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Guide vanes erosion and corrosion assessment: A comparative study of existing and manufactured guide vanes for improving energy generation

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Abstract:
Hydropower remains a vital renewable energy source, yet turbine performance (consequently energy generation) which is an underwater component, is severely affected by erosion-corrosion of guide vanes. This study investigates alternative materials to improve the longevity and efficiency of hydro turbines. The guide vanes at Waya Dam suffer from severe erosion-corrosion due to high sediment loads and water chemistry, leading to reduced efficiency and high maintenance costs. Identifying durable materials is essential to extend service life and optimize hydropower output. This study develops an improve guide vane and compares its erosion-corrosion resistance with that of the existing guide vane. The study also involved determining the hardness. The corrosion rate was measured using sediment-laden water. Two materials (stainless steel and cast zinc alloy) were tested for suitability. Stainless steel exhibited the highest hardness (214.58 HV) and the lowest corrosion rate (0.0004 mm/year), making it the most resistant to degradation. The existing guide vanes had significant wear and the highest corrosion rate (0.010966 mm/year). Casted zinc alloy showed moderate performance, being more resistant than the existing material but less durable than stainless steel. Stainless steel is the most suitable replacement for guide vanes in reaction turbines due to its superior resistance to erosion-corrosion. The findings support improved material selection for hydropower turbines, leading to increased efficiency, lower maintenance costs, and sustainable energy generation.

Keywords: *Corrosion, Energy generation, Erosion, Guide vane, Performance, Reaction turbine*

1. Introduction

Hydropower contributes significantly to global electricity generation. The performance of hydro turbines directly impacts the reliability and efficiency of power production. However, material degradation due to erosion-corrosion remains a major challenge cause by contaminant in the water reservoir [1, 2]. Guide vanes are critical components of hydro power plants, directing water flow onto the turbine runner to optimize energy conversion efficiency [3]. The guide vanes play a crucial role in regulating the flow of water to the turbine runner, thereby affecting the overall performance of the hydro power plant. However, these components are susceptible to both corrosion and erosion, which can significantly impact the plant's performance and longevity [4, 5, 6]. Corrosion and erosion are significant concerns for hydro power plants, particularly for components such as guide vanes and runner blades [5, 6]. Sediment erosion and corrosion can lead to significant damage to guide vanes and other components, reducing the efficiency and lifespan of the hydro power plant [4].

Corrosion on guide vane include electrochemical, pitting and crevice corrosion which can occur due to exposure to water with dissolved oxygen, salts, and other corrosive agents. This causes surface roughening, material loss, weakening of structural integrity, and increased risk of fatigue failure under cyclic loads. These consequently affect the overall energy generation efficiency of the power plant [7]. Erosion on guide vane includes abrasive and cavitation erosion which can occur due to high-velocity water flow with suspended particles and turbulence. These causes material removal, surface roughening, increased friction losses, and reduced hydraulic efficiency [8 - 11].

Importance of corrosion and erosion resistance includes extended lifespan, improved efficiency and reduced downtime. Enhancing corrosion and erosion resistance reduces maintenance costs and extends the lifespan of guide vanes as reported by Kumar and kumar [12]. Smooth surfaces and reduced wear ensure optimal water flow, increasing turbine efficiency [13]. Resistant materials minimize the risk of failure, reducing downtime and associated costs [14, 15]. Among the most promising materials is stainless steel and the viable alternative is the cast zinc alloy. Stainless steel's chromium content provides excellent corrosion resistance in water environments [16]. Also stainless steel's high strength-to-weight ratio ensures durability and resistance to erosion [17]. Cast zinc alloys exhibit excellent corrosion resistance, particularly in water environments [18] and its high hardness and strength provide effective erosion resistance [19]. Therefore, new material provides benefits to the efficiency of the system. The most important benefits of new materials as reported by Kumar and kumar [12], Bhave, et al., [13], Singh and Singhal [14], Singh and Singh [15] and ASTM International [16] include ensuring reliable operation and reduced maintenance, increasing turbine efficiency and performance and reduced maintenance and replacement costs leading to significant cost savings respectively.

In Nigeria, hydroelectric dams, including Waya Dam, experience high sediment loads, leading to frequent maintenance issues [20]. Selecting durable materials for guide vanes is crucial for improving turbine performance and reducing operational costs. Improving the quality of hydro turbine guide vanes is crucial for enhancing the efficiency, reliability, and lifespan of hydroelectric power plants. One effective way to achieve this is by increasing the corrosion and erosion resistance of guide vanes using new materials such as stainless steel and cast zinc alloy. The existing guide vanes in Waya Dam turbines degrade rapidly due to erosion-corrosion, reducing turbine efficiency and increasing repair frequency. To enhance turbine longevity and operational efficiency, a more resilient material must be identified. This study aims to evaluate and compare the erosion-corrosion resistance of existing guide vanes, stainless steel, and cast zinc alloy to determine the most suitable replacement material for reaction turbines.

2. Methodology

2.1 Materials and equipment

The materials tested include existing guide vane material, stainless steel thick sheet and cast zinc alloy thick sheet. The equipment used include digital micro vickers hardness tester, spectromaxx metal analyser and corrtest electrochemical workstation.

2.2 Experimental Procedures

The experimental procedures involved corrosion testing, the samples were immersed in slightly acidic water with a pH of 5.125 and a total dissolved solids (TDS) concentration of 177.5 ppm to measure their corrosion rates under controlled conditions. Also, Vickers Hardness Test was conducted to evaluate the material's resistance to mechanical wear by applying a standardized load and measuring the indentation produced. These tests provided critical data for comparing the durability of the existing guide vane material, stainless steel, and cast zinc alloy.

2.3 Statistical and Modelling Tools

Data was analysed using Statistical Package for the Social Sciences (SPSS) to compare the performance of each material.

3. Results and Discussion

3.1 Erosion Resistance

Erosion resistance is a crucial factor in determining the durability of guide vanes in reaction turbines, as they are continuously subjected to high-velocity water flow and sediment impact. The hardness of a material plays a significant role in its ability to withstand erosion, as confirmed by the comparative analysis of the three tested materials as shown in Table 1.

Table 1: Hardness of the materials HV

Material	Hardness	Erosion Resistance
Existing Guide Vanes	136.125	Significant resistance to wear
Stainless Steel	214.58	High resistance to wear
Cast Zinc Alloy	90.7	Moderate resistance to wear

The existing guide vanes, with a hardness of 136.125 HV, exhibited significant wear, making them highly vulnerable to erosion-induced surface degradation, which can reduce turbine efficiency over time. This result aligns with the findings of Gautam, *et al*. [21, 22], who emphasized that lower hardness materials in hydro turbines experience rapid degradation due to sediment erosion. Similarly, Chitrakar, *et al*. [23] highlighted that erosion is more severe in materials with lower hardness when exposed to secondary flow and sediment impact. In contrast, stainless steel, with a hardness of 214.58 HV shown in table 1, demonstrated superior erosion resistance, attributed to its high hardness and enhanced mechanical wear properties. This observation is consistent with Chen, *et al*. [24], who found that stainless steel provides excellent protection against sediment erosion in hydro turbine guide vanes due to its ability to form a durable surface layer. Furthermore, Jia, *et al*. [25] confirmed through numerical simulations and experimental studies that materials with higher hardness values exhibit significantly lower sediment-induced wear, making stainless steel an optimal choice for environments where erosion is a major concern.

The cast zinc alloy, with a hardness of 90.7 HV, exhibited moderate wear, performing better than the existing guide vanes but not as well as stainless steel. While its slightly improved hardness provided some resistance, it remained insufficient to fully protect against erosive forces. This result aligns with Koirala, *et al*. [26, 27], who found that materials with moderate hardness values experience noticeable but slower erosion compared to softer alloys. Beraki [28] also reported that surface roughness and material hardness directly influence erosion rates, with smoother and harder materials showing greater resistance to sediment impact. Thus, the findings highlight that stainless steel is the most suitable material for minimizing erosion, enhancing the longevity and efficiency of guide vanes in sediment-rich turbine environments. The study further reinforces the importance of selecting high-hardness materials for erosion-prone applications to maximize performance and durability [29].

3.2 Corrosion Resistance

Corrosion resistance is a crucial factor in determining the longevity of guide vanes, particularly in hydro turbine environments where exposure to water with varying pH levels and dissolved solids accelerates material degradation. The corrosion rates of the materials are shown in Table 2.

Table 2: Corrosion rate for the materials

Material	Corrosion Rate (mm/year)
Existing Guide Vanes	0.010966
Stainless Steel	0.0004
Casted Zinc Alloy	0.00747

The study revealed that stainless steel exhibited the lowest corrosion rate (0.0004 mm/year) as shown in Table 2, primarily due to its chromium-induced passive layer, which forms a protective barrier against corrosive elements. This finding is consistent with Shah and Alam [30], who demonstrated that stainless steel alloys with high chromium content significantly reduce corrosion rates in hydro turbine applications. Similarly, Kirtay [31] found that protective oxide layers in stainless steel play a vital role in preventing corrosive attacks, making it a durable choice for water-exposed components.

In comparison, the cast zinc alloy recorded a moderate corrosion rate of 0.00747 mm/year, offering some resistance but still susceptible to gradual degradation over time. This aligns with the findings of Katiyar, *et al*. [32], who observed that zinc-based alloys provide moderate protection in aqueous environments but are prone to pitting and surface oxidation over extended exposure periods. Additionally, Maya-Visuet, *et al*. [33] reported that zinc-based coatings enhance corrosion resistance, though they may not be as effective as stainless steel in aggressive water conditions. The existing guide vanes, with a corrosion rate of 0.010966 mm/year, experienced significant material loss, confirming their vulnerability to corrosion and the urgent need for replacement. These results are supported by Nasir [34], who highlighted that turbine components made from lower-grade alloys deteriorate rapidly in hydropower systems due to continuous exposure to waterborne contaminants. Similarly, Omer [35] noted that total dissolved solids (TDS) and water acidity contribute to increased corrosion rates, further emphasizing the importance of using corrosion-resistant materials. Overall, these findings underscore the necessity of selecting highly corrosion-resistant materials, such as stainless steel, to improve the durability and efficiency of guide vanes in reaction turbines. The study reinforces previous research by Chitrakar, *et al*. [23] and Neopane, *et al*. [29], which emphasized the importance of material selection in mitigating corrosion-related failures in hydro turbines.

4. Conclusion

The findings highlight the superior performance of stainless steel, which exhibited the highest resistance to both erosion and corrosion, making it the most suitable material for replacing the existing guide vanes. In contrast, the cast zinc alloy demonstrated moderate durability, performing better than the current material but falling short of stainless steel's longevity. The existing guide vane material, however, suffered from severe degradation, confirming its vulnerability to corrosive and erosive forces and reinforcing the urgent need for an upgrade.

Looking ahead, replacing guide vanes with stainless steel is expected to significantly enhance turbine efficiency and extend its lifespan, reducing maintenance costs and operational disruptions. Additionally, future research should explore advanced protective coatings and composite materials, which could further improve erosion and corrosion resistance, ensuring even greater performance and durability for hydro turbine components.

Recommendations

Adopt advanced protective coatings like hybrid silica sol–gel and polyurethane/polysiloxane hybrids to reduce erosion and corrosion. Optimize guide vane design and clearance gaps using CFD simulations to enhance turbine efficiency and minimize wear. Implement regular water quality monitoring and sediment management to prevent turbine degradation and improve longevity.

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