Development of Multipurpose Off-road Vehicles MULE PRO Series

Since 2009, the market for multipurpose off-road vehicles (Side × Side vehicles) has been growing in the U.S.A. Targeting the utility vehicle market among them, Kawasaki has developed and marketed the MULE PRO Series, achieving a leap forward in its multipurpose off-road vehicles business. The MULE PRO Series is our first utility vehicle that can achieve a top speed of over 40 km/h. The engine power was increased with assuring vehicle performance comfortable and a new transformation mechanism was adopted.

Introduction

Because of an aging customer base, the U.S. powersports market is shifting from conventional motorcycles and ATVs (All-Terrain Vehicle) to multipurpose off-road vehicles (Side × Side vehicles). Side × Side vehicles are largely classified into utility vehicles and recreational vehicles, and the utility vehicle market is expected to increase to approximately 380,000 units by 2023. In addition, the demand for higher maximum speeds is increasing recently.

1 Background

Since the sale of the MULE 1000 began in 1988, Kawasaki's utility vehicles have been highly regarded in the market for their durability. In addition, Kawasaki has adopted several engine types and seat arrangements to meet diversifying market needs. In recent years, it is becoming essential to meet the demand for higher maximum speeds (over 40 km/h).

2 Development concept

In developing the MULE PRO series, inheriting the features of the previous MULE models, we set "meeting the recent demand for higher maximum speeds" and "developing a common platform" as concepts, and in addition, set "Durable, Stable, Comfortable, Dependable Work-horse" as development keywords.

(1) Meeting the demand for higher maximum speeds

We aimed to significantly improve engine performance, including an increased maximum speed (over 40 km/h), from the previous MULE models. In addition, we increased the wheelbase, tread, wheel travel, and tire size and changed the front and rear brake types to achieve chassis performance that fits the improved engine performance. **Table 1** compares the major specifications of the previous MULE model and the MULE PRO series.

(2) Developing a common platform (frame)

We decided to develop a profitable common platform that could be used for multiple engine types and seat arrangements. **Table 2** shows specific combinations of engine types and seat arrangements, and **Fig. 1** shows a schematic shape of the frame. We decided to provide a wider space for the engine behind the rear seat as shown in the figure and design the frame so that it can easily be extended and shortened near the longitudinal center.

(3) Realizing the development keywords

(i) Durability

We decided to focus on improving the water and mud protection of the engine and drive train and the strength and durability of the CVT (Continuously Variable Transmission) belt, axles, steering system, and suspension system.

(ii) Stability

We decided to achieve high stability and a secure steering feel at the same time.

Table 1 Comparison of major specifications against the previous MULE model

Item	MULE PRO-FXT (AF820C)	MULE 4010 TRANS4×4 (AF620R)
Maximum power	× 2. 38 (compared with MULE 4010)	Basis for comparison
Maximum torque 〔N·m〕	65/3, 500min^{-1}	47/2, 500min^{-1}
Maximum speed	+ 32km/h (compared with MULE 4010)	Basis for comparison
Wheel base 〔mm〕	2, 345	2, 165
Tread (F/R) 〔mm〕	2, 300	1, 160/1, 180
Wheel travel (F/R) 〔mm〕	222/217	100/70
Tire size (F/R)	26 × 9. 00 - R12/26 × 11.00 - R12, radial	23 × 11. 00 - 10, bias
Brake type (F/R)	Disk	Drum

Table 2 Engine type and seat arrangement

Engine type		Seat arrangement	
		Single-row seat model (three seats)	Double-row seat model (3 or 6 seats)
Gasoline	812cm^3	2016MY MULE PRO-FX	2015MY MULE PRO-FXT
	Four-stroke		
	Water-cooled in-line three-cylinder		
	DOHC, four-valve		
Diesel	993cm^3	2016MY MULE PRO-DX	2016MY MULE PRO-DXT
	Four-stroke		
	Water-cooled in-line three-cylinder		
	OHV, two-valve		

※ MY：Model Year

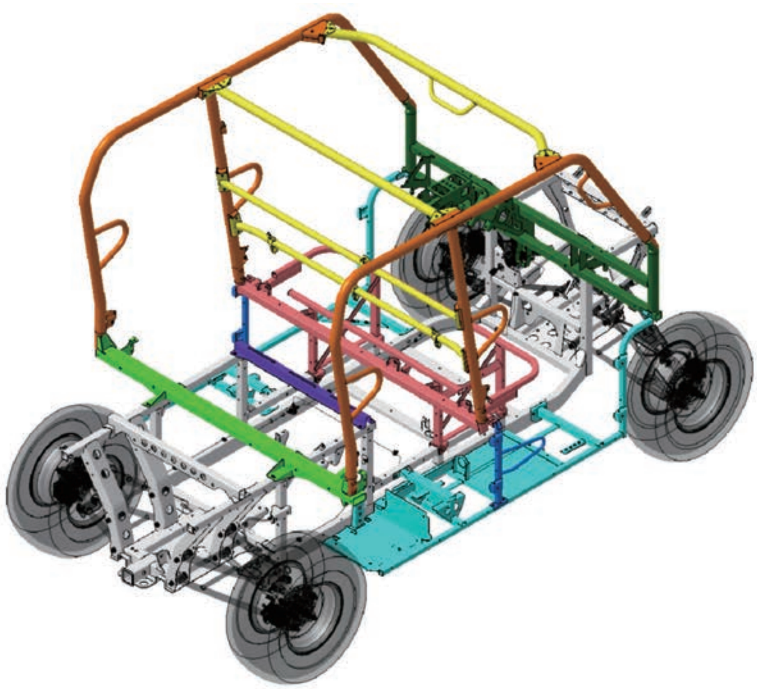


Fig. 1 Schematic shape of frame

(iii) Comfort

We decided to achieve easy-to-handle engine characteristics through optimizing the intake and exhaust systems as well as FI (Fuel Injection) and CVT settings; excellent capabilities with a highly dynamic ground clearance; adequate mud protection with doors; and a versatile, easy-to-handle vehicle with a new transformation mechanism.

3 Technical challenges

To realize the development concepts and development keywords, we set many technical goals for ourselves when we started the design and development.

(1) Increasing the gasoline engine power

For efficient development, we adopted one of CHERY's engines developed for passenger cars and the ECU (Electronic Control Unit) for controlling this engine as a set. We needed to improve the engine and ECU so that they could meet Kawasaki's design standards, and modify the ECU program and its settings so that the ECU could meet the requirements for off-road vehicles.

(2) Improving diesel engine reliability

The diesel engine adopted for the MULE PRO series does not require ignition and uses a mechanical fuel injection system, so it requires many electrical devices that gasoline engines do not have, such as a stop solenoid, which cuts off the fuel supply to stop the engine, and a glow plug, which is used for preheating. These devices needed to be controlled in an integrated manner in terms of cost and reliability.

(3) Improving the strength and reliability of the drive train

In off-road environments, there is much uncertainty in the road surface and vehicle usage, and the drive train may be subjected to an impact load. The rubber belt CVT, which was adopted for the MULE PRO series, has an advantage in that the vehicle can continue to run even if the belt slips to some degree on the sheave, but we needed to pay particular attention to the service life. In addition, the axle was required to have adequate strength because, depending on the road surface, the wheels may decelerate rapidly, causing damage to the axle due to inertia absorption.

(4) Ensuring lateral stability

The MULE PRO series has a seating capacity of six for the first time among Kawasaki's Side × Side vehicles, and we needed to ensure adequate lateral stability when turning not only with one passenger but also with six passengers.

(5) Developing a new transformation mechanism

In 2006, Kawasaki began selling the MULE TRANS 4 × 4 series, a Side × Side vehicle whose main feature is that it can transform between single-row seat mode (two seats) and double-row seat mode (four seats), ahead of competitors. Although the MULE TRANS 4 × 4 series has a shorter wheel base than competing vehicles, this series can be transformed between these seat modes by moving the screen at the front of the cargo bed back and forth. In developing the MULE PRO series, we improved this transformation mechanism significantly for improved ease of handling.

4 Processes of solving the technical challenges

(1) Increasing the gasoline engine power

To adopt CHERY's ECU for the off-road utility vehicle MULE PRO series, we modified the ECU program and at the same time significantly modified control-related settings.

① We achieved the engine power feeling characteristics that permit high vehicle performance during high-speed driving as shown in **Fig. 2**; the FI settings that can meet the exhaust emission regulation standard without sacrificing the feeling of power; and excellent cold startability, which is essential for working use.

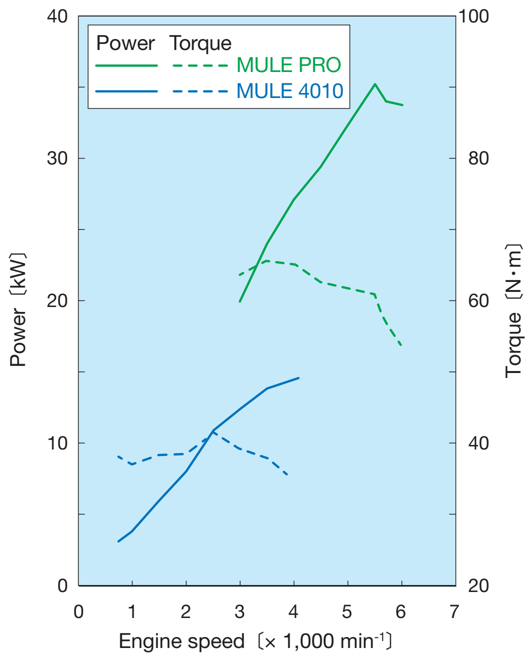


Fig. 2 Engine performance curve

② We added off-road vehicle functions that enable switching between 2WD and 4WD, switching between rear differential lock modes and stopping the engine if the vehicle rolls over.

③ For ease of maintenance in the market, we added the KDS (Kawasaki Diagnostic System) function, which enables failure diagnosis if there is a problem with the FI system.

④ For intake and exhaust system parts, which greatly affect the engine performance, we developed our own unique specifications to match the ECU settings, thereby achieving very easy-to-handle power characteristics.

(2) Improving the reliability of the diesel engine

We developed a new vehicle controller that controls switching between 2WD and 4WD, and rear differential lock modes as we did for the gasoline unit. Moreover, this controller also controls electric devices specific to diesel engines, such as the stop solenoid, glow plug, starter interlock control, and fuel pump, in an integrated manner. This has eliminated the need for many electric devices, such as relays, achieving both low cost and high reliability.

(3) Improving the strength and reliability of the drive train

(i) CVT settings for achieving high belt strength and good ratio change feeling

Figure 3 shows the structure of the CVT. We made the CVT settings so that the required performance, including feeling of acceleration, shifting to low during rapid acceleration, and engine braking, could be satisfied, and in addition, we were able to prevent the squealing that occurs due to the belt slipping. At this time, we optimized the belt clamping force by adjusting the drive-side pulley weight shape, spring load, and driven-side torque cam angle, spring load so that the load on the belt would not increase. We optimized the settings individually for the gasoline and diesel engines according to their engine characteristics.

(ii) Improving air introduction efficiency in the CVT chamber

We optimized a fin on the back of the drive-side fixed sheave and the case shape around the fin in the CVT chamber so that air swirls from around the drive pulley to around the driven pulley, and is discharged from the CVT chamber without getting stagnant. This has provided adequate cooling performance, significantly improving the life of the CVT belt.

(iii) Achieving top-level axle strength in its class

Taking cost and weight into consideration, we achieved top-level axle strength in this class while maintaining the strength balance throughout the entire drive train. **Figure 4** shows a comparison with the previous MULE model.

(iv) Adopting a highly durable CVT belt

We adopted a new CVT belt developed by Mitsuboshi Belting Ltd. that is four times more durable than the CVT belt of the previous MULE model.

(4) Ensuring lateral stability

We adopted a wide tread (see **Table 1**) and at the same time adopted high strength material to reduce the weight of the ROPS (Roll Over Protective Structure), which constitutes part of the upper structure, thereby achieving a lower center of gravity of the vehicle. Moreover, from early on in the design planning stage, we conducted a desk analysis simulating steady state turning to optimize the center of gravity of the vehicle and the alignment of the suspension system, thereby achieving a slight "under

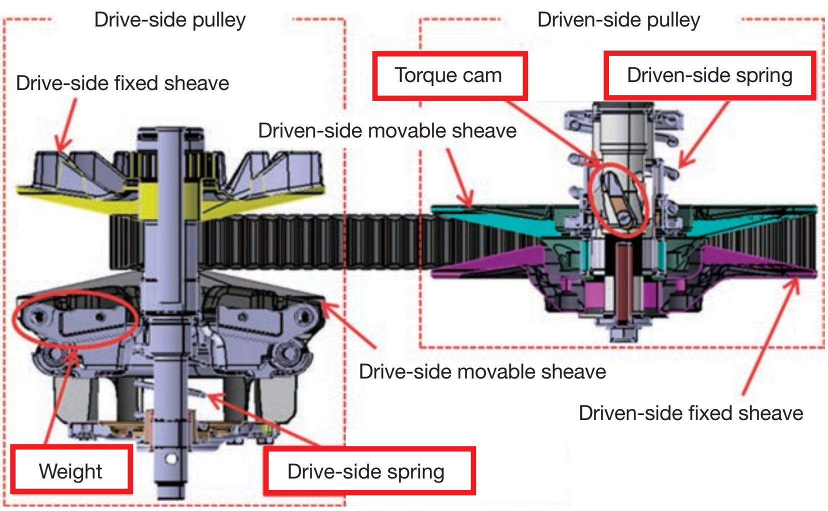


Fig. 3 Structure of CVT (main unit)

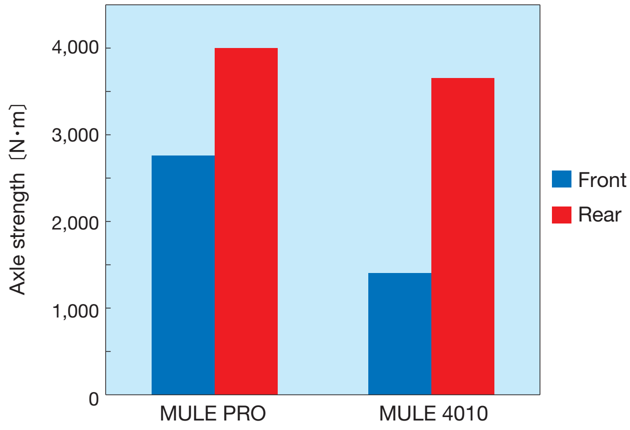


Fig. 4 Comparison of axle strength

steer" characteristic. **Figure 5** shows an example of the measurement results obtained in a vehicle handling test conducted according to the OPEI (Outdoor Power Equipment Institute) standards. From this figure, it can be seen that stable turning has been achieved without increasing the yaw rate rapidly even at a high lateral acceleration range.

(5) Developing a new transformation mechanism

With ensuring its durability in off-road environments, we developed an easy-to-handle, simple transformation mechanism that allows one person to transform the vehicle in one trip around the vehicle in one minute ("1:1:1" policy). More specifically, we changed the screen behind the rear seat from the detachable type to the slide type so that the screen can be moved by one person from one side whereas the screen was moved by two people from both sides before. **Figure 6** shows the right rear views of the screen and cargo bed.

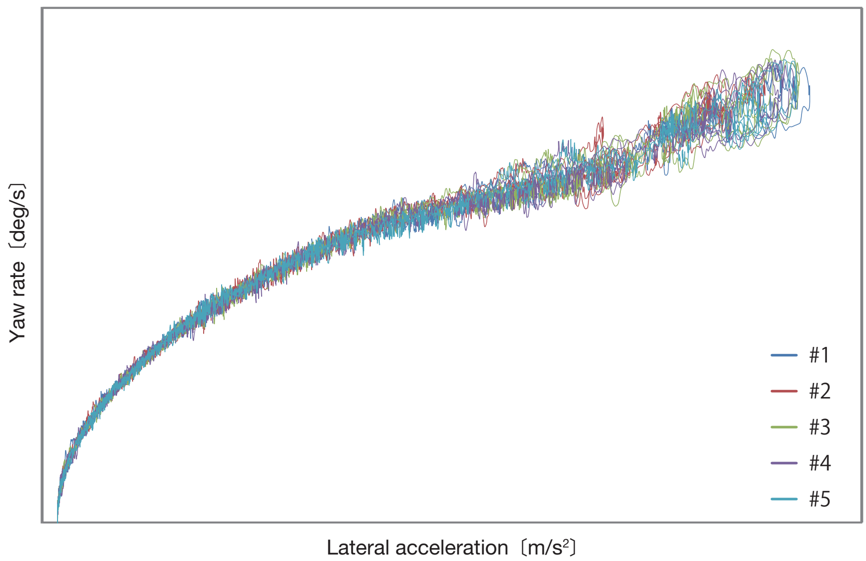
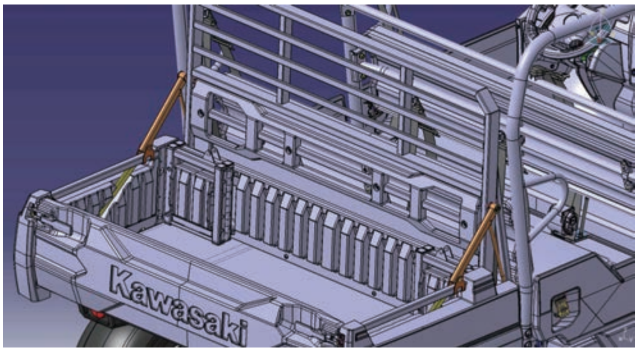
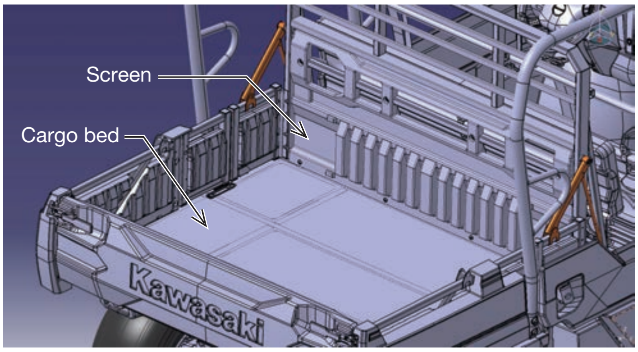


Fig. 5 Example of measurement results of vehicle handling test



(a) Double-row seat mode



(b) Single-row seat mode

Fig. 6 Screen and cargo bed

Kazumasa Hisada
Design Department 3,
Research & Development Division,
Motorcycle & Engine Company

Keiji Takahashi
Design Department 3,
Research & Development Division,
Motorcycle & Engine Company

Seiji Itoo
Design Department 1,
Research & Development Division,
Motorcycle & Engine Company

Yuji Kouma
Research & Development Administration Department,
Research & Development Division,
Motorcycle & Engine Company

Conclusion

Since we began mass-producing the MULE PRO-FXT as the first MULE PRO series model in 2014, we have developed four vehicle models using a common frame.

In addition, we added the MULE PRO-FXR in 2017, which has a shorter wheel base with a shorter frame than the MULE PRO-FXT, increasing model variations. Currently, the annual sale of these models has reached several tens of billions of yen, allowing Kawasaki's four-wheel vehicle business to grow rapidly. Moreover, in 2018, we began mass-producing the MULE PRO-MX, which has adopted a new engine and frame, as a mid-size model of this series.

We will be making continuous improvements to further enhance customer satisfaction.