

Introduction of Kart Racing Engine Using 4-stroke General Purpose Engine

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ABSTRACT

As a part of Honda R&D's Special Self-study Activities, a kart racing engine was manufactured using the GX200 4-stroke general purpose engine with a displacement of 196.1 cm³ as the base engine. A cylinder head that drives four valves using an OHV configuration was newly designed to secure charging efficiency at higher engine speeds than the typical range of general purpose engines. In addition, the lubrication system was changed from that of a splash lubricant system to a pressure lubrication system to help stabilize lubrication at high engine speeds and during actual driving. As a result, the developed kart engine achieved a power output of 12.0 kW or more at 8 500 rpm, as compared to the maximum power output of 4.1 kW at 3 600 rpm of the base engine. A kart fitted with the developed engine recorded actual lap times equivalent to or better than that of a kart fitted with an existing 2-stroke kart engine. Using a general purpose engine as the base engine enabled an engine to be manufactured that can be mounted in a beginner class racing kart with equivalent ease to that of a 2-stroke kart engine.

1. Introduction

Honda R&D Center provides activity space and manufacturing support for company-sponsored Special Self-study Activities. These activities aim to help employees realize their dreams and acquire skills and knowledge through autonomously creating things and other activities. As a part of these activities, a general purpose engine that can be mounted in a racing kart was manufactured.

Karts are divided into a number of classes (Fig. 1), and among the most easily enjoyed of these are rental karts, which can be used for a fee by anyone that meets certain requirements such as height and age. Most engines mounted in rental karts are 4-stroke general purpose engines with a displacement between 160 and 200 cm³ and a maximum power output of around 4 kW. This is because these engines have good starting performance, do not require gasoline mixed with oil, and have better durability and actual driving fuel economy compared to 2-stroke engines, which gives them good running cost performance.

Next, the class called sports karts^{(1), (2)} uses a general purpose engine mounted on a racing kart chassis, and has easy-to-handle power characteristics that make this vehicle class ideal for drivers starting motor sports. Formerly, sports karts often used 2-stroke scooter engines, but

general purpose engines have come to be widely used in recent years. Sports kart series races are starting to be held in various locations around Japan, and 4-stroke general purpose engines are also gaining widespread acceptance in Europe and America, as typically seen on indoor kart courses, because they produce less white smoke and exhaust gas smell, and are quieter than 2-stroke engines.

The upper class of karts is racing karts, which generally use lightweight, high power output 2-stroke engines. The beginner class uses engines with a displacement of 100 cm³ that produce axial power output

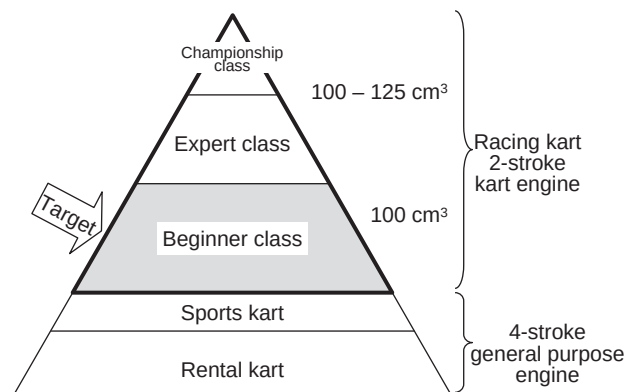


Fig. 1 Kart class conception diagram

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Table 1 Major specifications

		Kart engine	Base engine
Engine type		Air-cooled 4-stroke OHV single-cylinder	
Displacement (cm ³)		196.1	
Bore x Stroke (mm x mm)		68.0 x 54.0	
Compression ratio		10.0 : 1	8.5 : 1
Valve diameter	Inlet (mm)	25.5	25
	Exhaust (mm)	22	24
Number of valves		4	2
Max valve lift	Inlet (mm)	6.4	5.7
	Exhaust (mm)	5.9	5.7
Max power (kW/rpm)		12.0 / 8,500	4.1 / 3,600
Ignition system		Digital C.D.I.	Transistor magneto
Lubrication system		Pressure lubrication	Forced spray

of 10 kW or more, and the expert class uses engines with a displacement of 125 cm³ that produce axial power output of 20 kW or more and lateral acceleration of 3 G or more while running.

General purpose engines do not have a transmission like a motorcycle engine, so the engine itself is relatively lightweight and easily mounted. For this reason, mounting in racing karts has been desired, but general purpose engines produce lower axial output than that of 2-stroke engines, so they have been considered unsuitable for kart racing, which requires high output. General purpose engines with large displacement are sometimes mounted to obtain high output, but the larger engine size makes mounting on the chassis a challenge, and the increased engine weight hampers the quick driving that is characteristic of karts.

Therefore, the mid-sized GX200 general purpose engine, which is easily mounted, was used as the base engine. A cylinder head with revised inlet and exhaust systems, and the lubrication system were newly designed to achieve high engine speeds and high output, and a general purpose engine for kart racing that is suitable as a beginner class engine was manufactured. This paper reports this process.

2. Design Concept

The following two points are given as the basic performances required of kart racing engines.

- (1) Lightweight, unimpaired steering stability, compactness, and easy mountability.
- (2) High engine speed, high power output, providing good instantaneous power when accelerating out of corners.

Kart racing engines are mainly 2-stroke engines, so the following three items were set as design goals to manufacture a kart racing engine based on a 4-stroke general purpose engine.

- (1) The circuit lap time should be equal to or better than that of a kart fitted with a 2-stroke kart engine with a displacement of 100 cm³.

- (2) The engine should be lightweight, compact, and offer the same ease of mounting as a 2-stroke kart engine.
- (3) The structure should enable easy gear ratio setting at a race circuit.

3. Overview of Manufactured Engine

Figure 2 shows an external view of the newly manufactured engine. Table 1 lists the main specifications, and Fig. 3 compares the axial power output



Fig. 2 External view of engine

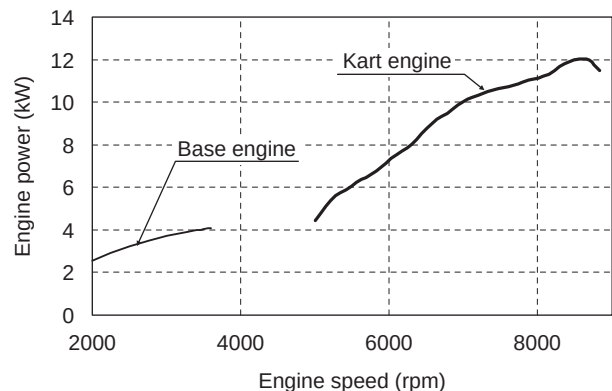


Fig. 3 Engine performance

with that of the base engine. The bore and stroke are the same as those of the base engine, but the cylinder head has been newly manufactured to support a 4-valve valve train. The new engine is designed for use with high-octane gasoline, and the compression ratio has been raised from 8.5 to 10.0 as a means of increasing power output. The lubrication system is a pressure lubrication system that uses an oil pump in order to support high engine speeds.

Figure 4 shows the engine layout drawing. When mounting a general purpose engine, the output is normally led from the crank case cover side, so when mounted on a kart, the power transmission chain is located between the engine and the driver, making it a challenge to change the sprocket. In karts that do not have transmissions, selecting the proper gear ratio to match each circuit is an important setting element, which means that the sprocket should be easy to change. Two-stroke kart engines have a structure that leads the output from the right side of the vehicle between the engine and the tires. Therefore, the output lead-out direction of the newly manufactured engine was made the same as that of a 2-stroke kart engine. This structure is described in detail in Section 4.5.

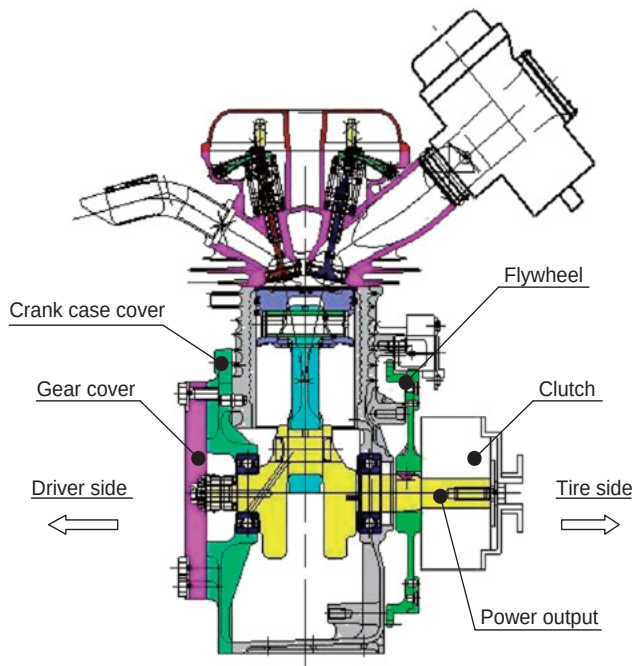


Fig. 4 Layout of kart engine

4. Technologies Enabling High Engine Speeds and High Power Output

The base engine has a maximum engine speed of 3 600 rpm, but the goal for the newly manufactured engine was set as 8 000 rpm or more, without changing the basic framework. The main technologies changed from the base engine are introduced below.

4.1. Increased Inlet Air Volume

The inlet port performance should be enhanced to secure charging efficiency at high engine speeds. The base engine is mounted in various power products such as generators and farm tractors, and is designed to achieve good charging efficiency at 2 500 to 3 000 rpm. However, when the engine speed is increased further, the inlet airflow speed also rises, which increases the airflow resistance and produces a drop in the charging efficiency at higher engine speeds.

In addition, the cylinder head of the base engine is manufactured by high pressure die casting, which accentuated productivity through mass production, so parts with the acute angles needed by the mold structure are formed within the inlet port. Figure 5 (a) shows the inlet and exhaust port shapes of the base engine, and Fig. 5 (b) shows the inlet and exhaust port shapes of the newly manufactured engine. The newly manufactured engine accentuated inlet performance, so the ports were changed to smooth ports manufactured by sand mold casting, and the number of inlet valves was increased from the one valve of the base engine to two valves.

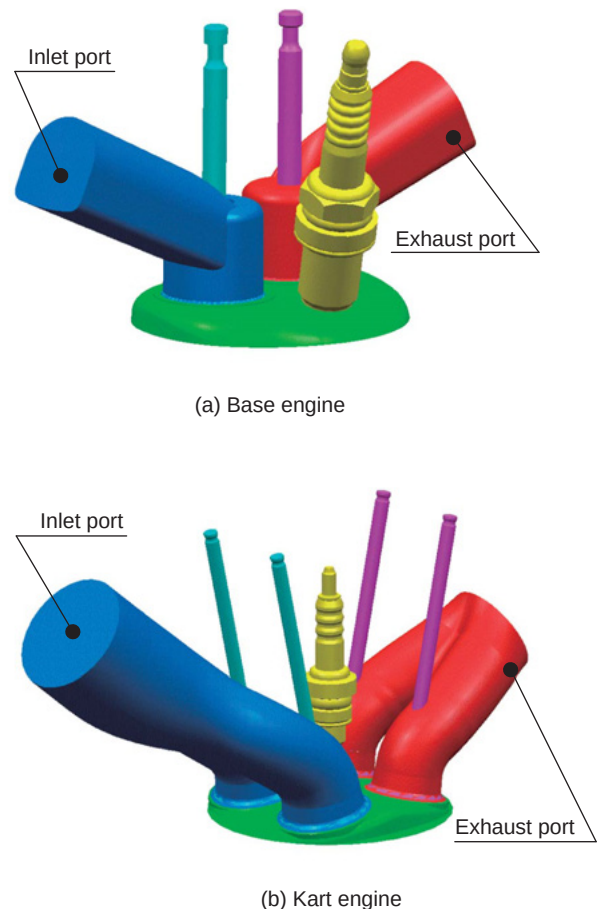


Fig. 5 Inlet and exhaust port 3D shape

Here, the effective opening area (Z) relative to the valve lift was calculated using originally developed Computational Fluid Dynamics (CFD) software⁽³⁾ as an index for evaluating inlet performance. Figure 6 shows the calculation results. The newly designed inlet port has a maximum effective opening area value 2.3 times larger than that of the base engine, which was predicted to reduce airflow resistance at high engine speeds.

The combustion chamber has a pent roof shape, and spark plugs with the small diameter of 8 mm were applied and positioned in the center of the combustion chamber. Note that the thermal load between the two exhaust valve seats increases, so cooling holes were provided to actively introduce cooling air.

4.2. High-speed Valve Train Operation

The basic valve train structure uses the same OHV mechanism as the base engine, but a new mechanism was devised to drive four valves using two push rods in order to increase the number of inlet and exhaust valves. Various mechanisms for driving four valves in an OHV configuration have been reported in the past^{(4), (5)}, but the new engine uses a layout with sub-rocker arms positioned orthogonally to the main rocker arm. This enables two inlet and two exhaust valves to be operated by the conventional rocker arm motion. Figure 7 shows the valve train configuration.

The valve size was changed from the IN: $\phi 25$ mm x 1, EXH: $\phi 24$ mm x 1 of the base engine to IN: $\phi 25.5$ mm x 2, EXH: $\phi 22$ mm x 2. In addition, the valve stem

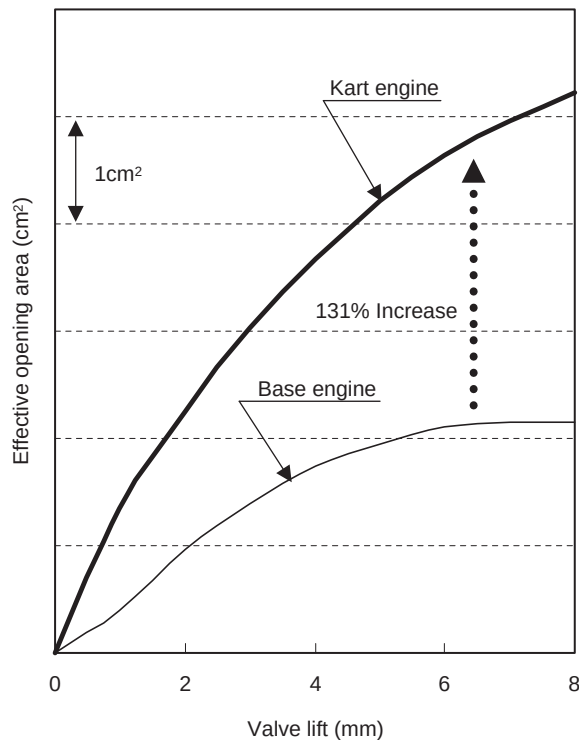


Fig. 6 Calculated intake effective opening area

diameter was reduced from the $\phi 5.5$ mm of the base engine to $\phi 4.0$ mm, which reduced the weight by 4 g per inlet valve and 7 g per outlet valve, and reduced the inlet resistance. The retainer was changed to a cotter type that can withstand high engine speeds, and special valve springs with an uneven pitch were newly designed. The new engine used $\phi 7.5$ mm solid aluminum shaft OHV push rods that have the same coefficient of thermal expansion as the cylinder block, while maintaining equal or greater rigidity than that of the $\phi 4.0$ mm steel push rods in the base engine. In addition, the valve lifter weight was reduced by 3 g by machining. Figure 8 shows the new valve lifter shape.

These measures resulted in a reciprocating part equivalent weight of 128 g compared to 70 g for the base engine, so the increase in weight was kept to 1.8 times despite the addition of two valves and two rocker arms to the base engine.

However, the new engine operates two valves with a single push rod, so the equivalent weight per cam

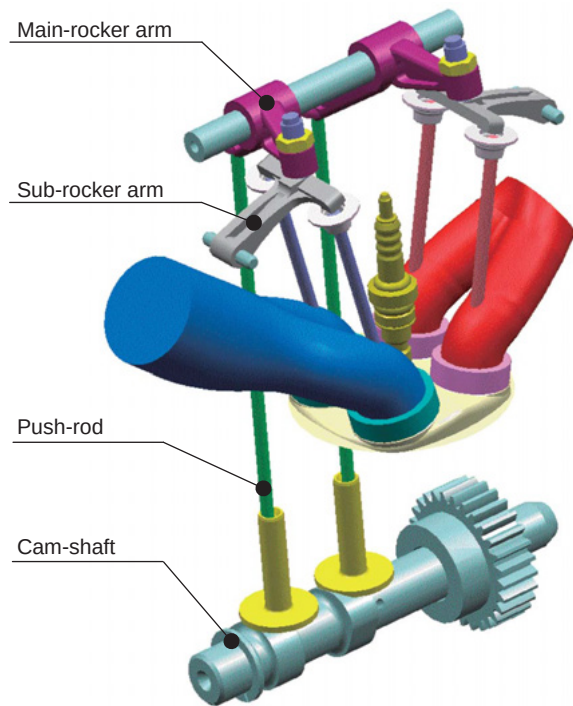


Fig. 7 Cylinder head for OHV 4-valve configuration

	Kart engine	Base engine
Shape		
Mass (g)	16	19

Fig. 8 Comparison of valve lifter shape

increases, and valve behavior may become unstable due to the effects of the dynamic rigidity of the valve train at high engine speeds. Therefore, the positive acceleration on the valve lift was reviewed to enhance charging efficiency and stabilize valve behavior at high engine speeds. Specifically, the maximum positive acceleration value was suppressed to 47% of that of the base engine by expanding the overlap and delaying the inlet valve close timing angle. The larger maximum valve lift amount increased the axial torque, but reduced power performance and drivability were confirmed, which were thought to be due to unstable valve behavior occurring at engine speeds lower than the maximum engine speed. Therefore, the valve lift amount was set at IN: 6.4 mm, EXH: 5.9 mm. This achieved a maximum engine speed of 8 000 rpm or more.

4.3. Pistons and Piston Rings

The piston skirt was shortened and the weight reduced by approximately 10 g to reduce the reciprocating part inertial force that is generated during high-speed operation and to minimize vibration during operation. In addition, the sliding surface with the cylinder bore was given a molybdenum coat to reduce friction. Figure 9 shows the differences in the piston shape.

The piston ring thickness was reduced to reduce the reciprocating part weight and friction. The top and second rings were made of steel, and the h1 dimension was reduced from 1.2 to 0.8 mm. The oil ring thickness was also reduced from the conventional h1 dimension of 2.5 to 2.0 mm. In addition, the total tension was reduced by 47% while still satisfying oil consumption performance during races and maintaining appropriate trackability. Table 2 compares the section shapes of the piston rings.

4.4. Lubrication System

The base engine uses a splash lubrication system that collects the lubricating oil on the inner bottom surface of the engine block, and splashes the lubricating oil using a dipper integrated with the connecting rod. The newly manufactured engine calls for a stable supply of lubricating oil to the large end of the connecting rod to support engine speeds in excess of 8 000 rpm and changes in the oil surface when subject to the lateral acceleration

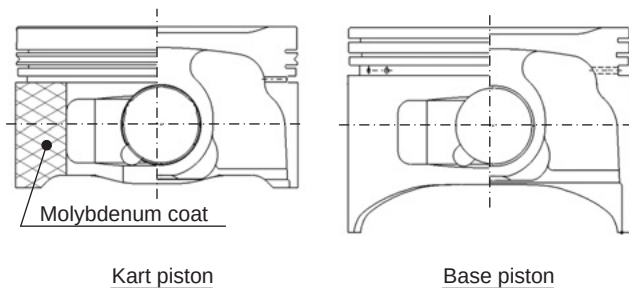
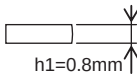
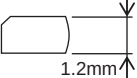
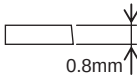
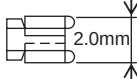
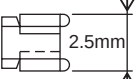


Fig. 9 Comparison of piston shape

Table 2 Comparison of piston ring

	Kart engine	Base engine
Top Ring	 h1=0.8mm	 1.2mm
2nd Ring	 0.8mm	 1.2mm
Oil Ring	 2.0mm	 2.5mm

described hereafter. Therefore, an oil pump was built into the newly designed crank case cover, and a pressure lubrication system was used to drive the oil pump gear from the crank shaft via the cam shaft. There are two sets of lubrication channels: one that passes from the oil pump through the cylinder head to the rocker arm parts, and another that passes from the oil pump through the crank shaft to the large end of the connecting rod.

The connecting rod of the base engine is made of aluminum, and the rod portion used in the new engine is the same as that of the base engine. Figure 10 shows the difference in the connecting rod shapes. The inertial load of the reciprocating part that is generated near the top dead center increases at high engine speeds, so the thickness of the cap side was increased by 1.7 times to increase the loop rigidity. In contrast to the mass production specifications that assume use in diverse environments from low- to high-temperature regions, races are not held at sub-zero temperatures, so the oil clearance of the newly manufactured engine was reduced, the rigidity of the large end increased, and the oil film holding toughness at high engine speeds also enhanced.

Next, the effects of changes in the oil surface on lubrication during actual driving were assessed. A big difference between bench tests and actual driving tests is the presence of lateral acceleration (hereafter, "lateral G")

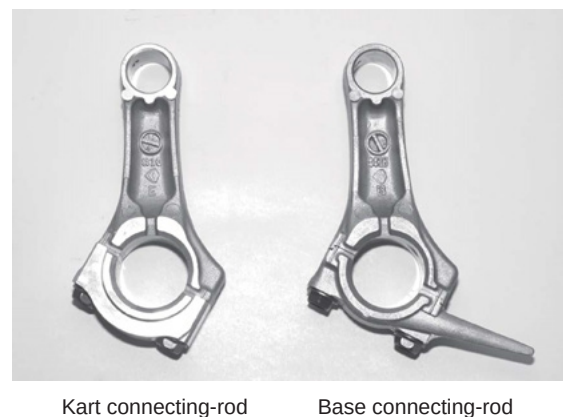


Fig. 10 Comparison of connecting-rod shape

generated during cornering. The general purpose engines mounted in generators and farm tractors are rarely subjected to sharp lateral G for long periods. However, when mounted in a kart, lateral G equivalent to 1.5 to 2.0 G is produced, and can continue for about 5 to 7 seconds. At this time, the oil surface is thought to become inclined as shown in Fig. 11, which reduces the amount of contact between the dipper and the oil surface, and the amount of splash produced by the cam gear in a splash lubrication system.

Figure 12 shows the lateral G and the change in oil temperature produced during actual driving. The horizontal axis shows the time, and the vertical axis shows the change in oil temperature and the lateral G produced. The red line in the upper level indicates the change in oil temperature for the pressure lubrication system, and the blue line in the middle level indicates the change in oil temperature for the conventional splash lubrication system. The orange line in the lower level indicates the lateral G,

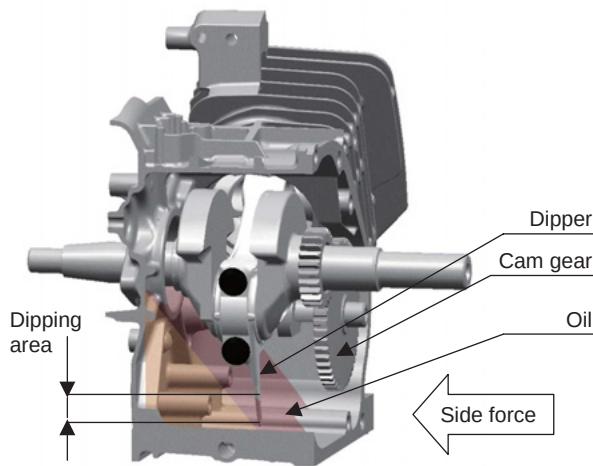


Fig. 11 Lubricant system of general purpose engine

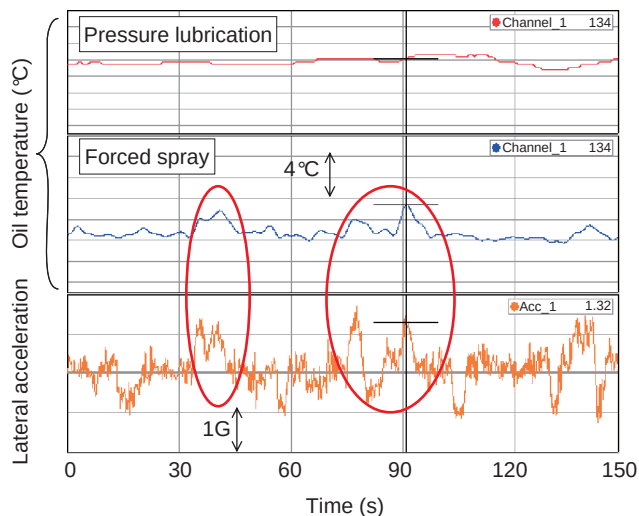


Fig. 12 Relation between lateral acceleration and oil temperature

and shows that the oil temperature rises at the timing when lateral G is generated. This is thought to be because lubrication becomes insufficient during cornering, which increases the friction heat on the large end of the connecting rod. Figure 13 shows a diagram of the new engine with the pressure lubrication system. The oil inlet is positioned near the center inside the case where there is little change in the oil surface due to lateral G, and a baffle plate has also been installed around the inlet to reduce the effects of changes in the oil surface. Changing to a pressure lubrication system and providing a stable supply of lubricating oil to the large end of the connecting rod was confirmed to effectively suppress fluctuations in the oil temperature due to changes in the oil surface under lateral G conditions.

4.5. Drive Train

In karts that do not have transmissions, the sprocket is replaced to change the gear ratio setting, depending on whether the maximum speed, cornering acceleration, or other factor is prioritized in the circuit course. Figure 14

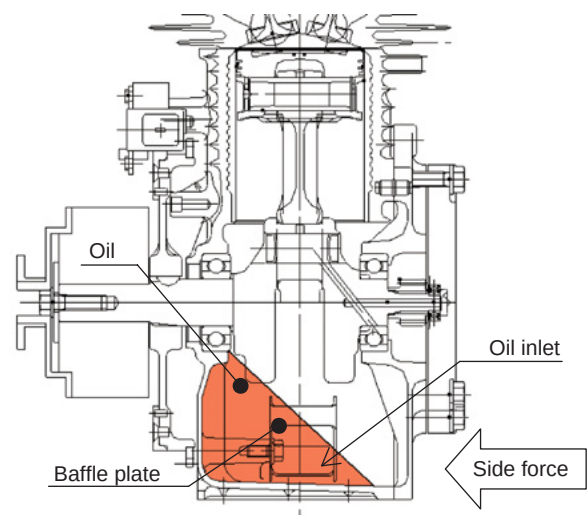


Fig. 13 Lubrication system of kart engine

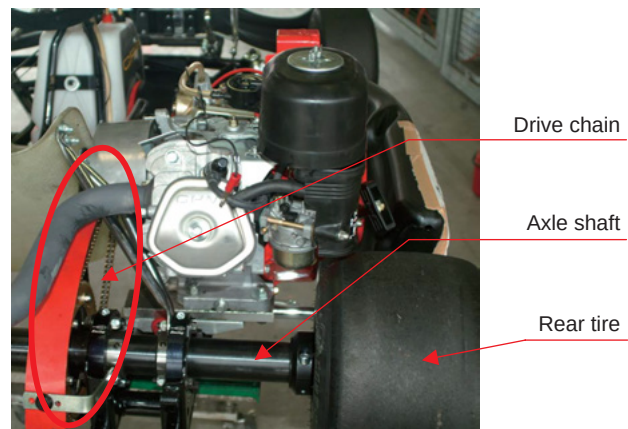


Fig. 14 Drive chain placement with general purpose engine

shows a typical kart fitted with a general purpose engine, and here the output is led from the crank case cover side, which is on the inside of the kart. This made it necessary to remove the axle shaft and replace it together with the chain when changing the rear sprocket, which entailed much time and effort. The rear sprocket can also be split in half and assembled, but level differences in the assembled condition may cause the chain to slip off. Furthermore, when it is necessary to also change the chain length when changing the sprocket, it is not enough to merely replace the rear sprocket.

Therefore, the output lead-out in the newly manufactured engine was changed to the flywheel side, which is located on the outside of the kart, and a centrifugal clutch was added. Figure 15 shows a photograph of the engine mounted on a kart. This enabled the sprocket and chain to be replaced in the engine-mounted condition without removing the axle shaft, which enabled easy setting of the gear ratio at the race circuit in the same manner as a conventional kart engine.

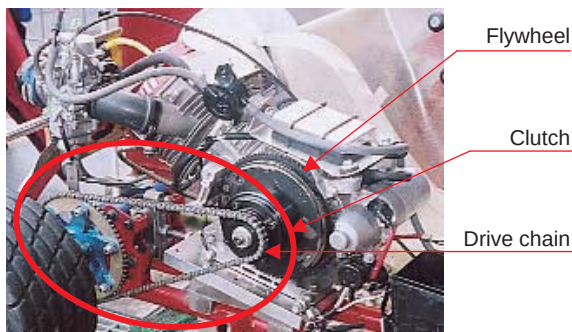


Fig. 15 Drive chain placement with kart engine

5. Actual Driving Results

The newly manufactured engine and the base engine were mounted in karts, and power performance was compared by the lap times on the Twin Ring Motegi road course. This road course is a circuit with a length of 4.8013 km. Figure 16 shows the lap time taken for the same test driver. A kart fitted with the newly manufactured engine achieved a lap time 52 s shorter than specifications with the speed governor removed from the GX200 base engine. This means that the kart fitted with the newly manufactured engine achieved an average lap speed of 108 km/h, in contrast to an average lap speed of 81 km/h for the kart fitted with the base engine. Furthermore, the new engine was also found to provide a running advantage of 5 s or more, compared to a kart fitted with a beginner class 2-stroke kart engine with a displacement of 100 cm³.

In addition, Fig. 17 compares the acceleration times from 85 to 95 km/h as a comparison of speeds when

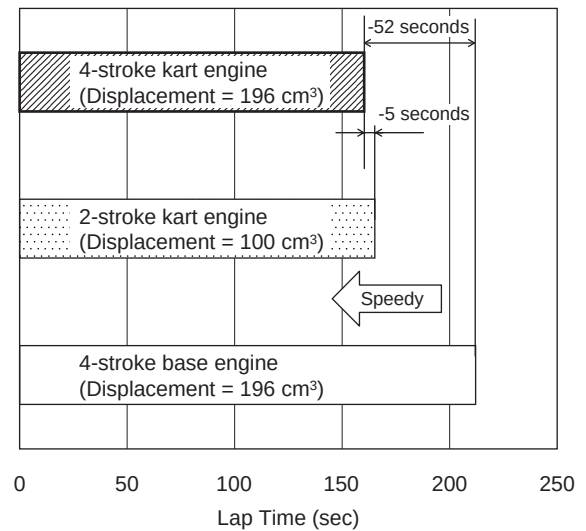


Fig. 16 Comparison of lap time

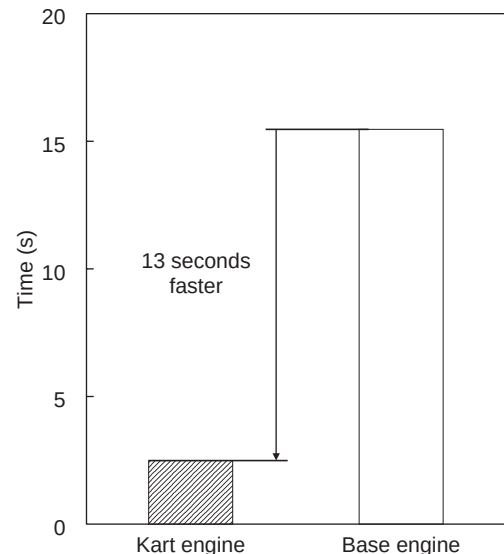


Fig. 17 Comparison of acceleration time

accelerating out of corners. Here as well, the new engine provides enhanced acceleration performance compared to the base engine.

6. Conclusion

A lightweight, compact, high power output kart racing engine was manufactured that makes the most of the advantages of a general purpose engine. Figure 18 shows a racing kart fitted with the newly manufactured engine.

- (1) A cylinder head that supports an OHV 4-valve valve train mechanism was newly manufactured, and achieved an engine power output of 12.0 kW or more at 8 500 rpm.
- (2) An engine with the same ease of mounting as that of a 2-stroke kart engine was manufactured using a 4-stroke



Fig. 18 Kart race at TWIN RING MOTEGI

general purpose engine as the base engine. In addition, the structure leads the engine power output from the flywheel side, which enables the gear ratio to be set as easily as that of a conventional kart engine.

- (3) Use of a pressure lubrication system stabilized oil temperature fluctuations under conditions with lateral G applied for long periods, and increased reliability at high engine speeds.
- (4) In actual driving tests on a circuit with a length of 4.8013 km, the developed kart engine was confirmed to shorten the lap time by approximately 5 s, compared to a kart fitted with a 2-stroke kart engine with a displacement of 100 cm³.

Afterward

Power products tend to be thought of as relatively estranged from motor sports. However, autonomously designing and manufacturing a race engine and entering a kart fitted with this engine in kart races enabled the authors to actualize their own ideas, and to autonomously put into practice Honda's Three Realities Principle of knowing the actual situation, going to the actual place, and being realistic. This greatly increases the motivation of young engineers, and it is also hoped that the skills and ideas acquired through this process can be fed back to other power products in the future.

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