Development of Advanced Dredger

Tamotsu Ogasawara*, Tamiya Fukushima*, Masahide Murase**, Yuzuru Nakamura***

* Kanto Regional Construction Bureau, Ministry of Construction
** Mitsubishi Heavy Industries, Ltd.
*** MEC Engineering Service Co., Ltd.

ABSTRACT

The "Dredger" was developed as a specialized vessel for improving the water quality of lake Kasumigaura by dredging its muddy bottom ooze.

Unlike normal dredging with a dredger, ooze dredging is a dredging operation performed under difficult constraints, namely, removing only the very oozy sludge built up on the surface layer of the lake bottom (about 30 cm thick) having a water content rate of 200-400% and including much phosphorus and nitrogen. Up till now, ooze dredging has presented many problems: because the mud content ratio is low and has a wide variation and the positioning of the ship and operation of the ladder is done by hand, ooze dredging has been of poor precision, with the dredging being either too deep or too shallow, and the operating efficiency has been low because the actual mud lifting time amounts to only a small fraction of the dredging time, and many workers are required.

By working to overcome these technical problems, developing and improving the dredging equipment, and developing a dredging automatic control algorithm to greatly automate the operations, an automated dredger dubbed the "Kasumizaurus" has been completed.

The automated system is divided broadly into an automatic control part for the dredging operation and an operation monitoring part for the operation of work management.

The Kasumizaurus, which began operation in March 1995, is designed to be considerably better than a conventional ship in dredging efficiency, high-mud-content-ratio dredging, operational precision, and labor saving.

1. INTRODUCTION

1-1 The special nature of dredging in Lake Kasumigaura

Dredging of the bottom sludge of Lake Kasumigaura is done under difficult constraints peculiar to this lake.
The main constraints include:

(1) The surface layer of the lake bottom (the top 30 cm or so) is rich in phosphorus and nitrogen, which lower the quality of the water, and the sludge is very soft, with a water content rate of 200-400%. Thus this is thin-layer dredging that removes only the top 30-cm-thick layer.

(2) The sediment dredged from the bottom of the lake is brought up onto land where it is given a primary treatment and is then reused, but the size of the disposal area needed for this primary treatment is directly affected by the apparent mud content ratio at the time of

dredging. The amount of bottom sludge dredged up from Lake Kasumigaura comes to 1 million cubic meters a year, making it difficult to procure all the primary treatment area that is needed and making it advantageous to dredge with a high apparent mud content ratio (high concentration) in order to reduce the amount of primary treatment.

(3) Stirring up bottom material during dredging disperses the nutrient salts (phosphorus, nitrogen) in it and promotes their elution, which is undesirable for the purpose of improving the water quality. Thus it is a necessary condition that dredging be done in such a way as to not disperse the bottom sludge.

Satisfying these constraints requires a special dredger that operates by a different method from conventional pump dredgers or mud suction type dredgers.

1-2 Method of dredging

Of the various dredging methods available, the method used by the recently developed automated dredger Kasumizaurus is outlined in Figure 1.

In the dredging operation, a dredging cycle is repeated in continuous 24-hour operation. Sludge collector swinging to the left and right suck up the bottom sludge and put it temporarily into a sludge storage tank. In doing so, debris is removed by a debris removal device. The capacity of the sludge storage tank is set so that the sludge transport pump can operates continuously, in contrast to the sludge collector, which operates intermittently. The bottom sludge that accumulates in the sludge storage tank is kept stirred to prevent its sedimentation and is fed under pressure to the disposal site by a sludge transport pump.

1-3 Special functions of the automatic dredger

(1) Adoption of the latest dredging mechanisms

Adoption of the latest dredging mechanisms, such as a spud carriage and a sludge collector rotary stand, makes it possible to operate the sludge collector continuously and minimize the indirect time during dredging (the time when sludge is not being lifted).

(2) High-mud-content-ratio dredging with a rotating bucket system and dredging to prevent dispersion of bottom material

High-mud-content-ratio dredging is made possible by adoption of a rotary bucket system in which bottom sludge is taken in with a bucket having a built in rotating drum with a slide-type blade edge, it is lifted up by a screw conveyor to a sludge suction pump at the top, and sucked in by the sludge suction pump. Dredging can be done without dispersing the bottom material by quietly cutting off the bottom sludge with a rotating drum while controlling the speed of the rotating drum and the swing speed of the dredge so that they are synchronized.

(3) Great labor saving through automation

The adoption of automation technology for more-efficient dredging and labor saving in all aspects of the dredging operation has made it possible to greatly improve operating efficiency, work precision, and labor-saving automated operation.

This dredger is a work vessel that demonstrates the highest level of dredging automation in Japan or abroad.

2. Dredging automation system

The dredging automation system consists of a system built to completely automate the portions involved in repeated operation of the dredging cycle (from step 1 to step 8 in Figure 1).

2-1 Goals of the dredging automation system

(1) Labor saving by automation of the dredging operation
The number of operational personnel is reduced and the operational burden is lessened by automating the dredging operation as much as possible.

(2) Improved operating rate and operating efficiency
Greatly automating the dredging operation makes it possible to operate with a continuous dredging cycle.

(3) Elimination of the variation in skill due to individual differences in operational personnel
Automation of the dredging operation eliminates the variation in dredge finishing precision and dredging operation time due to skill differences between different operational personnel and makes it possible to accurately execute dredging operation plans.

(4) Improved dredging work precision
By precise determination of the position of the dredge and precise automatic control of the swing amplitude and of the amount of advance, excessive or deficient dredging is eliminated and the precision of the dredging work is improved.

(5) Preparation of accurate work management data
Management of the work is simplified by automatically recording on a computer such dredging operation information as the precise location of the dredge and the depth of the dredging, making it possible to easily prepare work management data in accordance with any particular purpose.

2-2 Overview of the dredging automation system

The automation system is broadly divided into an automatic control part for the dredging operation and an operation monitoring part for the operation of work management. The equipment consists of two control computers (sequencers) that regulate the automatic control part, three industrial personal computers that regulate the operation monitoring part, a control panel that regulates automatic and manual operation of the dredging as a whole, an input-output panel that regulates input from various sensors and the output of instruction values to various drive devices, and various sensors that detect information needed for automation. Photo 1 shows the dredging control panel.

The automatic control part performs dredging operations by outputting instruction values for the swing winch, sludge collector, sludge transport pump, and spud carriage, takes in the state of the dredging as detected by various sensors as well as signals of the dredging results, judges the situation and does calculation processing, and once again outputs instruction values.

The operation monitoring part has three independent systems: a GPS ship positioning system that performs calculation processing such as coordinate conversion of the positioning data given by the real-time kinematic GPS, and displays the results on CRT as dredge position information; a dredging monitoring system that calculates input values from the various sensors and displays information on the CRT for monitoring the status of the dredging operation; and a work management system that automatically records on a computer various information about the state and result of the dredging as work management information, and prepares and outputs work management data.

2-3 Dredging automatic control

The dredging automatic control program is constructed in independent form according to the functions of the dredging equipment. The operation control is made in such a way that one can select automatic control separately for each function, thus freely combining automatic operation and manual operation according to function. The pattern of dredging operations often differs depending on the state of operation and the location, so the predetermined basic patterns are often not enough to handle the situation. Therefore by having an operator manually intervene as necessary during automatic operation, dredging operations can be continued with high efficiency while maintaining continuous operation. Table 1 lists the various automatic dredge control functions. Figure 2 shows an outline of control flow and typical examples (automatic control of the swing).

2-4 Operation monitoring

2-4-1 Dredging monitoring system

(1) Dredging cross-section display

To make it easy to monitor the state of the dredging operations, such information as the position of the sludge collector on a dredging cross-section, the depth before dredging, and the depth after dredge is displayed graphically on a CRT in an easy-to-understand way. In addition, various data is displayed numerically, making it possible to monitor the state of the dredging in greater detail.

Photo 2 shows a CRT display of the dredging cross-section.

(2) Spud interchange display

To make it easy to do monitoring during spud interchange, the position and height of the working spud and the height of the auxiliary spud in the profile of the dredge are displayed graphically on a CRT in an easy-to-understand way.

In addition, various data is displayed numerically, making it possible to monitor the state of the spud interchange operation in greater detail.

2-4-2 Work management system

(1) Function of preparing a work report format

Data recorded in real time automatically undergoes calculation processing for each dredging cycle (spud interchange), and work report data is prepared and output on a printer. And every time the date changes, calculation processing is automatically done, including the total, average, maximum, and minimum for the day, and a daily work report is prepared and is output on a printer.

(2) Function of preparing a depth contour plan

During dredging (during swinging), the depth before dredging, the depth after dredge, and the plane coordinate data is automatically recorded in real time. Since the data, being random-point data, cannot be used as data for preparing a depth contour plan, the data is modified, so that the data for many random points is approximated and interpolated by the least-squares method, and converted to depth contour plan data (data for coordinate-system lattice points that are spaced 1 m apart), and is recorded.

The depth contour plan data is retrieved offline, an arbitrary range is specified, and the depth contour plan is displayed on the CRT and is output on a plotter.

2-4-3 GPS ship positioning system

(1) GPS positioning device

For the GPS positioning device, a standard station is installed on land and a mobile station is installed on the dredge, the position is determined by the dynamic interference positioning (kinematic positioning) on-the-fly calibration method, data from the standard station on land is transferred by radio communication to the mobile station on the dredge, and the mobile station position data is corrected to precision positioning data and is output to the computer.

(2) Ship positioning system display computer

Using precision positioning information from the GPS positioning device (the position of the GPS reception antenna) as basic data, the position of the sludge collector and the position of the spuds are calculated in real time with the help of gyro azimuth information and information about the shape of the dredger's hull, and the path of the sludge collector and work district map of the dredge and plan view sludge collector are graphically displayed as dredger support information.

Photo 3 is a CRT display.

3. Results of automatic operation of bottom sludge dredging

The Kasumizaurus, which was built as an automated dredger, went into operation in March 1995. Table 2 compares its performance with that of its predecessor, the Koryu.
The following is a summary of the results of the automation embodied in the Kasumizaurus.

Table 2 Results of dredging

Item \ Dredger		KORYU	KASUMIZAURUS
Width of dredged bottom (cm)		40	40
Thickness of dredged layers (cm)		30	30
Advance (m/dredge cycle)		1.2	3.2
Theoretical dredge capacity (m^3/dredge cycle)		14.4	38.4
Specific gravity of delivered slurry		1.053	1.087
Apparent mud content ratio (%)		39	64
Dredged volume (m^3)		35	124
Time	Dredge cycle	23'08"	18'02"
	Swing	7'30"	15'02"
	Spud carriage travel and sludge collector rotation	—	56"
	Interchange of spuds	4'20"	2'04"
	Sludge storage tank high level	11'18"	0
	Sludge suction pump ON	7'16"	15'58"
	Sludge suction pump OFF	15'52"	2'04"
Dredging time efficiency (%)		31	89
Over dredge ratio (%)		37	13
Workers (1-watch)		8	6

(1) Labor is saved with the elimination of two on-deck crew members through optimized operation of the sludge transport pump, the level of the water storage tank, and the sludge suction pump, as well as through improved performance of the debris removal equipment. During dredging, everything but replacement of the anchor can be done automatically, greatly reducing the burden on the crew. Further labor saving is provided by the GPS and gyros, which practically eliminate the preparatory operation of positioning the dredger when changing the dredging position, direction, and lane, an operation that used to take three men several hours.

(2) In case of unautomated dredger so far, operations such as interchanging the spuds and swinging of the dredge were done by the crew manually, but on the Kasumizaurus, adoption of the latest mechanism for a sludge collector rotation system and spud carriage system, along with the automatic continuous operation functions described above, has reduced down time and greatly improved the actual dredging time ratio, to 89%.

(3) In work precision too, automation has been effective for reducing the amount of excess dredging and variation in the dredging depth.

(4) The apparent mud content ratio has been greatly improved, from an average of 39% with the Koryu to 64% with the Kasumizaurus. The variation has been reduced greatly, from 31-55% for the former, to 62-65% for the latter. Turbidity caused by dispersion of the bottom sludge during dredging has been reduced too: some was observed with the Koryu, but none was found with the Kasumizaurus.

4. Afterword

From planning to completion, the automated dredger Kasumizaurus was developed in less than two years and has roughly achieved its purpose. In the future, dredgers of this type are expected to be in active service for reviving lakes whose water quality has deteriorated. When the large-scale dredging of Lake Kasumigaura is completed in about the year 2000, the lake will once more present a scene of people enjoying swimming in its again-clean waters.

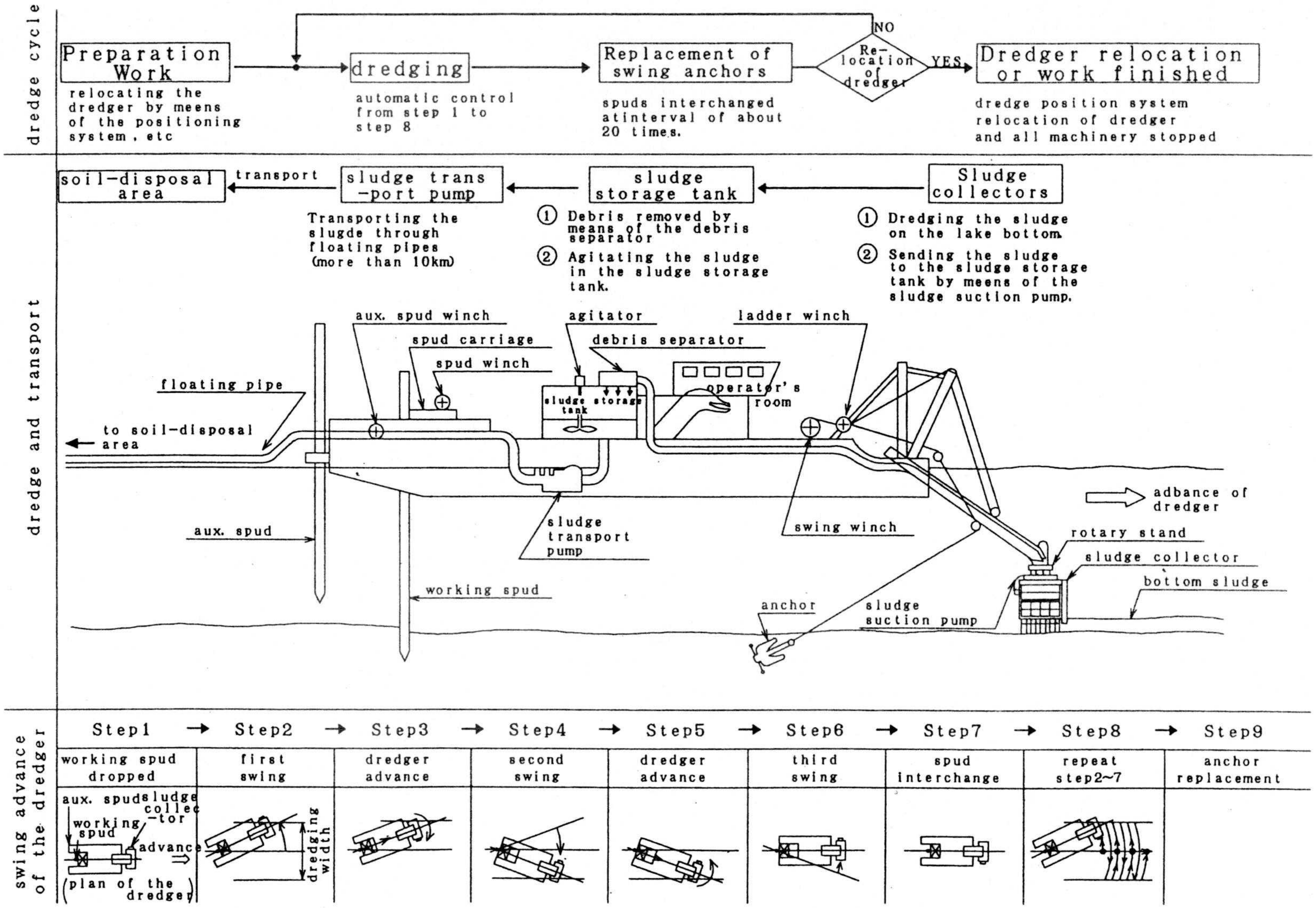
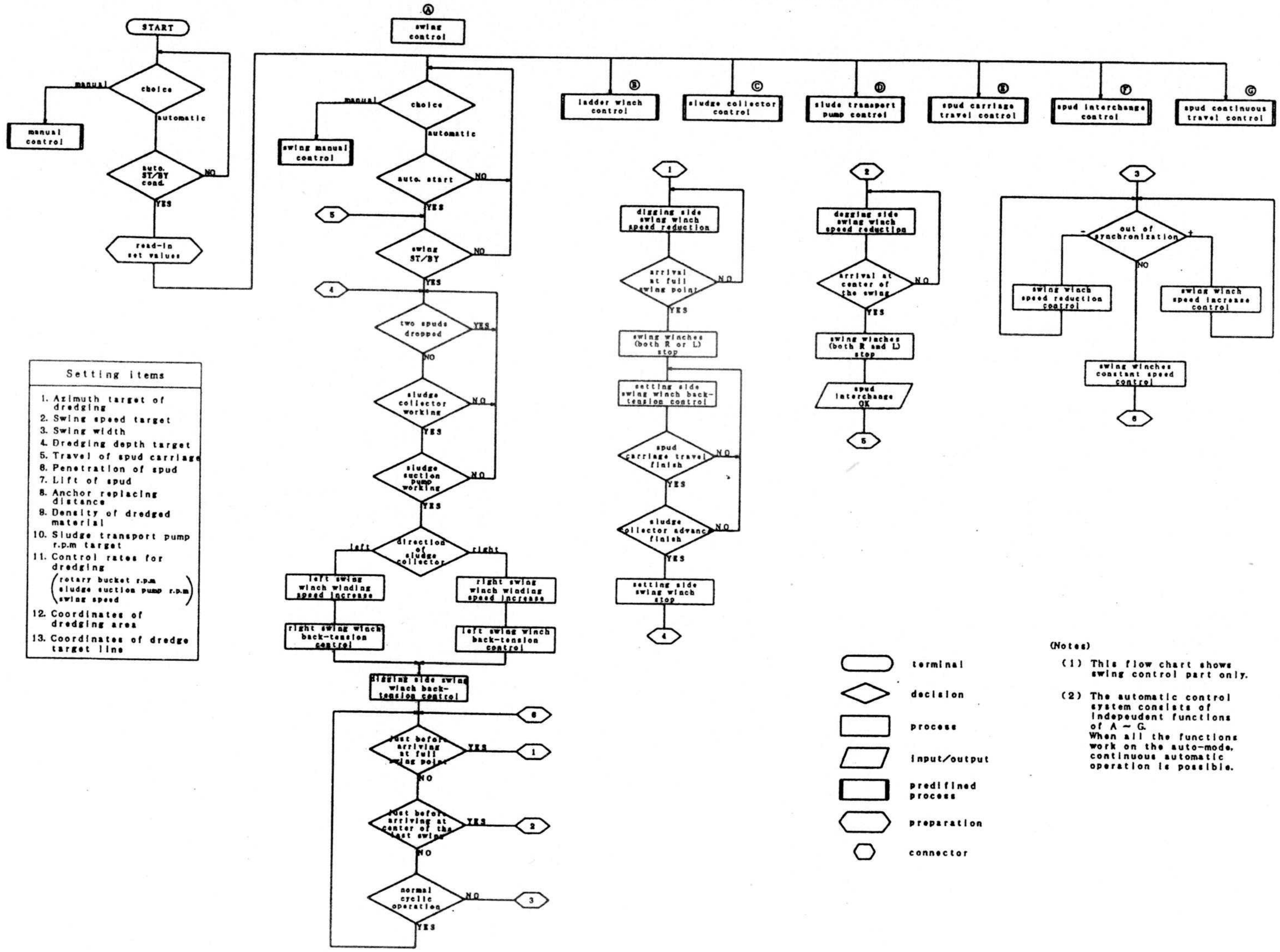


Fig-1 Outline of dredge works

Fig-2 Outline flow of automatic operation(example)



Setting items

1. Azimuth target of dredging
2. Swing speed target
3. Swing width
4. Dredging depth target
5. Travel of spud carriage
6. Penetration of spud
7. Lift of spud
8. Anchor replacing distance
9. Density of dredged material
10. Sludge transport pump r.p.m target
11. Control rates for dredging (rotary bucket r.p.m, sludge suction pump r.p.m, swing speed)
12. Coordinates of dredging area
13. Coordinates of dredge target line

(Notes)

(1) This flow chart shows swing control part only.

(2) The automatic control system consists of indepeudent functions of A ~ G. When all the functions work on the auto-mode, continuous automatic operation is possible.

Table-1 Automatic Dredge control

Item	Content of control	Input data (sensor)	Equipment to be controlled
Swing	1. To keep constant angular velocity of swing, according to the pre-set swing speed. 2. To slow and stop the swinging smoothly at the set point, and increase swing speed when started. 3. To reduce swing speed in accordance with r.p.m of sludge suction pump and rotary bucket, when level of sludge storage tank comes up to upper limit.	1. swing width 2. swing angle 3. swing speed 4. sludge storage tank level 5. sludge suction pump speed 6. sludge suction pump flow 7. swing winches r.p.m	1. right and left swing winches
Ladder winch	1. To control ladder winch in order to keep constant dredging depth to the pre-set target. 2. To lift and lower ladder by signal of dredge start/stop.	1. target dredge depth 2. sludge collector depth (echo sounder) 3. ladder winch r.p.m 4. signal of dredge start/stop 5. depth before dredging 6. depth after dredged	1. ladder winch
Sludge collector	1. To control r.p.m of rotary bucket and screw conveyor, corresponding to swing speed. 2. To control flow rate of sludge suction pump, corresponding to r.p.m of rotary bucket.	1. rotary bucket r.p.m 2. screw conveyor r.p.m 3. swing speed 4. sludge suction pump r.p.m 5. sludge suction pump flow 6. sludge transport pump flow 7. sludge collector rotary base position 8. sludge storage tank level	1. sludge suction pump 2. rotary bucket
Sludge transport pump	1. To start and keep sludge transport pump running at the set r.p.m, when the level of sludge storage tank comes to a certain depth. 2. To open the recirculation valve to circulate sludge sucked from sludge storage tank back to the tank and not to stop sludge transport pump when the level of sludge storage tank comes down to the lower limit or in case that excessive pressure arises in delivery pipe line due to clogging etc.	1. sludge storage tank level 2. delivery pressure 3. suction pressure 4. detection of valves open/close 5. flow rate of sludge transport 6. sludge transport pump r.p.m	1. sludge transport pump 2. related valves
Advance of dredger	1. To move dredger forward by the pre-set advance, by means of spud carriage, when swing is finished at the set point.	1. spud carriage stroke 2. signal of swing arriving at the set point 3. signal of spud dropped or lifted 4. swing angle	1. spud carriage
Spud	1. At stroke ends of spud carriage the next spud dropping point is calculated to get the stop angle of final swing, at winch angle swing winches stop in the final seving. 2. When swing control stops and spud interchange is ordered, working and aux. spud winches automatically interchange spuds. 3. Spud interchange is done dropping aux. spud and lifting working spud, after stop of swing is confirmed. 4. On this stage spud carriage is carried back to "0" position by means of hydraulic cylinder and aux. spud is lifted to finish the work.	1. stroke of working and aux. spuds 2. stroke of spud carriage 3. signal of swing winch operation 4. direction of dredger 5. spud position data	1. working spud winch 2. aux. spud winch 3. spud carriage 4. right and left swing winch

TABLE1

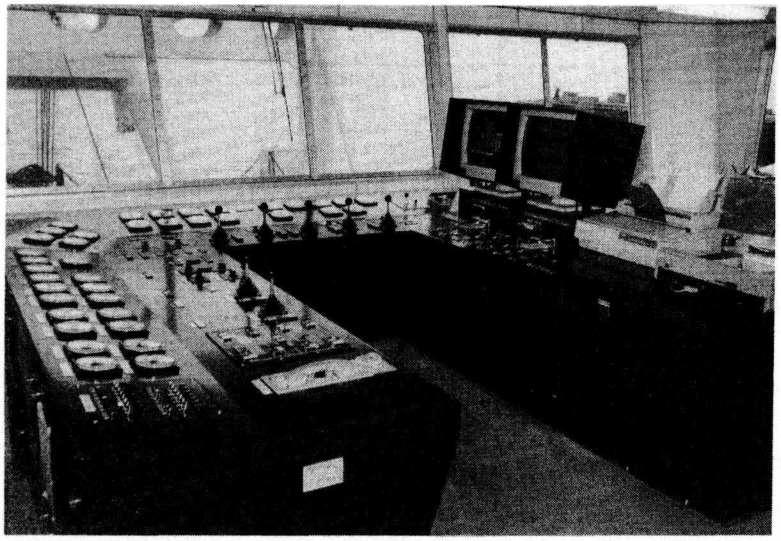


Photo 1
Dredging control panel

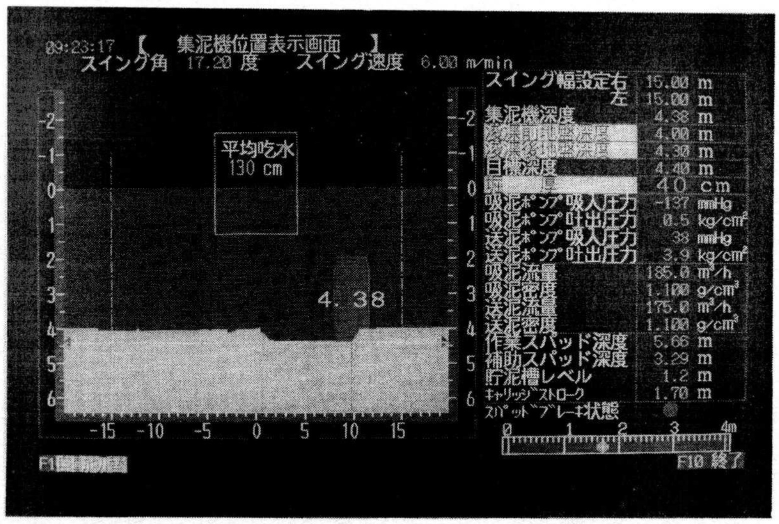


Photo 2
CRT display
position of sludge
collector

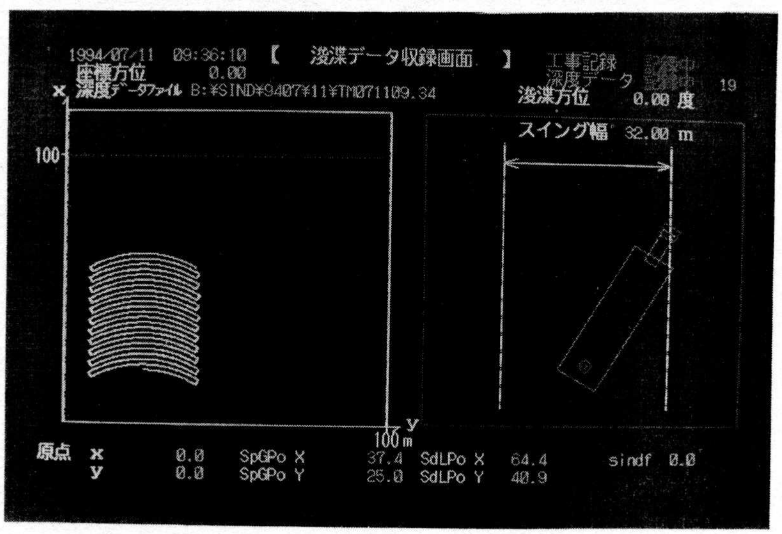


Photo 3
CRT display
ship positioning
system