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Measurement of Torque Moment of Aircraft Piston Engine

Jindřich Rosa[1]& Jan Cagáň[2]

Abstract: Aircraft Propeller Testing Laboratory of VZLÚ Praha-Letňany performed a commercial measurement for purpose of assessment whether maximal power of surveyed aircraft piston engine Lycoming AEIO-540 type (310 HP) matches declared values and so if it is possible using it for series of certification tests of a new propeller type. The torque moment was measured using a special shaft element equipped with strain gauges. This article deals with dynamic feature of the measured signal.

Keywords: Piston engine, Torque moment, Dynamic loading

1. Introduction

The Textron Lycoming AEIO-540-L1B5D is a horizontally opposed six-cylinder engine. The „540" family dates back to 1950s, the stated model (Type Certificate from 1974) is a version with fuel system and wet-sump oil system for aerobatic flight. It is reaching the power of 285 – 315 HP at maximal 2700 RPM. It is installed on many famous special aerobatic planes, for example Extra 300, czechoslovak Zlin Z-50LS/LX (remember sport achievements of Petr Jirmus) or Zivko Edge 540, which became the most common aircraft used in the Red Bull Air Race World Series – in fact all champions of the popular World Series have flown this aircraft.

Fig. 1. Aerobatic aircraft Zlin Z-50LS. Photo by M. Nedvěd, VZLÚ.

[1] *Ing. Jindřich Rosa; Výzkumný a zkušební letecký ústav, a.s. (Aeronautical Research and Test Institute); Beranových 130, 199 05 Praha - Letňany, Czech Republic; rosa@vzlu.cz*
[2] *Ing. Jan Cagáň; Výzkumný a zkušební letecký ústav, a.s. (Aeronautical Research and Test Institute); Beranových 130, 199 05 Praha - Letňany, Czech Republic; cagan@vzlu.cz*

VZLÚ Praha, the Aircraft Propeller Testing Laboratory respectively, was request, to size up the maximal power of an engine some time ago. The engine of Lycoming AEIO-540 type is eldery and is using for ground propeller testing only. Our customer asked the assesment, whether maximal power of the engine matches declared values and so if it is possible be using it for series of certification tests of a new propeller type. Because the engine was already installed on ground propeller testing station (wind tunnel), a measurement had to be performed in-situ and it was doubtfull using any professional torque-meters too.

2. Experimental method and power measurement

The experimental verification of the engine power was realized in a way of the measurement of transmitted torque moment on shaft, namely by using of a special element (mounted between engine shaft and propeller hub). It was equipped with strain gauges which read out its torsion deformation. The strain gauges 1-LY-43-6/350 type produced by the company HBM were mounted on the shaft element at angles of ±45° to the longitudinal axis of the shaft and their configuration was the full bridge circuit. It is expected that this typical wiring is able to compensate relative changes of temperature caused by air-flowing during shaft rotation and keep the fixed „zero". It is supposed too that this wiring of the gauges compensates a tension loading (by propeller thrust) or relevant bending of the shaft.

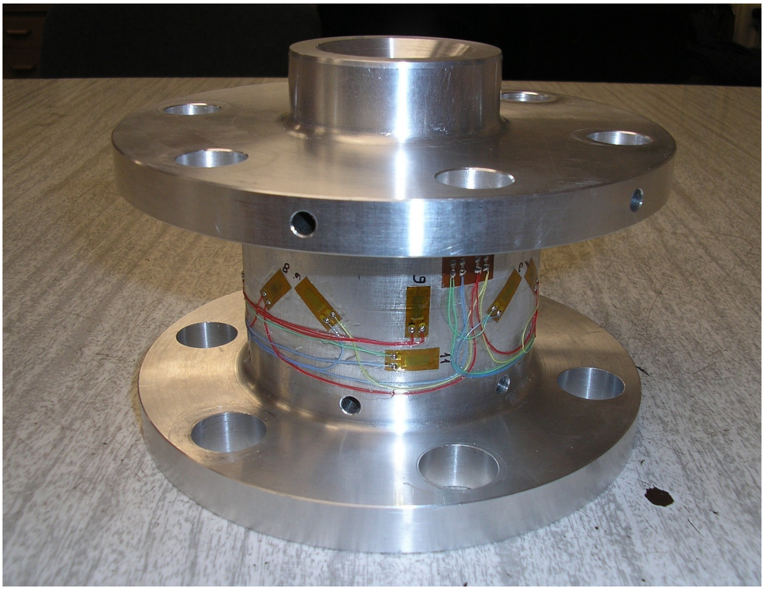

Fig. 2. Special shaft element equipped with strain gauges.

The key part of the measuring chain is a device for transmission of measured signals from rotating part to base. We are using a wire-less telemetric Kraus MT-32 system which transmitted the data on frequency 433 MHz using PCM modulation (high noise immunity). The KMT modules on rotating part (bridge amplifiers and transmitter) are assembled on a disk platform for our typical measurement on a propeller (Fig. 3), but a specific mounting to just measured structure must be very often designed and manufactured.

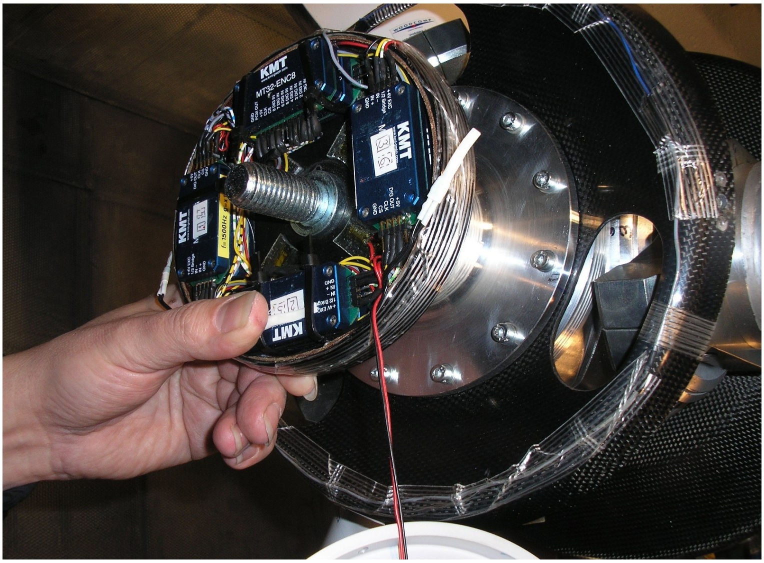

Fig. 3. Modules of the Kraus MT-32 system installed in the front of a testing propeller.

The measured signal was consequently led from the Kraus system receiver to a central measuring station based on Dewetron 2010 computer, where was sampled using „fast" DAQ card (sampling frequency 20 kHz), stored on hard-disk and continuosly analyzed. For data acquisition we are using software applications built on LabVIEW (by the National Instruments company) platform.

Calibration of whole measuring chain was performed in the laboratory using static loading of the shaft element, directly in sensitivity of „voltage – torque moment" for current setting of brigde amplifier and wiring configuration. Rotational speed for calculation of the engine power (1) was adopted from control system of the engine stand.

$$P = 2\pi n M_k \tag{1}$$

During presented experiment an aircraft propeller with setting of its blades on minimal angle of attack was used as a brake. So measured/evaluated values, in dependence on rising rotational speed of the engine, mean „propeller power" curve. The maximum finding value of power corresponds to a point of „engine power" curve for maximal open throttle (Fig. 5).

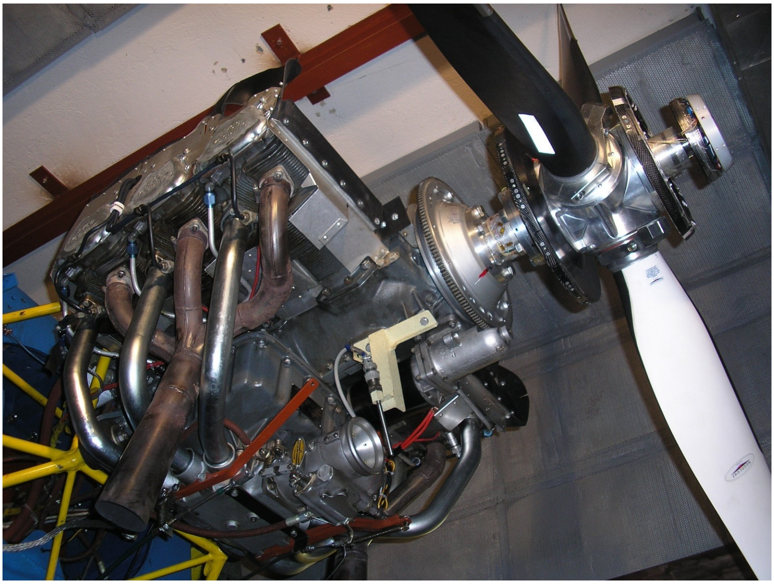

Fig. 4. Measuring of power-output of the Lycoming AEIO-540-L1B5 type engine.

The engine was accelerated and the mean value of each block of measured data (select number of samples) was evaluated along with rotational speed. The results are illustrated in Fig. 5. Our measurement confirmed good condition of the engine.

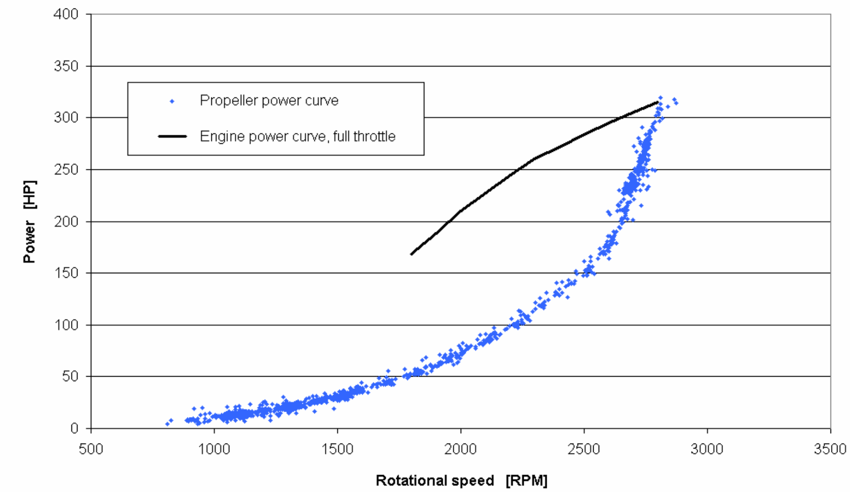

Fig. 5. Principle and results of maximal power measuring.

3. Evaluation of dynamic signal

However, measured data can be analyzed from the point of view of dynamic loading too. The torque moment of piston engine is pulsating in fact. That is given by phased firing in cylinders with impulsed behaviour. For example, in the case of six-cylinder and four-stroke cycle type engine we expected the pulsating moment with a dominant („firing“) frequency equal to three cycles per revolution (the third harmonic of frequency of rotational speed). In special publications (see [1]) it is noted that amplitudes of these oscillations are (depending on design conception of the engine) about 40 – 100 % of mean value of the transmitting torque moment. But we can find other harmonic frequencies in the spectrum of generated vibration too.

Aviation engineers should be at least notified of amplitudes of this dynamic component as compared with static (mean) value of the transmitted torque moment at various regimes of rotational speed to be able of correct and successful design of related parts.

As mentioned above, the measured data was stored in full extent (all samples) and so is capable to off-line evaluation again, from „dynamic“ point of view now. “Double-amplitudes” (rated from minimal to maximal values in a cycle) reach rather high and surprising levels (Fig. 6). Notice that there are even negative peaks (valleys dip below zero) on a waveform of the instantaneous torque-output curve.

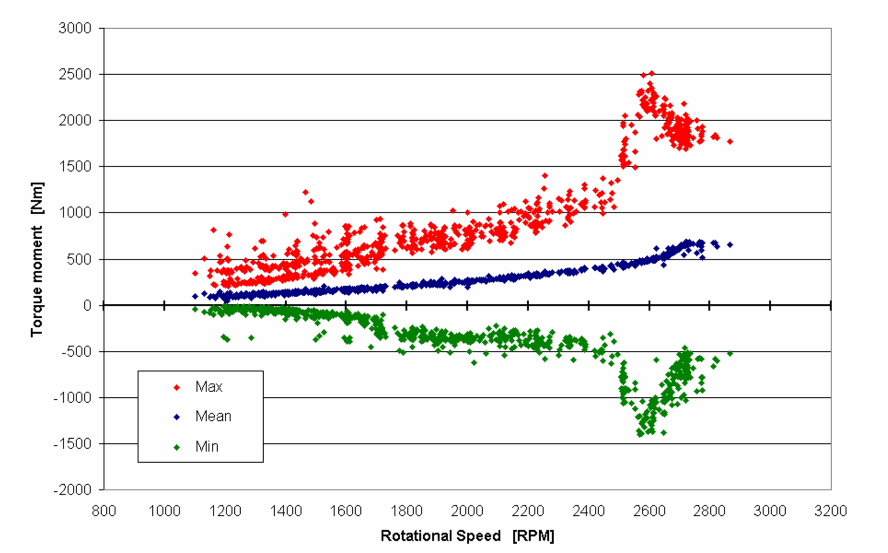

Fig. 6. Overall values – maximal and minimal values of oscillation observed in each data block.

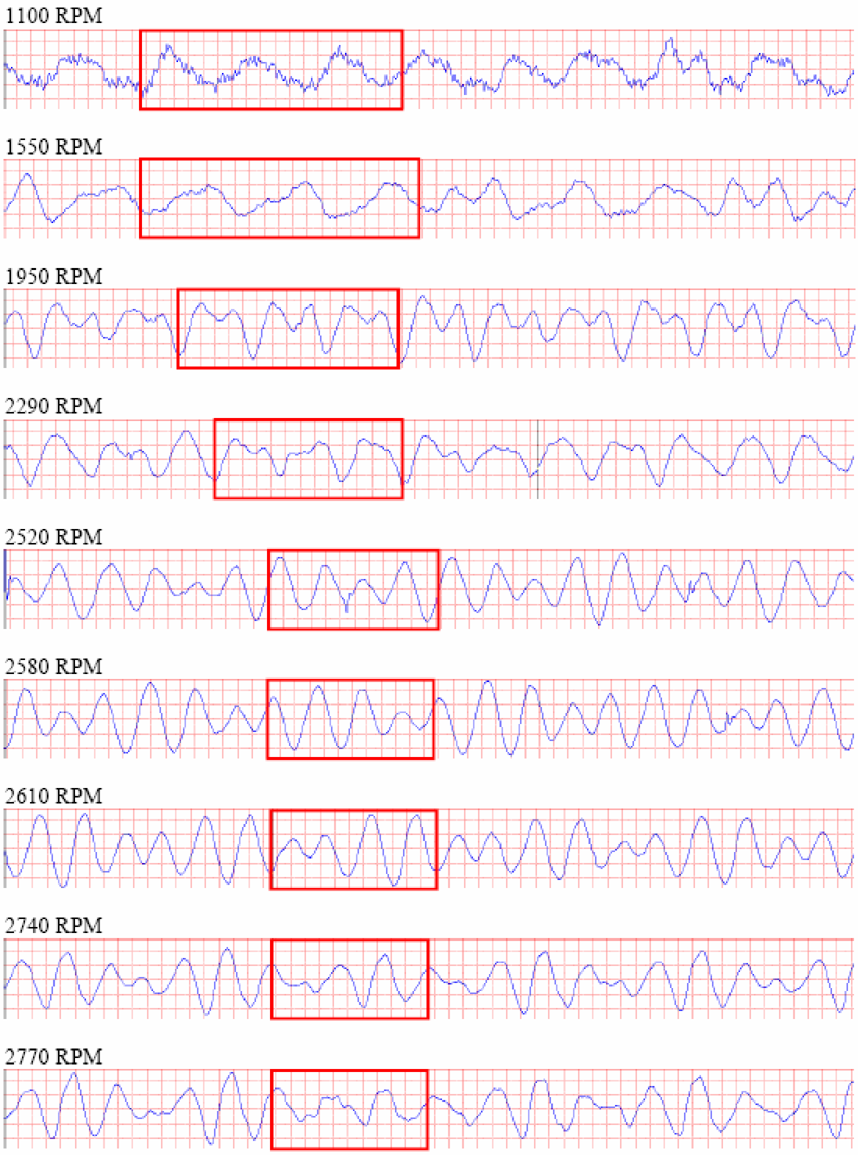

Fig. 7. Time domains of complex measured signal of the torque moment for select rotational speeds. One revolution of shaft is marked red. Note that scale is not the same for all graphs!

The evaluation of the measured signal in time domain shows that expected oscillation with dominant frequency three times per shaft revolution (so called 3N) is characteristic for low speed of revolution. But a domain around 2600 RPM is surprising because the vibration of four pulses per revolution (so called 4N vibration component) dominates definitely.

A spectral analysis by means of FFT method confirms (Fig. 8 and 9) that

- the 3N vibration component is excited in whole engine operational range and is rising along with rotational speed
- the 4N vibration component presents dramatically resonant behavior, just in the domain of 2600 RPM.

VZLÚ afterwards performed a measurement on just develop propeller, tested on the described ground engine stand. There were no excited resonant vibrations on the propeller blades in the mentioned domain. But when the rotational speed was close to maximal, a tendency to rising of the 4N vibration was observable. It must be noted that the propeller measurement was already realized on the engine without gauging shaft element. That is why a highly likely interpretation is that a natural frequency of the torsion „crankshaft – propeller“ system became lower with using the relative flexible shaft element, thus the vibration resonance was excited by the 4N oscillation which is insignificant from the point of view of vibration loading in other (out-of-resonance) regimes. The natural frequency of „untouched“ (original) system is likely higher, thus similar resonance excited by 4N vibration would appeared at rotational speed higher than allowed.

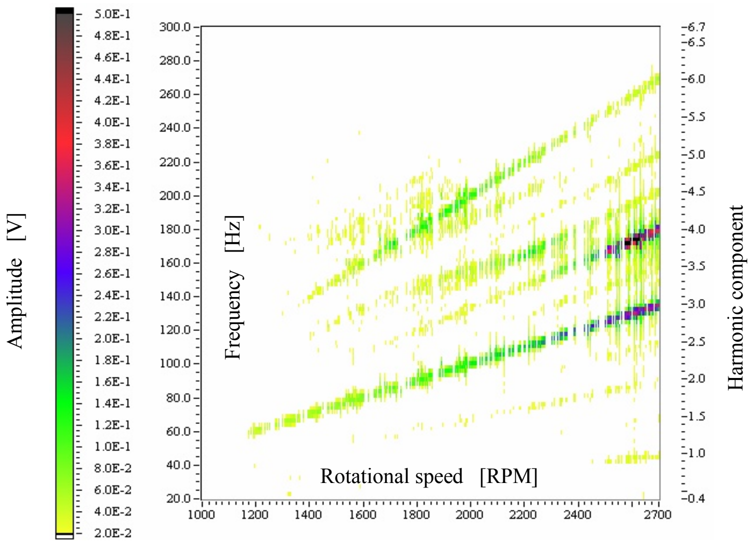

Fig. 8. Campbell diagram – typical form of analysis of dynamic signal measured on a rotating part

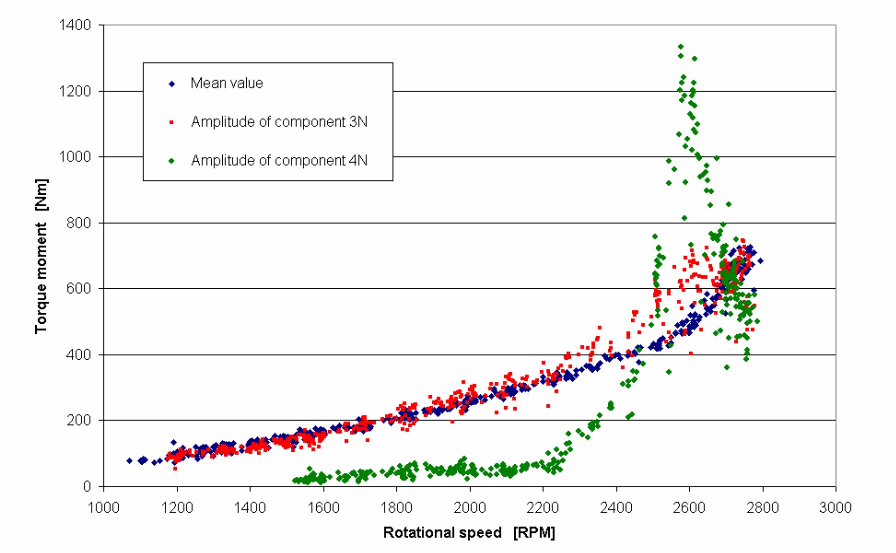

Fig. 9. Harmonic components of dynamic signal of the torque moment.

In presented case of changed dynamic system we can observe maximal amplitudes of complex torque oscillation equal to 2100 Nm, which is about 440 % of mean value of the transmitted torque moment, at resonance rotational speed (see Fig. 6)!

4. Conclusion

The measurement of torque moment, the engine power respectively, is not easy in service condition. It should be gone ahead carefully, because selected solution very often generates an intervention to original dynamic system. As is presented above in this article, the mean value of torque moment – the primary task of our measurement – is not affected, but a change can cause incorrect findings with regard to general dynamic loading of surveyed structure in common operation. The spectral analysis acknowledges that the amplitudes of dominant component of torque shaft vibration (with „firing" frequency) of the Lycoming AEIO-540-L1B5 type engine commonly reach 100 – 120 % of mean value of the transmitted torque moment.

References

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