DEVELOPMENT OF DOUBLE ARM WORKING MACHINE FOR DEMOLITION AND SCRAP PROCESSING

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ABSTRACT: The development of "The double arm working machine", that is suitable for demolition and scrap-processing, and its operation support technologies are described. The contents of these technologies are interference warning system, grasping force control system and weight measuring system. In addition, the succession machine, which is developed based on the field test results and operators usability, is mentioned.

Keywords: *Excavator, Demolition, Handling Arm, Construction Robot, Manipulator*

1. INTRODUCTION

Authors suggest the application of "Double arm working machine"[1] to build a new demolition method aimed at improving the recycling rate, work efficiency, and safety.

Before the development of the machine, we focused on the process of using secondary crusher that has significant influence for the demolition work efficiency to improve the overall efficiency. In this paper, we describe “Double arm working machine”, that suitable for the demolition work and the scrap processing work, developed based on work analysis.

2. DEMOLITION WORK ANALYSIS

In demolition work, the building frame is crushed by “Primary crusher” shown on the Figure 1. Then, the “Secondary crusher” shown on the Figure 2 is applied for waste separation and reducing volume. The waste is mainly concrete blocks including rebar and other metal material. The composite panels such as for example window frames are often difficult to separate by the secondary crusher. Therefore labors need to separate these wastes by their hand in near the machine in operation. In figure 3, the result of demolition work analysis is shown. Both the machine downtime is equivalent to 30% of all work time. The primary crusher downtime is due to delays the secondary crusher work. After reviewing, it is concluded that the development of "the double arm working machine" that have sufficient work-force and excellent dexterity can increase work efficiency for construction recycling. [2]

Fig 1.Primary crusher

Fig2.Secoundary crusher

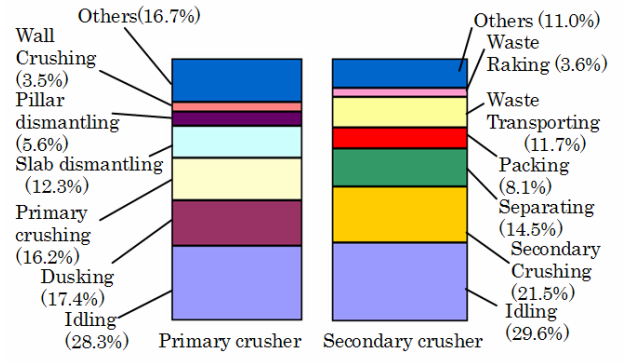

Fig.3 Demolition work analysis

3. OUTLINE OF DEVELOPMENT MACHINE

Figure 4 is the double arm working machine that we developed in 2008. The specifications are shown in table 1.

This machine has an 11-ton class hydraulic excavator arm as its right arm and a 3.5-ton class excavator arm as its left. The right arm is used to the heavy work that requires high output, such as lifting heavy loads, crushing concrete block, cutting steels scrap. The left arm is used to ancillary work that requires dexterity in order to aid the waste segregation work by grasping and severing debris. Depending on the work, each arm can be equipped with hydraulic-equipment (attachment) commercially available. The main arm DOF is equal to the conventional hydraulic excavator. On the other, in sub arm, many DOF and swing & roll device are adopted to cope with complex tasks. Table 2 shows the DOF for each arm.

Fig4.Development machine

Fig5.Multi Function hand

Table 1.Specifications (2008 model)

Operating Weight(1)			13.4 ton
Dimensions(2)	Overall width		2,730 mm
	Overall length		6,910 mm
	Overall height		2,780 mm
Engine	Model		Isuzu CC-4BG1TC
	Rated Power		63 kW / 1,950 rpm
	Piston Displacement		4,329 cc
Hydraulic system	Pumps		2variable displacement axial piston pumps, 2 gear pumps
	Relief valve setting		34.3 MPa
Working Range(3)	Max. reach	Main	4,300 mm
		Sub	4,300 mm
	Max. height	Main	5,500 mm
		Sub	3,535 mm

(1): Include Equipment, Crusher (1,100kg) for Main arm, Multi-function-hand (400kg) for Sub arm.
(2): At transport position (3): At tip pin of Arm

By the implementation of the hydraulic system and control system for double arm working machine that described later, simultaneous operation of these arms is possible. Therefore Double-arm cooperative work can be realized. For example while holding a work object in the main arm, sub arm cut it. Sub arm equips "Multi Function hand" shown in figure 5, which is newly developed and has both of cut-function and hold-function, in aim to perform complex tasks. The hydraulic circuit, which is based on standard 11t class excavator, is divided to main and sub circuit as shown in figure 6. Hydraulic source of the main circuit is used for the main arm, travel motor and swing of machine body. And sub hydraulic source is used for the sub arm. When the sub arm is not operated, all hydraulic sources are used for main circuit. Therefore, it is efficient even when the machine perform simple tasks using only the main arm, such as concrete crushing.

Table 2.DOF Structure

	Front DOF				Attachment DOF	Total DOF
		Roll	Pitch	Yaw		
Main	3	0	3	0	2	5
Sub	6	1	4	1	3	9

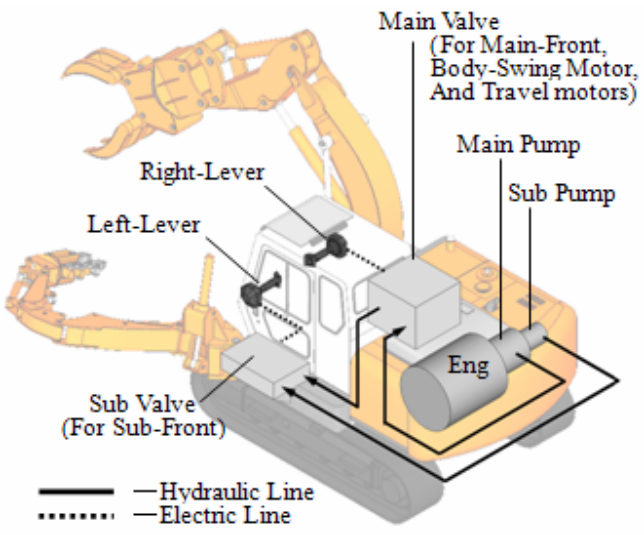

Fig6. Electric & Hydraulic System

Figure 7 is the appearance of operation device. In this, electrical levers are adopted except traveling operation. Both the machine arms can be controlled simultaneously by using left and right levers, allowing operators to viscerally convey their own arms movements to the machine arms. The direction of the levers and moving direction of the machine arms are approximately corresponding.

Fig. 7 Operation Device

Figure 8 shows the configuration of each arm. And figure 9 is the assignment of operation. In this, the letter "M" refers to the main arms, "S" means the sub arm, and numbers indicate the number of joints from the base of each arm. The insufficiency of the sub arm operation assignment is compensated by using the shift switch. As safety device, the emergency stop switches, that disconnect the right and left lever signals, is provided.

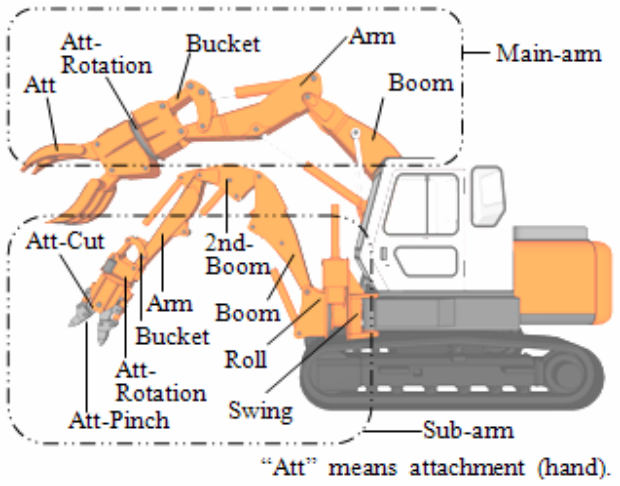

Fig.8 Main and Sub Front Composition

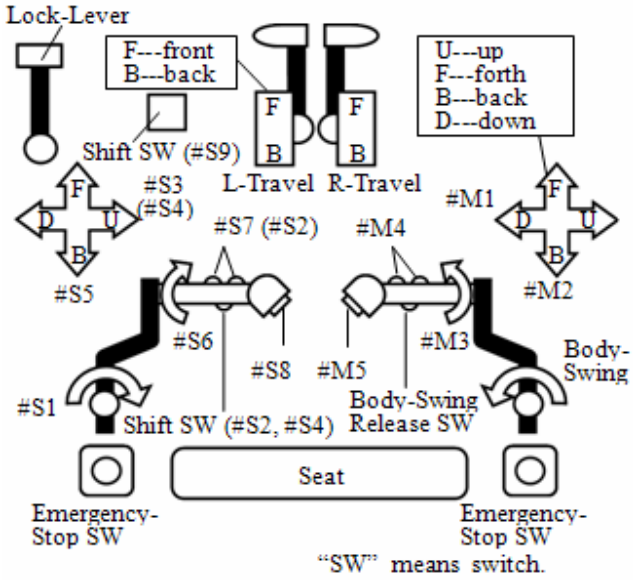

Fig.9 Operating System

4. INTERFERENCE WARNING SYSTEM

Figure 10 is the outline of interference warning system. As shown in the figure, the interference-judgment area and the escape-judgment area are provided in parallel to the working-area of the main arm. Warning lamp in the information monitor will light if the tip position of the sub arm is in the interference-judgment area. The lamp will turn off if the tip position is in the escape-judgment area. The tip position of each arms are calculated at all times, based on signal from each joint angle sensor. Tip position error of each arm is 10 cm in the main arm, 15 cm in the sub arm.

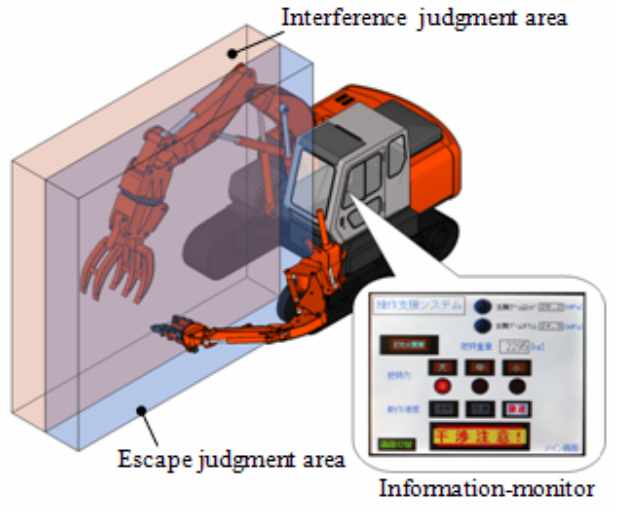

Fig.10 Interference Warning System

5. WEIGHT MEASURING SYSTEM

At the demolition site, main work of this machine is handling of heavy loads, such as concrete block or steel wastes. Grasping heavy weight object may lead instability of the machine. In embarkation-operation, operator estimates the object weight based on the experience, and conducts judgment whether conveyance can be safe. In teleoperation which will be expected in future, weight estimate seems difficult. Therefore, the weight measuring system is needed to examine. In this machine, the holding object weight is calculated based on the difference between the cylinder thrust and the weight moment of each constituent member. But, in this method, hydraulic circuit should be depressurized, in order to reduce the influence of friction between the cylinder inner wall and the sealing material. It is known that operation for take down the boom just a little is effective to depressure hydraulic circuit.

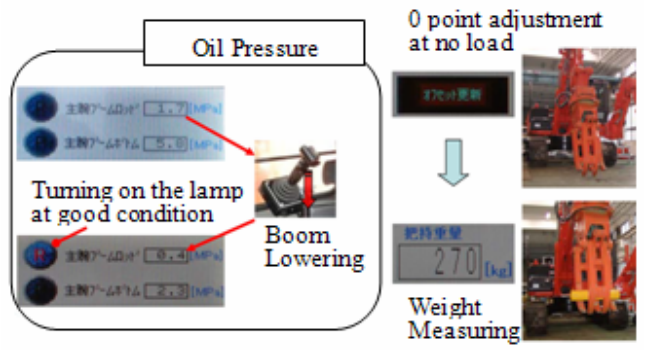

Fig.11 Weight Measuring System

The weight-measuring condition judgment system supports this operation by displaying the cylinder inside pressure in the information monitor constantly. When the cylinder pressure is lowered to prescribed pressure, the lamp will light, and it shows measuring-condition is appropriate. In addition, the switch for the zero point adjustment is provided, so that the influence of friction can be reduced as much as possible. Figure 11 shows outline of the weight measuring system.

6. GRASPING-FORCE CONTROL SYSTEM

It is effective that control the hydraulic pressure of attached equipment (hand), in order to improve work efficiency and machine operability. The grasping-force control system can prevent unnecessary crush of objects.

Figure 12 shows the outline of grasping-force control system. By selecting grasping force from three stages (large, middle, small) on information monitor, hydraulic pressure is controlled. It is not difficult a continuous numerical control, technically. As an operator can easily select, it is prepared in three stages.

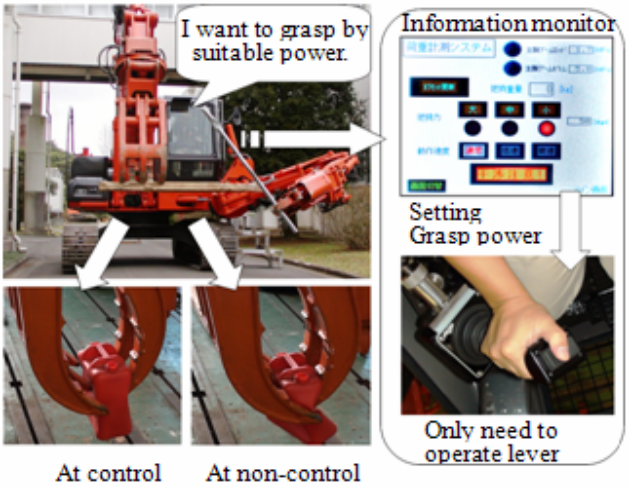

Fig.12 Grasping-Force Control System

7. FIELD TESTS OF DEVELOPMENT MACHINE

We have conducted field tests of "double-arm working machine" in demolition work sites. Table 3 shows the demolition work flow, and the machine operation, and required specifications. The work object is precast concrete wall (reinforced concrete structure). It contains rebar and the aluminum window frame or duct, rubber tarpaulin, plumbing equipment, handrails, etc. Figure 13-16 show the machine in operation. The insufficiency of the work area is seen in case of raking concrete blocks or transferring the objects. Most of the work is possible to perform only in the main arm. But, there are some separation tasks by cooperative work by double-arm, shown in figure 15.

The general hydraulic excavators (single-arm) crush the concrete wall while holding it by their own. Therefore, the concrete wall may fall down for dangerous direction by erroneous operation. The operator is required very delicate operation, and feels stress. As shown in Figure 16, it is noticed that while supporting the precast wall by sub arm, the machine crush it safely by the main arm become free.

An operator, of 10 years work experience late 30s, was appointed as a full-time embarkation operator for one week

testing period. Because we considered that he need some time to learning operation of machine.

The hearing result is shown in Table 4 with excerpts.

Table 3.Work flow of demolition site

1.Raking of precast concrete wall		
Machine-operation	Raking concrete wall by Main arm.	
Required-specification	Main arm	Sufficient work range
	Sub arm	No use
2. Peeling of aluminum sash etc.		
Machine-operation	Peeling by Main or Sub arm.	
Required-specification	Main arm	Sufficient force for peeling bonded member.
	Sub arm	
3.Crushing of precast wall		
Machine-operation	Put up concrete wall by Main arm, and Hold it by Sub arm. Then crush it by Main arm.	
Required-specification	Main arm	Suitable work area for Secondary crusher. Crushing power, and Opening /closing speed.
	Sub arm	Sufficient force for holding the wall.
4.Reduce the volume of rebar		
Machine-operation	Separate concrete and rebar by Main and sub arm. Crumple up rebar into a ball by Main arm, and cut some rebar by Sub arm.	
Required-specification	Main arm	Suitable work area, and Opening /closing speed.
	Sub arm	Cutting-force for rebar
5.Transfer of work objects		
Machine-operation	Hold objects by Main arm, and Body swing. Then release it	
Required-specification	Main arm	Sufficient work range
	Sub arm	No use

Fig.13 Raking Concrete

Fig.14 Peel alumi sashes

Fig.15 Double-arm working

Fig.16 Crush concrete wall

Table 4.Hearing Result

Comment about the Main arm	
Operability	After mastering operation, work-efficiency is almost same to a general excavator.
	Switches (open/close attachment) is cause of large fatigue. (wish to pedal operation)
Work-force	Sufficient.
Work-radius	Especially, work reach is not enough. So it is difficult to transport the object.
Comment about the Sub arm	
Operability	After learning operation, operability is same as the main arm.
	Simultaneous operation is possible. E.g. while holding object by one arm, cut it by the other arm.
Work-force	It looks delicate and work-force is not enough.
Work-radius	Work reach is not enough.

Judging from the hearing results, it is confirmed that there is no problem mostly in basic policy of operation system that is direction of the levers and moving direction of each arm are approximately corresponding. Assuming that the operation with the thumb is repeated throughout the day, the complaint about fatigue on table 4 is considered to be appropriate. Adopt of pedal operation with less fatigue is significant. At mechanical specifications, opinion about insufficient work area is conspicuous. And reinforcement of the sub arm that has many DOF is required. In addition, we recorded information on arm posture, load and lever operation during testing period, using the data logger. Analysis of the recorded information, confirmed the above-mentioned improvements. [3]

8. DEVELOPMENT OF A SUCCESSION MACHINE

In 2010, we developed the succession machine, which is based on results of field test, operator hearing, and working analysis, shown in figure 16.Table 5 is the specifications. About the sub arm, working-area is extended, and each structure is reinforced. One DOF of the sub arm, that is concluded to not use much, is obsolete.

Fig.16 Succession machine (2010 model)

Fig.17 Multi Function hand (New model) without covers

"Multi Function hand" is also redesigned newly, and is mainly enhanced in cutting force. Figure 17 is its internal mechanism. Also the main arm working-area and each structure are reviewed in aim to be suitable for secondary crushing or other work. In the machine body part, short-tail-swing and cab comfort improvement is achieved. Basic idea of operation system is kept, and some of the assignments of the operation are changed as required. For attachment opening and closing, the pedal operation is adopted instead of thumb switch operation. The sub arm rolling operation is simplified by use of thumb switch that become excess.

Toward practical use of this machine, we will continue to field-testing at work sites, and continue to improve the machine.

Table 5.Specifications (2010 model)

Operating Weight (1)			17.8 ton
Dimensions (2)	Overall width		2,890(3) / 2,490 mm
	Overall length		7,350 mm
	Overall height		2,900 mm
Engine	Model		Isuzu AJ-4JJ1X
	Rated Power		69 kW / 1,800 rpm
	Piston Displacement		2,999 cc
Hydraulic system	Pumps		2variable displacement axial piston pumps, 2 gear pumps
	Relief valve setting		34.3 MPa
Working Range(4)	Max. reach	Main	5,200 (5) / 6,400 mm
		Sub	5,810 mm
	Max. height	Main	4,800 (5) / 6,640 mm
		Sub	5,320 mm

(1): Include Equipment, Crusher (1,100kg) for Main arm, Multi-function-hand (450kg) for Sub arm.

(2): At transport position, (3): At working position

(4): At tip pin of Arm, (5): With Main arm limitation.

9. GRATITUDE

This research and development is conducted under the consignment of NEDO (New Energy and Industrial Technology Development Organization).

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