PARAMETRIC ANALYSIS OF AUTOMOTIVE MECHATRONIC SYSTEMS

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Abstract

The paper presents the analysis results of the fan system using hardware/software multi-technology language VHDL-AMS (IEEE 1076.1) and SystemVision design platform. The analysis was performed in the time domain for the selected sweep values of the component parameters.

The sensitivity analysis was used to vary selected, user-specified percentage of rated values .The parameters were arranged according to the effect on the selected waveforms. The further analysis was performed using statistic method Monte Carlo (MC) and Worst Case (WCA).

Results of simulation are presented and the advantage of MC simulation over sensitivity analysis was emphasized. Post processing measurement tools of MC results and calculator with the standard mathematical operators and advanced statistic functions were used to picture the system performance versus run number and to determine correlations between devices parameters and system performance.

The obtained characteristics enable the designer to evaluate the reliability of the system when manufactured in the large scale and to state the worst case limits for the project.

Keywords*: automotive mechatronics, parametric analysis, modelling and simulation*

1. Introduction

Designing, simulation and analysis of mechatronic systems of a vehicle comprises: units and electric installations, on board computer networks CAN, LIN and electronic control modules as well as units of mechanical, hydraulic, pneumatic and thermal (heating and cooling) installations. A system of virtual designing of vehicle mechatronic subsystems [1] takes into account all stages of the designing process and the structure interdisciplinary. Models of control units, sensors, actuators and microcontrollers allow for the control algorithms verification as well as for the analysis and optimisation of the system being designed. Especially the parametric analysis, providing answers concerning the system resistance to the changes of the deterministic and statistic parameter values and model structure changes is an important tool in the project realisation process.

Several programming packets, optimised from the point of view of various structures and production technologies, are currently available. Utilising proper programming tools, which allow shortening the creation time of the final product, is essential. Design platform SystemVision [2] with the hardware and software description language VHDL-AMS (IEEE Standard 1076.1) found several applications concerning vehicle mechatronic systems.

2. Investigations of dynamic properties of the mechatronic fan control system

Investigations of dynamic properties of the cooler fan system on the basis of program models VHDL-AMS of DC motor, fan, wiring harnesses (battery, wires, fuses, diodes, switches) and controller (described in [3]) - are presented in the hereby paper. The parametric analysis was performed in the time domain, investigating the dependence of the system model responses to changes of motor and fan parameters.

Tab. 1. Rated Parameters of the Fan System

Parameter	Name	Value
Motor terminal resistance	yfan_motor.r_wind	2 Ω
Motor torque constant	yfan_motor.kt	0.05 Nm/A
Motor rotor inductance	yfan_motor.l	0.01 H
Motor viscosity constant	yfan_motor.d	2.5e-5 Nm/rad/s
Motor moment of inertia	yfan_motor.j	1.4e-5 kgm^2
Fan second order coefficient	yfan1.d2	2.0e-6 $Nm/rad/s^2$
Fan rotor moment of inertia	yfan1.j	0.0003 kgm^2

3. Sensitivity analysis

An influence of a tolerance of parameters assumed for the model of the system performance was investigated by a sensitivity analysis. Determining percentage deviations from the rated value of the selected parameter it is possible to sort parameters according to the degree in which their tolerance influences the given characteristic.

Characteristics of the angular velocity for the model of the rotor cooler fan at rated parameters and maximum deviations of angular velocity at the assumption of 10% tolerance of the motor terminal resistance (r_wind) and the fan rotor moment of inertia (yfan1_j) – are shown in Fig. 1. The average angular velocity of 101.86 radians/s was recorded at the rated parameters while the maximum deviations of 103.29 radians/s values, and 100.01 radians/s were recorded at the assumed tolerance of parameters. The obtained results indicate a higher influence of the tolerance of engine windings (-1.8%) than the tolerance of the fan rotor moment of inertia (+1.4%) – on the average angular velocity.

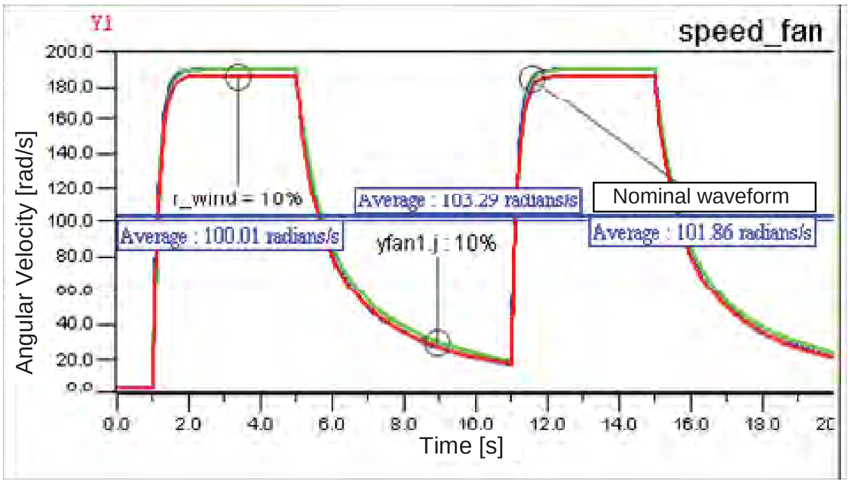

Fig. 1. Angular Velocity Waveforms versus Time from Sensitivity Analysis

The complete analysis of all seven motor and fan parameters, defined in Tab. 1, on the responses of the model are given in Fig. 2. Due to the determination of percentage deviations from the rated value of the individual parameters it was possible to arrange parameters according to the degree in which the tolerance influences the characteristics of the average fan angular velocity.

The presented diagram indicates, that the average angular velocity in the fan control system is the most sensitive to the motor torque constant .kt while the least sensitive to the motor rotor inductance l. Further analysis of influence of all parameters on the model response was achieved by means of the statistic tools.

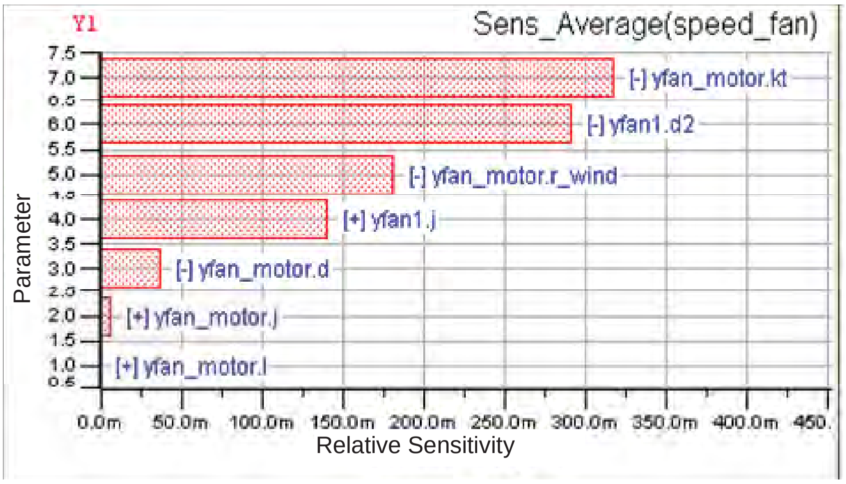

Fig. 2. Sensitivity Analysis Results Chart – Fan Parameter versus Relative Sensitivity

4. Statistic analysis

The MC analysis enables calculations of the model, which takes into consideration the parameters tolerance range being in conformity with the assumed random distribution. The Worst WCA takes into account only extreme values of the selected parameters and requires the previous estimation of relations between all assumed parameters and the selected system characteristics.

The diagrams of the angular fan velocity at the MC simulation - with 10% tolerance according to the normal distribution of all selected parameters - are presented in Fig. 3.

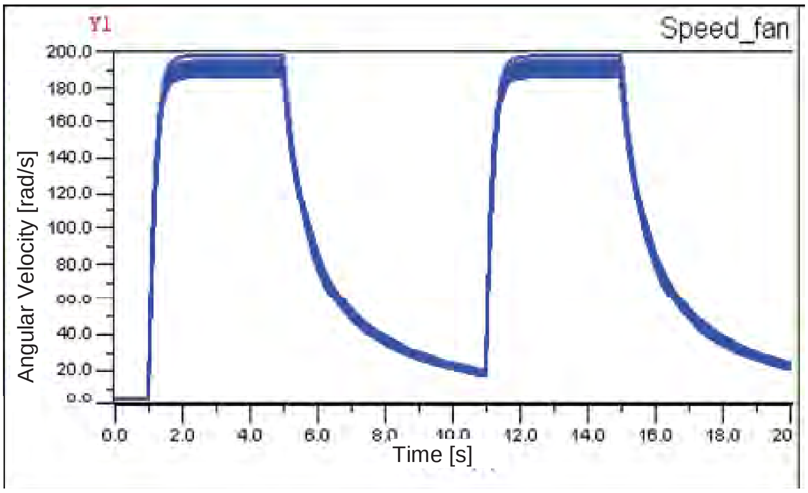

Fig. 3. Angular Velocity Waveforms versus Time from 2k Runs MC Analysis

Minimum and maximum average values and fan angular velocities, which were recorded at the WCA analysis - with 10 % tolerance according to the normal distribution of all considered parameters - are presented in Fig. 4.

Investigations were performed at assuming 20, 200 and 2000 simulation multiplication factor.

Subsequent diagrams present examples of the application of the calculating, measuring and graphic tools of the SystemVision platform. Apart from standard mathematical operators statistic functions were used. These tools can be applied for presenting the system properties in dependence on the MC test number and for the determination of correlations between the tested dependent variables and independent factors. When 2000 MC simulation ratio was realised, the minimum average angular velocity of the cooler fan was recorded in test No. 283, while the maximum average angular velocity was in test No. 1231, (which is shown in Fig. 5).

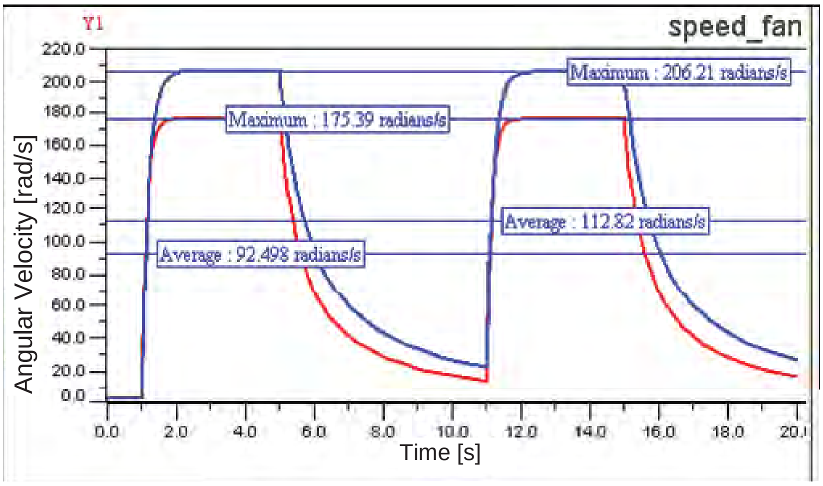

Fig. 4. Angular Velocity Waveforms versus Time from WCA Analysis

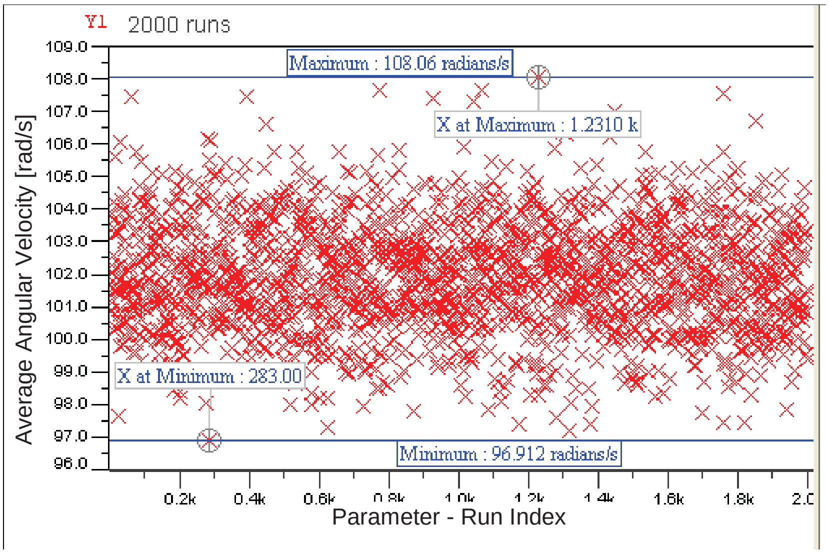

Fig. 5. Scatter Plot of Average Angular Velocity versus MC Run

The distribution of tests of the determined average angular velocity in the range +/- 3 of the standard deviation of the arithmetic mean value – are presented in Fig. 6.

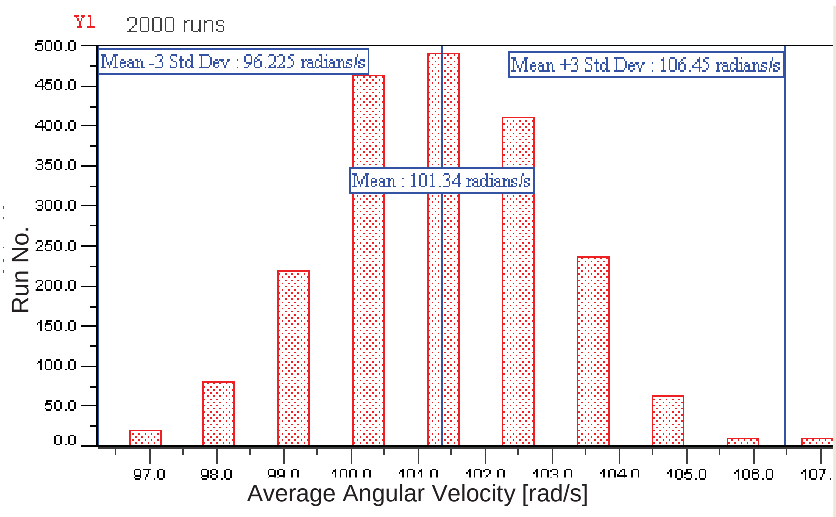

Fig. 6. Histogram of Run Number versus Average Angular Velocity

The diagram presented in Fig. 7 illustrates the correlation investigation aimed at the determination of the relation between the fan average angular velocity and the system parameters. The square of the multiple correlation factor (R-Squared) for the motor torque constant was equal to 0.381.

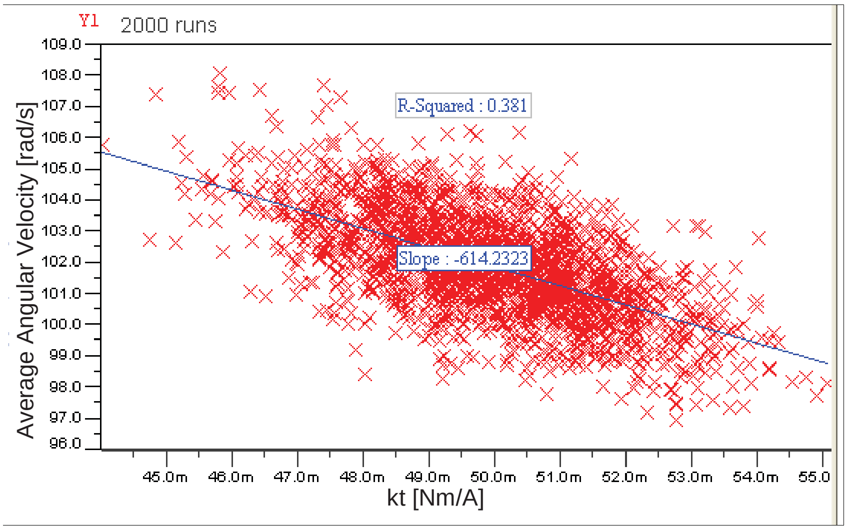

Fig. 7. Scatter Plot of Average Angular Velocity versus Motor Torque Constant

5. Conclusions

Sensors in mechatronic systems convert not electric values into electric signals. Executing elements assign certain forms of physical effects to electric signals generated by microcontrollers. The virtual designing based on models of the applied hardware and software enables an interactive monitoring of characteristics - in the interesting for us points - of not yet existing prototype. The parametric analysis, performed additionally, allows for the device optimisation, it means for increasing its stability and reliability. The superiority of the statistic Monte Carlo analysis over the sensitivity analysis is caused by the fact that during the MC investigation of the system the changes of all selected parameters are simultaneously simulated and not a change of one parameter in the given time instant. The obtained statistic data allow the designer to estimate the system behaviour at random changes of parameter values, which mean the model reliability at its implementation in a large scale. Thus, they increase effectiveness of the designer's work shortening the time of creation of the final project. This approach can be also applied for investigations of correlations between system properties and subsystem parameters as well as algorithms and control parameters of microcontroller systems – which are currently being studied by the author.

References

[1] Puchalski, A., *Mechatroniczne projektowanie układów EE pojazdu*, Journal of KONES, Vol. 15, No. 2, s. 393-398, Warsaw 2008.

[2] *Getting Started with SystemVision, A Tutorial*, Copyright Mentor Graphic Corporation, 2008.

[3] Puchalski, A., *Modelowanie i symulacja podukładów mechatroniki samochodowej*, Diagnostyka, Nr 3 (51), s. 101-104, 2009.

[4] *Fundamentals of VHDL-AMS for Automotive Electrical Systems*, Copyright Mentor Graphics Corporation, 2004, www.mentor.com.