13th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2009, Hammamet, Tunisia, 16-21 October, 2009

OPTIMIZATION OF SHIP STABILITY DURING CHANGABLE REGIME OF SAILING

Simona Cipirita
Joško Dvornik
Zlatan Kulenović
Srđan Dvornik
University of Split
Faculty of Maritime Studies
Zrinsko-Frankopanska 38, 21000 Split
Croatia

ABSTRACT
The paper deals with dynamic analysis of automatic ship steering gear systems utilising complex controls that function according to the principle of proportional, integral and derivation regulators. The analysis involves a system dynamic simulation modelling methodology as one of the most suitable and effective means of dynamic modelling of complex non-linear, natural, organisational and technical systems.
The paper discusses system dynamics simulation models being used in qualitative (mental-verbal, structural) and quantitative (mathematical and computer) simulation models on ships equipped with trailing steering systems and PID regulator.
Authors suggest using the presented models for designing and constructing new steering systems, for diagnosing existing constructions and for education in Universities.
The results presented in the paper have been derived from the scientific research project "New Technologies in Diagnosis and Control of Marine Propulsion Systems" supported by the Ministry of Science, Education and Sport of the Republic of Croatia.
Keywords: System Dynamics, continuous and discrete simulation, ship direction, heuristic Optimization

1. INTRODUCTION
Integrated transport ships as means of transport have an important place both in transporting cargo and passengers. The ship has to have the ability to follow a given trajectory and to change its course according to given regulations.
The regime of keeping the ship on its given course to ensure its stability, as results of analysis show, requires frequent turning of the rudder blade. Manual steering, needed for 4^o to 6^o degree turns, turns the steering gear engine on and off app. 400 in an hour, while automatic steering raises this up to 1500.
The most important regime of navigation is straight linear movement of the ships along its course. This is achieved by steering gear which compensates for external disturbances and influences which can cause departures from the given course. Automatic steering gear systems are used for automatic ship control. They can be stabilizational, trailing or programmed steering systems.
To steer the ship along its given course requires acquaintance with the nature and the power of forces affecting the ship, as well as the ship's manoeuvrability.

This paper deals with trailing systems of rudder control with PID-regulator. A mathematical model of the ship is given, in the form of a system of three differential equations, a model of a trailing system of ship rudder control, and a mathematical model of PID-regulator.
The third part discusses a dynamics structural model of automatic ship control with graphic displays of direct and indirect influences that each variable and parameter has on a particular element of the system.
The fourth part deals with a computer simulation model, where various disturbances affecting the ship's course are planned and anticipated, analysing their effect on ship direction, position of rudder and their frequency.
System dynamics is a research methodology for analysis modelling, simulating and optimising complex dynamic systems. This paper has utilised the system dynamics modelling as a relatively new scientific methodology applicable in analysis of technical, natural and social systems.

2. SYSTEM DYNAMICS SIMULATION MODELING

The dynamic mathematical ship navigation model gives a principle according to which ship parameters change during navigation on a horizontal plane and under influence of various disturbances.

$$\frac{d\psi}{dt} = \omega \tag{1}$$

$$\frac{d\beta}{dt} = f - k_1\alpha - k_2\beta - k_3\beta\left|\beta\right| - k_7\omega \tag{2}$$

$$\frac{d\omega}{dt} = m - k_4\alpha - k_5\beta - k_6\omega \tag{3}$$

Where are:

ψ - relative value for the change of the course angle;
α - relative value for the change in the rudder angle;
m - coefficient of disturbance depending on the influence of the wind, sea currents and waves, length of the ship, the moment of inertia of ship, ship speed and added water mass which is being moved by ship movement;
ω - relative value for the change of angular velocity;
β - relative value of angle of roll;
f - coefficient of disturbance depending on the forces on the wind, waves, currents, length of the ship, water mass being moved by ship movement and ship speed influences;
k_1-k_7 - corresponding coefficient of reinforcements.

In accordance with system dynamics quantitative or mathematical model (equations from 1-3) it would be possible to work out the structural and mental-verbal system dynamics simulation model of the vessel's navigation process.

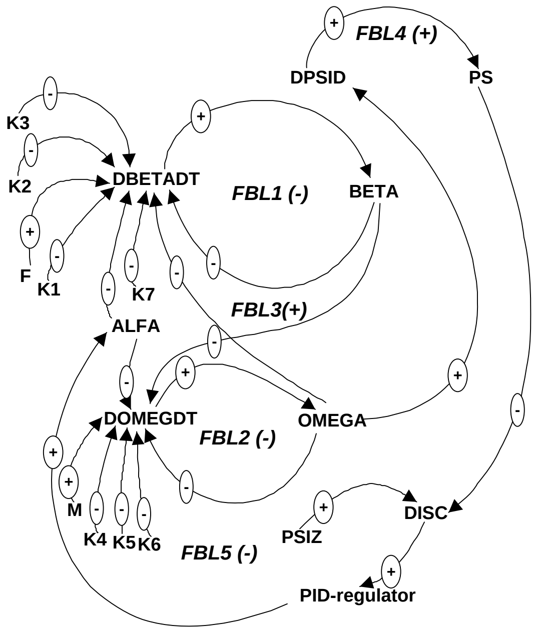

Figure 1. System Dynamics Structural modelof the vessel's navigation process

3. SIMULATION SCENARIO

The simulation of automatic navigation of a ship has the following scenario:
The horizontal axis represents the time variable.
The load on the ship under automatic navigation is as follows:

- In the 10th second, it changes 10% according to the bounce function,
- In the 20th second, it changes 20% according to the bounce function in the opposite direction,
- In the 25th second, the load decreases 10% according to the rebounce function,
- In the 60th second, an impulse load functions with 20%,
- In the 80th second there is a deviation in accordance with the sinus function with the amplitude of 10%.

Simulation results

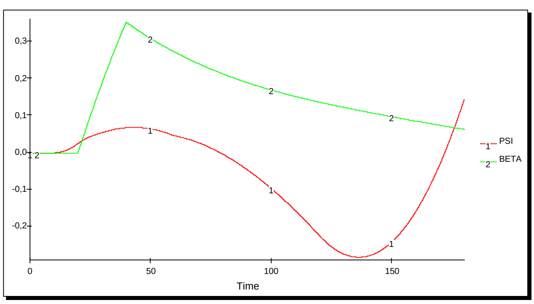

Figure 2. Graphic results of simulation

4. CONCLUSION

The application of System Dynamics Simulation Modeling Approach of the complex marine dynamic processes revealed the following facts:

1. The System Dynamics Modeling Approach is a very suitable software education tool for marine students and engineers.
2. System Dynamics Computer Simulation Models of marine systems or processes are very effective and successfully implemented in simulation and training courses as part of the marine education process.

5. REFERENCES

[1] Forrester, J.W.: Principles of Systems , MIT Press, Cambridge Massachusetts, USA, 1973/1971.,

[2] Richardson, G. and Aleksander, L.: Introduction to System Dymanics Modelling with Dynamo, MIT Press, Cambridge, USA,1981.,

[3] Milić, L., Batoš,V., Milić,I.: System dynamics comparative modelling of the "Woodward" and digital-electronics PID-Regulator, Proceedings of the VII Congress of IMAM, Dubrovnik 1995.,

[4] Freidzon, I. R.: Sudovie avtomatizirovannije elektroprivodi i sistemi, Sudostroenije, Leningrad, 1988.,

[5] DiStefano, J.J., Stubberud, A.R., Williams, I.J.: Theory and problems of feedback and control systems, McGraw-Hill book company, New York, 1987.,

[6] Dvornik, J., Munitić, A., Dvornik, S.: Modeling of Ship Stability During Changable Regime of Sailing, 6th International Conference on Mathematical Modelling, MATHMOD VIENNA 09, Technical University Vienna/Austria, 2009.