UNTYPICAL CASES AND INCORRECT RESULTS OF VIBRATION TESTS

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Abstract

The vibration analysis is the study of the behaviour and dynamic properties of mechanical structures under actuation by harmonic vibration forces. The aim of resonance tests of the structures is the experimental delimitation of frequencies and the modes of resonance vibrations. Vibration analysis, or more precisely experimental vibration analysis, is the field of measuring and analyzing the dynamic response of mechanical structures when excited by a mechanical input. The broadly applied method of research relies on the harmonic actuation of vibrations and the measurement of respective parameters. Examples would include measuring the vibration of an aircraft load bearing structure when it is attached to an electromagnetic force actuator. Current vibration testing systems are composed of actuators set with their control and powering circuits, the vibration measurement transducers (typically accelerometers), an analog-to-digital converter to digitize analog instrumentation signals) and a system host computer to analyze the data and view it. The result of researcher own accumulated experiences and those experiences known from the literature create the possibility for design of a stochastic frame model describing, what type of resonances are possible to expect in the given or other type of structure. The cases submitted below became perceived and tested in the course of research of several aircraft, glider and helicopter designs in the Resonance Tests Program of the Institute of Aviation

***Keywords**: vibration tests, vibration analysis, resonance tests, resonance analysis, modal analysis*

1. Introduction

The aim of resonance tests of the structures is the experimental delimitation of frequencies and the modes of resonance vibrations.

The broadly applied method of research relies on the harmonic actuation of vibrations and the measurement of respective parameters.

The result of researcher own accumulated experiences and those experiences known from the literature is the possibility for design of a stochastic frame model describing, what type of resonances are possible to expect in the given or other type of structure.

Deviations from such model expectations are called untypical cases. The notion of mistake refers not so much from inaccuracies of measuring tools used, than from mistakes resultant from the researcher not possessing the influence on factors restricting the range of the application of research apparatus.

The cases submitted below became perceived and tested in the course of research of several aircraft, glider and helicopter designs in the Resonance Tests Program of the Institute of Aviation

2. Realization of the research procedure „in accordance with the instruction"

In research of resonance essential is the choice of the actuators application points to researched object and appropriate proportion between forces generated by those actuators. Choosing of application points, the amplitudes of harmonic coercive forces and phase shift between the harmonic coercive forces gives the possibility of isolating of the individual resonances [2].

In the featured actual case the engineer-programmer prepared the computer program, which enabled the automatic selection of the amplitudes and mutual phase shifts of harmonic forces generated by actuators.

In order to disclose the program qualities, eight force actuators were used, four on each tested glider wings. Program realized its task.

The resonance with the mode „2-nodal symmetrical wings flexing" was tested. The measured frequency of this resonance was 6 Hz. Meanwhile, the real resonance frequency with the „2-nodal symmetrical wings flexing" mode was 1.5 Hz, therefore it was 4 times smaller.

Where from such difference?

The electro-dynamic actuator is built in the form of vibrating electric coil in the variable electromagnetic field. In the actuators used in tests, the coils were suspended (leaded) with the help of two spring diaphragms.

This added stiffness of 16 diaphragms acting on the outer parts of limp glider wings structure influenced the measurement result in so serious degree.

The correct method of actuating this resonance was possible with usage of one actuator situated under fuselage in axis of the wings.

The correct and incorrect method of vibrations actuation is presented on Fig. 1.

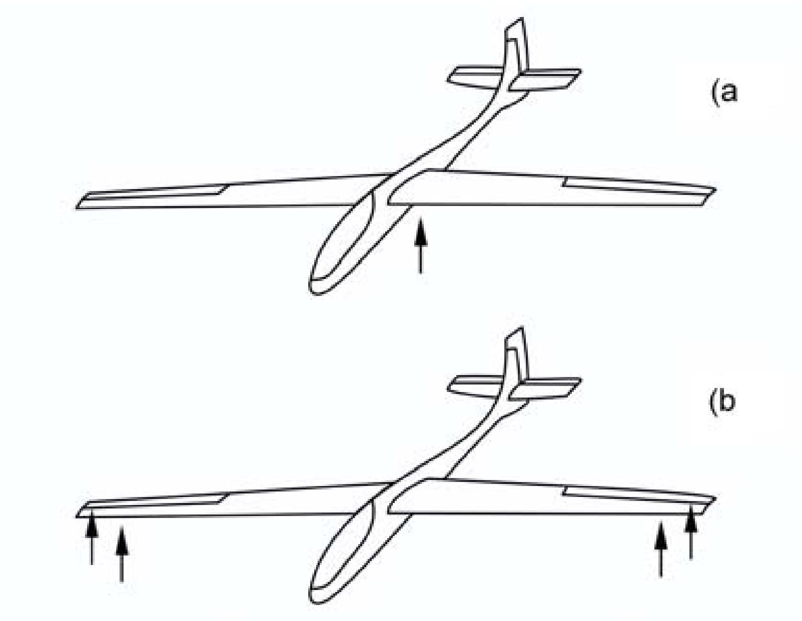

Fig. 1. Research of the glider structure resonances with the „2-nodal symmetrical wings flexing" mode, a) the correct actuation, b. the incorrect actuation

3. The surprising dependence course of the resonance vibrations amplitude from the harmonic actuating force amplitude

The one of the researcher tasks is the selection of the vibrations amplitude, with which the measurement of resonance parameters will be performed. The background which is making decision especially difficult is re-wrapping itself in the literature the notion of the small vibrations. These trends descend most likely from the considerations about linearization of equations.

In the real structure the smaller vibrations do not have any meaning and they do not encompass a whole structure, being getting lost in backlashes and dampings.

The alternative is to search for the amplitudes respondent of the real exploitation. That's the point that prototypes often are only „preparing" to the vibrations in the exploitation.

In the featured case decision was drawn about the execution of the measurements of dependence of the resonance vibrations amplitude on the excitation amplitude. The obtained dependences had course, like graph submitted on Fig. 2.

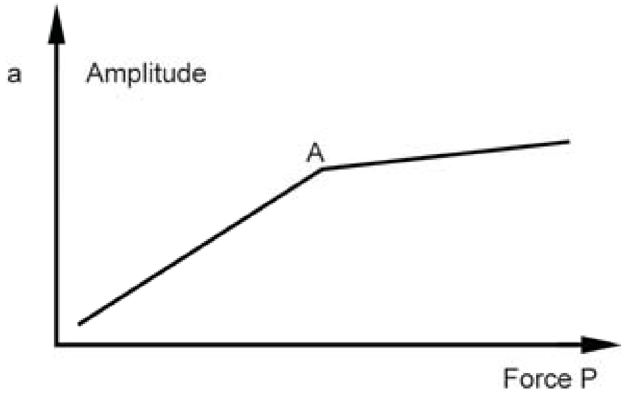

Fig. 2. Influence of the (P) excitation force value on the (a) resonance vibrations amplitude with resultant graph bend from usage of an unsuitable measuring system.

The search for the causes of the slant change of characteristics (linear) revealed, that this bend was caused by saturation of the vibration transducers preamplifiers. The piezoelectric acceleration transducers were used, the measuring signal of which was proportional to generated charge. To large input charge „saturated" the preamplifiers. In measurements of this type the point A was assumed as maximum possible amplitude to the realization in investigations.

4. Really the uncertainty of the frequencies of resonance vibrations

All was begun from the measurement of the frequencies of the resonance vibrations of the system of the steering of aircraft. This measurement was reduplicated on the following day. The measured resonance frequencies differed from each other for several tens percent.

After a thorough full analysis of the two runs of measurements it appeared that the difference was in the use of different actuating forces.

So backlashes in the steering system gave about to be known. This case was the inspiration to a new way to present the resonance vibration frequencies of systems with backlash.

The resonance vibration frequencies of systems with backlash are submitted in the form of graph showing dependence of the resonance vibration frequencies from the amplitude of resonance vibrations.

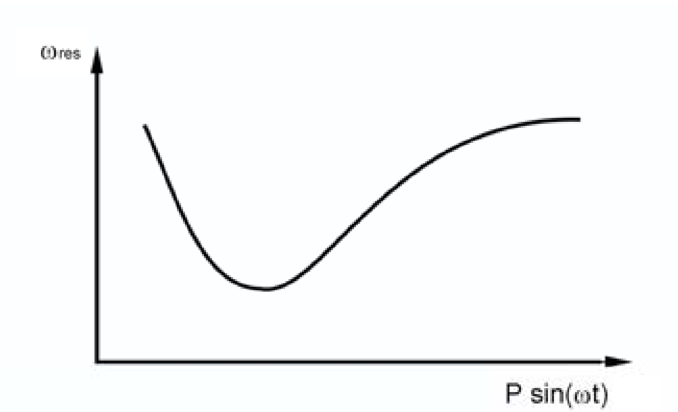

Fig. 3. Typical course of dependence of the resonance vibration frequencies (ω_{res}) of system with backlash from the amplitude of resonance vibrations

Such graph can be utilized to the estimation of backlash participation in the total amplitude of vibrations [3].

Resonances of systems with backlash, depending on their amplitude, can be added or not to the other near resonances of the structure.

Example of such correlation is shown on Fig. 4.

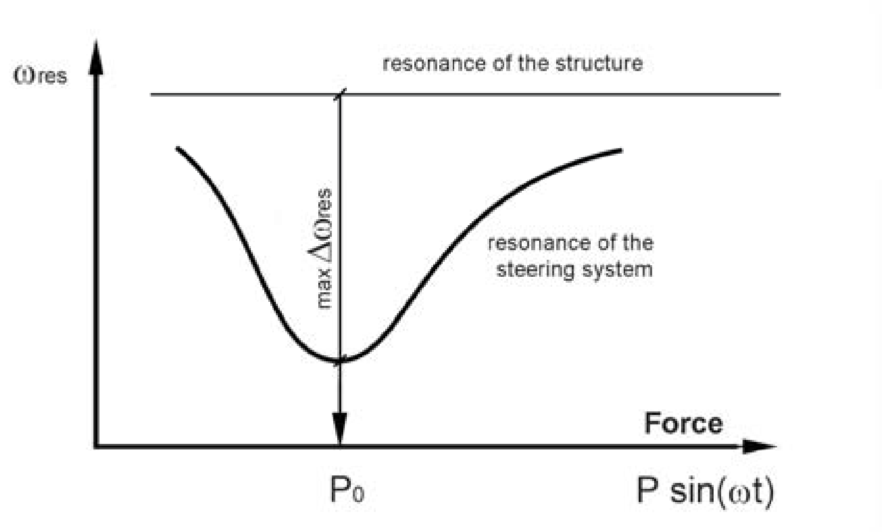

Fig.4. The correlation of the resonance vibration frequencies (ω_{res}) of the steering system and the resonance vibration frequencies of glider structure

5. About the value of coercive forces, continued

In each of the resonances it is necessary to overshoot the excitation power by a certain level, so that the resonance can be fully developed.

In the considerations on the subject of sizes of forces necessary to the experimental actuation of the structure vibrations, the extreme cases are determined by tests of: swinging of the aircraft or helicopter on its own undercarriage and such resonances of helicopters in which are involved: vibrations of undercarriage, fuselage, power plant – including transmission, rotor head and rotor blades.

In such vibration configuration the different backlashes with the different damping exist (pneumatic tires, shock absorbers, bearings and transmissions submerged in oil).

Forcing the structure resonance in which the mentioned elements will take part requires usage of the harmonic coercive forces in range of several hundred Newton's.

6. The resonance with one degree of freedom is the answer of the structure on wideband actuation by the engine noise

The jet aircraft empennage usually works in the environment of wideband acoustic influence generated by aircraft engines. The task of researcher was to understand the phenomena of noise influence, but in particular the estimation of noise influence on the durability of the empennage surfaces.

Surprising was the result of investigations. On wideband noise actuation the empennage answered like system with one degree of freedom. The mode of the empennage vibrations is shown on Fig. 5.

Investigations were started with the resonance tests. Several resonances from the identified ones were suspected for their participation in the empennage vibrations. In the second step, the strain gauges were used, which were glued in the points which would enable identification of „suspected resonances". The results of strain gauge measurements univocally settled, that the answer of empennage is resonance with mode presented on Fig. 5.

The consequence of this discovery was the development of methodology for measurement of vibrations with the aid of dynamically graduated strain gauges [4], [5].

7. Really the uncertainty of the resonance vibrations modes?

Untypical occurrence was observed during the resonance tests of twin-engine aircraft. First of all resonance was identified in which the engines and wings vibrated symmetrically in the horizontal plane. The mode of this resonance is presented on Fig. 6.

In the second order case, the resonance was identified in which the engines and wings vibrated antisymmetrically in the horizontal plane.

The mode of this resonance is presented on Fig. 7.

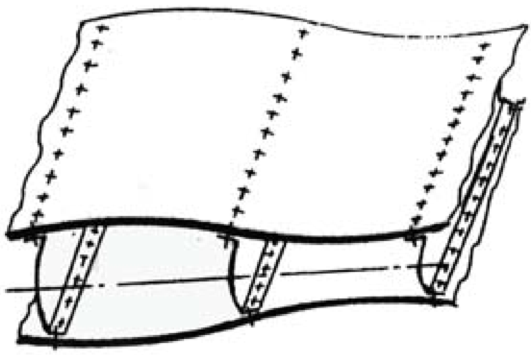

Fig. 5. The mode of the empennage resonance vibrations, actuated through wideband noise of jet engine

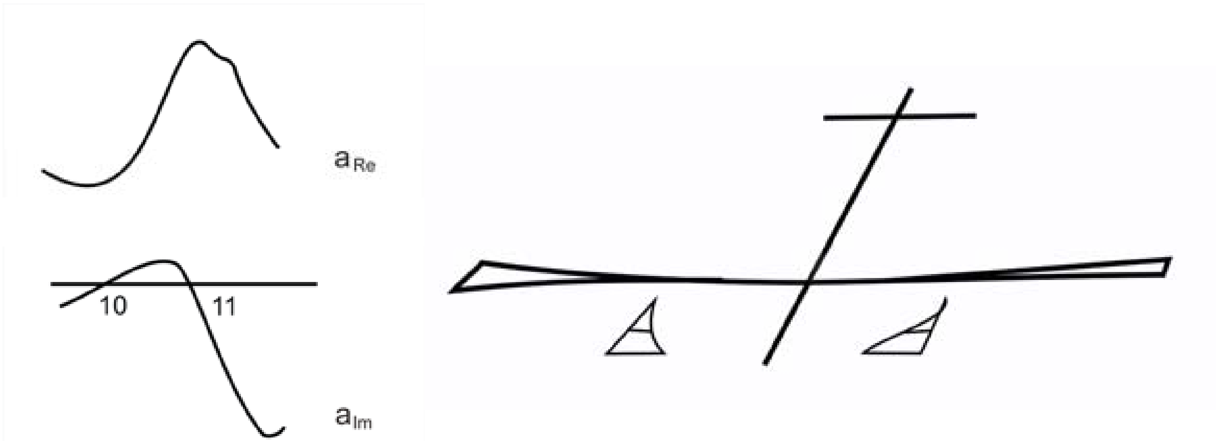

Fig. 6. Horizontal symmetrical sway of the wings and the engines

Both resonances had the same frequency. Therefore the conclusion was drawn, that both resonances are realized and are contained in the engine - aircraft wing system of elasticities and masses.

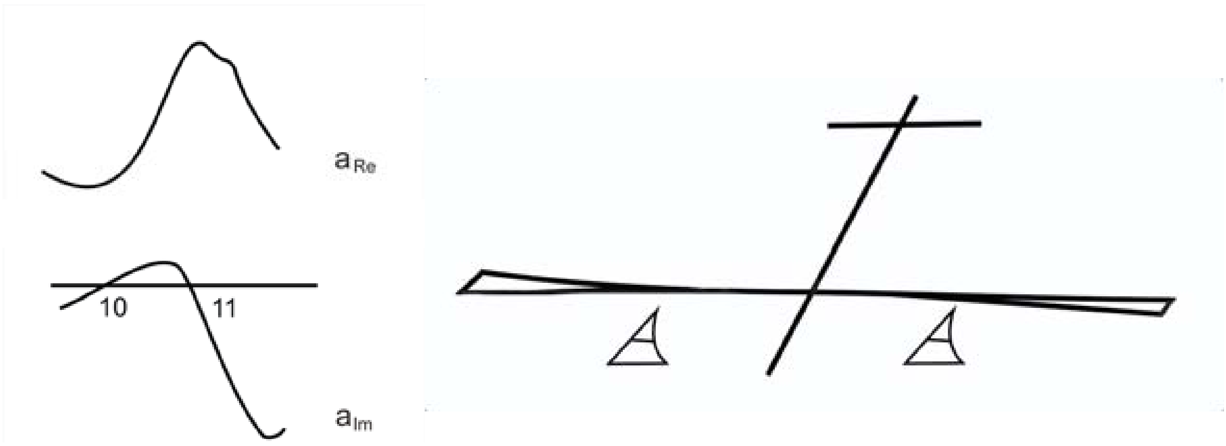

Fig. 7. Horizontal antisymmetrical sway of the wings and the engines

This case opened a new direction of investigations and research on the subject of resonances occurrence with similar or near frequencies. [6]

In following investigations of this case the actuation was applied only on one aircraft side, on the wing and on the engine.

In this case the same frequency of resonance vibrations was measured. The mode of this asymmetric resonance is presented on Fig. 8.

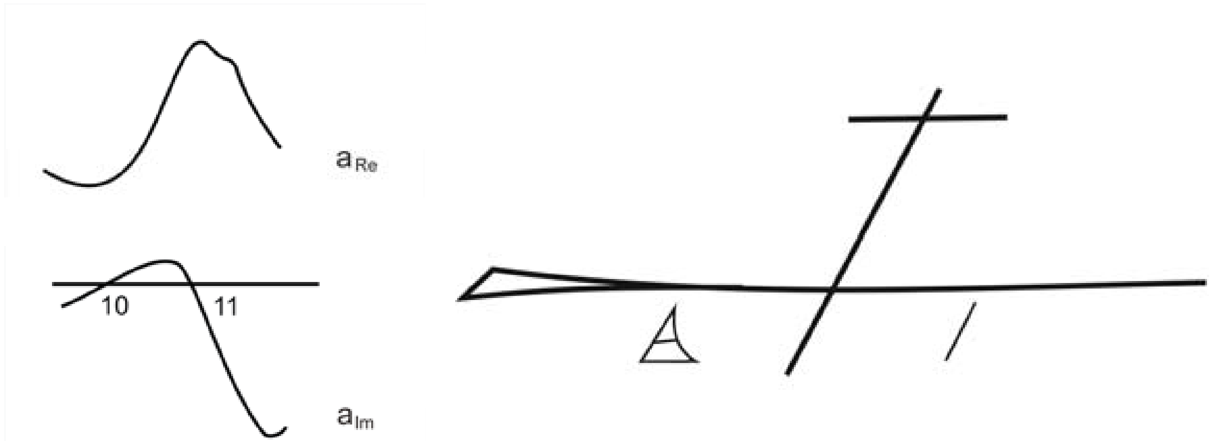

Fig. 8. Horizontal asymmetric swaying of aircraft wings and engine.

The third case closed full image of this resonance in which the mode of resonance vibrations is dependant on the configuration of actuation and can encompass the whole family of symmetrical, antisymmetrical and asymmetric vibrations.

8. Conclusion

The experimental research tests course and its results constantly, on day by day basis are delivering to researcher many riddles and vagueness. The researcher – as professional must find answers to the stated questions and the explanations of mayor doubts.

Because above all it is necessary to teach it on mistakes of someone else, author in the article presented a few of his experiences with the untypical cases of resonance tests.

The explained and identified cases were for the author of this paper the inspiration for the modifications of the research methodology procedures.

The thesis was justified, that scrupulous observation of the researched object behaviour and clearing up of all doubts leads to the creation of new knowledge.

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