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New concepts in manipulators

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Abstract

The civil engineering and building construction fields are currently experiencing a shortage of labor further aggravated by an aging workforce. Accordingly, various heavy, hazardous works are being mechanized and robotized to enhance worker safety.

Cranes and winches, etc., are currently used for carrying and installing heavy materials, but manpower is still required for slinging and placing work, and there has been little progress in the mechanization of this type of work.

Because cranes can easily sling, move and install heavy materials, they can be easily adapted to match specific jobsite conditions.

1. INTRODUCTION

With both cranes and winches, however, slinging work is required to move materials, thus leading to the following problems:

(1) The suspended materials are subject to swinging. If the wire ropes are not correctly installed, the load may become unbalanced and fall. Accordingly, it is difficult to constantly maintain a high level of safety.

(2) Since a substantial working space is required above cranes and winches, working efficiency is greatly reduced on jobsites where a sufficient overhead operating area cannot be secured.

(3) Workers must fix wire ropes to the materials manually, and additional assistants are required.

We have revolutionized the entire concept of slinging by replacing it with manipulating, thereby avoiding the above problems. In cooperation with Shimizu Corporation, we developed a machine which grasps and manipulates materials freely and three-dimensionally.

We will introduce here a steel girder manipulator developed for underground work, as well as a Hume pipe manipulator for sewerage work which is a modified version of the first model.

2. DEVELOPMENT OF STEEL GIRDER MANIPULATOR

2.1. Purpose of development

In a subway or underground foundation jobsite, steel girders must be carried, installed and removed in spaces severely limited by numerous piles and existing upper struts. If these long, heavy materials are manipulated with a conventional crane, the following problems can occur:

(1) A steel girder may suddenly swing and trap a worker against a girder or pile. If it is improperly balanced, it may fall. When disassembling support timbers, workers must work at height under hazardous conditions to install wire ropes to each piece.

(2) Although a crane requires overhead working space, its boom end operation is limited by the upper struts present in an underground work site. When carrying materials by crane, the crane operating speed must be reduced sufficiently to prevent the load from swinging. This results in a corresponding lowering of working efficiency.

(3) Several workers are required to attach wire ropes and perform signaling. Also, when slinging materials, workers are required in order to keep the load steady.

With this as the background, we developed a new machine to heighten both safety and working performance and achieve substantial manpower saving in girder handling work, by replacing slinging work with manipulating. This machine allows an operator to manipulate a steel girder freely in a 3-dimensional space.

2.2. Outline of structure

Fig. 1 shows the general drawing of this machine and Table 1 lists its main specifications.

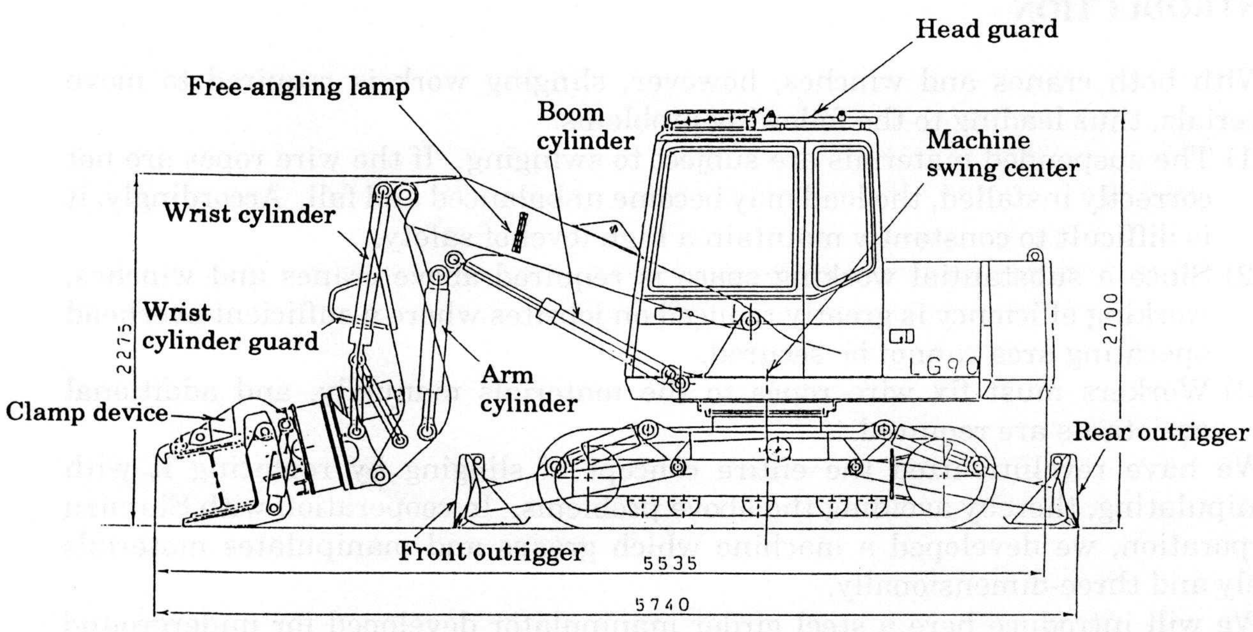

Fig. 1 General outline

Table 1
Main specifications

Operating weight	9310 kg
Flywheel horsepower	55 PS/2100 rpm
Overall length x Overall height x Overall width (For transportation)	5740 mm x 2700 mm x 2375 mm
Shoe width	450 mm (Rubber shoe)
Distance between track centers	1700 mm
Distance between tumbler centers	2200 mm
Engine	KOMATSU 4D95L
Engine type	4-cycle water-cooled in-line direct injection
Maximum handling load	2100 kg
Handling width	300 mm – 500 mm
Maximum installation height	4000 mm
Travel speed	3.3 km/h
Gradeability	30°
Drive method for traveling	Hydraulic drive unit
Shoe type	Rubber shoe

This machine is based on the hydraulic excavator, and consists of the three main components of the upper swing section, undercarriage and work equipment. The undercarriage features independent front and rear outriggers. The clamp device is installed to the top of the work equipment. The maximum manipulating weight is 2.1 tons and maximum installation height is 4 m.

The detailed structure of the clamp device is shown in Fig. 2. The clamp device has a 360-degree endless rotary mechanism consisting of a motor and swing circle. The rotary mechanism features an angling mechanism at the end which consists of dual angle cylinders arranged vertically and symmetrically and rocked to ±27° from the center of the angle turning shaft, and a clamp mechanism which consists of dual clamp cylinders arranged horizontally and symmetrically.

The clamp arms are rocked by the clamp mechanism cylinders, enabling clamping of steel girders 300 mm – 500 mm in size with the clamp plates connected by pins to the arm top.

2.3. Features

2.3.1. Manipulating mechanism for 3-dimensional operation

The machine features a mechanism for manipulating long, heavy materials freely in a 3-dimensional space using the clamp device described above.

Since long, heavy objects can be moved freely in the vertical, horizontal and diagonal directions, limited space can be used effectively and working efficiency heightened accordingly. In addition, since the manipulated object does not swing and requires no wire ropes, safety is heightened and savings in manpower are achieved.

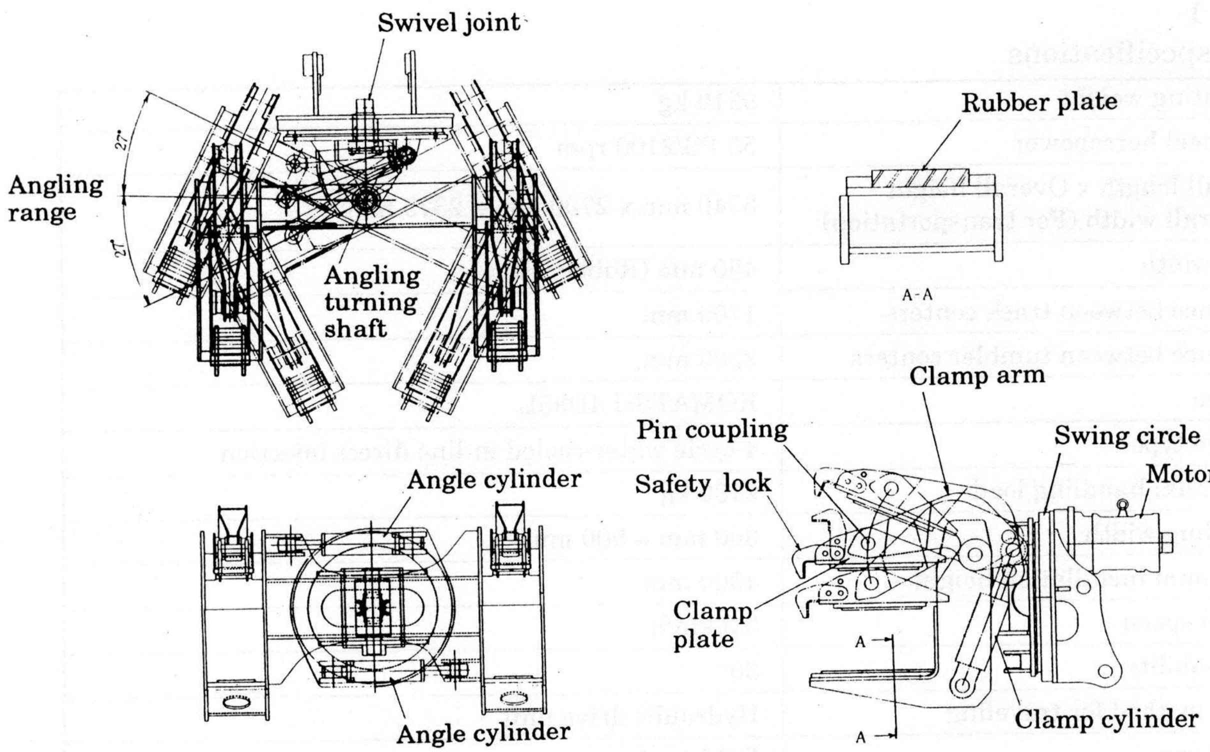

Fig. 2 Clamp device

2.3.2. Easy installation of materials with free-angling function

This machine has a free-hydraulic mechanism for the manipulator which allows a worker other than the operator to fine-adjust the position of the clamped steel girder to be installed. In other words, this function allows a worker to freely set the clamped girder just as if he were working with a crane-suspended load. This function is activated with a switch installed to the end of the work equipment lever in the operator cab. When turned on, the bottom circuit and head circuit of each of the two angle cylinders are connected by solenoid valve which frees the hydraulic force in the angling direction and allows the worker to easily adjust its position.

2.3.3. Design for higher safety

This machine was developed to heighten work safety. Operator safety is also secured. The main safety devices equipped on this machine are as follows.

(1) Drop-preventive valves on work equipment cylinders
Similarly to a crane, even if a hydraulic hose connected to a work equipment lever breaks while the work equipment lever is in the neutral condition, the hydraulic pressure on the bottom side of the cylinder is maintained to prevent the grasped item from suddenly dropping. This function is realized by the drop-preventive valves installed on the boom, arm and wrist cylinders.

(2) Installation of clamp pressure OK lamp
The clamp circuit is equipped with an accumulator to prevent reduction in clamping force when the hydraulic pressure lowers. In addition, a pressure sensor is installed. While the specified clamp pressure is applied, the clamp

pressure OK lamp in the operator cab remains lighted. This lamp allows the operator to confirm clamping at a glance.

(3) Installation of overload alarm
The angle of the boom and the bottom pressure of the boom cylinder are sensed. If the load exceeds the allowable value, the caution lamp in the operator cab lights up as an overload alarm.

2.4. Evaluation

This machine underwent a practical operation test in the construction of the Korakuen Subway Station in Tokyo. An evaluation of conventional work with a crane and with this machine are provided for comparison purposes in Table 2.

Table 2
Comparison with conventional work method

	Item	Working with LG90 Steel Girder Manipulator	Conventional work method (4.9-t crane)
Performance	Maximum slinging load	2.1 t	4.9 t
	Working radius	4.3 m	4.3 m
	Maximum lifting height	4.0 m	11.0 m
	Working space (At lifting height of 4 m)	4.7 m (±0.7 m)	6.6 m (+2.7 m)
Qualifi-cations	Operation of heavy construction machinery	Lecture on operation of traveling construction machinery	Lecture on operation of small-sized mobile cranes
	Wire rope slinging work	Unnecessary	Lecture on wire rope slinging work
Necessary number of workers		3	5
Maneuverability		1) Can operate in narrow site. 2) More effective in working in site where upper space is limited because of top down construction method, pipe roofing method, etc. 3) Grasped object can be manipulated in any direction. 4) Operator can manipulate materials by himself. 5) Since manipulated object does not swing, safety is secured. 6) Since no wire rope slinging work is necessary, work efficiency is heightened (This feature is very effective when removing materials). 7) Diagonal beams for top down construction method can be installed easily.	1) Widely applicable and less restricted as long as sufficient working space is secured. 2) Materials can be manipulated with boom even if vehicle cannot come near them. 3) Large working radius means less machine movement is required, and damage to roads is far less. 4) Since a slung object can be freely adjusted, it can be installed quickly.
Safety		1) Since less slinging work is required at height, safety is further improved. 2) Since manipulated object does not swing, there is far less danger to assistant workers. 3) Since machine operation is confined, it comes in contact with buried pipes less often.	

As a result of this test operation, we confirmed that our principal development objectives were attained.

Recently, the top down construction method and pipe roofing methods have been increasingly employed. If these methods are applied, the space above the work area becomes extremely limited. In its initial market introduction period, we confirmed that work with this machine is far more effective than that with a conventional crane when these methods are applied.

3. APPLICATION EXAMPLE OF HUME PIPE MANIPULATOR

3.1. Purpose of development

We applied the steel girder manipulator to the installation of Hume pipes.

Currently, Hume pipes are slung individually with a hydraulic excavator and lowered into the trench, then inserted into the adjoining pipe and positioned. This method has the following problems:

(1) When a Hume pipe is inserted, a lateral force is required, but this cannot be achieved by slinging and must be done by workers.

(2) A slung Hume pipe has a tendency to swing. If this occurs in a narrow work site, is is highly dangerous.

(3) Slinging work is necessary for each Hume pipe.

We solved these problems by applying the grasping and manipulating method to Hume pipes.

3.2. Outline of structure

Fig. 3 shows a general drawing of the Hume pipe manipulator and Table 3 lists its main specifications.

The body is based on the hydraulic excavator, and the operating system and safety devices of the steel girder manipulator are also employed here.

The clamp at the end is easily replaceable with a standard bucket by means of a quick coupler.

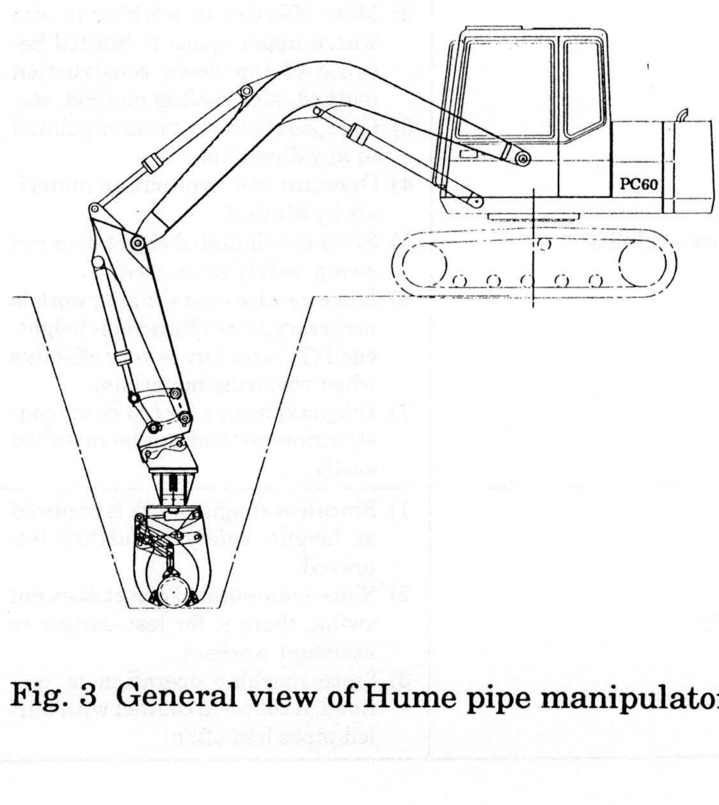

Fig. 3 General view of Hume pipe manipulator

Table 3
Main specifications of Hume pipe manipulator

Operating weight	7800 kg (Including optional quick coupler)
Applicable Hume pipe grasping diameter	ø306 – ø700
Maximum handling load	660 kg max.
Maximum installation depth	4600 mm

3.3. Features

The main feature is that it grasps and manipulates Hume pipes similarly to the steel girder manipulator. This machine also has the following two unique features.

(1) Can clamp and manipulate pipes of various diameters securely and easily.
The clamp structure is shown in Fig. 4.

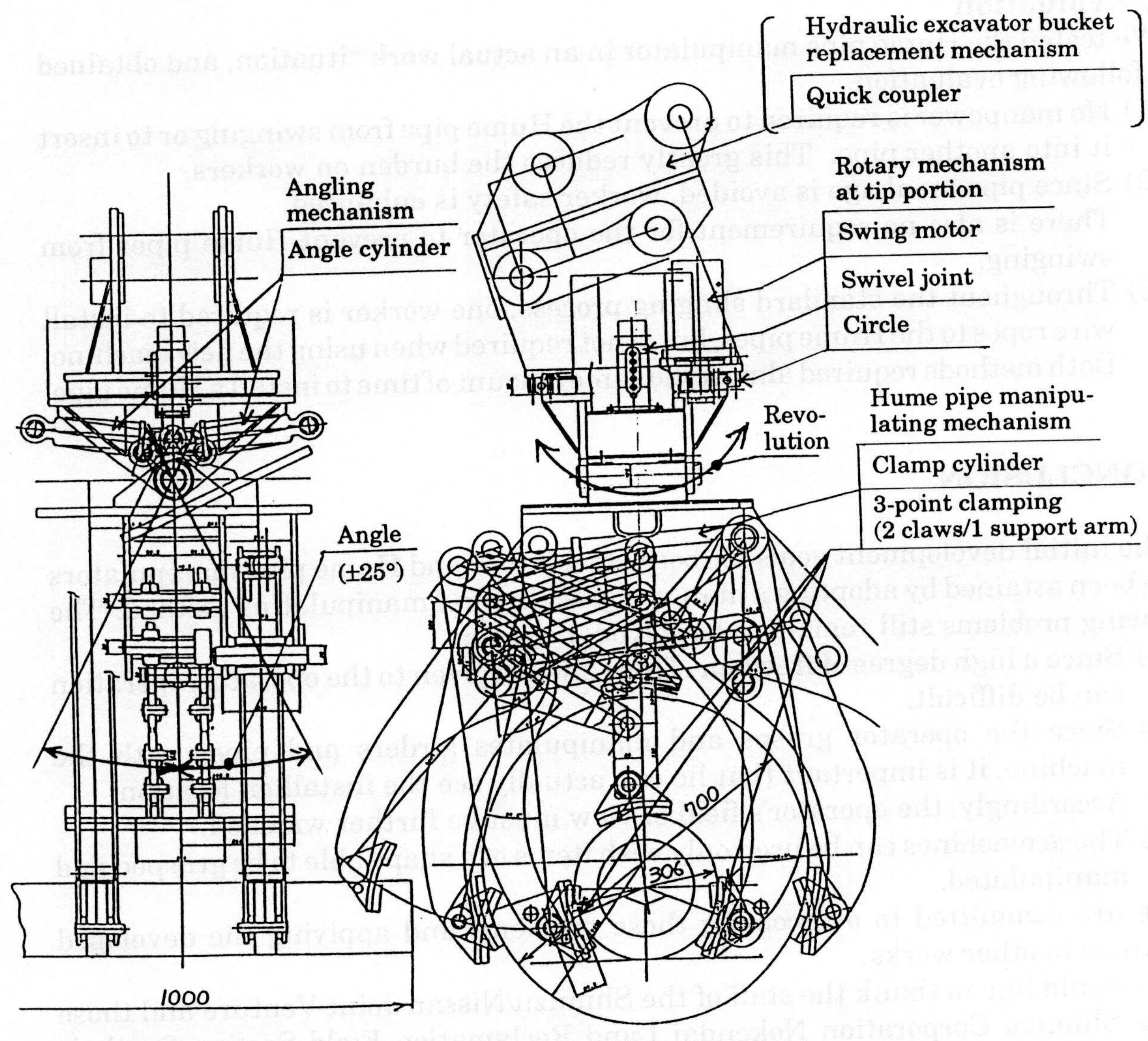

Fig. 4 General view of Hume pipe manipulating mechanism

The two claws grasp the Hume pipe and a small support arm extends from above simultaneously, thereby securing the pipe at three points.
Since these claws and support arm are inter-linked, the operator can manipulate Hume pipes of various outer diameters (306 to 700 mm) simply by operating the clamp pedal.
It is difficult to grasp a round concrete pipe securely yet gently to avoid it being broken. This mechanism, however, allows the operator to hold pipes securely and easily.

(2) Easy insertion of Hume pipes
After two Hume pipes are co-aligned, one can be inserted into the other by applying the machine's swing force.
Since both angling and twisting mechanisms are freed, Hume pipes can be easily co-aligned manually.

3.4. Evaluation

We tested the Hume pipe manipulator in an actual work situation, and obtained the following evaluation.

(1) No manpower is required to prevent the Hume pipe from swinging or to insert it into another pipe. This greatly reduces the burden on workers.
(2) Since pipe breakage is avoided, worker safety is enhanced.
There is also no requirement for the operator to prevent Hume pipes from swinging.
(3) Throughout the standard slinging process, one worker is required to install wire ropes to the Hume pipes, but is not required when using the new machine. Both methods required almost the same amount of time to install a Hume pipe.

4. CONCLUSION

The initial development goals for both steel girder and Hume pipe manipulators have been attained by adopting a material grasping and manipulating method. The following problems still remain to be solved, however.

(1) Since a high degree of freedom of operation is given to the operator, operation can be difficult.
(2) Since the operator grasps and manipulates girders and pipes with the machine, it is important that he can actually see the installion location. Accordingly, the operator's field of view must be further widened.
(3) These machines can be used only with items of a shape able to be grasped and manipulated.

We are committed to overcoming these problems and applying the developed machines to other works.

We would like to thank the staff of the Shimizu/Nissan Joint Venture and those of the Shimizu Corporation Nokendai Land Reclamation Field Section for their cooperation in the application of these new machines.