APPLICATION OF SIMULATION MODELLING TO THE SHIP STEAM BOILER SYSTEM

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ABSTRACT
The purpose of this paper is to present the efficiency of the application of the system dynamics simulation modelling (System Dynamics Modelling – Jay Forrester – MIT) in investigating the behaviour dynamics of the ship steam boiler. The ship steam boiler is presented in POWERSIM simulation language through mental – verbal, structural and mathematical – computer models. In addition to the mathematical model for the marine steam boiler, we have as well presented the mathematical model for the feed water heater that is fitted in the system. These models serve as a basis for qualitative and quantitative simulation models for complex systems.
The results presented in the paper have been derived from the scientific research project „SHIPBOARD ENERGY SYSTEMS, ALTERNATIVE FUEL OILS AND REDUCTION OF POLLUTANTS EMISION“ supported by the Ministry of Science, Education and Sports of the Republic of Croatia.

Keywords: ship steam boiler, simulation modelling, continuous and discrete simulation

1. SIMULATION MODELLING OF THE MARINE STEAM BOILER

1.1. Mathematical model for the marine steam boiler

The boiler may be considered as a homogenous device, a thermal accumulator, i.e. a homogenous thermal capacity. The equations of thermal balance of such a thermal accumulator (capacity) suggest determining the equation for the level of the water in the boiler, (Nalepin and Demeenko 1975).

System dynamics mathematical model for the marine steam boiler is defined by explicit form of differential equations, (Nalepin and Demeenko 1975):

Equation of the boiler dynamics for the steam pressure

$$\frac{d\varphi_K}{dt} = \frac{1}{T_{a1}} \cdot (\mu_G + a_1 \cdot \mu_V - a_2 \cdot \mu_P - a_3 \cdot \frac{d\mu_P}{dt} - k \cdot \varphi_K) \quad (1)$$

Equation of the boiler dynamics for the water level

$$\frac{d\varphi_Y}{dt} = \frac{1}{T_{a2}} \cdot (\mu_V - b_1 \cdot \varphi_K - b_2 \cdot \frac{d\varphi_K}{dt} - b_3 \cdot \mu_P - b_4 \cdot \frac{d\mu_P}{dt}) \quad (2)$$

Where the following denote:

φ_K - relative state of the steam pressure in the boiler,

φ_Y - relative state of the water level in the boiler,

T_{a1} - time constant of the steam boiler for the steam pressure [s],

T_{a2} - time constant of the steam boiler for the water level [s],

k - coefficient of self-regulation of the steam boiler,

μ_G - relative change of the position of the fuel valve,

μ_V - relative change of the valve of the feed water,

μ_P - relative change of the position of the steam discharge valve,

$\frac{d\varphi_K}{dt}$ - speed of the change of the relative increment of the boiler steam pressure,

$\frac{d\mu_P}{dt}$ - speed of the relative change of the position of the steam discharge valve,

$a_{1,2,3}$ - coefficients of the steam boiler for the steam pressure,

$b_{1,2,3,4}$ - coefficients of the steam boiler for the water level.

1.2. Mathematical model for the feed water heater in the marine steam boiler system

Equation of the feed water heater dynamics has been derived on the basis of thermal balance and has the following form:

$$T_{1X}\frac{DT_{X2}}{dt}+T_{X2}=T_{2X}\frac{DT_{X1}}{dt}+K_{1X}T_{X1}+K_{2X}T_{CX} \quad (3)$$

Where the following denote:

T_{1X} - time constant for the water medium,

$\frac{DT_{X2}}{dt}$ - speed of the relative change of the outlet water temperature,

T_{X2} - relative change of the outlet water temperature,

$\frac{DT_{X1}}{dt}$ - speed of the relative change of the inlet water temperature,

K_{1X} - transient coefficient of the water medium,

T_{X1} - relative change of the inlet water temperature,

K_{2X} - transient coefficient of the water medium,

T_{CX} - temperatures of the cooling surface wall of the water medium.

1.3. System dynamics structural model for the marine steam boiler

On the basis of the stated mental- verbal models (Dvornik and Tireli 2007), it is possible to produce structural diagrams of the marine steam boiler, as shown in Figures 1, 2 and 3.

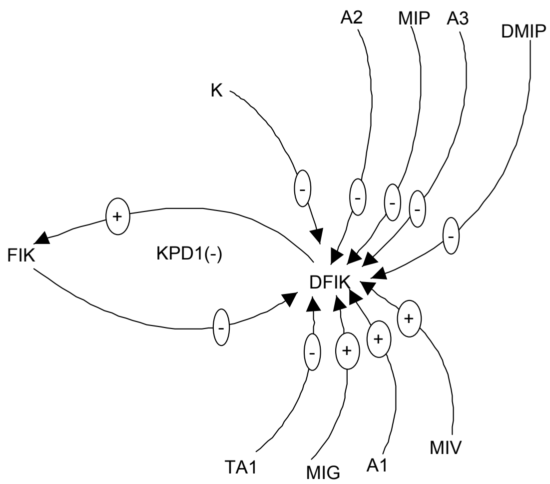

Figure 1: Structural Model for the Marine Steam Boiler – for Steam Pressure

In the observed system there is a feedback loop (KPD1).

KPD1(-):FIK=>(-)DFIK=>(+)DFIK=>(+)FIK; which has self-regulating dynamic character (-),
because the sum of negative signs is an odd number.

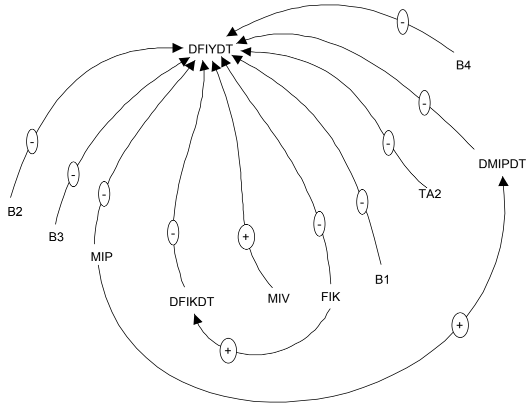

Figure 2: Structural Model for the Marine Steam Boiler – for the Water Level

In the observed system there is not a feedback loop KPD, because the dynamic process of the performance of the steam boiler with natural circulation for the water level does not have the self-regulation property.

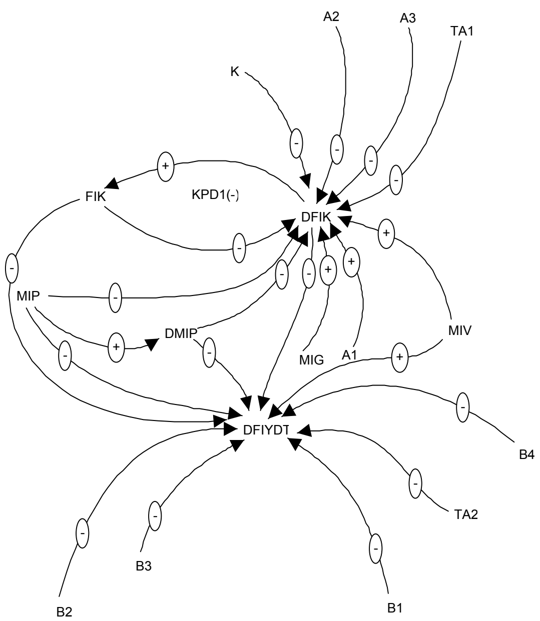

Figure 3: Global Structural Model for the Marine Steam Boiler

1.4. System dynamics structural model for the feed water heater in the marine steam boiler system

On the basis of the dynamics, i.e. stated mental - verbal model (Dvornik and Tireli 2007), it is possible to produce structural model for the feed water heater, as shown in Figure 4.

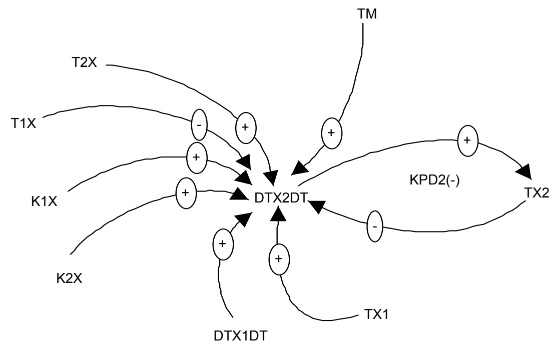

Figure 4: Structural Model for the Feed Water Heater

In the observed system there is a feedback loop (KPD2).

KPD2(-):TX2=>(-)DTX2DT=>(+)DTX2DT=>

(+)TX2; which has self-regulating dynamic character (-), because the sum of negative signs is an odd number.

1.5. System dynamics flowchart of the marine steam boiler

On the basis of the produced mental - verbal and structural models, the flowchart of the marine steam boiler in POWERSIM simulation language is produced (Byrknes 1993).

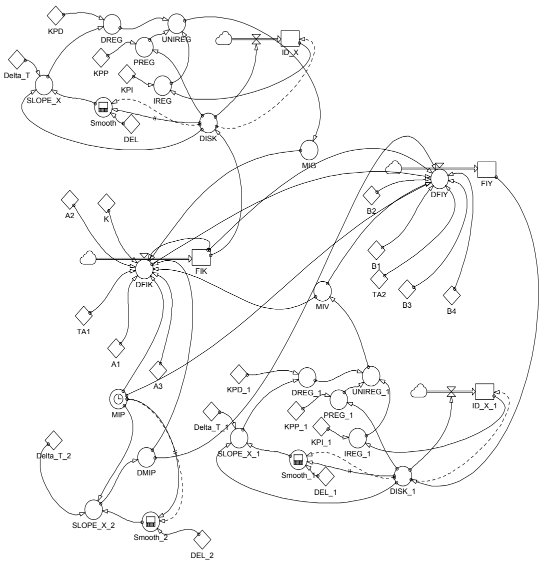

Figure 5: Global Flowchart of the Marine Steam Boiler with the built-in PID Governors

2. INVESTIGATING PERFORMANCE DYNAMICS OF THE MARINE STEAM BOILER IN LOAD CONDITIONS

After system dynamics qualitative and quantitative simulation models have been produced, in one of the simulation packages, most frequently DYNAMO (Richardson and Aleksander 1981) or POWERSIM (Byrknes 1993), all possible operating modes of the system will be simulated in a laboratory.

After an engineer, a designer or a student has conducted a sufficient number of experiments, or scenarios, and an insight has been obtained into the performance dynamics of the system using the method of heuristic optimisation, the optimisation of any parameters in the system may be performed, provided that the model is valid.

In the presented scenario the simulation model for the marine steam boiler for the steam pressure and the water level with two built-in PID governors will be presented.

1. Consumption of the steam is determined by the impulse function of 50-sec duration, which means from 200 – 250 sec, and MIP = 0, FIK = 0, FIY = 0.9999 at the initial TIME = 0.
2. Fuel supply MIG is determined as an outlet of PID-governor, at which inlet there is the discrepancy of the steam pressure (1-FIK) and correspondingly, the water supply MIV is outlet of the other PID-governor, to which the inlet is discrepancy (1- FIY).
3. Other parameters of the marine steam boiler equal nominal values.

Graphic results of the simulation:

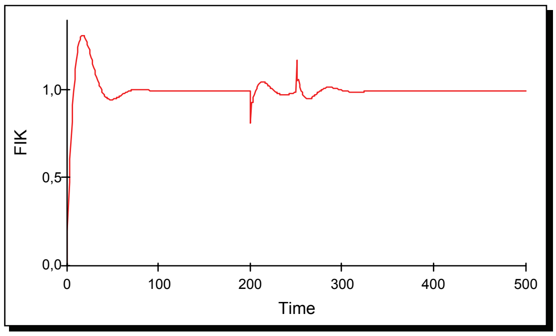

Figure 6: Relative State of the Steam Pressure in the Steam Boiler

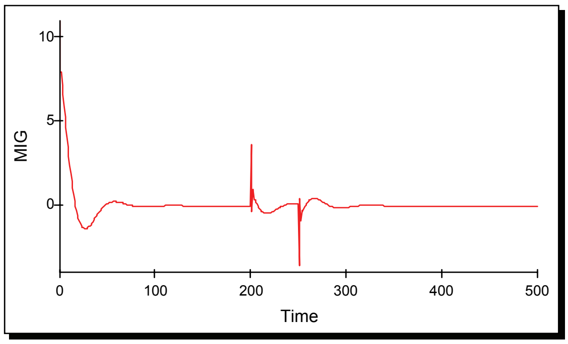

Figure 7: Relative Change of the Position of the Fuel Valve

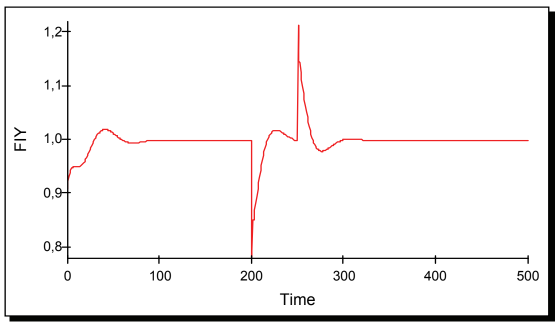

Figure 8: Relative State of the Water Level in the Steam Boiler

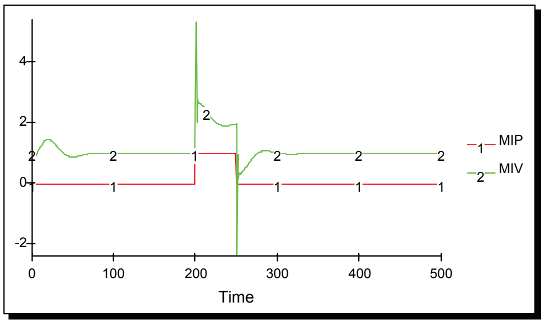

Figure 9. Relative Change of the Position of the Feed Water Valve and Relative Change of the Position of the Steam Discharge Valve

From the results of the simulation it may be observed that the model shows real performance dynamics and that by applying PID governors and adequate values of coefficients a better levelling and attenuation of the transition occurrence of the variables FIK and FIY will be achieved.

3. CONCLUSION

System dynamics is a scientific method that allows simulation of the most complex systems. The method used in the presented example demonstrates a high quality simulation of complex dynamic systems, and provides an opportunity to all interested students or engineers to apply the same method to modelling, optimising and simulating any scenario of the existing elements.

Furthermore, the users of this method of simulating continuous models in digital computers have an opportunity to acquire new information on dynamic systems performance. The method is also important because it does not only refer to computer modelling, but also clearly determines mental, structural and mathematical modelling of the elements of the system.

This brief presentation gives to an expert all the necessary data and the opportunity to collect information about the system using a fast and scientific method of investigation of a complex system.

Which means: Do not simulate the performance dynamics of complex systems using the method of the "black box", because the education and designing practice of complex systems has confirmed that it is much better to simulate using the research approach of the “white box,” i.e. System dynamics methodology.

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He was born in Rijeka in 1947. He completed undergraduate studies at Faculty of Engineering in Rijeka in 1970 and was awarded the BSc degree – marine engineer. He was awarded the master's degree at Faculty of Engineering in Ljubljana, Slovenia, in 1975 – MSc in technical sciences, the field of energetics. In 1978 he won the doctor's degree at Faculty of Engineering in Ljubljana, Slovenia – PhD in technical sciences. In 1970 he worked as a planner at Rade Končar factory in Rijeka. From 1970 to 1973 he was the Development and production manager at the factory of thermal installations TTU in Labin. From 1974 to 1991 he was the Plant manager of the thermo-electric power plant TE Plomin 1, as well as the Construction manager of the TE Plomin 2. Since 1992 he has been Vice-dean for business relations at Faculty of Maritime Studies in Rijeka. Since 2004 he has been Full professor in charge of courses in Failure diagnosis, Marine thermal turbines, Exploitation of marine steam boilers, Exploitation of marine thermal turbines, Fuels, lubricants and water, Optimisation of the ship's propulsion, and Thermal science.

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He was born in Split in 1966. He completed undergraduate studies at Faculty of Maritime Studies in Split in 1990 and was awarded the BSc degree – graduated engineer in Maritime transport, marine engineer. From 1990 to 2005 he sailed as an engineer officer on domestic and foreign merchant ships. He passed the exam for Chief engineer officer on a ship powered by the main propulsion machinery of 3,000 kW or more in 1995 in Split. Since 2005 he has been an assistant at the Department of marine engineering of Faculty of Maritime Studies in Split in the area of Technical sciences, the field of Traffic and transport technology. He is the author of more than 10 scientific papers in the area of System dynamics computer simulation modelling, dealing with various systems and processes.