ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0010.2385

SYMPTOMS DAMAGE TO THE HYDRAULIC REGULATOR PROPELLER LUN-7816

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Abstract

The article deals with key issues related to the operation of the driving unit of the PZL-130TC1 'Orlik' aircraft. The author has focused in particular on deficiencies of the aircrew drive LUN-7816, whose intensity affected both operational safety of the PZL-130TC1 'Orlik' aircraft and continuity of training programs for pilots.

The article puts forward some hypotheses on why airscrew drives have been damaged and presents the methodology of the studies. The structure of the object under investigation is described along with the chain of measurement, with consideration to the fact that frequencies characteristic for detrimental dynamic phenomena are virtually unknown and there are substantial constraints to measurements that can be taken in-flight. Initial results are outlined of investigations of the driving unit tests completed both on the ground and in-flight. All the addressed topics are illustrated by examples. An initial comparison between results obtained during ground tests makes it impossible to exclude the influence of the airfield surface on the occurrence of adverse operating circumstances. An unambiguous identification of reasons for failures and development of efficient preventive measures is possible only after carrying out pressure measurements

Keywords: *investigation of avionic events, diagnostics of avionic driving systems*

1. Introduction

The PZL-130TC-I "Orlik" aircraft is a plane that is used by the High School of Air Force Officers for education and training purposes in fundamental education of future air force pilots.

The analysis of problems related to the operation of these aircrafts has demonstrated frequent cases of exceeding of the technical conditions prescribed for the M-601T engine and the V 510T airscrew.

The recorded moments of rpm and torque exceeding presented a set of factors that caused typical failures of the driving unit. Particularly dangerous were defects of the LUN-7816 hydraulic drive for the airscrew (Fig. 1) since these defects have led to several failures and a few dozen of hazardous situations that could possibly lead to an air accident.

The airscrew drive (Fig. 1) comprises a gear pump (1), pressure reduction valve RV-1 (2) for the maximum oil pressure, pressure reduction valve RV-2 (3) for the minimum oil pressure, centrifugal governor (4) and a reverse flow valve (5) – a set of bushings.

The drive enables a steady operation of the control system and a faultless rotation of the airscrew when flight conditions are changed or when the Engine Control Lever (DSS) or the Airscrew Pitch Control Lever (DSSŚ) are repositioned. Smooth operation of the drive makes it possible to maintain the predefined airscrew characteristics, including system efficiency – Fig. 2 that, in turn, affects the level of fuel consumption.

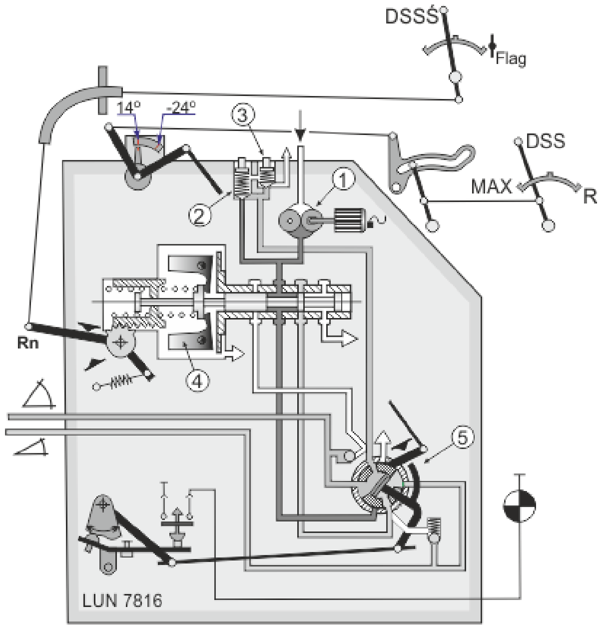

Fig. 1. Diagram of the LUN-7816 airscrew drive

The drive also protects the aircraft against circumstances where negative thrust is achieved in flight – Fig. 3 – that presents a danger of quick acceleration of an unloaded turbine up to overspeeding and in consequence to its disruption.

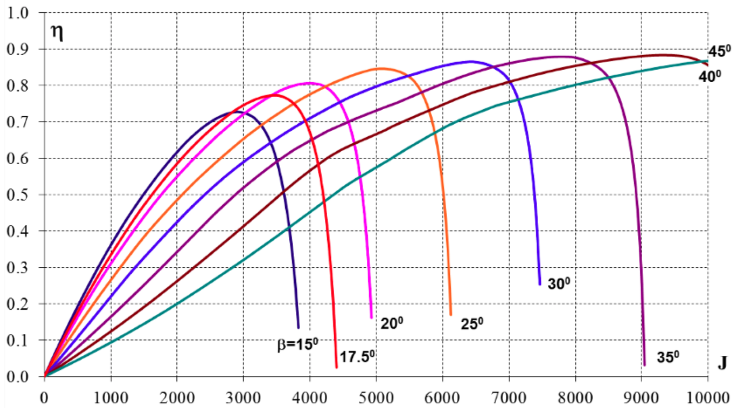

Fig. 2. Variations of the system efficiency as the function of the velocity factor J and the twist angle β of airscrew blades

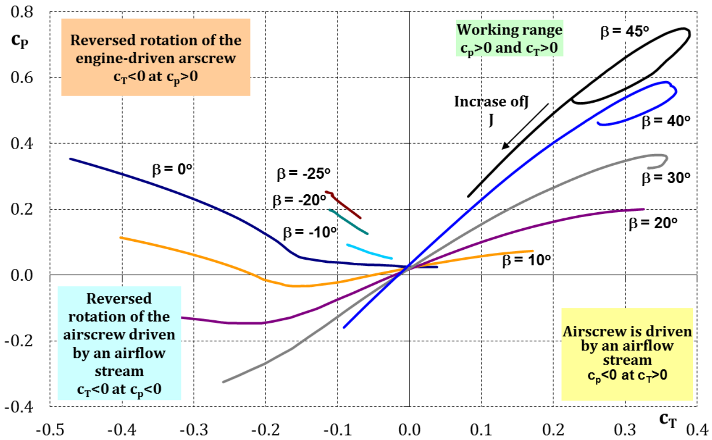

Fig. 3. Variation of the power factor c_P as the function of the thrust coefficient c_T at the specific twist angle of airscrew blades

2. Identification of failure symptoms

A detailed analysis of information recorded by the on-board flight analyser indicated some possibilities of initial identification of symptoms that precede a failure of the LUN-7816 airscrew drive. These symptoms include variations of airscrew rpm. Fig. 4 shows an inexplicable, spontaneous rise of airscrew rpm $n_{ś}$ during a ground test of the PZL-130TC1 'Orlik' aircraft #034, which broke down during its second flight after the recorded event.

It was thus possible to identify deficiency symptoms of the LUN 7816 airscrew drive even two flights before its eventual failure.

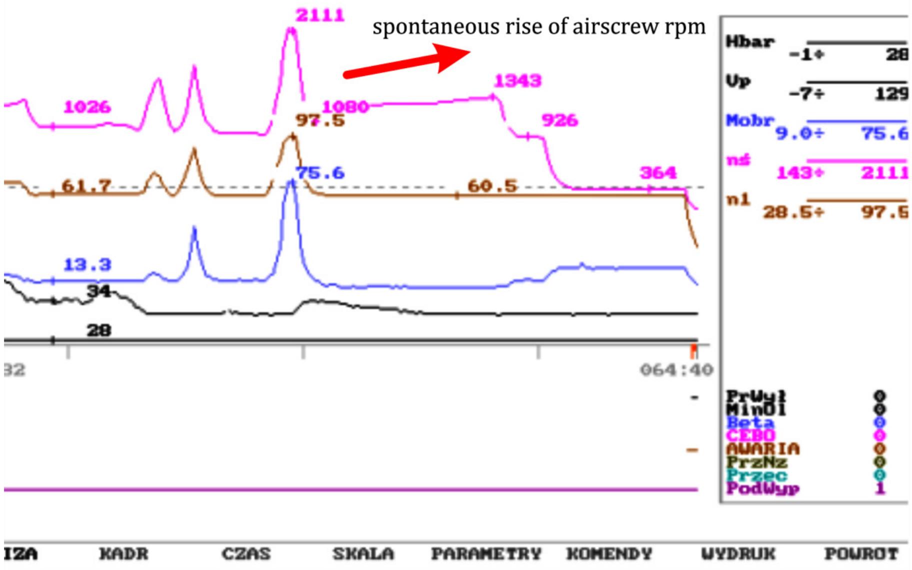

Fig. 4. The waveform with a spontaneous rise of the airscrew rpm $n_{ś}$ recorded during a ground test of the PZL-130TC1 'Orlik' aircraft #034

Another event that also illustrates the preliminary phase of the drive deficiency happened during a flight of the aircraft #022 – Fig. 5. The aircraft drive was then disassembled in witness of a commission at the premises of the drive manufacturer and the examination demonstrated a crack of a roll in the HK1015 bearing.

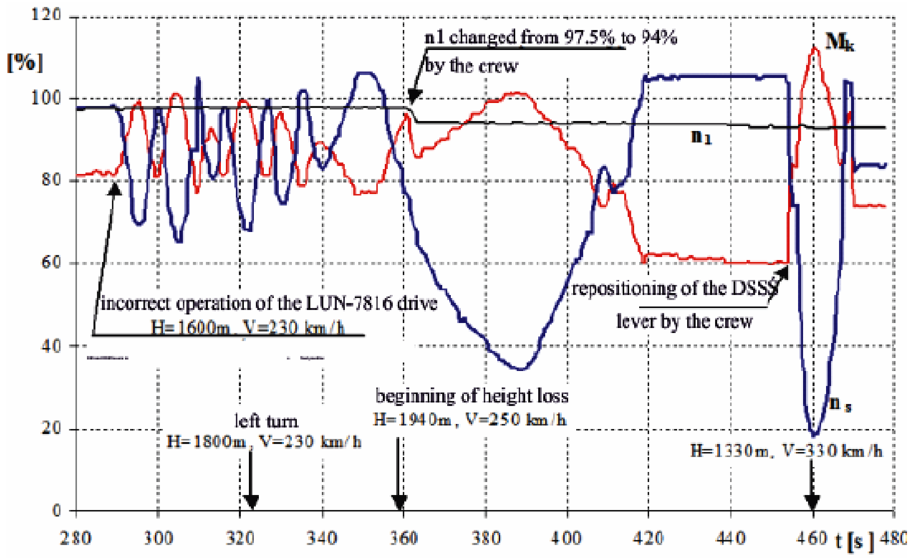

Fig. 5. Changes of airscrew rpm during a flight of the aircraft #022

However, the foregoing identification method requires extensive experience and currently does not guarantee a sufficiently high efficiency under conditions of regular operations.

An initial examination of the subassemblies within the LUN-7816 airscrew drive after its disassembling made it possible to determine its parameters that include:

- the characteristic frequency of the forcing pump (f_{zp} = 26.375 kf_v, where k ∈ **C**) as well as the technical conditions for verification of the permissible level of oil pressure pulsation (0.25p_{rvl} for f_{pvl} < 100 Hz),
- free vibration frequencies of the RV1 valve (719 Hz for a non-modified valve and 680 Hz for a modified one), and the RV2 valve (302 Hz), and the centrifugal governor (2 Hz),
- range of operation pressures for the RV1 valve (2.0-2.49 MPa) and the RV2 valve (0.24-0.39 MPa) ignoring the effect of hydromechanical forces,
- characteristic curve of the centrifugal (spring) governor and theoretical rpm ranges for steady operation of the airscrew, for a specific position of the Airscrew Pitch Control Lever (DSSŚ),
- ranges for such airscrew rpm for which resonance vibrations of the RV1 and RV2 valves occur.

The analysis of the damaged drives demonstrated that the component that is most vulnerable to failures is the needle bearing HK1015 of the driven gear of the gear pump (1).

Before starting the investigations, the following hypotheses were adopted concerning root reasons for failures of the HK1015 bearing of the airscrew drive:

- excessive forcing pressure of the pump,
- excessive misalignment of the bearing race (more than ±0°2'),
- excessive contamination of the oil system with abrasive products of the bearing wears.

Subsequent phases of the failure development consist in:

- exceeding of dynamic surface stress on the inner bearing race,
- pitting of the inner race – appearing of Fe, Cr or Ni metal dust in oil,
- slip of needles, their deformations and cracks,
- damage to the bearing separator,
- excessive play of the driven gear of the pump (a modulation of oil consumption),
- rubbing of the top surface of the driven gear against the body, presence of aluminium dust in oil,
- drop in the volumetric efficiency of the drive pump,
- oscillations of airscrew rpm and torque.

3. Supplementary investigations

To assess actual operating conditions of the LUN-7816 airscrew drive it was necessary to carry out some additional ground and in-flight tests of the driving unit with measurements of drive parameters, such as oil pressure at characteristic points of the oil system for the automation functions of the airscrew (Fig. 1). These pressure values comprise: p_{op} – oil pressure across the inlet of the gear pump of the drive, p_{RV} – oil pressure downstream the drive pump (but upstream the RV-1 valve), p_{ld} - pressure across the trunk line for the large angle of the airscrew hub, p_{lm} – pressure across the trunk line for the low angle of the airscrew hub. The measurements were taken with use of membrane pressure transducers with their operation ranges properly selected according to the expected pressure values and the transmission bandwidth of ca. 5 kHz.

When the driving unit was running on ground, the following measurements were carried out simultaneously with use of the following dedicated equipment:

- p_{op}, p_{RV}, p_{ld} and p_{lm} pressure with use of the S2-3ap on-board monitoring recorder manufactured by ITWL with a sampling frequency of 34 Hz /channel,
- p_{op}, p_{RV}, p_{lm} and p_{ld} pressures with use of the ADC board (PCB) of the AT MIO-16L type from National Instrument with a sampling frequency of 20 Hz /channel,

– asynchronous measurements of the turbogenerator and the airscrew rpm with use of two CTM-PER boards of counter-timers from Keithley-Metrabyte with a clock frequency of 10 MHz.

For the in-flight tests, the only source of information about the operation of the LUN-7816 airscrew drive was the on-board S2-3ap monitoring recorder.

In the measurements there had to be considered the sampling rates for the oil pressure signals, transmission bandwidth of pressure transducers and the expected spectrum of the acquired signals. Therefore, the analysis of data stored in the on-board monitoring recorder took account of the following impacts:

– duplication and offset of the continuous signal spectrum $y(t)=\sum_i A_i \sin(\omega_i t+\varphi_i)$ in the numerical signal $y(k)=\sum_i A_i \sin\left(2\Pi \frac{\omega_i}{\omega_s} k=\varphi_i\right)$,
– masking of components in the numerical signal due to aliasing.

The comparative analysis between information gathered during ground tests of the motor and recorded by the ADC boards (PCBs) with consideration to Nyquist conditions and the ones downloaded from the S2-3ap recorder made it possible to find out the correction factor for the characteristic frequencies of amplitude pulsations. For instance, for a pulsation frequency of about 500 Hz the correction factor is 1.45.

Figure 6 depicts discrepancies of peak values obtained for signals from the on-board monitoring recorder (sampling frequency of 34 Hz /channel) and the ADC measurement board.

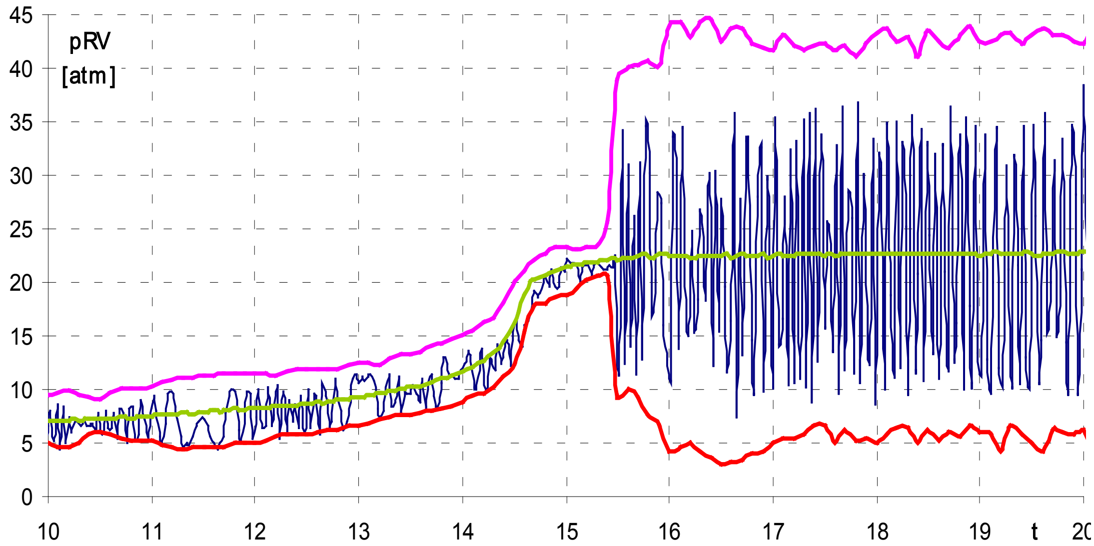

Fig. 6. The effect of the sampling frequency for the signal of the p_{RV} pressure onto values of pulsations measured during tests

The determined correction factors for the pulsation spectrum made it possible to find out the actual amplitude of pressure pulsations recorded during in-flight tests.

4. Samples results

The completed on-ground measurements of pressure values provided a profuse amount of data. The detailed analysis of that information makes it possible to assess technical condition of the airscrew drive and to find out the characteristic resonance frequencies. Fig. 7 presents profiles for the ground test of the aircraft engine, whilst Fig. 8, 9 presents waveforms for the measurements taken for the oil pressure.

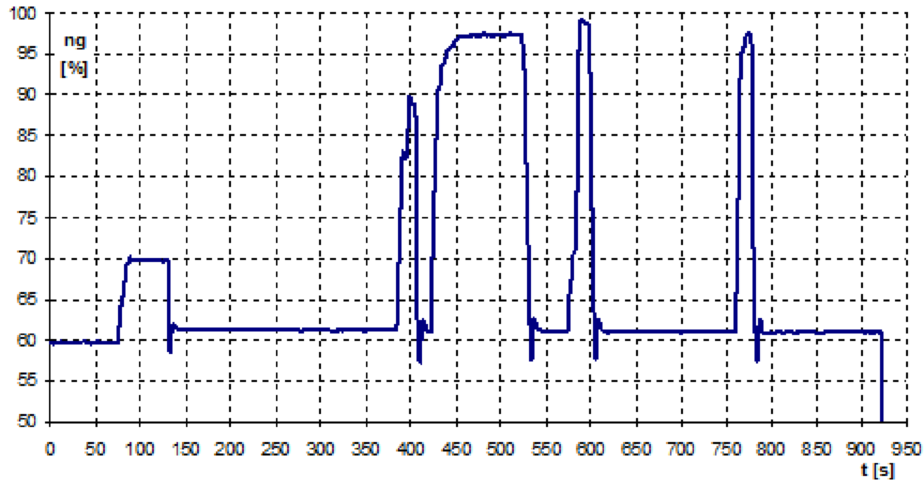

Fig. 7. The waveform for variation of the engine rpm (n_g) during a ground test

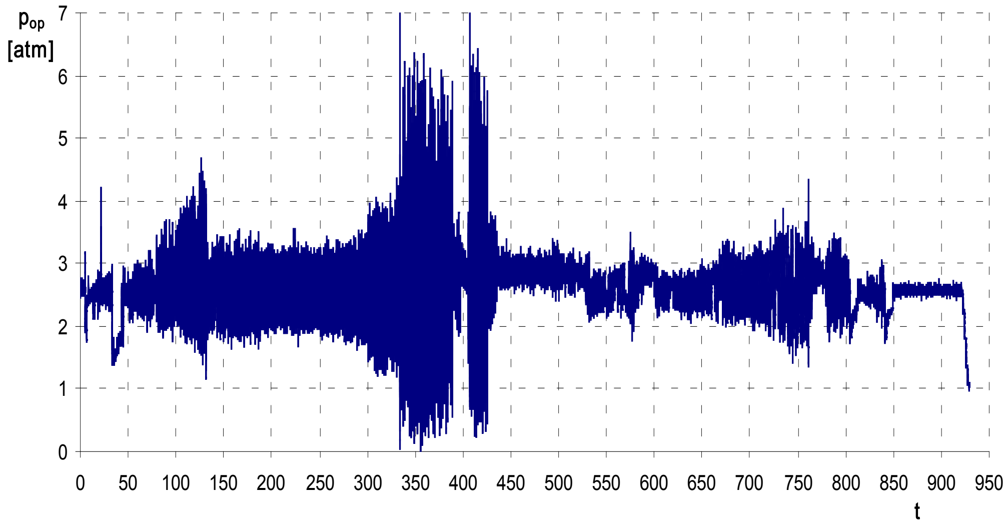

Fig. 8. Variation of oil pressure measured across the inlet to the gear pump of the LUN 7816 airscrew drive during a ground test of the aircraft #012 with the engine # 994002

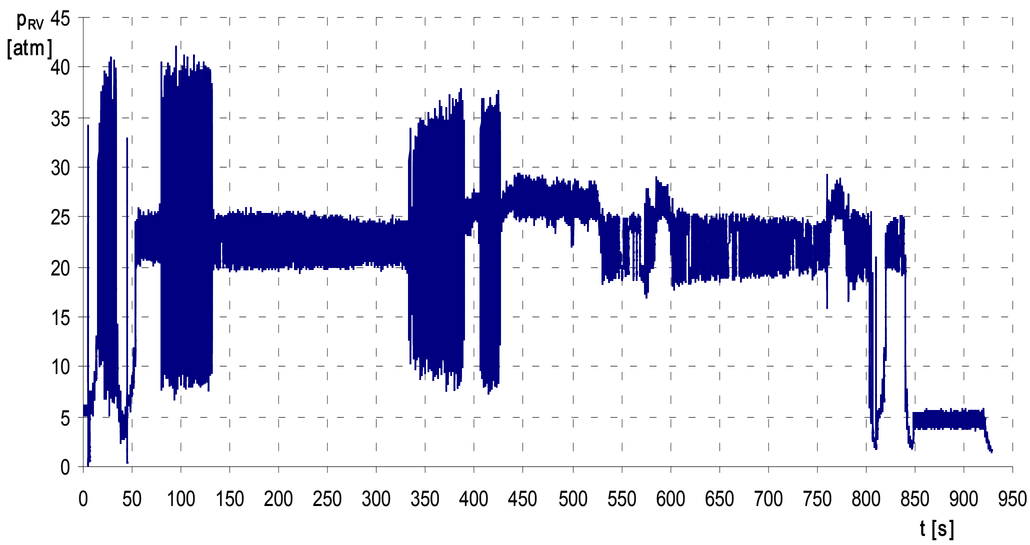

Fig. 9. Variation of oil pressure measured across the outlet from the gear pump of the LUN 7816 airscrew drive, during a ground test of the aircraft #012 with engine # 994002

The analysis of characteristic curves of oil pressure vs. engine rpm made it possible to find out that excessive pulsations occur mostly downstream the gear pump of the airscrew drive (the p_{RV} pressure) and predominantly for ranges from the idle run to about 80% and the turbine generator rpm (n_g).

With consideration to the characteristic frequency (about 500 Hz) and to the pulsation amplitude (about 20 atm.) it was found out the observed phenomenon is hazardous to the HK1015 bearing of the airscrew drive. In addition, 0 depicts also the dynamic properties of the phenomenon mapped onto the data downloaded from the flight recorder.

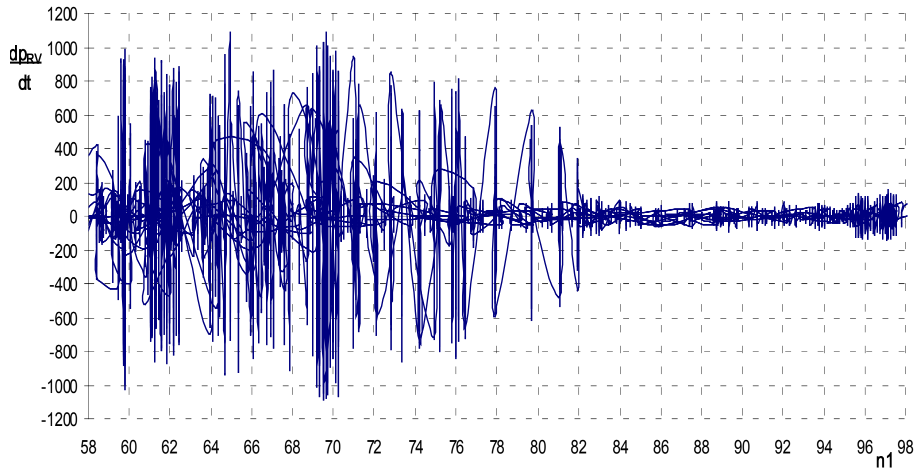

Fig. 10. Dynamic variations of the differential oil pressure (p_{RV}) downstream the pump for the LUN 7816 airscrew drive as the function of the turbine generator rpm (n_g)

The test results that were obtained at that stage of studies made it possible to reveal that considerable pulsations of the p_{RV} pressure occurred predominantly during ground tests of the driving unit.

The foregoing observation gave an incentive to carry out an experiment with the aim to find out whether or not the airfield surface affects the measurable oil pressure jumps. The aircraft engine was started up twice for short times of operation, once on a concrete pavement, the second time on grass – Fig. 11 and Fig. 12. The measurement results revealed some slight differences of oil pressure pulsations (recorded when the DSSŚ lever was repositioned and during the 1st phase of warming up), which makes it impossible to reject the hypothesis about the effect of the airfield surface onto provoking oil pressure pulsation.

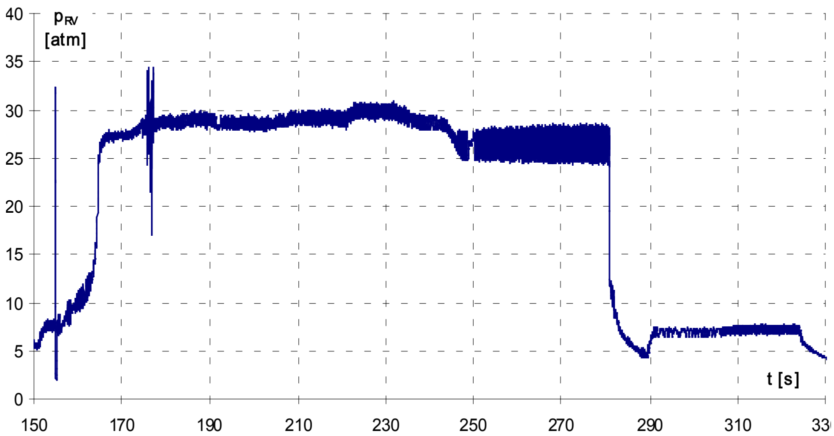

Fig. 11. Test on concrete pavement – a pressure jump is visible during movement of the DSSŚ lever from the 'flag' position to the position of 'released' (switchover of oil flow from the channel of a large angle to the low angle channel). Oil pressure pulsation recorded for the n_g range was about 70%

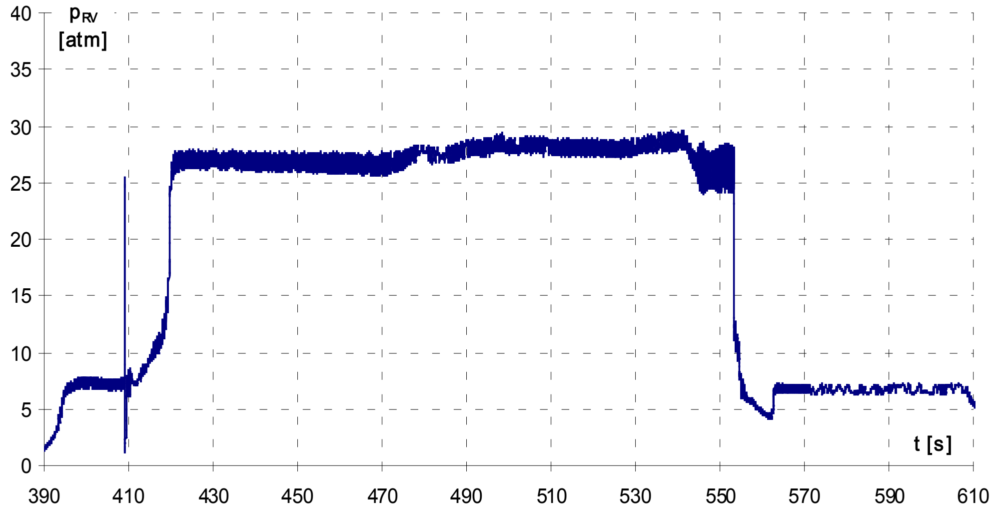

Fig. 12. Test on grass – no pulsation is visible and the pressure jump associated with moving the DSSŚ lever from the 'flag' position to the position of 'released' is much less

5. Conclusions

The performed studies demonstrated the occurrence of excessive pulsation of the p_{RV} pressure during ground tests of the aircraft engine when the turbine generator rpm was about 80%.

Incidental (two cases) short-term (several-second long) pulsations of the p_{RV} pressure were recorded during in-flight tests when aerobatic manoeuvres of medium difficulty were performed, for the rpm range (n_g) above 90% (a roll) and 60% (a stall). A short-term pulsation of the p_{RV} pressure was also detected for the range of reverse thrust that is normally used for an aircraft landing (on a runway) at the speed $V < 150$ km/h.

An initial comparison between results obtained during ground tests makes it impossible to exclude the influence of the airfield surface (aircraft cushioning) on the occurrence of adverse operating circumstances for the airscrew drive.

An unambiguous identification of reasons for failures of LUN 7816 airscrew drives, as well the development of efficient preventive measures is possible only after carrying out pressure measurements of all PZL-130TC1 "Orlik" aircrafts equipped with M601T engines and V510T airscrews.

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