SYSTEM DYNAMIC SIMULATING MODELLING OF DRIVING SYSTEM "ANCHOR WINDLASS DRIVEN BY ASYNCHRONOUS MOTOR" (BSVPAM)

ANTE MUNITIĆ, MARIO ORŠULIĆ, MAJA KRČUM, JOŠKO DVORNIK

Split College of Maritime Studies
University of Split
Zrinsko-frankopanska 38,
21000 Split, Croatia
e-mail: munitic@pfst.hr

Abstract

System dynamic simulating modelling is one of the most appropriate and successful scientific dynamics modelling methods of the complex, non- linear i.e. natural, technical and organisational systems. Investigation of behaviour dynamics of the ship's propulsion system as a typical example of complex, dynamic technical systems requires application of the most efficient modelling methods. The aim of this essay is to present the efficiency of application of the system-dynamic simulating modelling in investigation of behaviour dynamics of the BSVPAM propulsion system. The anchor windlass and its driving asynchronous motor shall be presented by mental - verbal, structural and mathematical computing models. The System Dynamics Models are, in essence, continuous models because the realities are presented by the set of non-linear differential equations, i.e." equations of state". They are at the same time discrete models, because they used basic time step for counting i.e. discrete sampling DT, which value is determined in total accordance with "SAMPLING THEOREM" (Shannon and Koteljnikov). With the choice of basic time step DT it is possible to do computer modelling of continuous simulation models on digital computer, which is very suitable for education of the marine students and engineers, because they can study complex dynamics behaviour of marine systems and process.

Keywords

System Dynamics, Modelling, Asynchronous Engine, Windlass, Continuous and Discrete Simulation

1. INTRODUCTION

The System Dynamics Modelling is in essence special, i.e. "holistic" approach to the simulation of the dynamics behaviour of natural, technical and organisation systems, and it contains quantitative and qualitative Simulation Modelling of various natured realities. The concept of optimisation in System Dynamics is based on belief that the manual and iterative procedure, i.e. optimisation by the method "retry and error" can be successfully executed using heuristic optimisation algorithm, with the help of digital computer, and in complete coordination with System Dynamics Simulation Methodology. This simulation model BSVPAM is small part of scientifically macro project called: Intelligent Computer Simulation of the Model of Marine Processes.

2. SYSTEM- DYNAMIC SIMULATING SYSTEM MODELS "ANCHOR WINDLASS DRIVEN BY ASYNCHRONOUS MOTOR"

2.1. System dynamic model of the anchor windlass

Anchoring is an operation by which the ship is fixed to the ship's bottom. This is performed by the anchor arrangement consisting of: anchor, anchor chains, stoppers, chain locker and windlass. Some elements of the anchor arrangement are also used for the mooring of a ship. All ships are provided with the bow anchor arrangement and some of them with the stern anchor arrangement. Ships of less size may be provided with anchor windlasses driven by the internal combustion engines while on tankers where such drive may cause explosion windlasses are driven by steam. Windlasses on other ships are mostly driven by electric motors and recently are also hydraulically driven. Electric drive of windlasses shall be performed by: - the alternative three phase electric motor, in Leonard's connection, alternative three phase electric motor directly coupled with overlapping of two or three pairs of pole.

Anchor windlass consists of driving electric motor with stopper, reduction gear and main shaft unit laid

Proceedings 17th European Simulation Multiconference
(c) SCS Europe BVBA, 2003 ISBN 3-936150-25-7

in solid bearings. Reduction gear where safety-sliding coupling is located includes a few pairs of front gears with associated shafts and bearings. High-speed rotating shafts are laid in rolling bearings while the main shaft is fitted in sliding bearings. Chain locker is situated in the main shaft having the belt brake and tightening drum. Claw clutch is located between chain locker and reduction gear enabling the independent operation of the tightening drum from the chain locker.

Reduction gear is lubricated by oil sump while main shaft and other sliding surfaces are grease lubricated.

The basic equations of anchor windlass are:

$$\frac{ds}{dt} = \omega r_0 \qquad (1)$$

$$F_t = (G_l S + G_s) g \qquad (2)$$

$$F_{uz} = \varphi g A S \qquad (3)$$

$$F_u = F_t - F_{uz} \qquad (4)$$

$$M_v = F_u r_0 \qquad (5)$$

$$S = S_0 - \int v_s \, dt \qquad (6)$$

According to the basic equations the mental verbal model of ship anchor windlass may be developed or structural and anchor windlass course diagrams, respectively.

Table 1: Marks and mode of records in Dynamo language

Marks	Description	Dynamo language
M_V	Winch torque	MTVA
G_s	Anchor weight	GS
G_l	Chain weight	GL
S	Chain length	SM
φ	Seawater density	GU
G	Gravity	GR
A	Anchor and chain area	POVRSR
S	Chain length	S
V_S	Anchor lifting speed	VS
F_T	Loading force	FU
F_{UZ}	Buoyancy force	FZ

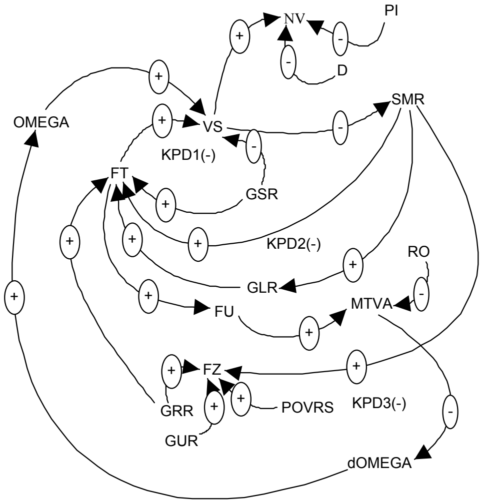

Figure 1: Structural simulation model of the anchor windlass

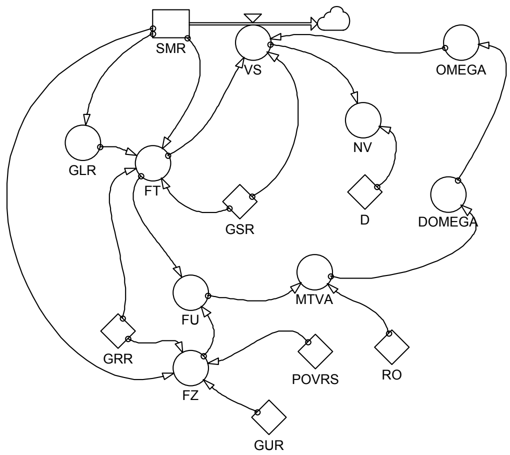

Figure 2: Structural simulation model in DYNAMO symbolic-flow diagram

Three feedback loops are present in the concerned anchor arrangement system (KPD).

KPD1 (-): VS=.> (-) SMR =>(+)FT=>(+)VS; which has self-regulating dynamic character (-) because the sum of negative signs is odd number.

KPD2(-):VS=>(-)SMR=>(+)GLR=>(+)FT=> (+)VS; which also has self-regulating dynamic character .

KPD3(-)SMR=>(+)GLR=>(+)FT=>(+)FU=> (+)MTVA=>(+)dOMEGA=>(+)OMEGA= >(+)VS;which has also self-regulating dynamic character.

Within KPD a few cause and effect relations are acting (UPV) for which the following dynamic relations are valid:

“ If the anchor and chain VS lifting speed is increasing, chain length SMR is reducing what results in the negative sign of cause-effect relation”; by increasing chain and anchor VS lifting speed, the number of revolutions of shaft NV is also increased resulting in positive sign of UPV.”

By increasing the relative anchor mass GSR, chain and anchor VS lifting speed is reduced resulting in

negative sign of UPV". "By increasing of relative chain length SMR loading force is increasing as well as the total chain weight GL and also buoyancy force FU resulting in positive sign UPV."
"By increasing the loading force –FT as well as speed of rotation of asynchronous motor, the anchor-VS and chain lifting speed is increased resulting in positive sign of the observed UPV." By increasing gravity-G the loading force-FT and buoyancy force-FU are increased and accordingly observed UPV has positive sign." " By increasing loading force-FT total force is increased and consequently by increasing total force winch torque-MTVA is increased and thus the observed UPV has a positive sign."
" By increasing buoyancy force-FU total force is decreasing resulting in a negative sign UPV." " By increasing chain and anchor-A area as well as seawater density buoyancy force is increased resulting in positive sign of the observed UPV."

2.2. System dynamic model of asynchronous motor

The following cause and effect relation is applicable to the first equation:

$$\frac{d\psi_{ds}}{dt} = u_{ds} - \frac{1}{T'_s}\psi_{ds} + \frac{k_r}{T'_s}\psi_{dr} + \omega_k \psi_{qs} \qquad (7)$$

Variation speed of system - d condition is decreasing what results in negative sign of the observed cause and effect relation." " By increasing rotor linkage factor –Kr, system condition variation is also increased resulting in positive sign of the observed UPV." " By the increase of stator - Ts transient time constant, system condition variation is reduced resulting in negative sign of the observed UPV." " If product is increasing and if stator voltage variation in axis d - Uds is increasing then system condition variation speed is also increasing resulting in a positive sign of the observed UPV."
On the basis of the specified model given in the form of cause and effect relation of system elements, the mental verbal model of equation of asynchronous motor condition may be determined and thus a structural model and continuity diagram of the mentioned equation may be elaborated.
In this short paper, it is impossible to give a complete model (27 equations) of the asynchronous motor, complete model has been

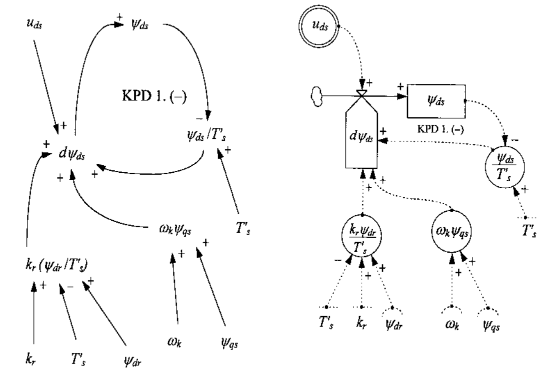

Figure 3: Structural diagram and continuity diagram of the first differential equation of the asynchronous motor condition

presented in IASTED 1998., Pittsburg, USA.

2.3. Computer simulating model BSVPAM

```
PARAMETERS OF SHIP'S ANCHOR WINDLASS:
C G=7000                    TOTAL NOMINAL WEIGHT
                            OF ANCHOR WITH CHAIN (kg)
C GS=3000          NOMINAL ANCHOR WEIGHT (kg)
K GSR=GS/G              RELATIVE VALUE OF ANCHOR
                            WEIGHT
K GL=4000/SM                NOMINAL CHAIN  WEIGHT
                            PER LENGTH UNIT (kg/m)
K GLR=GL/G                       RELATIVE VALUE OF
                  CHAIN WEIGHT PER LENGTH UNIT
C SM=100                           CHAIN LENGTH  (m)
C GR=9.81                           GRAVITY  (M/s*s)
K GRR=GR/SM                    RELATIVE GRAVITY
C GU=1.25       SEAWATER DENSITY  (kg/m*m*m)
K GUR=GU/SM                   RELATIVE SEAWATER
                                          DENSITY
C VOLUM=1000                 CHAIN AND ANCHOR
                                VOLUME  ( m*m*m)
K POVRSR=VOLUM/SM         CHAIN AND  ANCHOR
                                  AREA
R VS.KL=CLIP(STEP(OMEGA.K,0)
,0,FT.K,GSR)              ANCHOR LIFTING SPEED
C D=1
A NV.K=VS.KL/(D*3.14)               SHAFT NUMBE
                                   OF ROTATION
L SMR.K=SMR.J+DT*(-VS.JK)
N SMR=100
A MTVA.K=FU.K*RO               WINDLASS TORQUE
C RO=0.1                  CHAIN LOCKER DIAMETER
A FT.K=CLIP(STEP((GLR*SMR.K+GSR)
*GR,0),0,GLR*SMR.K*GR,GSR)  LOADING FORCE
A FZ.K=CLIP(STEP(GUR*GRR*POVRSR*SMR.K,0)
,0,SMR.K,15)                     BUOYANCY FORCE
A FU.K=FT.K-FZ.K                    TOTAL FORCE
SAVE SMR,MTVA,FU,FT,FZ,VS
PARAMETERS OF ASYNCHRONOUS MOTOR:
C Rs=0.0141                   STATOR TRANSFORMED
                             OPERATING RESISTANCE
C Rr=0.0934                    ROTOR TRANSFORMED
                    OPERATING RESISTANCE + 5Rr
C Lcs= 0.286 STATOR TANSFORMED  INDUCTANCE
C lcr= 0.1     ROTOR TRANSFORMED  INDUCTANCE
C Lm=3.32                   TRANSFORMED MUTUAL
                                     INDUCTANCE
C TCS=20.3                     STATOR TRANSIENT
                                  TIME CONSTANT
C Tcr=3.11              ROTOR WITH 5R TRANSIENT
                                  TIME CONSTANT
C Ks=0,965               STATOR LINKAGE  FACTOR
```

C Kr=0.95 ROTOR LINKAGE FACTOR
C Lsigs=0.12 STATOR LEAKAGE INDUCTANCE
C Lsigr=0.175 ROTOR LEAKAGE INDUCTANCE
C SIGMA=0.083LEAKAGEFACTOR(SIGMA=1-Ks*Kr)
CH=57.6 INERTIA CONSTANT
I DIFFERENTIAL EQUATION OF CONDITION:
R dPSIds.KL=Uds.K-(PSIds.K/Tcs)+
OMEGAk.K*PSIqs.K+(Kr*PSIdr.K)/Tcs
DPSIds= VARIATION SPEED OF LINKAGE FLUX
PSIds (Wb/s)
Uds= STATOR VOLTAGE IN AXIS d (V)
Tcs= STATOR TRANSIENT TIME CONSTANT
OMEGAk=OMP STATOR ROTATION
SYNCHRONOUS SPEED (rad/s)
PSIqs=STATOR LINKAGE MAGNETIC FLUX IN
AXIS q (Wb/s)
Kr= ROTOR LINKAGE FACTOR
PSIdr= ROTOR LINKAGE MAGNETIC FLUX IN
AXIS d (Wb)
L PSIds.K=PSIds.J+DT*(dPSIds.JK)
N PSIds=0
PSIds=STATOR LINKAGE FLUX IN AXIS d (Wb)
DPSIds=VARIATION SPEED OF STATOR
LINKAGE FLUX IN AXIS d (Wb/s)
A Uds.K=STEP(1,0)+
CLIP(1,0,FT.K,GSR+1e-20)+STEP(-1,0)
A OMEGAk.K=1
OMEGAk=OMP STATOR ROTATION
SYNCHRONOUS SPEED (rad/s)
II DIFFERENTIAL EQUATION OF CONDITION:
RdPSIqs.KL=Uqs.K-(PSIqs.K/Tcs)-
OMEGAk.K*PSIds.K+(Kr*PSIqr.K/Tcs)
DPSIqs=VARIATION SPEED OF STATOR
LINKAGE MAGNETIC FLUX IN AXIS q (Wb/s)
Uqs= STATOR VOLTAGE IN AXIS q (V)
PSIqs=STATOR LINKAGE MAGNETIC FLUX IN
AXIS q (Wb/s)
Tcs= STATOR TRANSIENT TIME CONSTANT
OMEGAk=OMP STATOR ROTATION
SYNCHRONOUS SPEED (rad/s)
PSIds= STATOR LINKAGE FLUX IN AXIS d (Wb)
Kr= ROTOR LINKAGE FACTOR
PSIqr=ROTOR LINKAGE MAGNETC
FLUX IN AXIS q (Wb)
L PSIqs=o
PSIqs=STATOR LINKAGE MAGNETIC FLUX IN
AXIS q (Wb/s)
DPSIqs= VARIABLE VARIATION SPEED PSIqs
(Wbs)
A Uqs.K=0
Usq=STATOR VOLTAGE IN AXIS q (V)
A Uas.K=SQRT(Uds.K*Uds.K+Uqs.K*Usq.K)
Uas=VECTOR SUM OF VOLTAGE
COMPONENTS IN AXES q AND d
III DIFFERENTIAL EQUATION OF CONDITION:
R DpsiDR.kl=Udr.K-(PSIdr.K/Tcr)+
(OMEGAk.K-OMEGA.K)*PSIqr.K+Ks*PSIds.K/Tcr
A Udr.K=0
DPSIdr=ROTOR VARIATION SPEED OF
LINKAGE MAGNETIC FLUX IN AXIS d (Wb/s)
Tcr=ROTOR SA 5R TRANSIENT TIME
CONSTANT
Ks=STATOR LINKAGE FACTOR
OMAGAk=OMP STATOR SYNCHRONOUS
ROTATION SPEED (rad/s)
L PSIdr.K=PSIdr.J+DT*(dPSIdr.JK)
PSIdr= ROTOR LINKAGE MAGNETIC FLUX IN
AXIS d (wB)
N PSIdr=0
IV DIFFERENTIAL EQUATION OF CONDITION:
R dPSIqr.KL=Uqr.K-(PSIqr.K/Tcr)-
(OMEGAk.K-OMEGA.K)*PSIdr.K+Ks*PSIas.K/Tcr
A Uqr.K=0
DPSIqr=ROTOR VARIATION SPEED OF
LINKAGE MAGNETIC FLUX IN AXIS q (Wb/s)
Tcr= ROTOR SA 5R TRANSIENT TIME CONSTANT
Ks= STATOR LINKAGE FACTOR
OMEGAk= OMP STATOR SYNCHRONOUS
ROTATION SPEED (rad/s)
LPSIqr.K=PSIqr.J+DT*(dPSIqr.JK)
PSIqr= ROTOR LINKAGE MAGNETIC FLUX IN
AXIS q (Wb)
NPSIqr=0
V DIFFERENTIAL EQUATION OF CONDITION:
RdOMEGA.KL=(1/(2*h))*(Ks/Lcr)*(PSIqs.K*PSIdr.K-
PSIds.K*PSIqr.K)-(1/(2*H))*MT.K
DOMEGA=VARIATION SPEED OF ANGLE SPEED
(rad/s(s)
H= INERTIA CONSTANT
Ks= STATOR LINKAGE FACTOR
Lcr= ROTOR TRANSFORMED INDUCTANCE
L OMEGA.K=OMEGA.J+DT*(dOMEGA.JK)
OMEGA= ANGLE SPEED (rad/s)
N OMEGA=0
VI EQUATION OF ELECTROMAGNETIC TORQUE:
A Mel.K=PSIds.K*Iqs.K-PSIqs.K*Ids.K
VII EQUATION OF LOADING TORQUE:
A MT.K=STEP(MTVA.K*KOPT,0)
C KOPT=1
VIII ADDITIONAL CURRENTS EQUATIONS:
A IDS.K=(1/Lcs)*(PSIds.K-Kr*PSIdr.K)
AIqs.K=(1/Lcs)*(PSIqs.K-Kr*PSIqr.K)
Aiqs.K=(1/Lcs)*(PSIqs.K-Kr*PSIqr.K)
Alas.K=SQRT(Ids.K*Ids.K+Iqs.K*Lqs.K)
A ldr.K=(1/Lcr)*(PSIdr.K-Ks*PSIds.K)
A lqr.K=(1/Lcr)*(PSIqr.K-Ks*PSIqs.K)
A lar.K=SQRT(ldr.K*ldr.K++lqr.K*lqr.K)
IX ADDITIONAL SLIP AND NUMBER OF ASYNCHRONOUS MOTOR REVOLUTION EQUATIONS:
S S:K=(OMEGAk.K-OMEGA.K)/OMEGAk.K
N S=1
SAVE dPSIds,PSIds
SAVE dPSIqs,PSIqs
SAVE dPSIdr,PSIdr
SAVE dPSIqr,PSIqr
SAVE dOMEGA,OMEGA,OMEGAk
SAVE Uds,Uqs,Uas,Ids,Iqs,Ias
SAVE ldr,lqr,lar
SAVE Mel,MT,S
SPEC DT=.01,LENGTH=180,SAVPER=1

2.4. The Results of Simulation

Graphical figure of the simulation results of the BSVMP:

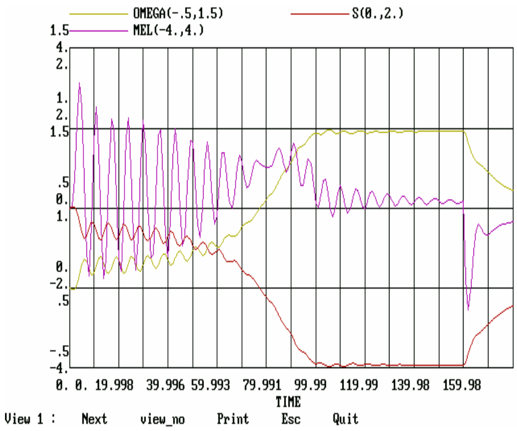

Figure 4: Diagram of loading torque, electric torque and slipping

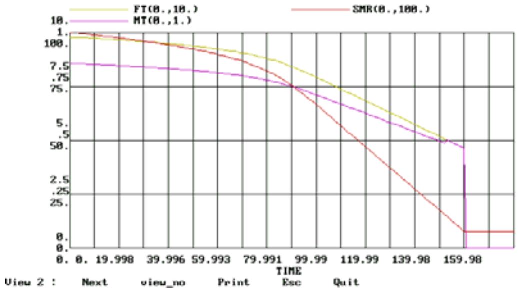

Figure 5: Diagram of loading force, buoyancy, chain length and speed

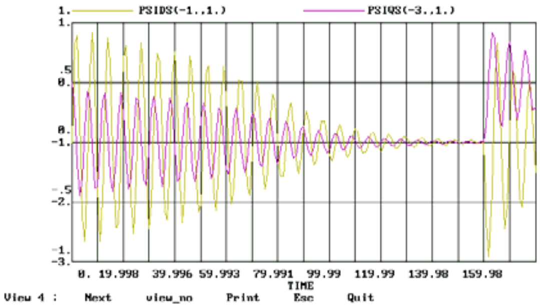

Figure 6: Stator magnetic fluxes

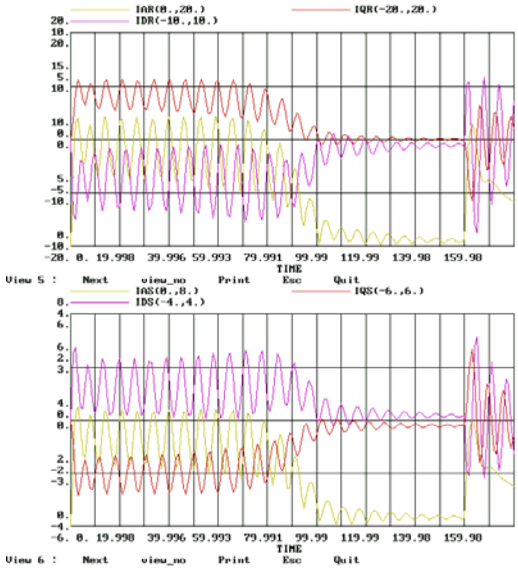

Figure 7: Stator and rotor currents

3. CONCLUSION

System Dynamics is such scientific methodology that provides the simulation of the most complex systems. In the shown example the methodology evidently indicates to the high quality of the simulations of the complex dynamical systems and it gives the opportunity to every student or engineer interested to by the same methodology modulates, optimises and simulates any scenario of the existing realities. Furthermore, the users which use this simulation methodology of the continuous models on a digital computer, create a possibility to themselves of the newest knowledge's in the behaviour of the dynamical systems. The Methodology is also significant because it doesn't contain only a computer type of modelling, but it clearly determinates the metal, structural and mathematical modelling of the same system realities. Based on our long-term experience in the application of the dynamical methodology of simulating and in this short presentation we provide every expert in need with the possibility to acquire additional knowledge about the same system in a quick scientifically based way of exploring the complex systems.

4. REFERENCES

Forrester, Jay W. 1973/1971. “Principles of Systems”, MIT Press, Cambridge Massa-chusetts, USA.

Jadric, M. and Francic, B. 1996. “Dinamikaelektričnih strojeva.”(in Croatian), Manualia Universitatis Studiorum Spalatiensis, Graphics, Zagreb, Croatia.

Munitic, A. and.Milic L. and M.Milikovic, 1997.“SystemDynamics computer Simulation Model of the Marine Diesel – Drive Generation Set 1997. AutomaticControl System.” IMACS World Congress on Scientific Computation, Modelling and Applied Matematichs, vol.5, Wiessenschaft & Technik Verlag, Berlin.

Munitic,A., I.Kuzmunic, M. Krčum, 1998. "System Dynamic Simulation Modelling of the Marine Synchronous Generator", IASTED, Pittsburg. pp.372.-375

Munitic, A. 1989. “Application Possibilities of System Dynamics Modelling.” System Dynamics, Edited by Susan Spencer and George Richardson, Proceedings of the SCS Western Multiconference, SanDiego, California, A Society for Computer Simulation International, San Diego, USA.

Munitić A., Milić L., Bupić, M.,Oct.18- 20, 2001. "System Dynamics Simulation Modeling and Heuristic Optimization of The Induction Motor", Simulation Symposium, Marseille.

Richardson, George P. and Pugh III Aleksander L. 1981. “Introduction to System Dynamics Modelling with Dynamo.”, MIT Press, Cambridge, Massachusetts, USA.

Ante Munitić received his first B.Sc. in Electric and Energetic Engineering in 1968, and his second in 1974, his M.Sc. degree Organisation System and Cybernetics Science (Operational Research) in 1978, and his Ph.D. of Organisation Science (System Dynamics), in 1983.

He is currently a full Profesor of Computer and Informatic Science at the University of Split. He has published over 100 papers on system dynamics modeling and simulation, operational research, marine automatic control system and the Theory of Chaos. He has published two books: "Computer Simulation with help of System Dynamics" and "Basic Electric Energetic and Electronics Engineering".

Mario Oršulić 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 the 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.

Maja Krčum graduated from the Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, University of Split on March 1981. She received a graduate degree (M Sc.) at the Faculty of Electrical Engineering, University of Zagreb in 1996. In 1997 she was appointed Head of Department, also working as a tutor and counsellor. She has participated in a number of both national and international conferences where her papers and lectures were generally acknowledged as an active and valuable contribution towards the development of her profession.
Her primary interest lies in the field of shipboard propulsion systems, with a special emphasis on electrical propulsion and its numerous applications (simulation methods).
She is also a member of several national and international societies (e.g. IEEE, EMAR…).

Joško Dvornik 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 behaviour of ship propulsion system: windlass – asynchronous engine*", with excellent 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 Modelling