MODELING OF SHIP STABILITY DURING CHANGABLE REGIME OF SAILING

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Abstract. The paper deals with dynamic analysis of automatic ship steering gear systems utilizing complex controls that function according to the principle of proportional, integral and derivation regulators. The analysis involves a system dynamic simulation modeling methodology as one of the most suitable and effective means of dynamic modeling of complex non-linear, natural, organizational 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 Sports of the Republic of Croatia.*

1 Introduction

Simulation Modeling, together with System Dynamics and intensive use of modern digital computer, which mean massive application, today very inexpensive and in the same time very powerful personal computer (PC-a), is one of the most suitable and effective scientific way for investigation of the dynamics behavior of non-linear and complex: natural, technical and organization systems. The methodology of System Dynamics (Prof dr. J. Forrester – MIT), e.g. relatively new scientific discipline, in former educational and designer practice showed its efficiency in practice as very suitable means for solving the problems of management, of behavior, of sensibility, of flexibility and sensibility of behavior dynamics of different systems and processes. The System Dynamics Modeling is in essence special, i.e. "holistic" approach to the simulation of the dynamics behavior of natural, technical and organization systems. Systems dynamic comprise qualitative and quantitative simulation modeling, and the concept of optimization of dynamic systems and processes is based on so call "heuristic" procedure. Meaning that on the method of manual and iterative procedure, which is automatized with the help of fast digital computer, named "heuristic optimization" (retry and error!). This simulation model is only one from the large number of made and educationally and practically used simulation models for education and training of young students – mariner, who use so call "white box" philosophy of investigation of complex systems, as distinguished from "black box" approach.

2 System dynamics simulation modeling

2.1 System dynamics simulation model of the vessel's automatic sea-going regulation

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 stabilization, 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 maneuverability.

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.

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

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

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

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.

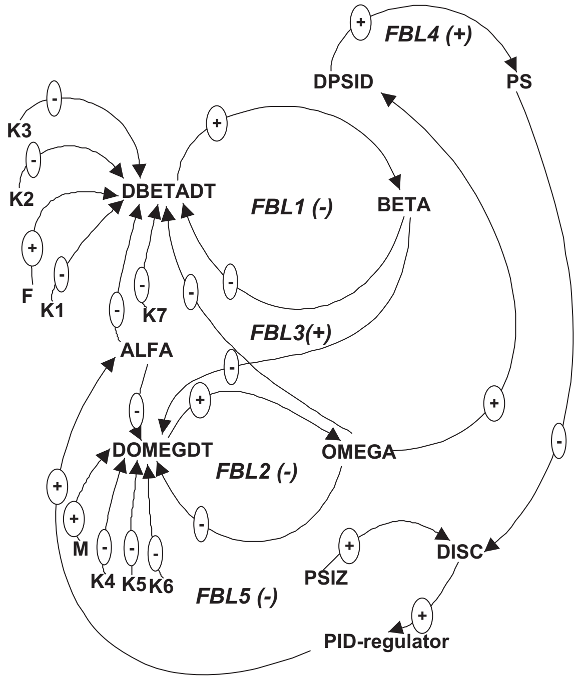

Figure 1. System Dynamics Structural model of the vessel's navigation process

It is possible to see that the structural model has a lot of the cause-consequences links (CCL), as well as four feedback loops (FBL).

The System Dynamics Mental-verbal model of the vessel's navigation system or process is:

“If the constants k_1-k_7 - coefficients of reinforcements grow, then the rate variable DBETADT-rate or speed of the relative value of angle of roll will drop. This means that the CCLs have a negative (-) dynamics character.”
Furthermore:
“If the coefficients F and M grow, then the rate variable DBETADT will grow also”. This means that both of the CCLs have a positive (+) dynamics character.”
On the same way, we could work out complete mental and verbal models of the all FBLs, but in the abreviated-simbolic way:

FBL1.(-):DBETADT (+) =>BETA (-)=>DBETADT;
FBL2.(-):DOMEGDT(+)=>OMEGA(-)=>DOMEGDT;
FBL3.(+):DOMEGDT(+)=>OMEGA(-)=>DBETADT(+)=>BETA(-) =>DOMEGDT;
FBL4.(+):DPSIDT(+)=>PSI(-)=>DISC(+)=>PID(+)=>ALFA(-)=> DOMEGDT(+)=>
OMEGA(+)=>DPSIDT;
FBL5.(-) : DBETADT(+)=>BETA()=>DOMEGDT(+)=>OMEGA(+)=>
DPSIDT(+)=>PSI(-) =>DISC(+)=>PID(+)=>ALFA(-)=>DBETADT

2.2 System dynamics simulation model of the vessel's rudder control

The task of the trailing system of automatic regulation is to change the regulated dimensions according to the changes of leading dimensions. In the analyzed example SSUBK consists of:

- a semi-conductor amplifier which amplifies the signal of the difference between the given and actual value of the rudder angle,
- a performing engine and reductor which, under the influence of the correct voltage, rotates the engine shaft and reductor,
- a lever transmission, which turns the circular movement of the shaft of the performing engine into steering movement of the distributor rod,
- a selsin sensor working in a transformer regime,
- elements of solid feedback; in a local feedback, the selesin sensor and reductor are used,
- elements of feedback of position of rudder sensor,
- member of feedback according to the ship's course, which is both a selsin giver and receiver,
- a hydraulic drive.

The following system dynamics mathematical model describes dynamic features of the given SSUBK elements:

$$U_{11} = U_{10} - K_{20} K_{22} \Theta_{12} - K_{23} K_{24} K_{25} \alpha_{12} \tag{4}$$

$$U_{12} = K_{21} U_{11} \tag{5}$$

$$U_{13} = f(U_{12}) \tag{6}$$

$$\frac{d\Theta_{11}}{dt} = K_{26} K_{27} U_{13} \tag{7}$$

$$\Theta_{12} = f(\Theta_{11}) \tag{8}$$

$$h_{11} = K_{28} \Theta_{12} \tag{9}$$

$$\frac{d\alpha_{11}}{dt} = K_{29} h_{11} \tag{10}$$

$$\alpha_{12} = f(\alpha_{11}) \tag{11}$$

Where are:

U_{10} - relative value of given voltage,
U_{11} - relative value of voltage at the exit from summator,
U_{12} -relative value of voltage at the exit from semi-conductor amplifier,
U_{13} - relative value of voltage which id in non-linear function,
Θ_{11}- relative value of the performing engine shaft's turning angle,
α_{11} - relative value of rudder turning angle,
h_{11} - relative value of the shift of handle that runs position of distributor piston,
K_{20-29} - coefficients of transmission of different mechanisms in SSUBK.

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

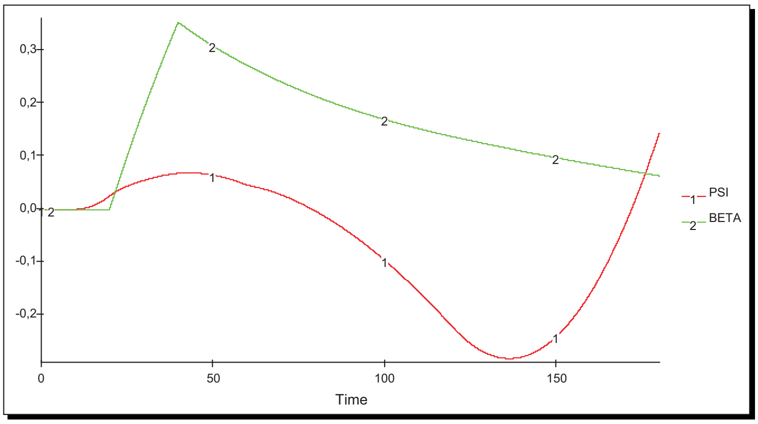

Figure 2. Graphic results of simulation

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.

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