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MODAL CALIBRATION OF VIBRATION SENSORS

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In the paper a method of modal calibration of vibration sensors is presented. The results of the modal calibration illustrate the realionship between motion and stress of a body resulting from vibration. Such calibration allows us to estimate vibration of an aircraft. The method allows us also to answer the question if the forced vibrations can be estimated at all on the basis of structural excitation during flight.

1. Introduction

Vibration tests of a structure include measurements of parameters of motion and stress. Measurement of motion is carried out with the help of sensors for displacements, velocities and accelerations, on the other hand, measurement of stress are generally carried out with the help of strain gauges. Sensors of motion are calibrated on laboratory stands where standard vibrations and sensor readings are compared. The sensors applied to the motion measurement are not generally calibrated once they are installed on the tested body. On the other hand, strain gauges may be calibrated after sticking them on the test body. If they are assigned to measure a quasi-static load then they are calibrated by imposing a static load on the structure in the form standard force. Strain gauges applied to vibration measurements are generally not calibrated (Wojtyra and Popławski, 1987).

Motion study of a body allows us to determine displacements of structural elements and acceleration acting on the crew and equipment on the board. It also allows us to carry out an identification of dynamic parameters of the body by determining modal parameters (frequency, superposition of mode of vibration, coefficients of damping and inertia). Study of stress resulting from vibrations allows us to estimate the strength of the structure on the basis of vibration and also to estimate the load of the structure resulting from vibration during operation.

For the investigator of mechanical structures vibration it is interesting to know the relationship between the displacements of vibrating body elements and relevant stress. In the paper it is proposed that this relation may be defined by modes and by modal calibration of stress sensors (strain gauges).

2. Modal calibration

The mode is a simple harmonic vibration in which all the points of the structure vibrate with identical phase. In linear systems, vibration of a body can be represented as a superposition of modes. It results from experimental studies that the structure of classical flying objects, for example sail planes, airplanes and helicopters, behave like linear systems in the range of typical vibrations (Maryniak and Wiśniowski, 1986).

Modes can be measured experimentally under laboratory conditions, with the help of a few numbers of vibration exciters. After determining an appropriate proportion of forces and an appropriate frequency of the harmonic excitement, the successive resonant vibration are excited in the way that they result in the isolated modes (Gutowski and Świetlicki, 1986). Frequencies of vibrations can be determined experimentally. Calibration of the strain gauges sticked on at the certain points of a structure can be done during carrying out the test on a specified mode.

The calibration is carried out at a constant resonant forcing frequency and at a constant mode of vibration. Carrying out the calibration means to determine the relation between the amplitude of vibration at the point of reference and the stress at the point of sticking on the strain gauge. Calibration of the strain gauge is repeated during the tests of the successive modes. Therefore the modal calibration is just an assigning to a single sensor (strain gauge) many divisions of the modal amplitude of vibrations at reference points[1].

Results of a modal calibration of a strain gauge sticked on the tail plane spar of an aircraft powered by a piston engine are presented in Fig.1. Calibration was carried out for 4 modes of the lowest frequencies. They were of the following order

1. swinging on wheels, $f = 4.6$ Hz
2. torsion of the fuselage, $f = 6.2$ Hz
3. two-node vertical bending of the fuselage, $f = 9.6$ Hz
4. vertical bending of the tail plane, $f = 17.5$ Hz

[1] Wiśniowski W., *Sposób pomiaru drgań przy pomocy tensometrów skalowanych modalnie*, Patent RP no. 156127

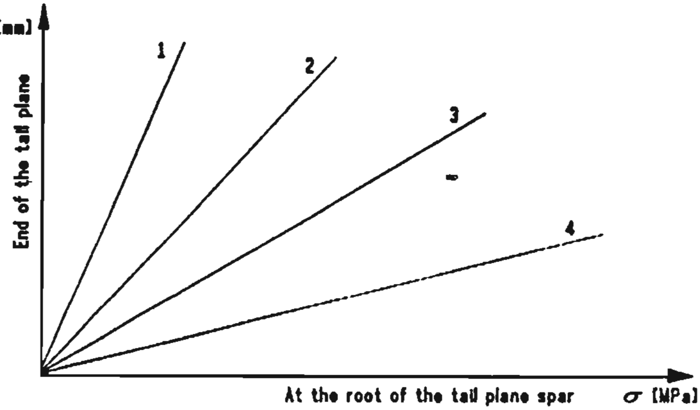

Fig. 1. Modal calibration of a strain gauge on the tail plane spar of a piston engine aircraft

3. Use of modal calibration in the study of vibration

Modal calibration of sensors may be used during vibration measurement of an aircraft in flight or on the ground with the engines working. An algorithm of vibrations measurement with the help of sensors calibrated modally is presented in Fig.2.

According to the presented algorithm the measurement of vibration is carried out with the help of one strain gauge sticked on at the root of tail plane spar. Vibration is measured with the engines working on the ground. Results of the harmonic analysis of the time histories of stress on the spar and also acceleration at the end of the tail plane are presented in Fig.3.

Comparing the results of stress and acceleration measurements, it is clearly seen that the strain gauges are considerably more useful for measuring the vibrations at lower frequencies. Fig.4 is prepared on the basis of results from (1) modal calibration, (2) measurement of vibration mode (both carried out in the laboratory) and (3) results of harmonic analysis of operational stress history. Vibration of the tail plane, i.e. the superposition of modes, frequencies and amplitudes are presented in Fig.4. Only their mutual phases remain undetermined parameters.

Modal calibration method of strain gauges may be applied in laboratories, for estimating possibilities of exciting and measuring of specified vibrations which are generally forced on the aircraft during flight. The analysis of the vibrations, specially those excited during the flight tests, is carried out to prove that in the region of operational velocities the self-excited vibrations of the flutter type do not occur.

During such experiments the vibrations of an aircraft are excited with the help

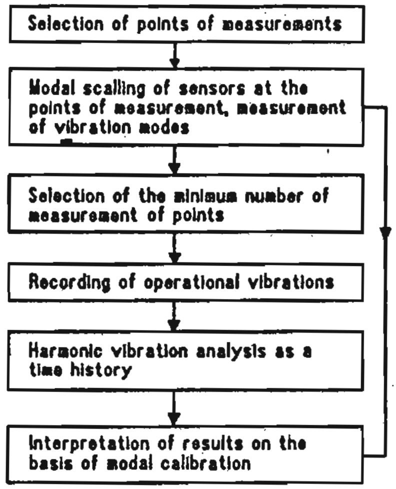

Fig. 2. Algorithm of vibration measurement with the help of sensors calibrated modally

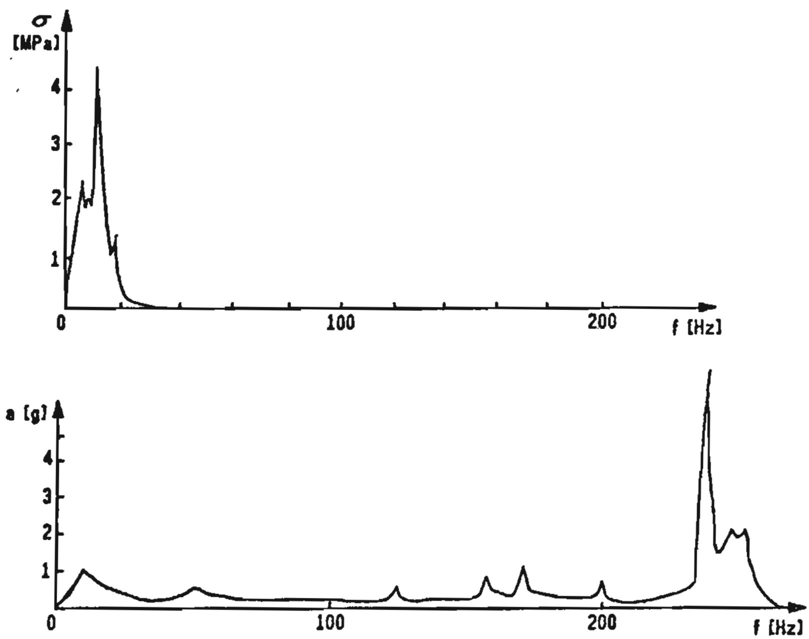

Fig. 3. Harmonic analysis of the stress on the spar and acceleration at the end of the tail plane of a piston engine aircraft

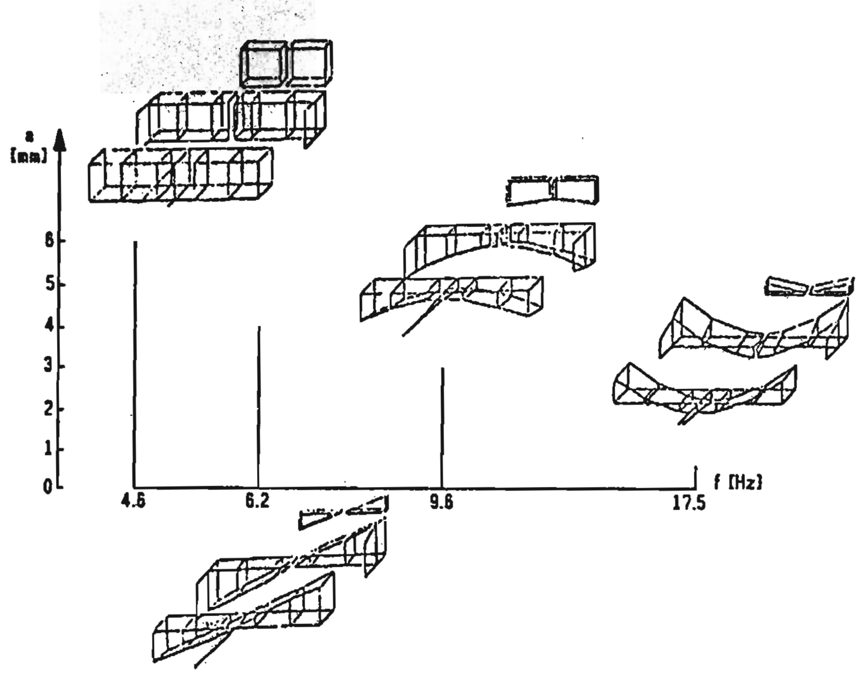

Fig. 4. Vibration of tail plane of an aircraft on ground with engines working at its maximum revolution

of a pulse generator of rocket type, an exciter of aerodynamic type, a mechanical type or even an electrodynamic type. Measurement of vibration is carried out with the help of the strain gauges or the accelerometers.

Experiments are made after carrying out the theoretical calculations, which lead to a determination of critical velocities of several predicted flutters. Each of these flutters has an analytically defined pattern, which is the linear combination of modes of free vibrations. Experiments in flight are done only if the calculated critical velocities of all the flutters are greater than the maximum velocity of the aircraft. During the test flights it is used to prove that components of flutter vibrations decrease.

In arranging the test, the selection of points of excitation and measurement of vibration is very important. For that purpose, drawings of the modes of free vibrations occurring in the group of flutters, under consideration, are used.

Laboratory estimation of the possibilities of excitation and measurement of forced vibration of an aircraft are made on the basis of the following tests if

- all the predetermined modes of vibration can be measured at least at one point of measurement
- all of the resonances of predetermined modes may be excited with the help

of exciters installed on board of the aircraft.

Fig.5 presents the algorithm for estimating the possibilities of exciting and measuring of the forced vibrations.

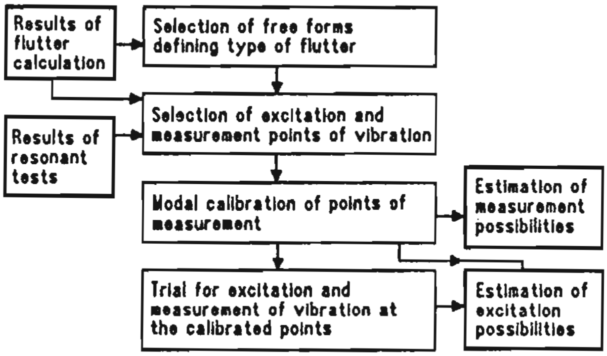

Fig. 5. Algorithm estimating the possibilities of estimation and measurement of forced vibrations on a aircraft

Measurements of vibrations can be done only if it is possible to measure specified resonant vibrations of minimum amplitude, decreasing of which can be observed at preselected points of measurements.

Such estimation of measurement possibilities may be carried out on the basis of results of the modal calibration of strain gauges.

Estimation of possibilities to excite resonant vibration of specified pattern is done by carrying out the excitation trial (firing of pulse generator). Such excited resonances and their amplitudes can be estimated by analyzing the signals measured with the help of modally calibrated strain gauges.

4. Conclusion

- Modal calibration of strain gauges is a way to determine the relation between the motion of vibrating body elements and the relevant stress.
- Modal calibration of sensors is the base of the measuring method for operational vibrations, which creates the possibilities of obtaining an elaborated picture of vibrations using only a single point of structure.
- Modal calibration of sensors allows us to estimate the possibility of excitation and to measure the specified forced vibrations on an aircraft in flight.

References

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Skalowanie modalne czujników drgań

Streszczenie

W pracy przedstawiono metodę modalnego skalowania czujników drgań. Wyniki skalowania modalnego opisują relację pomiędzy ruchem i naprężeniami od drgań obiektu. Skalowanie umożliwia ocenę drgań samolotu. Metoda pozwala również odpowiedzieć na pytanie czy wogóle można wnioskować o drganiach wymuszonych na podstawie wzbudzania konstrukcji w locie.

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