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SYSTEM DYNAMICS MODELLING AND SIMULATION AS PART OF EDUCATION IN MARINE SCIENCE COLLOQUIUMS

SUSTAV-DINAMIČKO MODELIRANJE I SIMULACIJA U NASTAVI POMORSKIH STRUČNIH KOLEGIJA

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Abstract

By showing a characteristic theme of an educational unit, which is presented with the aid of a computerised simulation based on a mathematical model, a statement is illustrated claiming that utilisation of computers can shorten the time needed for presenting expert knowledge. At the same time, the quality and the clarity of the lecture is improved. A positive and a favourable boost to the student's creative capabilities should be added.

Keywords: System Dynamics, Dynamic Modelling, Continuous Simulation, Marine Education.

Sažetak

Pokazivanjem karakteristične tematske nastavne jedinice, koja je predstavljena uz pomoć računalne simulacije na temelju matematičkog modela, ilustrirana je tvrdnja da uporaba računala može skratiti vrijeme potrebno za izlaganje stručnog gradiva. Istodobno se povećava kvaliteta i jasnoća izlaganja. Tome treba dodati pozitivni i povoljni poticaj na razvitak kreativnih sposobnosti studenta.

Ključne riječi: sustav-dinamički, dinamičko modeliranje, kontinuirana simulacija, pomorsko obrazovanje.

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INTRODUCTION
UVOD

There are different approaches to lecturing on the ship engine expert colloquiums that are possible. Still, regardless of the approach, the targets are always the same: the auditorium must understand the presented topic. This means understanding the complex dynamical non-linear processes and cause/consequence links which come with the subject, accepting contemporary way of thinking in this branch of the system dynamics science and becoming capable of having a critical attitude towards existing solutions. An active critical attitude, always looking for faults in order to formulate better solutions actually means creativity. This can be achieved in education if duties and responsibilities are properly distributed. In other words, the division of work between the lecturer and the listener can be efficient if all participants show initiative and responsibility towards their corresponding duties.

The lecturer has to use written, visual and verbal methods in presenting the problem, as well as ways and methods of solving the problem, coupled with comments and conclusions. Training sessions should be used to elaborate procedures in solving specific examples that are chosen based on experience and applicability so as to fortify the conclusions with competent backing.

The students are expected to follow the lecture carefully, think and accept the facts provided by the lecturer at a certain pace, so that through discussions at training sessions, and through practical exercises and active participation in the lectures, the student could develop an efficient way of thinking about the processes and events that need to be controlled in practice.

The educational target is therefore complex. Its success depends on subjective factors present with the persons involved in the process of learning. It is not possible to provide a universal recipe for all generations of students and teachers and their assistants. A mutual agreement, which is made at the beginning of each learning process and is continuously corrected through monitored progress, is a crucial factor of success and is instrumental in achieving a speedier and easier fulfilment of set targets. It is necessary to conduct a daily critical analysis of achieved results and based on observed failures, continuous corrections are made to the educational process.

The development of technology, ship engines included, has gone through a spectacular process in the last hundred years, especially the last three decades that have been marked by the data-processing revolution. A more detailed and a more accurate analysis of various physical phenomena, makes it possible to fulfil numerous new ideas because their effects are easily verified and solutions are easily corrected, modified and optimised. With the enormous possibilities provided by computers, numerous traditional analysis have lost their value and importance, while a new systematic approach shortens the time of interpretation, reduces the amount of educational matter and increases accuracy, precision and clarity of description of presented processes. The increased power of judgement in this field increases the responsibility of engineers to find better, therefore more profitable and more efficient solutions.

It is clearer from day to day that by introducing computers and computerised simulations into education numerous technical expert subjects can be reconstructed so that the contents are enriched and more clearly and easily presented. The education with computerised simulations makes it possible to increase its quality and its impact on development of student's creativity.

In the process of reconstructing the colloquium, preparation for lectures, naturally, means exceptional engagement on the part of the lecturer. Later, on the other hand, it is compulsory to use all possible rationalisations in special solutions, which, as contemporary practice has shown, are far from being irrelevant.

A MATHEMATICAL MODEL OF A SHIP DIESEL ENGINE

MATEMATIČKI MODEL BRODSKOG DIZELSKOG MOTORA

In this paper a topic unit from the *Ship diesel engines* colloquium will be shown – a dynamic regime of a ship diesel engine. Without the use of a computer the contents of this topic would be difficult to clearly and completely present because the problem boils down to solving a system of differential equations. The classic presentation of this problem involved producing the general mathematical expression, which was not illustrative enough in showing the changes that occurred while the engine was working. This is why the reliability of the analysis was reduced and the time needed to present this lecture was greatly prolonged, just like the time needed for learning, understanding and for developing the ability for a critical analysis.

The programme of numerical and graphical solutions simplifies the insight into the influence of specific construction parameters on the features of the system, and this is usually the beginning of any analysis, diagnosis of a fault or a synthesis in designing. It is interesting to point out that these programmes are just as suitable for those doing an analysis of characteristic failures in exploitation as those who are dealing with problems of modification or designing. By describing the working of a diesel engine through a computer language, it is possible to save time and money for conducting some experiments, especially in benchmarking the effects of malfunctions of some parameters in the construction. This makes it possible, on an example of a certain educational unit to see how a correct description of a problem equally helps the experts dealing with maintenance and exploitation and those engaged in constructing engines.

Diesel engines used for powering ships have great strength and a great number of mechanisms and systems that are mutually dependent. The conditions of seafaring and working conditions of the engine are not steady, but are constantly changing as a result of changing conditions of the sea and the atmospheric conditions, sea routes and maritime regions, tasks that need to be carried out and the working regime. It is necessary to constantly maintain high efficiency, reliability and long-life of the systems and the engine itself in accordance with technical regulations of exploitation. The fulfilment of these requirements, as well as the improvement of ship crew working conditions is closely connected to the automatization of complex processes that occur during the work of the diesel engines. Contemporary diesel engines, among other devices, as part of the system have a cooling system, an air collector, a collector of exhaust gas, a turbo-blower, a high-pressure fuel pump and a regulator of the number of turns.

A diesel engine works in a balanced regime if conditions for a static balance are achieved. The static balance conditions can be expressed in the following way:

For a diesel engine:

$$M_m - M_v = 0 \quad (1)$$

For the cooling system:

$$Q_p - Q_o = 0 \quad (2)$$

For the air collector:

$$G_k - G_m = 0 \quad (3)$$

For the exhaust gas collector:

$$G_p - G_t = 0 \quad (4)$$

For the turbo-blower:

$$M_t - M_k = 0 \quad (5)$$

where:

M_m - engine-revolving moment, Nm;

M_v - resistance revolving moment (ship propeller), Nm;

Q_p - the amount of heat that the engine passes over to the cooling system in a unit of time, W;

Qo - the amount of heat conducted from the cooler in a unit of time, W;

G_k - the amount of air acquired in the compressor of the air collector in a unit of time, kg/s;

G_m - the amount of air that enters the engine cylinders in a unit of time, kg/s;

G_p - the amount of exhaust gas leaving the cylinders and entering the collector of exhaust gas in a unit of time, kg/s;

G_t - the amount of exhaust gas entering the gas turbine in a unit of time, kg/s;

M_t - the revolving moment of the gas turbine, Nm;

M_k - the revolving moment of the compressor, Nm.

The balance regime of the engine in time can be disturbed by a change in the working conditions of the engine or the device powered by it. The dynamic regime, therefore, comes into existence when there is a disruption of balance in the working regime and is described by the following differential equations, or level equations:

For the diesel engine:

$$T_{11}\frac{d\varphi_1}{dt}+k_{11}\varphi_1=q+k_{13}\rho-k_{14}\alpha \qquad (6)$$

For the turbo-blower:

$$T_{21}\frac{d\varphi_2}{dt}+k_{21}\varphi_2=\xi+k_{23}q-k_{24}\rho+ \qquad (7)$$
$$+k_{25}\chi_{21}-k_{26}\chi_{22}$$

For the air collector:

$$T_{31}\frac{d\rho}{dt}+k_{31}\rho=\varphi_2-k_{33}\varphi_1+k_{34}\chi_{22} \qquad (8)$$

For the collector of exhaust gas:

$$T_{41}\frac{d\xi}{dt}+k_{41}\xi=\varphi_1+k_{43}\rho-k_{44}q-k_{45}\chi_{21} \qquad (9)$$

where:

φ_1 - ND change of engine axis angle speed, (→ FI1);

φ_2 - ND change of turbo-compressor axis angle speed, (→ FI2);

q - ND changes in fuel supply per cycle;

ρ - ND changes in air pressure, (→ RO);

α - ND changes in load power, (→ ALFA);

ξ - ND changes of gas pressure in the gas turbine, (→ KSI);

χ_{21} - ND changes in the angle of turbine blades;

χ_{22} - ND changes in the angle of diffusion compressor blades;

T_{11} - time constant of the diesel engine, s;

T_{21} - time constant of the turbo-compressor, s;

T_{31} - time constant of the air collector, s;

T_{41} - time constant of the exhaust gas collector, s;

k_{11} - ND self-balance coefficient of the diesel engine;

k_{13} - ND coefficient of diesel engine increase per compression pressure;

k_{14} - ND load coefficient;

k_{21} - ND self-balance coefficient of the turbo-compressor;

k_{23} - ND coefficient of increase per fuel supply;

k_{24} - ND coefficient of increase per compression pressure;

k_{25} - ND coefficient of increase per angle of diffuser turbine blades;

k_{26} - ND coefficient of increase per angle of compressor blades;

k_{31} - ND coefficient of increase of air collector self-regulation;

k_{33} - ND coefficient of increase per angle velocity of crankshaft;

k_{34} - ND coefficient of increase per fine-tuning the compressor diffuser;

k_{41} - ND coefficient of exhaust gas collector self-regulation;

k_{43} - ND coefficient of increase per compression pressure;

k_{44} - ND coefficient of increase per fuel supply;

k_{45} - ND coefficient of increase per regulation of entry turbine blades;

ND - Non-Dimensional;

(→ - notation in the diagrams 1-6).

SYSTEM DYNAMICS COMPUTERISED SIMULATION MODEL OF A SHIP DIESEL ENGINE

SUSTAV-DINAMIČKI RAČUNALNI SIMULACIJSKI MODEL BRODSKOG DIZELSKOG MOTORA

Based on the mathematical model a System Dynamics computerised simulation model was made for the dynamic regime of the ship diesel engine in the DYNAMO programming language. Using the model and accepted starting values of variables and parameter values provided by the model itself, numeric data and diagrams in a time interval from 0 to 100 sec. were produced. The produced data and the diagrams show that the system functions completely.

Heuristic optimisation means utilisation of all known methods, as well as the methods that cannot be expressed mathematically well, so that modelling knowledge of experts is used. In system dynamics, the term “heuristic optimisation” means “retry error”, a method that could be explained as step-by-step attempt to getting better results. In the DYNAMO language, the heuristic optimisation is done instantly, while in real-life specially developed “optimiser” program packages are used.

The scenario used for testing the system was this:

- The load was changed according to the bounce function for 100% in the 40th second and according to the impulse function for 50% in the 60th second.
- The change of angle on the entry blades of the turbine occurred according to the bounce function for 70% in the 10th second.
- The change of angle on the diffuser compressor blades occurred according to the bounce function for 40% in the 10th second.

Diagrams 1–4 were produced from equal values of time constants, while diagrams 5 and 6 sow the effect of variable values of the time constant T_{11}, starting with the value T_{11} = 1 to the value T_{11} = 10 on diagram 5, and on diagram 6 to the value T_{11} = 0,1. The coefficients of increase on all the diagrams had the same value.

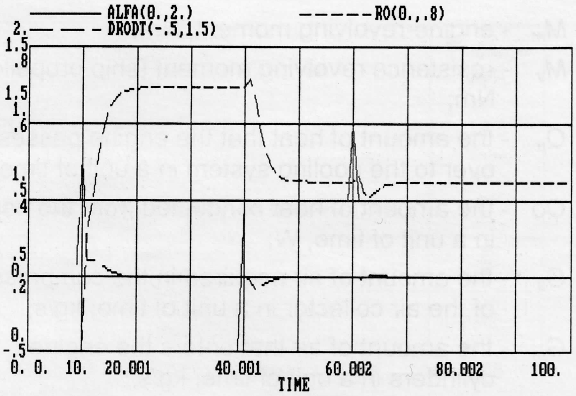

Diagram 3.

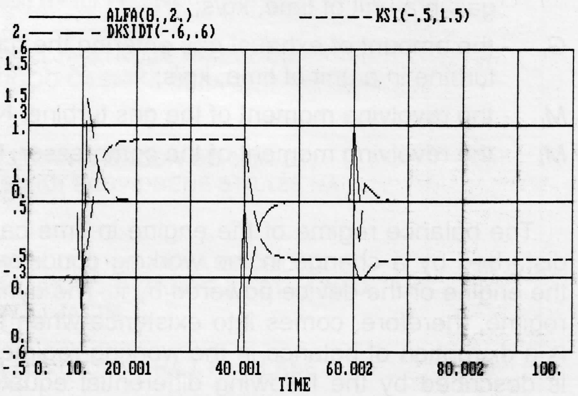

Diagram 4.

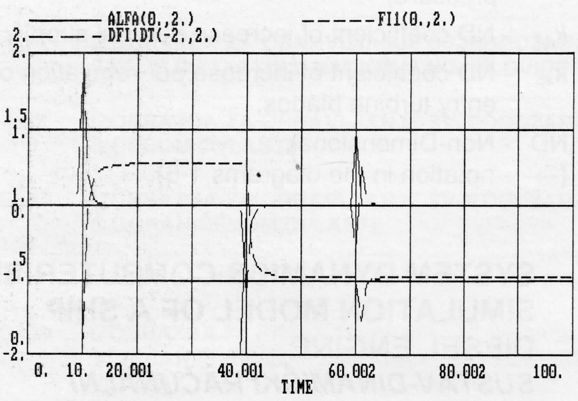

Diagram 1.

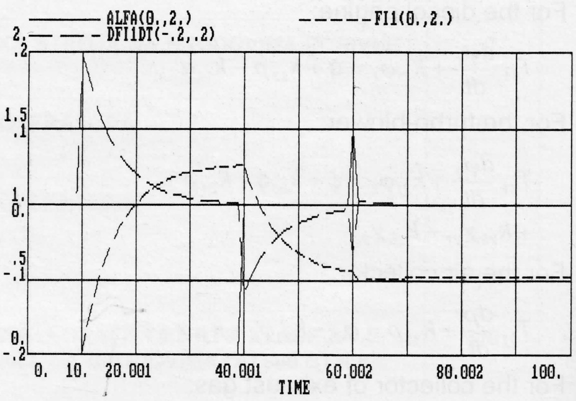

Diagram 5.

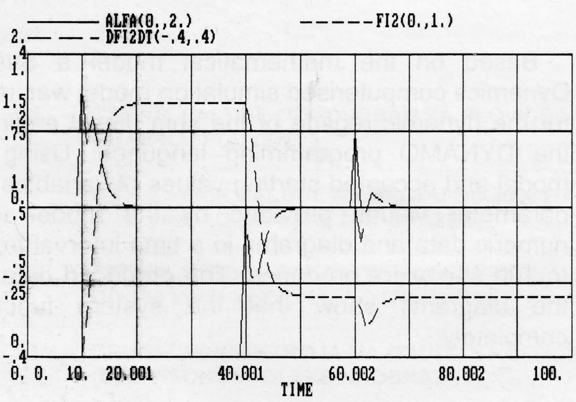

Diagram 2.

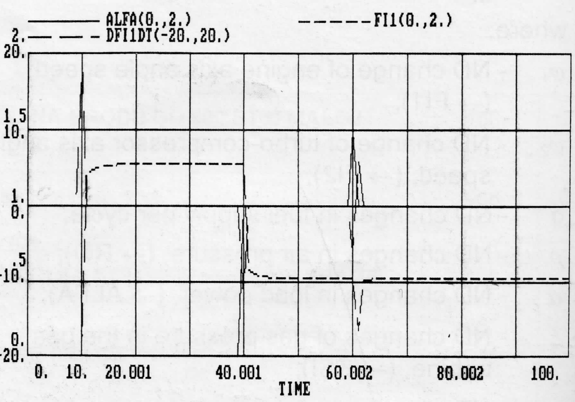

Diagram 6.

CONCLUSION
ZAKLJUČAK

The statements made in the introductory part of this paper are supported by an example of a System Dynamics Simulation of a dynamic regime of a ship diesel engine. This approach has been used by the authors in their work with students for several years. Achieved results bring a promise of multiple effects in computer-aided education, and that is why this perspective in education must not be looked upon with indifference.

The achieved results can stimulate the widening of the experiments using computers in lectures on expert technical colloquiums. A more frequent introduction of computers to lectures encourages new generations of experts to still widen the use of such devices. In this way, there is a realistic chance to improve analysis and synthesis, as well as significant shortening of the time needed to give a lecture and master a certain topic. Even if only this were achieved by the reconstruction of education, it would be a justifying benefit.

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REFERENCES
LITERATURA

[1] Bupić, M.; Milić, L. and Oršulić, M. 1997. "Simulacijski model rashladnog sustava brodskog dizelskog motora", *Naše more, science journal*, vol. 44, no. 1-2/97, 23-28, Dubrovnik, (in Croatian).

[2] Di Stefano, J. J.; Stubberud, A. R. and Williams, I. J. 1987. *Theory and Problems of Feedback and Control Systems*, McGraw-Hill Book Company, New York.

[3] Milić, L.; Batoš, V. and Milić, I. 1995. "System Dynamics Comparative Modelling of the Woodward and Digital-Electronics PID-Regulator", *Proceedings of the VII. Congress of IMAM*, Dubrovnik.

[4] Milić, L. and Milić, I. 1995. *Osnove automatizacije*, Sveučilište u Splitu, Pomorski fakultet u Dubrovniku, Dubrovnik, (in Croatian).

[5] Milić, L.; Munitić, A. and Milić, I. 1996. "System Dynamics Simulation Model of the Marine Diesel Engine", *Naše more, science journal*, vol. 43, no. 3-4/96, 97-102, Dubrovnik.

[6] Milić, L.; Šundrica, J. and Krile, S. 1997. "Sustav dinamički nelinearni kompjutorski simulacijski model automatske regulacije plovidbe broda", *Zbornik referatov 6. Mednarodni simpozij o elektroniki v prometu ISEP 97*, Ljubljana, (In Slovenian).

[7] Munitić. A. 1989. *Komjutorska simulacija uz pomoć sistemske dinamike*, Brodosplit, Split, (in Croatian).

[8] Munitić, A.; Milić, L. and Milković, M. 1997. "System Dynamics Computer Simulation Model of the Marine Diesel-Drive Generating Set Automatic Control System", *Proceedings of the 15th IMACS World Congress on Scientific Computation, Modelling and Applied Mathematics, vol. 5*, Wissenschaft & Technik Verlag, Berlin.