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Evaluation of Dynamic Loading of Aircraft Propeller Using Strain Gauges

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Abstract. Aircraft Propeller Testing Laboratory of VZLÚ Praha-Letňany has been performed strain measuments on rotating parts, expecially on aircraft propellers, for more than five decades. The means of signal recording and its processing have been changed during this age, following technical trends in electrical enginering, but a resistive strain gauge has remained the only one sensor easy practicable for measurement. The article describes the contemporary state-of-the art and presents some examples of signal evaluation to obtain the data required for purpose of design and certification.

Introduction

An experimental verification of the dynamic loading of a new designed aircraft propeller is still required by the Civil Aviation Authority pending its certification process. In contrast to the static loading that can be declared using calculations, simulations of the dynamic loading are never proved for this purpose, because of high uncertainties of coefficients of damping, mechanical compliance, excitations etc. The results of such dynamic loading measurement serve not only for the proof of the Regulation paragraph CS-P 530 [1], but of course they also provide data for a fatigue evaluation according to the paragraph CS-P 550 and for establishment of an acceptable loading for purpose of laboratory fatigue testing.

Measurement

Resistive strain gauges are the only one method of realization of measurements on the rotating propeller in practise. Recently, some attempts of use of optical means of measurement have been done, but these experiments are still under development, usually on the ground operation only because of extent devices. The main advantage is a complex vibration scan of all propeller blades. While the strain gauges (Fig. 1 and 2) provide data of strains from small areas of their grids only and so their number, depending on purpose of measurement, can be considerable. For example, in 1980s during the development of modern five-bladed propellers V 509 / V 518, the typical number of used strain gauges was about thirty five. Their wiring configuration is usually a simple two-wire quarter bridge, because no thermal-compensating elements and techniques are required in the case of dynamic measurements performed only.

The key part of the measuring chain is a device for transmission of measured signals from the rotating part to a stationary base. In the past, contact slip-rings were used (Fig. 3). Nowadays, wireless telemetry systems are prefered because of their high noise immunity. Another reason is that a measurement on the single-engined aircraft equipped with a tractor propeller can be realized, as there was an invincible problem in former time. The VZLÚ testing laboratory uses a Kraus MT-32 system, which modular conception makes variable user installations possible (Fig. 3). It transmits the signals on frequency of 430 MHz using PCM modulation. Some user-comfortable functions typical for more powerful strain gauge measuring units are absent, which is a price for very small dimensions of this device: only external calibration process using a shunt resistor or the need of an external completion of the circuit in the case of the solo measuring gauge due to the half-bridge input available only.

Fig. 1. Measurement of dynamic loading of aircraft propeller.

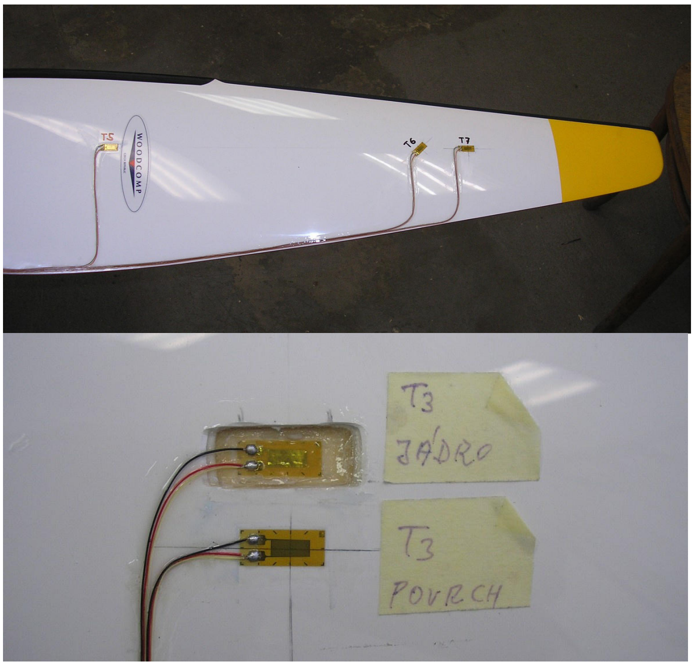

Fig. 2. Strain gauges HBM 6/350 LY41 mounted on the propeller blade.

Digital data acqusition devices must provide an appropriate rate of sampling, because various components of the propeller oscillation can be in the range up to 1000 Hz. Frequency of 5 kHz, which is provided by a small and very lightweight datalogger used on the board during flight experiments, is sufficient for sampling of the recorded signals. On-ground measurements, for example in the engine brake test plant, could utilize more powerful devices naturally.

Fig. 3. Slip rings HBM SK-12 used in 1970s/80s.

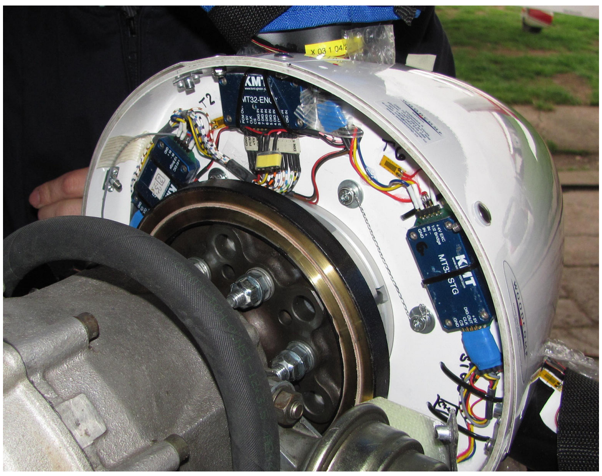

Fig. 4. Modules of the KMT-32 telemetry system mounted on the carrier of the spinner.

Evaluation

The means of performance of the propeller measurement and subsequent methods of data evaluation can be various and depend on the purposes of the measurement.

A fundamental verification of dynamic behavior of the propulsion unit (thus the system: Engine – gearbox – propeller) in dependence on the rotational speed is realized on special engine testing stations or just on an aircraft during ground measurements, usually in the regimes of controlled accelerations, deceleration runs respectively. Typical results, next to overall values of vibration levels, are frequency analyses in the form of so called *Campbell diagrams*. In fact, they are three-dimensional graphs, in which levels of frequency component of oscillation are expressed by colour range (an example in Fig. 5). Campbell diagrams allow fundamental statements on vibrational behaviour of machines and their elements (e.g. propeller blades) respectively. The crossings of excitations orders with natural frequencies define critical or dangerous rotational speeds. Similar predictions are calculated during a preliminary design, but the real amount of excitations is mostly unknown. That is why experimental determination of Campbell diagrams is carried out. Measured signals are divided into small time blocks in which they are analysed by the means of *Fast Fourier transformation* (FFT). Therefore, this method requires a sufficiently low rate of change of the rotational speed which could be considered relative constant in each data block. For given restrictions and in view of typical orders of propeller excitations, results of the FFT method are usually satisfactory, in spite of some disadvantages. Otherwise, so called *order analysis* must be used.

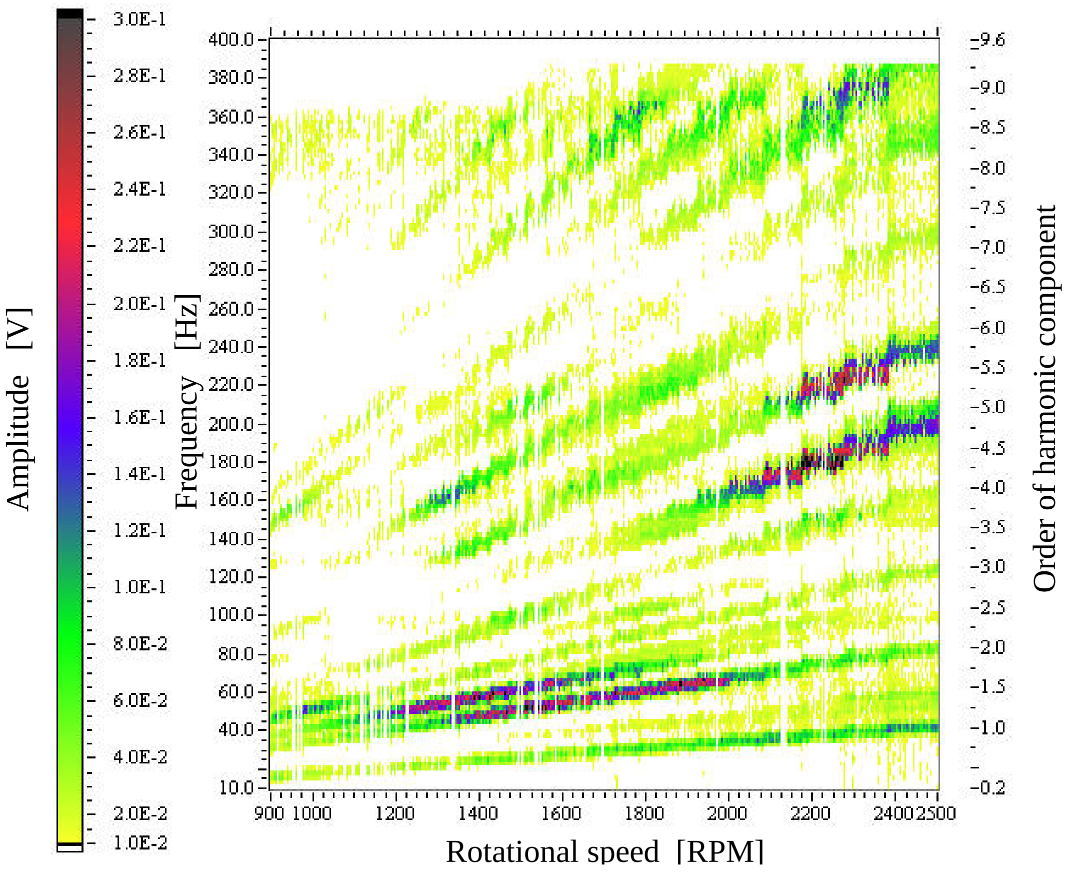

Fig. 5. Example of Campbell diagram.

Various accompanying measurements for the complete description of dynamic behaviour are very often realized simultaneously – torsional oscillations on the shaft, vibrations of the engine measured using accelerometers etc. A special case of the measurement often required by the Civil Aviation Authority is testing of occurance of flutter effects on propeller blades.

Evaluations in time domain are performed for purpose of finding levels of the dynamic loading during various flight regimes and fast transitional effect such as start or stopping of the propulsive unit, regulation process of setting blade angles etc. With regard to the typical frequencies of the propeller vibrations, statistic approaches to the evaluation have to be used. Typical waveforms of the strain loading measured on various places of propeller blades are shown in Fig. 6.

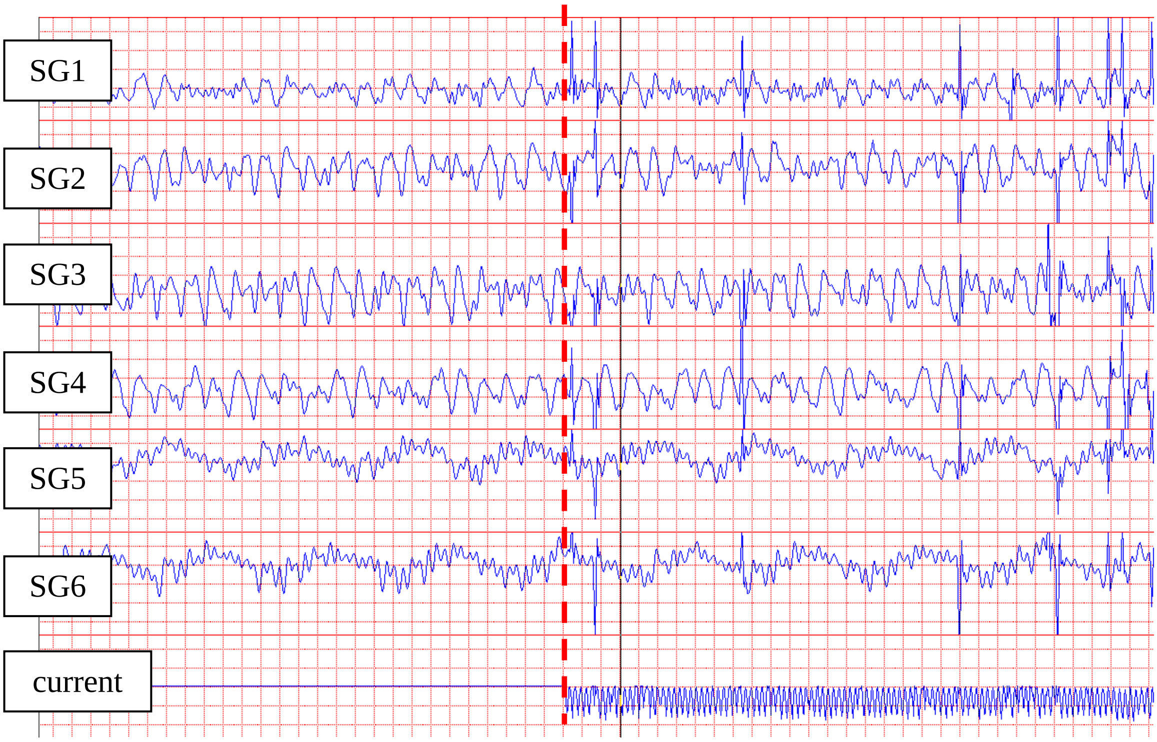

Fig. 6. Waveforms of measured signals with the point of beginning of occurrence of intensive disturbances caused by function of electric servomechanism of the constant-speed propeller.

Problems of Pre-processing of Signals

The measurements and their evaluations described shortly above are routine operations for the VZLÚ Aircraft Propeller Testing Laboratory in principle, but some small problems usually occure during each measuring campaign. In the past, appearances of signal disturbance were frequent in the case of using of the slip-rings, because of vibrations of whole propulsion unit. Such examples of disturbance have disappeared since this device was changed for the telemetry system. However, during evaluation of the last our measurement on an electrical in-flight adjustable propeller we had to solve the occurrence of harsh disturbances which were generated by electric energy transfer to the rotating propeller with using contact carbon brushes.

These intensive and extensive peaks influenced the results of the computed representative levels of blade vibration unaccetably. In Fig. 7 the time-domain evaluation of original signals of three strain gauges (mounted on each blade at the same place) is given. Of course, signals are always processed using a low-pass filter, but Fig. 8 shows, that the classic means of frequency filtering are effective only partially.

Therefore, a special software modul for identification and removing of the disturbing peaks of the signal was developped and implemented into our computer programme for dynamic signal evaluation. It is based on time derivative of signals and evaluation of their envelope pattern.

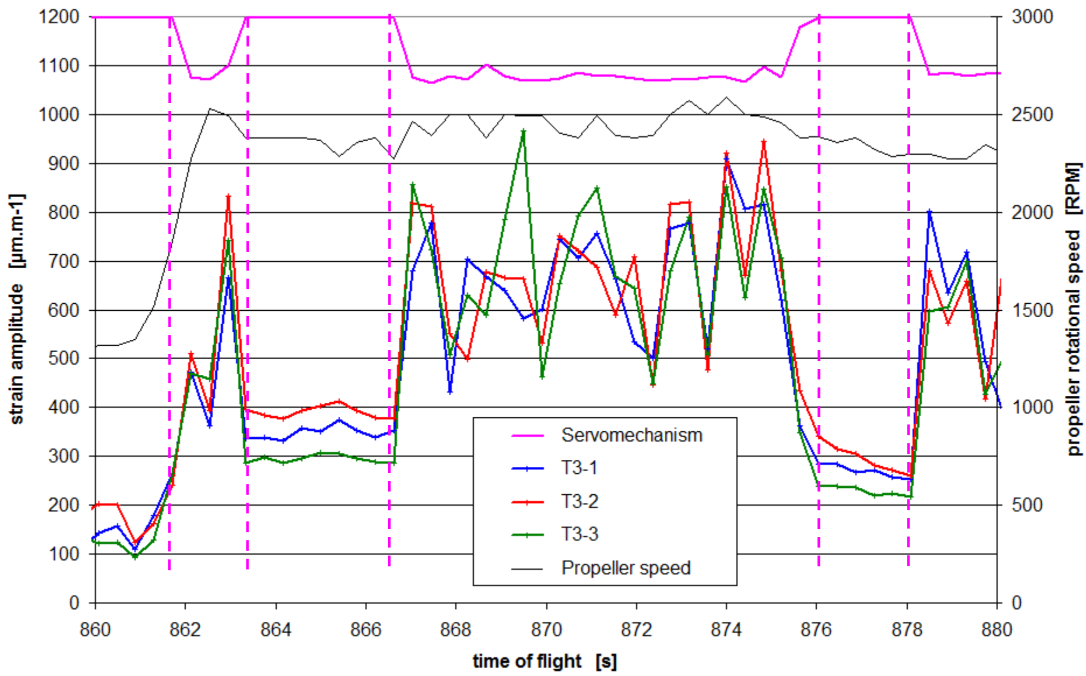

Fig. 7. Computed levels of blade vibrations are heavy influenced just in the periods of regulative intervention of the propeller speed controller.

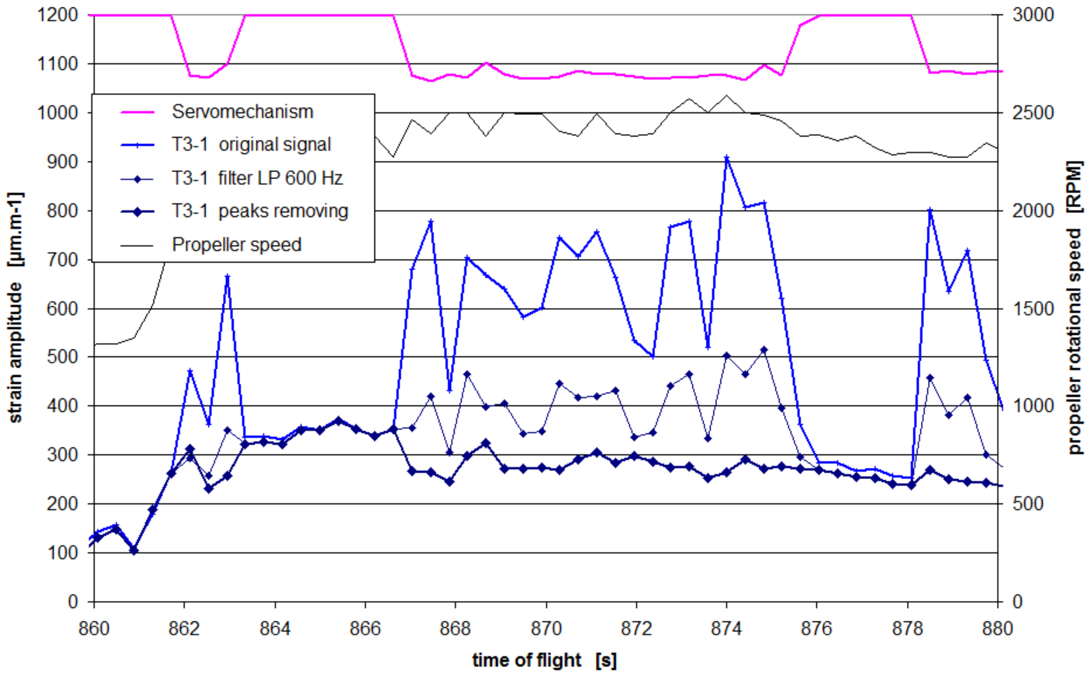

Fig. 8. Results for the various means of signal processing.

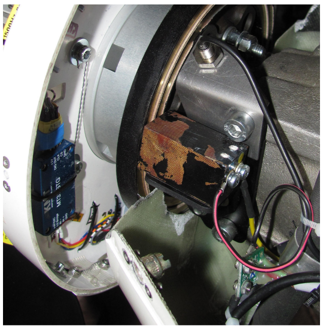

Fig. 9. Carbon brushes near telemetry aerials.

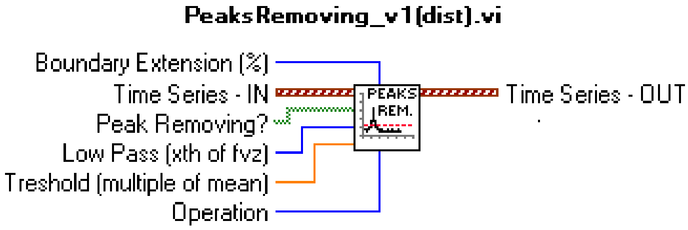

Fig. 10. Software modulus intended for better processing of measured signals was built on the LabVIEW platform.

Conclusions

The measurements of dynamic loading of the aircraft propellers using strain gauges are still non-substitutable not only for carrying out the requirements of their certifications, but also for follow-up technical development.

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