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DESIGN AND OPTIMIZATION OF SHAFT DRIVEN DIRT BIKE

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ABSTRACT

This abstract explores the innovative design of shaft-driven dirt bikes, ushering in a new era of off-road motorcycling. Unlike traditional chain-driven counterparts, these bikes employ a shaft and bevel gear mechanism, minimizing maintenance needs and wear. The absence of an exposed chain enhances rider safety by reducing the risk of debris accumulation. Beyond maintenance benefits, the shaft-driven system contributes to improved off-road performance, offering enhanced traction, stability, and responsiveness. While acknowledging challenges in weight distribution and customization, ongoing research seeks to optimize the design, positioning shaft-driven dirt bikes as a compelling alternative for riders seeking efficient, reliable, and exhilarating off-road experiences.

KEYWORDS

Shaft-driven system, Bevel gear mechanism, Power transmission efficiency, Maintenance reduction, Wear minimization, Debris management, Traction optimization, Stability improvement, ANSYS analysis, Design calculations.

INTRODUCTION

The evolution of off-road motorcycle technology has taken a significant leap with the advent of shaft-driven dirt bikes, a groundbreaking innovation designed to redefine the off-road riding experience. Departing from conventional chain-driven models, shaft-driven dirt bikes feature a sophisticated shaft and bevel gear mechanism, promising riders a host of advantages, including reduced maintenance requirements and enhanced safety. This paper delves into the unique design characteristics and performance benefits of shaft-driven dirt bikes, exploring their impact on traction, stability, and overall handling in challenging off-road terrains. To provide a comprehensive understanding, this study incorporates design calculations and employs advanced analysis through ANSYS, shedding light on the engineering intricacies that contribute to the bike's efficiency and durability. As we navigate through this exploration, it becomes evident that shaft-driven dirt bikes are not merely a technological advancement; they represent a paradigm shift in off-road motorcycling, offering riders an efficient, reliable, and exhilarating alternative.

DESIGN METHODOLOGY

The flow of design methodology is shown in Figure 1. Design methodology refers to a systematic and organized approach to the design and development of a shaft driven dirt bike.

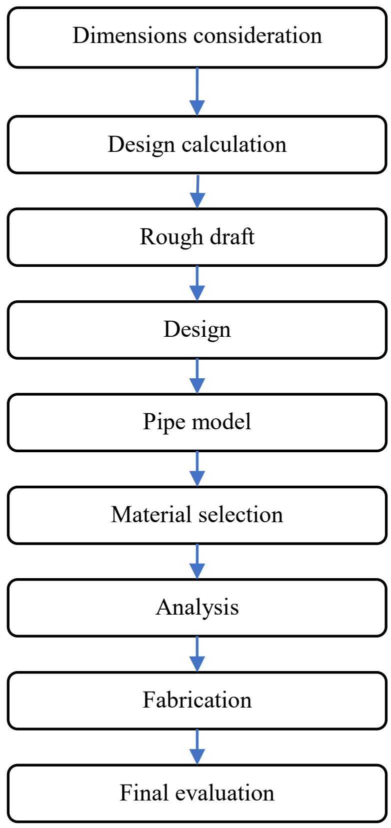

Fig.1.flow of study

Material selection for chassis

The selection of materials is a critical aspect in the design and construction of any engineering component, and in the context of a shaft-driven dirt bike, the properties of various materials play a pivotal role. ASTM A36, known for its general structural applications, exhibits a tensile strength of 400 MPa and a yield strength of 250 MPa. AISI 4130, a chromoly steel, boasts higher tensile and yield strengths at 670 MPa and 435 MPa, respectively. AISI 1018 offers good durability with a tensile strength of 483 MPa and a yield strength of 413 MPa. Aluminum alloys, such as Al-6061 and Al-7075, provide lower density (2.7 g/cc) and (2.81 g/cc) respectively, with Al-7075 demonstrating the best combination of strength (570 MPa) and yield strength (505 MPa). Docol R8, recognized for its exceptional strength, exhibits an impressive tensile strength of 800 MPa and a yield strength of 690 MPa. These materials also differ in cost per kilogram, with considerations of weldability playing a crucial role, making the selection process intricate, as engineers must weigh factors such as strength, weight, cost, and weldability to optimize the overall performance and durability of the shaft-driven dirt bike. From the above information, the material chosen for the chassis was AISI 4130 as it is cost-effective, the most reliable, and readily available in the market. **[1]**

PRINCIPLE

The principle of a shaft drive dirt bike involves the use of a shaft and bevel gear mechanism for power transmission from the engine to the rear wheel. Unlike traditional chain-driven systems, which employ a chain and sprocket arrangement, the shaft drive utilizes a shaft that connects to a bevel gear in the final drive housing. As the engine rotates, it turns the shaft, which, in turn, drives the bevel gear, ultimately transferring power to the rear wheel. This mechanism is enclosed within the bike's structure, reducing exposure to external elements and minimizing maintenance needs. The principle aims to provide a more reliable, cleaner, and low-maintenance solution, particularly advantageous in off-road environments where durability and ease of maintenance are crucial.

COMPONENTS USED

The main components of a shaft drive system in motorcycles typically include **[4]**

Shaft

The primary component responsible for transmitting power from the engine to the final drive.

Bevel Gears

Bevel gears are used to redirect the rotational motion of the shaft at an angle, facilitating the transfer of power to the rear wheel.

Final Drive Housing

Encases the bevel gears and provides structural support for the entire shaft drive mechanism.

Universal Joint

Connects the shaft to the bevel gears and allows for flexibility in accommodating changes in angle and direction.

Wheel Hub and Spline

The wheel hub incorporates splines or other connection mechanisms to transfer power from the final drive to the rear wheel.

Seals and Bearings

Seals and bearings are essential for smooth rotation and to prevent the ingress of contaminants into the shaft drive system.

Housing Covers

Covers enclose and protect various components, contributing to the system's overall durability and safety.

Support Brackets

Brackets and mounts are used to secure the shaft drive components to the motorcycle frame.

Lubrication System

A lubrication system ensures the smooth operation of moving parts within the shaft drive, reducing friction and wear.

These components work in concert to efficiently transfer power from the motorcycle's engine to the rear wheel while providing advantages such as reduced maintenance requirements and increased durability in comparison to traditional chain-driven systems.

DESIGN CALCULATION

By considering the specification for HERO SPLENDOR PLUS engine Maximum power from the engine = 6.15 KW at 8000 rpm and Maximum torque from the engine = 8.05 N-m at 5000 rpm we are calculating the diameter of the shaft and also calculating the bevel gear specifications.

VEHICLE SPECIFICATION

ITEM		SPECIFICATIONS
Dimensions		
Overall length		2000 mm
Overall width		720 mm
Overall height		1040 mm
Wheelbase		1230 mm
Saddle height		785 mm
Ground clearance		159 mm
Weight		
Kerb weight		109 kg (Kick Start)
		112 kg (Electric Start)
Capacities		
Engine oil		0.95 litre at disassembly and 0.75 litre at draining
Fuel tank		11.0 litres (Minimum)
Fuel reserve		1.1litres (Usable reserve)
Front fork oil		162-165 ml
Engine		
Maximum power		6.15 kW (8.36 Ps) @ 8000 rpm
Maximum torque		0.82 kgf-m (8.05 N-m) @ 5000 rpm
Bore and stroke		50.0x49.5 mm
Compression ratio		9.9:1
Displacement		97.2 cc
Spark plug		NGK-CR7HSA, BOSCH-UR4AC, Federal Mogul-P-RZ9HC
Spark plug gap		0.6-0.7 mm
Valve clearance	Intake (cold)	0.10 mm
	Exhaust (cold)	0.10 mm
Idle speed		1400±100 rpm
Chassis and suspension		
Front Suspension		Telescopic Hydraulic Shock Absorbers
Rear Suspension		Swingarm with 5 Step Adjustable Hydraulic Shock Absorbers
Caster angle		26°

Fig.2.specifications of hero splendor plus

VEHICLE SPECIFICATION

ITEM		SPECIFICATIONS
Tyre size	Front	2.75 x 18-42P/4 PR
	Rear	2.75 x 18-48P/6 PR
Brakes	Front (Drum type)	Dia. 130 mm
	Rear (Drum type)	Dia. 110 mm
Front Wheel		Spoke/Cast Wheel (Optional)
Rear Wheel		Spoke/Cast Wheel (Optional)
Transmission		
Primary reduction		3.722 (67/18)
Final reduction		3.143 (44/14)
Gear ratio, 1st		3.182 (35/11)
2nd		1.706 (29/17)
3rd		1.238 (26/21)
4th		0.958 (23/24)
Electricals		
Battery		Conventional Battery, 12V-2.5 Ah (Kick Start), *MF Battery,12V-3Ah ETZ 4 (Electric Start)
Alternator		115 W
Starting System		Kick/Electric Start
Headlamp (High/Low)		12V-35/35W Halogen Bulb-**MFR
Tail/Stop lamp		12V-5/10W **MFR
Turn signal lamp		12V-10Wx4 **MFR
Meter Illumination/Fuel indicator lamp		12V-1.7Wx2
Neutral indicator		12V-1.7W
Turn signal indicator		12V-3Wx2
Position lamp		12V-3.4W
Hi Beam indicator		12V-1.7W
i3s indicator		12V-1.7W
Fuse		7A, 10A (Kick) 10A, 15 A (Electric Start)

* MF stands for Maintenance Free
** MFR stands for Multi-Focal Reflector

Fig.3.specifications of hero splendor plus

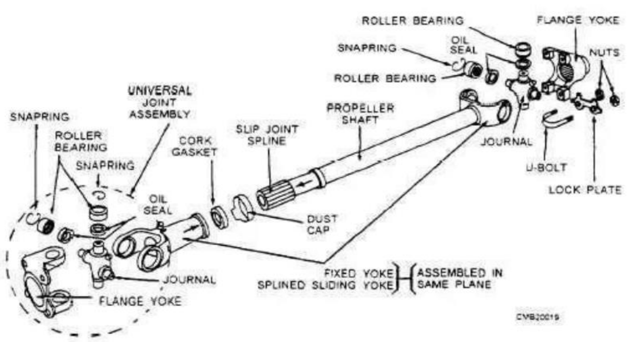

Fig.4.image of shaft drive components integration

Design calculation to find the diameter of the shaft [3]

$P = 2\pi nT \div 60$

$6.15 \times 10^3 = \frac{2\pi \times 8000 \times T}{60}$

T = 7.341 Nm

$T_{max} = 8.05$ Nm

$T_{min} = 7.341$ Nm

Assuming C 45 steel, $\sigma y = 380 \frac{N}{mm^2}, n = 2$

By using Soderberg equation,

$$\frac{1}{n} = \frac{\sigma m}{\sigma y} + kf\ \frac{\sigma a}{\sigma - 1}$$

To determine the τ_{max},

$$\frac{Tmax}{\frac{\pi}{32} \times d^4} = \frac{\tau_{max}}{\frac{d}{2}}$$

$$\frac{8.05 \times 10^3}{\frac{\pi}{32} \times d^4} \times \frac{d}{2} = \tau_{max}$$

$$\frac{8.05 \times 10^3 \times 16}{\pi \times d^3} \times \frac{d}{2} = \tau_{max}$$

$$\tau_{max} = \frac{40998.39}{d^3}$$

To determine the τ_{min},

$$\frac{\tau_{min}}{\frac{\pi}{32} \times d^4} = \frac{\tau_{min}}{\frac{d}{2}}$$

$$\frac{7.341 \times 10^3 \times 16}{\frac{\pi}{32} \times d^4} \times \frac{d}{2} = \tau_{min}$$

$$\frac{7.341 \times 10^3 \times 16}{\pi \times d^3} = \tau_{min}$$

$$\tau_{min} = \frac{37387.4}{d^3}$$

To determine τ_m,

$$\tau_m = \frac{\tau_{min} + \tau_{max}}{2}$$

$$\tau_m = \frac{\frac{40998.39 + 37387.4}{d^3}}{2}$$

$$\tau_m = \frac{39192.86}{d^3}$$

To determine τ_a,

$$\tau_a = \frac{\tau_{max} - \tau_{min}}{2}$$

$$\tau_a = \frac{\frac{40998.39 - 37387.4}{d^3}}{2}$$

$$\tau_a = \frac{902.725}{d^3}$$

Taking kf =1.425

$$\frac{1}{n} = \frac{\tau_m}{\tau_y} + kf\ \frac{\tau_a}{\tau - 1}$$

$$\frac{1}{2} = \frac{39192.86 \div d^3}{190} + 1.425 \frac{902.725 \div d^3}{600}$$

$$\frac{1}{2} = \frac{206.278}{d^3} + \frac{2.1439}{d^3}$$

D = 10.47 mm

On standardizing, the diameter of the shaft d = 15mm

Design of bevel gear Calculation

Maximum power = 6.15kw at 8000rpm
Gear ratio = 3
Transmission ratio i = 3
Material = C 45 steel

Step 1: Material [DDB 8.16]

For both pinion and wheel = C45 steel

$$\sigma c = Cr\ HRC\ Kcl$$

HRC = 40 to 55
HRC = 50
Cr=230

N = $60 \times n \times T$
=$60 \times 8000 \times 80000$
N = $3840 \times 10^7 cycles$

Let consider

HB of C45>350HB
Kcl = 0.585 for N = 3840 × 107 >= 25 × 107
$\sigma c = 230 \times 50 \times 0.585$
$\boldsymbol{\sigma c = 6727.5\ kgf/cm^2}$

To find σb [DDB 8.13]

$\sigma b = \frac{1.4}{n}\frac{kbl}{k\sigma}\sigma - 1$
$\sigma - 1 = 0.25(\sigma u + \sigma y) + 500$
$\sigma u = 7000 kgf/cm^2$
$\sigma y = 3600 kgf/cm^2$
Substitute the value in the above formula
$\sigma - 1 = 0.25(7000 + 3600) + 500$
$\sigma - 1 = 3150 kgf/cm^2$

Factor of safety(n) [DDB 8.19]

For C45 (forged & surface hardened)
FOS = 2.5
n = 2.5
kσ = fillet stress concentration factor [DDB 8.19]
for C45 surface hardened $0 \leq x \leq 0.1$
kσ = 1.5
kbl = life factor for bending
for steel C45
hardness ≤ 350
life = 3840×10^7
$\therefore kbl = 1$
Substitute all the values in σb
$[\sigma b] = \frac{1.4 \times 1}{2.5 \times 1.5} \times 3150$
$\sigma b = 1176$
$\boldsymbol{\sigma b = 1176 kgf/cm^2}$

Step 2: calculation of cone distance (minimum) [DDB 8.13][6]

$R \geq \varphi y[\left(\sqrt{i}^2 + 1\right)\sqrt[3]{\frac{0.72}{(\varphi_y - 0.5)(\sigma c)}}\frac{E[M_t]}{i}$
i = speed ratio or gear ratio
i = 3
$\boldsymbol{\varphi y = \frac{R}{b}}$ **[DDB 8.15]**
E = young's modulus
For C45, E = $\boldsymbol{2.16 \times 106\ kgf/cm^2}$ [DDB 8.14]
$\varphi = 3$
$[Mt] = M_t \times Kd \times k$
$K_d k = 1.3$
$M_t = 97420 \times \frac{KW}{n}$
$M_t = 97420 \times \frac{6.15}{8000} = 74.89\ kgf.cm$
$[M_t] = 74.89 \times 1.3$
$[M_t]$ = 97.35 kgf.cm
Substitute all the value in the above formula to find the (R)
R = 9.48 × 0.503
R = 4.77 cm

Step 3: calculation of minimum module [DDB 8.38]

Transverse module
R = $0.5M_t Z_1\sqrt{i^2} + 1$
where,
R = cone distance (cm)
Z_1 = no of teeth on pinion
i = gear ratio
R = 4.80 cm
Let us assume Z_1 = 14
$4.8 = 0.5M_t\ 14\sqrt{3^2}+1$
$4.8 = 22.1M_t$
$M_t = 0.2171$cm
$M_t = 2.2$mm
Standard module [DDB 8.2]
Let M_t = 4mm

Step 4: corrected centre distance

R = $0.5M_tZ_1\sqrt{i^2} + 1$
R = $0.5(0.4)14\sqrt{10}$
R = 8.85
Approx. R = 9cm > R_{min} = 4.77
Design is safe.

Step 5: calculation of average module(m_{av}) [DDB 8.13A]

$M_t = m_{av} + \frac{b}{Z_1}\sin\delta$
$M_{av} = M_t - \frac{b}{Z_1}\sin\delta$
To find b
$\varphi y = \frac{R}{b}$
$3 = \frac{9}{b}$
b = 3
To find $\boldsymbol{\delta}$ [$\boldsymbol{DDB\ 8.39}$]
$\tan\delta_2 = i$
$\delta_1 + \delta_2 = 90^{\circ}$
By calculating
$\delta = 18.43^{\circ}$
$M_{av} = [0.4 - \frac{3}{14}\sin 18.43]$
M_{av} = 0.33 cm
M_{av} = 3.3mm

Step 6: corrected design torque [M_t] [DDB 8.15]

$[M_t] = Mt\ k_d\ k$
Mt = 74.89 kgf.cm
k – load correction factor [DDB 8.15]
based on $\varphi p = \frac{b}{d_1}$
b = 3
$d_1 = Z_1(m_{av})$
$d_1 = 14(0.3)$

$d_1 = 4.2$ cm

$\varphi p = \frac{3}{4.2} = 0.714 \leq 1$

k = 1.6

k_d – dynamic load factor [DDB 8.16]

$v = \frac{\pi d_1 n_1}{60}$

$= \frac{\pi \times 0.042 \times 8000}{60}$

= 17.5 m/s

For v = 17.5m/s, $k_d = 1.1$

$[M_t] = Mt\ k_d\ k$

$= 74.89 \times 1.1 \times 1.6$

$[M_t] = 131.80$ kgf.cm

Step 7: checking for stresses [DDB 8.13]

$$\sigma c = \frac{0.72}{R - 0.5b}\sqrt{\frac{(\sqrt{i^2+1})^3}{ib} E\ [Mt]}$$

$$\sigma c = \frac{0.72}{9 - 1.5}\sqrt{\frac{(\sqrt{3^2+1})^3}{9}\ 2.15 \times 10^6 \times 131.80}$$

$$\boldsymbol{\sigma c = 3028.032 kgf/cm^2 \leq 6727.5 kgf/cm^2}$$

$\therefore$ ***design is safe***

$$\sigma b = \frac{R\sqrt{i^2+1[M_t]}}{(R-0.5b)^2\ b\ m y_v}\ \frac{1}{cos\alpha}$$

y_v = worm factor [DDB 8.18]

to find y_v we need to find Z_v

based on Z_v, pressure angle = 20°

$Z_v = \frac{z_1}{cos\delta_1} = \frac{14}{\cos 18.43} = 14.75$ approx. = 15

Standardize $Z_v = 16$, $y_v = 0.355$

$$\sigma b = \frac{R\sqrt{3^2+1(131.80)}}{(9-1.5)^2 \times 3 \times 0.4 \times 0.355}\ \frac{1}{\cos 20^\circ}$$

$$\boldsymbol{\sigma b = 166.58 kgf/cm^2 \leq 1176 kgf/cm^2}$$

$\therefore$ ***design is safe***

CAD MODEL OF THE CHASSIS

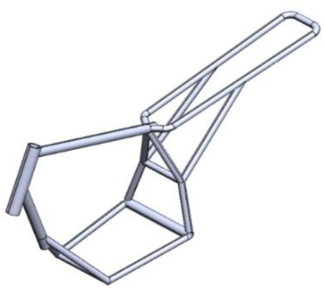

Fig.5. CAD model

Static structural analysis is a type of engineering analysis that focuses on the study of structures under static loading conditions. In this context, "static" means that the loads and conditions applied to the structure are assumed to be constant over time, and the goal is to determine the resulting stresses, strains, and deformations within the structure.[5]

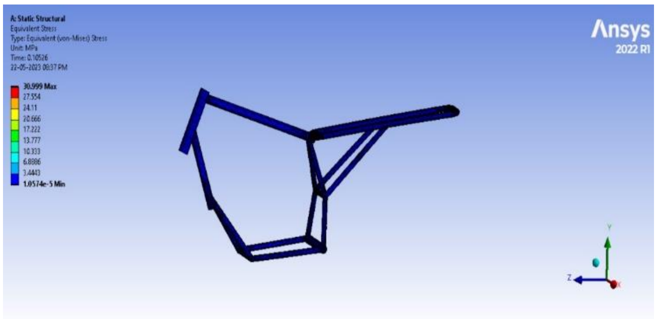

Fig.6. Structural analysis

Pipe model of chassis

Fig.7.Pipe model

CAD Design of Shaft driven transmission

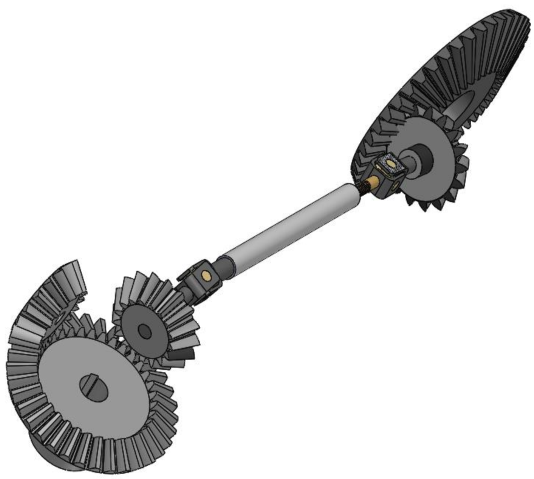

Fig.8. CAD design of Shaft drive transmission mechanism

In crafting a high-performance shaft-driven dirt bike, CAD design is paramount. Precision modelling of bevel gears, universal joints, shaft splines, and wheel hub designs ensures optimal power transfer, durability, and agility in off-road conditions. This digital approach allows engineers to fine-tune components for an exhilarating and reliable riding experience.

Comparison between chain drive and shaft drive transmission systems in Dirt bikes

Maintenance

Chain Drive: Requires regular adjustments, lubrication, and replacement, prone to wear and debris accumulation.
Shaft Drive: Significantly reduces maintenance needs, no chain adjustments, and less exposed components, minimizing wear and debris-related issues.**[2]**

Performance

Chain Drive: Offers a direct power transfer, often considered more responsive in certain off-road conditions.
Shaft Drive: Provides smoother power delivery, enhancing traction and stability, particularly beneficial in varied off-road terrains.

Safety

Chain Drive: Exposes riders to the risk of injury due to the exposed chain and sprockets.
Shaft Drive: Minimizes safety concerns by enclosing the drivetrain, reducing the risk of entanglement with debris.

Weight Distribution

Chain Drive: Generally, results in a lighter overall bike, potentially aiding manoeuvrability.
Shaft Drive: Can contribute to a slightly heavier bike, impacting agility, but advancements aim to address this concern.

Complexity

Chain Drive: Simple and well-established technology, easier for customization and repairs.
Shaft Drive: More complex mechanism, potentially limiting customization options, but advancements strive to balance complexity with performance.

While both chain drive and shaft drive systems have their merits, the choice often depends on the rider's preferences, riding style, and maintenance preferences. Advances in shaft drive technology continue to bridge the performance gap, making it an increasingly viable and attractive option for off-road enthusiasts.

Future scopes

Improved Efficiency and Performance:
Engineers might work on refining the design of shaft-driven systems to minimize power losses and improve overall efficiency.
Enhancements in materials and manufacturing processes could contribute to reduced weight and increased durability, addressing concerns about the added weight of shaft systems.

Adoption of Electric Powertrains:
With the growing interest in electric motorcycles, manufacturers might explore incorporating shaft-driven systems into electric dirt bikes.
The torque characteristics of electric motors could be well-suited for shaft-driven setups, providing a smoother and more controlled power delivery in off-road environments.

Integration with Advanced Electronics:
Future shaft-driven dirt bikes may feature advanced electronic systems, including smart traction control, stability control, and customizable power delivery settings.
Connectivity options for data logging and performance analysis could be integrated to enhance the rider's experience.

Enhanced Off-Road Capabilities:
Manufacturers could focus on optimizing shaft-driven systems for improved off-road performance, addressing concerns related to suspension travel, ground clearance, and maneuverability.
The development of variable transmission systems might allow riders to adapt to different terrains with ease.

Environmental Considerations:
As environmental awareness continues to grow, manufacturers might explore ways to make dirt bikes more environmentally friendly. This could involve the use of sustainable materials and energy-efficient technologies.

Market Acceptance and Consumer Education:
The success of shaft-driven dirt bikes will depend on market acceptance, which could be influenced by effective marketing strategies and consumer education.
Manufacturers might invest in educating consumers about the advantages of shaft-driven systems, such as reduced maintenance requirements and smoother power delivery.

Customization and Personalization:
Future designs might incorporate modular components, allowing riders to customize and personalize their shaft-driven dirt bikes according to their preferences and riding styles.

It's essential to stay updated with the latest developments in the motorcycle industry to understand how technology evolves and whether shaft-driven dirt bikes gain popularity in the market.

Results and discussion

The innovative design of shaft-driven dirt bikes presents a paradigm shift in off-road motorcycling, offering reduced maintenance needs and enhanced safety compared to traditional chain-driven counterparts. The absence of an exposed chain minimizes wear and reduces the risk of debris accumulation, promoting rider safety.

The shaft-driven system contributes to improved off-road performance, providing enhanced traction, stability, and responsiveness. Despite challenges in weight distribution and customization, ongoing research aims to optimize the design, positioning shaft-driven dirt bikes as compelling alternatives for riders seeking efficient, reliable, and exhilarating off-road experiences.

Material selection for the chassis involved a comprehensive analysis, with AISI 4130 chosen for its cost-effectiveness, reliability, and availability. The design calculations and ANSYS analysis ensured the structural integrity of the shaft and bevel gear mechanism.

The comparison between chain and shaft drive systems highlights the advantages of reduced maintenance, enhanced safety, and improved performance offered by shaft-driven dirt bikes. Future scopes include further advancements in efficiency, integration with electric powertrains, enhanced off-road capabilities, and increased market acceptance through consumer education.

In summary, the innovative design and ongoing research in shaft-driven dirt bikes signify a transformative era in off-road motorcycling, balancing performance, safety, and environmental considerations.

Conclusion

Finally, research into shaft-driven dirt bikes represents a major step forward for off-road motorcycling by bringing a design that reduces maintenance requirements, boosts rider safety, and enhances overall performance. The innovative shaft and bevel gear design solves issues with standard chain-driven systems and offers riders a strong substitute. The thorough material selection, structural analysis, and design process all add to the system's dependability and effectiveness. The benefits of lower maintenance and increased safety provided by shaft-driven devices are highlighted by contrast with chain-driven competitors. Looking forward, the future scope holds potential for greater breakthroughs in efficiency, integration with electric powertrains, and increased market adoption through consumer education. Shaft-driven dirt bikes are a revolutionary force in the off-road industry, providing off-road riders with a combination of efficiency, dependability, and an exciting riding experience as technology advances.

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