VIBRATION ANALYSIS OF RUNNING-UP TURBINE ENGINE GTD-350

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Summary

The article contains the example of practical application of the procedure for non-stationary signals processing developed at Department of Mechanics and Vibroacoustics University of Science and Technology (AGH). The developed method – Procedure of Linear Decimation (PLD) was applied for signal analysis of vibrations of GTD–350 turbine engine in unstable operating conditions. As a reference signal the rotational speed of driving shaft was adapted. The results were enclosed for turbine running-up and coasting state.

Keywords: diagnostics, turbine engine, unstable state.

BADANIE DRGAŃ ROZRUCHOWYCH SILNIKA TURBINOWEGO GTD-350

Streszczenie

W artykule przedstawiono przykład praktycznego zastosowania opracowanej w Katedrze Mechaniki i Wibroakustyki Akademii Górniczo-Hutniczej procedury przetwarzania sygnałów niestacjonarnych. Opracowaną metodę – Procedurę Liniowej Decymacji (PLD) zastosowano do analizy sygnałów drgań silnika turbinowego GTD–350 w nieustalonych stanach pracy. Jako sygnał referencyjny przyjęto prędkość obrotową wału napędowego. Wyniki przedstawiono dla stanu rozbiegu i wybiegu turbiny.

Słowa kluczowe: diagnostyka, silnik turbinowy, stan nieustalony.

1. INTRODUCTION

Many rotary machines are rated among crucial devices. Energetic turbines, and particularly aviation turbine engines, belong to this group. For safety reasons, specification of their technical state is vital in their exploitation period [3]. As they are required to feature very high reliability, the scheduled maintenance service is not sufficient nowadays – monitoring systems are more and more often applied. These systems enable real-time evaluation of technical state during the operation of an object. Technical state changes most often occur when operating conditions change. Unstable operating conditions, apart from creating a threat of emergency state or even distress, they can hamper the diagnosis process.

One of the methods assisting the specification of technical state in non-stationary conditions is a procedure for processing non-stationary measuring signals developed by the authors. Intended for cyclical machines, it enables converting signals recorded at variable rotation speeds into the form corresponding with stabilized operating states. It is known as Procedure of Linear Decimation (PLD) [2]. This method was oft-cited by the authors, and its theoretical bases were explained in many publications [11, 13, 10]. It involves oversampling of significantly oversampled signal with variable increment corresponding to the changes in reference cycle. It assumes linear increase of cycle tend in an observation window, which also results in its certain limitations [1]. Widening application range of the PLD method can be obtained through more accurate approximation of trend of cycle change.

At present it is also implemented on the basis of FPGA programmable systems in the hardware form. Implemented in a portable measuring device referred to as Programmable Unit for Diagnostic (PUD), it is successfully put into practice. The manufactured device with applied programmable systems enabled to significantly oversample signals (10 MS/s) creating vast capabilities of examining new PLD implementations. This solution allows for increasing decimation coefficient *Dc* even up to 1000 and signal analysis in high-frequency bands, e.g. gear meshing or turbine blades operating, without the necessity of applying interpolating filters. Furthermore, this implementation enables the realization of the method in real-time conditions. Results of the device implementation in former PLD method researches along with specification of its ranges are enclosed in publications [7, 8, 12].

2. SHORT-TIME PROCEDURE OF LINEAR DECIMATION

Developed method was meticulously tested on non-stationary signals recorded on various types of rotary machines. Simple in implementing, yielding positive results, it is also used for shock absorbers subject to cyclical excitation – the research was conducted at Silesian University of Technology.

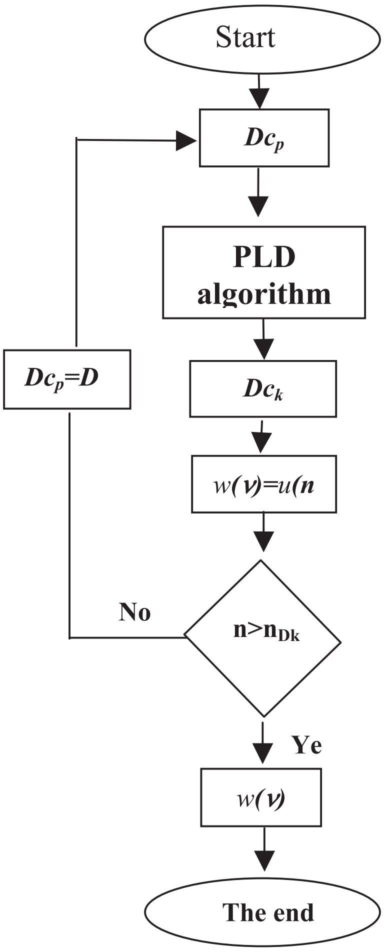

Fig. 1. Algorithm of Short-time Procedure of Linear Decimation STPLD

- v(n) – primary vector
- w(ν) – secondary vector
- Dc_p – initial decimation coefficient,
- Dc_k – final decimation coefficient,
- n – number of the sample of primal vector
- n_{Dk} – sample number enabling PLD ending on primary vector stage

Having manufactured device that enables to record diagnostical signals the purpose was to increase c_p decimation coefficient up to greatest possible value to obtain the most linear approximation function. Without the application of interpolation, it was the only way to preserve the highest linearity of approximating function. However, it turned out not to be suitable approach since it brought good results only with cycle trends being close to linear ones. As for rotary machines at the stage of run-up, particularly machines of dynamic changes of rotation speed, preserving linearity did not significantly improve spectral selectivity, especially in high-frequency band. This prompted developing modified algorithm of the method enabling adjustment to cycle change in short time-periods of an observation window. The new method of analyzing signals in narrow time-periods was referred to as Short-time Procedure of Linear Decimation STPLD. It is explained in the article [9]. Its algorithm is enclosed in fig. 1, and fig. 2 presents schematically the adjustment of linear approximation to cycle changes in observation window.

STPLD method was tested in high-frequency bands. Results obtained during examining signals in gear-meshing frequency band were very satisfactory, as presented in papers [9].

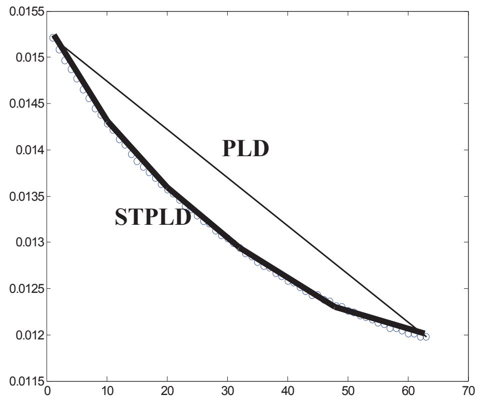

Fig. 2. Approximation of cycle change in observation window with STPLD

3. RESEARCH OBJECT

After successful laboratory tests on rotary machines in full frequency-band range, it was decided to test the method on a device of much greater rotation speed and featuring several reference speeds.

For those tests a GTD-350 turbine was selected [4]. This turbine normally works as an engine of MI-2 helicopter. It has two independent shafts [5]. High-pressure turbine rotates at maximum speed of 43 200 rpm, and propulsion turbine - 24 000 rpm. Rotation speed of output shaft is reduced to one fourth in relation to propelling turbine speed.

Cross section of the tested engine is enclosed in fig. 3 along with the descriptions of its individual elements. Photographs taken during the experiment at laboratory test bed at Navy Academy in Gdynia are presented in fig. 4 and fig. 5.

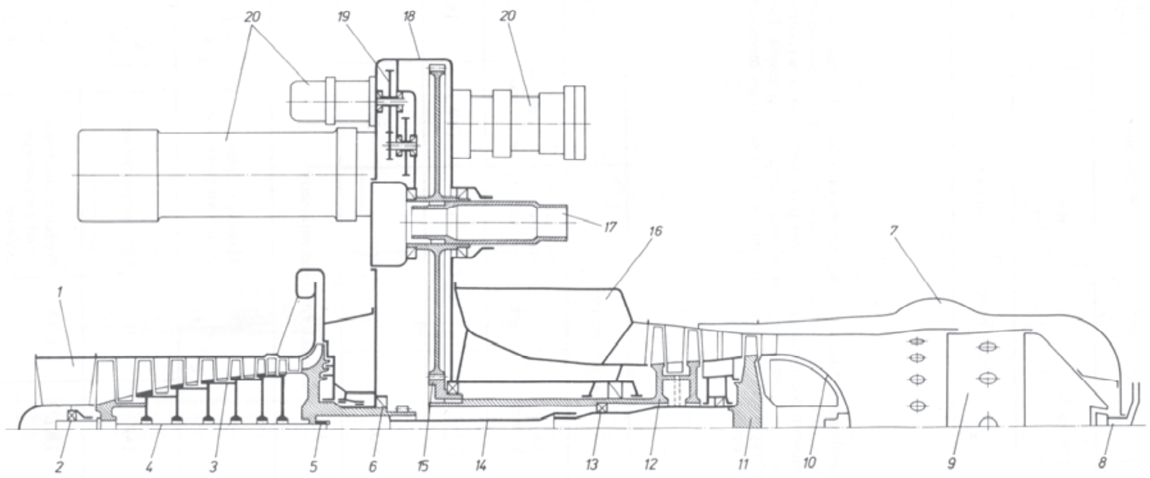

Fig. 3. GTD-350 turbine engine scheme (source [14]):
1 – intake stator blades, 2 – roller bearing, 3 – compressor rotor, 4 – screw attaching compressor rotor plates, 5 – nut, 6 – ball bearing, 7 – air duct leading to combustion chamber, 8 – fuel injector, 9 – fire pipe, 10 – turbine plate cap, 11 – generator turbine, 12 – propelling turbine, 13 – middle (roller) bearing, 14 – middle shaft, 15 – reducer driving wheel, 16 – exhaust manifold, 17 – engine output shaft, 18 – reducer casing, 19 – aggregate-drive gear box for, 20 – engine aggregates.

First of the photographs presents the attachment of laser sensor of reference speed with beam directed at output engine shaft. Rotation speed of the shaft was a reference speed of the executed decimation procedure algorithm. On the second photograph we can see attachment point of triple-axis ICP accelerometer.

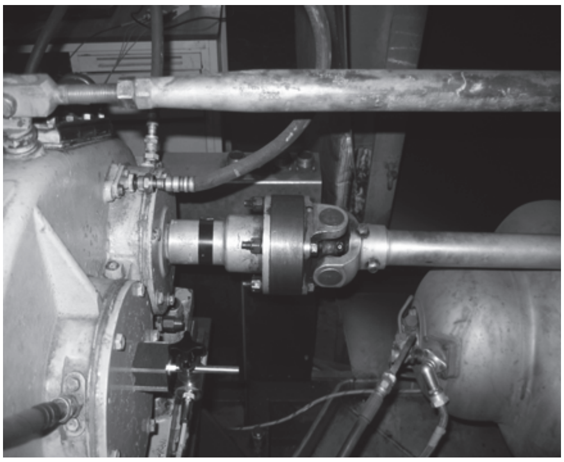

Fig. 4. Laser measurement of rotation-speed changes on output shaft

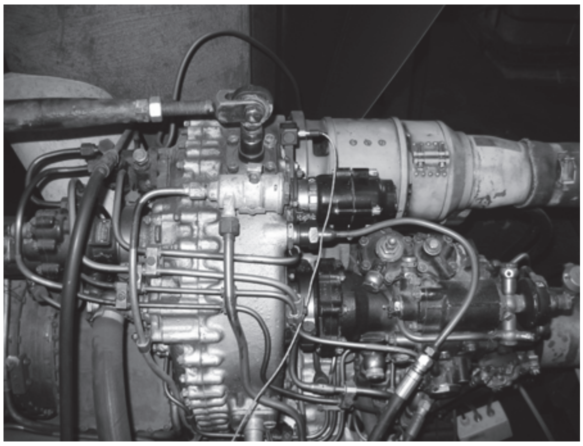

Fig. 5. Location of attachment point of triple-axis ICP acceleration sensor on GTD – 350 engine

4. PLD CAPABILITIES

Experiment was conducted in stabilized turbine operating conditions, during its run-up and coasting.

It also included variable work loading of tested GTD-350 engine.

Fig. 6 presents amplitude spectrum of vibration acceleration for stable working conditions in rotation frequency band. Three dominant frequencies are clearly visible. The first represents basic frequency of output shaft, the second, four times as great - basic frequency of propelling turbine shaft and the third, independent, being frequency of the turbine propelling engine compressor [6].

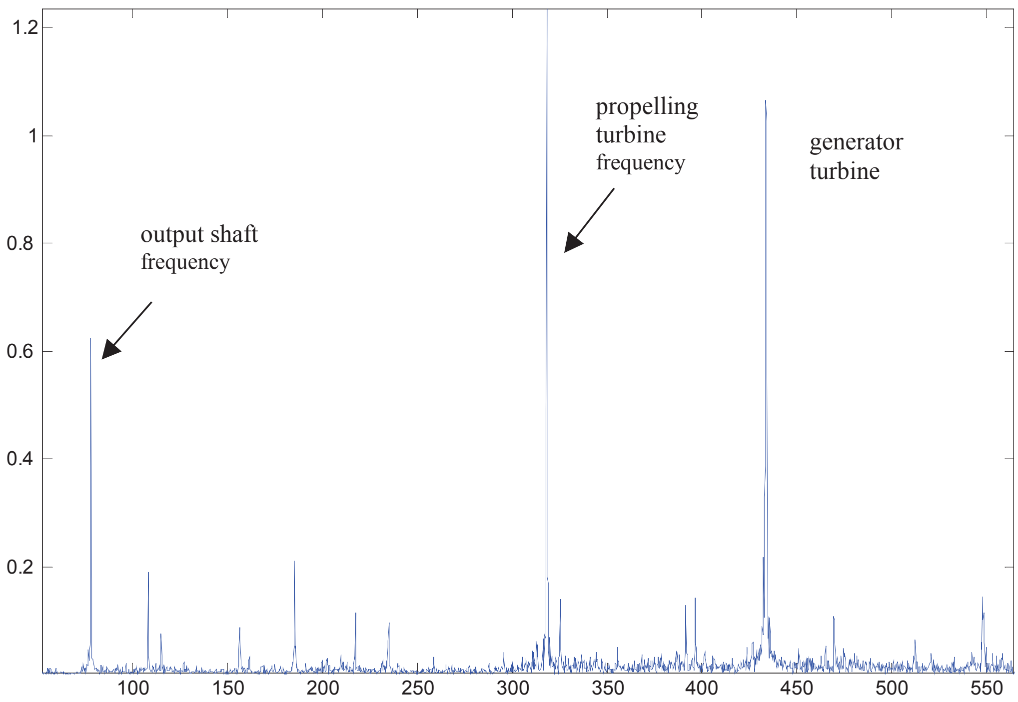

Fig. 6. Amplitude spectrum of GTD-350 engine in rotational frequency band in nominal operational conditions

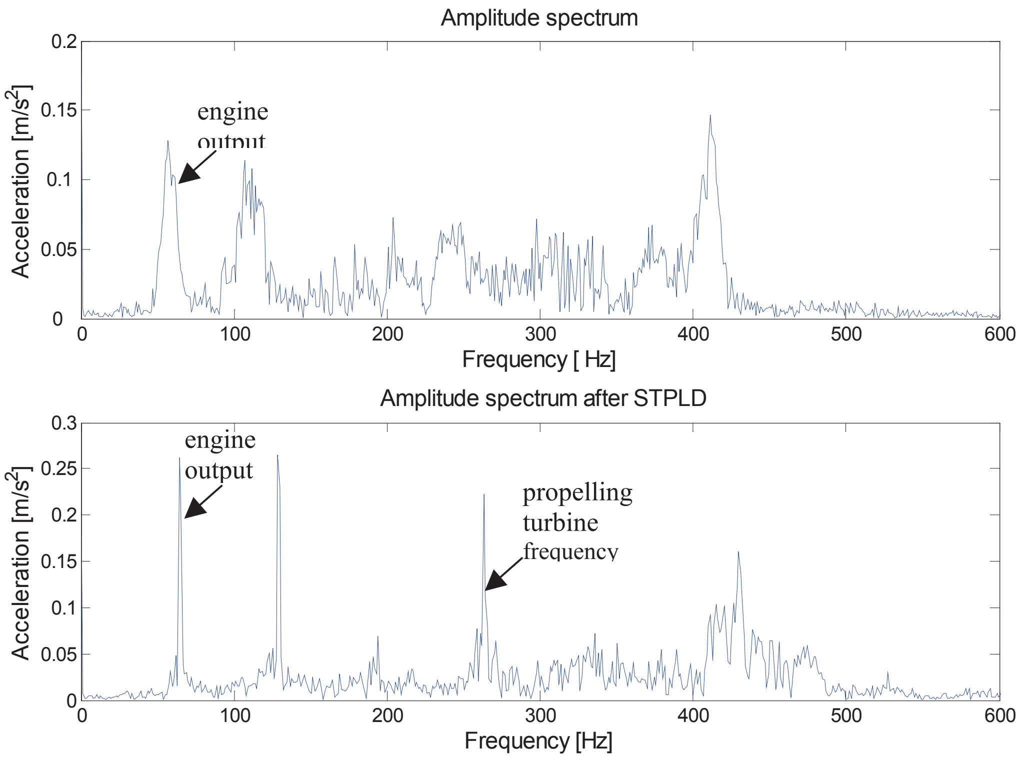

Fig. 7. Vibration-acceleration signal of running-up turbine.

Fig. 7 contains amplitude spectrum of vibration acceleration during run-up: a – spectral analysis, b - spectral analysis after applying procedure of linear decimation. Enhancement of spectral selectivity occurs at shaft frequencies corresponding with reference speed. The last of presented experiments introduces a situation of vibration interference of diagnostical signal by the components of voltage signals of aggregates.

Fig. 8 contains vibration acceleration spectra during turbine coasting: a - amplitude spectrum and b – spectrum after applying STPLD. After applying decimation procedure, components not synchronized formerly with reference speed become fuzzy and the components representing vibrations of propelling shafts, earlier fuzzy, now become distinct.

5. CONCLUSIONS

Experiments conducted on GTD-350 engine brought positive assessment of the effects of applying innovative method of processing non-stationary signals – Procedure of Linear Decimation. Those results though, were not accepted uncritically. Recapitulating, we can state that:

- newly developed method of Short-time Procedure of Linear Decimation based on the approximation in short time-spans reflects cycle-trend changes with sufficient accuracy
- with significant 10 MS/s oversampling it is possible to narrow decimation analysis to a single cycle period
- Short-time Procedure of Linear Decimation can be competitive for row analysis in terms of simplicity of calculations executed in real-time
- in terms of accuracy STPLD is based on actual samples without the application of filters interpolating signals
- further research will be directed to more accurate adjustment of approximation and cycle trend through the application of higher-level functions

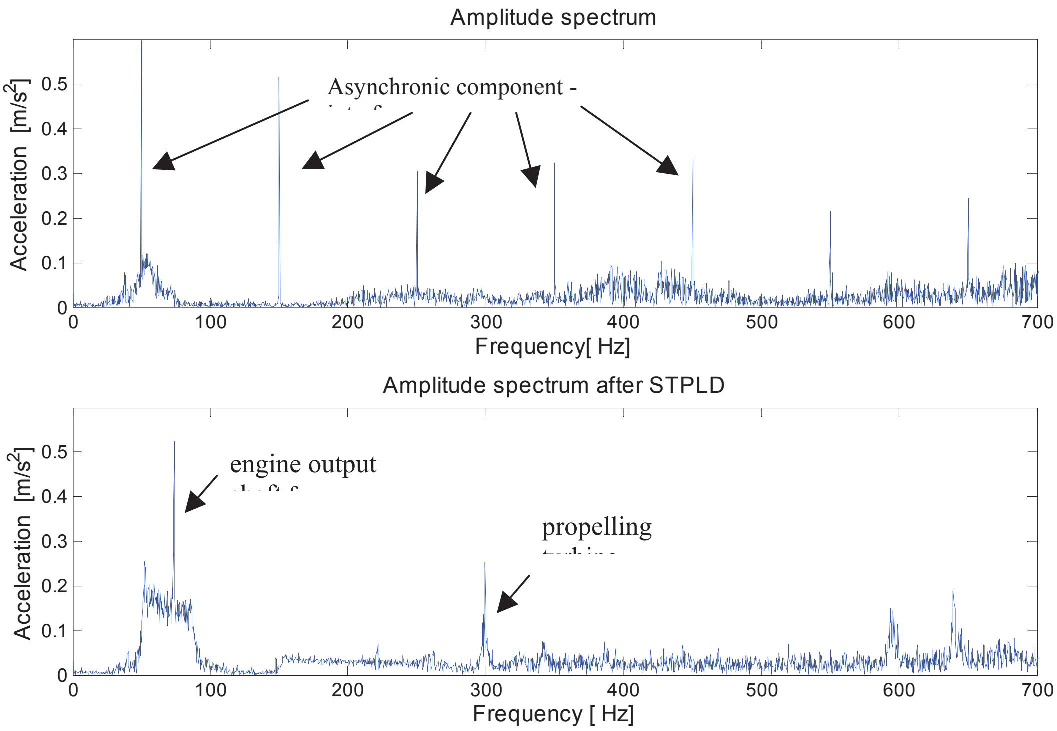

Fig. 8. Amplitude spectrum of vibration accelerations of engine during run-up with interfering frequencies coming from electric devices

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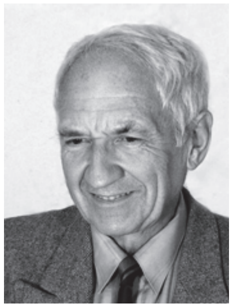

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