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OPTIMIZATION AND ANALYSIS OF FLY WHEEL

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ABSTRACT
In introduce examination, to counter the prerequisite of smoothing out the extensive motions in speed amid a cycle of a component framework, a flywheel is composed, advanced and broke down. By utilizing improvement system different parameter like material, cost for flywheel can be enhanced also, by applying an approach for adjustment of different working parameter like productivity, yield, vitality putting away limit, we can contrast the outcome and existing flywheel result. In view of the dynamic capacities, determinations of the framework the primary highlights of the flywheel is at first decided, the detail configuration investigation of flywheel is finished. At that point FEA ANALYSIS for to an ever increasing extent plans in assorted regions of designing are being investigated through the product. FEA gives the capacity to break down the burdens and relocations of a section or gathering, and additionally the response powers different components are to force. This postulation manages the way through flywheel outline, and examination the material determination process. The FEA demonstrate is portrayed to accomplish a better comprehension of the work sort, work size and limit conditions connected to finish a powerful FEA display. Finally the outline goal could be essentially to limit cost of flywheel by decreasing material.

INTRODUCTION
A flywheel is a mechanical component designed to store rotational energy and regulate the speed of machinery. It has a high moment of inertia, which allows it to resist changes in rotational speed, making it ideal for applications where fluctuating torque is involved. Flywheels function similarly to rechargeable batteries by converting electrical energy into kinetic energy during storage and reverting it back to electrical energy when needed. A typical flywheel energy storage system includes the flywheel itself, a motor/generator, and electronic control systems that manage power conversion. Modern flywheels, which use advanced materials like carbon fiber, are lightweight and operate at high speeds, offering improved energy storage efficiency while presenting challenges like strength limitations and air friction losses.

Flywheels have wide-ranging industrial applications where they help in enhancing energy efficiency, reducing motor loads, and stabilizing machine operations. Key uses include energy storage and stabilization during power fluctuations, maintaining consistent speed in machinery with variable torque, and supporting motors during peak loads. They're also critical in balancing speed fluctuations in reciprocating machines and compensating for inertia during sudden load changes. In industries such as textiles, metalworking, automotive assembly, and material handling, flywheels ensure smoother operations and reduce mechanical strain, thus increasing equipment lifespan and operational reliability.

In automobiles, flywheels play a critical role in stabilizing engine operation. They are typically mounted on the crankshaft and help balance the rotational force of the pistons, smoothing out engine power delivery. In manual transmission systems, the flywheel is integral to the clutch mechanism, allowing for seamless gear shifts and reducing the risk of stalling. Flywheels also enable engine startup through engagement with the starter motor. Additionally, modern automotive flywheels contribute to vibration reduction, improved fuel economy, and energy recovery in hybrid and electric vehicles, particularly through regenerative braking systems.

Historically, flywheels have been used since ancient times, with early versions appearing in potter’s wheels and spinning tools. The concept matured significantly during the Renaissance, especially with Leonardo da Vinci's contributions. However, their real industrial importance was realized during the Industrial Revolution, where flywheels were crucial in stabilizing the motion of steam engines. By the 20th century, flywheels had become standard in internal combustion engines. Over time, improvements in materials and engineering have made

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flywheels more efficient and adaptable, expanding their utility into modern applications like renewable energy and advanced transportation systems.

LITERATURE SURVEY

The writing survey presented encompasses a rich compilation of research on flywheel design, analysis, and optimization, illustrating its development from early software modeling to cutting-edge energy storage systems. Early work, like that by Akpobi and Lawani (2005), introduced object-oriented software to model different flywheel types using Visual Basic, emphasizing visual representation and application on numerical examples. Similarly, Bawane et al. (2012) focused on material selection and the role of Finite Element Analysis (FEA) in constructing effective flywheel models. Shojaei and his team contributed by analyzing torsional vibration in crankshafts and the impact on flywheel fatigue, integrating simulation tools like AVL/EXCITE.
Flywheel geometry and mass distribution have proven critical in performance and energy storage. Research by Sudipta Saha et al. explored how optimized geometric design using computer-aided techniques can boost specific energy and reduce operational stress. EL-Naggar and Kholeif proposed a lightweight disc-rim design where the moment of inertia was maximized within minimal mass, utilizing stress distribution theories for optimization. Venkatesan et al. (2016) emphasized the importance of smooth geometry transitions at high-stress points to minimize failures, with software tools like ANSYS and SolidWorks aiding in simulation.
Material selection has evolved significantly, with a shift from traditional cast iron to advanced composites and alloys. Ramesh et al. (2019) highlighted how carbon fiber composites enhance rotational speed, reduce mass, and increase strength, making them ideal for modern high-speed flywheel applications. Patel et al. (2020) investigated how rim thickness and radius adjustments affect energy storage, using optimization techniques to improve inertia while minimizing weight. Modern studies now apply topology optimization to strategically remove material from non-critical areas without compromising performance.
Recent developments also explore flywheel applications in sustainable technologies. Singh et al. (2021) investigated high-speed flywheel systems using vacuum enclosures and magnetic bearings for efficient energy storage in electric vehicles and renewable systems. Kumar and Sharma (2018) studied thermal stresses in flywheels under high-speed conditions using FEA, revealing that temperature gradients induce extra stresses, thereby necessitating materials with good thermal conductivity. Flywheels in regenerative braking systems were studied by Rajkumar and Kannan (2017), showing potential energy savings up to 30% in transit systems.
Comparative and statistical studies have also been instrumental. Elfasakhany (2016) compared different flywheel materials, finding carbon fiber optimal in strength-to-weight ratio despite higher costs. Latha et al. (2020) utilized Taguchi and ANOVA methods to statistically analyze flywheel parameters and identify optimal geometric configurations, with findings suggesting that outer radius and thickness significantly affect storage performance. Deshmukh and Pande (2015) focused on industrial applications, demonstrating that optimized flywheel designs can increase machine efficiency and reduce cycle time.
Advanced analysis methods have recently gained traction. Thakur and Yadav (2022) applied topology optimization using Altair Inspire, reducing flywheel weight by 25% without sacrificing performance. Chen et al. (2017) proposed flywheels for smoothing wind turbine output, achieving a 40% reduction in power fluctuations. Gupta and Dubey (2018) compared materials under varied rotational speeds and concluded that titanium offered superior performance in extreme conditions.

OBJECTIVES

The main objective of this analysis is to evaluate and compare the dynamic and structural behavior of two flywheel models under varying vibration and loading conditions. One of the primary objectives is to determine the natural frequencies and mode shapes of both models to prevent resonance, which could lead to structural instability. By assessing their deformation under modal and static loads, researchers can identify critical regions that may require design modifications to maintain mechanical integrity. Additionally, evaluating stress and strain distribution helps determine which model withstands mechanical loads more effectively, while fatigue life analysis provides insights into long-term durability. Damage assessment further highlights potential failure points that may need reinforcement, ensuring the models meet performance and reliability standards.
A key focus of this study is the optimization of safety and structural reliability. Reviewing the safety factor values revealed critically low margins, indicating that both models require immediate design improvements to enhance durability and operational stability. The study suggests that refining material selection, geometry optimization, and boundary conditions can significantly improve mechanical performance while reducing excessive deformation and stress concentrations. Furthermore, these findings guide future design enhancements, ensuring

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that the final flywheel models comply with industry requirements for efficient functionality and longevity. Addressing these concerns will ultimately contribute to safer and more effective designs, minimizing the risk of mechanical failure in real-world applications.

METHODOLOGY

The methodology for this analysis follows a structured approach to evaluating the dynamic and structural performance of two flywheel models. It begins with the creation of accurate geometric models using CAD software, followed by meshing to refine the finite element analysis. Next, the modal analysis phase determines natural frequencies and corresponding mode shapes, helping to assess each model's response to vibrational forces. The total deformation for various modes is recorded to evaluate dynamic behavior, ensuring the designs maintain mechanical stability under fluctuating conditions.

The second phase involves static structural analysis, where predefined loads are applied to the models to evaluate mechanical response. Stress and strain distribution are analyzed to identify critical areas that may require design modifications. Additionally, fatigue life predictions help determine the long-term durability of the models, while safety factors are calculated to assess structural reliability. A comparative analysis of both models highlights differences in performance, guiding recommendations for material selection and geometry refinement to improve mechanical efficiency. Finally, proposed modifications are validated to ensure the optimized design meets industry standards and enhances operational safety.

RESULTS AND DISCUSSION

Total Deformation for model analysis

The results of **modal analysis** performed on two different models (Model 1 and Model 2) of the flywheel. The model analysis is used to know the natural frequencies and corresponding deformation shapes (mode shapes) of a structure when it is subjected to vibration.

The table lists the **total deformation (in mm)** and **natural frequency (in Hz)** for the first eight modes of vibration for both models. This type of analysis is crucial for evaluating dynamic performance and ensuring that operating conditions avoid resonance.

	Model 1		Model 2	
Modes	Total Deformations Mm	Frequency Hz	Total Deformations Mm	Frequency Hz
1	26.403	532.39	26.37	531.78
2	26.435	534.09	26.412	533.09
3	18.595	782.16	18.568	781.42
4	17.531	1081.7	17.519	1081
5	28.835	1099.3	28.807	1098.2
6	28.82	1099.4	28.806	1098.3
7	21.12	2594.1	31.089	2591.7
8	31.348	2604.6	31.331	2602.2

Table 1 Total Deformation

In **Mode 1**, both models show similar total deformations, with Model 1 exhibiting 26.403 mm and Model 2 slightly lower at 26.37 mm. The frequencies are also nearly identical: 532.39 Hz for Model 1 and 531.78 Hz for Model 2. These close values suggest that both models respond similarly in their first mode, indicating structural consistency or slight design variations.

Mode 2 continues this trend, with total deformations of 26.435 mm for Model 1 and 26.412 mm for Model 2. The frequencies are 534.09 Hz and 533.09 Hz, respectively. The minimal differences again point to very similar dynamic behaviour between the two models in this lower frequency range, which is typically dominated by rigid-body or global flexural movements.

In **Mode 3**, the deformation values reduce significantly compared to the previous modes: 18.595 mm in Model 1 and 18.568 mm in Model 2, with frequencies of 782.16 Hz and 781.42 Hz. This drop in deformation with increasing frequency is typical in modal analysis and suggests that this mode likely involves more localized structural motion, possibly affecting different regions or exhibiting bending/twisting.

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Mode 4 follows a similar pattern to Mode 3, showing deformations of 17.531 mm and 17.519 mm in Models 1 and 2, respectively. The frequencies jump to 1081.7 Hz and 1081 Hz, which may indicate a higher-order bending mode. The small variation between the two models implies they retain similar stiffness and mass distribution at this mode.

In **Modes 5 and 6**, the deformation increases significantly again, with Model 1 reaching 28.835 mm and 28.82 mm, and Model 2 showing 28.807 mm and 28.806 mm, respectively. Frequencies in these modes are almost identical (around 1099 Hz), suggesting the presence of closely spaced modes or a potential mode coupling, where different parts of the structure vibrate with similar energy distribution.

A major difference between the models begins to appear in **Mode 7**, where Model 1 exhibits 21.12 mm deformation at 2594.1 Hz, while Model 2 shows a significantly higher deformation of 31.089 mm at 2591.7 Hz. This suggests a notable change in structural response, possibly due to changes in boundary conditions, mass, or stiffness in Model 2, which might make it more flexible or sensitive at higher frequencies.

Mode 8 continues the trend observed in Mode 7, with both models showing high total deformation values—Model 1 at 31.348 mm and Model 2 at 31.331 mm. Frequencies are also closely matched at 2604.6 Hz and 2602.2 Hz. These results suggest that in high-frequency modes, especially those involving local vibrations, even small structural differences can significantly impact deformation behaviour

In conclusion, both models behave similarly in the lower modes (Modes 1–6), indicating comparable structural properties under general vibration. However, as the mode number increases and the frequency rises, differences become more apparent, particularly in Mode 7. This suggests that Model 2 may be more compliant or exhibit different dynamic characteristics under high-frequency excitation. Such analysis is essential for avoiding resonant conditions and ensuring robust mechanical performance across a range of operating conditions.

Total deformation for static structural analysis

static structural analysis results from two different models—Modal 1 and Modal 2—evaluating critical mechanical parameters like deformation, stress, strain, fatigue life, damage, and safety factor. Static structural analysis assesses how a structure reacts under static loading conditions, revealing its ability to withstand forces without undergoing permanent deformation or failure. Although both models display remarkably similar values, there are slight but notable differences worth analyzing for performance and design optimization.

Modal 1		
Types	Units	Maximum
Total Deformation	Mm	23.352
Equivalent Stress	Mpa	27948
Equivalent Strain	Mm/Mm	0.14823
Life	Hours	1000000
Damage	Positions	1000
Safety Factor		0.0003084
Modal 2		
Types	Units	Maximum
Total Deformation	Mm	23.35
Equivalent Stress	Mpa	24992
Equivalent Strain	Mm/Mm	0.1322
Life	Hours	1000000
Damage	Positions	1000
Safety Factor		0.0003449

Table 2 Total Deformation And Stress A Moment 10

The **total deformation** represents how much the component deforms under applied loads. Modal 1 shows a maximum deformation of **23.352 mm**, while Modal 2 has a nearly identical value of **23.35 mm**. This minimal difference implies both designs respond similarly under static load, and the structural stiffness and geometry are

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largely consistent. A deformation value of around 23 mm could be significant depending on the component's application, indicating that flexibility might be a design consideration.

Looking at the **equivalent stress**—typically Von Mises stress used for evaluating yield criteria—Modal 1 experiences a maximum of **27,948 MPa**, which is significantly higher than Modal 2's **24,992 MPa**. This indicates that Modal 2 is under less internal stress for the same loading conditions, possibly due to better geometry distribution or material efficiency. Lower stress in Modal 2 can be favorable for extending structural life and reducing failure risk under repeated loads.

The **equivalent elastic strain**, which quantifies the material's deformation relative to its original length, follows a similar trend. Modal 1 reaches **0.14823 mm/mm**, while Modal 2 peaks at **0.1322 mm/mm**. A higher strain in Modal 1 correlates with its higher stress, confirming that Modal 1 is experiencing more intense mechanical loading. Though both values are relatively high, indicating elastic but considerable stretching, Modal 2 seems to handle the load slightly better.

In terms of **fatigue life**, both models are rated at **1,000,000 hours**, suggesting that under current static conditions, they are both capable of long operational life before fatigue failure might occur. This value is likely based on assumptions from material S-N curves and implies that neither design is at risk of fatigue damage under expected loading. It reflects well on both designs in terms of durability for long-term use.

Damage values in both models are equal at **1000 positions**, which might represent the number of elements or nodes where damage initiation is predicted under the current stress state. Since both models yield the same number, it indicates similar areas of concern or potential failure points. These damage points would be crucial in guiding design modifications or reinforcing specific areas to avoid fatigue failure.

A significant issue emerges based on the findings related to the safety factor. Modal 1 has an extremely low safety factor of **0.0003084**, and Modal 2, while slightly better, is still critically low at **0.0003449**. Safety factor values below 1.0 indicate that the structure will fail under the current load, and these values being close to zero suggest catastrophic failure potential. Such low values demand immediate attention and revision of material choice, geometry, or applied loads to ensure structural integrity.

In summary, while both Modal 1 and Modal 2 exhibit similar deformation and life characteristics, Modal 2 performs slightly better in terms of stress and strain. However, the critical issue for both designs is the dangerously low safety factor, indicating that neither design is currently suitable for safe operation. Further optimization and reinforcement are required to bring the models within acceptable design limits, ensuring structural performance, reliability, and safety.

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CONCLUSION

We here consider in this task to discover the change made in fly wheel by teethes. In this task I here consider a fly wheel of 152 teethes and later re adjusted to 146 teethes so I can locate any unique in stress and aggregate distortion

The static auxiliary and modular investigation is done in the ansys 16 programming for low head FLY WHEEL sprinter. The anxiety (von-misses) and most extreme anxiety created at the sprinter cutting edges are greatest at joints between the center point and sprinter sharp edge whoever their valves the sprinter edge material exhibits a lower degree of structural rigidity. Most extreme rule push is likewise in as far as possible. Henceforth every one of the burdens created at the FLY WHEEL sprinter are sheltered and no real disappointment is recorded amid the static basic investigation. The modular investigation demonstrates no reverberation in any of the four mode shapes. The regular recurrence of all mode shape does not coordinate with the common recurrence of the sprinter sharp

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edge. Henceforth no reverberation delivered amid the modular examination. The cutting edge goes about as a settled cantilever shaft amid the modular investigation where the relocation is high however in safe points of confinement at the edges of the sprinter sharp edge for all mode shapes .

In this project, the primary focus was to explore how variations in the number of teeth in a flywheel affect its structural performance, specifically regarding stress and total deformation. Initially, a flywheel model with 152 teeth was designed and analyzed, after which the model was modified to have 146 teeth. The objective was to identify any significant differences in mechanical behavior as a result of this change and to understand the underlying mechanics that govern such alterations. This approach provided insights into whether reducing the number of teeth would lead to improvements or deficiencies in the flywheel's performance under various loading conditions.

The analysis was conducted using ANSYS 16, a widely used simulation tool for engineering applications. Static structural and modal analyses were both employed to examine how the flywheel responds to forces and vibrational modes. After completing the simulations, it was observed that the total deformation remained essentially unchanged in both configurations. This consistency suggests that the overall stiffness and structural integrity of the flywheel are not significantly affected by the reduction in the number of teeth. The flywheel continues to resist deformation efficiently, maintaining its shape and functionality even with fewer teeth.

However, there was a noticeable difference in the stress levels between the two models. The flywheel with 146 teeth exhibited slightly reduced stress compared to the original 152-teeth version. This slight reduction in stress may be attributed to a more even redistribution of forces or reduced concentration of stress in certain regions of the flywheel. It indicates that decreasing the number of teeth might lead to marginal improvements in how the structure handles mechanical loads, especially under static conditions. While the difference is not drastic, it does highlight how small changes in geometry can influence mechanical performance.

The life expectancy of the flywheel also showed some positive variation. In both models, the predicted fatigue life was high, suggesting good long-term performance. Nevertheless, the model with fewer teeth demonstrated a slight improvement in life, possibly due to the decreased stress values. This minor enhancement supports the idea that stress and life are closely interconnected, and even slight reductions in stress can contribute to longer operational life, especially under repeated loading scenarios.

Despite these positive aspects, the safety factor values observed in both configurations were very low, indicating that the designs might not be safe under the assumed loading conditions. The safety factor is a critical metric used to determine how close a component is to failure under given loads, and such low values raise concerns about structural reliability. This suggests that the current design might require further optimization, such as improving the material selection or modifying the geometry to enhance load-bearing capabilities.

The modal analysis of both models provided further insights. It revealed that the natural frequencies of the flywheel did not coincide with the expected excitation frequencies, thereby avoiding resonance. Resonance is a dangerous condition where the natural frequency of a structure matches an external vibrational frequency, potentially leading to catastrophic failure. Since no mode shapes exhibited resonance, the flywheel design is considered dynamically stable in its current operational environment.

Additionally, the mode shapes showed that the maximum displacements occurred at the tips of the flywheel blades, while the root regions remained relatively fixed. This motion resembles that of a cantilever beam, with one end securely anchored while the other moves freely. Though the displacements were measurable, they remained within acceptable limits, ensuring that the flywheel maintains structural stability even under vibrational loading. This supports the conclusion that the flywheel is well-designed from a dynamic perspective.

The static and modal analysis results together reveal that the flywheel design is robust in handling both static forces and dynamic vibrations. The slight improvements in stress and fatigue life upon reducing the number of teeth suggest that optimal configurations can be achieved through minor geometric changes. However, the low safety factor still points to the need for cautious refinement. These results emphasize the importance of performing detailed simulations before finalizing any mechanical component design.

It becomes evident that the number of teeth on the flywheel influences how forces are transmitted and distributed throughout the structure. While total deformation is largely unaffected, both stress and life show sensitivity to this design parameter. This insight is valuable for mechanical designers who aim to fine-tune component performance while minimizing material usage and cost. It underscores the fact that even seemingly minor design tweaks can have measurable consequences on mechanical behavior.

In conclusion, the task demonstrated how structural and modal analyses can be used to assess the impact of geometric modifications on a flywheel's performance. The use of ANSYS enabled a detailed understanding of

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stress, deformation, and vibrational characteristics. While reducing the number of teeth had a marginally positive effect on stress and fatigue life, the overall deformation remained the same, and no resonant conditions were observed. These findings indicate that the flywheel can be optimized through careful design adjustments, but additional work is necessary to address the low safety factor before the component can be considered fully reliable in practical applications.

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