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FREQUENCY ANALYSIS DECIMATION VIBRATION SIGNALS OF PASSENGER CAR'S SUSPENSIONS

Summary. The paper presents possibilities of applying linear decimation procedure in frequency analysis of non-stationary signals. It shows the results of analytical experiments conducted with vibration signals registered during examination of car suspension which was activated to vibration on harmonic stand research. Working cycles identification algorithm was helpful to make LDP of working cycles parts of a signal. Signals spectrum results confirm amplitude selectivity for typical frequency of researching dynamic system.

CZĘSTOTLIWOŚCIOWA ANALIZA DECYMOWANYCH SYGNAŁÓW DRGANIOWYCH ZAWIESZEŃ SAMOCHODÓW OSOBOWYCH

Streszczenie. W artykule zaprezentowano możliwości zastosowania procedury liniowej decymacji w częstotliwościowej analizie sygnałów niestacjonarnych. Przedstawiono wyniki eksperymentów analitycznych przeprowadzonych na sygnałach drganiowych zarejestrowanych w trakcie badań zawieszenia pojazdu pobudzanego do drgań na stanowisku harmonicznym. Algorytm umożliwiający identyfikację kolejnych cykli pracy umożliwił przeprowadzenie PLD sygnału podzielonego wg cykli pracy. Uzyskane widma sygnałów potwierdzają selektywność amplitud dla charakterystycznych częstotliwości badanego układu dynamicznego.

1. ANALYSIS METHODS OF VIBRO-ACOUSTICS SIGNALS

Acoustics or vibrations signal as the results of changes which occur in technical system or associated processes is a medium of the vibro-acoustic information. As the information we understand everything what is used to get more efficient selection of the leading operation to the specified objective [3].

Information is related indissolubly with the signal because this signal is the medium of it. It informs us about conditions, changes or process of physical or technical system taking under consideration. Vibro-acoustics signals have the biggest information's capacity which enables us to observe changes on a wide frequency band. That is why vibro-acoustics research methods are use in wide application in technical objects diagnostics.

Vibro-acoustics signals analysis is very difficult. There are many methods of signals analysis. The main problem in vibro-acoustics research is the difficulty of useful signal components separation from the rest of signal without any important information.

It is possible to consider many of measurement problems on general signal level so it is considered as the total signal in observation time. To define this kind of signals it can be used with such quantities as:

a) amplitude domain, for example: rms value, mean value, peak value etc.;
b) time domain, for example: autocorrelation function, probability density function etc.;
c) frequency domain, for example: Fourier transform.

Due to the complexity of this problem this paper focuses only on frequency domain analysis of vibration signals.

2. FREQUENCY ANALYSIS OF SIGNALS

Spectrum of signal is signal energy distribution in frequency domain. It shows dominant frequency components and dynamic changes in research system. Fourier transform signal conversion enables to obtain signal spectrum as shows this equation:

$$F(\omega)=\frac{1}{T}\int_{0}^{T} f(t)\cdot e^{-j\omega t}dt \tag{1}$$

In digital signal transformations Fast Fourier Transform (FFT) is used. Using FFT is well-grounded only in case of stationary signals.

In analysis of non-stationary signals random processes have fundamental meaning, in which interesting random effects can be functions of frequency and time domain. For this kind of processes the most often used analysis methods are:

- short time Fourier transform (STFT),
- continuous wavelet transform (CWT),
- Wigner-Ville distribution (WVD).

The results of these transformations are signal distribution in time-frequency domains. Multidimensional analysis methods of non-stationary signals enable to observe with good quality of distributed signal but they are time-consuming.

Different approach in analysis of non-stationary signals is Linear Decimation Procedure (LDP) application [1, 5, 6].

3. LINEAR DECIMATION PROCEDURE

In signals digital processing for maximal spectral resolution diagnostics signal should be synchronism sampling with sampling frequency so the sample number are integral multiple of N samples number for FFT analysis. To get the expected effect of series length we can make decimation of signal [2]. Signal decimation is the process of reduction of effective samples number of signal which is sampling frequency reduction.

Linear Decimation Procedure is coefficient-variable dynamic decimation. The method involves dynamic sampling signal in form of linear increase decimation coefficient. It assumes linear approximation of trend cycle in the observation window. The procedure eliminates linear cycle trend preserving its fluctuations in the transformation range. The sample number per cycle must be constant in the newly created vector, it is the condition of stationary characteristics.

Process of obtaining secondary signal vector after LDP from primary vector is presented on figure 1.

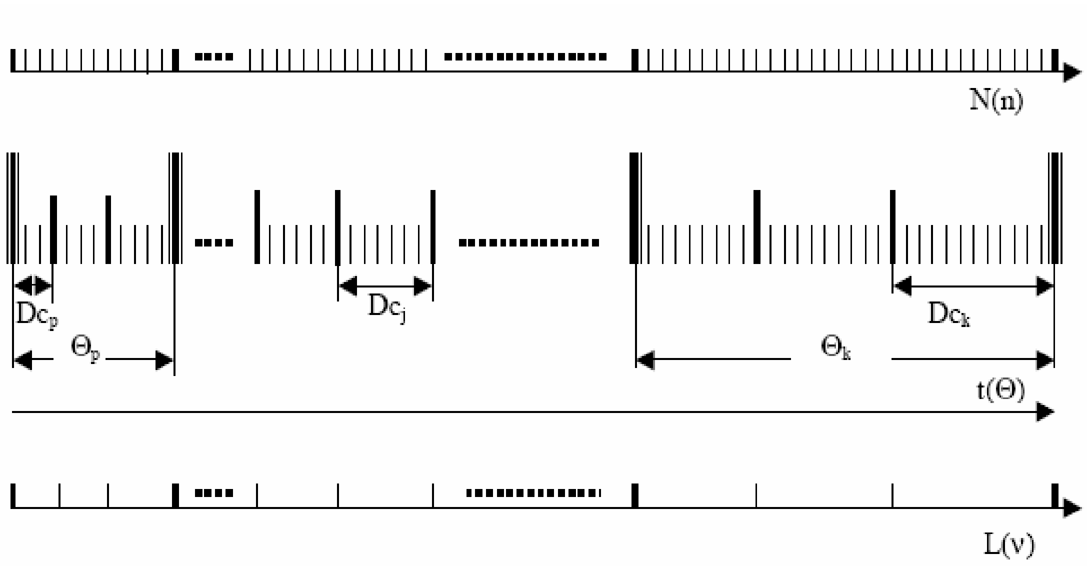

Fig. 1. Linear Decimation Procedure [5, 7]
Θ – cycle time, t(Θ) – observation time, N(n) – primary ample-cluster in the observation window, - L(v) – secondary ample-cluster in the observation window after LDP, - Dc_p – initial decimation coefficient, - Dc_k – final decimation coefficient.
Rys. 1. Procedura liniowej decymacji [5, 7]

For the sake of FFT correctness the number of samples N (power of digit 2) is specified by the relation:

$$N = 2^k \geq \frac{f_s}{r}, k \in C \tag{2}$$

where: f_s - sampling frequency, which must satisfy a condition:

$$f_s > 2 f_{\max} Dc \tag{3}$$

where: $f_{\max}$ - upper frequency of analyzed signal band limited by low-pass filter with frequency $f < f_{\max}$.

Decimation coefficient, with which the signal is resampled, agrees with the increase or decrease of rotational speed, that is cycle change (run up, braking). For stationary characteristics the sample number per cycle must be constant:

$$L_{\Theta j} = L_{\Theta k} = L_{\Theta p} = const \tag{4}$$

where: $L_{\Theta j}$ - number of samples in the j^{th} cycle of observation window for newly created vector, $L_{\Theta k}$ - number of samples in the last cycle of observation window for newly created vector, $L_{\Theta p}$ - number of samples in the first cycle of observation window for newly created vector.

Assuming, based on number of samples in the last period of signal, final decimation coefficient Dc_k we can determine in succession decimation coefficient Dc_n finishing on n_{Dk} sample.

$$Dc_n = Dc_k \left[\frac{N_{\Theta p}}{N_{\Theta k}} + \frac{n}{n_{Dk}} \left(1 - \frac{N_{\Theta p}}{N_{\Theta k}}\right) \right] \tag{5}$$

where: $N_{\Theta p}$ – number of samples in the first cycle of observation window of primary signal, $N_{\Theta k}$ – number of samples in the last cycle of observation window of primary signal, n – number of sample, n_{Dk} – number of sample finishing LDP:

$$n_{Dk} = n_k - Dc_k \tag{6}$$

where: n_k – number of last sample of observation window of primary signal.

4. RESULTS OF TRANSFORMATIONS

Within the framework some analytic experiments were conducted on vibration signals registered during research of automotive vehicle suspension at the station regarding harmonic enforcement, were performed such as:

1. run up the stand – constant increase of rotational speed of the forced system (10 s),
2. work with constant frequency of forced system (20 s),
3. coasting – station shut-down and frequency decrease of the forced system with constant step (10 s).

This method allows for vibration acceleration signals recording of springing and non-springing vehicle masses. It enables us to determine relative acceleration vibration signals of shock absorber. These are non-stationary signals so FFT is useless for diagnostics information to obtain. It shows the spectrum of exemplary analyzed signal on figure 3. There is only unequivocally selected amplitude of near 21 Hz which is the frequency of constant work of forced system the rest of spectrum picture is illegible.

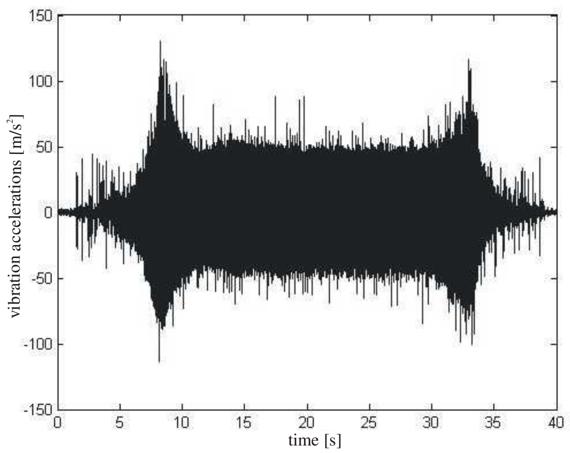

Fig. 2. Relative vibration acceleration signal
Rys. 2. Sygnał względnych przyspieszeń drgań

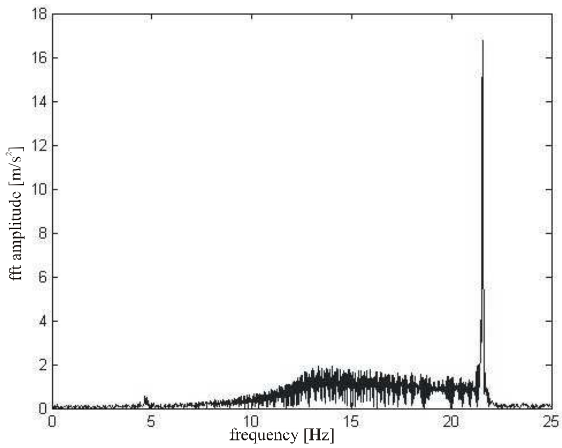

Fig. 3. Spectrum of relative vibration acceleration signal
Rys. 3.Widmo sygnału względnych przyspieszeń drgań

For signal dividing on next cycles of forced machine working were next phases of vibration inductor working identification measure formulated. The markers of next cycles of forced machine working measures based on STFT transformation were used. The main reason of choosing this transformation was short realization time. Example of STFT distribution is presented on 4 figure.

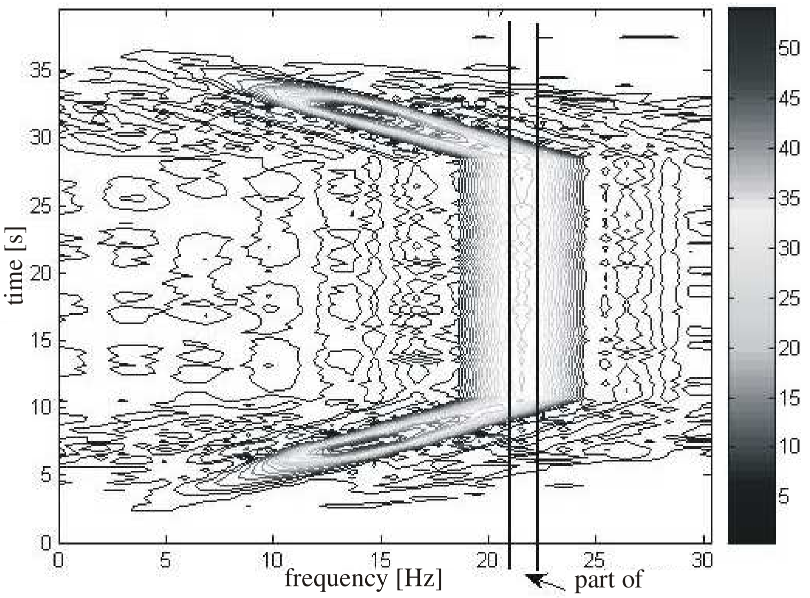

Fig. 4. STFT spectrum with marked part of the frequency band for further analysis
Rys. 4. Widmo STFT z zaznaczonym pasmem wyciętym do dalszej analizy

There was 21-22 Hz frequency band cut out from STFT spectrum as presented on figure 4. Based on time function of cut off frequency band identifying algorithm of end of stand run up and start of stand coasting time coordinates was created. This is presents on figure 5.

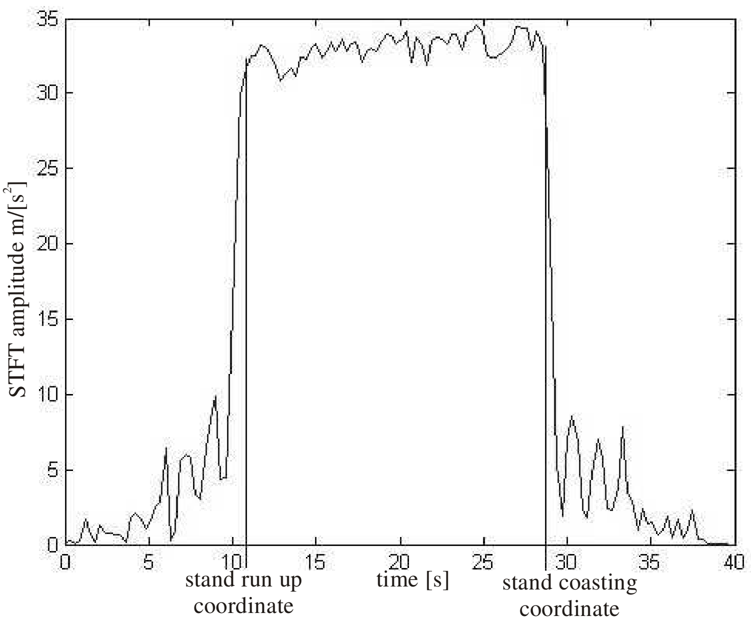

Fig. 5. Time function of STFT coefficients for analysis frequency with end of rotational speed stand iput function increment and start decrease of rotational speed stand input function
Rys. 5. Przebieg czasowy współczynników STFT dla analizowanej częstotliwości z zaznaczeniem końca rozbiegu i początku wybiegu

Elaborated algorithm is based on comparing the next value of analysed frequency band („analysis of edge") around set parameters.

Locating of end of stand run up and start of stand coasting enables to divide signal on three time windows. First window for fragment of signal growing according to constant frequency increase of the forced system. Second window for signal with constant frequency and the third one for coasting stand – decrease of signal amplitudes according to constant frequency decrease of the forced system.

Signal decimation requires earlier use of lowpass signal filtration to avoid aliasing after decimation [7]. In the case of linear decimation procedure it is indispensable to filter with changeable stopband. It was suggested to filter with changeable stopband inversely proportional to changeable decimation coefficient.

After the newly created vector summation we get the whole signal after the linear decimation procedure, which is quasistationary (fig. 6). Spectrum of exemplary signal after the LDP was presented on figure 7.

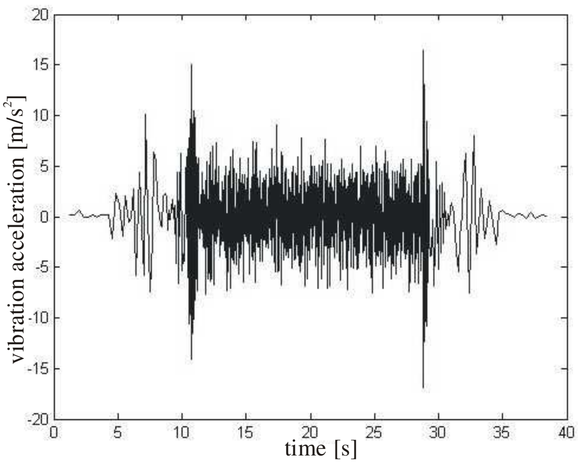

Fig. 6. Analysed signal after LDP
Rys. 6. Analizowany sygnał po PLD

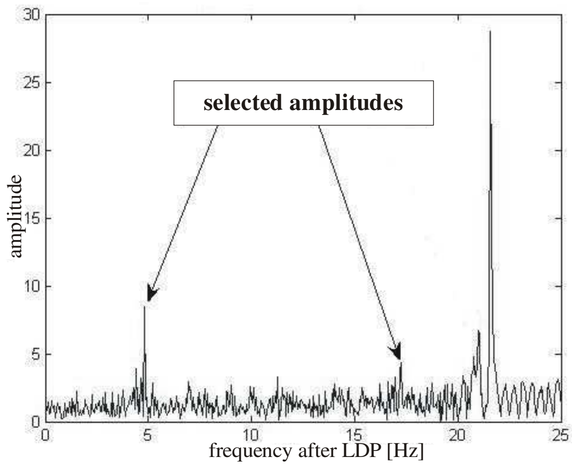

Fig. 7. Spectrum of analysed signal after LDP
Rys. 7. Widmo analizowanego sygnału po PLD

As it is observed on the figure, LDP used for non-stationary vibration signals enables to select characteristic single amplitudes from the spectrum. Frequency scale signal after LDP is not exactly like frequency of primary signal. That is why domain is described as frequency after LDP on figure 7. However we can conclude that selected signal amplitudes correlate with resonance frequencies of springing and non-springing vehicle masses.

5. SUMMARY

The paper presents possibilities of technical condition identification of mechanical object based on analysis of vibro-acoustic signals recorded during work of the system. Basic methods and measures in signal processing and criteria of their applications were presented. Linear Decimation Procedure as the tool rarely used in non-stationary signals processing were widely discussed. Example results of the analytic experiments conducted on vibration signals registered during research of automotive vehicle suspension were presented. Elaborated algorithm of next working cycles of the station regarding harmonic enforcement identifying enabled to signal divided and LDP made for next working cycles. Primary and after LDP signals spectrum compare effectiveness of presented method confirm. These results enable to identify technical condition of the system based on spectral analysis of non-stationary vibration signals. Presented method of diagnostics information receiving as the results of vibration signals processing enables elaborate of automatic system of passenger cars shock absorbers diagnosis. However it is necessary to make more investigation in this direction.

Literature

1. Adamczyk J., Krzyworzeka P., Cioch W.: *Wykorzystanie decymacji dynamicznej w diagnozowaniu maszyn.* XXVIII Ogólnopolskie Sympozjum Diagnostyka Maszyn, Katowice 2001, s.7-18.
2. Adamczyk J., Krzyworzeka P., Łopacz H.: *Systemy synchronicznego przetwarzania sygnałów diagnostycznych.* Kraków, Collegium Columbianum, 1999.
3. Basztura C.: *Komputerowe systemy diagnostyki akustycznej.* PWN, Warszawa 1997.
4. Burdzik R., Gardulski J., Konieczny Ł.: *Nowe metody diagnozowania amortyzatorów.* VI Konferencja Naukowa Telematyka i Bezpieczeństwo Transportu, Katowice 2006, s.86-95.
5. Cioch W.: *Sztuczne sieci neuronowe w diagnostyce zagrożeń eksploatacyjnych systemów technicznych.* Praca doktorska, Kraków 2002.
6. Krzyworzeka P.: *Wspomaganie synchroniczne w diagnozowaniu maszyn*. BPE, Radom 2004.
7. Krzyworzeka P., Adamczyk J., Cioch W., Jamro E.: *Monitoring of nonstationary states in rotating machinery.* ITE, Kraków 2006.
8. Lyons R.: *Wprowadzenie do cyfrowego przetwarzania sygnałów.* WKŁ, Warszawa 1999.

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