OPTIMIZING COUPLING SYSTEMS FOR EFFICIENT POWER TRANSMISSION AND NOISE REDUCTION IN AQUATIC ENVIRONMENTS

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ABSTRACT: This study evaluated a new coupling system for low rotation and minimal power transmission from an electric drive to a propeller in fish ponds, focusing on performance across various bend angles and rotational speeds while measuring noise generation. The methodology included using brass and polyethylene shafts tested with and without grease at rotational speeds up to 2200 RPM. Findings revealed that the bend angle significantly impacts performance, establishing a maximum operational angle of 25 degrees for effective power and rotation transmission, and that grease application results in a 2% noise reduction, underscoring lubrication's importance in enhancing system efficiency and reducing noise. Brass was found inadequate for high-load applications despite its noise reduction and corrosion resistance advantages, suggesting carbon steel with medium carbon content as a superior alternative, given its strength and wear resistance properties. The study emphasizes the need for further research to explore energy losses and environmental impacts to optimize transmission systems in aquatic environments. Future work should also focus on developing specialized design strategies that consider shaft diameter, support spacing, friction resistance, and temperature management for improved long-term performance and reliability.

KEY WORDS: Coupling, Bend angle (ϕ), Noise assessment, Power transmission, Shaft materials

1. INTRODUCTION

The background of this research emerges from field experiences gained during community service conducted last year [1][2], which highlighted the need for a drive shaft with one or more bends to power a propeller at the end of the shaft, thus facilitating water circulation in the pond. Existing drive shafts were inadequate, as they could not efficiently handle the necessary bends while maintaining performance, underscoring the importance of developing innovative solutions.

During that time, the flexible shaft experienced several issues that hindered its performance and reliability. Firstly, it exhibited a high corrosion rate, particularly concerning in an aquatic environment with constant moisture exposure. This corrosion vulnerability not only reduced the shaft's lifespan but also threatened the overall efficiency of the water circulation system. Secondly, the shaft's design was not specifically tailored for wet environments, leading to inconsistent performance during extended operational periods. Additionally, the shaft's reliability for long-term use was questionable, raising concerns about maintenance and the potential need for frequent replacements.

The primary objective of this transmission system is to generate water currents within the pond, promoting more dynamic activity among aquatic organisms and enhancing dissolved oxygen levels, which are critical for ecosystem health and sustainability (Fig. 1). A consistent flow of water supports biodiversity and contributes to the efficient distribution of nutrients throughout the pond. Due to these challenges with the existing shaft, there was a pressing need for innovation. Consequently, a completely new flexible coupling was designed to address the specific limitations of earlier models and was not found in existing literature sources [3]-[5]. This design is illustrated in Fig. 2, showcasing its potential for improved performance and reliability in pond-based applications.

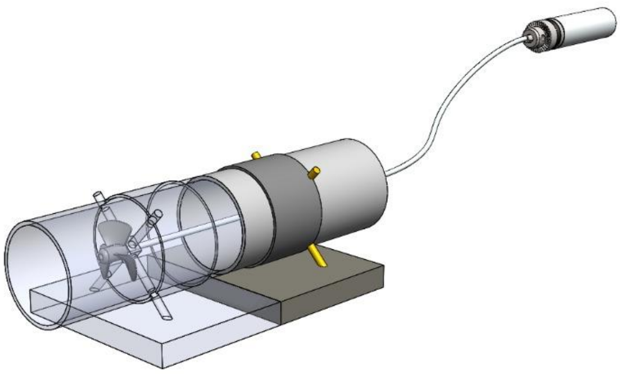

Fig. 1. Flexible shaft as power transmission to propeller [1]

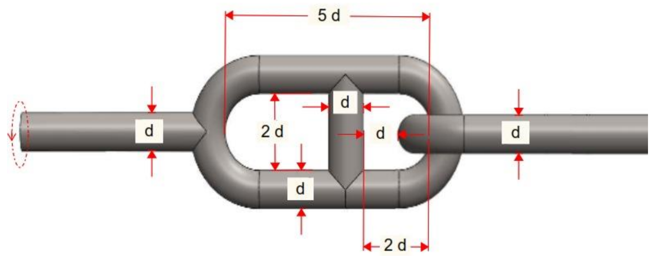

Fig. 2. The chain clutch concept, the main object of study in this research. [2]

The proposed clutch construction anticipates several operational phenomena, including an axial movement of ±1d due to a 1d clearance at the chain's end. This relative axial movement is expected to occur at any point during operation. To accommodate this movement, the shaft's supports, preceding the propeller shaft, are designed as sliding bearings that solely support radial loads. In contrast, the support for the propeller shaft is constructed to handle a combined axial-radial load, thus restraining the axial movement of the drive shaft and ensuring it does not adversely affect propeller operations.

Moreover, radial movement relative to the drive shaft axis is anticipated due to the 1d clearance on both sides of the clutch column. The drive shaft's movement will be moderated by the propeller shaft, supported by a bearing capable of accommodating both axial and radial loads. Both axial and radial movements in the drive shaft will be contained within this axial-radial configuration. However, such movements may lead to vibrations and contribute to noise production. This research does not focus on calculating or measuring the clutch's efficiency but instead emphasizes measuring noise levels and evaluating the performance characteristics of steel and brass when used as clutch and shaft materials. Noise levels are critical regarding parameters such as clearance, wear, fit, and eccentricity. A test concept was developed to ensure this clutch operates effectively at an angle to the drive shaft, as represented in Fig. 3.

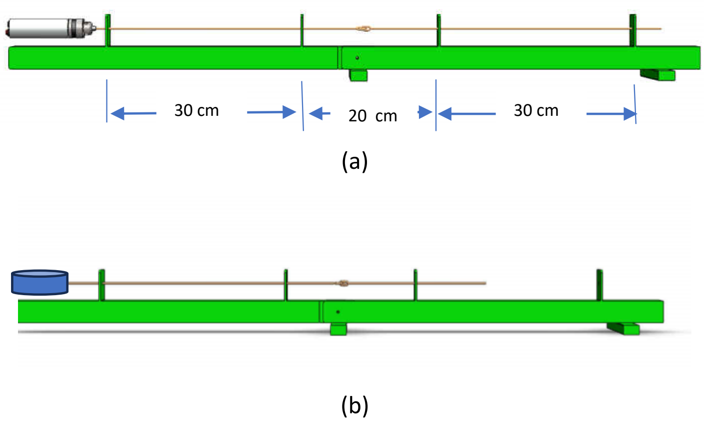

Fig. 3. Test module with 4 supports (a) and 3 supports (b)

The testing module comprises fixed and moving components, connected via a hinge, allowing one section to pivot at a designated angle relative to the other. The clutch being evaluated is situated centrally within this connection. At the left end, a dynamo capable of a rotation range from zero to 3000 RPM is incorporated (Fig. 4).

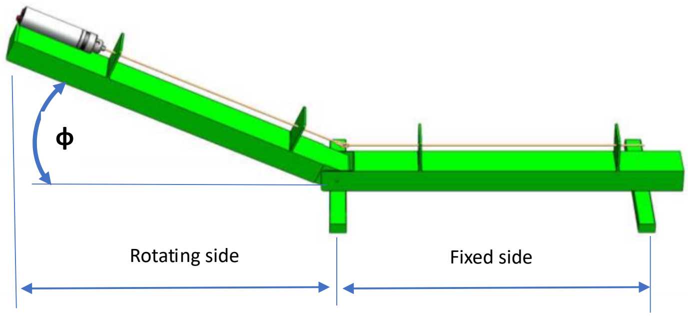

Fig. 4. Test module with rotating side and fixed side. The driving motor is an electric dynamo with a rotation range of 0 – 3000 RPM.

Two test modules were constructed: one equipped with three supports and the other with four supports. The spacing between supports was configured to be 30 cm for the first and last supports and 20 cm for the central support, as illustrated in Fig. 5.

Fig. 5: Chain coupling installation

Grease is identified as a critical variable in this study since numerous prior investigations have focused on shaft lubrication and its influence on power efficiency. Hammami et al. provided an in-depth examination of the impact of lubrication on shaft power loss, affecting the economic viability of the system [5]. Additionally, researchers such as Fernandez et al. explored the relationship between lubrication and torque loss in shafts [6][7]. Noise also emerges as a significant variable in this study, serving as a benchmark for future research. Jaehyeon Nam et al. [8] established that noise generation is linked to instabilities in both the torsion and axial loading modes. Furthermore, the clutch under investigation exhibits instability in the radial loading mode. The friction encountered between the tested shaft and its supporting friction surfaces also contributes to noise production. These factors collectively indicate the need for further research aimed at optimizing and improving the overall system.

The objective of this study is to evaluate a new coupling system for low rotation and minimal power transmission from an electric drive to a propeller in fish ponds. It aims to assess the coupling's performance at various bend angles and rotational speeds, while quantifying the noise generated during operation. The findings will offer insights for optimizing transmission systems in aquatic environments and inform strategies for noise reduction.

2. MATERIALS AND METHOD

The materials used in this study included brass and polyethylene plastic for the shafts. The brass shaft had a diameter of 4 mm, chosen for its advantages in corrosion resistance and lower noise characteristics, while the polyethylene plastic shaft measured 6.8 mm in diameter. A chain-type flexible coupling was implemented to facilitate effective power transmission while accommodating necessary bends in the shaft. The testing configurations employed either four or three supports to evaluate the impact of the number of supports on system performance and noise generation.

The test apparatus was assembled with either the brass or polyethylene shaft connected to an electric motor capable of rotations ranging from 0 to 2200 RPM. One end of the shaft was attached to the motor, while the other end was connected to a propeller. During each test, the rotational speed of the shaft was gradually increased from 0 RPM to a maximum of 2200 RPM, with each RPM increment maintained for a specific duration to ensure stable measurements. Noise levels were monitored using a calibrated sound level meter in an open environment, with an average motor noise level of 90 dB serving as the baseline for readings.

To further assess the impact of lubrication on system performance, tests were conducted both with and without the application of grease. Noise measurements and RPM readings were recorded during operation for each configuration, both in the presence and absence of grease.

The bend angle (ϕ) of the shaft was varied during testing to evaluate its effect on power transmission and noise generation, ranging from zero degrees (straight) to the maximum bend angle accommodated by the coupling design.

Data collection included RPM recordings and noise levels (in dB) at various speeds for each shaft material and support configuration. The focus was on comparing the performance characteristics of brass and steel materials under each testing condition, revealing insights into the effects of grease on noise reduction and overall efficiency. The comprehensive analysis of this collected data provided valuable information regarding material composition, support configurations, the influence of lubrication, and the implications of the bend angle on overall system performance. This structured methodology ensured a thorough evaluation of the new coupling design under varying operational conditions.

3. RESULT AND DISCUSSION

The testing phase of the transmission system did not account for energy loss, as this aspect was not yet considered; the primary goal was to establish whether this type of clutch could effectively transmit power and rotation. Future research will explore these additional factors.

Various authors have extensively discussed the implications of energy loss in mechanical systems. Han Ding et al. emphasized that the increasing shortage of energy resources, combined with growing awareness around conservation and environmental sustainability, has brought the issue of energy loss in gear power transmission and mechanical efficiency to the forefront of research [6]. Notably, energy losses incurred during transmission and delivery can consume nearly half of the energy produced [7]. In automotive applications, Holmberg indicated that approximately one-third of the fuel energy in passenger vehicles is used to overcome friction in systems such as engines, transmissions, tires, and brakes [8]. This underscores the significant role energy losses play in diminishing system efficiency and contributing to environmental degradation by requiring greater energy expenditure for the same output.

Tests conducted with a four-support module using a 6.8 mm diameter carbon steel shaft revealed that noise levels were elevated from the outset, showing an approximate increase of 1% for every 800 RPM rise in speed. Additionally, noise levels tended to rise in direct relation to the bend angle (ϕ). Applying grease within the system resulted in a noise reduction of about 2% at the same operational speeds and diameters, highlighting the critical role of lubrication in enhancing system functionality and reducing noise, a vital aspect of drive system design.

Noise reduction observed during tests with three supports yielded an approximate 7-8% decrease at the same 6.8 mm diameter (see Fig. 6-10). This suggests that the configuration and type of support significantly influence noise emission, where sliding supports can generate considerable noise due to clearance and associated frictional vibrations between moving components. Widder et al. noted that prominent wear phenomena in harsh operational conditions are often induced by dominant impact and abrasive wear mechanisms [9]. Similarly, Sundström et al. reported that steel surfaces often exhibit rough topographies marked by distinct craters and grooves due to high- and low-angle impacts related to abrasive wear [10]. These impact angles are directly influenced by the variable bend angle (ϕ) within the testing module, emphasizing the interconnectedness between design parameters and performance outcomes.

The study results indicate that variations in the bend angle (ϕ) directly correlate with noise levels; specifically, increasing the bend angle tends to heighten noise generation due to changes in the impact angles between interacting surfaces. It is noteworthy that wear within the clutch system can alter impact angles, leading to fluctuations in noise over time. Sundström et al. emphasized that the wear resistance of materials in specific tribosystems is profoundly affected by system parameters (including environmental conditions, types of abrasive particles, and temperature) and intrinsic material properties (like toughness and work hardening capacity) [10].

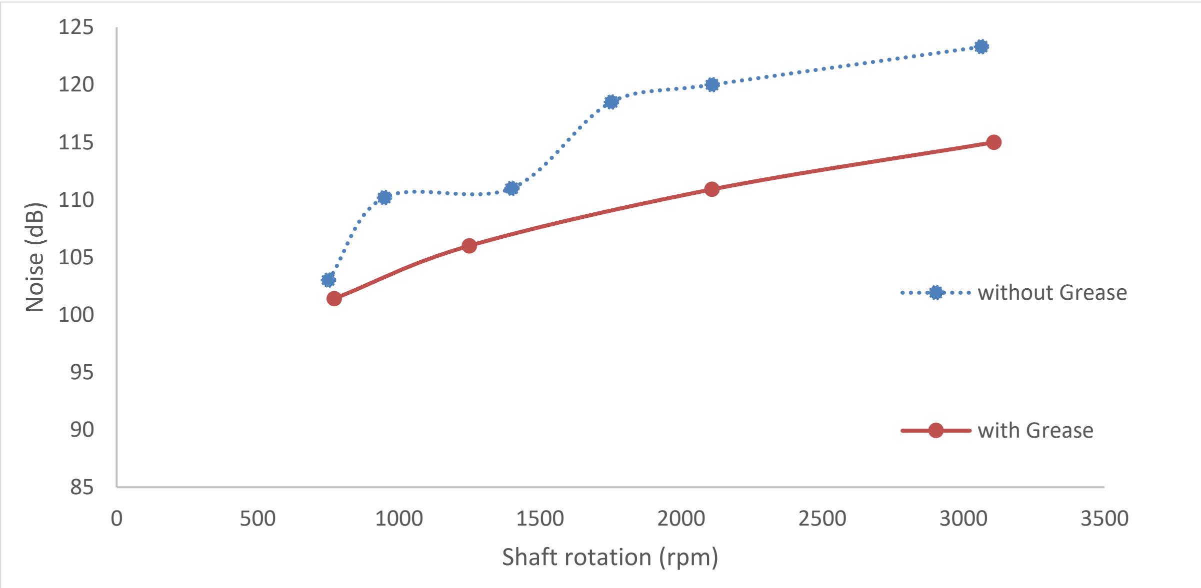

Fig. 6. Clutch noise at experiments with steel of 6.8 mm, four supports and the bend angle ϕ = 0^0.

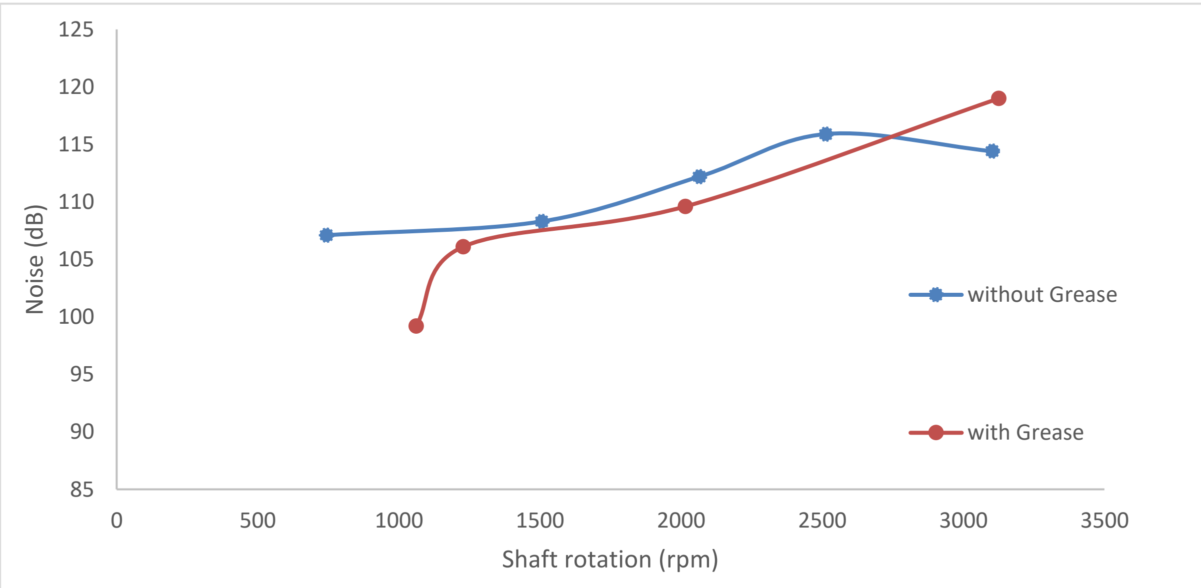

Fig. 7. Clutch noise of 4 supports shaft of carbon steel of 6.8 mm diameter at bend angle ϕ = 10^0.

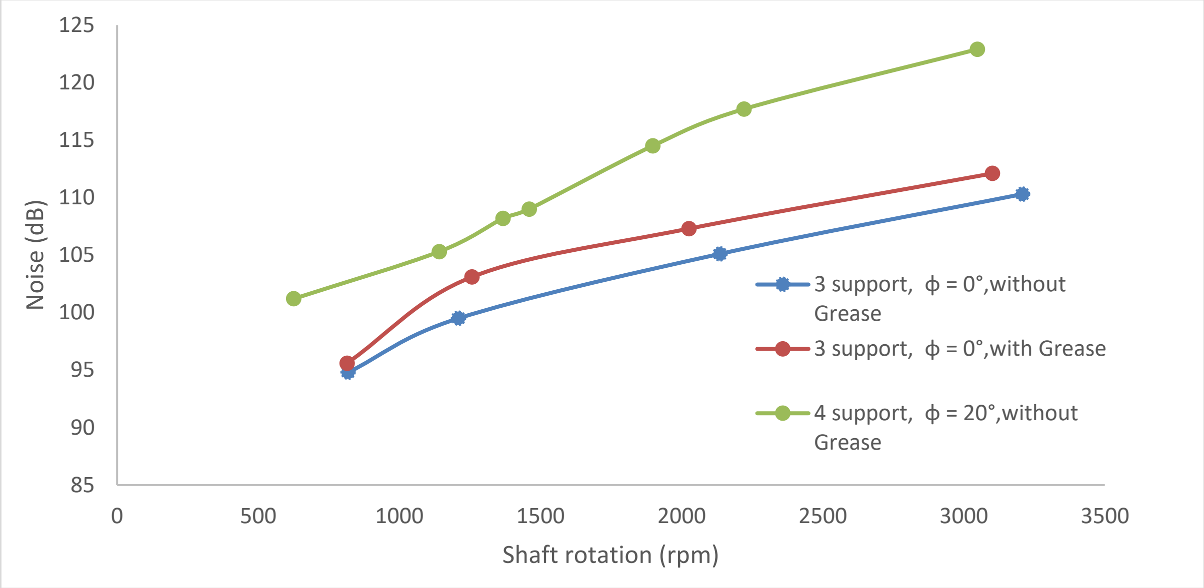

Fig. 8. Clutch noise of 3 and 4 supports shaft of carbon steel of 6.8 mm diameter at bend angle ϕ =0 and 25^0.

Surface hardness significantly contributes to wear resistance; numerous studies demonstrate that wear in steel materials decreases as hardness increases [9][10]. A crucial relationship exists between wear and the resulting clearances between clutch components—greater wear results in increased clearances, which consequently heightens noise levels due to less effective contact and engagement during operation. Considering these factors, brass is an unsuitable option for shaft construction due to its lower hardness characteristics. Conversely, steel is posited as a more viable candidate, provided it has medium carbon content to ensure sufficient surface hardness and specific treatments to enhance wear resistance.

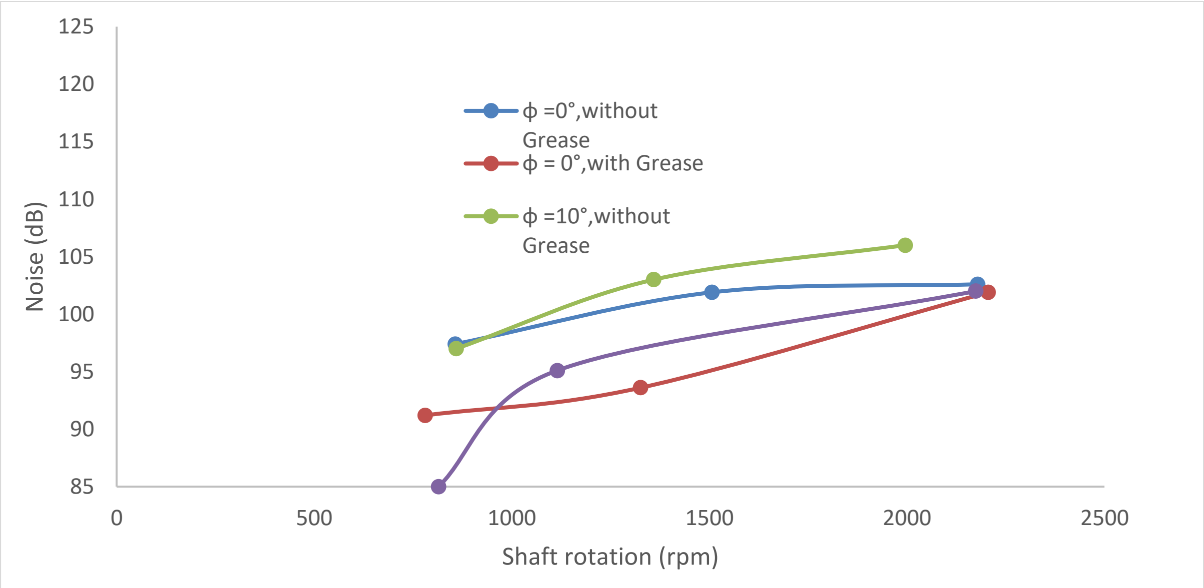

Fig. 9. Clutch noise during testing with a brass shaft of 4 mm diameter, four supports, and bend angle ϕ = 0°-10°

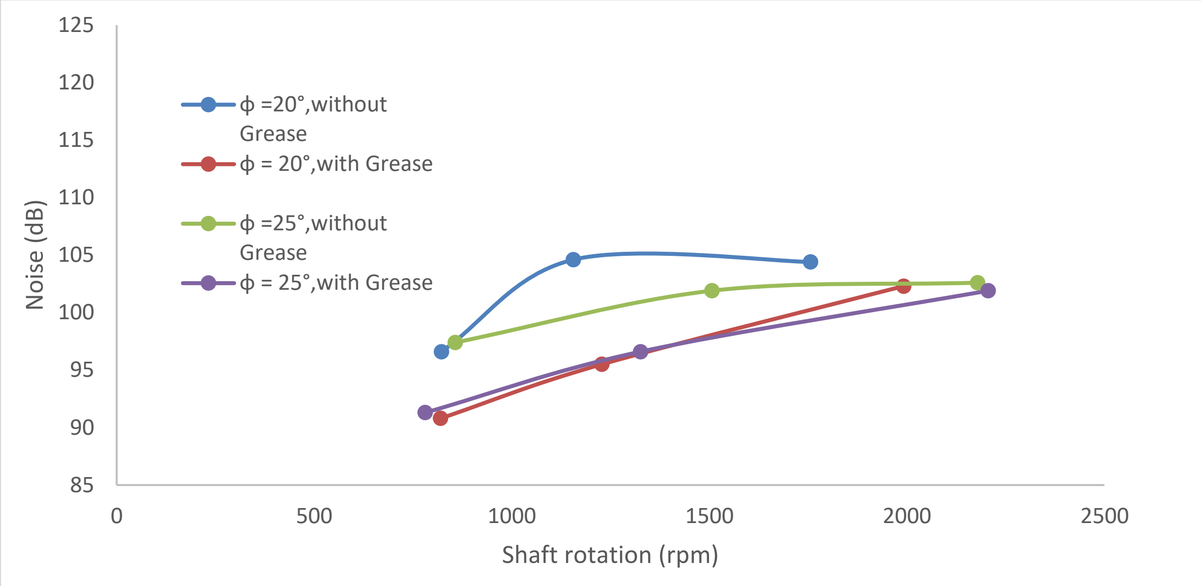

Fig. 10. Clutch noise during testing with a brass shaft of 4 mm diameter, four supports, and bend angle ϕ = 20°-25°

Data on brass shafts configured with three supports and bend angles of ϕ = 0°, 10°, 20°, and 25° have been excluded from this report because the material lacks the requisite strength and stiffness for optimal operational performance (see Fig. 9 and 10). The findings show that, based on the specified clutch design and dimensions, the highest bend angle (ϕ_max) at which the clutch can effectively transmit power and rotation is 25 degrees. Additionally, it was observed that noise levels rise with increasing shaft rotational speeds. In tests with a four-support brass module without grease, the maximum recorded noise level was 103 dB, while the lowest was 96.4 dB.

The collected data clearly indicate the need for a specialized design strategy for using specific carbon steel as both the shaft and chain clutch. This design must integrate considerations of shaft diameter, support spacing, and configuration to ensure effective operation at high rotational speeds over prolonged periods. Such considerations inherently include resistance to friction, surface temperature mitigation, and endurance against fatigue and wear.

The use of grease proved effective in noise reduction, achieving decreases in the range of 2-4%. However, this effect depends on multiple factors, including the type of grease used, shaft rotational speed, loading conditions, and materials in the shaft and supporting structures. While brass has advantages in terms of reducing noise and providing water resistance, it lacks the requisite stiffness and strength for many applications, highlighting the need for thorough analysis and careful calculation related to support distances and bearing configurations. As articulated by Drozdov and Gavrikov, the friction coefficient in mechanical systems is influenced by a variety of factors, including sliding and rolling speeds, the radius of curvature of the contact interface, load-related parameters such as unit linear load or contact pressure, surface roughness, and lubricant viscosity, all of which play significant roles in defining the overall performance and efficiency of the transmission system in practical applications.

4. CONCLUSION

This study evaluated a new coupling system for low rotation and minimal power transmission from an electric drive to a propeller in fish ponds, revealing that the bend angle (ϕ) significantly affects performance—establishing a maximum operational angle of 25 degrees for effective power and rotation transmission—and underscoring the necessity of considering bend angles in clutch design; the introduction of grease reduced noise by approximately 2%, highlighting lubrication's critical role in enhancing system efficiency and minimizing noise; while brass offers corrosion resistance and reduced noise, its lack of strength for high-load applications points to carbon steel with medium carbon content as a better material choice, offering improved strength, wear resistance, and structural stability; the study underscores the need to assess factors like wear, resilience to dynamic loads, and friction characteristics, recommending further research into energy losses and environmental influences to optimize transmission system performance in aquatic environments.

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