

Development of Hybrid HS1390i Snow Thrower

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ABSTRACT

Honda has developed the HS1390i hybrid snow thrower for general consumer use based on the key concept of enhanced handling and operability. The snow clearing system is driven by an engine that simultaneously generates power for two drive motors. Computer-controlled travel motion combined with automatic load sensitive speed control make travel motion and work smooth. Operator load has been reduced by mounting the driving levers on the driving system frame and placing the operating controls in a fixed location. In addition, the use of an electric operating system reduces the amount of force required to operate the various controls. Fuel consumption per volume of snow removed is also better than previous models, making this product strongly competitive in the market.

1. Introduction

Snow clearing is a difficult task that imposes hard labor on people who live in regions with heavy snow. Honda sought to lighten the burden of that hard labor when it entered this market in 1981 with development of the HS35 compact snow thrower for consumer use in America. In Japan, it placed the consumer-use HS50 (5-HP class) compact snow thrower on the market in 1982. Honda snow throwers are now used by customers in some twenty countries around the world, and their cumulative sales have passed the 500,000-unit mark.

In Japan today, Honda has a line-up of snow throwers ranging from gasoline-engine-powered models (6 HP) to those with diesel engines (25 HP). It now leads the industry as the top manufacturer, having acquired a 40% share of the overall market for snow throwers.

In recent years, what has been termed a phenomenon of global warming has caused increased snow coverage. Larger regions have been experiencing falls of heavy snow (snow with a high specific gravity), and the removal of heavy snow is coming to be an increasingly difficult task.

There has been growing demand for a mid-sized snow thrower (10-HP class) that will satisfy the desire to make snow clearing faster, easier, and simpler to accomplish.

The circumstances of snow clearing are also under change, influenced by the recent transition to an aging society and the lack of workers to perform the labor, among other factors.

It was in order to meet the demands of this market that the HS1390i was developed, and this model will be introduced here.

2. Development Goals

The development concept for this product was defined as a high-performance snow thrower that anyone can easily use. In specific terms, the goals were as follows:

- (1) Use a 2-motor driving system in order to improve turning and slow speed control which simplifies operation.
- (2) Increase the efficiency of snow clearing work by using electric power and linking it with the engine.
- (3) Utilize electric control to reduce the load on the operating system and improve operability.

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Fig. 1 External view of HS1390i

3. Basic Configuration and Major Specifications

In general, the drive train of the conventional snow thrower is made up of the snow clearing system and the driving system. The snow clearing system has an auger that fragments the snow and gathers it in a central location, and a blower that blows the snow up to distances of nearly 20 m. It is driven by a belt from the engine. The driving system is made up of a transmission that is either gear drive transmission or a hydro static transmission (HST), and a crawler that generates traction to provide performance on rough surfaces as well as to force the snow clearing system into contact with the snow.

The present HS1390i has a hybrid drive train that, when it is clearing snow, uses the engine to drive the snow clearing system, which requires large amounts of power, and uses two independent motors on the left and right to power the driving system, which must be capable of more delicate operation. Fig. 1 shows an external view of this product, and Fig. 2 shows a schematic drawing of the hybrid system. The use of a computer to control the driving system makes it possible to achieve smooth travel motion and smooth work operations geared to the load. This makes it easier even for beginners to perform snow removal operations that require experience when handling a conventional snow thrower. There is also an auger automatic rise function that automatically lifts up the auger housing, when the machine moves in reverse. A height mechanism maintains the operating controls at a fixed height regardless of changes in the auger height setting, and the amount of force required to operate the various controls has been reduced. The use of these mechanisms reduces the load on the operator. Table 1 shows the major specifications.

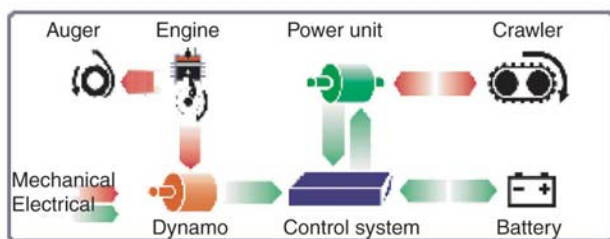


Fig. 2 Hybrid system

Table 1 Major specifications

Items	Specifications
Overall length (mm)	1 650
Overall width (mm)	920
Overall height (mm)	1 350
Dry weight (mm)	250
Engine model name	Gx350
Engine type	Air cooled, 4-stroke, single cylinder gasoline engine (OHV)
Maximum power (kW)	9.6
Snow-clearing width (mm)	920
Snow-clearing height (mm)	680
Maximum Snow-clearing volume (ton/h)	80
Drive system	Independent left and right drive motors
Speed control	Revolution feedback PWM

3.1. Driving System Configuration

The driving system power unit consists of the motor, magnetic brake, reduction gear, wheel shaft, revolution sensor, and thermo sensor. The source of driving power is electricity supplied by a battery and an alternator. The reduction gear is used to reduce motor revolutions. The crawler is driven by the wheel shafts via the wheels.

Two independent power units are installed as configured above, one each on the left and right. Fig. 3 shows the driving system, and Fig. 4 shows the layout of the motor and reduction gear.

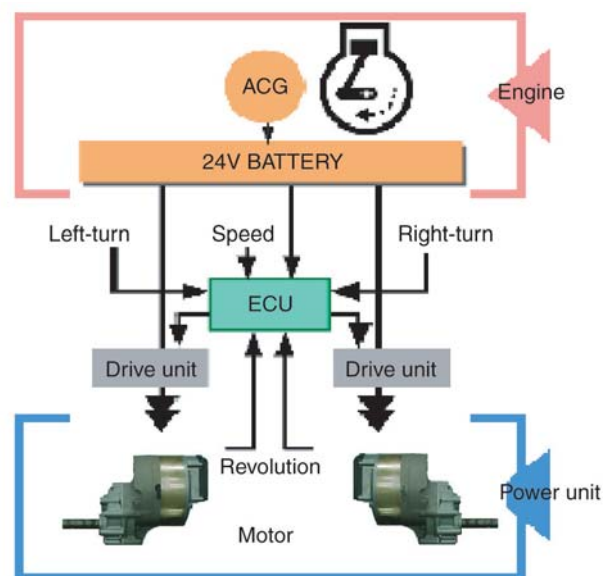


Fig. 3 Driving system

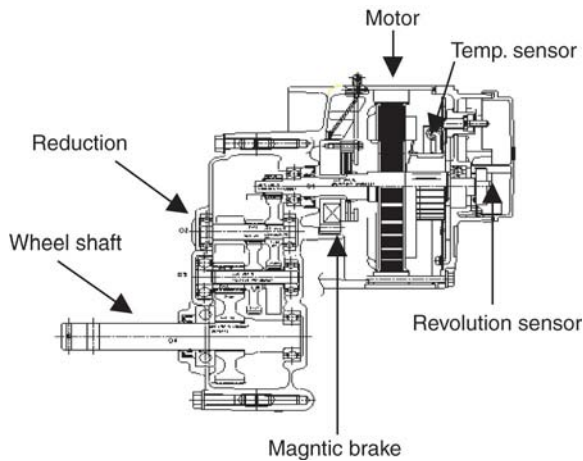


Fig. 4 Power unit layout

3.2. Snow Clearing System Configuration

The snow clearing system of the snow thrower is made up of an auger that fragments the snow and gathers it in a central location, and a blower that blows the snow to a maximum distance of nearly 20 m. This system is required to be capable of being raised and lowered independently of the frame of the driving system in order to control the amount of work and the depth to which snow is cleared.

The snow clearing system is ordinarily attached to the frame on which the engine is mounted in order to make use of the engine's power directly. In conventional models, the limitations of the drive train meant that the driving levers were also fixed to this frame, and as a result they would move up and down around the fulcrum of the crawler drive shaft together with the snow clearing system as it was raised and lowered. With the HS1390i, the driving levers are instead attached to the driving system frame and the operating system is fixed in place. This reduces the load on the operator. Fig. 5 shows a conceptual view comparing the operator posture with these different models.

The fulcrum for raising and lowering the snow clearing mechanism was located near the attachment point for the driving levers, thus greatly increasing the range of vertical movement of the snow clearing system. Table 2 shows the lift height of the snow clearing system and the height of the handle. The snow clearing system is raised and lowered by the telescopic motion of a hydraulic unit that is built into the motor and operated by a lever on the control panel.

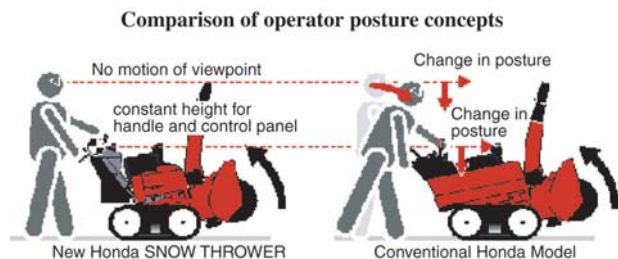


Fig. 5 Outline of figure

Table 2 Comparison of operation posture (Unit: mm)

	Lift height Auger	Handle height (Max/Min)
HS1390i	220	830/830
Conventional	125	890/620

3.3. Operating System Configuration

During snow clearing work, the operating system engages simultaneously during several activities. It operates the clutches for both travel motion and snow clearing, while also controlling the amount of snow clearing (by varying speed and depth), it also determines the snow-throwing direction. Previously operation required experience and most of the operations involved rods and wire-operated clutches. This required greater operation force, and imposed more load on the operator. (Sequential travel speed control with the engine load was used as described above for the purpose of making operation less complicated and difficult.) For the HS1390i, the two points described below were implemented to resolve these issues.

3.3.1. Improved layout of controls

The turn control levers, conventionally located on the control panel, were attached to the left and right handlebar grips. In the past, the running speed control lever had an H-gate because there was a sub-transmission with two speeds as well as the HST. With the adoption of electric power, this has become a continuously variable arrangement with just one gear that is basically in the form of an I-gate. These changes allowed considerable freedom to rearrange the control panel layout, and the controls, including the shooter and auger control levers, have been placed for greater ease of use.

Fig. 6 shows the layout of the control panel.

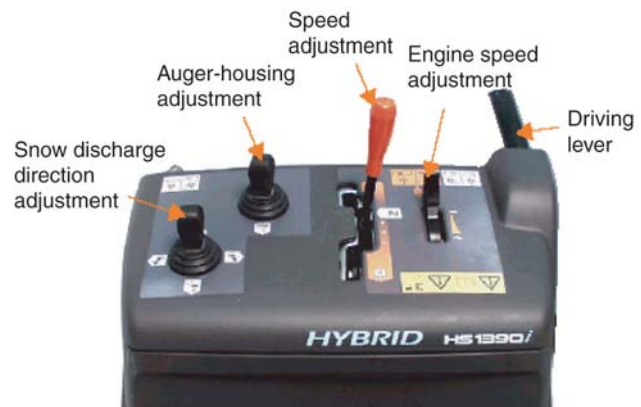


Fig. 6 Control panel

3.3.2. Reduction of operation force

The change to electric power for the driving system made it possible to reduce the force required for operation of controls to a great extent. The running speed control lever and the turn control levers are now controlled by voltage volume. A magnetic clutch that operates as an on/off switch was adopted for the snow clearing system, and the clutch lever for travel motion was also replaced with an electrically operated switch.

Table 3 shows the force required to operate the various controls.

Table 3 Force required to operation control (Unit: N)

	Speed lever	Turn lever	Driving lever
HS1390i	11	16	15
Conventional	41	46	43

4. Component Technologies

4.1. Motor

The flat disk type motor was given a flat ratio of 1:8.75 compared to the cumulative thickness and armature outer diameter ratio of 1:1 in ordinary motors. The motor installed in the Monpal ML100 electric scooter⁽¹⁾ was used as the base. Table 4 shows the major specifications. The power and durability of the motor were enhanced relative to the Monpal ML100 by changing the winding specification from wave winding to lap winding and by increasing the number of brushes from two to six.

Thermistors placed close to the brushes monitor the temperature and guard against overheating in the motor.

A magnetic brake was placed on the motor output shaft. The motor case was integrated with the reduction gear case.

Table 4 Specifications of motor

Motor	Rated power (V/W)	24/600
	Armature (mm)	Φ 140 × 16 (31 slots)
	Winding	Wave class B
Sensor	Revolution	2-phase magnetic pickup
	Temperature	Thermistor

4.2. Control System

The system uses an electric control unit (ECU) with a 16-bit microprocessor and two 8-bit microprocessor drive units, one each on the left and right, to perform linked control of the left and right motors.

Apart from the above travel motion control, the ECU is used for an on/off control for the magnetic clutch that transfers power from the engine PTO shaft to the snow clearing system, an interlock control for the starter motor, and controls for the various other devices. Together these make up the total control system.

4.2.1. Drive unit

The forward/reverse direction and speed of the motor are controlled by two field effect transistors (FET) in parallel used in a full-bridge configuration. Cooling fins are formed on the aluminum case for improved cooling efficiency, and this extends motor power. Pulse width modulation (PWM) control is used to control the motor, with signals from the ECU passed through an interface to be processed by the 8-bit microprocessors. The voltage, temperature, and current monitoring functions were added, and they output signals to the ECU in case of malfunction. Fig. 7 shows the drive unit.



Fig. 7 Drive unit



4.2.2. ECU

(1) Travel motion control functions

The ECU works with voltage detection sensors installed on the speed control lever, which regulates running speed, and on the left and right turn control levers, which are used for turning. It determines the travel motion control mode using the engine speed and the setting of the i-control switch (control mode selector).

Fig. 8 shows the control unit. Fig. 9 shows a diagram of the control system.

Travel speed control operates by digital proportional integral (PI) control that feeds back the speed and turning direction from the hole IC turn sensor built into the motor. Fig. 10 shows the speed control system.

The ECU evaluates separate speed signals from the left and right motors and performs linked control of the two motors. The categories of linked control are straight forward movement control, forward and reverse movement control, turn control, and travel speed control linked to the engine load.

(a) Straight forward movement control

There are conditions in which straight forward movement cannot be assured by speed control of the independent left and right motors alone. This is the case, for example, while climbing over a bump when the weight is unbalanced, or when the motors become overloaded while climbing a slope, and so on.

Such situations when the motors run at different speeds can be handled by synchronizing the speed of the faster motor with the one that is running more slowly. For cases when the motor on one side is running at a slower speed while climbing a slope, the system incorporates a control that instructs both motors to slow down to the speed prescribed for direct forward movement. The resolution of the speed control lever has also been changed to allow finer speed adjustment within the snow clearing speed range.

(b) Forward and reverse movement control

Given the form of snow clearing work, there are occasions when forward and reverse movements are frequently repeated. In such cases, the machine may move in a skewed manner because variations between the two motors causes one motor to lag behind the other when shifting between forward and reverse movement by independent motor control.

This is handled by having the system constantly compare the speeds of the left and right motors. The timing of the shift between forward and reverse is then synchronized between the two according to the speed level of a running stop.



Fig. 8 Control unit

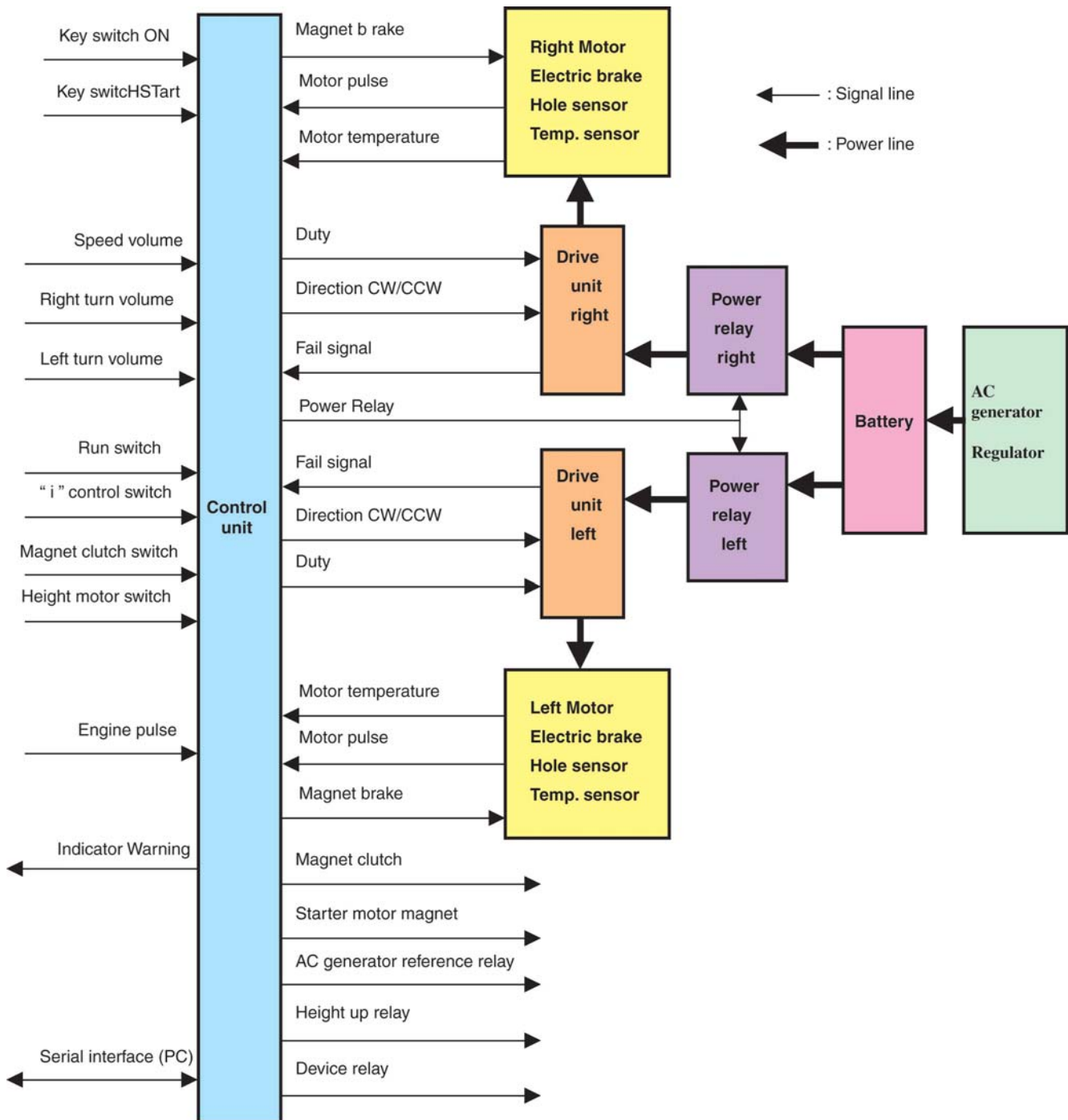


Fig. 9 Control system diagram

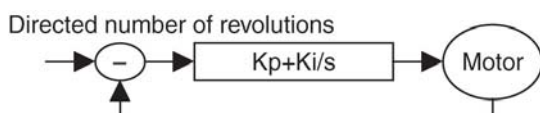


Fig. 10 Speed control system

(c) Turn control

Turn control adjusts the speed of the left and right motors to their optimum level according to the amount of grip pressure on the speed control lever and turn control levers. This has enabled smooth, easy turns within the traveling speed range, and axis turns (zero turns) within the working speed range.

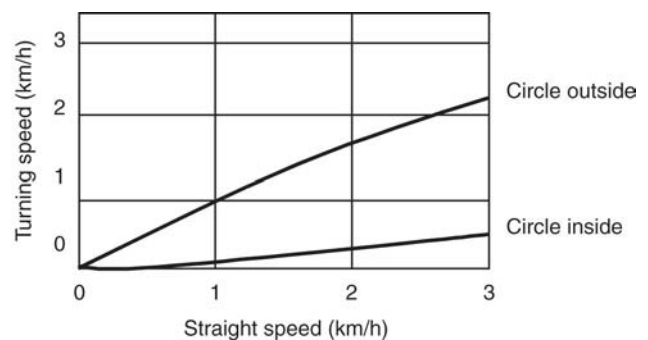


Fig. 11 Turn control

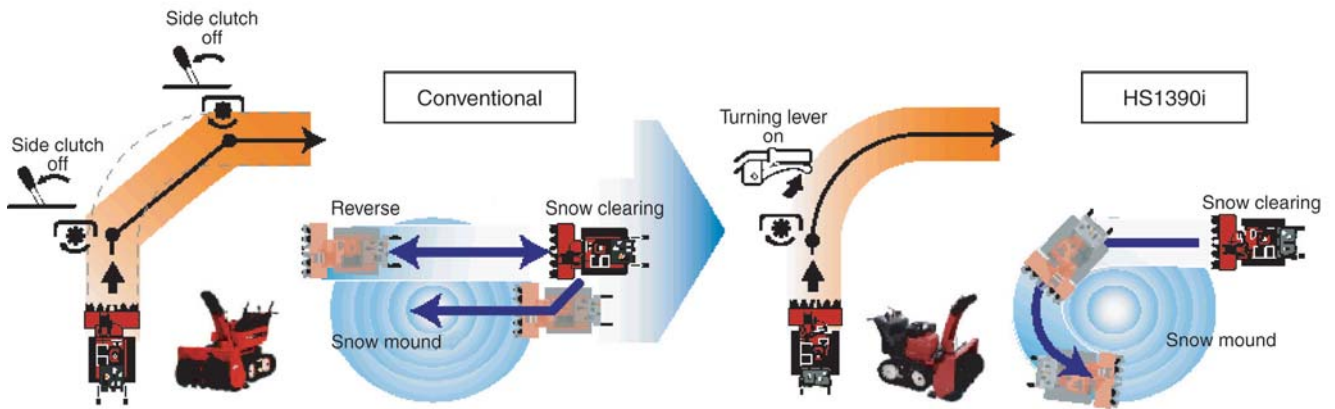


Fig. 12 Outline of turn control

Fig. 11 shows the running speed characteristics for the motor on the outside and inside of a turn made using only one of the turn control levers. At a travel speed of 3 km/h, smooth, easy turning is obtained by reducing the traveling speed on the outside of the turn. In the low speed range (1 km/h or less), the speed on the inside of the turn is reduced to zero.

Fig. 12 shows a comparison of turns with conventional snow throwers.

(d) Sequential travel speed control with the engine load

When clearing snow with the i-control switch turned on, the control system links the travel speed adjustment with the engine speed. Specifically, the control links travel speed with the engine speed so that it reduces travel speed to as little as 10% of the set value.

This function inhibits the reduction of snow clearing capability that occurs when the engine stops or slows down.

Fig. 13 shows the characteristics of the slowdown rate of the running speed when the engine running speed set by control is 3,500 rpm and the engine speed drops. For example, when travel speed while clearing snow is 0.5 km/h and the engine speed drops to 2,400 rpm, then the travel speed will be 0.05 km/h.

As shown in Fig. 14, the travel speed when clearing snow is adjusted automatically according to the depth of the snow being cleared. This has reduced the necessity for the operator to use the running speed lever. It has been confirmed that the use of this function by a beginning operator when clearing snow will bring about a maximum improvement of approximately 10% in snow clearing fuel consumption (amount of snow cleared/amount of fuel consumed) over conventional models.

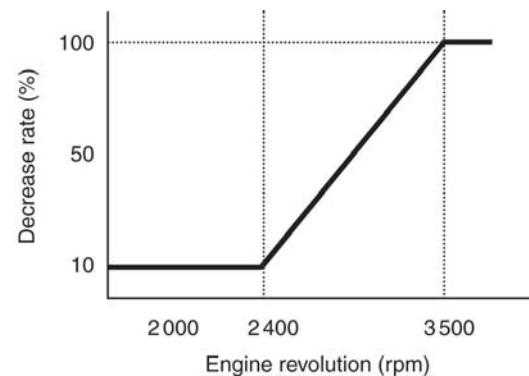


Fig. 13 Speed control

(e) Parking brake

A magnetic brake is built into the axle of the driving system motor. Power is supplied during travel motion, and it is cut off when the travel motion clutch is turned off, or when the running speed lever is placed in neutral, then the parking brake is activated, in that sequence. When snow clearing involves frequent forward and backward movement, operation of the magnetic brake is cancelled when the running speed lever passes through the neutral position. This makes for smoother shifting between forward and backward movement and improves usability.

(2) Sensor position correction function

The ECU has a function that collects the initial values from the voltage sensors installed on the running speed lever and the left and right turn control levers. This corrects for mechanical error.

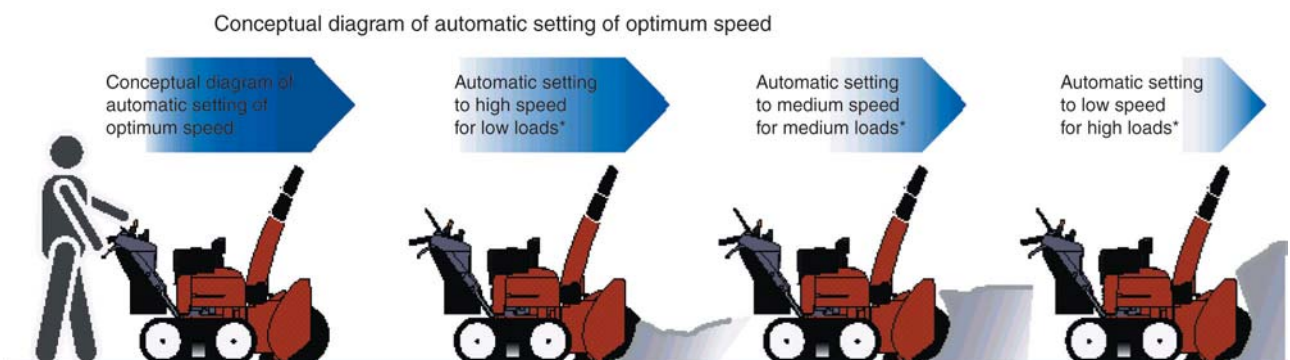


Fig. 14 Outline of speed control

(3) Protective functions and malfunction detection functions

A protective function was set up to prevent damage to the motors and drive unit. Notice of the operation of this protection is provided by red and orange lights installed on the left side of the control panel. The operator is alerted by the light in orange flashing mode. The protective function has two modes, reduced power and power off. In reduced power mode, low-speed travel is possible. When a malfunction occurs, the system turns on the red light on the control panel, and indicates the location of the malfunction by the number of times the orange light flashes. Fig. 15 shows the control panel with the key turned on and the lights illuminated during the self-diagnosis process.

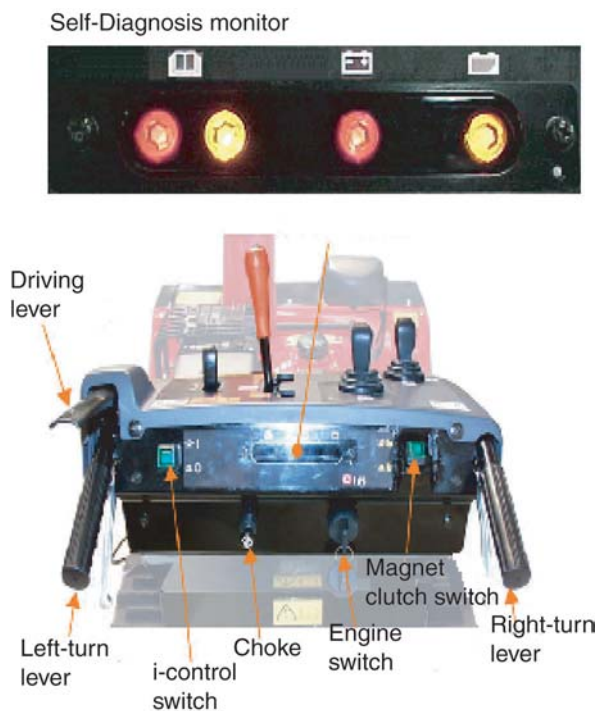


Fig. 15 Control panel

(4) Starter and magnetic clutch control functions

By using both a starter interlock and a magnetic clutch interlock, smooth and correct snow clearing is provided. The ECU controls the on/off status of the starter magnet and magnetic clutch.

(5) Height motor control function

(a) Automatic height function

A hydraulic height motor was installed to raise and lower the snow clearing part in order to control the amount of work and the depth to which snow is cleared. An auxiliary function for frequent raising and lowering operations was provided by incorporating a function that will automatically raise the snow clearing part for two seconds when the running speed lever is set to reverse while the i-control switch is turned on. Lowering it requires a manual operation by the operator. Fig. 16 shows a comparison of snow clearing operations with the conventional snow thrower.

(b) Timer function

The system was given a timer function to limit the electric current consumption when the height motor is operated for long periods of time. Specifically, one timer was set up so that the ECU would add up the operation inputs to the height switch, and another timer was set up that would stop when the switch is operated continuously.

(6) Personal computer monitor port

A port has been included to allow verification of motor control output and voltages of the various operating controls during shipment inspections of completed units. This makes it possible to evaluate the load current in the motor transmissions, which also contributes to quality improvement. The port was designed to allow for the possibility of future use as a tool for inspection using a personal computer.

4.3. Power Supply System

In light of motor efficiency, a 24-V power supply system was adopted and all devices from the starter motor to the engine electric devices were designed to run on 24 V. The charging system uses a new 24-V alternator to assure balanced consumption during travel, and the output was set to a 24-V, 40-A specification.

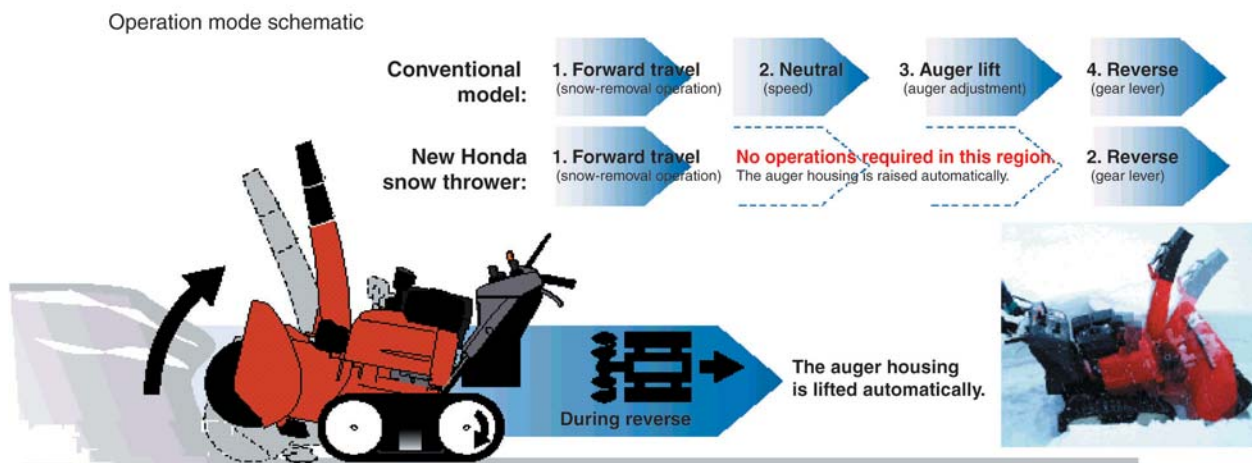


Fig. 16 Outline of HIT control

5. Summary

In development of the HS1390i hybrid snow thrower equipped with a two-motor driving system using electric power supplied from the engine, the following achievements were made:

- (1) Two independent motor power units were installed on the left and right to power the driving system, each was equipped with its own drive unit, and a control system was established with an ECU. This allowed for better turning control and made it possible to adjust low speeds, thus achieving simple operation.
- (2) Computer control was instituted for engine load and the driving system. This allowed automatic adjustment of travel speed during snow removal work, and it has been confirmed to reduce the necessity for the operator to use the running speed lever, lower the load on the operator, and enhance the snow clearing fuel consumption.
- (3) Enhancements in the operating position have reduced the load on the operator and improved performance on difficult surfaces by increasing the range of vertical movement of the snow clearing mechanism.
- (4) The use of electric control made it possible to arrange the operating system for greater ease of use and to reduce the amount of force required to operate the controls.
- (5) Shifting the running speed lever into reverse causes the snow clearing components to be raised automatically. This simplifies the operation procedure and enhances usability.
- (6) The ECU monitors the various functions and indicates the location of malfunctions when they occur, thus enhancing maintainability.

6. Conclusion

The HS1390i achieved a new concept of driving system known as hybrid, which combines an engine and machinery with motors and electricity. This came about through the pursuit of ease of use and efficient snow clearing for the customer. This system was combined with an automatic control system run by a CPU, thus making it possible to take full advantage of the strengths of a hybrid system and to make the product easier to use. The power unit has also created new possibilities for further application to general-purpose power products.

This snow thrower hopes to reduce the burden on customers who live in regions with heavy snow. This development project received substantial cooperation from people inside and outside the company. Here, in closing, the authors express their heartfelt gratitude.

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