

STRUCTURAL NONLINEARITIES SIMULATION ON THE FLUTTER ELECTROMECHANICAL MODELING TEST BENCH

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Abstract

In this paper the problem of structural nonlinearities simulation on the flutter electromechanical modeling test bench (EMM) is considered. This work is a development of previous studies concerning aerodynamic forces simulation on EMM.

1 Introduction

This paper is a continuation and further development of research on the EMM test bench [1]. Relatively complete overview of the work with the EMM, since 60-ies at TsAGI (including early work at the University of Bristol, England, and at ONERA, France), was presented in the report [2].

Flutter electromechanical modeling test bench (Fig.1) is designed for experimental flutter studies without wind tunnels. In order to simulate increments of aerodynamic forces during model's oscillations in airflow, distributed aerodynamic forces are reduced to concentrated ones, according to aerodynamic hypotheses. This simulation can be applied for flight modes with wide range of air densities, Mach numbers and airspeeds.

Wind tunnel testing of dynamically scaled models is one of the most important tools of aeroelasticity characteristics research, in particular flutter research. However, the cost of the models for such tests and the cost of the tests themselves are high enough, besides the tests are associated with the risk of model crash.

To minimize the risks and get more information about the possible behavior of the model in the flow it is advisable to perform preliminary studies on a special electromechanical modeling bench.

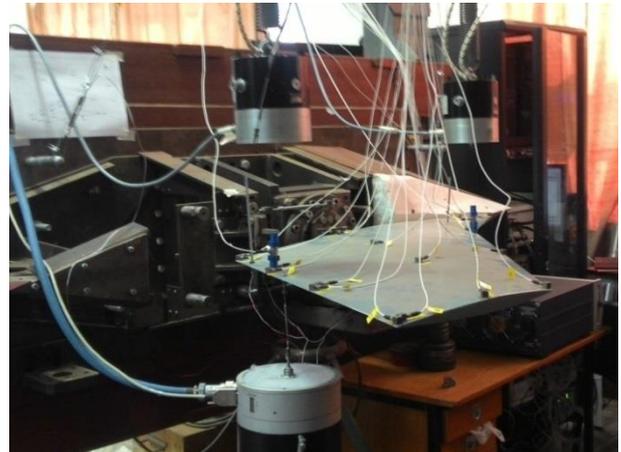


Fig.1. Flutter electromechanical modeling test bench

Studies on such a stand have several advantages:

- there is no constraints in the range of simulated flow regimes;
- low-cost tests;
- safety of the model during tests;
- wide opportunities for the training of students and staff;
- ability to install the additional measuring instruments, which fundamentally cannot be used in a wind tunnel experiment.

An important advantage of such a bench is the ability to study various aerodynamic theories and input into the construction of a variety of regulated nonlinearities. Three different types of

structural nonlinearities are realized on the EMM test bench: cubic nonlinearity, dead zone and backlash.

In this paper the results of the simulation of structural nonlinearities on the EMM test bench are presented.

2 Nonlinearities modeling system description

Structural nonlinearities modeling system consists of feedback sensor, nonlinearities modeling unit, power amplifier and modal shaker. This system is external to the regular vibration testing equipment and is intended to simulate various nonlinear characteristics of the model under research.

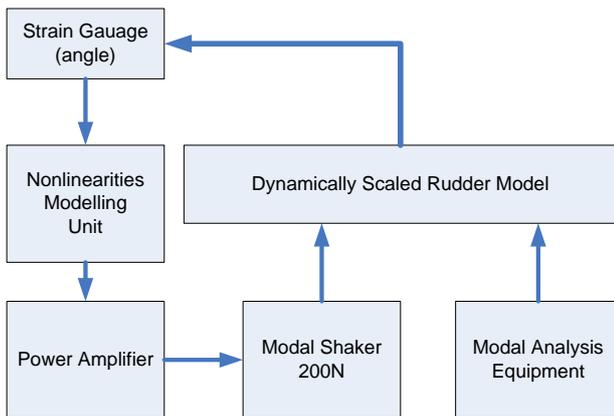


Fig.2. Nonlinearities modeling scheme

Rudder's rotation angle is used as a feedback signal. The angle is measured using strain gauges with amplifying equipment. Gauges are installed on the spring which provides torsion stiffness of the rudder model.

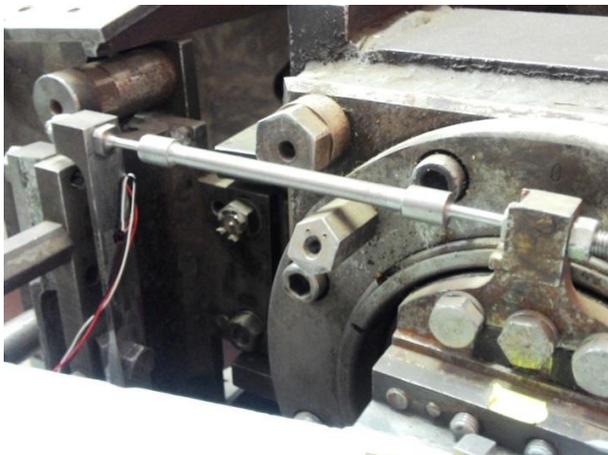


Fig.3. Torsion spring with strain gauges

Sensor calibration was performed using precise electronic inclinometer. The calibration curve is shown in Fig.4. The voltage linearly depends on the rudder rotation angle.

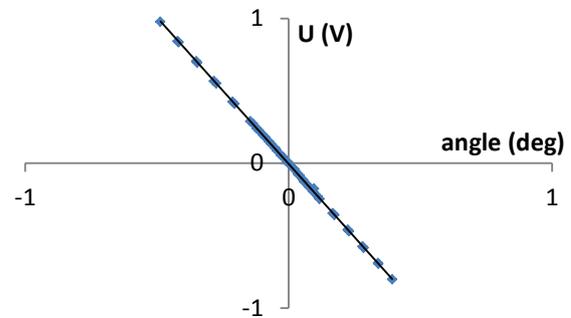


Fig.4. Strain gauges calibration curve

Nonlinearities modeling unit (NMU) is a specialized computer which converts the feedback signal into a signal transmitted to the shaker through a power amplifier so as to provide the required force on the model. NMU consists of National Instruments controller with real-time operating system and FPGA board.

This equipment provides measuring the voltage via 16-bit analog-to-digital converter (ADC), calculation of output signal and digital-to-analog conversion (DAC) in deterministic amount of time.

Software implementation of NMU consists of the FPGA board software and graphical user interface which is used for monitoring, control and configuration of system. FPGA board software block diagram is shown in Fig.5.

The data from ADC is converted to rudder rotation angle. Angle is then supplied to the subroutine modeling different types of nonlinearities, which calculated the corresponding forces. Then all the forces are summed, converted into voltage (according to the calibration curve) and transmitted to the DAC.

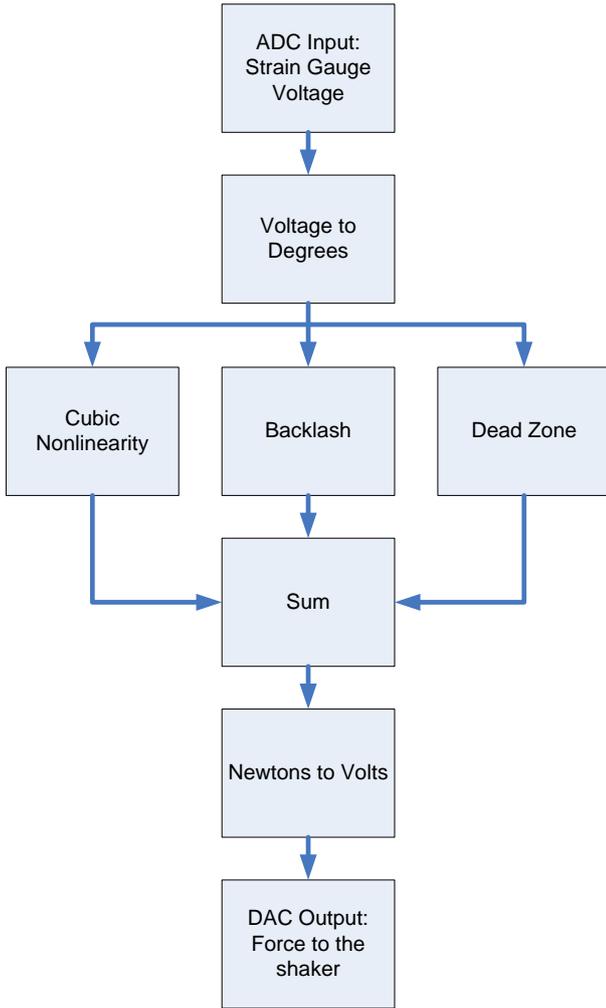


Fig.5. FPGA software block diagram

3 Cubic nonlinearity

Cubic nonlinear dependence of torque M on the angle δ has an analytic description (1) and is shown in Fig.2.

$$M = K_1 \delta + K_3 \delta^3 \quad (1)$$

Spring with $K_3 < 0$ (Fig.6) is called a soft spring and spring is hard when $K_3 > 0$ (Fig.7).

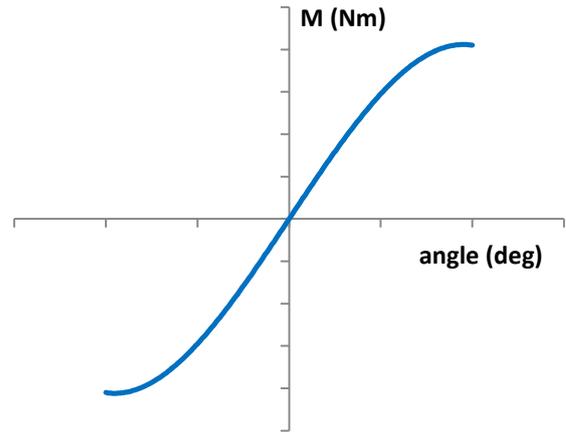


Fig.6. Cubic nonlinear dependence of torque moment on the angle (soft spring)

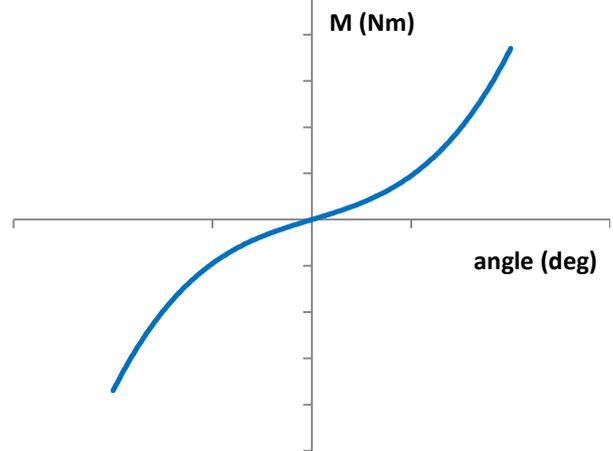


Fig.7. Cubic nonlinear dependence of torque moment on the angle (hard spring)

Rudder's torsion spring has its original elasticity K_1 . The force (2) is generated by the modal shaker to provide the required torque on the rudder.

$$F = \frac{K_3 \delta^3}{x_{shaker}} \quad (2)$$

, where x_{shaker} is the x-coordinate of modal shaker's attachment point.

Vibration testing of the rudder with cubic nonlinearity turned on was performed. In figures 8 and 9 frequency responses for both hard and soft springs and different coefficients are shown. Stepped sine method was used to measure the frequency response. The graphs show the difference in frequency response for two directions (up – increasing of frequency and down – decreasing of frequency).

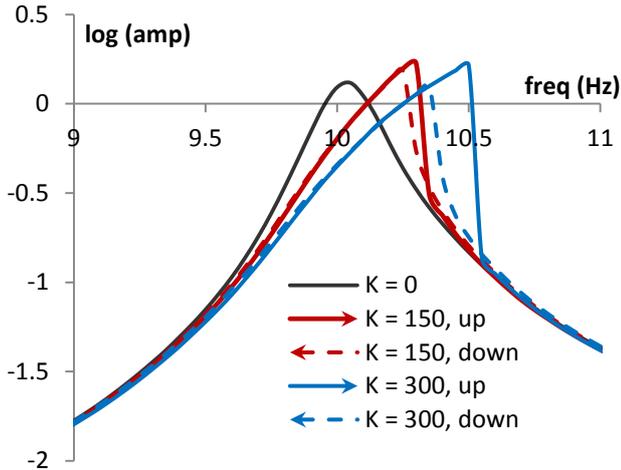


Fig.8. Frequency response curves for hard spring with different cubic coefficients

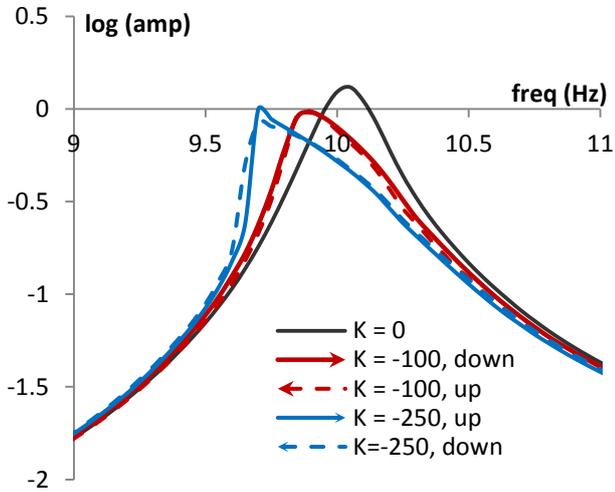


Fig.9. Frequency response curves for soft spring with different cubic coefficients

4 Dead zone

The dead zone is described by the equations (3), in which $\pm\Delta$ - dead zone value. In Fig.3. dependence of the torque on the angle in the system with dead zone is shown.

$$M = \begin{cases} 0, & |\delta| \leq \Delta \\ K_1(\delta - \text{sign}(\delta)\Delta), & |\delta| > \Delta \end{cases} \quad (3)$$

In order to provide such torque the force (4) is generated by shaker.

$$F = \begin{cases} \frac{-K_1\delta}{x_{shaker}}, & |\delta| \leq \Delta \\ \frac{K_1\text{sign}(\delta)\Delta}{x_{shaker}}, & |\delta| > \Delta \end{cases} \quad (4)$$

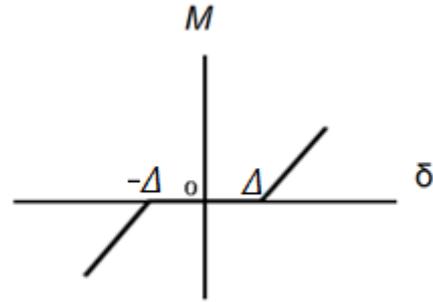


Fig.10. Dependence of the torque on the angle in the system with dead zone

Frequency response curves for rudder oscillations with different dead zone values are shown in Fig.11. The maximum amplitude is increasing with increasing value of dead zone, as well as the “hysteresis band”.

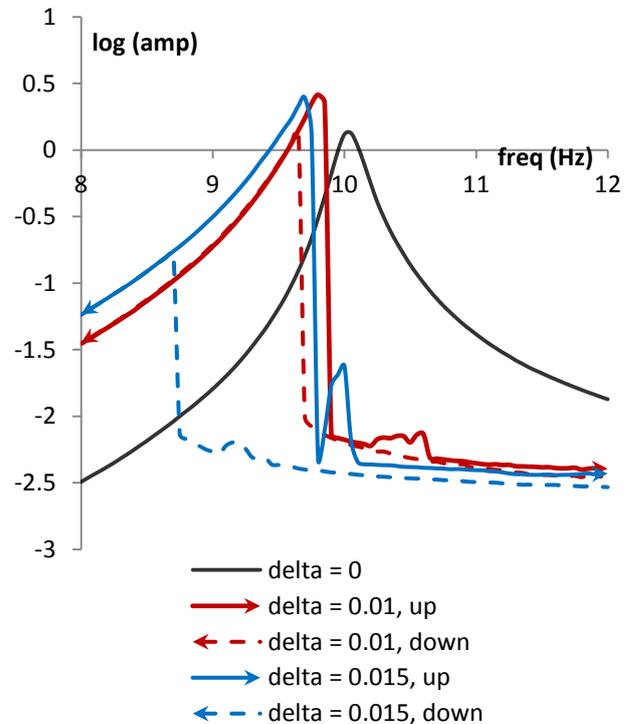


Fig.11. Frequency response curves for rudder oscillations with different dead zone values (Δ)

5 Backlash

Backlash modeling algorithm's mathematical description is given in Table 1, where δ – rudder rotation angle, δ_m – maximum angle, δ_0 – the angle when derivative sign was changed, Δ –backlash size, F – output force. The illustration of backlash in two gears is shown in Fig.12.

Table 1. Backlash analytic description

$\dot{\delta}$	δ	F
$\dot{\delta} \geq 0$	$-\delta_0 \leq \delta \leq -(\delta_0 - \Delta)$	$\frac{-K_1 \delta}{x_{shaker}}$
	$\delta > -(\delta_0 - \Delta)$	$-\frac{K_1 \text{sign}(\delta) \Delta}{x_{shaker}}$
$\dot{\delta} < 0$	$(\delta_0 - \Delta) \leq \delta \leq \delta_0$	$\frac{-K_1 \delta}{x_{shaker}}$
	$\delta < (\delta_0 - \Delta)$	$-\frac{K_1 \text{sign}(\delta) \Delta}{x_{shaker}}$

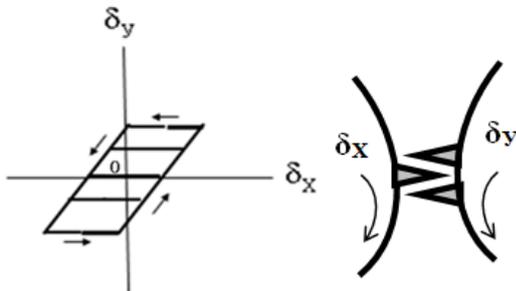


Fig.12. Backlash example: two gears

Backlash often occurs in rudders and affects the flutter's critical velocity.

Conclusion

The research revealed the possibility of nonlinearities reproduction on the flutter electromechanical test bench. The results confirming the correctness of the simulation (in both dynamic and static ways) were obtained.

References

- [1] Smyslov V, Karkle P and ProninM. Aerodynamic Force Simulation Demo Model for Experiment-calculated Flutter Research *International Forum on Aeroelasticity and Structural Dynamics*, Paris, France, IF-061, 2011.
- [2] Karkle P., Smyslov V. Electromechanical simulation method in dynamic aeroelasticity – usage experience and future trends *International Forum on Aeroelasticity and Structural Dynamics*, Stockholm, Sweden, 2007.

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