

Operating System of a Double-Front Work Machine for Simultaneous Operation

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Abstract: Many kinds of work machines based on hydraulic excavators have been developed for various work fields, e.g. demolition and industrial waste disposal. These work machines have also played an important role in the recovery work after disasters such as earthquakes, typhoons, and floods. We think that adapting these work machines to complex works will be expected in the near future. For this purpose, we developed a new type of work machine named ASTACO, which features two front arms and is based on 7-ton class hydraulic excavator. We also developed a new operating system for ASTACO that enables operators to handle the two front arms simultaneously through two controll devices. In this paper, we present an overview of ASTACO and its operating method.

Key Words: double-front work machine, excavator, demolition, disaster recovery

1. Introduction

Because of the need to cope with global environmental problems, such as global warming and resource depletion, efforts to achieve the recycling society are becoming more important. In Japan, legislations requiring recycling in various industrial fields have been introduced. A lot of work machines based on hydraulic excavators therefore have been developed for various work fields like demolition and industrial waste disposal. These work machines have also played an important role in recovery work after disasters such as earthquakes, typhoons, and floods. Therefore, we think that adaptation of such machines to do more complex works will be expected in the near future. However, current work machines are mainly based on traditional excavators with a single front arm, and thus are difficult to do complex works.

To achieve handling functions for complex works, a possible approach is giving a machine two front arms. We have developed a new type of work machine, a double-front work machine, that we have named ASTACO (Advanced System with Twin Arms for Complex Operations). In the following sections, we will first present the background leading to development of ASTACO, then will present the operation method, which is the most important factor in achieving complex works with the two front arms, and last, we will describe our field-testing of ASTACO.

2. Background of ASTACO development

2.1 Scope of work machines

Figure 1 shows the scope of work by humans and machines in two-dimensional space with power and complexity axes. Human workers can deal with a simple and light-load work using one hand. When the work becomes more complex, they handle it by using

both hands cooperatively. On the other hand, work machines were developed to support humans in dealing with simple heavy-load work. For example, excavators were developed as earthmoving equipment. For more complicated works than simply digging, including handling heavy loads of material or house demolition, work machines with special attachments on the ends of their front arms have been utilized. However, current work machines are mainly based on traditional excavators with only a single front arm and tool, and difficult to conduct complicated work. One approach to solve this problem is using machines with two front arms.

Some double-front work machines (robots) that are operated manually have been developed [1][2]. Almost all of these have a structure that imitates the human arm, and they generally have 6 or 7 degrees of freedom (DOF) just as human arms do. They can perform complex operations, but they cannot deal with the kind of heavy-load work that construction machines do. This is because the structure complexity of these multi-DOF front arms caused operability deterioration, lowered work ability, and structural weakening. On the other hand, the hydraulic excavator is applied to various works as previously mentioned, although the

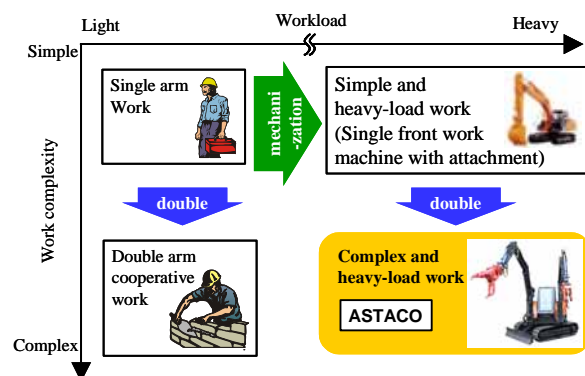


Fig. 1 Scope of Work Machine

structure of an excavator's front arm is different from that of man. Therefore, we decided to develop ASTACO with this key concept: "Enhance the functions of the hydraulic excavator resulting in a work machine."

2.2 Design Concept

Following the key concept stated above, we decided on the following design concepts for the ASTACO.

- Front arms have the same degrees of freedom as that of hydraulic excavators (generally 3-4 DOF).
- A hydraulic system drives all actuators at the same time so that operators can simultaneously operate the two front arms.
- An operating system allows operators to control intuitively without undue tiredness so that ASTACO can be used for a long time in one day.
- House demolition is main target work to decide the machine specifications.
- Fundamental performance is to be the same as that of a hydraulic excavator, because this machine must have sufficient power and speed to deal with complex and heavy works.



Fig. 2 ASTACO

2.3 Key Features

The external appearance of ASTACO, as developed with the concept described above, is shown in Fig. 2, and its specifications are listed in Table 1. The main features of ASTACO are the following.

- **Main body:** This machine is based on a 7-ton hydraulic excavator, and with the same static stability.
- **Front arms:** We gave different roles to the left and right front arms. The right arm is a 3.5-ton house demolisher for reaching high place and handling light loads, while the left is a 5-ton excavator's front arm for heavy work such as breaking and cutting. We analyzed house demolition work and searched for the best front arm composition for meeting a variety of demands.
- **Degrees of freedom:** Both front arms have the same DOF. The DOF consists of the basic 3 DOF of a hydraulic excavator (boom, arm, and bucket), and 1 DOF of a boom swing (boom swings right and left), thus the number of total DOF of the front arm is four. Additionally, the front arms can be equipped with an attachment with a maximum of 2 DOF. As for the other DOF, ASTACO has right and left running with a rotating main body and blade, therefore, it has 16 DOF in total.
- **Hydraulic system:** A load-sensing system is employed for simultaneous drive of a great number of actuators and various controls of the front arms. This system is needed because ASTACO has 16 DOF, which are about twice as much as those of ordinary hydraulic excavators, and because driving all actuators at the same time is necessary.
- **Operating method:** A following new operating method in which one control lever drives all functions of one front arm is adopted. With this operating method, the

Table 1 Specifications

		ASTACO (with attachments)	
		Left	Right
Weights	Operating weight	kg	8710
	Shoe width	mm	450
	Ground pressure	kPa(kgf/cm ²)	40 (0.41)
Engine	Model	Isuzu CC-4JG1	
	Rated power	kW/min ⁻¹ (PS/rpm)	40.5/2100 (55/2100)
	Piston Displacement	L(cc)	3,059 (3059)
Hydraulic system	Pumps	2 variable displacement axial piston pumps, 1 gear pump	
	Relief valve setting	MPa(kgf/cm ²)	24.5 (250)
	Swing motor	1 axial piston motor	
	Travel motors	2 variable displacement axial piston motors	
Front	Degrees of freedom	4	
	Available attachment DOF	2	
	Attachment	Hydraulic cutter	Rotating grapple
	Boom swing deangle (L/R) ¹	70/30	30/45
Service refill capacities	Fuel tank	L	100
	Hydraulic oil tank	L	100
	Engine oil	L	12
Working Range	Max. operating reach	mm	6540
	Max. operating depth	mm	3820
	Max. operating height	mm	5800
	Max. dumping height	mm	3740
	Min. swing radius	mm	2970

ASTACO operator is able to control both front arms simultaneously. This method makes it possible to provide intuitive control and to prevent undue operator tiredness. In the following section, we will explain the operating system in detail.

3. Operating System

In this section, we will describe the operating system, one of the key features of ASTACO. The detailed development concept is given below.

- Simultaneous operation of both front arms is possible.
- Intuition of the operation is easy.
- Tiredness resulting from working for a long time is minimized.



To accomplish simultaneous operation of the two front arms, we adopted the following operating method such that one control lever deals with one front arm (hereinafter referred to as “one lever control method”). There are many kinds of robots with two operating front arms in various fields, such as industry, medical operations, and amusement games. Most of them use a so-called master-slave control, one kind of one-lever method. Also in hydraulic excavators with one front arm, some examples of applying the master-slave method can be found [3].

We compared the master-slave method with the velocity directive method that traditional excavators adopted (Table 2).

In the master-slave system, when the position of the master (control lever) changes, that of the slave (machine's front arm) is controlled to be the same. The relation of the master and slave are generally homothetic. The advantage of this method is that the operator can manipulate the front arm very intuitively. So that even beginners can easily operate a machine with this operating system. However, in the case of a work machine like a hydraulic excavator, the front arm has to make large-scale movements frequently in various positions that are difficult for a human arm to imitate. Directing the position of the front tip is always necessary, and it is difficult for an operator to continue working for long time using this method. Minute control of the slave is also difficult because of the magnitude of the homothetic ratio

On the other hand, the velocity directive method is typically selected for the operating system of conventional construction machines. In this system, the operator sets the speed of front actuators by using the angle of the control lever. In the case of a hydraulic excavator, as shown in Fig. 3, a 2-DOF lever is set at each sides of the operator seat, and each lever can be moved in right, left, forward and backward directions. The individual DOF of the levers rotate the boom, the arm, the bucket and the main body. In addition, if a machine has a boom swing DOF, an operator generally controls it with a pedal or a switch. With this method,

Table2 Comparison of control methods

Control method	Position directive method (master - slave)	Velocity directive method (ordinary construction machines)
		
Intuition	Homothetic	Non homothetic
Tiredness	Hand movement is large	Hand movement is little
One hand control	Possible	Impossible

the operator can make large-scale movements of the front arm with only a little movement of his own hand so that he can work a long time without becoming overly tired. However, because the lever positions have little relation with front arm postures, the operator cannot operate the operating system intuitively. Moreover, one lever can control only two actuators at most. Since one front arm of the ASTACO consists of four actuators (boom swing, boom, arm, and bucket), the operator would have to use both hands to handle only one front arm using this method and could not operate two front arms simultaneously.

In the development of ASTACO, to solve the problems described above, we introduced a new style velocity directive operation method that is based on the conventional speed directive method used for excavators, but with an alternative composition and arrangement of the levers. The new operation system allows the operator to handle the two front arms by using both hands freely and intuitively. As shown in Fig. 4, a 3-DOF lever (top and bottom, back and forth, and rotation) is installed at the tip of a control arm. The control arm itself also swings from side to side. With this control device, the operator can control 4 DOF with his forearm on an armrest so that the operator is

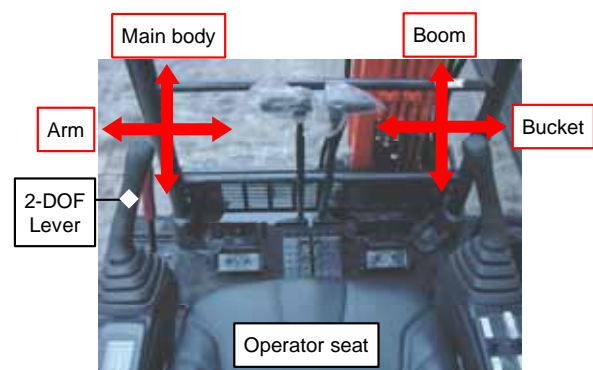


Fig. 3 Operating system of a excavator

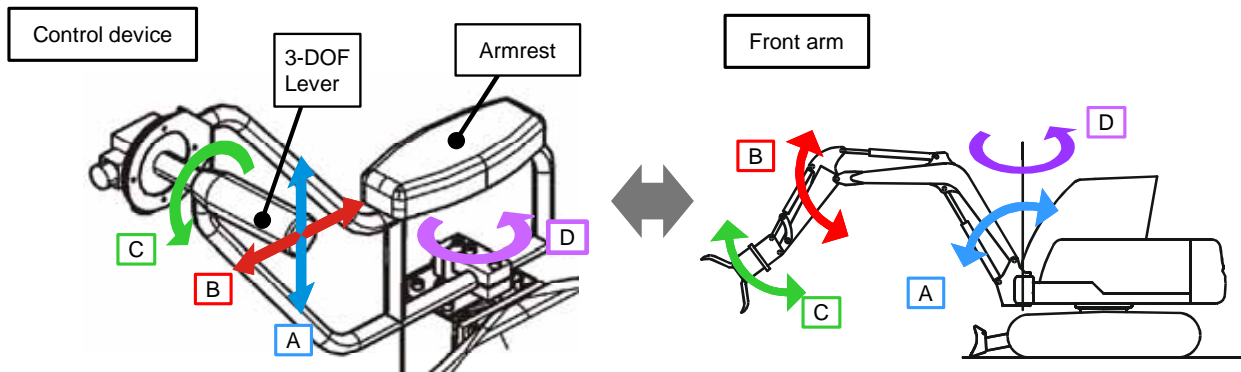


Fig. 4 Operating method of ASTACO

able to operate the machine for a long time without becoming overly tired. Next, we explain the correspondence between the control lever and the front arm. As shown in Fig. 4, (A) moving the lever up and down controls the boom, (B) moving it forward and backward controls the front arm, (C) rotating it controls the bucket, and (D) swinging the control arm swings the boom. With this arrangement, the directions of the lever movements are almost equal to the directions of the front arm movement. Therefore, the operator only has to move the lever intuitively in the direction he wants the front tip to move, and the front tip moves in that direction. The DOF of each lever barely interfaces with each other in a neutral position, and we maintain independent controllability of each lever when the operator drives some actuators at the same time. In addition, we have control devices for other components, for example, switches on the levers that control various attachments, and four pedals in the cabin that control the motion of the main body and blade.

4. Field Testing

We have conducted field tests of ASTACO on some work sites, e.g. house demolition, scrap handling, and disaster recovery training. The results of these field tests proved the effectiveness of the double front work machine and the new operating method.

The operators could handle tasks like holding a steel pipe with one mechanical hand, and cutting it with the other, and bending a long piece of metal plate with ASTACO (Fig. 5). These tasks are considered to be complex and difficult when current working machines are used. As for the operating system, we found the followings. Though we found a difference among various operator proficiency in using the operating method, almost all of them got used to it easily. Moreover, some operators became skillful enough to achieve complex tasks as fast as after about one day of operating ASTACO. Regarding the tiredness of the operator, they were able to continue working for a full day.

For putting the machine into practical use, we plan to continue field-testing at work sites and to continue evaluating and improving the machine.



Fig. 5 Field Testing

References

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