29th Congress of the International Council of the Aeronautical Sciences
St. Petersburg, Russia; September 7-12, 2014

IMPACT OF IRREGULARITIES IN THE PISTON ENGINE OPERATION ON THE INFLIGHT VIBRATION LEVEL

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Keywords: *Piston engine, engine leaning, frequency analysis, vibration signal, working condition*

Abstract

Knowledge about the vibration sources on an aircraft is an important prerequisite for modelling adequate response/isolation of initially discovered vibration. The following paper shows results and analysis from changes in low-frequency vibration spectrum located in the engine of Serbia's Lasta aircraft (Figure 1). Due to different working states and various conditions of engine, changing of vibrations is transmitted from the engine to pilot seat, as a consequence of changing quality composition of air/fuel mixture, while testing on a flying aircraft equipped, with piston propelled propulsion group. Test-measure systems used for researches in vibration dynamics characteristics are shown. Values of vibrations are shown in relation to changes of engine working parameters. Research results show that knowledge of engine vibrations gives wide options for an evaluation of response from piston propeller propulsion group on impact from changing quality composition of air/fuel mixture in the engine leaning process.

1 Introduction

Correct working conditions and managing aircraft propelling propulsion group is of huge importance due to two reasons. The first reason regards obtaining the aircraft declared performances and the second one regards safe working condition i.e. avoiding working conditions that can cause damage or eventually disaster. In monitoring engine condition the measuring of vibrations and analysis of engine vibration spectrum are of great importance.

Monitoring work and analysing changes in engine working conditions are based on attaining huge number of its working parameters requiring a large number of sensors. Based on engine working parameters and its vibrations it is possible to establish contribution made to disorder in working condition of engine parts via changes of vibration spectrum. Using vibration analysis is important to establish contribution of vibrations on improper work of particular engine part. Furthermore, it is needed to verify that recorded vibration signal is a relevant indicator for working irregularity [1].

L. Barelli, G. Bidini, C. Buratti, R. Mariani, [2] have confirmed that variations of cylinder charging pressures, while valve is opening, contributing in generating vibrations on the engine, hereafter this is confirming that engine vibration signal is an excellent indicator for variations in the cylinder charging pressure.

S. Liu, F. Gu and A. Ball [3] have defined detection technique how to establish engine/engine/cylinder valve malfunction on engine Shanghai Diesel Works model 4135D, based on measurements for engine head vibrations. It is confirmed that vibration characteristics while in time and frequent domains are very useful in establishing working engine conditions. Similar to this, deBotton C, Ben-Ari J. & Sher E., [4] have confirmed existence of few irregularities connected to anomalies/inconsistencies on spark timing and change in sparkplug clearance, based on analysis of signals from engine vibrations.

C.P. Ratcliffe and D.F. Rogers [5] have analysed vibrations, fuel economy and temperature of exhaust gases on 6 cylinder engine Continental IO 520 BB installed in Beech Bonanza aircraft. Research has been initiated due to appearance of engine vibrations caused by unbalanced mixture of fuel and air in cylinders. Conducted are parallel evaluations of engine tests with different fuel injectors. The main measured parameters are amplitude and vibration frequency during engine specific fuel economy and relative temperature of exhaust gases, as per each cylinder separately. Produced are evaluated results for measured parameters of engine working condition and engine vibrations, and their mutual relations for two different types of fuel injector.

Listed researches clearly showing that vibration analysis on piston-propeller propulsion aircraft group should focus onto differences that are appearing in relation to specific vibration spectrum of propulsion group. With this analysis it is possible to establish contribution from changes in work operations of some components/parts to vibration spectrum of propulsion group and furthermore for observed part of aircraft structure.

2 Experimental setup

All measurements are completed on the first prototype of Lasta aircraft in Technical Test Centre of Serbian Army on Batajnica Airport.

Fig. 1. Lasta aircraft

Vibration measuring is carried out with multi-channel digital acquisition systems, NetdB12 - 01 Metravib, which has an internal rechargeable battery and recorder. The device characteristics are shown in Table 1.

Table 1–Characteristics of NetdB12 system – 01 Metravib

Input channels	
No. channels	12 BNC
Resolution	24 bits
Voltage	AC / DC /AC ICP
Range	-20 db: 14.1 V (10 V RMS) 0 db: 1.41 V (1 V RMS) +20db: 141 mV (100 mV RMS)
CHP	>105 dB RMS full scale

For vibrations measurements have been used uniaxial piezo accelometers B&K 4383P. Installation position for accelerometers is shown in Figure 2.

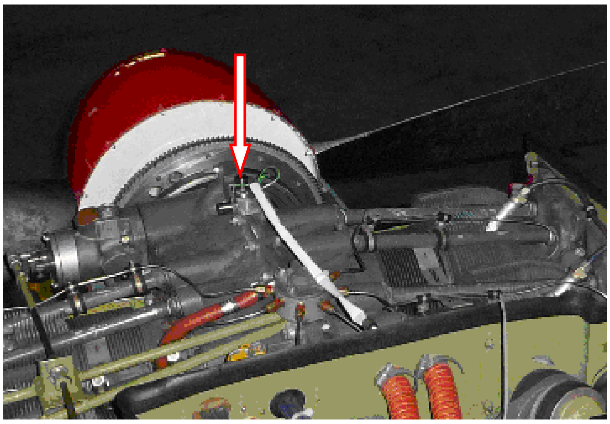

Fig. 2. Installation position for accelerometers on the engine

During the experiment engine and aircraft parameters were continually measured by Electronics International MVP-50P device that are utilised for in line monitoring and analysis.

The results of the vibration measurement should match the real vibration condition on the construction part where it was measured. This is achieved by organizing vibration measurement process through several interrelated steps. Data were captured in the frequency range 0-200 Hz, using 801 point Fourier transforms with a Hanning window and a 50% overlap and frequency resolution of 0.25 Hz.

The experiment was carried out during horizontal aircraft flight; the aircraft was exposed to periodic changes in several parameters that characterize the current mode of operation. The aircraft cruising flight was carried out at an altitude of 1500 meters and fuel / air mixture was leaned and fed into the engine. Leaning of an aircraft piston engine is the process of using leaned and enriched fuel-air mixture to achieve optimal fuel economy and engine working conditions.

During the experiment, vibrations are measured on the cylinder heads in directions of X, Y and Z axises (Figure 2).

Shown are results of vibration measured on an engine and the engine parameters while aircraft is in flight at an altitude of 1500 metres, as per the following engine working regimes:

- leaning process in a working regime 2450 RPM and fuel charging pressure of 23.6 In Hg;
- leaning process in a working regime 2350RPM and fuel charging pressure of 20.8 In Hg.

In this research frequencies of 40.83 Hz and 39.16 Hz which are correspond engine shaft revolutions of 2450 RPM and 2350 RPM, are called fundamental frequencies [6].

In both working regime leaning was completed in several steps of fuel supplies into the engine. As per each step fuel flow has been decreased by 5 l/h from start to finish. At each working regime the engine was kept working at least one minute until the next leaning of fuel mixture.

3 Results and discussion

Changes in engine fuel quantity supply and changes in air/fuel ratio mixture combusted in engine, as a consequence has a change in exhaust gas temperature (EGT) on all 6 cylinders and also a change in cylinder head temperature (CHT) on all 6 cylinders.

Figure 3 and 4 are showing exhaust gas temperature from all 6 cylinders in function of fuel flow change at 2450 RPM and 2350 RPM respectively.

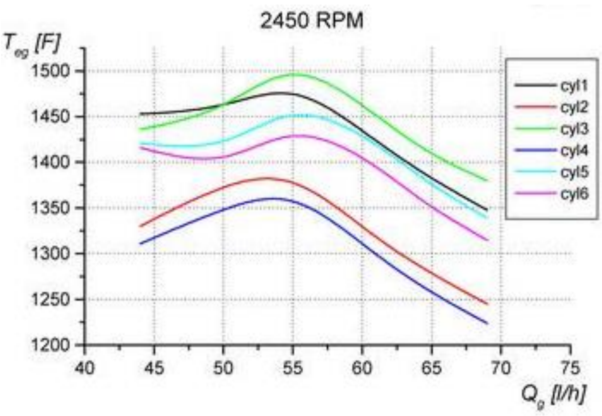

Fig. 3. Exhaust gas temperature in function of fuel flow changes during leaning process in regime 2450 RPM

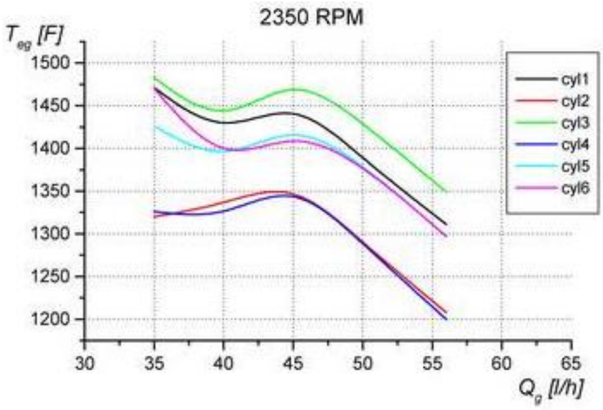

Fig. 4. Exhaust gas temperature in function of fuel flow changes during leaning process in regime 2350 RPM

Exhaust gas temperature curves for engine working regime at 2450 RPM (Figure 3) confirm theoretical trends. Exhaust gas temperature does peak-out at fuel flow of 55 l/h that presents stoichiometric air-fuel mixture ratio. Exhaust gas temperature for engine working regime at 2350 RPM does not have theoretical trend, instead it has got two temperature peaks (at fuel flow from 45 l/h and 35 l/h) (Figure 4).

The above presented is the first important indicator.

Figures 5 and 6 are showing, for an optimal fuel economy, averaged vibration frequency spectrums by an engine during leaning process in regimes of 2450 RPM and 2350 RPM toward all three axises.

On Figures 5 and 6, it is noticeable that in leaning process at both engine working regimes, the dominant vibration acceleration is on Blade

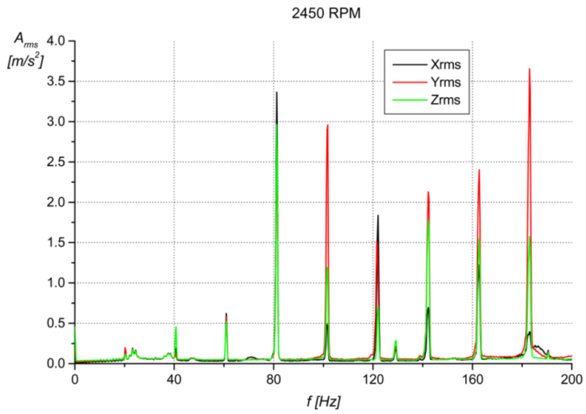

Fig. 5. Averaged vibration frequency spectra in leaning process at 2450 RPM (fundamental frequency 40.83 Hz)

Pass Frequency (BPF) (81.67 Hz and 78.33 Hz) in directions of X and Z axis. In Y axis direction, in both mentioned engine working regimes, dominant acceleration is at 3rd harmonic frequencies.

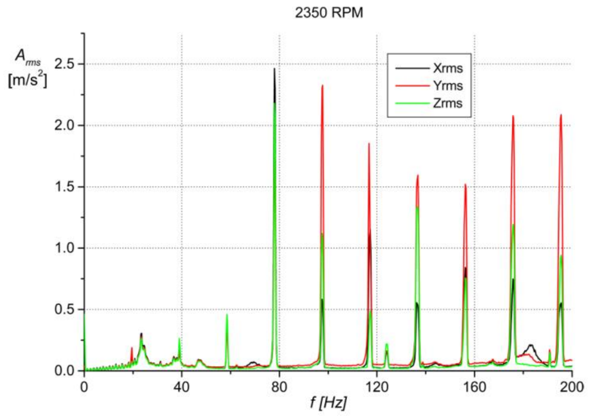

Fig. 6. Averaged vibration frequency spectra in leaning process at 2350 RPM (fundamental frequency 39.16 Hz)

The aircraft Lasta was built with a six-cylinder piston engine, and therefore the 3rd harmonic Engine Crankshaft Rotation Frequency coincides with the Engine Firing Frequency. The aircraft propeller is fitted with two blades, so the Blade Pass Frequency coincides with the 2nd fundamental harmonic Engine Crankshaft Rotation Frequency.

Oscillation frequencies, for both regimes, corresponding to 1st harmonic are 39.16 Hz and 40.83 Hz, corresponding to 2nd harmonic are 78.32 Hz and 81.66 Hz, 3rd harmonic frequencies corresponding to 117.48 Hz and 122.49 Hz and 4th harmonic frequencies corresponding to 156.64 Hz and 163.32 Hz.

Figures 7 and 8 are showing engine power HP [%], temperature on cylinder head CHT [°F], fuel flow q_f [l/h] and RMS vibration acceleration A_{rms} [m/s^2] in directions of X, Y and Z axises in a function of relative temperature of exhaust gases T_{eg}[°F]. The drawn curves are based on data for engine working regimes at 2450 RPM and 2350 RPM.

Curves of horse power in engine working regime 2450 RPM (Figure 7) confirm theoretical trends. Maximum power will be achieved during maximum temperature of exhaust gases T_{eg}. In the further engine leaning, reducing the fuel flow to the lowest will proportionally reduce the engine power. Curves of horse power in engine working regime 2350 RPM does not have theoretical trend (Figure 8). Instead it has got two horse power peaks (at fuel flow from 45 l/h and 35 l/h).

This is the second important indicator.

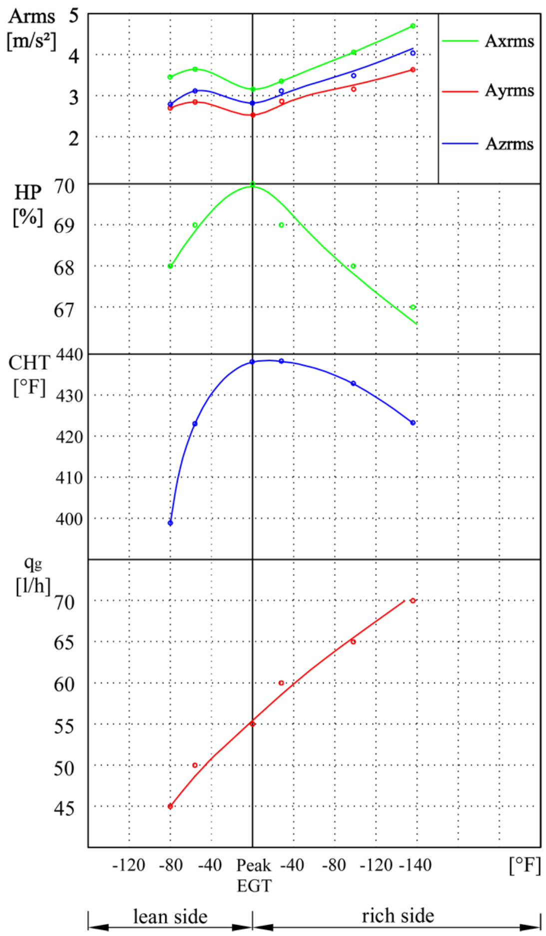

Fig. 7. RMS accelerations of engine vibrations, engine power, CHT, and fuel flow as in function of relative temperature from exhaust gases for 2450 RPM and BPF=81.67 Hz

Figures 7 and 8 show that the value of vibration acceleration of the engine at BPF (in the direction of the three axises have their minimum at maximum T_{eg}).

Maximum engine power typically corresponds to the maximum value of the engine vibration. For the leaning regime it is different, because the maximum power is achieved at maximum exhaust gas temperature, where fuel mixture is the best and closest to stoichiometric, affecting a more uniformed engine running.

Acceleration of vibration at BPF, in both fuel mixtures leaning regimes, is lowest for flow rate of fuel at the maximum exhaust gas temperature, and the minimum fuel flow rate.

This is the third important indicator.

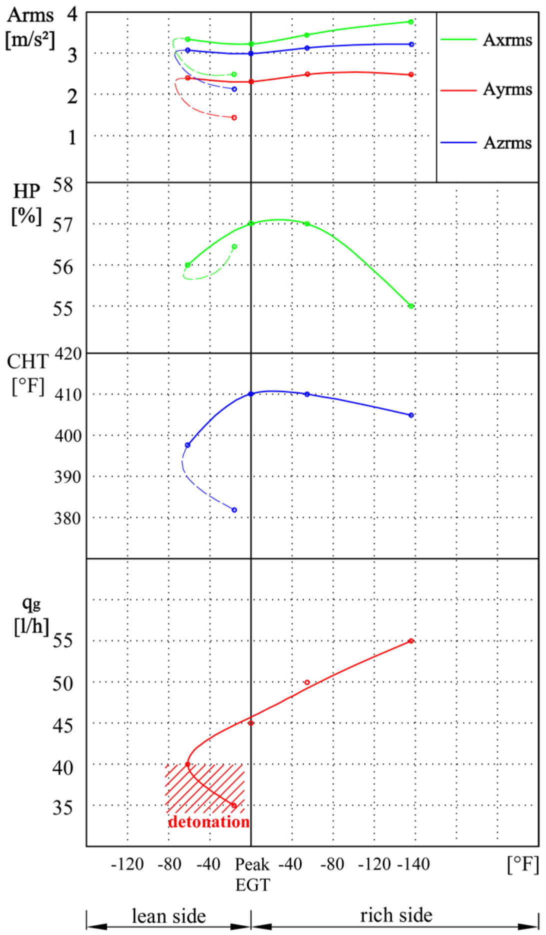

Figure 8. RMS accelerations of engine vibrations, engine power, CHT, and fuel flow as in function of relative temperature from exhaust gases for 2350 RPM and BPF=78.33 Hz

Reducing fuel flow can lead to improper combustion of fuel and air in the cylinders, which cannot be detected by analysing engine vibration only on the BPF.

To assess the impact of engine vibrations, it is necessary to analyse the vibration spectrum in the direction of the Y-axis, as it is the direction of piston motion.

The waterfall diagram (Figure 9) shows changes in vibration spectrum during fuel leaning process at the frequency range of 0 Hz to 200 Hz, in the direction of the Y axis, and the engine running at 2350 RPM.

On diagram 9 in the direction of Y-axis, there is a decrease vibration at BPF, and increase in vibration to the 3rd harmonic frequencies, which occur during engine leaning, by reducing fuel flow to the lowest.

Dispersion of energy at frequencies few times greater than the main frequency, apart from showing on condition in quality of combustion process it can present existence of some other engine malfunction.

In the area with lean mixture, combustion is incorrect, furthermore resulting in an increase of 3rd harmonic vibration toward the direction of Y-axis in both leaning regimes at 2450RPM and at 2350 RPM.

This is the fourth important indicator!

Reducing fuel flow of the mixture fuel/air into the cylinders can cause combustion with detonation, which cannot be safely detected by monitoring the engine parameters or the engine vibration. Therefore, it is necessary to make a careful analysis of all stated indicators.

Detection of these occurrences is hugely important as combustion with detonations can cause high mechanical loads on working parts inside the engine and its reservoirs, which rapidly leads to the degradation of their working life.

4 Conclusion

To achieve proposed performances, the aircraft with piston propeller propulsion group, it is necessary not only to monitor engine working parameters and aircraft flight, it is also necessary to complete measurements and analysis of the engine vibration spectrum.

During the experiment four indicators have been defined, and by using them it is possible to identify phenomenon that occurs in the engine.

1. Curves of exhaust gas temperature for engine working regime at 2450 RPM confirm theoretical trends. The exhaust gas temperature for engine working regime at 2350 RPM does not have theoretical trend, instead it has got two temperature peaks (fuel flows of 45 l/h and 35 l/h).

2. Horse power curve during engine working regime at 2350 RPM does not have theoretical trend. Instead it has got two horse power peaks (at fuel flow from 45 l/h and 35 l/h).

3. Vibration acceleration at Blade Pass Frequency, in both regimes of fuel mixture leaning, is the lowest during flow of fuel providing the maximum exhaust gas temperature, and during the lowest flow of fuel.

4. Vibrations in the direction of Y-axis at Engine Firing Frequency (3rd harmonic Engine Crankshaft Rotation Frequency) are increasing

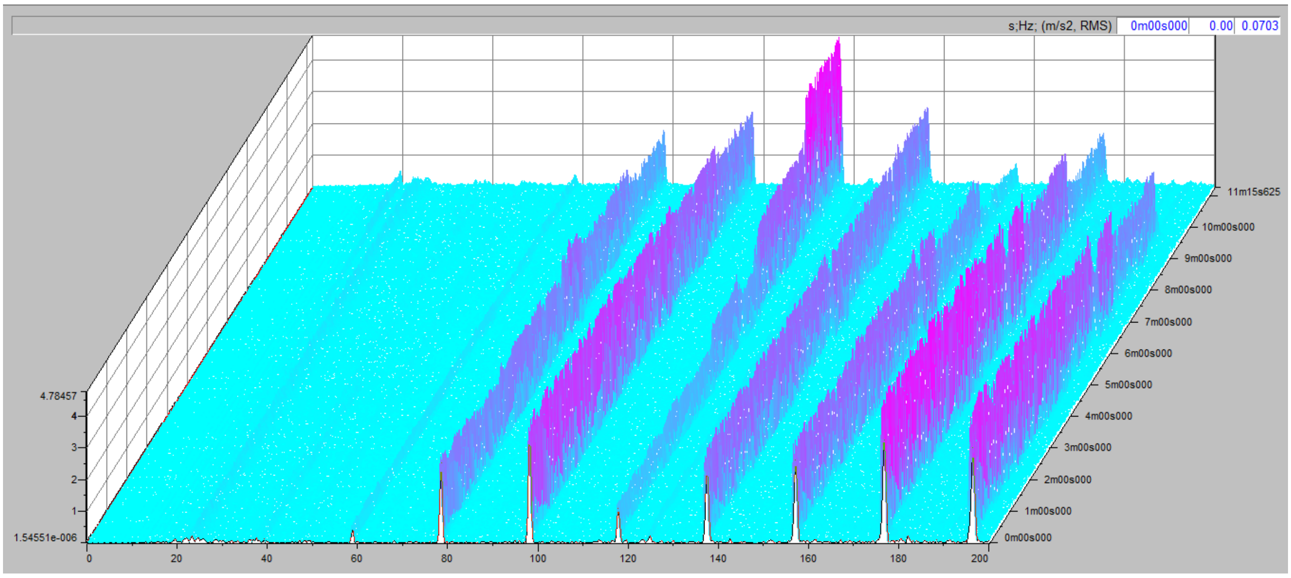

Fig. 9. Vibration spectrum for engine leaning regime at 350 RPM in Y axis direction [1]

with decreasing of fuel flow at both engine implemented leaning regimes (leaning at 2350 RPM and 2450 RPM), and reaches its maximum during leanest fuel / air mixture.

These indicators are closely connected and dependent on each other. Their existence during the piston propeller engine working process clearly shows the occurrence of combustion with detonations due to insufficient amount of fuel in the mixture.

By measuring vibrations on the engine, analysing exhaust gas temperatures and measuring engine horse power occurring at appearance of combustion with detonations during frequency that is three times greater than the fundamental one, which will make easier to exploit and maintain the engine.

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