TECHNICAL RESEARCH ON THE PRECISE DREDGING OF CONTAMINATED SEDIMENT

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ABSTRACT

This paper provides an introduction to a project involving technical research in relation to the precise dredging of contaminated sediment and the design ideas for the high precision positioning for a cutter suction dredger (CSD) and a dredging depth automatic control system. This was researched and developed with the help of high precision horizontal positioning technology, computers, sensors, automatic control and other technology in order to realize high precision environmental dredging. The research began with the Wuxi Wuli Lake demonstration project as the background. The research into the key technology and construction techniques, development and technical integration of environmental dredging instrumentation, adoption of suitable construction techniques was applied to the validation of the demonstration project. A technical index determined by this project has been reached that as a consequence managed to control the after-dredging precision to within 10cm. The research on key technology brought higher dredging precision which also benefited the bio-environmental protection and provided positive social effects. This established a firm basis in China for reducing impacts on the undisturbed soil while removing contaminated sediment during environmental dredging and for providing further quality improvements when undertaking environmental dredging in shallow lakes.

Key words: Precise dredging technology, high precision positioning, dredging depth, control, environmental dredging, after-dredging precision

RESEARCH PURPOSE

In recent years, China has continuously strengthened its effort on environment protection especially for the water environment. Environmental dredging represents a developing trend in dredging industry and is drawing great attention. It has become the major way to remove the contaminated sediment under rivers and lakes. In environmental dredging projects, stricter dredging quality control technology should be adopted in order to protect the undisturbed soil under rivers and lakes and to remove the contaminated sediment. In this case, the quality monitoring system for environmental dredging and accurate dredging equipment is essential to provide effective control for dredging depth and horizontal positioning and also ensure the correct dredging of undisturbed soil. In a word, high precision positioning and dredging depth auto-control equipment is desired for environmental dredging.

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Being a sub-sub subject of the national fifteenth major science and technology particular research project "Heavily Contaminated Water Sediment-environmental-dredging and Ecosystem Re-build Technology", the Heavily Contaminated Water Sediment Environmental Dredging Technology demonstration project, is based on research carried out during the West Wuli Lake demonstration project. In order to meet environmental dredging technical requirements with a Beaver 1200 environmental dredger as the test ship, research was started involving high precision positioning, computer and sensor technology to develop a Cutter-suction Dredger High Precision Positioning and Dredging-depth Auto-control System. This wholly Chinese interface system has taken account of the characteristics of contaminated sediment under shallow lakes in China; it collects the data on the ship's horizontal position, water / tide level, cutter head depth, spud carrier, controlling equipment. It realizes these functions on a cross section display, dredging depth monitor and dredging depth auto-control based on measured data. This greatly improves the precision of environmental dredging and reduces the amount of over-dredged material. The key to precise dredging technology is to control the angle of ladder and environmental cutter head and to realize automatic monitoring to the dredging process, which is an important innovation to environmental dredging automatic technology.

DEVELOPMENT OF ENVIRONMENTAL DREDGING TECHNOLOGY

The Environmental Dredging Technology of Foreign Countries

Environmental dredging equipment has gone through a period of great development and improvement due to the boom in environmental dredging technology. The earlier immerging environmental dredging technology of foreign countries enjoyed faster development and in the recent two decades successfully developed environmental dredging equipment for applying to various dredging conditions and dredgers. In 1975, Japan developed a screw-type dredging device and sealed bucket wheel dredging equipment which improved dredging depth and reduced water contamination. In the 1990s, Italy developed a pneumatic dredge pump for contaminated sediment dredging which featured high intake concentrations and created little bottom disturbance during dredging and almost no contamination to the water around the dredging site. In 2000, IHC Holland designed an environmental dredger equipped with an environmental cutter head modified and equipped with a cover. This dredger dredges a thin-layer in order to reduce disturbance to the bottom and increases intake concentrations while reducing turbidity caused by turbulence.

Development of computers and communication technology has brought the fast development of instruments for high precision environmental dredging. Meanwhile the improved precision for horizontal positioning and dredging depth has contributed to a leap forward in the quality of dredger operations. IHC Holland's Beaver 600 and Beaver

1600 cutter suction dredgers are equipped with automatic dredging control and display systems. These dredgers use spud carriers and DGPS for the purpose of positioning. They successfully removed a 15-20cm layer of contaminated sediment in Bala-ton Lake in Hungary. Thanks to the submerged cameras installed on environmental cutter heads, the dredging precision can be controlled to within 10cm.

The HAM291 environmental dredger is at present the most advanced environmental dredger in the world. As well as the positioning spud carrier this dredger has also adopted a three-cable positioning system and on-site monitoring system which improves the dredging precision to 5cm - 10cm.

In order to remove the contaminated soil with a thickness of 0.3 - 0.9m, RCI Construction Group & Environment Corporation installed oblique sensors on the boom, stick and bucket plus a RTK GPS positioning system to precisely determine the position of bucket and dredging depth. This helps to control bucket position and depth to within a centimeter in level.

Environmental dredging demands higher operating precision, so foreign dredging projects have broadly adopted RTK GPS positioning technology in order in meet the strict operational quality requirements laid down. RTK GPS positioning technology involves the use of a dredging cross section display device that controls horizontal positioning precision within a centimeter of level and dredging depth precision within 5-10cm. Its automation level and technology are superior to any environmental dredging technology in China.

Analysis to the Problems Existing in Environmental Dredging Technology in China

Environmental Dredging Technology in China

Sediment dredging on lakes had already begun in China as early as the 1950s with the first dredging being implemented on XiHu Lake in Hangzhou from 1953 to 1958. The modified dismountable dredger BeiJing carried out lake sediment dredging in YiHe garden in Beijing. Limited by the technology and conditions at that time, these projects didn’t show much difference when compared with regular engineering dredging and could only be called a de-silting project. However, these projects provided experience and the basis for the application and development of present environmental dredging technology. In recent years a strengthening effort was put into environmental protection especially for the restoration of the water environment. Environmental dredging was done, for example, on Dianchi Lake in Kunming, ChaoHu Lake in Anhui, ErHai Lake in Dali and XiHu Lake in Hangzhou. Typical environmental dredging projects in China were those carried out on CaoHai Lake and Dianchi Lake where cutter suction dredgers were put into use to dredge contaminated sediment which was pumped to confined disposal sites on shore through pipelines. In Hangzhou Xihu Lake environmental dredging project, an environmental cutter suction dredger took the job and used pipelines that involved several booster stations to pump the contaminated sediment to the disposal pit outside the city. After environmental dredging the water quality of Dianchi Caohai Lake and Hangzhou Xihu Lake have been greatly improved.

Analysis on Existing Problems

- Dredging precision control methods are still lagging behind with precise horizontal positioning and dredging depth control systems of a lower standard than in foreign countries.
- Due to various reasons, not many technicians gets themselves involved in environmental equipment research and the type and quality of research equipment is also below the standard of foreign equipment. Many dredgers are still using old dredging equipment which gives the possibility of lower control on dredging precision and sediment re suspension caused by dredging.
- Due to limited attention put on research and development for environmental dredging equipment less investment was made, hence few mature products were generated

RESEARCH CONCEPTS

Dredgers that adopted precise thin layer dredging concepts would have their environmental dredging equipment precisely positioned and real-time controlled so that the dredging thickness can be adjusted with respect to variation of material and be able to achieve precise control of the dredging depth. Also to establish suitable operating techniques according to the conditions of site in order to achieve a relatively level cut in the dredged area and have the dredging depth meeting the precise environmental requirements. In this way, dredgers are able to effectively remove the contaminated sediment while avoiding over-dredging of undisturbed soil and unnecessary fine particle re suspension.

The Beaver 1200 environmental cutter suction dredger was chosen as the test ship for this research project so as to research and develop the “Cutter suction dredger high precision positioning and dredging depth automatic control system”.

With the help of advanced computer technology, sensor technology, high precision positioning technology and the collected information relating to the ship’s horizontal position, water / tide level, lowered cutter depth as well as spud carrier are controlled . The system is able to display a dredging cross section and cutter position, ladder winch controller is able to adjust cutter lowering depth to realizing automatic dredging depth monitoring as well as high precision positioning and accurate dredging depth.

CURRENT SITUATION WITH SHIPS AND SHIP SELECTION

For many years, rivers and lakes in China have been used for travel and the production of resources and due to these historical activities the environment of some has suffered from man-made damage. In recent years, our country has experienced great economic development and more attention and investment has been put into environmental protection with a great amount of money used to renovate rivers and lakes. At the end of the 1990s the Ministry of Water Resources and Electric Power brought forward the “Plan of a hundred of ships” aimed at building small dredgers to dredge bottom sediment from rivers and lakes. The majority of these dredgers were cutter suction and bucket wheel dredgers. In China, rivers and lakes always seem to be located around cities and become, therefore, limited by environmental and transportation difficulties. Small dredgers play an important role in the environmental dredging for rivers and lakes. At present, most cutter suction dredgers are installed with low precision dredging gauges and have a relatively low automation level. Therefore, researching and developing high precision dredging gauges has became one of the major issues that environmental dredging operators have to deal with in order to improve the environmental dredging situation in China. The gauges researched are not only suitable for cutter suction dredgers but are also can be installed on bucket wheel dredgers.

After investigation and with confirmation from the project group it was decided that the dredger “Junhu” of the Tianjin Dredging Corporation would to be the test dredger designated to carry out research on the “cutter suction dredger high precision positioning and dredging automatic control system”.

OVERALL DESIGN OF THE SYSTEM

After investigation, the main hardware of the system was determined with the overall design based on the functions needed and the ship’s current situation. The overall design of the system is shown in block diagram (Figure 1).

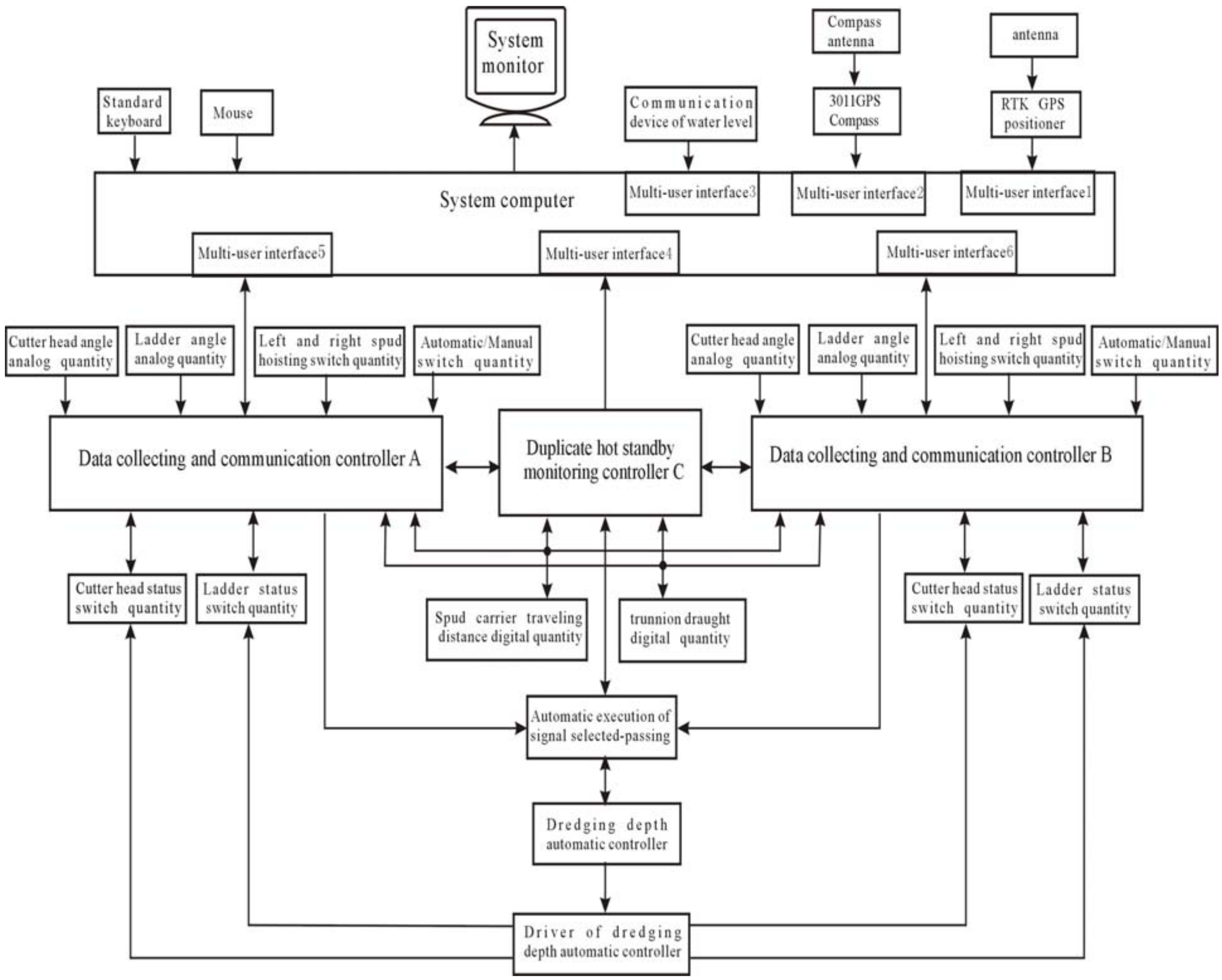

Figure 1. Block diagram for overall design of the system.

INTEGRATION OF THE SYSTEM EQUIPMENT

This system mainly involves:

- system main computer,
- two duplicate hot standby “data collection and communication controllers” as collecting and monitoring equipment for the system,
- one “duplicate hot standby monitor controller”
- dual angle sensor for ladder data collecting and controlling, dual angle sensor for cutter status data collecting
- trunnion controlling draught sensor,
- high precision carrier digital sensor,
- 3011GPS compass,
- RTK GPS positioning system,
- switch quantity circuit board,
- linear power supply,
- digital power supply,
- Cabinet for the main computer, structural components, etc.

RESEARCH AND DEVELOPMENT FOR MAIN HARDWARE AND SPECIFIC TESTING EQUIPMENTS OF THE SYSTEM

Research and Development for Main Hardware of the System

- One smart magnetically controlled draught digital sensor.
- One high precision carrier travel distance digital sensor.
- Two high precision data collecting and communication controllers (device A, B).
- One duplicate standby monitoring controller (device C); dual angle sensor for ladder data collecting and controlling and a dual angle sensor for cutter status data collecting and controlling

Research and Development of Specific Testing Equipment

- In order to adjust the software and realizing system's function on schedule, the multi-channel data simulator was developed to simulate data from RTK GPS positioning system, 3011 GPS electronic compass, water level gauge and other outside equipment to complete the test to system software.
- In order to verify the quality and function of research phase achievement a "system simulator desk" and "simulation testing controller" were designed (see figure 2). The Simulator desk is made to a scale of 1:10 relative to the real ship installation and is used to test the system online and to perform simulation tests.

Figure 2. Simulator desk for the system.

SYSTEM HORIZONTAL POSITIONING

System horizontal positioning adopted RTK (Real Time Kinematic) technology which could provide 3D coordinates of the monitored area with centimeter levels of precision.

The positioning data acquired from the GPS receiver goes through a coordinate system conversion, ie. WGS84 to BJS54 coordinate system conversion and the gauss horizontal coordinate of measured point can be calculated by using geodetic coordinate and gauss projection.

The real-time horizontal coordinates after coordinate conversion, real-time azimuth angle of the ship and the known ship parameters are used to calculate the horizontal and vertical project distance from the GPS coordinate point to the center of cutter. From this the real-time horizontal coordinates of the cutter head can be calculated. Using the same theory, the spud coordinates can also be calculated.

Dredging Depth Calculation and Dredging Depth Measurement Principle of the System

Dredging depth of cutter suction dredger is varied corresponding to the lowing/hoisting of the ladder. The axis of ladder namely the trunnion is installed at both sides of the ship, and its center is used as the origin for cutter dredging depth measurement. By measuring the hull draught at the trunnion, the ladder angle, cutter angle and hull dimension and the cutter dredging depth can be acquired. (See Figure 3 for the principle of cutter dredging depth measurement.)

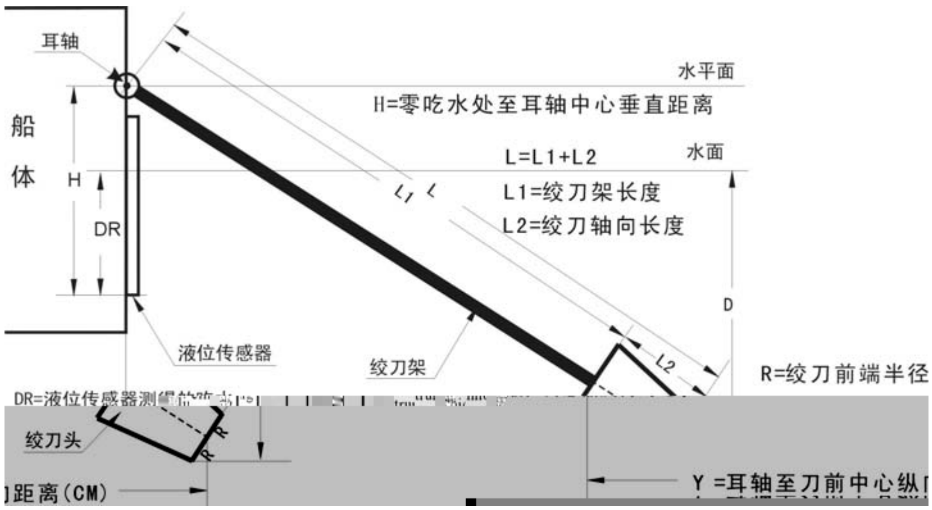

Figure 3. Principle of cutter dredging depth measurement.

Formula for cutter dredging depth (D) calculation is shown as follows:

$$D = L_1 \sin A + L_2 \sin B + R\cos B - H + DR \quad (1)$$

In which
- A: ladder lowering angle
- B: cutter lowering angle
- R: cutter front side radius
- H: vertical distance from zero draught point to the center of trunnion
- DR: the draught measured by liquid level sensor
- L_1: distance between the center of trunnion and the center of cutterhead joint
- L_2: distance between the center of cutterhead joint and the dredging position of cutterhead.

PRINCIPLE OF SYSTEM CONTROL

Shown by the block diagram, the system computer receives data from the RTK GPS positioning system and 3011 GPS compass to calculate the current position, then sends the set of operation parameters to controllers for data collecting and communicating (machine A,B).

Two controllers are for data collecting and communicating. One controller is at the hot-standby status and one is handling the current work. The working status of these controllers is determined by the duplicate hot standby monitor (machine C). When the controller for data collecting and communicating encounters a failure, the duplicate hot standby monitor then switches the controller at hot standby status to working status, and sends a "failure repair request" to the system computer.

The dredging operation board on the operation desk is installed with an automatic/manual switch which can be controlled by the dredge master who will select an operation mode. The system will enter automatic dredging depth control as the operation mode is switched to automatic. At the same time the operator could interrupt at any time, using the manual control, with the system then quitting its automatic status.

The principle of system control is shown as Figure 4.

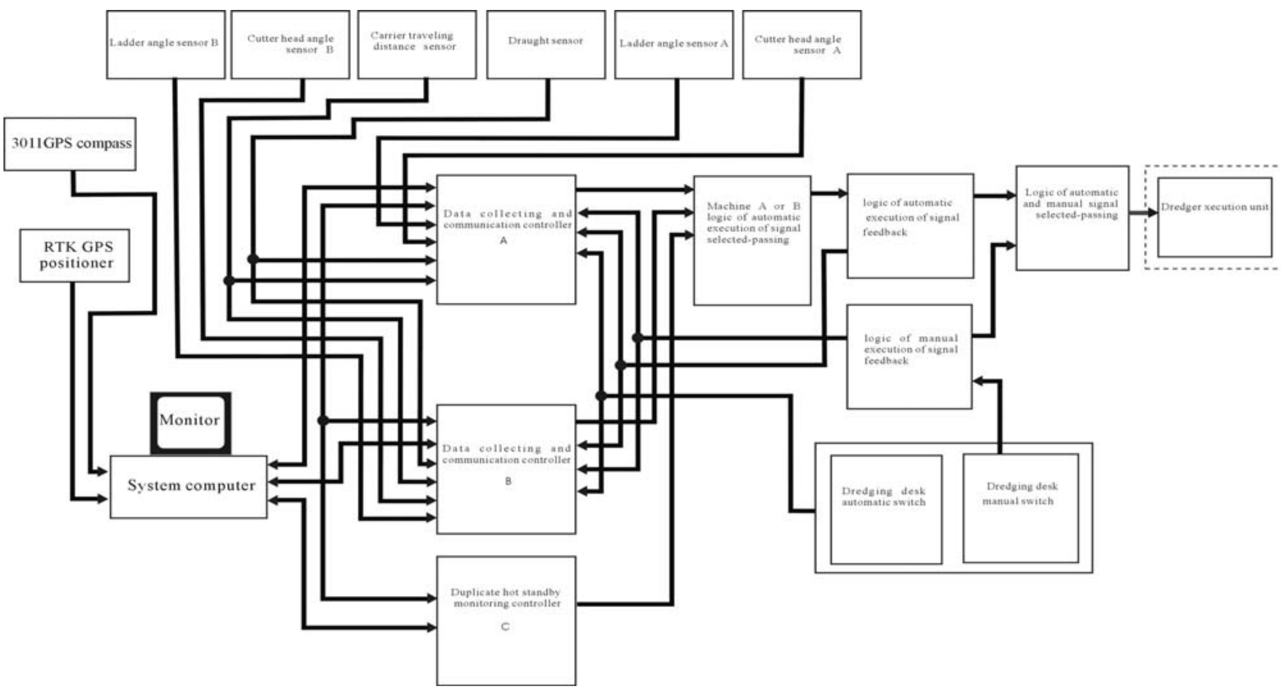

Figure 4. System control principle logistic diagram.

SYSTEM PROGRAM MODULE

Project main module is shown in Figure 5. Area A: marine chart background of the dredging area, water depth color block, dredger status and dredging depth.

Area B: real-time display dredging cross section.
Area C: example of water depth color block.
Area D: real-time display cutter gesture.
Area E: real-time display operation parameters of the dredger.

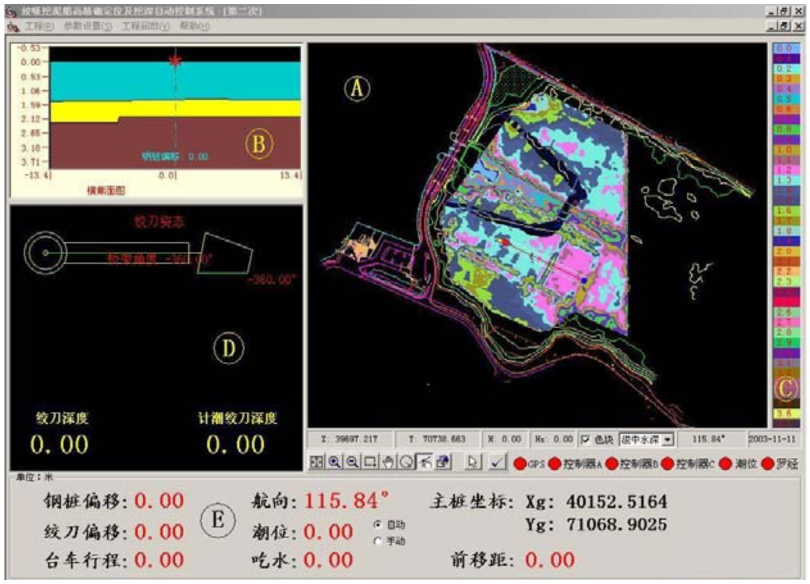

Figure 5. Project main module.

DREDGING PROCESS CONTROL

The dredging capacity and material transportation capacity of a cutter suction dredger are determined by the ship design index and performance of the installed equipment. The pipe length between West Wuli Lake dredging demonstration area and disposal area was up to 5500 m. Under this operating condition the dredging capacity of the dredger JunHu is better than its transportation capacity especially when dealing with soft sediment involving a fast swing speed, deep cutter depth and a large dredging thickness. In this case, some sediment may remain in place not having been fully sucked in and transported. If too much sediment is left behind it could cause shallow areas. Alternatively, with a slow swing speed and a shallow cutter depth and thin dredging thickness casing a condition under which more sediment may be sucked in than is required may cause over dredging. Shallow points and over dredging are most likely to happen with the dredging of the lowest layer. Factors that influence dredging quality include:

- Swing speed. Swing speed of dredger Junhu: 0-26m/min; stepless speed control
- Cutter dredging thickness. Biggest designed dredging thickness of environmental cutter head suitable for silt dredging is 0.3m,
- Spud carrier traveling distance. Spud carrier traveling distance is 0-4 m.
- Cutter speed. Three gears for cutter speed: first gear 9 turns; second gear 15 turns; third gear 34 turns.

In order to maintain the precision during dredging, the swing speed, cutter speed, dredging thickness and spud carrier traveling distance must be controlled according to the sediment characteristics. The test dredging was implemented in an area where it was relatively easy to dredge and the controlled dredging thickness was in a range from 0.25-0.30m. The test used a 2m long environmental cutter head, a controlled spud carrier with a traveling distance of 1.5m, and with all three cutter speed gears. The swing speed in the test was controlled at 15m/min, 20m/min, and 25m/min respectively. After the test the water depth of the area after dredging was measured, and then we concluded the following parameters could control dredging quality after dredging:

- Swing speed controlled at 15-18m/min.
- Cutter dredging thickness controlled at 0.25-0.30m.
- Spud carrier traveling distance controlled at 1.5m.
- Cutter speed at second gear.

The operational staff on the dredger Junhu was required to self-check the water depth after dredging at least once as spud carrier twice moved forward. The check after dredging proved satisfactory resulting in 95% of the sediment layer after dredging having been controlled within ±10cm.

APPLICATION RESULT AND VERIFICATION

On Nov.26th 2003, the dredger Junhu started to work on the dredging demonstration area of West Wuli Lake and the system was put into use after verification together with training given to the staff. Researchers in the project group stayed onboard to monitor the system status and adjusted the system according to the hardware and software problems as they occurred. This was also so they were able to further improve the system.

The application at the demonstration project at West WuLi lake has proven that the system with high levels of horizontal positioning, accurate dredging depth control and effective control of the environmental sediment dredging, with a precision of <10 cm. The system can automatically control the dredging depth and display the status of the cutter as well as the angle between the cutter head and the horizontal. As well it is able to precisely control the cutter head dredging level. All of these features have proven the system's simplicity, reliability and practicality.

CONCLUSIONS

Through the research on the key technology and operation techniques for environmental dredging, research and technical integration of environmental dredging instruments, application of suitable operation techniques and test and verification in the demonstration project, all technical indexes has been met. After research and development, the precision of environmental dredging has been improved. This has a beneficial meaning for environmental protection and has a great social effect. The system enjoys a promising future for its application and has founded a basis for further improvement to the quality of environmental dredging in the shallow lakes of China.

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