pond Sealer. Citing internet sources URL https://www.swelluk.com/hutton-aquatic-products-gold-label-pond-sealer

[8] V. B. Bhandari, "Design of Machine Elements" (2010), Tata McGraw-Hill Publishing, Ed 3, Pages 189-190, 192-193.

[9] Power-sonic, "What is a battery C rating," Power-sonic, Para. 4. Citing internet sources URL https://www.power-sonic.com/blog/what-is-a-battery-c-rating

[10] Zeb Ultimate Pro. Citing internet sources URL https://zebronics.com/products/zeb-ultimate-pro