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Kinematics Characteristics Analysis of the Naval Ship Survival Training Simulation System in Longitudinal Shake Case of the Anti-Sinking Chamber

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***Abstractt*—*During operations at sea and ocean, the case of ships encountering calm sea conditions is almost non-existent. The impact of waves and wind causes changes in the ship's posture and acceleration in many different directions, especially vertical acceleration. These are the main factors causing seasickness in the human body and many other problems affecting the health and performance of crew members. Moreover, in emergency situations such as extreme weather conditions (big waves, strong winds, ship flooding, etc.), only a part of the crew members are strong enough to resist, while others are affected to varying degrees. Therefore, the research and manufacture of a practical training system simulating the operating state of ships with the ability to create vibrations such as big waves and strong winds for ships in general and anti-sinking chambers in particular is very necessary. This paper focuses on studying and analyzing the kinematics characteristics of the Naval Ship Survival Training Simulation System (NSSTSS) in the case of longitudinal shake of the anti-sinking chamber on the ship. Based on the analysis of the motion state and the designed system structures, a mathematical model of the system is established. Geometric and analytical analyses methods based on mechanical theory allow determining the relationship between the kinematics characteristic parameters of the system. With the piston-cylinder active drive system, the kinematics motion characteristics of each part are determined including their position, velocity and acceleration. Accordingly, the inverse kinematics problem is considered and analyzed on the basis of actual system parameters. With the requirement that the longitudinal vibration does not exceed 2 degrees in both directions according to real-time constraints, the required displacement, velocity and acceleration values of the piston in the cylinder are specifically determined. The research results serve as a basis for analyzing the system's motion capability, accurately controlling the positions of interest, and contributing to completing the problem of describing the overall motion state of the entire system.*

***Keywords*—*Naval ship, anti-sinking chamber, longitudinal shake, kinematics analysis*

I. INTRODUCTION

Currently, maritime is an extremely important industry in the world and accounts for a large proportion of activities in cargo and military transport. All incidents on ships can lead to unsafe risks and make rescue work at sea very difficult [1], [2]. When a ship has problems while moving at sea or in the ocean such as fire, flooding with a high risk of sinking or the possibility of capsizing due to large waves, the crew must take emergency measures to protect the safety of the ship. Timely command and action to control the incident will directly affect that safety. The NSSTSS is one of the effective solutions to train crew members on how to prevent ships from sinking when encountering major incidents. Through practical exercises trained on this simulation system, the basic operations of ship damage control, organization and command of ship damage control can be trained and have great effect in real situations at sea [3]. A ship fire training simulation system was developed to train maritime students [4]. Standard fire fighting procedures were applied and combined with multi-sensory interaction techniques between humans and computers in three-dimensional space. The research results have determined the realism of behavior and can be effectively applied in practice. The relationship between hydrodynamic factors and the volume of a sunken ship is studied and presented specifically in [5]. The research results allow for accurate assessment of the sinking of a ship in an incident with measurable input values. These results are of great significance in real-time ship navigation and provide the basis for building simulation systems and training close to reality.

On the other hand, navies of all countries attach great importance to training in the fight to protect the life of ships, considering it a regular task when ships are anchored at ports as well as performing tasks at sea. They have organized and implemented this training content in a relatively systematic and professional manner with modern simulation training systems. Training courses are deployed from basic to advanced. The content of ship life protection training of these countries includes specific theoretical and practical training such as fire prevention, anti-sink training, and prevention and combat of mass destruction weapons. Training can be organized on ships or at shore-based training simulation centers with specially designed training plans and programs. The courses are suitable for each subject and each specific training stage. In Europe, the AutoShip project is implemented with the upgrading of a series of practical training simulation equipment to better support testing, operational training and operation [6]. In China, the China Coast Police Academy has applied the anti-submergence simulation system to train students for many years. Currently, with the strong development of computer technology and artificial intelligence, this system has been upgraded to a high level of modernity and is being used effectively [3]. The Myanmar Navy is equipped with 02 training simulation systems capable of creating different training environments such as fire, flooding, ship roll with horizontal and vertical roll angles of up to 20˚ [7]. The Singapore Navy is equipped with a modern anti-submergence simulation center, fully equipped with sensors and equipment to simulate many different anti-submergence scenarios. The system is integrated with 2 emergency controllers and many surveillance cameras to ensure the safety of sailors during the training process as well as provide data as a basis for evaluating results [7]. The Royal Navy is currently using the Phoenix anti-submergence training system - known as DRIU. This is a system that simulates a submerged ship swaying [8]. The Turkish company Meteksan Defense has developed and supplied the DCSIM Damage Control Simulator system to the Turkish Navy, the Royal Navy of Oman and the Republic of Korea Navy. The simulation system allows training of crews to practice fire fighting, anti-sinking with simulation exercises in realistic conditions: sound simulation, lighting effects, smoke generation [9]. The Indian Navy is using two training systems ‘Akshat’ and ‘Avinash’ designed and manufactured by Goa Shipyard Ltd. These systems have achieved many good results in the training of Indian Navy crews with the ability to roll 15˚, roll 20˚ along with a submerged load of up to 75 tons [10].

Based on practical needs, the application of technical advances in automatic control and automation mechanics to the research and design of a training center for practical combat to protect the vitality of surface ships with the ability to create vibrations for the anti-sinking practice chamber is very necessary. This issue meets the needs of training work well, ready to meet the requirements in actual operations at sea. Accordingly, this paper focuses on analyzing the kinematics characteristics of a motion part in many vibration-generating movements parts for the NSSTSS system. The research content is focused on two main sections. Section 2.1 presents the problem of modeling the dynamics of the system under consideration on the basis of mechanical theory and geometric analysis. The relationship between the kinematics quantities characterizing the longitudinal shake motion is solved. Next, Section 2.2 shows the numerical simulation results of the kinematics parameters values with specific input data and closely related to reality. Finally, some results are evaluated and shown to have potential applications in future problems aiming at perfecting the entire NSSTSS system.

II. METHODS AND MATERIALS

2.1. Modeling of NSSTSS system under longitudinal shake

The NSSTSS is designed to create shaking movements of the anti-sinking chamber in the longitudinal and transverse directions to simulate large wave situations that often occur on seagoing vessels. The shaking movements of the anti-sinking chamber are created by cylinder-piston transmission pairs in the corresponding directions through the cross-shaped block. However, in this study, only shaking movements along the length of the anti-sinking chamber are considered. The basic structure of the system is described in Fig.1 and Fig. 2. The clockwise shaking state is described in Fig. 3 and Fig. 4.

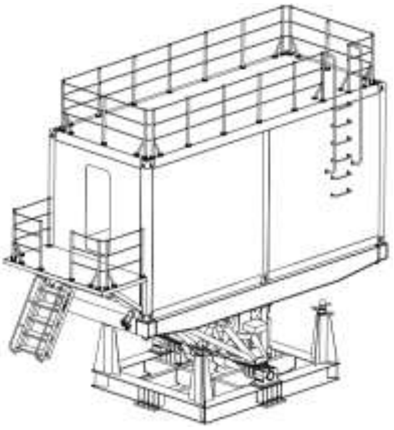

Fig. 1. Overall model of the system NSSTSS

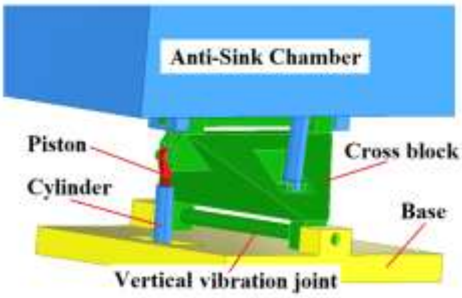

Fig. 2. General structure of the system

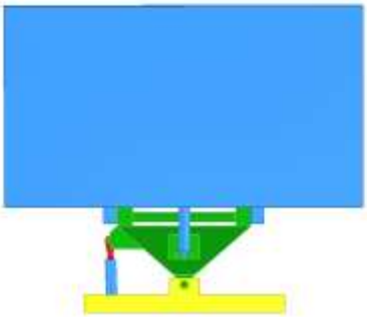

Fig. 3. Initial equilibrium state of the system

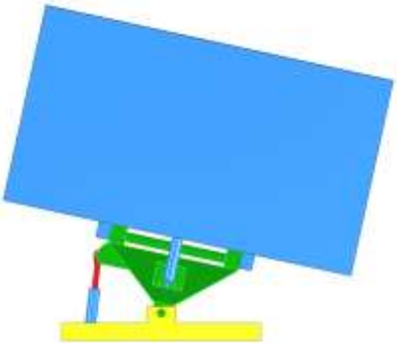

Fig. 4. Clockwise longitudinal shaking system

With piston-cylinder drive, the motion system has 1 degree of freedom and is mathematically modeled as shown in Fig. 5.

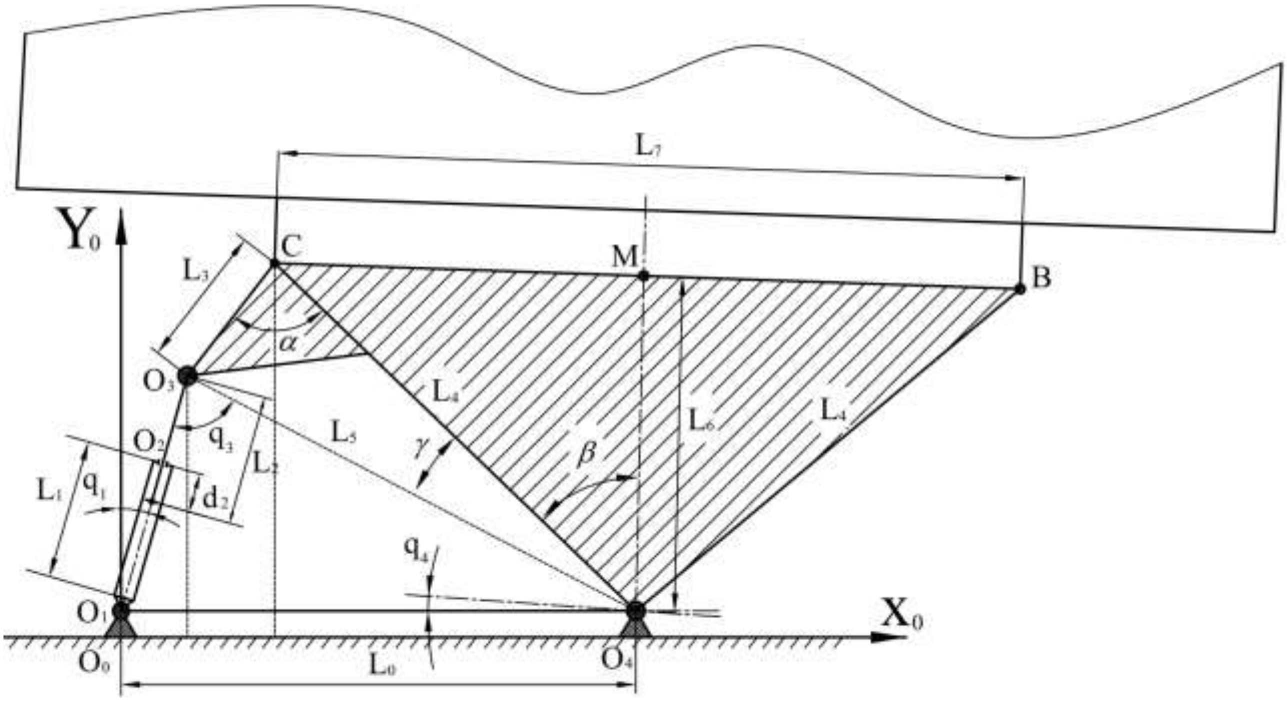

Fig. 5. System kinematics model

In which, the fixed coordinate system is $(OXY)_0$ and $O_0 \equiv O_1$. Length of O_0O_4 is L_0. The cylinder length is L_1, The piston length is L_2, length of CO_3 is L_3, length of CO_4 and BO_4 is L_4. Angles α, β and γ are fixed. The piston travel distance is represented by the variable d_2. Quantities q_1, q_3 and q_4 are the corresponding hinge angles at O_1, O_3 and O_4. These quantities change depending on the change in value of d_2. Consider the coordinates of the point O_3 following to fixed coordinate system $(OXY)_0$ with branch O_1O_3:

$$\begin{cases} x_{03} = (L_1 + L_2 - d_2)\sin q_1 \\ y_{03} = (L_1 + L_2 - d_2)\cos q_1 \end{cases} \tag{1}$$

Consider the coordinates of the point O_3 following to fixed coordinate system $(OXY)_0$ with branch $O_1O_4O_3$:

$$\begin{cases} x_{03} = L_0 - L_5 \sin(\gamma + \beta - q_4) \\ y_{03} = L_5 \cos(\gamma + \beta - q_4) \end{cases} \tag{2}$$

From Eq (1) and Eq (2), the relationship between the kinematic parameters is considered as follows

$$\begin{cases} (L_1 + L_2 - d_2)\sin q_1 = L_0 - L_5 \sin(\gamma + \beta - q_4) \\ (L_1 + L_2 - d_2)\cos q_1 = L_5 \cos(\gamma + \beta - q_4) \end{cases} \tag{3}$$

While,

$$L_5 = \sqrt{L_3^2 + L_4^2 - 2L_3L_4\cos\alpha} \tag{4}$$

Therefore,

$$\tan q_1 = \frac{L_0 - L_5 \sin(\gamma + \beta - q_4)}{L_5 \cos(\gamma + \beta - q_4)} \tag{5}$$

Eq (5) shows the relationship between q_1 and q_4 with other geometric size constraints. Furthermore, the relationship between the angles q_1, q_3 and q_4 are determined as follows

$$q_3 = q_1 + \beta + \gamma - q_4 \tag{6}$$

On the other hand, consider the triangle $O_1O_4O_3$ to determine the relationship between d_2 and q_4 as follows

$$O_1O_3{}^2 = O_1O_4{}^2 + O_4O_3{}^2 - 2(O_1O_4)(O_4O_3)\cos\left[\frac{\pi}{2} - (\gamma + \beta) + q_4\right] \tag{7}$$

Therefore,

$$(L_1 + L_2 - d_2)^2 = L_0^2 + L_5^2 - 2L_0L_5 \sin(\gamma + \beta - q_4) \tag{8}$$

And,

$$d_2 = L_1 + L_2 - \sqrt{L_0^2 + L_5^2 - 2L_0L_5 \sin(\gamma + \beta - q_4)} \tag{9}$$

From Eq (9), the velocity relationship between the translational motion of the cylinder and the shaking motion of the NSSTSS system is completely determined as follows

$$\dot{d}_2 = -\frac{L_0L_5\dot{q}_4 \cos(\gamma + \beta - q_4)}{\sqrt{L_0^2 + L_5^2 - 2L_0L_5 \sin(\gamma + \beta - q_4)}} \tag{10}$$

Similarly, the velocity relationship between angles $\dot{q}_1, \dot{q}_3$ and $\dot{q}_4$ can be determined based on Eq (5) and Eq (6).

Based on the analysis of the relationships between the quantities obtained above, the kinematics characteristics of the system including the position, velocity, acceleration of representative joints can be accurately determined. For example, given the value $q_4 \in \left[A_{\min}, A_{\max}\right]$, values of d_2, q_1 and q_3 can be determined based on Eq (9), Eq (5) and Eq (6). Assume that the value change law of q_4 is described as follows

$$q_4 = A\cos(\omega t + \varphi) \qquad (11)$$

In which, the shaking amplitude of q_4 is $A = \left[A_{\min}, A_{\max}\right]$. Angular velocity is $\omega = \frac{2\pi}{T}(rad/s)$ and the initial phase angle is $\varphi(rad)$. The shaking time is $t(s)$. The period of shaking is $T(s)$. Assume at initial time ($t = 0$), system in equilibrium ($q_4 = 0$), then $\cos\varphi = 0$ or $\varphi = \pm\frac{\pi}{2}$. At the time $t = \frac{T}{4}(s)$ so $q_4 = A_{\max}$ and assuming the system is tilted clockwise so $\varphi = -\frac{\pi}{2}$. The expression of q_4 has the following form

$$q_4 = A_{\max}\cos\left(\frac{2\pi}{T}t - \frac{\pi}{2}\right)(rad) \qquad (12)$$

The corresponding angular velocity achieved

$$\dot{q}_4 = -\frac{2\pi}{T}A_{\max}\sin\left(\frac{2\pi}{T}t - \frac{\pi}{2}\right)(rad/s) \qquad (13)$$

And the angular acceleration is calculated as follows

$$\ddot{q}_4 = -\left(\frac{2\pi}{T}\right)^2 A_{\max}\cos\left(\frac{2\pi}{T}t - \frac{\pi}{2}\right)(rad/s^2) \qquad (14)$$

The position, velocity and acceleration can calculated corresponding to other quantities including d_2, q_1 and q_3 from Eq (9), Eq (5) and Eq (6).

2.2. Longitudinal shaking numerical simulation of NSSTSS

Based on the working requirements of the system, the cylinder-piston assembly acts as a leading assembly with the variable value d_2 changing. Accordingly, the angles q_1, q_3 and q_4 as well as the position of the system will change. In this study, the inverse kinematics problem of the system is considered to be solved. The input of the problem is the system's shaking angle q_4 that needs to be achieved within the allowed time, then it is necessary to determine the motion law of the piston in the cylinder corresponding to the value of variable d_2. Consider the geometrical parameters of the system as in Tab. 1 and the input law of q_4 with $A = \left[A_{\min}, A_{\max}\right] = \left[-\frac{\pi}{90}, \frac{\pi}{90}\right]$, $T = 12(s)$. The above values describe that the system will shaking periodically with an amplitude of 2 (degrees) in both directions, the time to complete a cycle is 12 (s). The angular value and angular velocity of q_4 are determined as follows

$$\begin{aligned} q_4 &= \frac{\pi}{90}\cos\left(\frac{\pi}{6}t - \frac{\pi}{2}\right)(rad); \\ \dot{q}_4 &= -\frac{\pi}{90}.\frac{\pi}{6}\sin\left(\frac{\pi}{6}t - \frac{\pi}{2}\right)(rad/s) \end{aligned} \qquad (15)$$

TABLE I. Geometric parameters of the system

Parameters	Values
L_1; L_2; L_3 (m)	0.755; 0.72; 0.28
L_4; L_6; L_7 (m)	1.576; 1.568; 2.269
α ; β ; γ (degree)	96^0; 24.5^0; 10^0
L_5 (m)	1.629

Fig. 6 shows the input law of rotation angle and angular velocity of q_4 with a total operating time of 3 cycles corresponding to 36 (s).

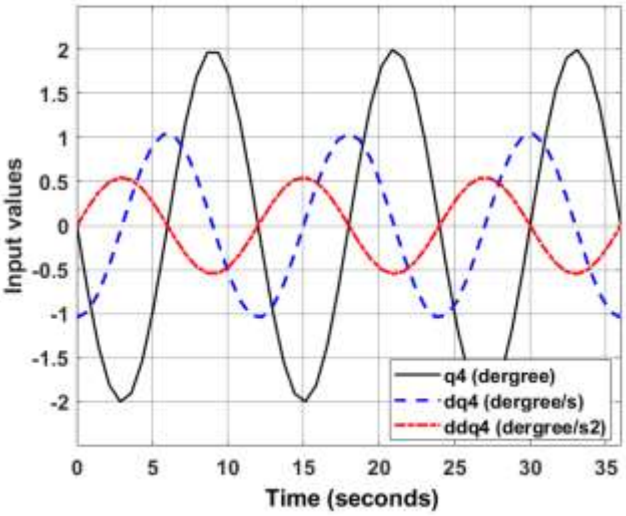

Fig. 6. Input parameters of the inverse kinematics problem

Tab. 2 presents the limiting kinematics values of the shaking angle q_4 corresponding to the desired longitudinal motion of the anti-sinking chamber on a ship.

TABLE II. Kinematics parameters limit values of anti-sinking chamber

Parameters (units)	Min. Value	Max. value
q_4 (degree)	-2	2
$\dot{q}_4$ (degree/s)	-1.05	1.05
$\ddot{q}_4$ (degree/s^2)	-0.55	0.55

Fig. 7, Fig.8 and Fig.9 show the position, velocity and acceleration values of the piston in the cylinder. Accordingly, from the initial equilibrium position (Fig. 3), to allow the anti-sinking chamber to swing back and forth with an amplitude of 2 (degrees), the piston moves back and forth with a value in the range of (-41.8; 41.8) (mm). The corresponding velocity and acceleration are in the range of (-22.1, 22.1) (m/s) and (-11.3, 11.3) (m/s^2). These values are actually extremely important to control the problem of selecting structures, selecting equipment and the problem of control.

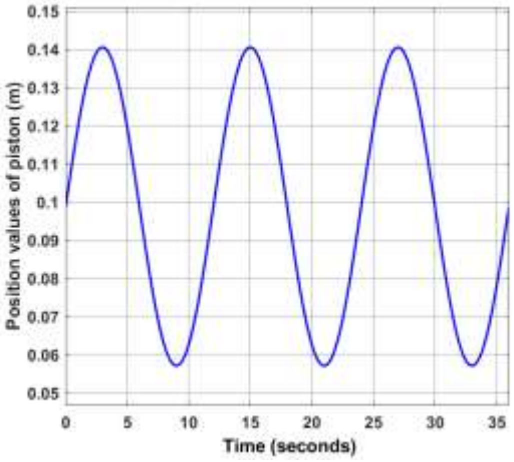

Fig. 7. Position value of piston movement in cylinder

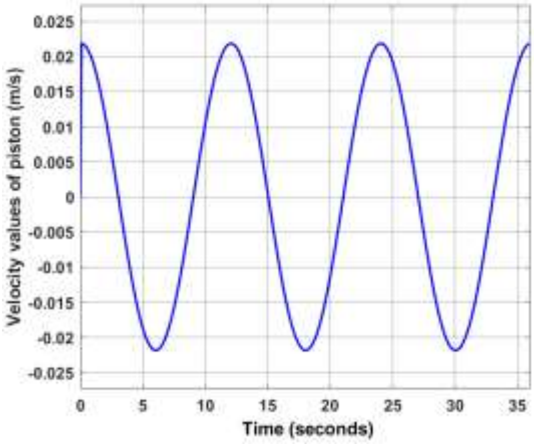

Fig. 8. Velocity value of piston

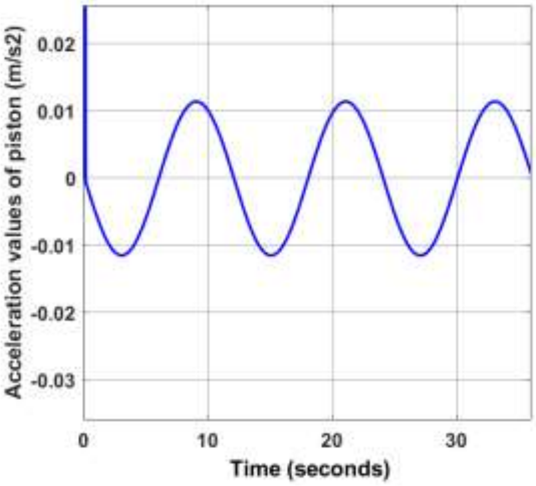

Fig. 9. Acceleration value of piston

The angular, angular velocity and angular acceleration values of q_1 are shown in Fig. 10, Fig.11 and Fig.12.

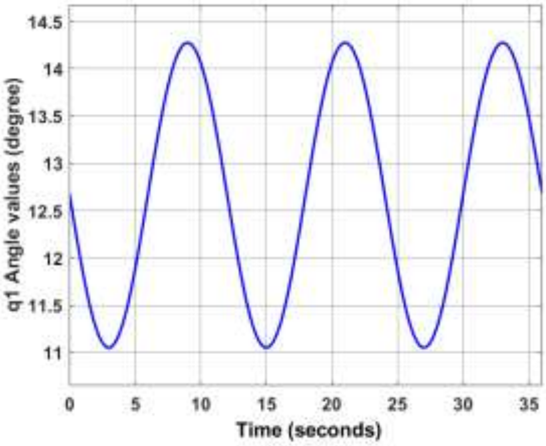

Fig. 10. Angle value of q_1

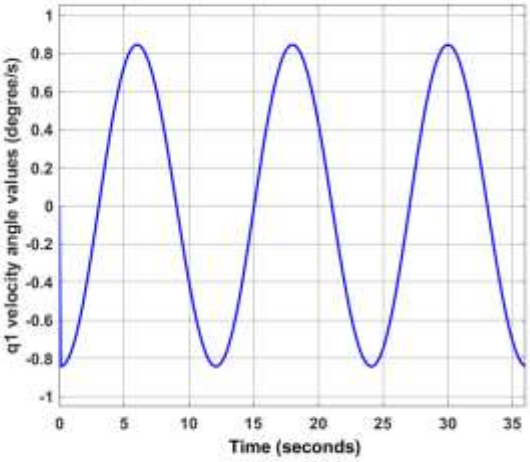

Fig. 11. Angular velocity value of q_1

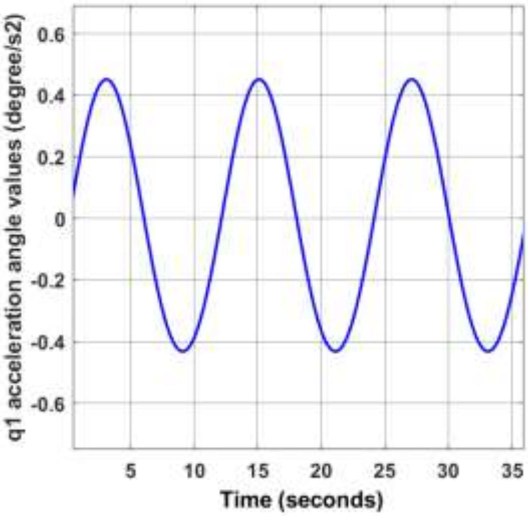

Fig. 12. Angular acceleration value of q_1

In terms of structure, in fact, joint q_1 is a ball joint to respond to the horizontal sway motion. However, this study only considers the vertical sway motion, so joint q_1 can be considered as a hinge joint. With the shaking amplitude of joint q_4 in the range (-2; 2) (degree), the rotation angle of joint q_1 changes in the range (-1.59, 1.59) (degree) around the equilibrium position. Correspondingly, the angular velocity and angular acceleration of q_1 change in the range (-0.84, 0.84) (degree/s) and (-0.45, 0.45) (degree/s^2). The above analysis results show that joint q_1 moves with a very small amplitude.

The angular, angular velocity and angular acceleration values of q_3 are shown in Fig. 13, Fig.14 and Fig.15.

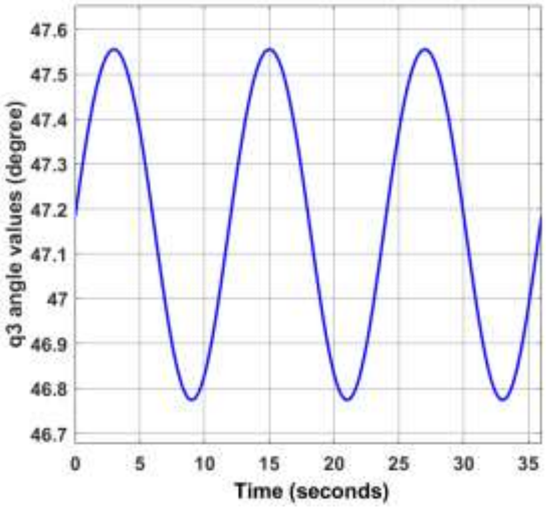

Fig. 13. Angle value of q_3

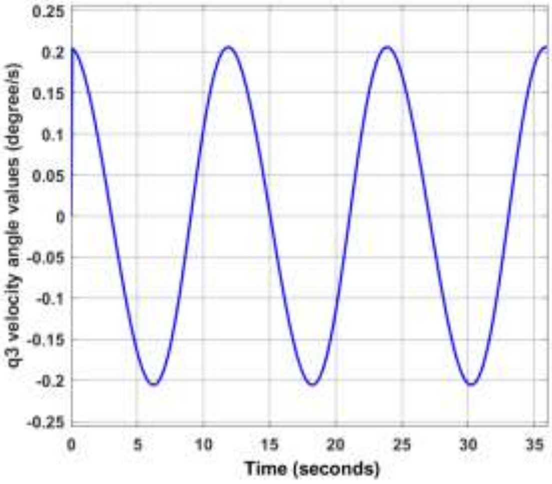

Fig. 14. Angular velocity value of q_3

Similar to the variation of parameters d_2, q_1, and q_3 also has changes. The point to note here is that joint q_3 is a hinge joint attached between the top of the piston and the cross block. In terms of structure, the position, velocity and acceleration of q_3 will characterize both the cross block and the anti-sinking chamber in the longitudinal direction. In other words, the value of q_3 will be equal to the angle q_4. However, because of the joint q_1 change, the value of q_3 is no longer equal to q_4. Actual calculations show that the angular value of q_3 changes in the range (-0.38, 0.38) (degree), the angular velocity change range is (-0.84, 0.84) (degree/s) and the angular acceleration value is in the range (-0.38, 0.38) (degree/s^2). It is easy to see that the values of the joint q_3 kinematics characteristic parameters are smaller than those of joint q_1.

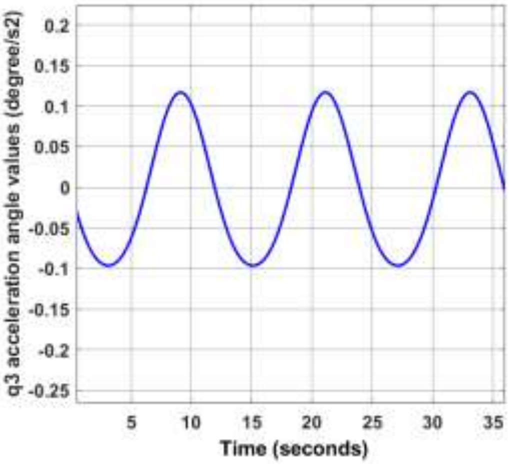

Fig. 15. Angular acceleration value of q_3

Fig. 16 and Fig. 17 show the position change in the two directions OX and OY of O_3 point in the fixed coordinate system.

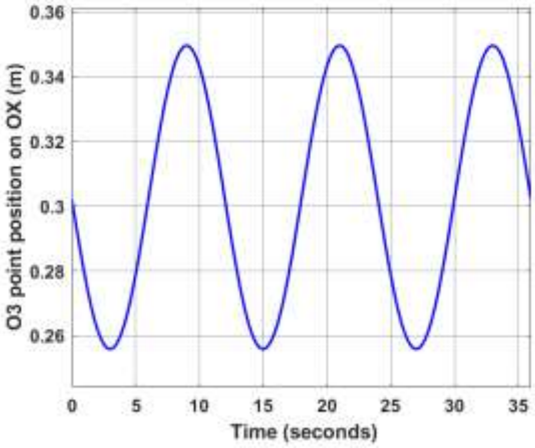

Fig. 16. O_3 position on OX

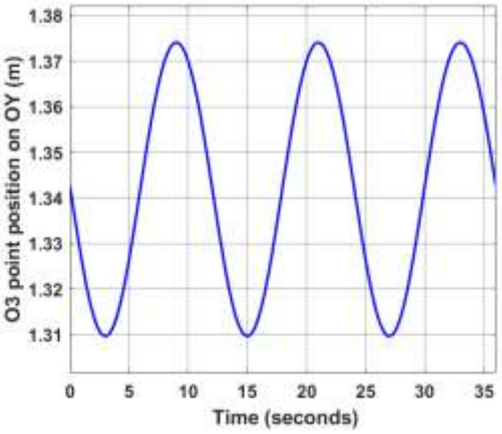

Fig. 17. O_3 position on OY

Accordingly, the amplitude of shaking of this point changes in the range OX of (-47.4, 47.4) (mm) and in the range OY of (-31.4, 31.4) (mm). This result shows that the O_3 position in the vertical plane does not change too much.

To facilitate the monitoring of the dynamic characteristics of joints and special points, Tab. 3 briefly describes the minimum and maximum limits of the parameters during system operation corresponding to the input requirements as shown in Fig. 6 and Tab. 2.

TABLE III. Limit values of kinematics parameters

Kinematics parameters	**Limit value compared to initial**		**Original position**
	Min. value	**Max. value**	
d_2 (mm)	-41.8	41.8	98.7
$\dot{d}_2$ (mm/s)	-22.1	22.1	0
$\ddot{d}_2$ (mm/s^2)	-11.3	11.3	0
q_1 (degree)	-1.59	1.59	12.7
$\dot{q}_1$ (degree/s)	-0.84	0.84	0
$\ddot{q}_1$ (degree /s^2)	-0.45	0.45	0
q_3 (degree)	-0.38	0.38	47.2
$\dot{q}_3$ (degree /s)	-0.21	0.21	0
$\ddot{q}_3$ (degree /s^2)	-0.1	0.1	0
x_{03} (mm)	-47.4	47.4	302.2
y_{03} (mm)	-31.4	31.4	1342.7

Fig. 18 and Fig.19 show the system with its complete structure as designed and in practice.

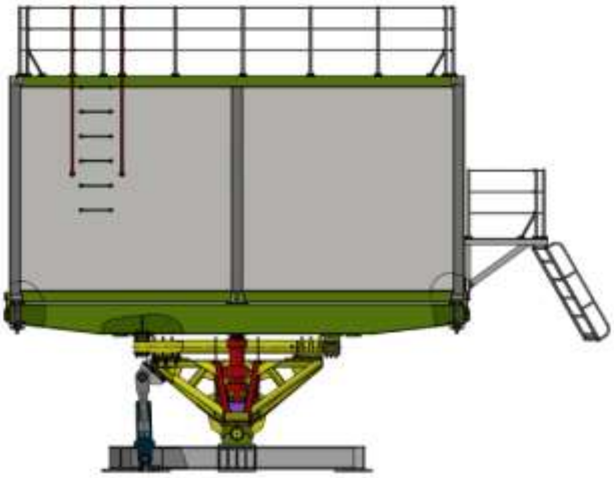

Fig. 18. The simulated system design

III. CONCLUSIONS

As presented above, NSSTSS is designed and manufactured to serve the training process of simulating the state of ships operating in conditions of big waves and strong winds. This system is extremely suitable for use in military and civilian training for those who plan to go to sea for a long time. With the perspective of considering the system as a mechanical system, the kinmatics modeling and calculation of kinematics characteristics are completely suitable and feasible. It is easy to see that, based on the geometric method and mechanical theory, the relationship between the quantities characterizing the motion of the system has been determined. Accordingly, with the given input motion requirements, the necessary driving parameters are calculated and their limit values are controlled. These research results are very important in providing advice on the selection of driving mechanisms, structural design in practice and effectively solving the problem of dynamics and control.

Fig. 19. The system is fabricated in reality

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