CONTINUOUS COMPUTER SIMULATION MODEL OF THE MARINE GAS TURBINE

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KEYWORDS
System dynamics, modelling, twin shaft gas turbine, continuous and discrete simulation and heuristics optimization.

ABSTRACT

Simulation Modelling, 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 behaviour 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 behaviour, of sensibility, of flexibility and sensibility of behaviour dynamics of different systems and processes.
System-dynamics computer simulation methodology have been used from 1991 to 2003 for modelling of dynamics behaviour of the large number of non-linear ship electrical, thermo-dynamical, hydraulically, mechanical and pneumatically systems. This methodology is used by students as a material for graduate these at Maritime faculty Split. Investigation of behaviour dynamics of the ship propulsion system, as one of the complex, dynamics, non-linear and technical system, requires application of the most effective modelling methods.
The aim of this paper is to show the efficiency of the application of the System Dynamics Simulation Modelling in investigation of behaviour dynamics, one of the complex marine system and process i.e. "gas – turbine". Twin shaft gas turbine shall be presented with mental-verbal, structural and mathematical-computing modules, and will simulate working process of turbine.

SYSTEM DYNAMICS SIMULATING MODELLING OF TWIN SHAFT GAS TURBINE

Basic equations of twin shaft gas turbine:

Most often dynamical analyze of gas turbine is based on observation of plan as accumulator of kinetic energy, while dynamics of thermal energy can be conditional ignored.
We presume that process of fuel combustion is momentarily, condition of pressure in turbine is constantly, engine air rate is equal as gas consumption, parameters of atmospheric pressure are relatively unchanged, and ideal heat transfers. Linear behaviour of plan is available when fuel consumption not depend on angular velocity of turbo compressor rotor.

Equations of shaft of turbo compressor with low pressure – consumer:

$$T_{a1}\varphi_{\omega1} + k_1\varphi_{\omega1} = \mu_G + k_{\omega2}\varphi_{\omega2} \qquad (1)$$

$$\frac{d\varphi_{\omega1}}{dt} = \frac{k_1}{T_{a1}}\left[\frac{\mu_G}{k_1} + \frac{k_{\omega2}\varphi_{\omega2}}{k_1} - \frac{f(t)}{k_1} - \varphi_{\omega1}\right] \qquad (2)$$

$$\frac{d\varphi_{\omega1}}{dt} = \frac{1}{T_{a1}}\left(\mu_G + k_{\omega2}\varphi_{\omega2} - f(t) - k_1\varphi_{\omega1}\right) \qquad (3)$$

Mental- verbal model:
When relative variation of fuel consumption μ_G and product $k_2 {*} \varphi_{\omega2}$ are increasing, relative angular speed variation is increasing also, resulting in positive cause-consequence relation UPV (+).
When relative variation of possible external act of cargo and product $k_1 {*} \varphi_{\omega1}$ are increasing, relative angular speed variation is decreasing and observed UPV(-) is negative.
Further, when time of shaft running T_{a1} is increasing, relative angular speed variation is decreasing, resulting in negative sign UPV (-).

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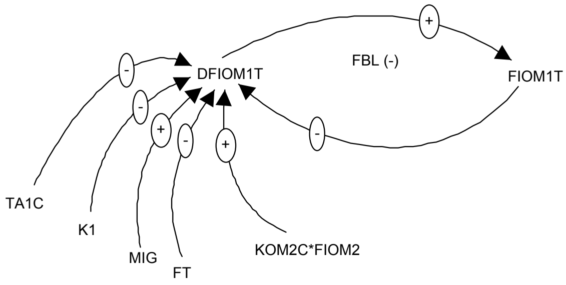

Figure 1. Structural diagram of turbo compressor with low pressure

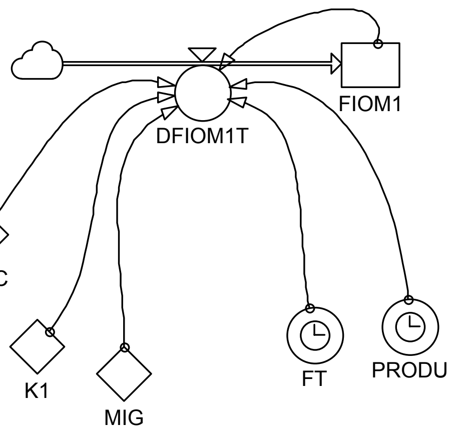

Figure 2. Flow diagram of turbo compressor with low pressure

In observed system there is one feed back loop (FBL):
FBL1(-): DFIOM1T=>(+) FIOM1T=>(+) FIOM1T=>(-)DFIOM1T; with self regulating dynamic character (-), because the addition of negative sign is odd number.

Equations of shaft of turbo compressor with high pressure:

$$\mathrm{T}_{a2}\varphi_{\omega2} + \mathrm{k}_2\varphi_{\omega2} = \mu_G + \mathrm{k}_{\omega1}\varphi_{\omega1} \qquad (4)$$

$$\frac{d\varphi_{\omega2}}{dt} = \frac{k_2}{T_{a2}}\left[\frac{\mu_G}{k_2} + \frac{k_{\omega1}\varphi_{\omega1}}{k_2} - \varphi_{\omega2}\right] \qquad (5)$$

$$\frac{\mathrm{d}\varphi_{\omega2}}{\mathrm{dt}} = \frac{1}{\mathrm{T}_{a2}}\left(\mu_G + \mathrm{k}_{\omega1}\varphi_{\omega1} - \varphi_{\omega2}\right) \qquad (6)$$

Mental- verbal model:
When relative variation of fuel consumption μ_G and product $k_2*\varphi_{\omega2}$ are increasing, relative angular speed variation is increasing also, resulting in positive cause-consequence relation UPV (+).
Further, when time of shaft running T_{a1} is increasing, relative angular speed variation is decreasing, resulting in negative sign UPV (-).

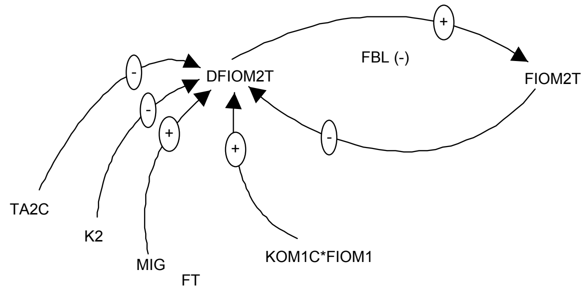

Figure 3. Structural diagram of turbo compressor with high pressure

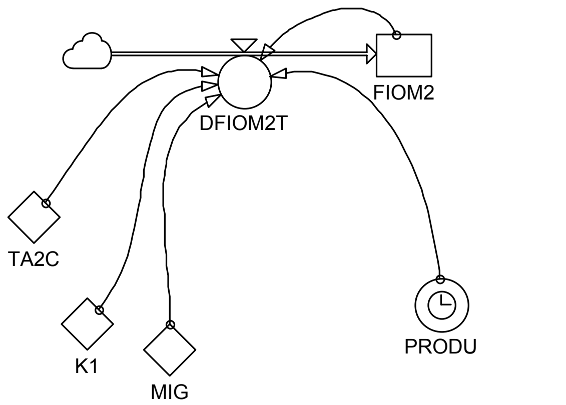

Figure 4. Flow diagram of turbo compressor with high pressure

In observed system there is one feed back loop (FBL):
FBL1(-): DFIOM2T=>(+) FIOM2T=>(+)FIOM2T=> (-)DFIOM2;
with self regulating dynamic character (-), because the addition of negative sign is odd number.

The equations are:
Time of shaft 1.and 2. running:

$$T_{a1} = \frac{I_1\omega_{1n}}{\left(\frac{\partial M_{T1}}{\partial G_T}\right)_0 G_{Tn}}; \quad T_{a2} = \frac{I_2\omega_{2n}}{\left(\frac{\partial M_{T2}}{\partial G_T}\right)_0 G_{Tn}} \qquad (7)$$

Self regulating coefficient of shaft 1. is:

$$k_1 = \frac{\left[\left(\frac{\partial M_{K1}}{\partial \omega_1}\right)_0 - \left(\frac{\partial M_{T1}}{\partial \omega_1}\right)_0\right]\omega_{1n}}{\left(\frac{\partial M_{T1}}{\partial G_T}\right)_0 G_{Tn}} \qquad (8)$$

Self regulating coefficient of shaft 2. is:

$$k_2 = \frac{\left[\left(\frac{\partial M_{K2}}{\partial \omega_2}\right)_0 - \left(\frac{\partial M_{T2}}{\partial \omega_2}\right)_0\right]\omega_{2n}}{\left(\frac{\partial M_{T2}}{\partial G_T}\right)_0 G_{Tn}} \tag{9}$$

Coefficient of increasing of angular speed ω_2 upon angular speed ω_1

$$k_{\omega 1} = \frac{\left[\left(\frac{\partial M_{T2}}{\partial \omega_1}\right)_0 - \left(\frac{\partial M_{K2}}{\partial \omega_1}\right)_0\right]\omega_{1n}}{\left(\frac{\partial M_{T2}}{G_T}\right)_0 G_{Tn}} \tag{10}$$

Coefficient of increasing of angular speed ω_1 upon angular speed ω_2

$$k_{\omega 2} = \frac{\left[\left(\frac{\partial M_{T1}}{\partial \omega_2}\right)_0 - \left(\frac{\partial M_{K1}}{\partial \omega_2}\right)_0\right]\omega_{2n}}{\left(\frac{\partial M_{T1}}{G_T}\right)_0 G_{Tn}} \tag{11}$$

Relative variation of possible external act of cargo

$$f(t) = \frac{\Delta M_G[f(t)]}{\left(\frac{\partial M_{T1}}{\partial G_T}\right)_0 G_{Tn}} \tag{12}$$

Relative variation of angular speed ω_1 and ω_2

$$\varphi_{\omega 1} = \frac{\Delta\omega_1}{\omega_{1n}}; \qquad \varphi_{\omega 2} = \frac{\Delta\omega_2}{\omega_{2n}} \tag{13}$$

Relative variation of fuel consumption

$$\mu_G = \frac{\Delta G_T}{G_{Tn}} \tag{14}$$

where are:

ω_1 - angular speed of first shaft (s^{-1}),
ω_2- angular speed of second shaft (s^{-1}),
$\Delta_{\omega 1}$- absolute change of angular speed of first shaft (s^{-1}),
$\Delta_{\omega 2}$- absolute change of angular speed of second shaft (s^{-1}),
ω_{1n}- nominal angular speed of first shaft (s^{-1}),
ω_{2n}- nominal angular speed of second shaft (s^{-1}),
ΔG_T- absolute variation of fuel consumption (t/h),
G_{Tn}- nominal fuel consumption (t/h),
I_1- moment of inertia of rotating masses of first shaft
I_2- moment of inertia of rotating masses of second shaft
M_{K1}- moment of low-pressure compressor (Nm)
M_{K2}- moment of high-pressure compressor (Nm)
M_{T1} - moment of low-pressure turbine (Nm)
M_{T2}- moment of high-pressure turbine (Nm)

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Scenario:

Run of the turbine is triple-stage, which mean that in TIME=1 second we accelerate turbine by bringing the fuel. On 10% of nominal number of revolution in TIME=5 seconds we increase fuel consumption to the 35% of nominal number of revolution, and in TIME=10 we increase fuel supply, and in that way obtain "uniform" heating of turbine i.e. nominal number of revolution. In TIME=15 PID regulator is under the shock loading from gas turbine, in amount of 50% from nominal load, meaning that F (t)=0.5. In TIME=30 stochastically load occurs.

Graphics results of the simulation:

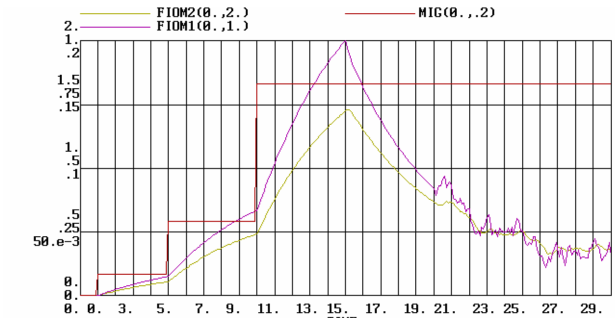

Figure 1. Relative angular speed variation, relative angular speed variation of second shaft, relative variation of fuel consumption

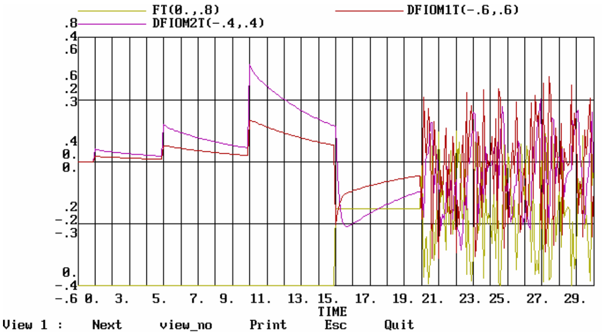

Figure 2. Speed variation of relative angular speed, speed variation of relative angular speed of second shaf

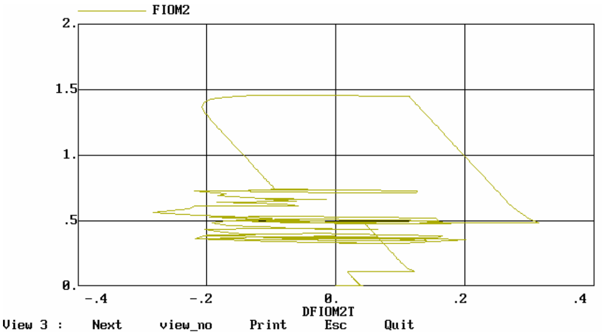

Figure 3. Dependence of relative angular speed of second shaft on its derivation (speed of change) diagram

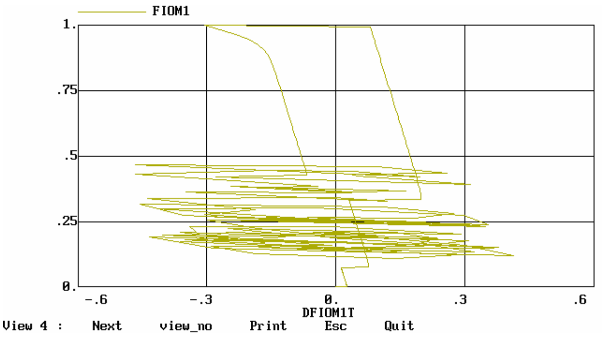

Figure 4. Dependence of relative angular speed of first shaft on its derivation (speed of change) diagram

CONCLUSION

The application of System Dynamics Simulation Modelling Approach of the complex marine dynamic processes, which the authors, together with their graduate students, carried out at the Maritime Faculty University of Split - Croatia eleven years ago, revealed the following facts:

1. The System Dynamics Modelling 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.

Finally, we may quote the Chinese proverb saying:

"When I hear I forget. When I see I remember. When I work I understand"

or we may express it a system dynamic way, i.e.:

"WHEN I HEAR MENTAL-VERBAL MODEL OF DYNAMIC PROCESS, I FORGET". "WHEN I SEE STRUCTURAL MODEL AND REALITY OF DYNAMIC PROCESS, I REMEMBER." "WHEN I MAKE MATHEMATICAL OR COMPUTING SIMULATING MODEL OF DYNAMIC PROCESS, I LEARN". "WHEN I MAKE SIMULATION OR EXERCISE EITHER ON SYSTEM DYNAMIC MODEL OR DYNAMIC PROCESS, I REFRESH MY TECHNICAL KNOWLEDGE WITH GAINED THEORETICAL AND PRACTICAL KNOWLEDGE ON DYNAMIC PROCESS".

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BIOGRAPHY

ANTE MUNITIC was born 08. 26.1941. in Omis, near Split, Croatia! He received his first BSc. in Electrotechnics Engineering in 1968, and his second BSc. in Electronics Engineering in 1974; his MSc. degree in Electronics/Organization /Operational Research/Cybernetics Science in 1978, and his Ph.D. of Organization/Informatics Science (exactly: System Dynamics Simulation Modeling) in 1983. He is currently a University Professor of Information/Computer Science at the University of Split, Croatia. Prof. Munitic has published over 100 scientific papers on system dynamics simulation modeling, operational research, marine automatic control system and The Theory of Chaos. He has published several books (as there are: "Computer Simulation with help of System Dynamics" and "Marine Electrotechnics and Electronics Engineering", ...). Today, he is professionally active university professor and scientist in the System Dynamics, Relativity Dynamics, System Dynamics Analogous Processes, Theory of Chaos and Informatics Scientific area.

MARIO ORSULIC received his B.Sc, M.Sc. and Ph.D. in mechanical engineering from Faculty of Mechanical Engineering University of Rijeka in 1968, 1984 and 1988 respectively. He is currently an associative professor at University of Split, College of Maritime Studies. He is author or co-author of a number of bibliographical units (scientific and professional conference and journal papers, research projects, text books, etc.). His research interest is in Marine Engineering, auxiliary marine engines and technical mechanics theory and practise.

JOSKO DVORNIK was born 1978. at Split Croatia, were he finished elementary and high Maritime school. In school year 1996/97 he enrolled Maritime University in Split, Marine engineering Department, completed all theoretical and practical subjects included in school program on time, and passed all exams. He graduated in 2000. year on theme "*Application on computer simulation dynamics of behavior of ship propulsion system: windlass – asynchronous engine*", with very good degree as a first student in his class. Since December 2001. year he has worked as younger assistant at Maritime University in Split on scientific project titled "Computer simulation model of maritime educative system of Croatia". In June 2002. he has enrolled postgraduate study of engineering at Faculty of Mechanical Engineering and Naval Architecture. He has published 20 scientific papers on System Dynamics simulation modeling. He is a member of the SCS, The Society for Computer Simulation International.