Technical Paper

Development of Hybrid Start Brush Cutter

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The cell start system of handheld brush cutters has not been accepted in the market in the past due to the poor workability caused by its heavy weight, battery reliability and start performance. A hybrid start system featuring lightweight and improved reliability accomplished by merging three new technologies has been developed. The target and accomplishment means of the hybrid start brush cutter "One Touch Cutter" are described below.

Key Words: *Hybrid Start, Lithium Ion, Auto Choke*

1. Introduction

The graying of the farming population is progressing recently in Japan (**Fig. 1**). More people of advanced age are working on farms, and products that can be handled easily by beginners are in demand.

Almost all motive power sources of handheld brush cutters are compact two-stroke engines that are started in the orthodox way by pulling the cord of the recoil starter by hand. As was the case in the automobile engine starting method in the past, manual choking operation is needed to start the engine, and this operation has been very cumbersome for the layperson. Female users have frequently experienced failure to start the engine because of slow speed in pulling the cord. A user survey clearly shows that engine start is an important consideration when consumers purchase brush cutters (**Fig. 2**).

The manufacturers of brush cutters have attempted to make engine start easy employing various methods. Komatsu has been active in the R&D of commodities that are user friendly and global environment friendly and has developed a hybrid start system embodying this concept. The key technologies and development results of the new system are reported.

2. Technology for easy start

As shown in **Fig. 3**, the means for easy start can be roughly divided into three categories: 1) Reduction in recoil pulling force, 2) Reduction in recoil pull speed and 3) Simple start operation. The newly developed system aimed to achieve light weight, simple operation and reliability, to eliminate the cumbersome recoil starter system.

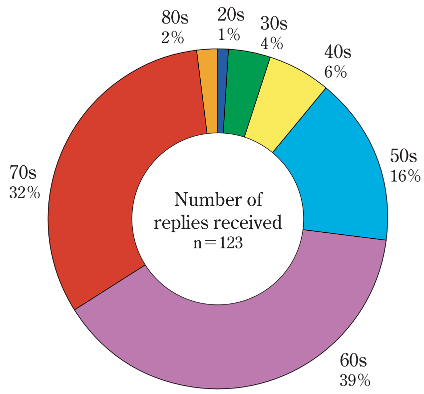


Fig. 1 Age brackets of users in Japan

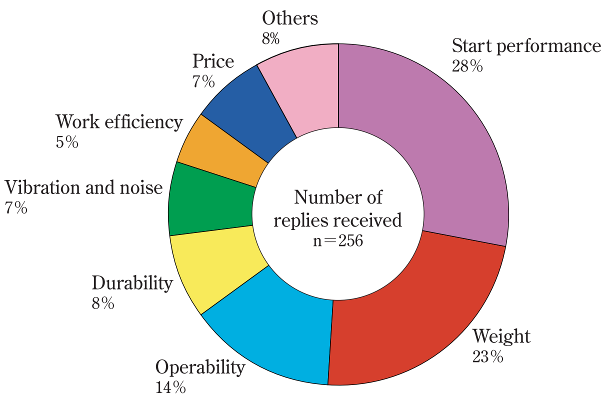


Fig. 2 Items consumers pay attention to when making purchases

The system was constructed by employing a compact self-starting motor and an assist spring. Easy operation was achieved by an auto choke mechanism, and reliability was achieved using lithium ion batteries.

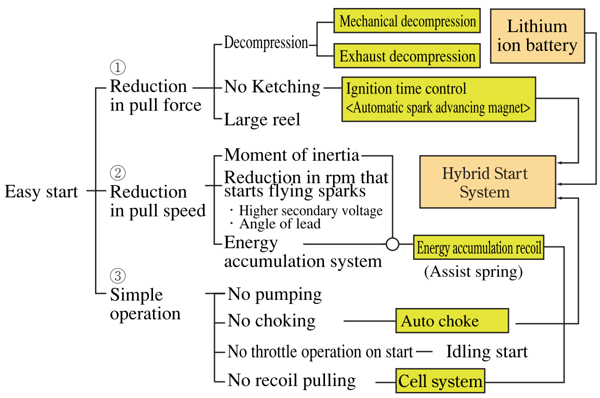


Fig. 3 Technology for easy start

These new measures have enabled engine start operation in three steps, instead of seven steps as at present (**Fig. 4**). "Easy engine start by all just by pressing buttons" is now possible by eliminating the choking operation, which has been difficult for the layperson, to solve the problem of cumbersome start operation.

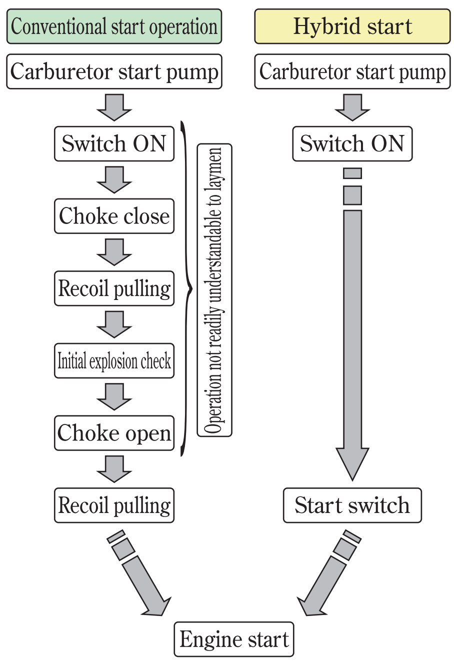


Fig. 4 Comparison of start operation

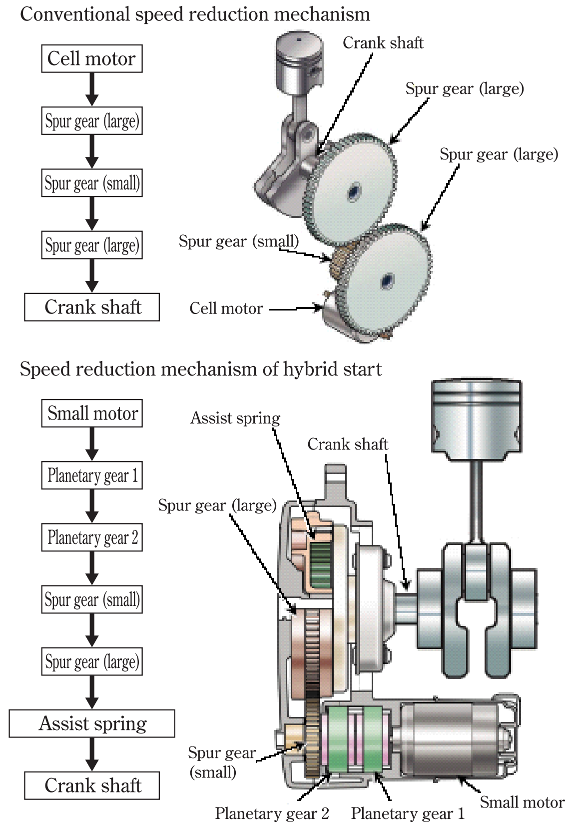
3. Contributions for Easy Engine Start

3.1 Light weight (Hybrid start)

The conventional cell-start system rotates the crankshaft using a self-starting motor through a speed reducer. For this reason, a large self-starting motor has to be provided to ensure the required cranking rpm to start the engine. A large motor inevitably increases the weight. The speed reducer configuration requires three spur gears, making the gear box bulky and increasing the weight. Thus, conventional speed reducers cannot be mounted in handheld equipment.

(1) Light weight

Light weight could be achieved by a compact self-starting motor, by a compact speed reduction mechanism and by an assist spring that assures adequate cranking rpm when the spring is released to get through engine compression. The speed reduction mechanism reduces the speed in two stages of planetary gears and spur gears taking miniaturization and gear transmission efficiency into consideration (**Fig. 5**).



*Speed reduction ratio of conventional cell: 16.35
Speed reduction ratio of hybrid start: 53.5

Fig. 5 Comparison of structures

A target weight increase of less than 10% of the total was set by dispersing the weight to the engine side and to the cutter body side taking the weight balance as a handheld brush cutter into consideration. The engine weighs 200 g more than a conventional recoil start machine, while the body weighs 180 g more, including the weight of the battery and other elements (**Table 1**).

Table 1 Target weight of developed cutter

Weight kg	Hybrid start	Recoil start
Engine	2.94	2.73
Cutter body	1.60	1.42
Overall weight	4.54	4.15

2) Principle of hybrid start

As mentioned above, the conventional cell-start system rotates the crankshaft by the combination of a motor and speed reducer so that the crank rpm lowers when the battery voltage lowers, often resulting in failure to start. The hybrid start system rotates the crankshaft as the motor winds the assist spring through a high-speed reducing mechanism. The compression increases until the piston approaches the top dead center and the assist spring is wound further. When the piston reaches the top dead center, the piston speed decreases to zero. When the torque of the starter motor through the speed reducer surpasses the cranking torque, the energy stored in the assist spring is released in one breadth, to rotate the crankshaft at high speed, accelerating to the engine start rpm (**Fig. 6**).

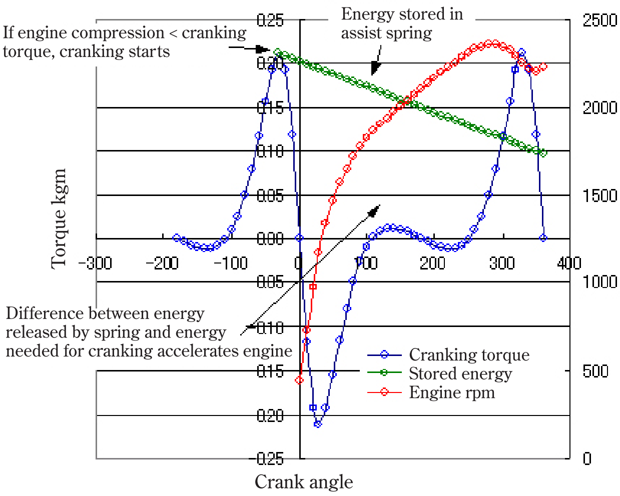


Fig. 6 Principle of hybrid start

The most significant feature of hybrid start is that the engine can be started without fail because the engine is started by the energy released by the assist spring so that the assist spring can be wound by a speed reducer that is set to a high-speed reduction ratio, even if the motor speed lowers due to low battery voltage. The specifications of the assist spring were decided assuming a high compression state due to carbon deposition inside the combustion chamber and on the top of the piston, which is considered to be the destiny of the dual cycle engine, and the friction loss caused by the adhesion of tar in the cylinder and on the piston that is generated by low-load work. By actualizing this concept, a compact motor to accomplish light weight could be used. The specifications of the hybrid starter and conventional cell-start system are compared in **Table 2**.

Table 2 Comparison of starter specification

	Conventional cell system	Hybrid start system	Remarks
Starter unit weight (auxiliary to engine)	1260g	418g	Hybrid system does not include battery weight
Maximum torque generated	0.47kg・m	0.63kg・m	Measured value
Cranking rpm	1420rpm	1840rpm	Measured value

3.2 Easy controllability (Intelligent auto choke system)

(1) Conventional auto choke system

The conventional auto choke system supports engine start by adjusting the air and fuel ratio to match the engine ambient temperature. The conventional auto choke system is installed with a solenoid valve to supply start fuel to the carburetor, always feeding start fuel when the engine is started. Therefore, start fuel is also supplied when the engine is warmed up so that the engine sometimes cannot be started due to the super-enriched mixture.

(2) Intelligent auto choke system

The intelligent auto choke system in the new cutter assures optimum start suiting the ambient temperature and solving problems caused by fuel fogging by controlling the solenoid valve drive. The system has the following components: (1) Carburetor with a solenoid valve, (2) Temperature sensor for controlling the drive of the solenoid valve and (3) Heater to prevent fuel fogging. In the flow, cranking is started by pressing the start button, and the digital magneto detects revolutions of the flywheel. When the temperature sensor installed inside the digital magneto detects the coil temperature and determines it to be below 30°C, the solenoid valve is driven and start fuel is supplied. If the temperature at the temperature sensor is always 30°C or lower, start fuel is continuously supplied, resulting in fuel fogging. In conventional manual choking, the operator is entrusted with the decision to reset choking to avoid fuel fogging. With the newly developed cutter, this decision is controlled by the temperature sensor and heater installed near the sensor (**Fig. 7**).

In the intelligent auto choke system, a current is impressed to the heater near the sensor when the engine start button is pressed, to overheat the area near the temperature sensor. **Fig. 8** plots the number of cranking cycles and the heater temperature.

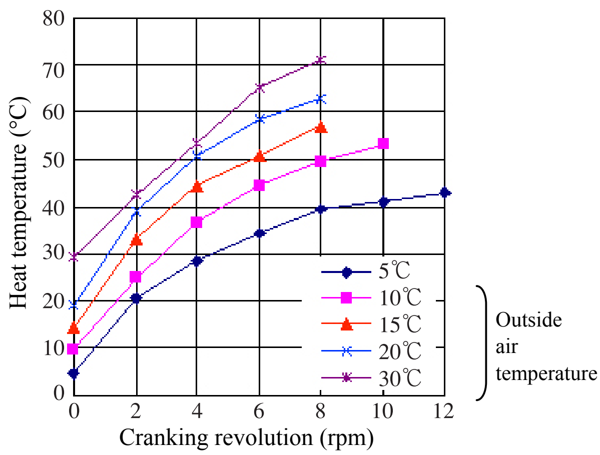


Fig. 8 Relationship between Cranking revolution and the Rise of Heater temperature

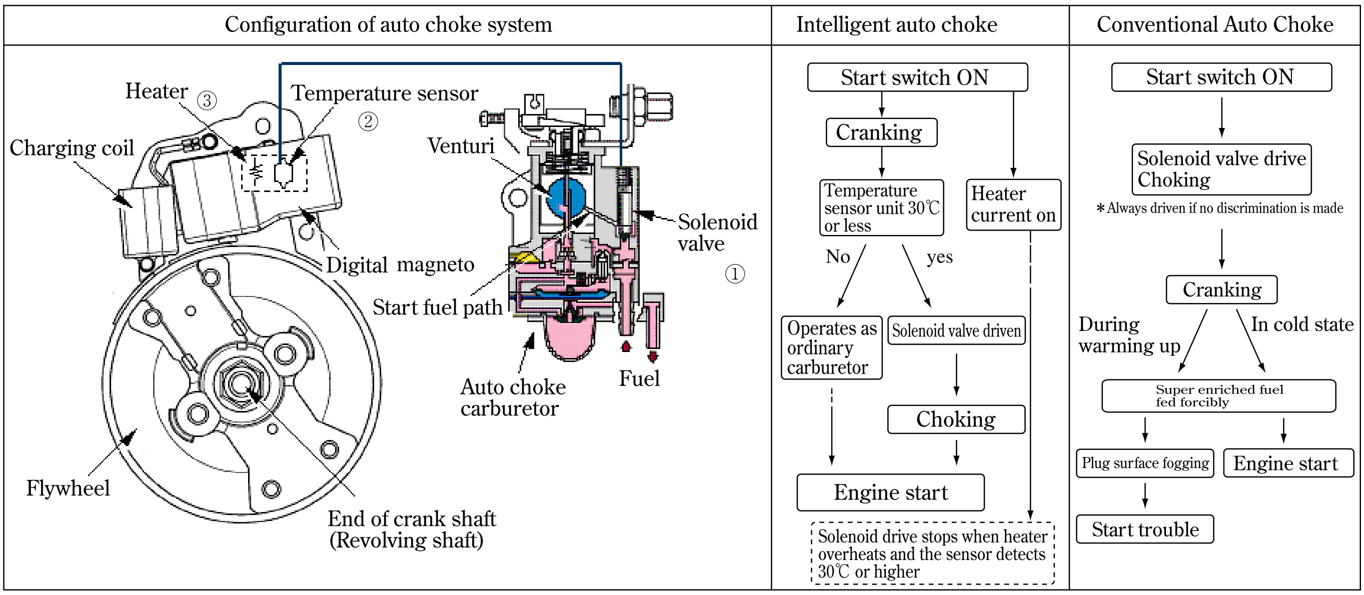


Fig. 7 Method for controlling auto choke mechanism

Little fuel is vaporized when the temperature is low, and more start fuel has to be supplied. When the outside air temperature is 5°C, fuel needed for engine start is supplied before the crank turns four times, and the solenoid valve closes when the heater reaches 30°C.

When the outside air temperature is 30°C, the engine can be started without supplying start fuel. Fuel fogging is caused if start fuel is supplied below 30°C. For these reasons, the sensor temperature was set to 30°C. Thus, reliable start at a low temperature has been achieved and starting errors caused by fuel fogging have been solved by regulating the choking cycles through a set temperature of the temperature sensor.

3.3 Reliability (Lithium ion battery)

The reliability of the hybrid start system depends on batteries as in automobiles and other equipment. This means that enhanced battery reliability is the foremost issue. Battery power exhaustion can be countered by increasing the electrical capacity, but this inevitably increases the overall weight.

(1) Nickel cadmium battery

The nickel cadmium battery installed in the conventional cell-start system weighs 425 g, accounting for 10% of the entire equipment weight. This is quite heavy for a piece of handheld equipment, which is destined to decrease in weight. The nickel cadmium battery is prominent in self-discharge properties and its voltage is expected to lower to a voltage region that is low enough to disable start in less than 30 days in summer.

(2) Lithium ion battery

The new cutter contains a lithium ion battery to solve three problems, namely, it has improved battery reliability, achieved lightweight equipment and no charging in one season. The features of the lithium ion battery can be summarized as follows.

(1) The weight energy density is high, about 155 Wh/kg, which is about three times that of the nickel cadmium battery, and equipment can be smaller and lighter.

(2) The voltage per cell is high, 3.6 V, which is about three times that of the nickel cadmium battery, and equipment space can be saved.

(3) It has excellent shelf characteristics and self-discharge is 5% per month, which is very low and is less than 1/5 that of the nickel cadmium battery.

The batteries of the newly developed equipment weigh 75 g with various protection circuits installed, which is about 18% of the battery used in the conventional cell-start system and is capable of driving the system. By installing a battery in the switch box, the weight balance of the equipment is improved.

Fig. 9 shows that the lithium ion battery is superior to the nickel cadmium battery in self-discharge. A test of self-discharge from the neighborhood of 8 V to room temperature showed that the nickel cadmium battery was no longer capable of driving a start system in about 50 days. Compared with this, self-discharge with the lithium ion battery was low, about 0.3 V, after 50 days, adequately capable of driving the system. Self-discharge in one season is expected to be about 1.5 V, showing that the battery does not have to be removed for charging for one season.

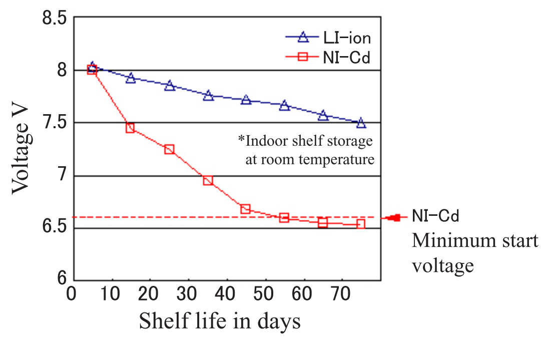


Fig. 9 Self discharge characteristics of lithium ion and nickel cadmium batteries

The characteristics required for batteries are described. The operating environment during the drive of a start system is very severe, and the following characteristics are required.

(1) A large current (20 to 30 A) flows at start of the engine, and discharge of about 30 C is necessary when the battery capacity is 800 mAh.
(2) The equipment operating environment is severe, and durability against vibration is needed.
(3) High reliability must be ensured because the start system is driven by a battery.

Fig. 10 plots current and voltage waveforms on start. The peak current of 23 A is attained when the battery voltage is 7.8 V. In the relationship between the waveform on start and the piston position, the motor is first started by an inrush current to start the crankshaft. The load applied to the motor increases as the piston approaches the top dead center, increasing the current. The current increases to about 20 A maximum near the top dead center. The average current of this one cycle is 9.5 A and is about 0.7 s in time. Thus, the battery pack of the newly developed equipment demonstrates performance that adequately meets the requirements of the hybrid start system.

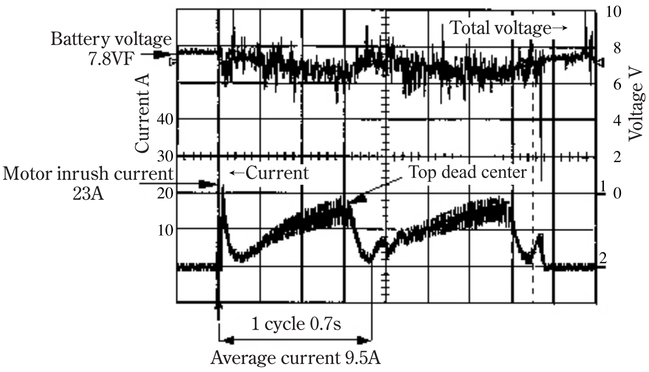


Fig. 10 Battery voltage and current on engine start

A charging waveform in an excitation state is shown in **Fig. 11**. Voltage at a battery terminal was measured under severe conditions of 3 to 15 G in sweep at an engine vibration frequency band of 83 to 200 Hz. The measurement confirmed that sensing on the terminals at each vibration acceleration level was stable, indicating that reliability against vibration when installed in the brush cutter was adequate.

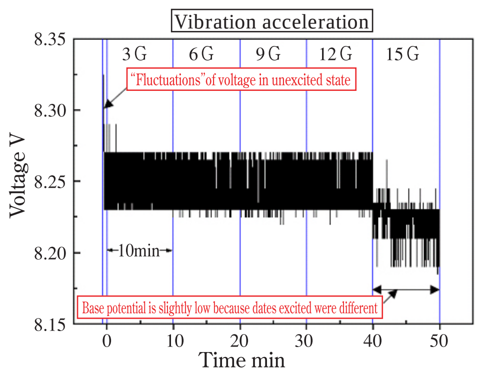


Fig. 11 Voltage at charging terminal in excited state

The results of a cycle test at DOD100% (depth of discharge) to determine the impact on the battery when a user perfectly discharges the battery are shown in **Fig. 12**. In the test, charging was performed at a constant current of 1 A, and constant voltage and discharging was performed at a constant current of 20 A. The capacity preservation rate was 85% after 500 cycles. When usage of the hybrid start system is considered, complete discharge is extremely rare because the system recovers discharge energy by power generation of the engine after the start system is driven. Therefore, this system is considered to have sufficient reliability.

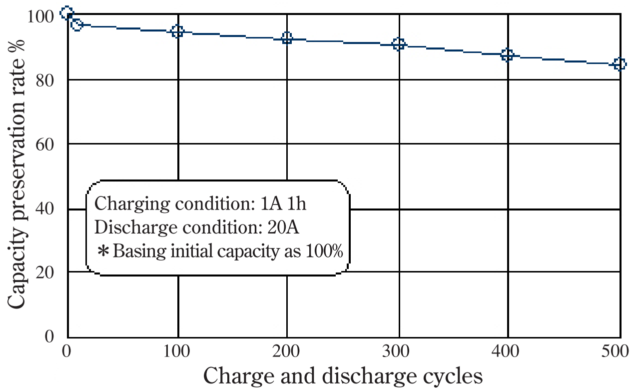


Fig. 12 Result of cycle test at DOD 100%

Fig. 13 shows the data with which the cycle characteristics were confirmed in charging at a 150-mA constant current and constant voltage for 10 minutes and 30 A constant current discharge for 3 s to verify the cycle characteristics of shallow charge and discharge assuming actual usage of the hybrid start system. An excellent 93% capacity preservation rate is exhibited after 10,000 cycles compared with the target of 85% or higher. Furthermore, the lithium ion battery has no memory effect and is suitable for the hybrid start system that repeats shallow charge and discharge.

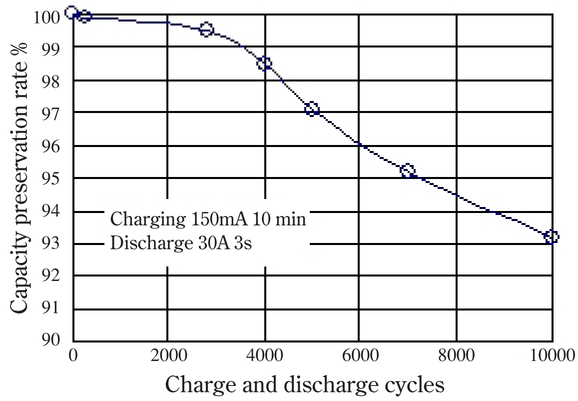


Fig. 13 Result of cycle test assuming cutter operation

Verification of the mechanical characteristics could be conducted adequately with battery reliability. However, performance over time depends on verification by calculation and simulation. The continuation of analysis based on experimental data is a future task.

4. Conclusion

(1) A lightweight start system that can be installed in a hand-held brush cutter has been developed.
(2) A system to control fuel fogging that has caused problems with the choke system was incorporated to enhance reliability.
(3) A lithium ion battery capable of discharging a large current was developed to achieve light weight and enhanced reliability of the hybrid start system.

The newly developed hybrid start system is mounted on two-stroke engines of 23 and 26-cc class and has been on the market in Japan since July 7 2005. The system is enjoying a high reputation in the market as a cell-start system thanks to its excellent starting performance and light weight that is unrivaled by other products. Skillful identification of potential user needs has enabled this development.

Komatsu plans to further upgrade its product design and development capability using this experience as a springboard.

Introduction of the writers

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[A few words from the writers]

Recalling this development project, the project was a history of product development and technology development conducted simultaneously. The fact that an excellent product could be put on the market as a development result after clearing various restrictive conditions to commercialize a brush cutter, on which severe environmental conditions are imposed, makes us proud as engineers. This fact further motivates us when we tackle the development of products in the coming generations, and this was a unique experience. Another factor essential in commercializing new products was that the departments concerned cooperated with each other toward high-volume production overcoming their interests. Good results were produced through joint development with a battery manufacturer by contributing expertise and complementing each other in adopting the lithium ion battery as the first attempt in the industry.

In the market, home centers are prominently increasing their sales and more low-priced brush cutters are sold. However, this development has assured us that products that have an added value can meet potential needs. We plan to continue developing innovative and excellent products by incorporating state-of-the-art technology into agricultural machine.