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A Simulation-Based Approach To Spiral Pump Design

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Abstract

The consistent availability of irrigation water in agricultural areas remains a challenge to this day, due to the fact that rivers are always located at a lower elevation than farmland. As an alternative solution, a spiral pump has been introduced that operates solely using the kinetic energy of river water flow, unlike conventional water pumps that always require electricity or fossil fuels. This study aims to develop a simulation-based spiral pump design by integrating findings from previous analyses regarding fluid flow behavior and water wheel performance. Accordingly, using SolidWorks software, a comprehensive geometric model of the spiral pump was created, consisting of a 1.2-meter-diameter undershot water wheel, an eight-coil spiral hose with a 2-inch diameter, and a support frame. Through static structural simulation, it was also determined that a hydraulic force of 72.63 N and a torque of 32.68 Nm act on the water wheel, with the shaft withstanding a force of 174.06 N. The von Mises stress on the shaft is 3.746×10^6 N/m², while on the blades it is 1.711×10^7 N/m²; these stress values are well below the yield strength of A36 steel for the shaft and aluminum alloy for the blades. Thus, based on CFD-based flow rate analysis, hydraulic head evaluation, and structural validation, this study has produced an integrated design that ensures operational efficiency and structural safety. This spiral pump design can be developed into a prototype for field application as a cost-effective renewable energy solution.

Keywords: Spiral Pump, Renewable Energy, Water Wheel, Water Supply, Simulation And Design

1 Introduction

Water has a significant impact on agricultural productivity. This is particularly evident in rural areas that rely heavily on river water for irrigation. The situation is further complicated by the fact that rivers are generally located in low-lying areas and are often quite far from farmland. Under such conditions, farmers use mechanical pumps powered by electricity or fossil fuels. However, the operational costs are often prohibitively high, leading to significantly increased production costs [1].

Spiral pumps, as a renewable energy technology, can provide a solution to irrigation system issues on agricultural land. First introduced by H. A. Wirtz in 1746, the spiral pump is a water pumping technology that operates without an external power source. Rediscovered and refined by Peter Morgan, the spiral pump harnesses the kinetic energy of flowing water to lift water from a water source to agricultural fields, making it particularly well-suited for agricultural environments in remote areas [2]. Spiral pumps feature a simple mechanism, low maintenance requirements, and high reliability, making them an effective solution for irrigation in rural areas.

The performance of a spiral pump depends heavily on two main components: the impeller and the spiral hose. Previous research has shown that impeller parameters such as diameter, blade angle, and flow velocity directly influence the mechanical power transmitted to the spiral pump [1][3]. On the other hand, the fluid flow velocity within the hose largely determines the discharge rate and head that can be achieved, as verified through computational fluid dynamics (CFD) simulations [4][5]. These fundamental principles form the basis of a multi-year research project conducted from 2023 to 2025.

In the 2023 study, CFD simulations identified the relationship between hose diameter and flow performance. Furthermore, the 2024 study analyzed the power characteristics and head of an undershot-type water wheel based on flow velocities measured in the field. Based on these findings, the 2025 study focused on the design of a comprehensive spiral pump system using CAD modeling and structural simulation. This design integrates validated parameters from the previous two years to produce a safe, manufacturable pump prototype suitable for agricultural applications.

2 Theoretical Background

The wetted cross-sectional area represents the portion of the blade or paddle surface of the water wheel that is directly exposed to or immersed in the flowing water [6][7]. For d as the water depth on the wheel and w as the width of the wheel, the wetted cross-sectional area (A) can be calculated using the following equation.

$$A = d.w \tag{1}$$

On the water wheel, a force is generated due to the impact of flowing water [7][8]. For a water velocity V, wetted cross-sectional area A, and fluid density ρ, the resulting force Facting on the water wheel can be calculated using the following equation.

$$F = ½\, \rho\, A\, V^2 \tag{2}$$

Subsequently, a torque is generated on the shaft as a result of this force [9]. For the resulting force $F$and the water wheel radius r, the torque Tcan be calculated using the following equation

$$T = F.r \tag{3}$$

The output power of a spiral pump refers to the amount of mechanical or hydraulic power delivered by the pump as it transfers water from a lower elevation to a higher one [10][11]. The power generated is also directly proportional to the density (ρ), gravitational acceleration (g), water discharge (Q), and pump head (H), which can be formulated as follows.

$$P_{out} = \rho.\ g.\ Q.\ H \tag{4}$$

3 Method

The design process begins with integrating CFD-based discharge outputs and hydraulic head analysis from the previous researches. SolidWorks software was used to create precise parametric models of all components, thereby ensuring dimensional accuracy for the subsequent fabrication process. The structural simulations in this study included mesh generation, determination of loading conditions, stress analysis, and deformation evaluation based on the properties of A36 steel and aluminum alloys. The boundary conditions in this study include hydraulic forces, torsional loads, the effects of gravity, and structural constraints. Thus, a comprehensive approach has been taken to ensure the manufacturability and reliability of the spiral pump design.

4 Application and Results

4.1 Integration of Previous Findings

The key performance parameters of the spiral pump were derived from the results of previous studies. Computational analyses from prior research on fluid flow within the spiral hose indicated that the optimal hose diameter is 2 inches to achieve a maximum flow rate of 0.00183 m^3/s. Furthermore, based on a previous evaluation of the waterwheel's performance, it was found that the spiral pump system can operate effectively up to a height of 5 meters, which generally meets the needs of small-scale agricultural irrigation. Ultimately, based on these two findings, the dimensional and mechanical parameters for developing a suitable spiral pump design have been determined.

4.2 Structural Simulation Results

To ensure the mechanical reliability of the spiral pump system under operational loads, a structural simulation was conducted. The loads acting on the system consist of a thrust force of 72.63 N acting on the impeller blades, which results in a torque of 32.68 Nm transmitted to the impeller shaft. In addition, the shaft also bears a gravitational load from other components of 174.06 N. Simulation results show that the von Mises stress on the shaft is 3.746×10^6 N/m², a value well below the yield strength of A36 steel, which is 6.204×10^8 N/m². On the other hand, the von Mises stress on the water turbine blades is 1.711×10^7 N/m², which is also below the yield strength of the aluminum alloy material. Fig. 1 displays the distribution of von Mises stress occurring on the shaft. This indicates that the stress levels remain below the material's failure limit. Thus, these results confirm a safe design for the spiral pump.

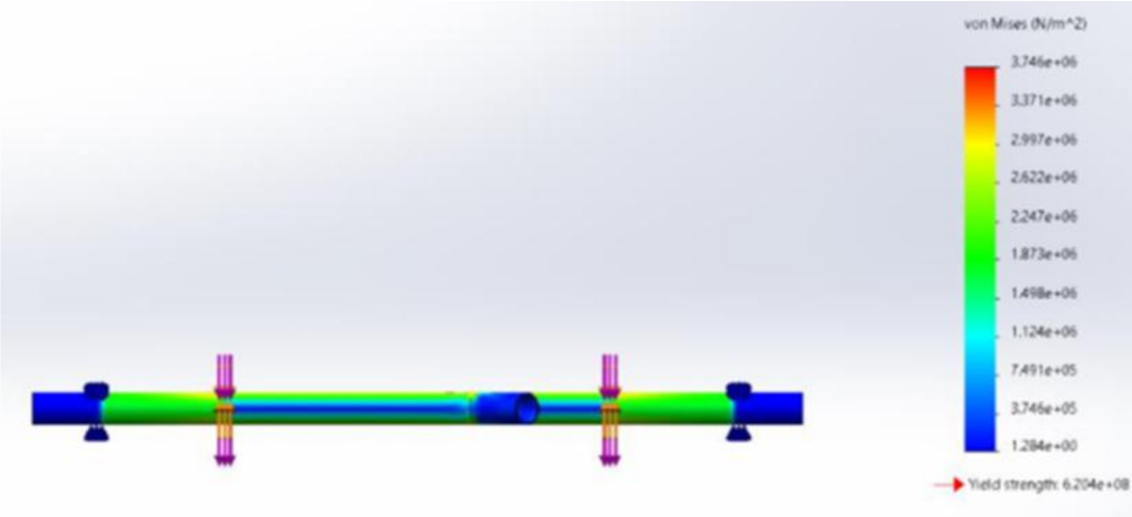

Figure 1. Results of the shaft stress simulation

4.3 Overall Integration

In this study, a CAD model was developed consisting of a water wheel with a diameter of 1.2 meters and a width of 0.6 meters, along with an optimal configuration of a 2-inch-diameter spiral hose with eight coils. The shaft was designed with an outer diameter of 50.8 mm and is made of ASTM A36 steel. The wall thickness and shaft length are 8 mm and 1200 mm, respectively, to ensure adequate stiffness and strength. On the other hand, an aluminum alloy is used for the water impeller blades, with lengths, widths, and thicknesses of 60 mm, 30 mm, and 1.5 mm, respectively, ensuring structural durability and reducing polar inertia. Fig. 2 shows the spiral pump with its complete geometric design, including key dimensions and component configurations, which will serve as the basis for structural evaluation.

The combination of the results of the previous analyses and the structural evaluation has formed an integrated design framework based on simulation. Based on the flow analysis, the appropriate pipe size has been determined; based on the hydraulic performance analysis, the achievable head can be estimated; and based on the structural simulation, the mechanical safety and overall design durability of the spiral pump can be confirmed. Ultimately, this spiral pump design is viable and ready to proceed to prototype fabrication and further testing.

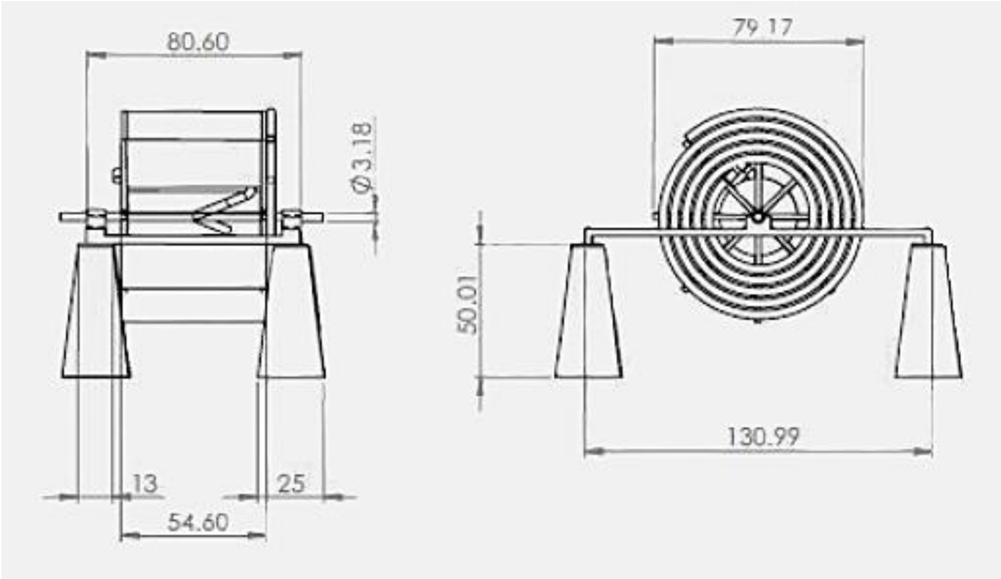

Figure 2. The spiral pump design

5 Conclusions

The success of the spiral pump design in this study was achieved thanks to insights gained from previous research phases. Furthermore, the structural simulations conducted in this study have confirmed that the shaft, impeller, and other critical components are within safe strength limits when subjected to the anticipated loads. Therefore, the finalized spiral pump design is structurally robust, functionally feasible, and ready for prototype fabrication and subsequent field testing.

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