

## MULTI-JOINTED PILE DRIVING MACHINE WITH A COMPUTER-ASSISTED GUIDING SYSTEM

Toru Uchino, Junichi Narisawa, Yuhei Sato, Koji Kumazawa

Hitachi Construction Machinery Co., Ltd. Tsuchiura Works  
650 Kandatsu-machi, Tsuchiura-shi, Ibarakiken 300, JAPAN

### ABSTRACT

Today, in big cities of Japan such as Tokyo, a number of urban renewal and infrastructure development projects are on. Because of restrictive work site conditions in urban areas, such as overhead roads or railways, compact construction machines with high mobility are favored. To meet this need, we developed a new type of pile driving machine: the HITACHI RX 2000.

With this machine, a piling attachment, such as an earth auger or a vibratory hammer, is directly connected to the tip of the multi-jointed pile driver arm. The pile driver arm uses the computer-assisted guiding system that allows the arm tip to move in perpendicular or horizontal directions with ease. We call this new system "arm tip locus control."

As of today, the RX 2000 has been applied to many H-steel-piling and sheet-piling work in the field.

### 1. INTRODUCTION

Prior to the development of the RX 2000, operators of multi-jointed pile driving machines had to manually control the combined movement of two arms in order to achieve linear movement of the arm tip. This is a very difficult task, requiring a great deal of special skill and dexterity. (See Fig. 1.)

Therefore, development of an easy-to-operate control system, such as our "arm tip locus control", has long been awaited. The requirements of such a system include: highly-accurate piling, including both positioning and piling angle; fast arm tip movement; tough, able to withstand adverse conditions; and a reasonable production cost. Our computer-assisted multi-jointed arm control system meets all of these requirements.

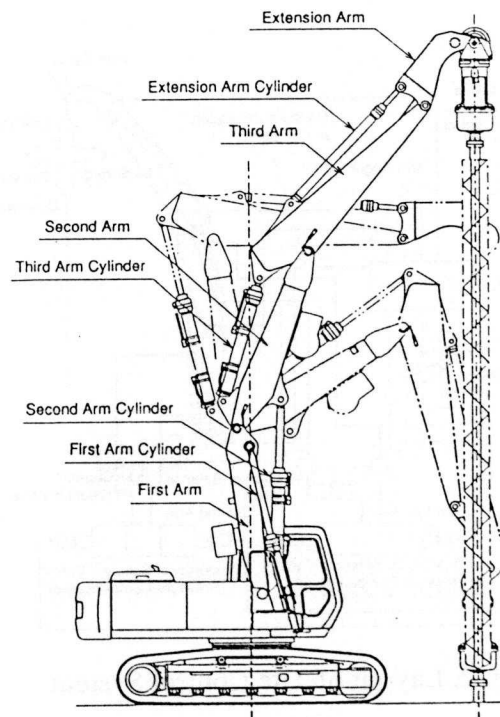


Fig. 1. RX2000

Herein we report on this new system, focusing on the overall system design, the control lever operation system, the proportional solenoid valve operation system, as well as a few examples of RX 2000's field applications.

## 2. SYSTEM DESIGN

The layout of the control system is shown in Fig. 2. Fig 3 shows a block diagram of the system. The position of each arm is detected by the angle sensors provided at each joint of the arm. Then, the coordinates of the arm positions are calculated. With the operative velocity control signal generated in proportion to the control lever stroke and the coordinates of the arm positions, a target control angular velocity of each arm is calculated. Each arm's control angular velocity can be converted to the arm cylinder operating speed, by which the oil flow rate necessary to operate each arm is calculated.

To extend the service life under adverse job site conditions, and to lower the production cost of the control system, a proportional solenoid valve actuated by an electric signal, given in the form of pulse width modulation[PWM], is employed in the oil flow rate control section.

The arm tip locus control system employs both an open loop and a feedback system. As for the feedback system, this new system employs a potential feedback system well suited to arm tip locus control. As show in Fig. 3, using divergence  $\Delta X$  in the arm coordinates and velocity control signal (arm lowering and raising) vector  $\dot{Y}$ , the arm tip locus velocity (arm retracting and extending) correcting vector  $\dot{X}$  is obtained. Then, vector  $\dot{X}$ , perpendicular to  $\dot{Y}$ , is used as a velocity control signal in the potential feedback system together with  $\dot{Y}$ . Thereby, steady feedback performance in a wide range of speeds, from slow to high, is possible.

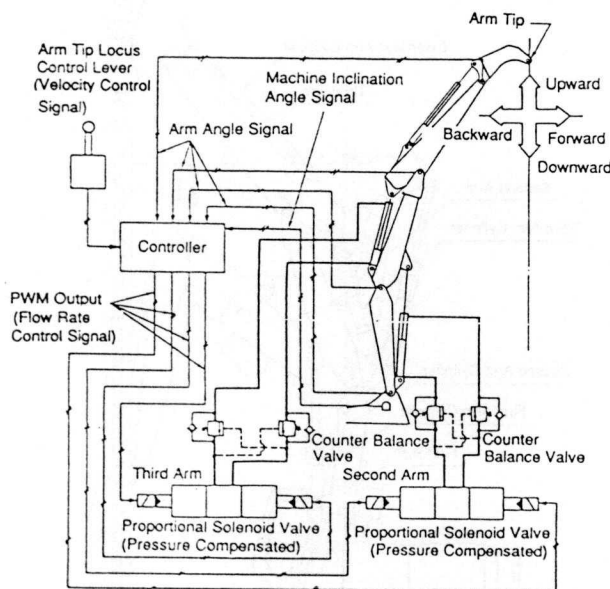


Fig. 2. Layout of The Control System

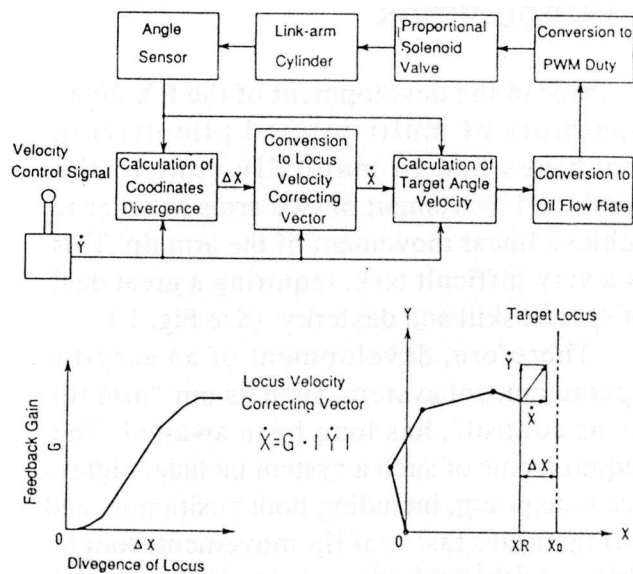


Fig. 3. Arm Tip Locus Control

### 3. CONTROL LEVER OPERATION SYSTEM

Piling or boring jobs are mostly done on rough, unimproved land. To increase work efficiency under such adverse worksite conditions, ease and speed of positioning the machine and front attachment in the most ready-to-work place is a priority. Next, once the work is started, the machine must offer accurate workability. For these reasons, a vector control lever system was employed (Fig. 4).

This system allows the operator to select either linear movement control, which employs the feedback system, ensuring operative accuracy, or free movement control, which ensures high speed machine control by employing the open loop system. The selection of either system is automatically made. When linear movement control is required, the operator moves the control lever in a single direction either forward or backward (lower/raise) or left or right (extend/retract). However, for combined, free arm movement, the operator can move the control lever at angles between the forward/backward, left/right directions. Therefore, accuracy and speed can both be obtained with this system.

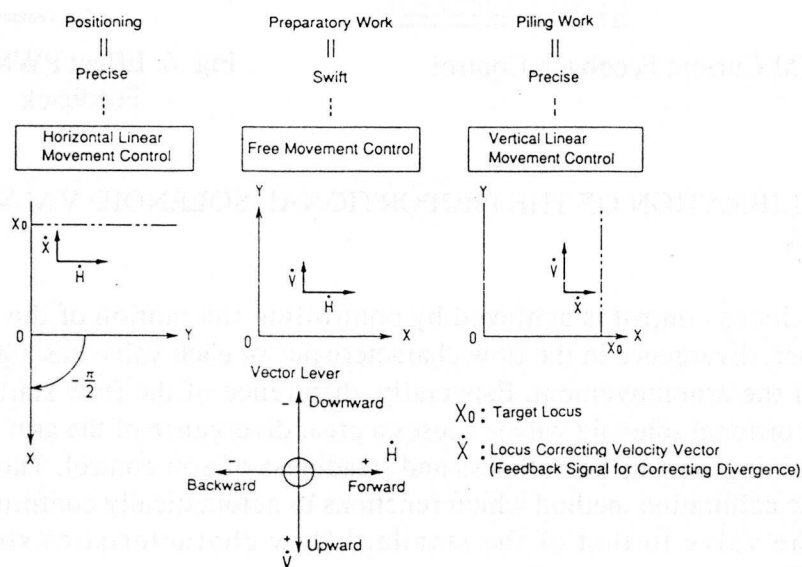


Fig. 4. Operative Pattern of Vector Lever

### 4. PWM CURRENT FEEDBACK CONTROL

Proportional solenoid valve activation method using PWM electrical signal has come to be widely used because proportional solenoid valves can be directly operated by digital signals from a microcomputer, at a low cost. However, with this control, the coil current is hard to be maintained constantly, as heat generated in the coil causes the coil resistance to vary.

To solve this problem, we have developed a highly accurate PWM current feedback control which is directly controlled by a microcomputer, as shown in Fig. 5.

As shown in Fig. 6, the coil current is stabilized and becomes indifferent to changes of coil temperature. Thus, we were able to greatly enhance the accuracy of the proportional solenoid valve control.

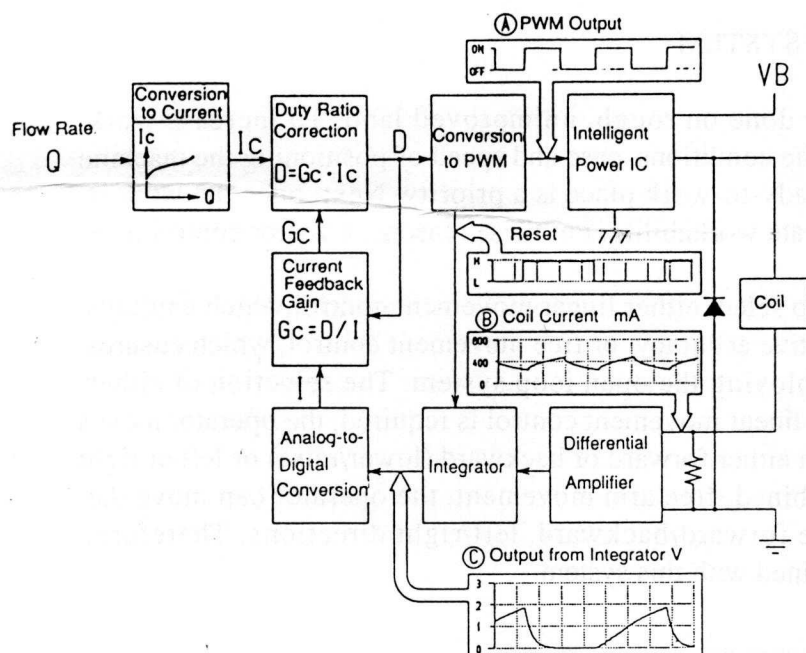


Fig. 5. PWM Current Feedback Control

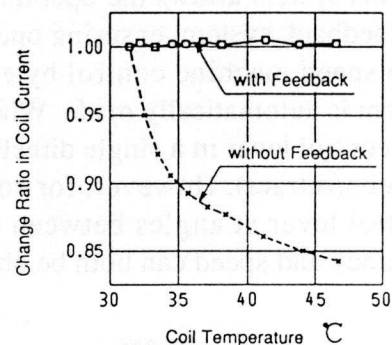


Fig. 6. Effect PWM Current Feedback

## 5. AUTOMATIC CALIBRATION OF THE PROPORTIONAL SOLENOID VALVE FLOW CHARACTERISTICS

Since the arm tip locus control is achieved by controlling the motion of the two arms relatively to each other, divergence in the flow characteristics of each valve has a great effect on controllability of the arm movement. Especially, difference of the flow start-up point between the two proportional solenoid valves causes a great divergence of the arm movement control, as well as ruining start-up smoothness and steadiness of arm control. Therefore we invented an automatic calibration method which functions to automatically conform the flow start-up point of the valve to that of the standard flow characteristics stored in a microcomputer (Fig.7).

When calibration is conducted, correction current  $\Delta I(I_0 - I')$  is acquired and stored in the memory. When the arm tip locus control is operated, the directive current calculated based on the standard flow characteristics is added to the correction current  $\Delta I$ . This combined current is used as the control signal to activate the proportional valve. Consequently, displacement at flow start-up points in the two proportional solenoid valves is minimized, enhancing operative smoothness.

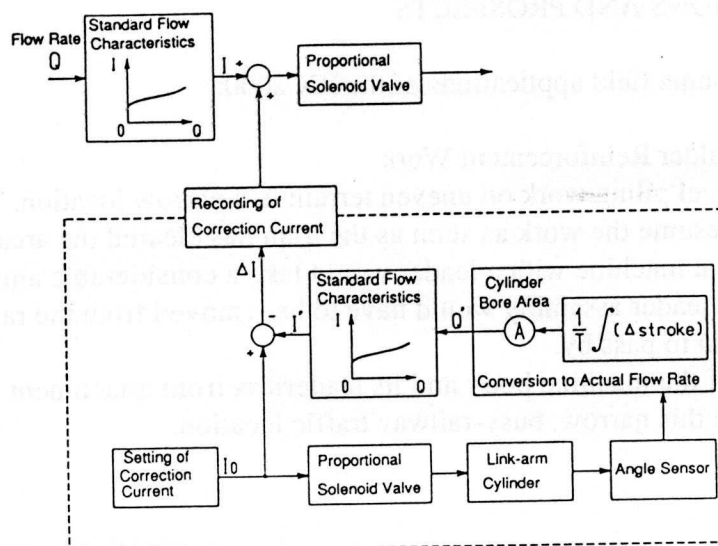


Fig. 7. Self-calibration by Flow Characteristics

## 6. CONCLUSION

This newly developed system can move the arm tip at the following velocities:

Free movement control: 25 m /minute

Linear movement control: 15 m/minute within  $\pm 50$  mm errors along the arm tip locus.

Fig. 8 shows one sample of the divergence of the arm tip movement for linear movement control.

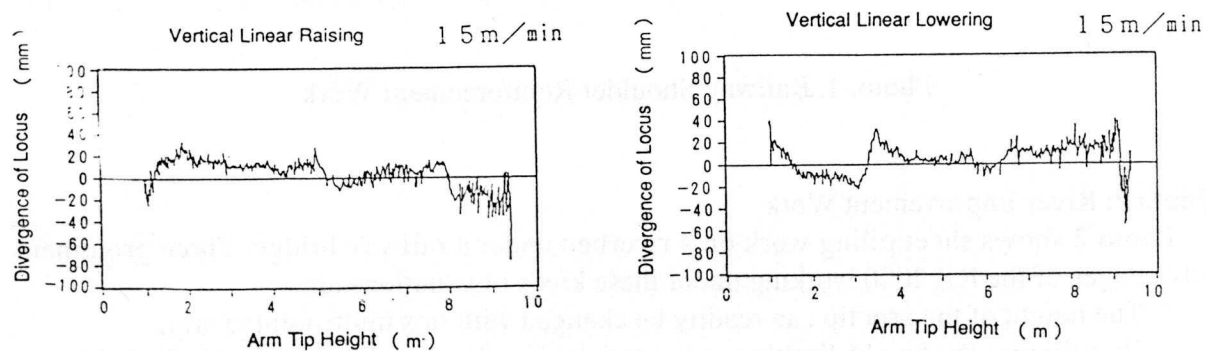


Fig. 8. Errors Along The Tip Locus

## 7. FIELD APPLICATIONS AND PROSPECTS

Photo 1 to 4 show some field applications of the RX 2000.

### Photo 1: Railway Shoulder Reinforcement Work

Photo 1 shows H-steel piling work on uneven terrain in a narrow location. The machine is standing by ready to resume the work as soon as the train has cleared the area. In a situation like this, a conventional machine with a leader would take a considerable amount of time to resume the work as its leader assembly would have to be removed from the railway shoulder while waiting for a train to pass by.

The compactness of the machine body and its leaderless front attachment make efficient piling work possible in this narrow, busy-railway traffic location.

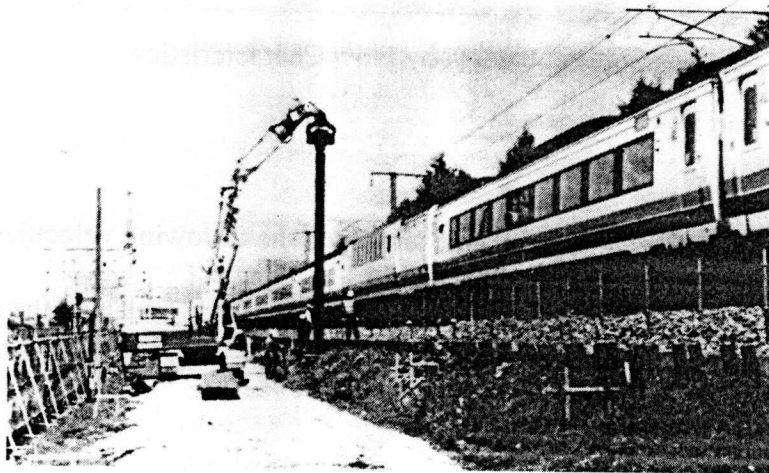


Photo. 1. Railway Shoulder Reinforcement Work

### Photo 2: River Improvement Work

Photo 2 shows sheet piling work on a riverbed under a railway bridge. Three prominent advantages of the RX 2000 working under these kinds of situations are:

1. The height of the arm tip can readily be changed with this multi-jointed arm.
2. By utilizing the height-limiting auto-stop device, the arm tip does not hit the bridge, increasing the safety.
3. Because the machine requires no leader, it has high mobility, making getting in and out of the site easy, and not much ground stabilization work is needed.



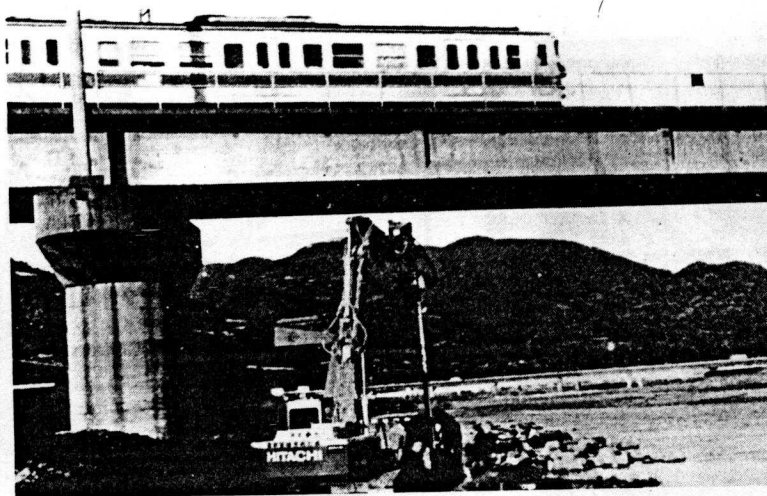


Photo. 2. River Improvement Work

Photo 3: Foundation Piling Work on Housing Construction in a Mountainous Area

Because the housing construction site was located on a slope in a mountainous area, no foundation work equipment, but the RX 2000, could get into the site. The mobility of the RX 2000 to get into and out of the site almost matches that of an excavator without any preparation work to get into the site necessary.

Photo 4: Foundation Work for Railway Bridge Pier in a Railway Expansion Construction  
( from Two Tracks to Four Tracks)

As the footing for the machine in this case was a two-lane road, a crane suitable for the work would occupy the whole width of the road, interfering with the traffic. Therefore, the RX 2000 was used because of its compactness, in which the machine fits within one lane of the road. As for accuracy and efficiency of the sheet piling work, RX 2000 matched those of a conventional machine.

In addition, this vibratory hammer has a special center hole chuck that firmly chucks the middle part of a sheet pile or a H-steel pile. Because of this special chuck, pile length is not limited by the base machine's dump height as in the case with a conventional vibratory hammer.



Photo. 3. Foundation Piling Work on Housing Construction in a Mountainous Area

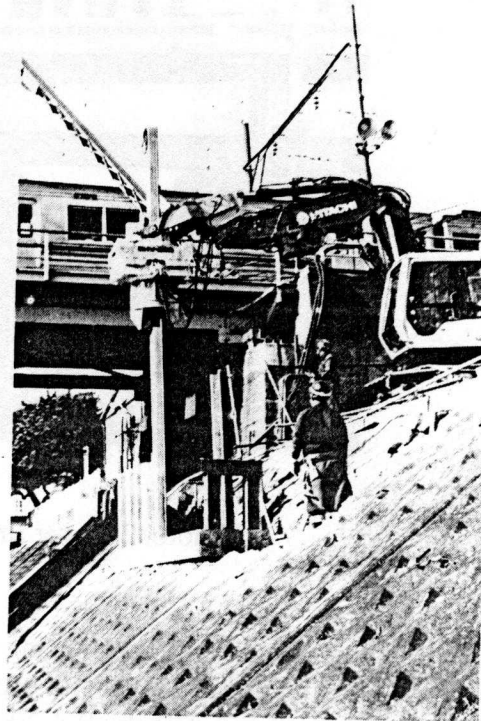


Photo. 4. Foundation Work for Railway Bridge Pier in a Railway Expansion Construction

As shown in the above examples, this machine can perform boring work using a leaderless type earth auger, or highly precise piling work using a vibratory hammer. Because of its ease of applicability, preparatory work, and controllability, the machine is gaining high acclaim from customers.

Lifting loads and working ranges available from multi-jointed arm pile driving machines can by far exceed those offered by general industrial robots. In addition, the construction field in Japan is recently suffering from lower number of workers, aging of the workforce, and an influx of inexperienced workers. Therefore, applications of this type of machine will expand further, as a measure of coping with the need for automation in construction jobsites, a need which robotization of construction machines can help meet.