Contribution to the Investigation of the Performance of the Marine Diesel Drive Generating Set Using System Dynamics

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Abstract. The System Dynamics Computer Simulation Modeling Methodology is one of the most suitable and effective ways of dynamics modeling of complex non-linear, natural, technical and organization systems. Studying the dynamics behavior of Marine Electric Power Systems, as one of the more complex dynamic non-linear technical systems, requires the application of only the most effective modeling methods. The aim of this paper is to show the efficiency of the System Dynamics Computer Simulation Modelling of the dynamics behavior of Marine Diesel-Drive Generating Set, as one of the most complex and non-linear marine technical systems. The Marine Diesel-Drive Generating Set will be presented as a qualitative and quantitative system dynamics computers model with a special automation aspect provided by two UNIEG-PID-regulators (Electronics Universal PID Regulators). One of them will be used for diesel-motor speed (frequency) regulation and the other will be used for the synchronous electrical generator voltage regulation.

Continuous Simulation Model of the Marine Diesel-Drive Synchronous Generating Set

The Mathematical Model of the Marine Diesel Motor with Turbo Compressor

The mathematical model or level equations of the diesel engine with turbo-compression are:

\[
\frac{d^2 \phi}{dt^2} = \frac{1}{T_H} \left( -T_{DH} \frac{d\phi}{dt} + K_{DH} \phi + T_S \frac{d\chi}{dt} + K_S \chi - T_U \frac{d\alpha_D}{dt} - K_U \alpha_D \right)
\]

where:
- \(\phi\) - relative change of angular velocity,
- \(\chi\) - relative shift of the high-pressure fuel pump cogged shaft,
- \(\alpha_D\) - relative consumer load change,
- \(T_H\) - time constant proportional to the moment of inertia,
- \(T_{DH}\) - time constant opposite-proportional to the moment of inertia of the engine as the object of regulation,
- \(K_{DH}\) - self regulating and amplification factor,
- \(T_S\) - motor time constant of inertia, \(K_S\) - motor amplification factor,
- \(T_U\) - generator time constant of inertia and \(K_U\) - load amplification factors.

System Dynamics Mental-Verbal Simulation Model of the Marine Diesel Motor with Turbo Compressor

In the accordance with the System Dynamics Structural-qualitative (Figure 1.) and Mathematical-quantitative (Equations 1.) models of the Marine Diesel Motor with turbo compression, it is possible to work out the next System Dynamics Mental-Verbal-qualitative Simulation Model of the Diesel Motor:

“If the constants: \(TH= T_H\) = time constant proportional to moment of inertia, \(TDH= T_{DH}\) = time constant opposite-proportional to moment of inertia of the engine as the object of regulation,
- \(KDH\) = self-regulating and amplification factor, \(TU= T_U\) = generator time constant of inertia and \(KU= K_U\) = load amplification factor, then there will be a growth of the \(D2FIDT2\) = acceleration, or
the second derivation of the relative changing of angular velocity \( FI = \varphi \) will drop”. This means that those cause-consequence links have a “negative” (-) dynamics character.

“If the constants: \( TS = T_s = \) motor time constant of inertia and \( KS = K_S = \) motor amplification factor grow, then the \( D2FIDT2 = \) acceleration or the second derivation of the relative changing of angular velocity \( FI = \varphi \) will be grow also”. This means that those cause-consequence links have a “positive” (+) dynamics character.

“If the variables \( DFIDT = \) speed or the first derivation of the relative changing of angular velocity \( \varphi \), \( FI = \) relative changing of angular velocity \( \varphi \), \( ALFAD = \) relative consumer load change \( \alpha_0 \) and \( DALFADT = \) speed or the first derivation of the relative load change \( \alpha_0 \) grow then the \( D2FIDT2 = \) acceleration or second derivation of the relative changing of angular velocity \( \varphi \) will drop”. This means that those cause-consequence links have a “negative” (-) dynamics character.

“If the variables \( DKAPADT = \) speed or the first derivation of the relative shift of the high-pressure fuel pump cogged shaft \( \chi \), and \( KAPA = \) relative shift of the high-pressure fuel pump cogged shaft grow, then \( D2FIDT2 = \) acceleration or the second derivation of the relative change of angular velocity \( \varphi \) will be grow”. This means that those cause-consequence links have a “positive” (+) dynamics character. It is important to analyze the dynamics character of the next “exogenous” variables: \( CFI \) and \( MEL \).

“If \( CFI = \) nominal (goal’s) relative change of angular velocity \( \varphi \) grows, then the variable \( DISK1 = \) discrepancy between \( CFI \) and \( FI = \) relative change of angular velocity \( \varphi \) will also grow”. This means that these cause-consequence flows have a “positive” (+) dynamics character.

“If \( MEL = \) generator’s relative electromagnetic moment (diesel-motor’s burdening) grows, then \( ALFAD = \) relative consumer load change and \( DALFAD = \) speed or the first derivation of the \( ALFAD \) will be grow also”. This means that these cause-consequence links will have a “positive” (+) dynamics character.

“If the \( D2FIDT2 \) grows than the \( DFIDT \) will grow also. This means that the CCL-cause consequence links have a “positive” (+) dynamics character, and if the \( DFIDT \) grows, then the \( FI \) will grow also. This means that the CCL has a “positive” (+) dynamics character, and if the \( FI \) grows, then the \( D2FIDT2 \) will drop, which means that the CCL has a “negative” (-) dynamics character. Further, this FBL has a global “negative” (-) or self-regulating dynamics character”, because “the sum of the negative sign in the FBL is an odd-number.

Every one of those FBLs has a global “negative” (-) or “self-regulating” dynamics character. It is important to the following two variables: the \( KAPA1 = \) UNIREG1 as the output, and the \( DISK1 \), as the input of the first universal PID regulator. It is possible to deduce that the diesel-motor global model is represented as a “IVth order” system (the second order differential equation model of the diesel-motor and second order differential equation model of the PID regulator), because in each elementary DT-iterative simulation-calculating time period, this model did four integrating mathematical operations.

The \( KAPA = \) relative shift of the high-pressure fuel pump cogged shaft has a logically protected automatic switch installed, which has the next mathematical and logical system dynamics model in the DYNAMO-language package:

\[
A \ KAPA.K = CLIP(KAPA1.K,0,DELAY1(RL.K,2),1E-18) \tag{2}
\]
where: \( A = \) DYNAMO symbol for an auxiliary equation; \( KAPA = \) relative shift of the high-pressure fuel pump cogged shaft; \( .K = \) DYNAMO symbol for the time dependent function; \( CLIP = \) DYNAMO MACRO logical function; \( KAPA1 = \) output of the UNIREG1 PID regulator; \( DELAY1 = \) DYNAMO symbol for the MACRO function of the material flow exponential delay of the first order; \( RL = \) load resistance; \( 2 = \) delay time of the \( DELAY1 \); \( 1e-18 = \) computer zero:

The system dynamics mental-verbal model is:

“If the \( RL \) is \( >= 1e-18 \) then \( KAPA = KAPA1 \)”, and

“If the \( RL \) is \( < 1e-18 \) (short circuit) then \( KAPA = 0 \)” (closed fuel feed pump).
System Dynamics Structural Simulation Model of the Marine Diesel Motor with Turbo Compressor

According to the described mental-verbal model it is possible to determine the System Dynamic structural model.

In observed system there are few feedback loops (FBL):

\[
\begin{align*}
FBL_1: & \quad D2FIDT2(+) \Rightarrow DFIDT(+) \Rightarrow FI(-) \Rightarrow D2FIDT2 \\
FBL_2: & \quad FI(-) \Rightarrow DISK1(+) \Rightarrow KAPA1(+) \Rightarrow KAPA(+) \Rightarrow D2FIDT2(+) \Rightarrow DFIDT(+) \Rightarrow FI \\
FBL_3: & \quad FI(-) \Rightarrow DISK1(+) \Rightarrow KAPA1(+) \Rightarrow KAPA(+) \Rightarrow DKAPADT(+) \Rightarrow D2FIDT2(+) \Rightarrow DFIDT(+) \Rightarrow FI
\end{align*}
\]

Simulation Model of the Marine Diesel-Drive Generating Set

The mixed scenario has been built into this computer simulation model of DDSGS: 1. - diesel engine starts at TIME= 0 (s) and KAPA= gears batten relative shift of high-pressure fuel pump is shifted (opened), and it is self-started in “idle-running” mode; 2. - synchro-generator starts with its self-exiting process at TIME= 20 (s); 3. - load impedance or resistance $R_L$ and reactance $X_L$ starts at TIME= 0 (s). The $R_L=150$ and $X_L=0$, which means that DDSGS is in the “idle-running” mode. At TIME= 40 (s), the $R_L=1$ and $X_L=1$ (nominal load); and 4. - stator short-circuit start at TIME = 70 (s) and $R_L=0$ and $X_L=0$, which means that DDSGS is in the “short circuit” mode. The authors had installed two automatic short-circuit protection switches also. One of them had taken out the $u_f$ = rotor exciting voltage time reaction delay, which is $.4$ (s) and the other had taken out the KAPA= relative shift of the high-pressure fuel pump cogged shaft time reaction delay, which is 2 (s).

Results:

![Figure 2. FI.](image-url)
The dynamics behavior reaction to this mixed scenario, after the modeler had finished the process of "heuristic optimization" by parameters of two UNIREG-PID regulators ("retry and error" computer manual method), is the following set of time curves (Figure 4. and 5.), where: FI= relative rate of angular velocity, U= u = stator effective voltage, I= stator effective current. Everyone acquainted with thermodynamics and electrodynamics machine sets recognizes the dynamically transient well-known behaviors of the Marine Diesel-Drive Synchronous Generating Set.
Conclusion

The application of System Dynamics Simulation Modelling Approach of the complex marine dynamic processes revealed the following facts:

1. 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.

References