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RESEARCH ON DYNAMIC STABILITY OF AN ELASTIC MODEL USING TESTS IN ARTIFICIAL FLOW

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Abstract: Modal tests and experiments in artificial flow (provided by electromechanical modeling method - EMM) are conducted with elastically scaled model developed for wind tunnel (WT) flutter research before entering WT for actual tests. The main objective of EMM tests is to determine modal characteristics of the model out of the flow and “in the EMM flow” within stability boundaries and their dependence on model parameters and flow conditions. Concentrated aerodynamic forces which depend on oscillations of several points of the scaled model are being computed in real time by special computing unit based on different aerodynamic theories that may be selected by a tests engineer. Data acquisition and excitation systems intended for wind tunnel flutter tests may be adjusted during EMM tests. Some additional measurements with EMM are carried out at the end of wind tunnel tests including conditions not investigated in the WT. Some experimental results on dynamically scaled elevator model are presented. Analysis of the data, assessment of the advantages and limitations of the EMM method are given in this work.

1 INTRODUCTION

Research problems on dynamic aeroelasticity related to the usage of test benches with artificial flow (also referred to as flutter electromechanical modeling – EMM) have quite a long history summarized in [1].

In authors’ previous works devoted to this subject [2],[3], the EMM testing technique, the theory of concentrated aerodynamic forces calculation and structural nonlinearities modeling have been considered.

This work expands previous research. In contrast to the earlier works velocity sensors are used instead of accelerometers to measure the mode shape of the elastic model. New software for real-time calculation of aerodynamic concentrated forces and for test bench control has also been developed. This paper describes the operational principle of the flutter EMM test bench. The software architecture, concentrated forces calculation algorithms and experimental results are given in this paper.

2 ELECTROMECHANICAL MODELING TEST BENCH

The test bench is designed for EMM test technique improvement. EMM test bench scheme is shown in Figure 1. The appearance of the bench is shown in Figure 2. Dynamically scaled rudder model is used as a test model. The rudder is mounted on the spring that simulates the control drive stiffness.

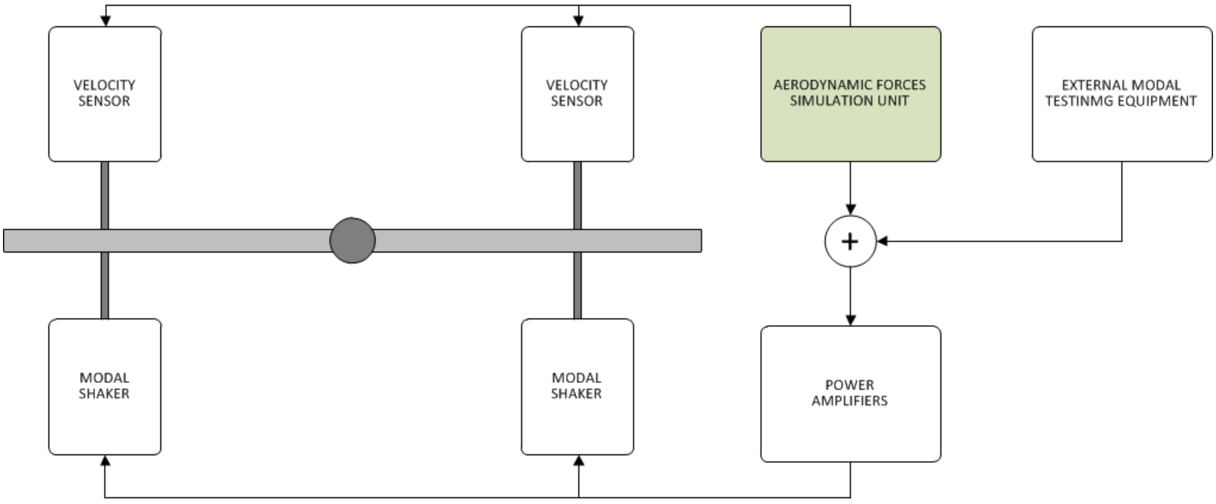


Figure 1. EMM test bench scheme

Figure 2. EMM test bench appearance

Inductive velocity sensors (Figure 3) are attached to the rudder. The analog signal from the sensors is fed to the aerodynamic forces modeling unit developed by means of the National

Instruments equipment. This unit calculates the corresponding concentrated aerodynamic forces and outputs an analog signal to power amplifiers which in turn control the modal shakers.

Figure 3. Inductive velocity sensor

The analog signal from external modal testing equipment (LMS SCADAS) is also fed to the power amplifiers through the analog summer. To measure the construction’s modal characteristics modal testing equipment is used. Different excitation methods (stepped sine, random excitation, etc.) can be applied.

The usage of modern computation devices allows real-time aerodynamic forces simulation. Efficient controller based on the field-programmable gate array (FPGA) allows performing calculations without significant phase shifts.

EMM test bench allows conducting research of new aerodynamic forces calculation algorithms and verification of these algorithms based on the WT test results. In addition, the test bench serves as a visual aid in the teaching process of students as well as junior researchers who specializes in dynamic aeroelasticity.

3 SOFTWARE

In order to provide EMM test bench operation special software has been developed. EMM test bench software architecture is shown in Figure 4. The software consists of four main parts: aerodynamic matrices calculation software, bench control software, real-time operation software and FPGA software.

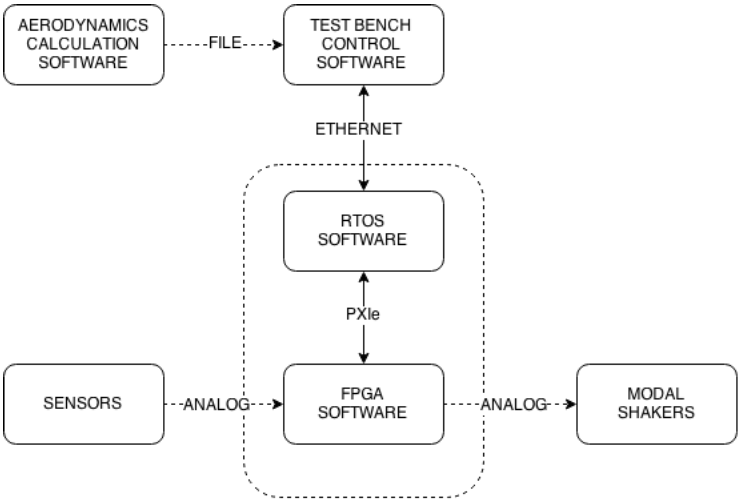


Figure 4. EMM test bench software scheme

The results of aerodynamic matrices calculation software operation are files containing tables of aerodynamic stiffness and damping matrices elements calculated at different Mach and Strouhal numbers for given aerodynamic model. The range of Mach and Strouhal numbers as well as the grid size can be set by a user. For the sake of increasing the system performance these values are approximated rather than being calculated during an experiment.

FPGA software is designed to transform signals from the sensors to an analog signal, which is fed to modal shakers. The supported sensors are: accelerometers, velocity sensors and displacement sensors. Signals from the sensors are converted into displacement. For accelerometers double integration and for velocity sensors single integration is performed. The signal to be fed to the digital-to-analog converter in each channel is a linear combination of displacements. The coefficients of this combination are calculated in the real-time controller and depend on Mach and Strouhal numbers, density, flow velocity and calibration coefficients of sensors and modal shakers. FPGA software block scheme is presented in the Figure 5.

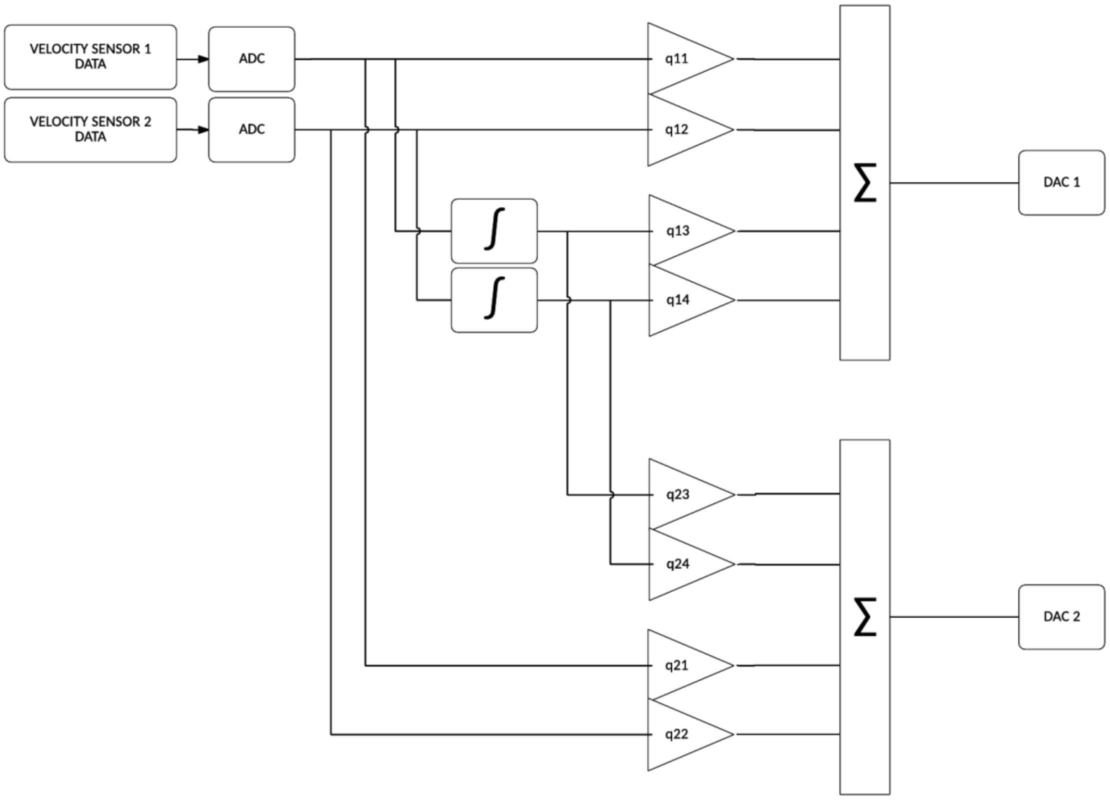
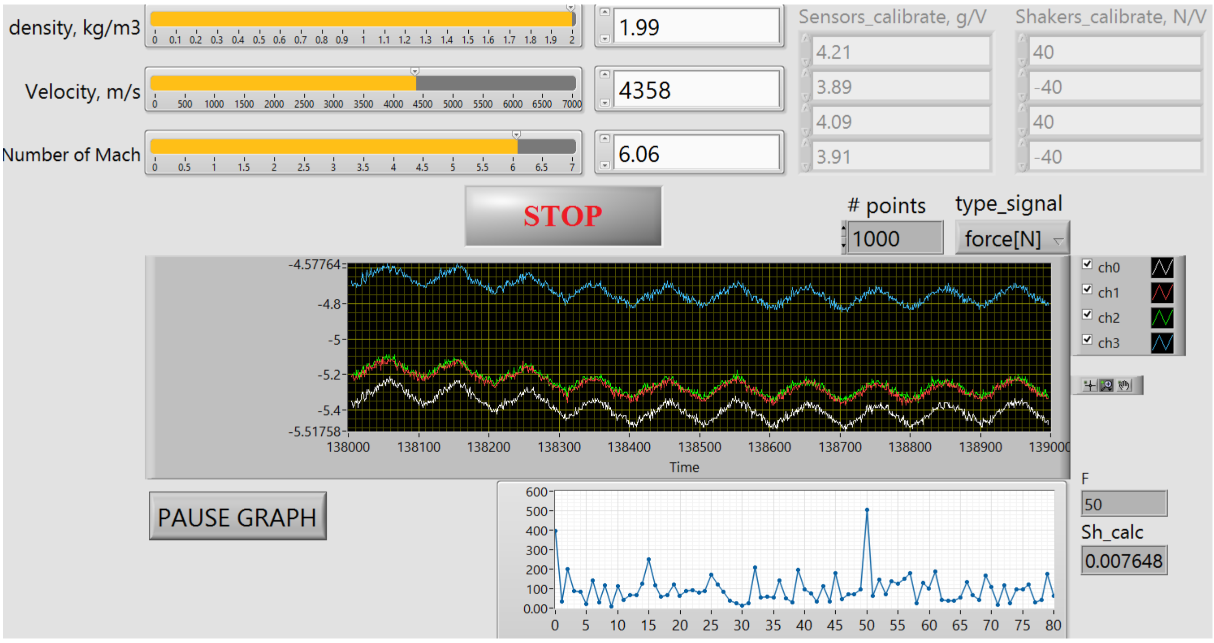


Figure 5. FPGA software block scheme

The bench control software is designed for test process control, visualization and documentation of the results. The program graphical user interface is shown in Figure 6.


density, kg/m3 1.99

Velocity, m/s 4358

Number of Mach 6.06

Sensors_calibrate, g/V
4.21
3.89
4.09
3.91

Shakers_calibrate, N/V
40
-40
40
-40

points 1000

type_signal force[N]

F 50

Sh_calc 0.007648

Figure 6. Bench control graphical user interface

The software performs following functions:

- artificial flow start/stop;
- emergency stop (at a given threshold value);
- flow parameters control (Mach, Strouhal, density, speed);
- sensors and modal shaker calibration coefficients settings;
- sensors data and output signal visualization in both time and frequency domains;
- aerodynamic model loading from file.

Real-time operation software serves as an interface between FPGA software and test bench control software. Commands and parameters entered to the test bench control software are transferred to FPGA via user datagram protocol. Then the data from FPGA is transmitted to operator's computer for visualization.

4 EXPERIMENTAL RESULTS

During the experiment Mach number and density were fixed while flow speed was being increased. To account for the effect of flow unsteadiness Strouhal number was automatically computed for experimental mode frequency and coefficients of the aerodynamic matrices were accordingly corrected. A small number of iterations are usually required to reach a predetermined accuracy.

LMS SCADAS equipment with special software was used for modal characteristics measurement (frequency, shape and damping). Stepped sine excitation method was applied.

The experimental results for Mach equals 0.7 and a density of 1 are shown in Figures 7 and 8. Flutter critical speed was estimated using Zimmerman criterion. The comparison of experimental and calculated results showed their close match. The calculations were performed using special flutter analysis software developed by TsAGI.

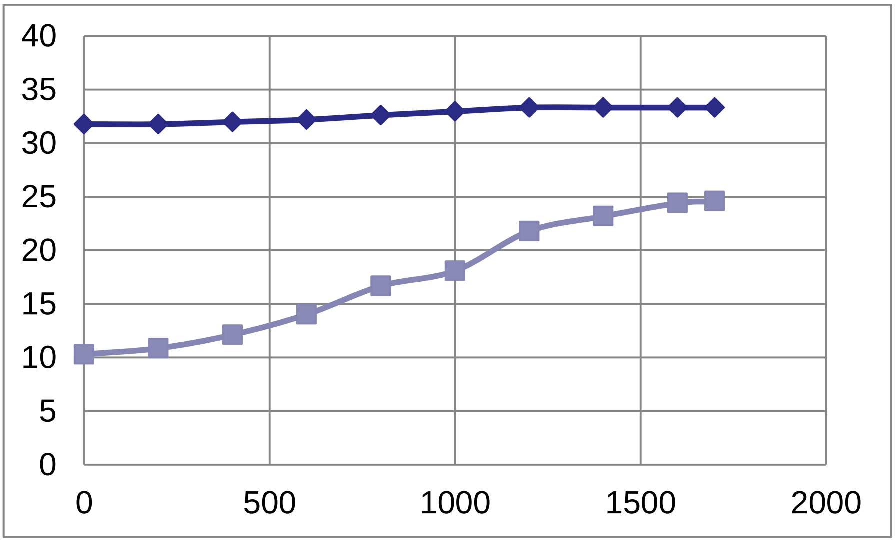


Figure 7. The dependence of torsion and bending modes frequencies from speed.

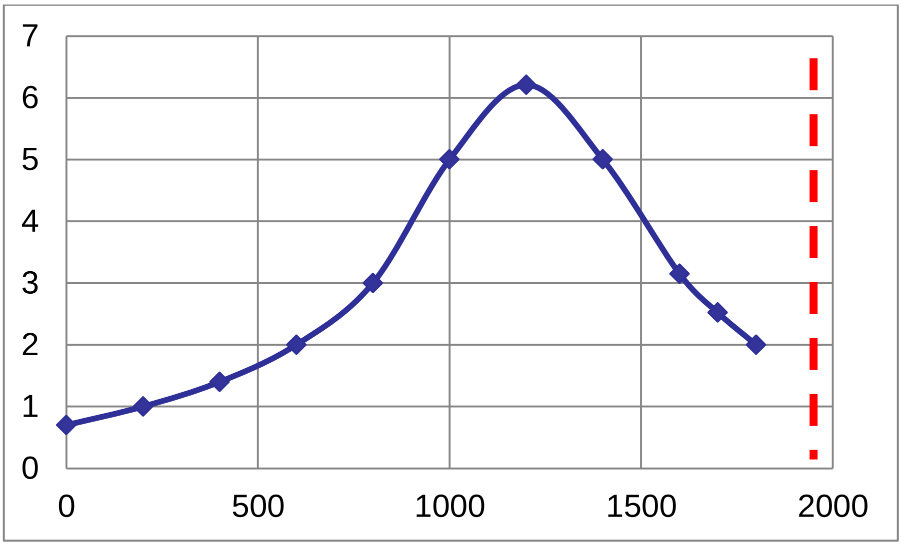


Figure 8. The dependence of torsion mode damping from speed. Red dashed line – flutter margin calculated by Zimmerman criterion.

5 SUMMARY

The EMM test bench operational principles were described. The software architecture, concentrated forces calculation algorithms and experimental results are given in this paper. In contrast to the earlier works velocity sensors are used instead of accelerometers measure the mode shape of the elastic model. New software for real-time calculation of aerodynamic concentrated forces and for test bench control has also been developed.

1 REFERENCES

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