

Introduction of CRF450R Equipped with 4-Stroke Engine

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ABSTRACT

The first 4-stroke engine motocrosser (CRF450R) in Honda was developed focussing on the fastest motocrosser for all motocross races and to enable riding without stress according to the rider's intention. The development targets were to obtain a linear characteristic in torque and traction, which was controlled easily by adopting the 4-stroke engine, and to achieve the equivalent power-weight ratio to the 2-stroke engine motocrosser of the same race class. A lightweight forged piston with an extremely short skirt, a valve train of SOHC 4-valve engine (UNICAM system), titanium inlet valves, and a separated lubrication system for both the crankcase and the transmission were adopted in the engine as means to get a linear characteristic in torque and high power. As a result, 29.5 kg of engine mass and 41 kW of maximum power were achieved. Engine startability via the kick-starter was also improved by adopting a newly developed auto-decompression system. A total vehicle mass of 102 kg was realized by lightening each part of the frame body and suspension through techniques such as a newly shaped aluminum frame and a titanium exhaust pipe.

1. Introduction

The 2-stroke motocrosser is presently the mainstream for motocross racers. However, in light of the demand for a cleaner motocrosser Honda has developed a new type of motocrosser equipped with a 4-stroke engine.

2. Development Concept

Since motocross has jump sections and series of tight corners, the greatest emphasis is placed on a compact frame body and low weight. No matter how superior its engine's power characteristics, a motocrosser that is large and heavy

will be difficult to race. Motocross also involves riding on slippery offroad surfaces, so even though maximum power is required, it is also of great importance to have linear torque and traction characteristics that allow easy handling. In order to satisfy these requirements, the aim was to achieve a vehicle body size and power-weight ratio on a par with 2-stroke motocrossers, together with the power characteristics of a 4-stroke engine, which make for easy handling in a motocrosser.

This development concept for the CRF450R, Honda's first 4-stroke motocrosser, was further defined as follows:

- A motocrosser that is the fastest even beyond its class
- Easy to handle and refreshingly fun to ride

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3. Model Overview and Objectives

Fig. 1 shows an external view of the CRF450R, and Table 1 gives the major specifications. The vehicle was made equivalent to the 2-stroke motocrosser CR250R in size. In determining the vehicle mass and maximum power, the positioning of the power-weight ratio in relation to various classes of displacement, comparison of the mixed racing results and lap times in every class were taken into account. A target of 102 kg was set for vehicle mass and 41 kW for maximum power, in addition to the goal of linear torque characteristics. Fig. 2 shows the power-weight ratio comparisons. The 4-stroke engine has a higher compression ratio and fewer igniting chances, firing once out of every two crankshaft revolutions, so it was necessary to improve the startability using the kick-starter. It was desirable to provide



Fig. 1 External view of CRF450R

Table 1 Major specifications

Items		Specifications
Overall length	(mm)	2 187
Overall width	(mm)	825
Overall height	(mm)	1 254
Wheelbase	(mm)	1 488
Seat height	(mm)	945
Ground clearance	(mm)	331
Vehicle dry mass	(kg)	102
Engine type		Liquid cooled 4-stroke OHC single cylinder
Engine displacement	(cm ³)	449
Bore x Stroke	(mm)	96 x 62.1
Compression ratio		11.5 : 1
Valve train		SOHC 4valve
Max.power	(kW/r/min)	41/9 000
Max.torque	(Nm/r/min)	49.8/7 000
Carburetor type		FCR40
Fuel capacity	(L)	7.4
Clutch type		Wet multi-plate type
Transmission		5 speed constant mesh
Caster angle		27° 50'
Trail length	(mm)	114
Tire size	Front	80/100-21 51M
	Rear	110/90-19 62M
Brake system	Front	Single 240mm disc with twin-piston caliper
	Rear	Single 240mm disc
Suspension	Front	Telescopic
	Rear	Pro-link
Frame type		Aluminum twin-tube

fast restarting to recover from stalls due to over-braking or falls during motocross races. The goal was set for startability using the kick-starter on a par with 2-stroke engines in order to make the bike enjoyable for a wider range of riders.

4. Engine

The width, length, and height of the engine were set to make it a size that could be mounted on the CR250R platform. In terms of mass, the target mass for the completed vehicle was set, and the various individual targets for engine, frame body, suspension, and electric equipment were then assigned accordingly. The target engine mass was set at 29.5 kg. Fig. 3 shows a cutaway drawing of the engine as a whole.

The engine speed at maximum power was held to a low 9,000 r/min to emphasize rear wheel traction and instantaneous acceleration characteristics. The bore/stroke was set to 96 mm × 62.1 mm and the engine displacement to 449 cm³ in order to achieve the target power of 41 kW. Fig. 4 shows the engine performance curve.

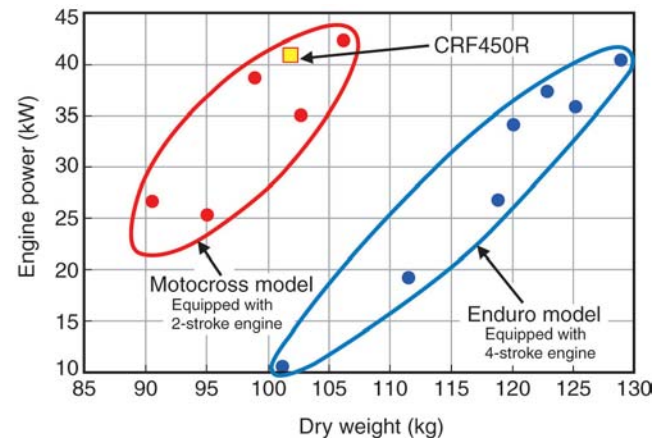


Fig. 2 Comparison of power-weight ratio between motocross models and enduro models

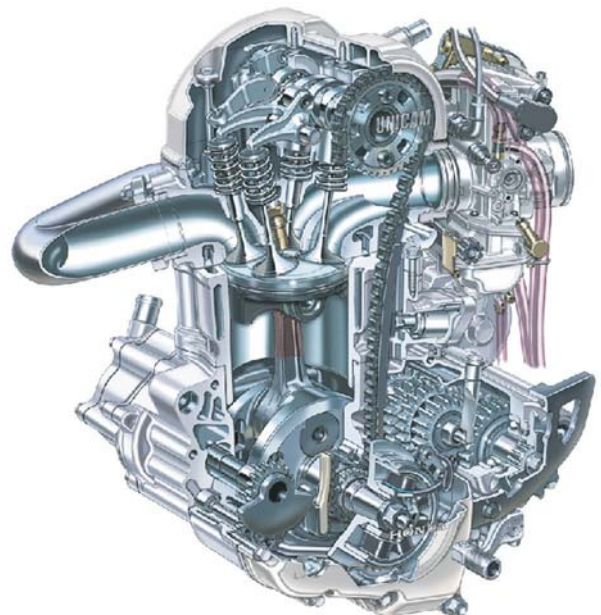


Fig. 3 Cutaway drawing of CRF450R engine

Fig. 5 presents a comparison of engine size with the XR400R, an earlier 4-stroke engine with the same displacement. The CRF450R achieved an engine weight reduction of 23% relative to the XR400R, an improvement of 53% in maximum power, and an improvement of 31% in maximum torque.

The valve timing and intake-exhaust assembly were optimized, friction was reduced, and other such measures were taken to enhance power and speed without degrading the linear torque characteristics of the 4-stroke engine. A torque contour that included partial gate opening ranges was used as a guide for linear torque characteristics. Torque characteristics allowing for easier handling were achieved by selecting those characteristics that yielded a contour with uniform pitch. Fig. 6 presents a comparison of torque contours with the 2-stroke CR250R.

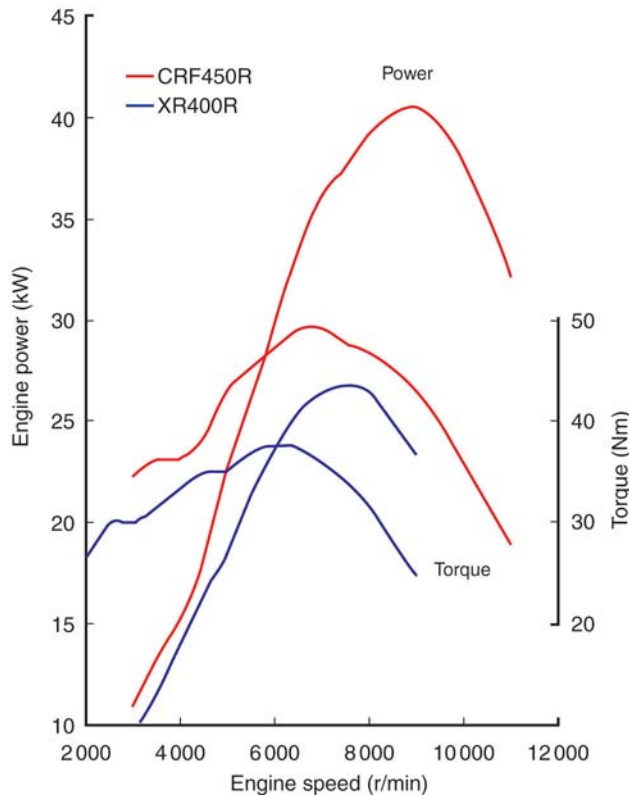


Fig. 4 Engine performance curve

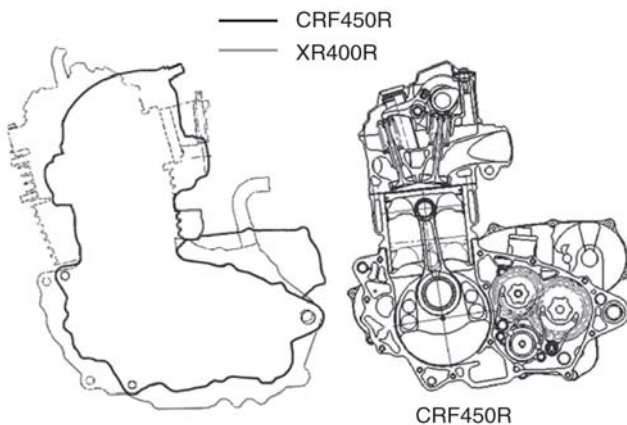


Fig. 5 Comparison of engine size

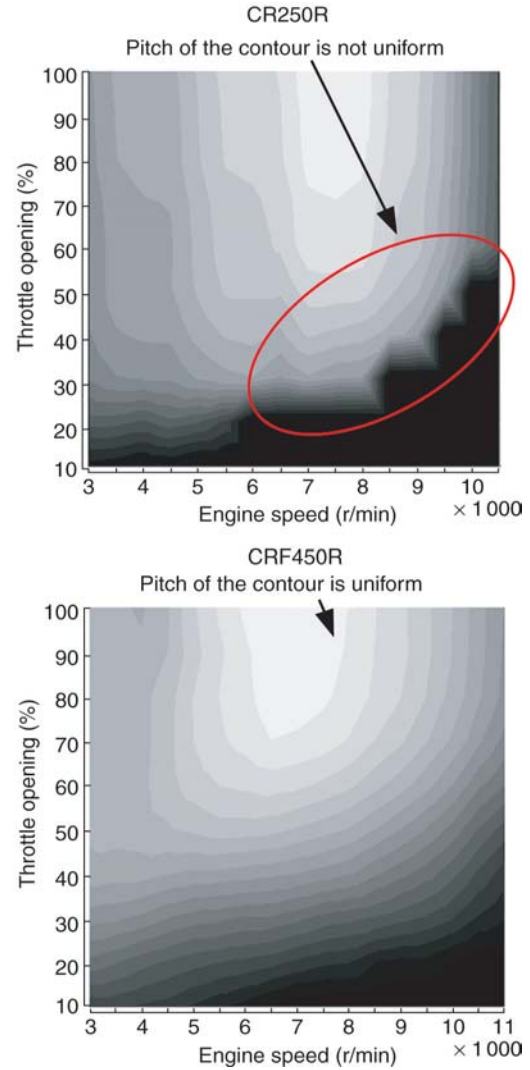


Fig. 6 Torque contour

4.1. Valve Train System

Fig. 7 gives an overall view of the valve train system. Adoption of DOHC for the valve train system is one method for achieving higher speed than in conventional single-cylinder engines. With DOHC, however, separate camshafts become necessary for intake and exhaust assemblies, which is inappropriate in terms of weight reduction. For the CRF450R, titanium valves were used on the intake side where the large valve diameter is disadvantageous at high speeds, and they were made directly actuated for greater stability of behavior. The exhaust side was given an SOHC configuration that uses a rocker arm. The cam holder was made as a single diecast unit with the valve lifter hole and rocker arm shaft supports. This is called the UNICAM system, for unit-type cam. The camshaft shown in Fig. 8 uses SCM carburizing and quenching rather than the conventional FC to increase fatigue strength while thinning the walls to the limit. The overall valve train system achieved a 376 g weight reduction relative to a DOHC layout.

The rocker arm is a roller type with a forked structure. The spark plug hole is located between the forks so that the spark plug can be centered for greater flame spread speed. This valve train system allows the valves to be set at a narrower angle than the DOHC layout, at 21.5° . This makes the combustion chamber more compact, and contributes to the higher compression ratio and higher output power.



Fig. 7 UNICAM system



Fig. 8 External view of camshaft

4.2. Dual Lubrication Systems

As shown in Fig. 9, the crankcase was developed as an extension of the closed crankcase used in the XR650R.⁽¹⁾ The balancer is placed outside the crankcase and the pressure inside the crankcase is allowed greater variation in order to improve oil discharge performance. Taking advantage of the closed construction of the crankshaft, which has oil seals at both ends, a dual lubrication system was adopted that separates the lubrication on the crankshaft and piston side from that on the transmission and clutch side. For the crankshaft, piston, and valve train system, a trochoid pump similar to those in conventional engines is used for pressurized oil delivery. Fig. 10 shows the structure of the oil pump. An oil bath lubrication like that in a 2-stroke engine is used for the transmission and clutch side. Despite the compactness of the crankcase, the space between the left side crankcase and the cover on that side is used as an oil tank so that stable lubrication can take place even throughout the severe changes in frame body angle that occur during motocross races. A housing was created on the crankcase joint surface and used as the oil pump body to make it 147 g lighter than the conventional structure.

4.3. Shorter Piston Skirt and Lighter Forged Piston

In order to make the engine more compact, it was necessary to reduce the mass of the reciprocating parts. The slipper-shaped, ultra-short skirt piston shown in Fig. 11 is

36 mm in height with a bore of 96 mm, and achieved a weight of 267 g, or a reduction of 108 g over a piston with a conventional design. Fig. 12 shows the relationship between piston bore and piston mass for conventional models. Optimization of the piston profile, correct adjustment of lubrication, reduction in lateral pressure of the piston skirt, and correct adjustment of the clearance between the small end of the connecting rod and the piston pin boss made it possible to use this short skirt.

4.4. Automatic Decompression System

The heavy force on the kick pedal and insufficient igniting chances had been existing issues for the conventional 4-stroke engine. In order to address them, a unique pin-rotational type automatic decompression system was adopted. Fig. 13 shows the system structure, and Fig. 14 shows the decompression cam. This system provides improved cold starting and hot restarting on a par with 2-stroke engines.

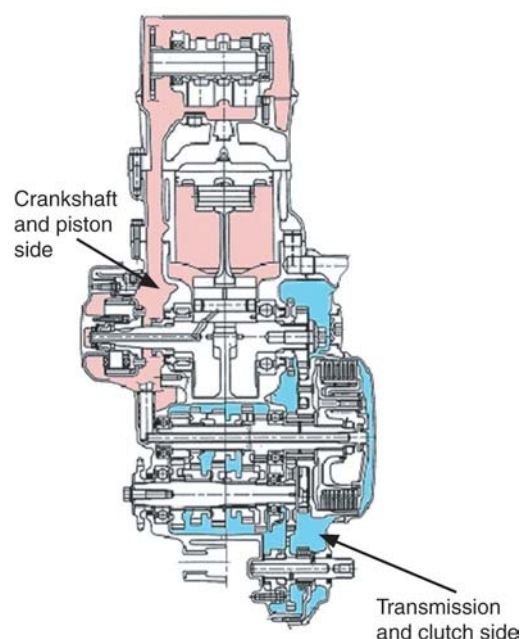


Fig. 9 Structure of dual system lubrication

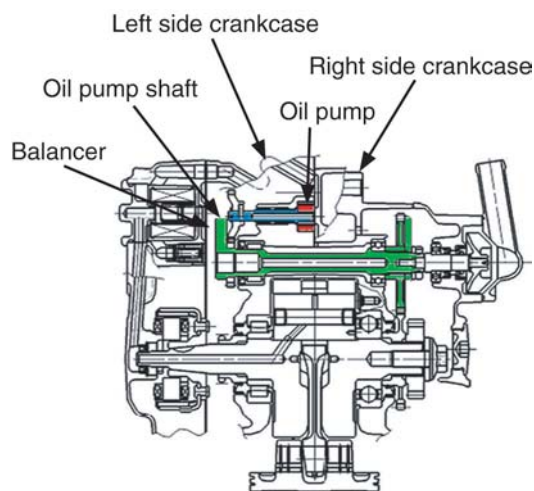


Fig. 10 Structure of built-in oil pump

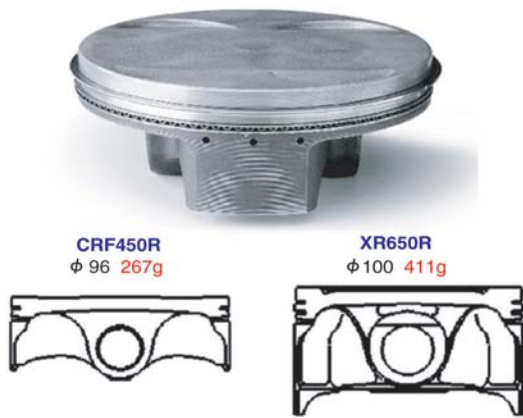


Fig. 11 Short skirt piston

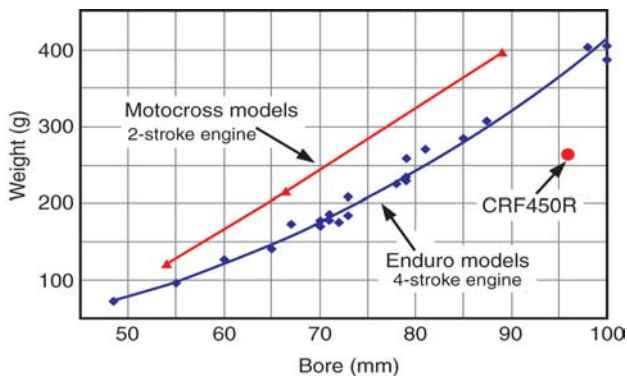


Fig. 12 Relation between piston bore and weight

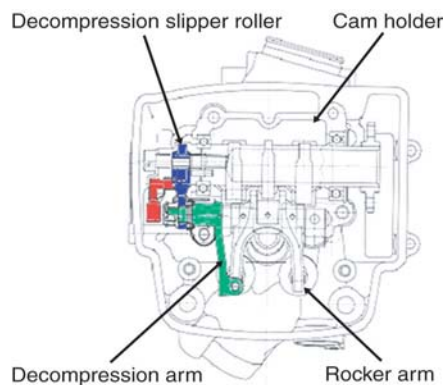


Fig. 13 Structure of automatic decompression system

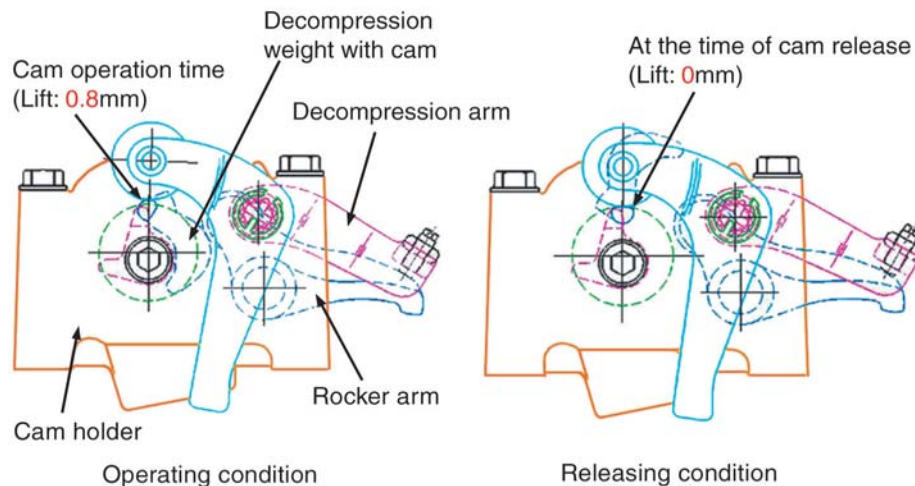


Fig. 15 Operation of automatic decompression system

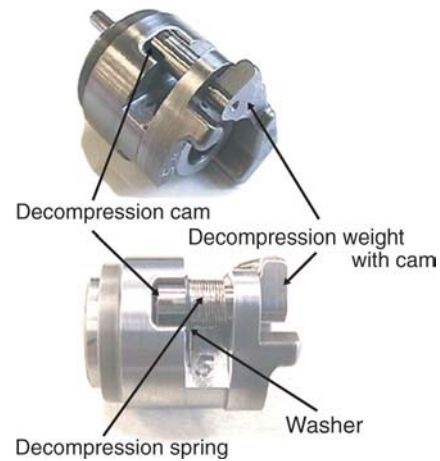


Fig. 14 Decompression cam

Fig. 15 shows the operation of the system. When starting, the decompression cam formed from a pin, works through the decompression slipper roller to press the rocker arm on the exhaust side. This reduces the pressure inside the cylinder and reduces the amount of force on the kick pedal. After starting, centrifugal force causes the decompression weight, which is integrated with the pin, to turn and release the decompression cam. The issue of igniting chances is addressed by adjusting the operating range and the lift of the decompression cam to the proper amount, which provides a significant improvement compared to operation without a decompressor. Fig. 16 shows the relationship between the force on the kick pedal and the crank turning force for different crank angles with and without the decompression system.

4.5. Crankshaft and Connecting Rod

The crankshaft was changed from the conventional S48C induction hardened material to SCM420H carburization and quenching hardened material in order to reduce the weight while providing the same fatigue strength. The connecting rod has different requirements for fatigue strength at the big end and the small end, and a balance between fatigue strength and weight reduction was sought by varying the depth of heat treatment in these areas. This achieved a reduction of 262 g in the mass of the crankshaft alone compared to conventional crankshafts. Fig. 17 gives an external view of the crankshaft.

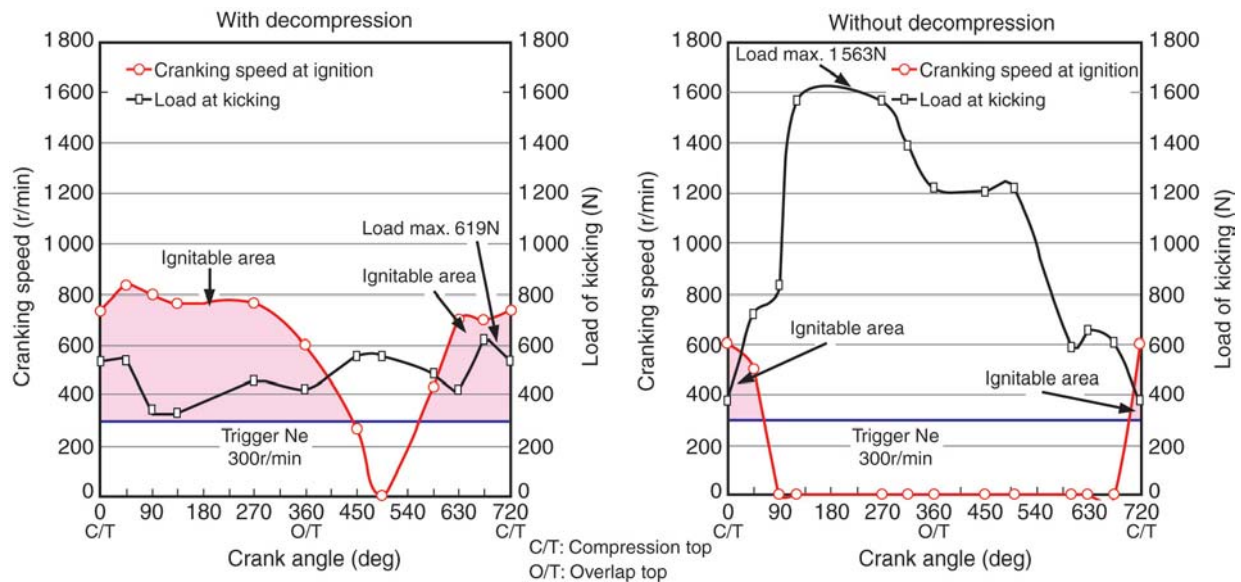


Fig. 16 Comparison of ignitable area, with or without decompression system



Fig. 17 External view of crankshaft



Fig. 18 FCR carburetor

4.6. Flat Slide Valve Carburetor

The flat slide valve of the FCR carburetor made by Kehin is equipped with four rollers on both sides to provide sharp response and enable light, smooth throttle operation. A separate route is also provided as a fresh air induction path in order to improve startability by adjusting the air-fuel ratio to the proper level when hot starting the engine or starting after a fall. Fig. 18 shows an external view of the carburetor, and Fig. 19 shows the geometry of the fresh air induction path.

4.7. Hot Start Lever

A hot start lever is provided for easier starting of a hot engine and restarting after a fall as described in section 4.6. This device opens a fresh air induction path to the carburetor in order to adjust the air-fuel ratio to the proper level when starting a hot engine or restarting after a fall. This lever was previously an integral part of the carburetor. For the CRF450R, the hot start lever is connected through a cable to the carburetor and mounted coaxially with the clutch lever in a location where riders can operate it without removing their hands from the handlebars. Not only does this help avoid operating mistakes, but it also makes it possible to operate the hot start lever simultaneously with the clutch lever when restarting after a fall, so that the bike can be restarted quickly in any gear. Fig. 20 shows how the hot start lever is mounted.

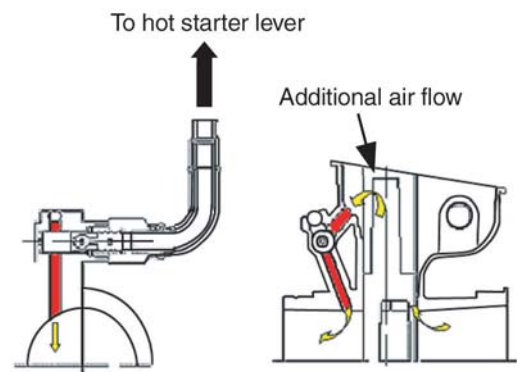


Fig. 19 Fresh air induction path



Fig. 20 Hot start lever

4.8. Ignition System

The ignition system utilizes a highly accurate 8-bit electronic control unit (ECU) that incorporates capacitive discharge ignition (CDI). This provides the optimum ignition timing suited to throttle opening and engine speed. Fig. 21 shows the map of the ignition timing.

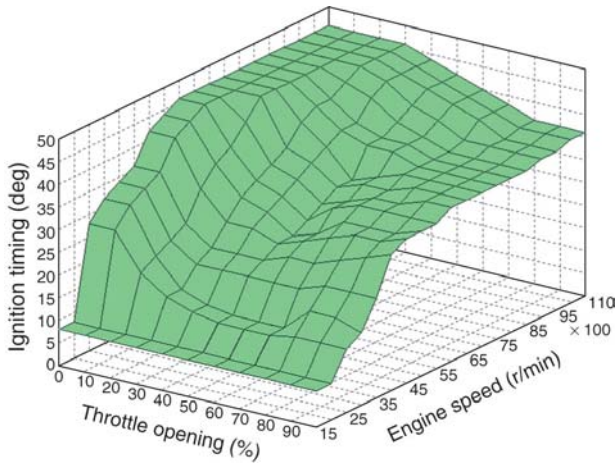


Fig. 21 3-D map of ignition timing

5. Vehicle Body

In order to realize the development concept of a motocrosser that is easy to handle and refreshingly fun to ride, the objective was to attain a body size and vehicle mass equal to the CR250R 2-stroke motocrosser, which has a high competitiveness that has been developed over many years. Further objectives were easy-to-control turning characteristics and reduction of bump impact.

5.1. Vehicle Dimensions

In order to provide free maneuvering performance, the engine mounting position was determined using the dimensions of a 2-stroke motocrosser as a basis and with consideration for the optimum location of the engine center of gravity, ground clearance in order not to interfere with rough-road running ability, fuel tank capacity sufficient to complete a race, and other such conditions. This resulted in vehicle dimensions generally the same as the CR250R and realization of stability when going straight that takes advantage of the traction characteristics of a 4-stroke engine, turning characteristics equal to a 2-stroke motocrosser, and good handling characteristics resulting from a compact body. Fig. 22 shows the vehicle dimensions.

5.2. Frame Body

The CRF450R frame body was enhanced based on the aluminum semi-double-cradle twin-tube frame used for the CR250R. Fig. 23 shows an external view of the frame body. In order to have an optimum balance of rigidity and strength, a tapered tube fabricated by the swaging process used for swing arms was selected for the down tube. A cross member was added to the center part of the frame, and this cross member was integrated with the rear cushion bracket. This created the space required for mounting a 4-stroke engine without altering the frame width and size. Not only does this structure provide the space layout, but it also contributes to

the proper degree of deflection. Together with the down tube described above, this optimizes longitudinal rigidity, lateral rigidity, and torsional rigidity, and realizes high stability and easy-to-control turning characteristics.

The compact steering head pipe made of forged aluminum was newly designed following reevaluation of the joint structure on the 2001 model of the CR250R. In order to reduce weight and reduce bump impact while riding, a large opening was also made in the inside wall, as shown in Fig. 24, and the frame was given the proper rigidity balance. This made it possible to achieve a high-order balance of agile steerability and stability. The mass of the frame body was reduced by 200 g.

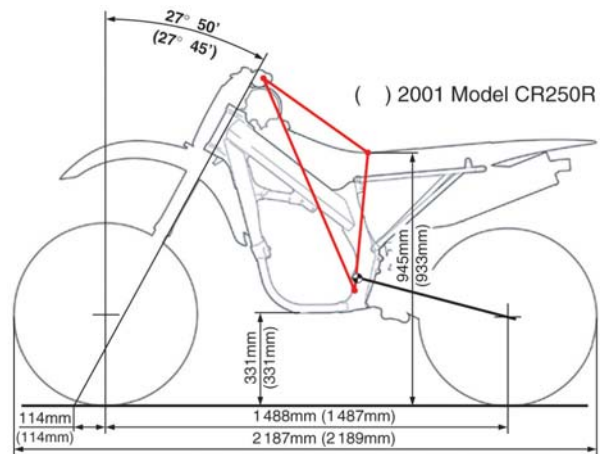


Fig. 22 Geometric dimension of CRF450R



Fig. 23 External view of frame



Fig. 24 Forging aluminum steering head pipe

6. Suspension System

Suspension performance, strength and durability are of great importance for motocrossers, which ride on rough roads, jump, and so on. In terms of performance, the suspension is required to undergo constant improvement for maneuverability, stability, and rough-road running ability. Continuous efforts are being made to reduce weight and increase rigidity as one means for achieving this end.

In general, mounting a 4-stroke engine will cause higher traction and a heavier engine so that the suspension will have a higher spring rate and becomes heavier. The CRF450R suspension, however, has been optimized for rigidity and strength, yielding a weight reduction of 1,260 g over the CR250R. This has realized a mass of 45.8 kg, which is on a par with 2-stroke motocrossers.

6.1. Rear Suspension

The rear suspension is of the swing-arm type with an axle stroke of 315 mm. A single shock absorber of the remote reservoir gas presser risen type, with a piston that is 50 mm in diameter, is located at about the center of the frame body. It is equipped with adjusters that allow separate tuning of low-speed and high-speed compression damping force, and tuning of the tension damping force. The shock absorber is attached to the swing arm by means of a linking device known as the PRO-LINK, which changes the shock absorber stroke progressively according to changes in the axle. This PRO-LINK was given shanks with a low-load design and was optimized for link ratio, yielding a superb ride feel and rough-road running ability. In order to provide ground clearance and to achieve low weight and low positioning of the rear caliper, the swing arm was shaped with a vertically asymmetrical taper. Fig. 25 shows the layout of the rear suspension.

6.1.1. Swing arm

The objectives for the swing arm were in the direction of increasing torsional rigidity, lateral rigidity, and weight reduction. The front portion of the structure utilizes AC4CH-T6 cast aluminum, which allows design freedom and high durability, and the rear portion utilizes tapered tube with tensile strength of 380 MPa that has been processed by non-rotating dies swaging manufacturing method. The target rigidity was achieved with the minimum mass by applying CAE to perform repeated calculations of rigidity and mass. This made it possible to optimize the thickness of each part of the swing arm and to locate the ribs properly so that the torsional rigidity was improved by 15%, the lateral rigidity was improved by 4%, and the weight was reduced by 200 g compared to the CR250R. As a result, the CRF450R achieved an improvement of 18% in the mass-rigidity ratio, a figure that shows design efficiency. Fig. 26 shows an external view of the swing arm.

6.2. Front Suspension

The front suspension is a telescopic type with a 305-mm axle stroke and inverted front forks with an inner tube 47-mm in diameter. The front forks have internal shock absorbers of the low-friction remote reservoir spring presser risen type equipped with adjusters that allow the damping force to be tuned on both the compression and extension sides. A review was conducted of the materials used for bolts, nuts, damper rods, and springs in the front forks, the margin of thread engagements, and other such factors. As a result, a weight saving of 300 g relative to the CR250R was achieved, despite the higher spring constant. Fig. 27 shows the front fork structure.



Fig. 25 Structure of rear suspension



Fig. 26 External view of swing arm

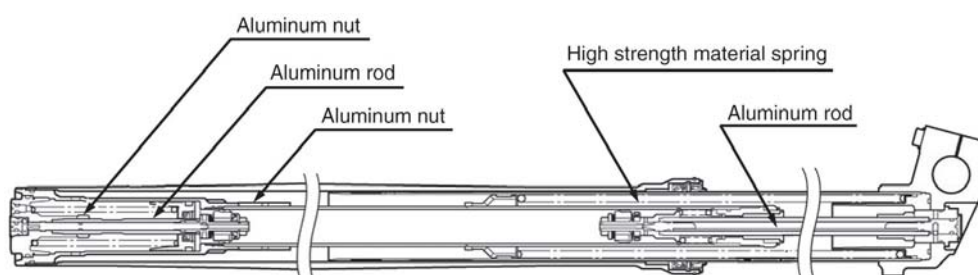


Fig. 27 Structure of front fork

6.3. Brakes

Hydraulic disc brakes with a 240-mm disc are used for both the independent front and rear brakes. Since their caliper bodies and caliper brackets are unsprung parts, they are made using light cast aluminum. The front brakes have two-pot calipers using aluminum pistons, while the rear brakes use newly-designed one-pot calipers.

6.3.1. Rear brake system

Issues involved in the brake system include the objectives of improved maintainability and reduced weight as well as two design issues specifically related to the 4-stroke engine:

- The mufflers located on the upper part of the rear calipers require a larger capacity than in 2-stroke engines. Therefore, it was necessary to give the mufflers a larger cross-section. It was a challenge to realize the enlarged cross-section, however, because of insufficient clearance between the caliper and muffler when the rear suspension is fully stroked.
- The exhaust pipe for a 4-stroke engine reaches higher temperatures than that of a 2-stroke engine. This causes a challenge with placement of the brake fluid sub tank that belongs to the master cylinder and with arrangement of the tubing between the master cylinder and sub tank.

Calipers with a compact piston 22.65 mm in diameter and a master cylinder integrated with an ultra-compact reserve fluid tank and a cylinder 9.52 mm in diameter were developed in order to address these issues. Making the caliper piston 22.65 mm in diameter not only made it possible to reduce the caliper size, but also reduced the reserve tank size with reduction of the amount of brake fluid compensation required when the pad is worn, and this allowed considerably greater freedom of layout for the reserve tank. As a result, it was possible to reduce the caliper size and position it lower down, so that the muffler could be given a diameter 25 mm larger than the XR400R. In addition, protective parts such as the disc cover and caliper guard could be made more compact so that the rear brake system achieved a weight reduction of 300 g. Fig. 28 shows an external view comparison of the developed caliper and master cylinder with previous components for the CR250R.

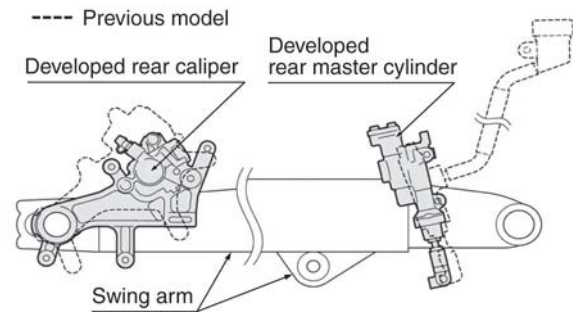


Fig. 28 Developed rear caliper and master cylinder

while achieving a 150-g reduction in weight. Fig. 29 shows a comparison of the conventional and developed wheel sections.

The size of the bolt used to attach the brake disc, the method of attaching spokes, and other aspects of the rear wheel hub were reviewed. This yielded a weight reduction of 50 g.

7. Other Lightweight Technologies

7.1. Titanium Exhaust Pipe

Use of titanium material for the exhaust pipe resulted in a weight reduction of approximately 400 g compared to conventional materials. Fig. 30 shows the exhaust pipe attached to the engine.

7.2. Engine Covers

A magnesium alloy was used for the cylinder head cover and clutch maintenance cover.

6.4. Wheels

Offroad vehicles generally use spoked wheels for their rigidity, strength, and mass.

Super-duralumin nipples were used for both front and rear wheel spoke nipples. A weight reduction of 180 g relative to conventional SWCH material was sought for the front and rear wheels together.

The rims are required to be lightweight with wheel rim compression strength, wheel rim flange strength, strength of spoke hole, and crack toughness against stress and corrosion. When the bike is being ridden, in particular, the rim may strike rocks or other objects with great force, causing permanent deformation of the rim in the direction of the opening. Increasing the strength of the flange opening was an issue for weight reduction. A high-strength Al-Zn-Mg-Cu material of 520-MPa grade has been used as the rim material for some time, and no further improvement could be expected in this regard. Instead, therefore, the rear wheel rim was given a section that is not JIS-specified but had been under study for use with a works motocrosser. This rim section raised the angle of the rim flange, giving it a shape that minimized the moment generated when a load was applied to the flange and made the flange less likely to deform. This rim has strength equal to conventional rims

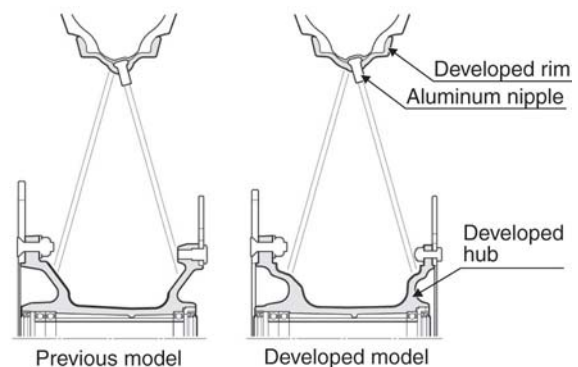


Fig. 29 Comparison of wheel structure

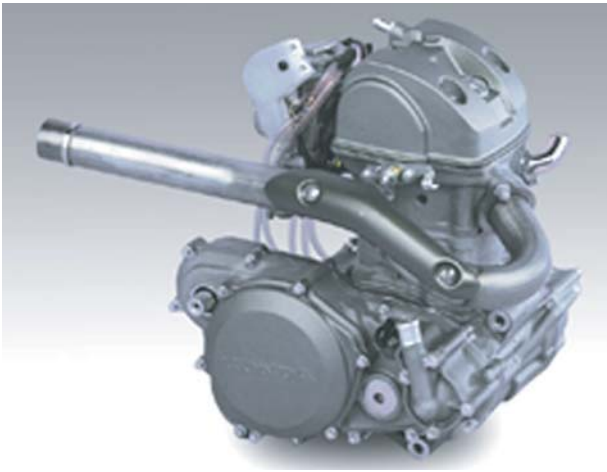


Fig. 30 External view of engine with titanium exhaust pipe

8. Conclusion

Taking advantage of the easy-handling traction characteristics of the 4-stroke engine, the CRF450R achieves a compact, lightweight engine and performance enhancements that include startability, a vehicle mass of 102 kg, maximum output of 41 kW/9,000 r/min, and maximum torque of 49.8 Nm/7,000 r/min. It is hoped that the CRF450R, as the flagship high-performance motocrosser that is also engineered with consideration for the environment, will help to improve the image of offroad vehicles as a whole.

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