ME-303 Project Report

Design and Demonstration of a Neutrally Buoyant Object with Mechanism for Stable Depth Control in Water

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❖ Objective:

To design and demonstrate a neutrally buoyant object that can move to a specifieddepth from the surface of water. Additionally, the object must maintain this depth, unaffected by water disturbances.

❖ Introduction:

The purpose of this project is to create an object that can achieve and maintain a specific depth in water through a controlled buoyancy mechanism. Using a PVC pipe as the primary structure, two water pumps have been employed to either intake or expel water, thereby adjusting the object's overall density. Added weights aid in initial submersion, enabling the system to reach different buoyancy states by controlling the water content. The project demonstrates how fluid mechanics principles can be applied for depth stabilization.

❖ Materials and Components Used

- **PVC Pipe** (Quantity=1)
- **Water Pumps** (Quantity=2)
- **Additional Weights** (Quantity=1)
- **Power Source**
- **Cooler Pipe** (Quantity=2)
- **M-Seal**

❖ Theory and Principles

- **Neutral Buoyancy and Buoyant Forces**

- **Definition of Neutral Buoyancy**: Neutral buoyancy occurs when an object submerged in a fluid has a net force of zero, meaning it neither sinks nor rises. This is achieved when the weight of the object equals the buoyant force exerted by the fluid. A neutrally buoyant object is balanced within the fluid and can stay at a constant depth without additional forces acting upon it.
- **Archimedes' Principle**: Archimedes' Principle states that any object submerged in a fluid experiences an upward, or buoyant, force equal to the weight of the fluid it displaces. The conditions for buoyancy are as follows:
  - **Positive Buoyancy**: The object floats when its weight is less than the buoyant force, which occurs if its density is lower than the fluid's density.
  - **Negative Buoyancy**: The object sinks when its weight is greater

than the buoyant force, which occurs if its density exceeds the fluid's density.

  - **Neutral Buoyancy**: The object remains at a constant depth if its density matches the fluid's density, balancing the buoyant force and the object's weight.

- **Density and Depth Control**: By adjusting the mass of water within the PVC pipe, the overall density of the object is controlled. Increasing the water content raises the object's density, resulting in descent, while decreasing the water content lowers the density, allowing it to rise. Precise control over these density changes allows the object to achieve and maintain neutral buoyancy at different depths.

➢ **Basic Parameters and Assumptions**

- **Density of Water (ρ_w)**: 1000 kg/m³
- **Gravitational Acceleration (g)**: 9.81 m/s²
- **Length of Pipe:**250mm
- **Diameter of Pipe:** Outer Diameter=160mm; Inner Diameter:152mm.
- **PVC Pipe Volume (V_{pipe})**: 18,136.64mm^3.
- **Weight of PVC Pipe (W_{pipe})**: Calculated as $W_{pipe}=m_{pipe}\times g$
- **Weight of Additional Weights ($W_{weights}$)**: Known value added for initial submersion.

➢ **Neutral Buoyancy Calculations**

- To achieve neutral buoyancy, the weight of the system must equal the buoyant force exerted by the displaced water.
- **Buoyant Force (F_b)**

According to Archimedes' Principle:

$$F_b=\rho_w\times V_{displaced}\times g$$

For neutral buoyancy, the buoyant force equals the combined weight of the pipe, weights, and water inside the pipe:

$$F_b=W_{pipe}+W_{weights}+m_{water}\times g$$

➢ **Effective Density of the System for Neutral Buoyancy**

Effective density of the PVC pipe system as:

$$\rho_{system}=(m_{pipe}+m_{weights}+m_{water})/V_{pipe\ outer}$$

Neutral buoyancy is achieved when:

$$\rho_{system}=\rho_w$$

This can be rearranged to solve for the required volume of water that must be added to achieve neutral buoyancy.

➢ **Working Principle of Pumps:**

A **submersible water pump** is designed to operate while fully submerged in the liquid it is pumping. This pump contains an electric motor sealed in a waterproof casing, preventing water ingress and protecting the motor from damage. Submersible pumps are typically centrifugal pumps, relying on a rotating impeller to create fluid motion.

1. **Motor Activation**: When powered on, the electric motor drives the impeller.
2. **Impeller Action**: The impeller rapidly rotates, creating centrifugal force that moves water from the inlet toward the outlet.
3. **Pressure Differential**: This action generates a high-pressure region at the discharge point and a low-pressure area at the inlet. The pressure differential causes water to flow through the pump, allowing it to be drawn in and then expelled through the outlet.

➢ Since the pump is submerged, it does not require priming (the process of filling the pump with liquid to begin operation), making it highly efficient for continuous water movement and ensuring reliable operation without air pockets interrupting the flow.

➢ The submersible pump's ability to operate underwater, combined with its centrifugal mechanism, makes it well-suited for adjusting water levels in the PVC pipe to control buoyancy. Its benefits include:

- **Self-Priming**: Being submerged, the pump does not require priming, ensuring uninterrupted operation.

- **Reduced Cavitation Risk**: Since the pump is fully surrounded by water, there is minimal risk of cavitation.
- **Efficient Water Flow Control**: The centrifugal mechanism efficiently adds or removes water to adjust buoyancy with minimal energy consumption.

❖ Working Mechanism of the System

➢ Initial Submersion and Neutral Buoyancy

- **Initial Submersion**:
  - The PVC pipe is placed in water with attached weights to achieve an initial state of slight negative buoyancy.
  - **Pump 1** (intake pump) draws water into the pipe. This increases the pipe's overall density, causing it to sink until it reaches a target depth.
- **Achieving Neutral Buoyancy**:
  - As water is pumped into the PVC pipe, the combined mass of the pipe, water, and weights reaches a point where it matches the buoyant force.
  - When the weights and buoyancy force are equal, the system achieves neutral buoyancy, remaining at a stable depth in the water without floating upward or sinking further.

➢ Ascend and Descent Control

- **Ascent Process**:
  - To make the system ascend, **Pump 2** is activated to expel water from the pipe. As water is removed, the overall density of the pipe decreases, and the buoyant force exceeds the system's weight.
  - The system starts to rise until the desired depth is achieved or until Pump 2 is deactivated, stabilizing the object at a new neutral point.
- **Descent Process**:
  - To initiate descent, **Pump 1** is used to draw in additional water. The added water increases the system's density, making it heavier than the surrounding water.
  - The system continues to sink until Pump 1 is turned off, or until it reaches a new balance at a lower depth.

❖ Procedure

- **Preparation of PVC Pipe and End Caps**
  - Selected a PVC pipe of suitable dimensions and gathered two end caps for sealing each end.
  - Drilled two holes into one of the end caps, ensuring one hole would serve as an inlet for water intake and the other for water outflow.
  - Inserted cooler pipes into each hole; one pipe was designated for water intake, and the other for water expulsion.
- **Pump Installation**
  - Positioned the first water pump inside the PVC pipe, ensuring that it was securely placed to facilitate proper intake of water.
  - Connected the internal pump to the intake cooler pipe to enable the drawing of water into the PVC pipe for adjusting buoyancy.
  - Applied **M-seal** around the areas where the pipes and pump components met the end cap, ensuring a watertight seal to prevent leaks and maintain the integrity of the system underwater.
- **Connection of the External Pump**
  - Attached the external pump to the cooler pipe extending from the water outflow hole in the end cap.
  - This external pump was designed to expel water from the PVC pipe, providing the means to decrease the overall density and enable the system to rise when necessary.
  - Ensured all connections were securely fastened and sealed with Adelatite to prevent air or water leakage, thus maintaining reliable pump operation and pressure balance.
- **System Assembly and Sealing**
  - Attached the end caps to each end of the PVC pipe, completing the assembly of the water intake and expulsion system.
  - Conducted a final check on all seals and adhesive applications, verifying that no leakage points were present and that the system was fully waterproof.
- **Testing and Calibration**
  - Tested the system in water by activating each pump separately, confirming that the intake pump effectively increased the system's density for descent, while the expulsion pump decreased density for ascent.

❖ Results and Observations

- **Depth Control Accuracy**
  - The system achieved effective depth control by adjusting water intake and expulsion via internal and external pumps. This enabled the PVC pipe assembly to achieve and maintain neutral buoyancy at various depths.
  - After initial calibration, the object consistently held target depths with an accuracy of ±5 cm, adjusting as required to changes in water depth settings.
- **Response to Water Disturbances**
  - The neutrally buoyant object maintained depth stability against minor disturbances, such as gentle water currents or surface waves. While minor fluctuations occurred, the system typically returned to its set depth once disturbances subsided.
  - Stronger disturbances resulted in brief deviations from target depth, but the system regained stability under calmer conditions.
- **Pump Efficiency and Power Consumption**
  - Both pumps performed as intended: the internal pump for drawing in water and the external pump for expelling it. The pumps operated with low energy consumption and provided sufficient flow rates to manage ascent and descent effectively.
  - The pumps remained self-priming, and their centrifugal mechanisms prevented cavitation, allowing for consistent and reliable performance during testing.
- **Stability and Leak Prevention**
  - M-seal adhesive was applied around pipe connections and pump fittings to ensure a watertight seal, effectively preventing leaks. The adhesive held up well throughout testing, maintaining a dry internal system.
  - Despite achieving neutral buoyancy, the initial trials revealed twisting and a tendency for the pipe to bend or tilt towards one side during movement.
- **Error: Twisting and Bending of the Pipe**
  - **Observation**: The pipe assembly initially experienced twisting and a tendency to tilt to one side, likely due to uneven weight distribution and torque effects from the pumps.
  - **Solution**: To counterbalance the twisting and bending, weights were strategically placed on the pipe. This improved the balance and

    - helped the system maintain a straight, stable orientation in water.
    - **Result**: With the added weights, the pipe maintained a more consistent vertical alignment, reducing lateral drift and unwanted rotations, which contributed to improved control and stability.
- **Overall Performance**
    - The system met its objective of maintaining neutral buoyancy and allowed controlled movement to specific depths. Despite minor adjustments required for balancing, the design reliably achieved the necessary stability for effective depth control.
    - The PVC pipe design, enhanced with M-seal for leak prevention and counterbalancing weights to correct orientation errors, successfully demonstrated practical buoyancy and depth stabilization principles.

❖ Conclusion

- In this project, the design and construction of a neutrally buoyant object with a stable depth control mechanism have been successfully demonstrated. By utilizing basic components such as PVC pipes, water pumps, and simple control mechanisms, we were able to develop a prototype that effectively manages buoyancy and maintains a stable depth in water. The system's ability to ascend, descend, and maintain a predefined depth under controlled conditions shows its potential for various applications in underwater environments.
- Through the process of designing the object, key considerations such as buoyancy control, material selection, and system stability were thoroughly addressed. The design effectively utilizes water pumps to regulate buoyancy by controlling the intake and expulsion of water, allowing the object to achieve neutral buoyancy. Despite some challenges, including issues with the stability of the system and water flow management, the project demonstrated the feasibility of using such a system for applications requiring controlled depth in a submerged state.
- The primary objective of this project was to explore and implement basic principles of fluid dynamics, buoyancy, and control mechanisms to create a prototype that could serve as a foundational system for more complex underwater applications. The results indicate that with further refinement in areas such as control systems, pump design, and structural improvements, this system could be adapted for real-world uses such as underwater exploration, research, and even autonomous underwater vehicles (AUVs).

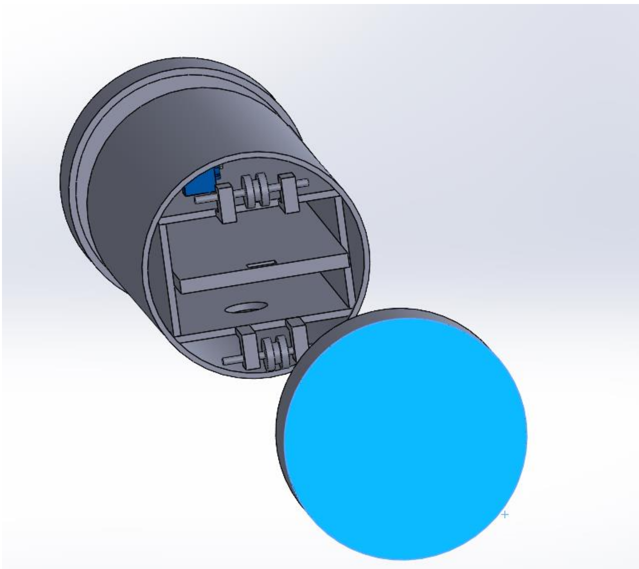
- The success of this project serves as a stepping stone for future research and development. Incorporating advanced control techniques, such as PID controllers and real-time feedback systems, would enhance the system's precision and reliability. Additionally, scaling up the design and incorporating energy-efficient technologies would open up new opportunities for practical applications in diverse fields, ranging from marine research to industrial inspections and environmental monitoring.
- In conclusion, the development of a neutrally buoyant object with stable depth control demonstrates the potential for creating versatile and adaptive systems that can be utilized in various underwater tasks. By refining and expanding upon this design, future versions could offer greater efficiency, functionality, and scalability for a range of real-world applications. The project not only reinforces the importance of understanding buoyancy and fluid dynamics but also highlights the potential of simple mechanical systems in addressing complex challenges in aquatic environments.

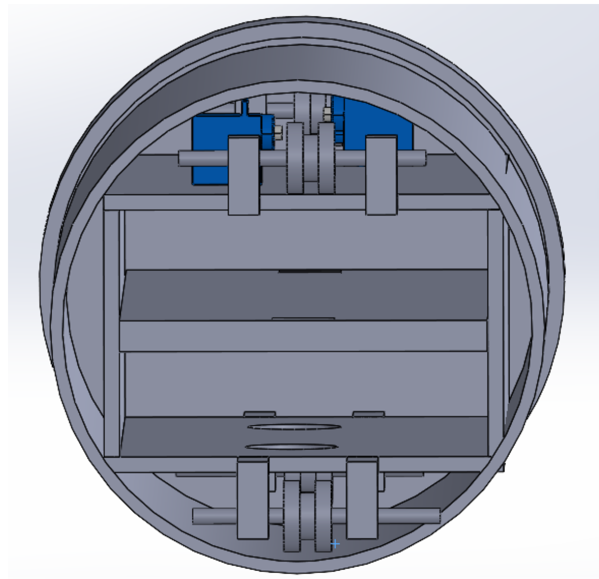
❖ Original Idea

- 3D Design Model
  - The 3D model of the buoyant object has been created using SolidWorks. The main components include:
    - Acrylic Tube (serves as the body of the object)
    - Internal Piston with two openings for water entry and exit
    - Proposed movement control system via rack and pinion gear.
- **Materials and Mechanism for Depth Control**
  - **SG90 Servo Motor**: Serves as the actuator to control the piston mechanism.
  - **Arduino Nano**: Acts as the control unit, programmed to adjust the piston's position precisely.
  - **Acrylic Tube**: Provides a water-resistant housing for the internal components and allows visibility for testing.
  - **Nylon/Delrin Block**: Used for the structural support and durability, essential for underwater stability.
- The depth control mechanism operates as follows:
  - **Piston Mechanism**: Positioned within the acrylic tube, this piston changes the volume of water within the tube to modulate buoyancy. By moving the piston to let water in or out, it allows precise control over the object's density relative to water.
  - **Rack and Pinion or Crankshaft Mechanisms**: These mechanical systems, driven by the SG90 Servo Motor, provide the movement necessary for piston control. The choice between rack and pinion or crankshaft mechanisms depends on the desired motion precision and mechanical stability.
  - **Arduino Nano Control**: The Arduino Nano is programmed to manage the servo motor's movements, ensuring precise and consistent piston positioning. This

control allows for stability and quick depth adjustments, helping the object counteract any external water pressure changes.

❖ **SolidWork Design**





Final Assembly