Energy Saving System for Crawler Cranes

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KOBELCO CRANES CO., LTD. has developed a new crawler crane equipped with a system for improving fuel consumption and reducing CO_2 emissions. The system comprises a fuel-saving mode, a high-speed winching mode, an auto idling-stop mode and the positive control of hydraulic pumps. The new crawler crane has achieved a fuel efficiency that is about 30% better than that of the conventional cranes produced by the company.

Introduction

The "Act on Regulation, Etc. of Emissions from Non-road Special Motor Vehicles" (commonly known as the "Off-Road law") was revised. In October 2011, a more stringent emission standard came to be applied to special vehicles using diesel fuel. Transportable crawler cranes are subject to this regulation. To meet the new regulation, KOBELCO CRANES CO., LTD. has made a full model change in a general purpose crawler crane and has begun selling the newly-developed machine (**Fig. 1**). This machine emits less nitrogen oxide (NO_x), non-methane hydrocarbon (NMHC) and particulate matter (PM) in its exhaust. With the concept of placing importance on environmental performance, the machine incorporates new features for saving energy and reducing CO_2 emissions. As a result, the newly-developed machine has a fuel consumption that is approximately 30% less than that of conventional machines (during the general crane work of framing construction in building applications). This paper introduces these new features for energy saving and the reduction of CO_2 emissions. There is also an outline of the technology that enabled these features.

Fig. 1 New crawler crane

1. Energy saving technology for crawler cranes

Conventional crawler cranes place more importance on ease of operation and operational stability than on energy saving performance. Energy saving measures in conventional crawler cranes, such as those manufactured by KOBELCO CRANES CO., LTD., have been limited to reducing power consumption during no-load operation.

When the running torque of a hydraulic pump is given by T (Equation (1)), the power L is expressed by Equation (2). This sort of no-load operation is attained by placing the operating lever of the actuator in the neutral position. The equations indicate that minimizing the displacement q of the variable displacement hydraulic pump decreases the pressure loss of the hydraulic system, which reduces the running pressure of the pump. Therefore, minimizing the running torque T, expressed by Equation (1), decreases the power consumed during no-load operation.

$$T = pq/2\pi \quad \cdots\cdots (1)$$

$$L = 2\pi TN/60000 \quad \cdots\cdots (2),$$

wherein,

T : running torque of the hydraulic pump (N・m)
p : discharge pressure of the hydraulic pump (MPa)
q : hydraulic pump capacity (cm^3)
L : hydraulic pump power (kW)
N : hydraulic pump revolution (min^{-1}).

The newly-developed crawler crane is also equipped with a system consisting of the following four features designed for energy saving and the reduction of CO_2 emissions:

i) Energy saving mode
ii) High-speed winching mode
iii) Automatic idling-stop

iv) Positive control for hydraulic pump

Other energy-saving features include the improved fuel consumption characteristics of the engine itself and reduced pressure loss in the hydraulic devices and piping. This paper describes the above four new features.

2. Energy saving mode

Fig. 2 shows the specific fuel consumption of an engine installed in the newly-developed crawler crane. In general, the actuator moves at the maximum speed when the engine revolution reaches its maximum. On the other hand, the specific fuel consumption is known to deteriorate with maximum engine revolution. Rather, a relatively high level of specific fuel consumption is known to be achieved near the revolution at which the engine gives the maximum torque. The newly-installed engine also exhibits this behavior.

In order to drive the hydraulic pump in a zone in which the engine exhibits a favorable specific fuel consumption−hence, to save energy−an energy saving mode (trade name "G engine") has been devised to limit the maximum revolution of the engine.

Meanwhile, the efficiency of crane work, or the speed of winching up and down, must not be sacrificed under this energy saving mode. For this reason, the capacity of the hydraulic pump for the main actuator has been increased beyond that of the conventional pump and the pump is constructed such that its maximum capacity can be switched between two levels as shown in **Fig. 3**. Switching between the two maximum levels is configured in such a way as to preserve the relationship expressed by Equation (3). When the energy saving mode is selected, the maximum capacity is switched to q_1. This enables the hydraulic pump to achieve the same discharge rate (rated flow), Q, as that achieved by the maximum revolution (N_2) and the maximum capacity (q_2) in the standard mode, even when the engine revolution N_1 is limited by the energy saving mode (**Fig. 4**).

$$q_1N_1 = q_2N_2 = Q \quad \cdots\cdots (3)$$

wherein,

- q_1: the maximum pump capacity (cm^3) in energy saving mode,
- q_2: the maximum pump capacity (cm^3) in standard mode,
- N_1: the maximum engine revolution under the restriction of the energy saving mode (min^{-1}),
- N_2: the maximum engine revolution in the standard mode (min^{-1}), and
- Q: the rated flow of the hydraulic pump (cm^3/min).

Fig. 5 is a schematic diagram showing a typical hydraulic system for driving the hydraulic devices in a crawler crane. The newly-developed machine is equipped with a hydraulic pump that has a large capacity for running traveling devices and winches

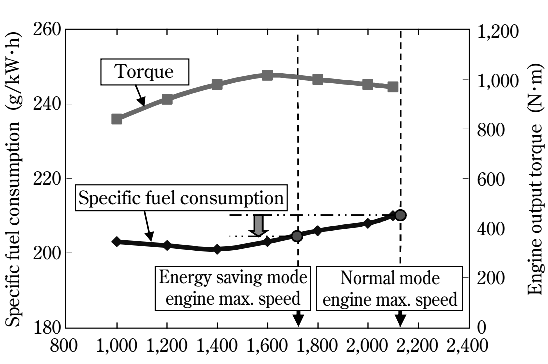

Fig. 2 Specific fuel consumption of engine

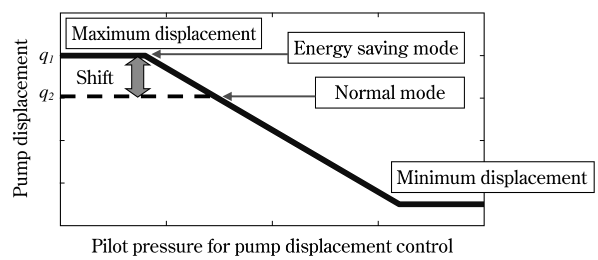

Fig. 3 Pump displacement characteristics

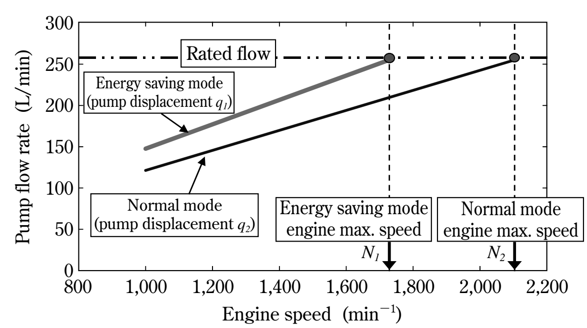

Fig. 4 Characteristics of pump flow rate in energy saving mode

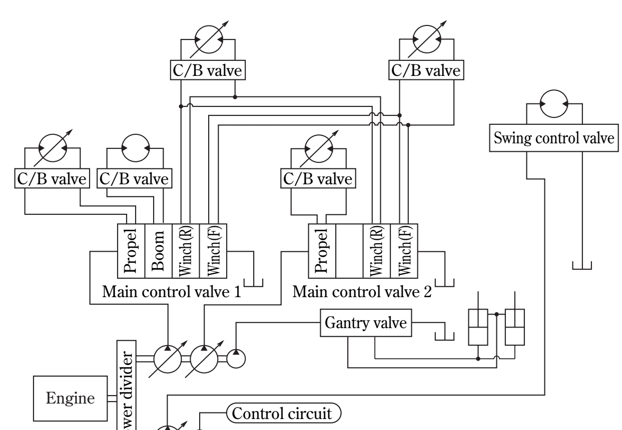

Fig. 5 Hydraulic system of crawler crane

(i.e., main and auxiliary winches). The increased pump capacity, along with the energy saving mode, has realized an energy saving effect during general crane work and continuous traveling.

The system is adapted for switching between an energy saving mode and standard mode. This adaptation was made because limiting the maximum revolution of an engine decreases its power. The switching capability allows an operator to choose the standard mode, which prioritizes engine power in heavy duty work where full engine power is required.

In order to verify the energy saving effect, the specific fuel consumption was measured on an actual machine operating under an average engine load of 20%, emulating general crane work for framing construction in building applications. For a machine equipped with a 271kW engine, the specific fuel consumption was measured to be 35.7L/h for the standard mode and 31.7L/h for the energy saving mode. The result confirms that the energy saving mode achieved an energy saving effect of about 11%. For a machine equipped with a 213kW engine, the standard mode yielded 32.5L/h, while the energy saving mode yielded 28.0L/h for the specific fuel consumption, verifying an energy saving effect of about 14% when in energy saving mode.

3. High-speed winching mode

A conventional crawler crane sets its engine revolution to the maximum even for a small lifting load to operate its winch at maximum speed and to shorten the up/down time. To prevent free fall during the descending operation, the hydraulic circuit that controls the winching is provided with a valve called a "counterbalance valve." This valve is opened with a small supply of pressure to generate a braking pressure that corresponds to the lifted load on its discharge side. This mechanism prevents free fall, while enabling descending operations to be performed with a small amount of power and in correspondence with the supply flow.

However, a varying load and other factors may cause instability, with hunting of the winch during lifting-down operation. Therefore, the valve is generally provided with a dumping property in its open direction. This stabilizes the operation, but sacrifices responsiveness. Because of the dumping property, the counterbalance valve does not open fast enough to discharge a sufficient flow when a small load is lifted. Winching down at maximum speed, with the engine rotating at its maximum revolution, increases the amount of oil in the flow passage on the discharge side, which causes a boost pressure to be generated at the inlet of the hydraulic motor. This boost pressure causes the hydraulic pump to be driven at a high pressure (designated by ◆ in **Fig. 6**), which generates unnecessary power, deteriorating the fuel efficiency during descending operations. In other words, the prevention of hunting has caused unnecessary power consumption.

The high-speed winching mode (trade name "G winch") focuses on the above issue and enables the winch to move at a rate almost equal to the maximum speed, even when the lifted load is small (**Fig. 7**). More specifically, this feature employs a hydraulic winching-motor that has the capability of switching among three capacity levels characterized by a special intermediate capacity, as shown in **Fig. 8**. This feature allows for setting the hydraulic motor to rotate at a high revolution even when the engine rotates at a low revolution and both the discharge rate of the hydraulic pump and the flow supplied to the hydraulic motor are small. Under normal conditions, the capacity of the hydraulic motor is set to the intermediate level (a), which allows the winch to move at the maximum speed. In a high-

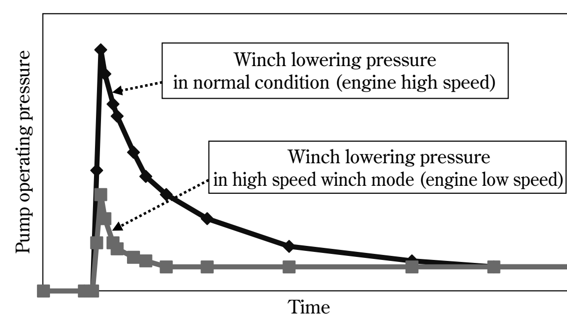

Fig. 6 Pump operating pressure in winch lowering

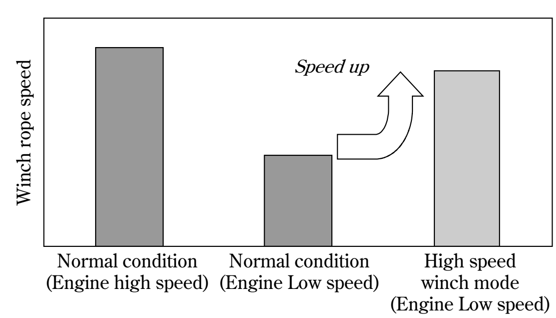

Fig. 7 Winch speed in high speed winch mode

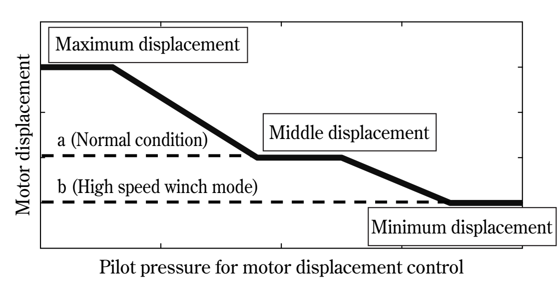

Fig. 8 Motor displacement characteristic of three position displacement control type

speed winching mode, the motor is set to the minimum capacity level (b), such that the winch speed is maintained at the maximum rate.

The new hydraulic motor system enables the winching up and down of a small lifting-load at a maximum speed with the engine set at a low revolution, not at the maximum revolution. In addition, the low engine revolution maintains only a small discharge rate in the flow passage on the outlet side of the counterbalance valve, which minimizes the boost pressure acting on the hydraulic pump. As a result, the hydraulic pump is operated at a low pressure (as designated by ■ in Fig. 6), while enabling high-speed winching up-and-down with the engine rotating at a low speed. Furthermore, as expressed by Equation (1), decreasing the driving pressure of the hydraulic pump decreases its running torque, which reduces the fuel consumption by a commensurate amount.

Actual measurement has verified that the momentary fuel consumption is decreased by 60 to 80% when winching down the hook alone.

4. Automatic idling-stop system

Typical crane operations, excluding cyclic loading, have long intervals between the steps in a job. An automatic idling-stop system has a computer that determines if the crane is in idle and automatically stops the engine during idle time. This system cuts unnecessary fuel consumption and exhaust gas (CO_2) emission during idle time. Safety is the major priority in crane work, and all the safety conditions must be satisfied in an idle condition before starting the countdown to the activation of the idling-stop system. The countdown is displayed on a monitor in the cab such that the operator can cancel it. Once the countdown expires (for example, in ten seconds) without a cancelation, the engine stops automatically. Rebooting the engine can be accomplished by simply rotating an accelerator grip, which permits quick restoration from the idle mode (**Fig. 9**).

A study on general crane operations has revealed that, in most cases, idle time accounts for 50 to 75% of the entire operating time of an engine. Assuming that the idle time occupies 75% and the engine can be stopped for 37% of the operating time (i.e., half the idle time), it is calculated that there is a maximum energy saving of about 15% (in the case of crane work for general framing construction where the engine load rate is assumed to average 20%).

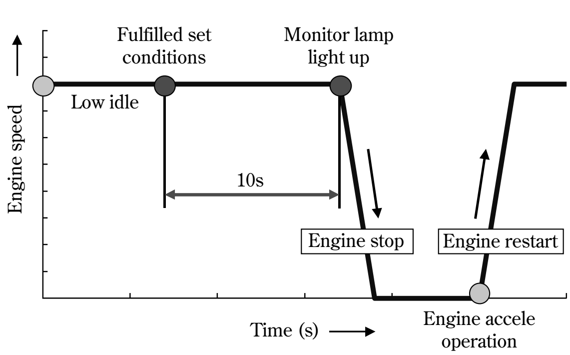

Fig. 9 Auto-idling-stop system

5. Positive control for the hydraulic pump

As previously described, a conventional crawler crane has been equipped with an energy saving system in which the capacity of its variable-capacity hydraulic pump is minimized only when the operating lever is put into the neutral position. When the lever is in an operational position, however, the hydraulic pump runs at its maximum capacity. In addition, a loss of energy is caused by a surplus flow when the flow (for controlling acceleration, deceleration and precise velocity) is controlled by a valve for controlling operative directions and speed.

The newly-developed crawler crane has a positive control (**Fig.10**) which further upgrades the capacity control of the variable-capacity hydraulic pump. This feature enables the hydraulic pump to discharge a flow of just the amount required by actuators that are controlled by the operating lever. Therefore, the surplus discharge, unnecessary for the work, is minimized, as is the loss of energy during speed control using the operating lever.

The energy saving effect of the positive control is verified by measuring the fuel consumption of an actual machine operating according to a winching pattern as shown in **Fig.11**. The result indicates that significant fuel reductions have been achieved for the

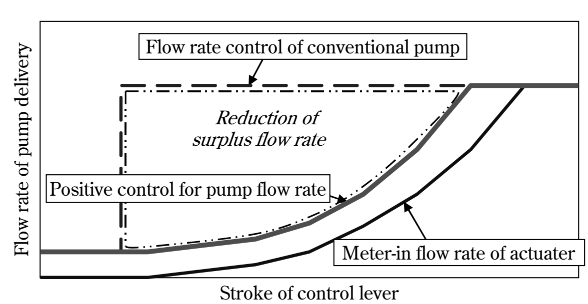

Fig.10 Positive control system for delivery flow rate of pump

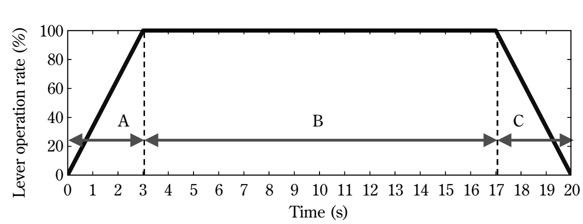

Fig.11 Winch operation pattern

speed control during interval A and interval C. The energy saving effect for the entire operating pattern (interval A + interval B + interval C) has turned out to be about 7%.

Conclusions

This paper introduces new features installed in a crawler crane newly-developed for energy saving and the reduction of CO_2 emissions. The requirements for reducing the environmental burden will become increasingly stringent. We will strive to further advance technologies for reducing the environmental burden so as to meet user needs and thus contribute to society.