SIMULATION MODELLING OF A MARINE TURBOGENERATOR

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ABSTRACT
Marine steam turbine at the load of synchronous generator is a complex non-linear system, which needs to be systematically investigated as a unit consisting of a number of subsystems and elements, which are linked by cause-effect feedback loops. In this paper the authors will present the efficient application of scientific methods for the research of complex dynamic systems called qualitative and quantitative simulation methodology of System dynamics. This will allow continuous computer simulation of various models and significantly contribute to acquisition of new information about the non-linear character of performance dynamics of turbo generator systems in the process of designing, failure diagnosis, optimization and education. The results presented in the paper have been derived from the scientific research project "Shipboard energy systems, alternative fuel oils and reduction of pollutants emission" supported by the Ministry of Science, Education and Sports of the Republic of Croatia.

Keywords: steam turbine, simulation and heuristic optimisation, failure diagnosis

1. INTRODUCTION

The model of marine steam turbine machinery which drives electric synchronous generator, shown in Figure 1 (Isakov 1984), has two essential situations of energy accumulation: in the steam volume (steam area, steam volume of the turbine) and in the turbine rotor. The main condenser is observed as a special governing object.

Each of the stated parts can be described by its mode equation, that is, by the differential equation which describes the performance dynamics.

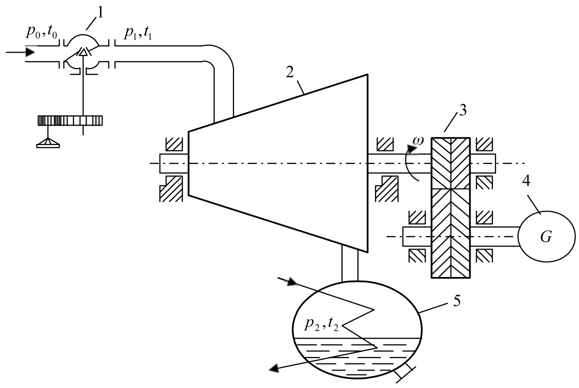

Figure 1: Steam condensation machinery of the marine turbine generator (1- governing valve, 2- turbine, 3- reduction gear, 4- generator, 5- condenser)

2. SIMULATION MODELLING OF MARINE STEAM TURBINE

The system dynamic mathematical model of the marine steam turbine can be defined by means of differential equations (Isakov 1984).

Equation of the turbine steam volume:

$$\frac{d\Psi_1}{dt} = \frac{\mu}{R_\mu} + \frac{\Psi_0}{R_{\Psi 0}} - \frac{\Psi_1}{R_{\Psi 1}} \quad (1)$$

Equation of the turbine rotor dynamics:

$$\frac{d\varphi}{dt} = \frac{\Psi_1}{T_{\Psi 1}} - \frac{\Psi_2}{T_{\Psi 2}} - \frac{\varphi}{T_\varphi} \quad (2)$$

Where the following symbols stand for:

ψ_1 - relative increment of the steam pressure in the steam volume, φ - relative increment of the turbine rotor angular velocity, $T_{\psi 1}$ - time constant of the turbine rotor, T_φ - time constant of the turbine rotor, R_μ - time constant of the steam volume, $R_{\psi 1}$ - time constant of the steam volume, ψ_0 - relative increment of the steam pressure before the manoeuvring valve, $R_{\psi 0}$ - time constant of the turbine rotor, μ - relative change of the position of the manoeuvring valve, ψ_2 - relative increment of the steam pressure in the main condenser, $T_{\psi2}$ - time constant of the boiler.

2.1. System dynamic mental-verbal model of marine steam turbine

On the basis of a mathematical model, or the explicit form of the mode equation of the marine steam turbine (1), it is possible to determine the mental-verbal model of the marine steam turbine.

If the relative increment of the steam pressure in the turbine steam volume ψ_1 increases the speed of the relative increment of the steam pressure in the turbine steam volume ψ_1 will decrease, which gives a negative cause-effect link.

If the relative increment of the steam pressure before the manoeuvring valve ψ_0 increases the speed of the relative increment of the steam pressure in the turbine steam volume will increase, which gives a positive cause-effect link.

If the relative change of the position of the manoeuvring valve μ increases the speed of the relative increment of the steam pressure in the turbine steam volume will increase, which gives a positive cause-effect link.

If the time constant of the steam volume R_{μ} increases the speed of the relative increment of the steam pressure in the turbine steam volume will decrease, which gives a negative cause-effect link.

If the time constant of the turbine rotor $R_{\mu0}$ increases the speed of the relative increment of the steam pressure in the turbine steam volume will decrease, which gives a negative cause-effect link.

If the time constant of the steam volume $R_{\mu1}$ increases the speed of the relative increment of the steam pressure in the turbine steam volume will increase, which gives a positive cause-effect link.

On the basis of a mathematical model, or the explicit form of the mode equation of the marine steam turbine (2), it is possible to determine the mental-verbal model of the marine steam turbine.

If the relative increment of the steam pressure in the steam volume ψ_1 increases the speed of the relative increment of the turbine rotor angular velocity will increase, which gives a positive cause-effect link.

If the relative increment of the turbine rotor angular velocity φ increases the speed of the relative increment of the turbine rotor angular velocity will decrease, which gives a negative cause-effect link.

If the relative increment of the steam pressure in the main condenser ψ_2 increases the speed of the relative increment of the turbine rotor angular velocity will decrease, which gives a negative cause-effect link.

If the time constant of the turbine rotor $T_{\psi1}$ increases the speed of the relative increment of the turbine rotor angular velocity will decrease, which gives a negative cause-effect link.

If the time constant of the turbine rotor T_{φ} increases the speed of the relative increment of the turbine rotor angular velocity will increase, which gives a positive cause-effect link.

If the time constant of the turbine rotor $T_{\psi1}$ increases the speed of the relative increment of the turbine rotor angular velocity will decrease, which gives a negative cause-effect link.

If the time constant of the turbine rotor $T_{\psi2}$ increases the speed of the relative increment of the turbine rotor angular velocity will increase, which gives a positive cause-effect link.

2.2. System dynamic structural model of the marine steam turbine

On the basis of the stated mental-verbal models it is possible to produce structural diagrams of the marine steam turbine, as shown in Figures 2, 3 and 4.

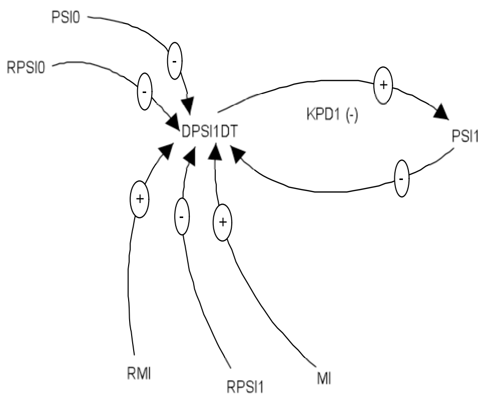

Figure 2: Structural model of the steam turbine – steam volume

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

KPD1(-):PSI1=>(-)DPSI1DT=>(+)DPSI1DT=>(+)PSI1; which has self-regulating dynamic character (-), because the sum of negative signs is an odd number.

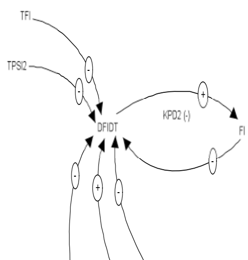

Figure 3: Structural model of the marine steam turbine – rotor dynamics

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

KPD2(-):FI=>(-)DFIDT=>(+)DFIDT=>(+)FI; which has self-regulating dynamic character (-), because the sum of negative signs is an odd number.

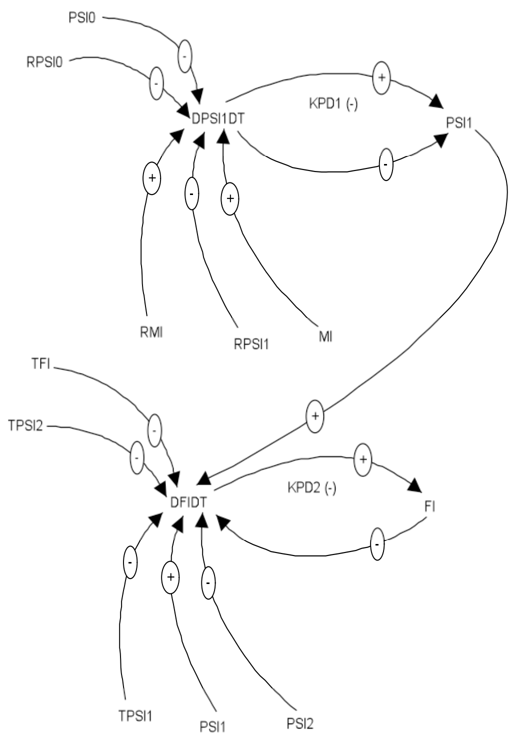

Figure 4: Global and structural model of the marine steam turbine

2.3. System dynamic flowcharts of the marine steam turbine

Flowcharts shown in Figures 5, 6 and 7 are based on the produced mental-verbal and structural models.

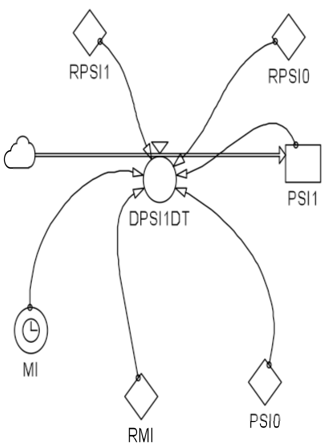

Figure 5: Marine steam turbine flowchart – steam volume

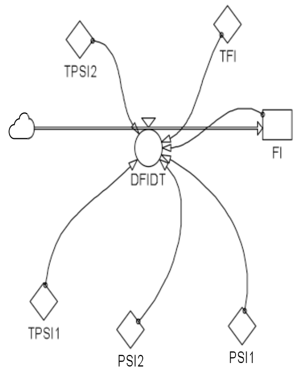

Figure 6: Marine steam turbine flowchart – rotor dynamics

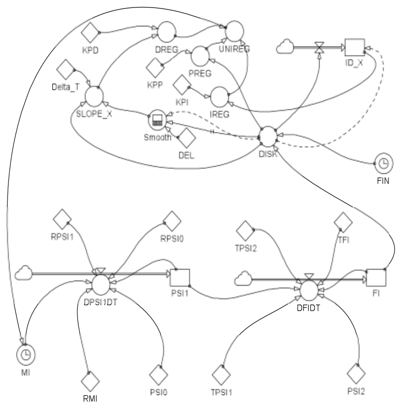

Figure 7: Global flowchart of the marine steam turbine with built-in PID governor

MACRO DYNAMO functions built in the simulation model of the marine steam turbine: CLIP, STEP and UNIREG.

3. QUANTITATIVE SIMULATION MODEL OF THE MARINE STEAM TURBINE

Simulation model of the marine steam turbine in the simulation language:

MACRO SLOPE(X, DEL)
*
A SLOPE.K=(X.K-SMOOTH(X.K,DEL))/DT
*
MEND
* ....
* UNIREG-PID REGULATOR:
*
MACRO UNIREG(X, KPP, KPI, KPD)
*
INTRN IBD, PREG, IREG, DREG
*

```
A PREG.K=KPP*X.K
*
L IBD.K=IBD.J+DT*X.J
*
N IBD=X
*
A IREG.K=KPI*IBD.K
*
A DREG.K=KPD*SLOPE (X.K, DT)
*
A UNIREG.K=PREG.K+IREG.K+DREG.K
*
MEND
*
R    DPSI1DT.KL=(MI.K/RMI.K)+(PSIO.K/RPSIO.K)-(PSI1.K/RPSI1.K)
*
L PSI1.K=PSI1.J+DT*DPSI1DT.JK
*
N PSI1=0
*
A MI.K=CLIP(STEP(.05,10)+STEP(.95,50)+PIDFI.K,0,DELAY1(RE.K,2),1E-16)
*
A RMI.K=5
*
A PSIO.K=0
*
A RPSIO.K=5
*
A RPSI1.K=5
*
SAVE DPSI1DT, PSI1, MI, RMI, PSIO, RPSIO, RPSI1
*
R    DFIDT.KL=(PSI1.K/TPSI1.K)-(PSI2.K/TPSI2.K)-(FI.K/TFI.K)
*
L FI.K=FI.J+DT*DFIDT.JK
*
N FI=0
*
A TPSI1.K=5
*
A PSI2.K=0
*
A TPSI2.K=5
*
A TFI.K=.1+MEL.K
*
* UNIREG-PID REGULATOR INSTALLING:
*
A DISK.K=FIN.K-FI.K
*
A FIN.K=STEP (.05, 10) +STEP (.95, 50)
*
A PIDFI.K=CLIP (UNIREG (DISK.K, KPP, KPI, KPD), 0, TIME.K, 10)
*
C KPP=100
*
C KPI=0.1
*
C KPD=100
SAVE DISK, PIDFI, FIN
*
SAVE TPSI1, PSI2, TPSI2, FI, TFI
```

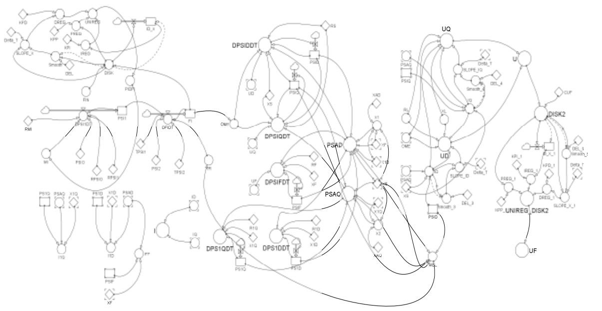

Figure 8: Global flowchart of the marine steam turbine generator system with built-in PID governors in POWERSIM simulation language

4. INVESTIGATING PERFORMANCE DYNAMICS OF THE MARINE STEAM TURBINE

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

After the engineer, designer or a student has conducted a sufficient number of experiments, or scenarios, and an insight has been obtained about the performance dynamics of the system using the method of heuristic optimisation.

For the example, the scenario of starting the marine steam turbine and connecting the synchronous generator on switchboard in TIME = 100 has been simulated. Figure 9 shows changes in relative increment of the angular speed of the rotor FI and relative increment of the steam pressure in the steam volume PSI1 and Figure 10 shows voltage and current changes.

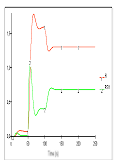

Figure 9: Relative increment of the angular speed of the rotor FI and relative increment of the steam pressure in the steam volume PSI1

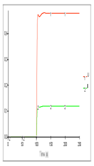

Figure 10: Voltage and electric current of marine turbogenerator

The model can be used to simulate deviation of operating parameters such as main condenser pressure inlet steam pressure, opening and closing of manoeuvring valve and etc. It may also be used in heuristic optimisation of the PID governor coefficient.

Change of these parameters will have an important influence on the performance (frequency and voltage) of turbo generator when working in load operating condition. All these results of simulation are very valuable in process of failure diagnosis, optimization of steam turbine thermodynamic process and educational purposes for future marine engineers.

5. CONCLUSION

System dynamics is a scientific method which allows simulation of the most complex systems. The method used in the presented example demonstrates a high quality of simulations of complex dynamic systems, and provides an opportunity to all interested students or engineers to apply the same method for 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 in dynamic system 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 in fast and scientific method of investigation of a complex system.

This means: “Do not simulate the performance dynamics of complex systems using the method of the "black box", because education and designing practice of complex systems 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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Josko Dvornik was born in Split in 1978. He completed undergraduate studies at Faculty of Maritime Studies in Split in 2001 and was awarded the BSc degree – graduated engineer in Maritime transport, marine engineer. In 2001 he employed at the Maritime Faculty in Split as Junior Researcher at the scientific project No 01717007, 2004 graduated from post graduate studies at the Faculty of Electrical Engineering, Mechanical Engineering and Shipbuilding as a Master of Science in Technical Sciences, filed of Mechanical Engineering. In 2001 he won the doctor’s degree at Faculty of Maritime Studies in Rijeka – doctor of Technical Science, field of Traffic and Transport Technology, branch of Marine and River transport. He published over 50 scientific papers about the field of System Dynamics Computer Simulation Modelling, of which over 20 paper relate to the ship steam and gas turbines, ship engines and complex ship propulsion systems.

Enco Tireli 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 energetic. In 1978 he won the doctor's degree at Faculty of

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Josip Orovic was born in Zadar in 1979 where he graduated at the Nautical School – Engineering Department in 1997. In 2002 he got his BSc degree and in 2006 his MSc degree at the University of Rijeka, Faculty of Maritime Studies in Rijeka. Currently, he is lecturing as a member of the Marine Engineering and Ship Power Systems Department at the University of Rijeka, Faculty of Maritime Studies. His expertise is mainly in areas dealing with marine boilers, marine steam turbines, engine room simulators, failure diagnosis and thermodynamics. He sailed several years as certified engine officer on crude oil tankers and LNG carriers.