DYNAMIC POSITIONING CONFERENCE
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Design and Control

Dynamic Positioning System for Deep Ocean Drill Ship "CHIKYU"

Koh Murata, Santoru Nagase, Hiroomi Ozawa
Mitsui Engineering & Shipbuilding Co., Ltd. - Japan

Kazuyuki Igarasi
Akishima Laboratories (Mitsui Zosen) Inc. – Japan

Kazuyasu Wada

Japan Agency for Marine-Earth Science and Technology - Japan

1. INTRODUCTION

It is required for the drilling vessel to keep her position and heading with high accuracy under the external disturbances. If the vessel moves widely during the drilling operation, it will give rise to damage of riser pipe or drilling pipe and so on, and become impossible to continue the drilling operation. For the drilling vessel working in deep water area, DPS using thrusters, propellers etc. is used instead of jack up rig or mooring system with anchor.

CHIKYU has to keep her position and heading over the long term for scientific drilling operation. To control her motions, DPS has been developed and installed in the vessel. The characteristics of this DPS are shown as follows.

2. DEVELOPMENT OF DPS

2.1 Principal Dimensions

The principal dimensions and general arrangement of CHIKYU are shown in Table 1 and Fig.1.

Table 1 Principal Dimensions

Length (L_{OA})		210 (m)
Breadth		38 (m)
Draft		9.2 (m)
Displacement		Abt. 57,500 (ton)
Passengers		150 (p)
Operational Depth	Riser Drilling	2,500 (m)
	Riser-less Drilling	7,000 (m)
Length of Drilling Pipe		10,000 (m)

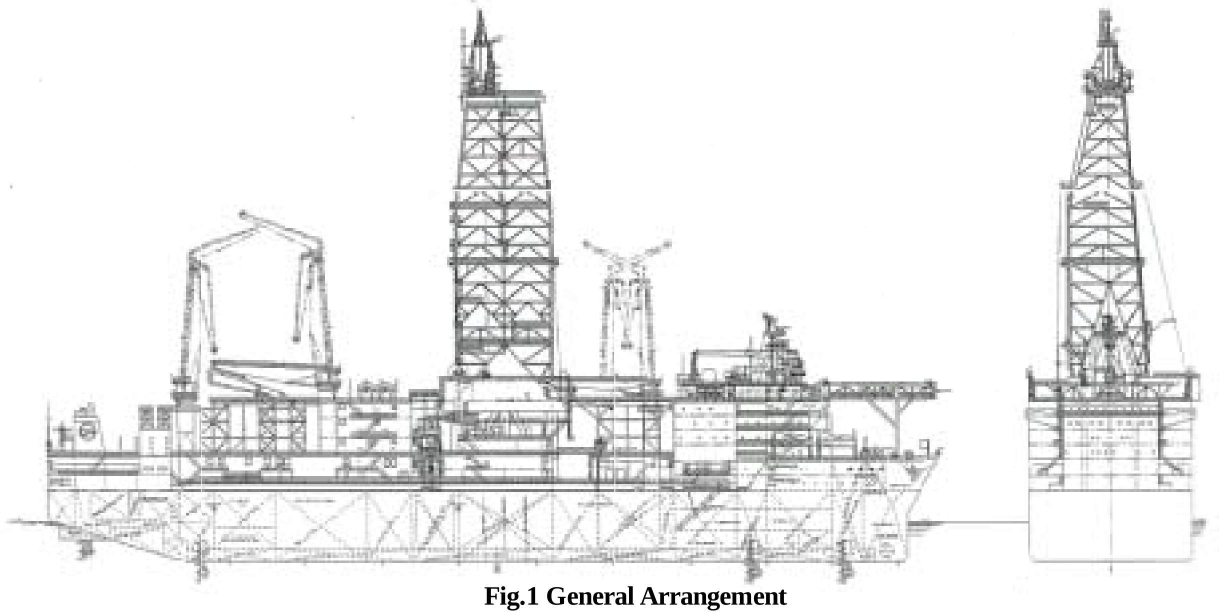


Fig.1 General Arrangement

2.2 Required Position Keeping Ability

CHIKYU is required to keep her position under the conditions of external disturbances, drilling condition, stand by I condition and stand by II condition as the design conditions described in the specification. These conditions are shown in Table 2.

Table 2 External Disturbances in Design Conditions

			Drilling	Stand by I	Stand by II
Current	Speed	(kt)	1.5	1.5	2.5
	Direction	(deg.)	±30 against the Heading		
Wind	Speed	(m/sec.)	23	30	23
	Direction	(deg.)	±30 against the Heading		
Wave	Height	(m)	4.5	5.5	5.5
	Period	(sec.)	8.2	9.0	9.0
	Direction	(deg.)	±30 against the Heading		

Where,

- Wind velocity is written in one minute average speed.
- Wave height is written as the significant wave height.
- Wave period is written as the mean wave period.

Additionally, current, wind and wave were assumed as follows.

- Current velocity and direction are stable.
- Wind velocity fluctuates based on the Harris spectrum.
- Wave height fluctuates based on the ISSC spectrum.

For the drilling operation, it will be required to make the deviation from the desired position as small as possible. About the position keeping accuracy, it is specified using "$2\sigma_P$" which is two times of standard deviation of the vessel's deviation from the target point. This figure means the scale of position's spread around the target point. This vessel is required to control her position and heading to keep $2\sigma_P$ less than the defined allowable positioning accuracy.

The allowable positioning accuracy under each design condition is described in the specification as follows and shown in Table.3.

< Allowable Positioning Accuracy >

$2\sigma_P$ has to be less than following definitions.

- Drilling Condition ： 1.5% of water depth or 15 (m), whichever is larger.
- Stand-by Condition ： 3.0% of water depth or 30 (m), whichever is larger.

Table 3 Allowable Positioning Accuracy(m) Depending on Water Depth(m)

Water Depth (m)	1,000	2,500	7,000
Drilling	15	37.5	105
Stand by I and II	30	75	210

Additionally, under the much more severe external disturbances, it becomes impossible to keep both her position and heading. In this case, survival condition, the vessel has to be controlled to maintain her heading in Auto Heading Mode. In this controlling mode, the heading is kept automatically, but the position is controlled manually using the joystick. The survival condition is defined as shown in Table 4.

Table 4 External Disturbances in Survival Condition

Current	Speed	(kt)	2.5
	Direction	(deg.)	Against the Heading
Wind	Speed	(m/sec.)	51.4 (=100 (kt))
	Direction	(deg.)	Against the Heading
Wave	Height	(m)	16
	Period	(sec.)	15.4
	Direction	(deg.)	Against the Heading

2.3DPS Design Flow

In order to design the DPS, at first, various tank tests and wind tunnel tests etc. were carried out, and various numerical simulations were conducted to design the optimal DPS combining thrusters, generators, sensors and so on. Fig. 2 shows the general pattern diagram of DPS design.

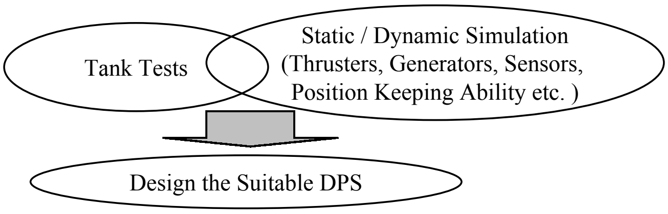


Fig.2 General Pattern Diagram of DPS Design

2.4Controlling Logic

The control diagram for this DPS is shown in Fig.3. Controlling forces are determined to minimize the deviation from the target position and heading against the external disturbances. These forces consist of feed forward forces and feed back ones. Feed back forces are calculated based on the deviation of her position and heading. On the other hand, the feed forward forces are obtained using the wind forces and the summation of estimated external forces from the Kalman filtering technique.

The electric power load and the number of running thrusters always are monitored when DPS decide the azimuth angle and propeller speed for each thruster.

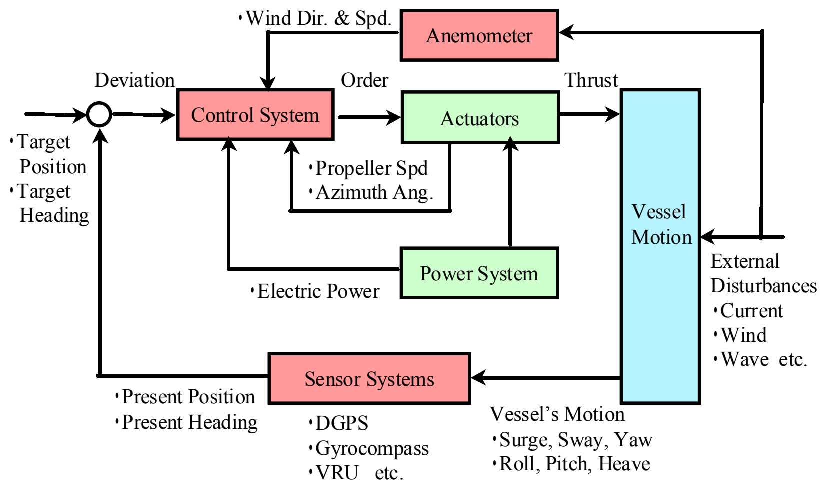


Fig.3 Control Diagram of DPS

3. SYSTEM COFIGURATION OF DPS

3.1 Signal and Electric Power Source System

The system configuration of DPS is shown in Fig.4. In this DPS, all lines of signal and electric power source have redundancy. If any trouble occurred on using line, the line will be switched to normal line immediately, and it is possible to continue the controlling operation.

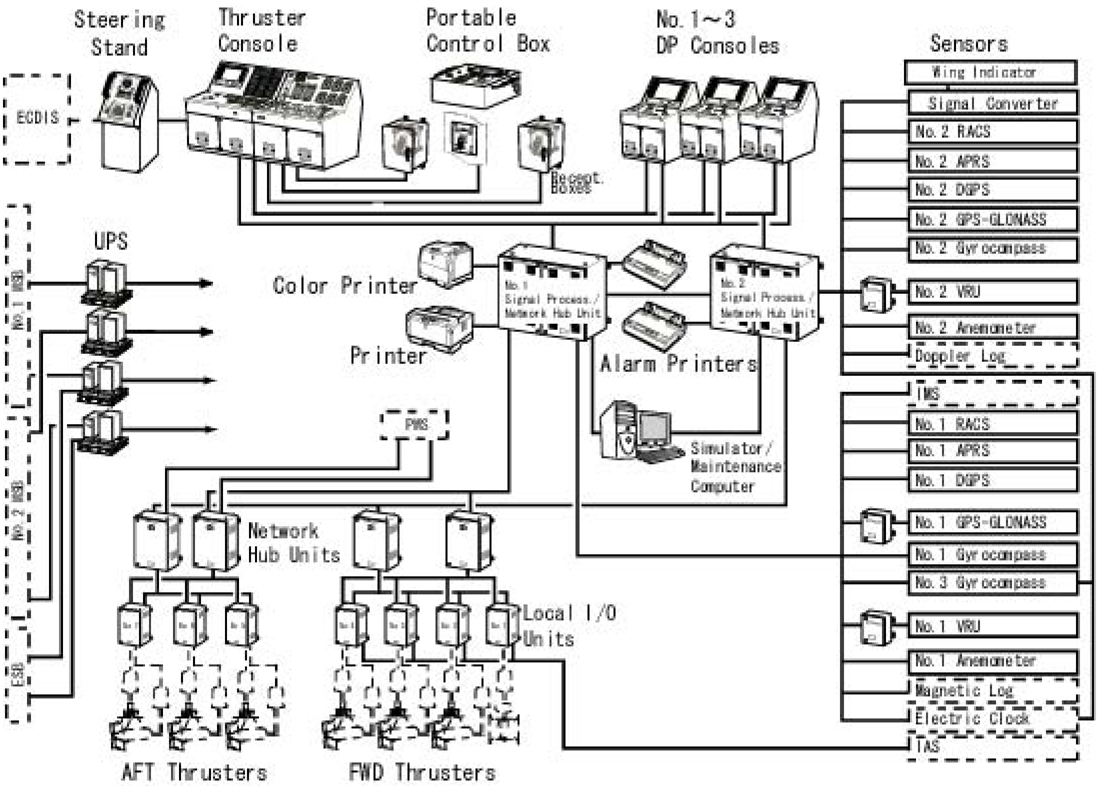


Fig.4 The System Configuration Diagram of "CHIKYU"

This DPS has 3 operating consoles (DP consoles), and each console has CPU to calculate for control independently at same time. Then, it is possible to find the CPU error easily and deselect the CPU from control automatically by majority decision of triple voting system.

3.2 Sensors

CHIKYU is equipped with three kinds of position reference sensor to measure her position throughout the world, 2 units for each Sky-Fix DGPS utilizing INMARSAT satellites, GPS-GLONASS hybrid system and Acoustic Position Reference System (APRS).

During the riser drilling operation, it is important to minimize the riser pipe's top and bottom tilt angles. Therefore, Riser Angle Control System (RACS) has been developed not only for minimizing the angles but also estimating the vessel's position without any other position reference sensors.

3.3 Thrusters and Generators

This vessel has one side thruster (S/T) and six azimuth thrusters (A/T) as the control actuators. S/T and three A/T are equipped as bow thrusters, and other three A/T are as stern thrusters. Fig.5 shows the general configuration of these thrusters.

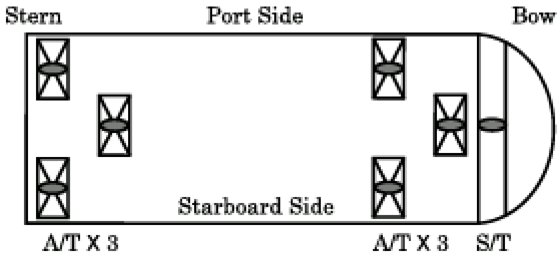


Fig.5 Thrusters' Configuration

The principal dimensions of S/T and A/T are as follows.

< Azimuth Thruster >

- Diameter : 3.80 (m)
- Propeller Speed : 162.3 (min^{-1})
- Power : 4,200 (kw)
- Maximum Thrust : 701.7 (kN)
- Number of Blade : 4

< Side Thruster >

- Diameter : 2.85 (m)
- Propeller Speed : 250.8 (min^{-1})
- Power : 2,550 (kw)
- Maximum Thrust : 374.6 (kN)
- Number of Blade : 4

This vessel has 6 main generators and 2 auxiliary ones in 2 engine rooms (port side and starboard side). Each engine room has 3 main generators and an auxiliary one.

< Main Generator >

- Type : Mitsui 12ADD30V
- Capacity : 5,000 (kw)
- Number of Units : 6

< Auxiliary Generator >

- Type : Mitsui 6ADD30V
- Capacity : 2,500 (kw)
- Number of Units : 2

4. CONTROLLING FUNCTIONS

This DPS has several controlling functions depending on the operations of CHIKYU. Major controlling functions are as follows.

4.1 DP Mode

In DP mode, all thrusters are controlled automatically to keep the vessel's motion steady and minimize the deviations of position and heading from the target under the external disturbances.

If the target position is changed, the vessel will move toward to the new target at selected flat speed, High(about 0.5kt), Middle(about 0.25kt) and Low(about 0.1kt) with keeping her heading.

Even if weather condition becomes rough as "Stand-by" conditions shown in Table2, it is possible to continue the position keeping operation by changing the control gain from "Normal" to "High".

On the other hand, under the calm weather condition, it is also possible to keep her position steady using "Azimuth Fix Mode". In this mode, azimuth angles of all A/T are fixed at the predetermined angle to generate stream to outside of this vessel's hull.

4.2 Auto Head Mode

In this mode, all thrusters are controlled automatically to keep the vessel's heading on the target one and move toward to the ordered direction by using the joystick manually.

As with DP Mode, under the very severe weather condition as shown in Table4, it is possible to control her bearing by changing the control gain from "Normal" to "High".

4.3 JOY Mode

In this mode, it is possible to control the vessel's motion using the joystick and turning dial. The thrust for fore-and-aft direction is increased to about 4 times of normal thrust by using the power up button equipped with the joystick.

4.4Navigation Mode

When this vessel is navigated to the drilling site, all thrusters are controlled using the throttle lever and steering stand as usual vessel. Additionally, auto pilot function and tracking function with ECDIS (Electronic Chart Display and Information System) are available in this mode.

4.5 RACS

When the riser pipe is used for drilling operation, Riser Angle Control System (RACS) can estimate her position referring the top and bottom riser's tilt angle. Using RACS for position keeping in DP mode, it becomes possible to control the vessel's position to minimize the riser's tilt angle. Fig.6 shows the conceptual figure.

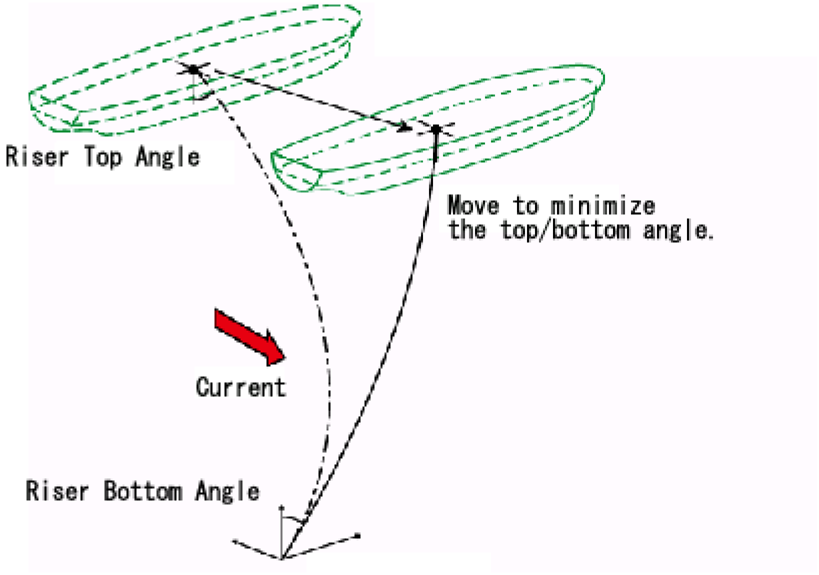


Fig.6 RACS

4.6 Consequence Analysis

During DP mode, DPS constantly watches the position keeping capability. It is also possible to simulate and check the capability setting the optionally relevant conditions, external disturbances, generators, thrusters and so on. In Fig.7, the capability in all directions is shown as the sequential round line graph. If the capability in the present heading becomes less than the preset allowable value, "Insufficient Thrust" warning will be occurred to notice the operators.

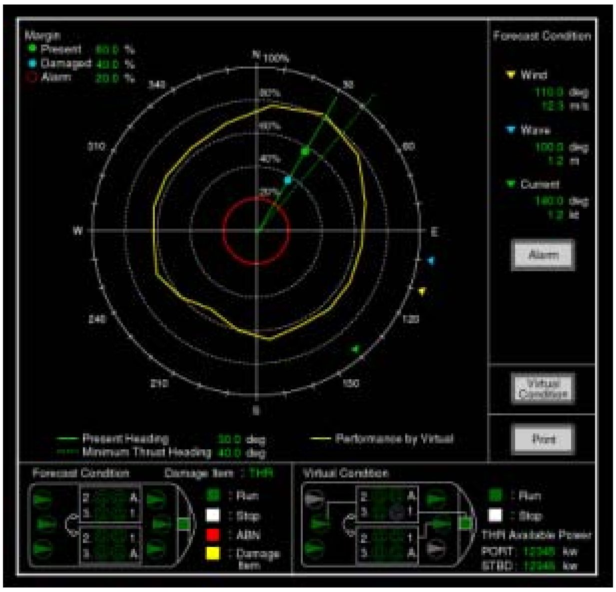


Fig.7 Example of Display for Consequence Analysis

5. REDUNDANCY

CHIKYU has been designed to have the redundancy meeting the rules of DPS Class-B of Nippon Kaiji Kyokai (NK). She can continue the position keeping operation if any single failure occurs in kinetic equipment. Additionally, the engine room and high voltage switchboard room is partitioned by watertight and fireproof bulkhead.

This DPS has 3 operating consoles, and each console has CPU to calculate independently at the same time. Then, it is possible to find the CPU error easily by majority decision using these consoles.

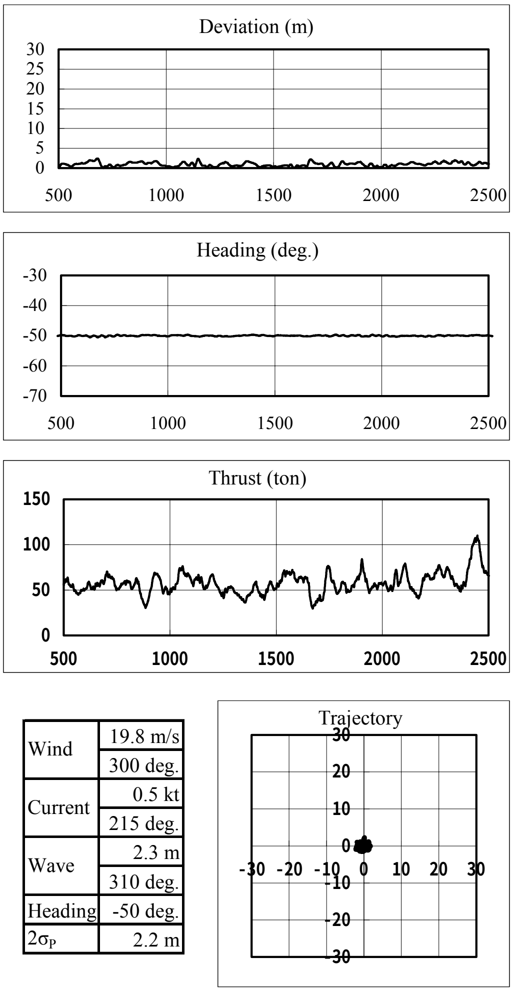
6. POSITION KEEPING ABILITY

6.1 The Validity of the Method for Evaluation

In 2003, sea trials were held without any drilling equipment on the deck. In December 2004, all equipment was installed completely, and the position keeping ability was checked at the sea trials. Fig.8 shows time histories and a trajectory as the example of recorded data under the most serious external disturbances at the sea trials in 2004.

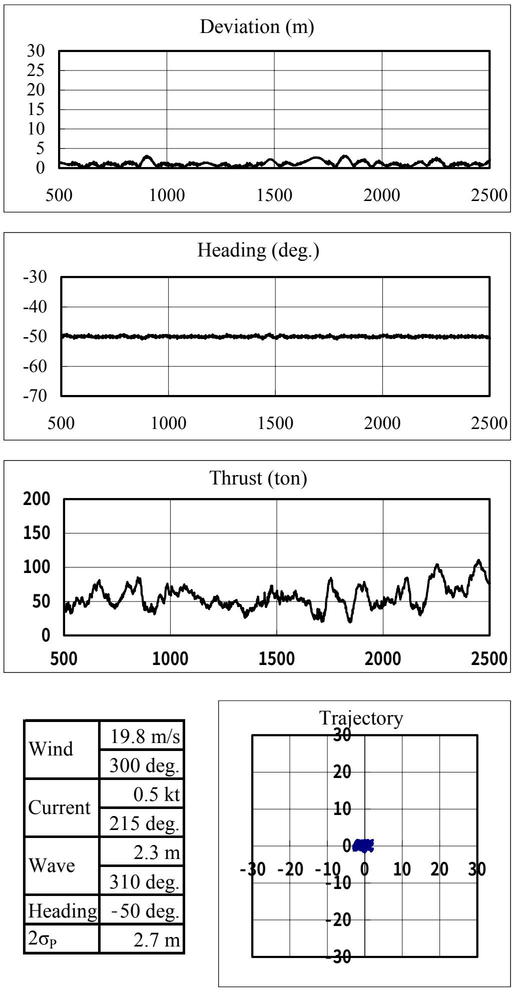
In this case, $2\sigma_P$, which is two times of standard deviation of the vessel's deviation from the target point, was 2.2m and it is found that this vessel had controlled her position and heading steady with high accuracy.

The position keeping ability under the design conditions must be confirmed using numerical dynamic simulations. The validity of the method for evaluation of simulations has to be confirmed by comparing the results of simulations with the measured and recorded data at the sea trials. For example, Fig.9 shows the results of numerical simulation under the same conditions with Fig. 8, measured or estimated external forces, thrusters, sensors, generators and so on.



Wind		19.8 m/s
		300 deg.
Current		0.5 kt
		215 deg.
Wave		2.3 m
		310 deg.
Heading		-50 deg.
$2\sigma_P$		2.2 m

Fig.8 Time Histories and Trajectory of Vessel (Recorded at Sea Trial)



Wind		19.8 m/s
		300 deg.
Current		0.5 kt
		215 deg.
Wave		2.3 m
		310 deg.
Heading		-50 deg.
$2\sigma_P$		2.7 m

Fig.9 Time Histories and Trajectory of Vessel (Simulation)

In this simulation, $2\sigma_P$ is 2.7m. From comparing Fig.8 and Fig.9, it is possible to say that the vessel's motion is simulated very well.

Fig.10 shows the summery of comparison of $2\sigma_P$. In this figure, ◆ and ● show the results of comparing simulation and the recorded data at sea trials in 2003 and 2004 respectively. If the $2\sigma_P$ from the recorded data is equal with simulation, the symbol will be located on the diagonal bold line.

From Fig.10, the validity of the numerical simulation is confirmed, and it is possible to say that the numerical simulations can be used for the evaluation of position keeping ability.

6.2Position Keeping Ability under the Design Conditions

The position keeping ability $2\sigma_P$ under the design conditions are shown in Fig. 11. In this figure, the dotted line shows the strictest allowable positioning ability for each condition. It is found that this vessel has enough ability to keep her position under the design conditions.

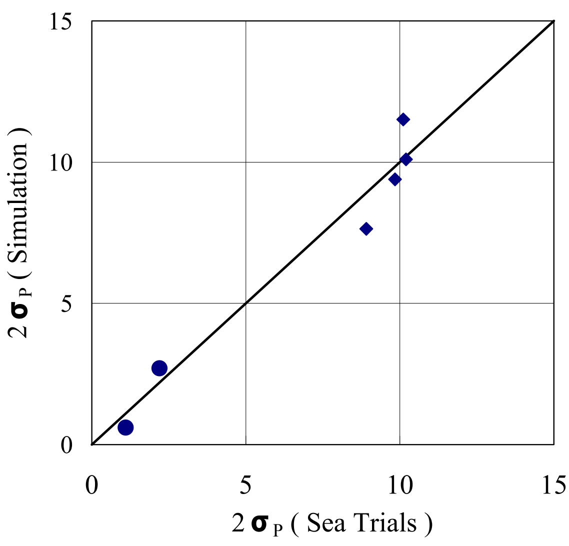


Fig.10 The Comparison of 2 σ_P (Recorded at Sea Trial and Simulation)

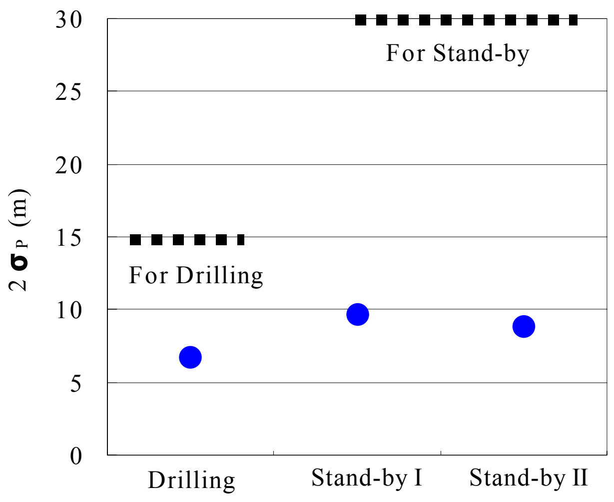


Fig.11 The Position Keeping Ability 2 σ_P under the Design Conditions (Simulation)

7. CONCLUSION

In this paper, the characteristics of the DPS installed in CHIKYU were shown as the system configurations and controlling functions, designed optimizing her operations.

Depending on the results of sea trials and numerical simulations, it was confirmed that this vessel has enough position keeping ability and redundancy to control her motion under rough external disturbances as the design conditions.