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DIAGNOSIS OF AVIATION REDUCER CONVERSION USING HILBERT-HUANG AND WAVELET ANALYSIS

In this work we propose method of aviation reduction drive diagnosis, which use Hilbert-Huang transform and wavelet analysis.
Keywords: Hilbert-Huang transform, wavelet analysis, vibration, air gear, diagnosing.

Introduction

Diagnosis of aircraft gears in emergency and pre periods of their work is a complex organizational and technical plan process. The aim of this paper is to analyze two methods of signal processing based on Hilbert-Huang transformation and wavelet analysis. Object is vibrating alerts taken from aviation hub in the mode of his test bench. During the testing stages recorded changes in the technical state (TS) gear. Measurements performed on the stage of the transition process, allowed to diagnose the state of gearbox the above methods.

The choice of methods is made on the basis of the positive results of the analysis of vibration signals of rotary engine capacity of 2.2 kW, obtained using these methods [1, 3]. During the solution was found dependent parameters HHT and wavelet transform signal from TC engine, characterized by a change in the energy spectrum of the analyzed signal. As will be shown below, such a dependence is typical in the analysis of the technical state of aviation hub.

Hilbert-Huang Transform

Hilbert-Huang Transform is applied to the process under study empirical Mode decomposition and Hilbert spectral analysis [2]. HHT gives the possibility of time-frequency analysis.

Convert real Hilbert function *x(t)*, $-\infty < t < \infty$ is a real function defined as

$$\tilde{x}(t) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{x(\tau)}{1-\tau} d\tau. \quad (1)$$

Functions *x(t)* i $\tilde{x}(t)$ called conjugated by Gilbert. Typically [2], this transformation changes the phase of all frequency components of the signal *x(t)* на $\pi/2$. This fact allows to generate signals of these complex analytical signal *z(t)*:

$$z(t) = x(t) + j\tilde{x}(t). \quad (2)$$

This representation allows to determine the current time the signal *z(t)*, namely instantaneous amplitude and phase. However, this only applies to stationary monoharmonichnyh signals and for signals with continuous slow change in frequency. Instantaneous amplitude of the signal with several components will not reflect the amount of harmonics in the current time, and the envelope of the interference signal. At the same time, the instantaneous frequency signal with multiple harmonics of equal amplitude in all its points will correspond to the average frequency harmonics. Moreover, if the amplitude of the harmonics are not equal, the value of the instantaneous frequency is shifted toward the frequency harmonics of greater amplitude and becomes pulsating character.

Thus, for the analysis of complex signals they need to be decomposed into several monoharmonichnyh components that meet the condition of symmetry. This problem can be solved by N. Huang [2], which is also called the method of "empirical signals decomposition Mode", and is adaptive iterative computational procedure output expansion in empirical fashion. In the method is based on the assumption that the original complex signal is the sum of modal functions, superimposed on an arbitrary type of trend.

Mode decomposition algorithm empirical signal consists of the following steps.

Step 1: The output signal is determined by the coordinates of the extreme points and grouped into two arrays (highs and lows) *k* and processed in the same way the corresponding amplitude $y(k)$. This number of points of maxima and minima should differ by no more than 1, due to the properties of modal functions.

Step 2. cubic splines (or using other approximating curves) build upper $u_t(k)$ and lower $u_b(k)$ envelope of extreme points, and define the function of the mean values between:

$$m_1(k) = \frac{(u_t(k) + u_b(k))}{2}. \tag{3}$$

The first component signal screening ($h_1(k)$)comes from the difference between the signal $y(k)$ and $m_1(k)$. Function $h_1(k)$ is a first approximation to the first IMF:

$$h_1(k) = y(k) - m_1(k) \tag{4}$$

Step 3. Repeat the previous steps, but instead $y(k)$ використовуємо $h_1(k)$, and finds a second approximation to the first IMF.

$$h_2(k) = h_1(k) - m_2(k). \tag{5}$$

Subsequent iterations are performed the same way. In the process of increasing the number of iterations function $m_i(k)$ tends to zero, and the function $h_i(k)$ - to constant form. In this regard, the criterion of stopping iterations is normalized square difference between two successive iteration approximation:

$$\delta = \sum_k \left[\frac{(h_{i-1}(k) - h_i(k))^2}{h_{i-1}^2(k)} \right]. \tag{6}$$

For qualitative IMF usually enough 8 iterations. On the one hand, a large number of iterations will lead to a screening of useful information on the other - bad eliminated components can lead to what Hilbert transform adequately work for these IMF.

After screening quality IMF, writes it to a separate array $c_1(1) = h_i(k)$, which is then subtracted from the original signal:

$$r_1(k) = y(k) - c_1(k). \quad (7)$$

Array $r_1(k)$ handled in the same way for the other functions of the - $c_2(k)$, then the process continues:

$$r_2(k) = r_1(k) - c_2(k). \quad (8)$$

Stop the process of decomposition of the signal into its constituent IMF should occur when converting the balance $r_n(k)$ trend in the number of extrema signal to three.

Then, the obtained IMF is performed on Hilbert transform:

$$\tilde{c}(t) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{c(\tau)}{t - \tau} d\tau. \quad (9)$$

From the expression (9) can be seen that the Hilbert transform is the result of the convolution signal *c(t)* (modal function, resulting transformation H. Huang) function $h(t) = \frac{1}{\pi t}$, called kernel Hilbert transform. In fact, the Hilbert transform operation implements linear filtering with impulse response *h(t).* This output filter is formed orthogonal application input. Using input *c(t)* and its orthogonal application $\tilde{c}(t)$, formed a complex analytic signal *z(t)*

$$z(t) = c(t) + j\tilde{c}(t), \quad (10)$$

where $z(t)$ is a vector in the complex plane with projections for real and imaginary axes respectively $c(t)$ and $\tilde{c}(t)$. The advantage of this representation is that it becomes possible to uniquely determine the current timing signal $z(t)$, namely - its instantaneous amplitude and phase.

Thus, the HHT method allows to estimate the beginning of the process parameters deviation instantaneous amplitudes and phases of several empirically selected, frequency components in the range of stationary. While the carrier frequency components determined by Fourier transform function phase shifter performs conversion Hilbert.

The analysis of vibration signals aviation hub

In this section of the article presents the results of the identification process TC aviation hub (BS) methods HHT and wavelet transform [1, 3, 4]. The results of the processing of vibration signals characterizing TS AB in four modes (files SIGNAL_i =), are presented in Tables 1-3.

Below is a table of indicators HHT, which were calculated by three methods:

1. The amplitude envelope signal demodulation method. This method is based on the discrete Hilbert transformation:

$$H[y(n)] = F^{-1}\{F\{y(n)\} * u(n)\}, \quad (11)$$

where $F\{\}$ i $F^{-1}\{\}$ - direct and inverse fast Fourier transform, *y(n)* - of mode function (IMF), the calculated transformation Huang, $u(n)$ set to:

$$u(n)=\begin{cases}1, n=0, \frac{N}{2} \\ 2, n=1,2,\ldots,\frac{N}{2}-1 \\ 0, n=\frac{N}{2}-1,\ldots,N-1\end{cases}, \quad (12)$$

and $|a(n)|$ calculated as follows:

$$|a(n)|=\sqrt{y^2(n)+(H[y(n)])^2}. \quad (13)$$

2. Spectral power density spectrum of Hilbert. Method is to calculate the power spectral density (SHP) Hilbert spectrum using the periodic method:

$$W(\omega)=\frac{1}{N}\left|\sum_{k=0}^{N-1} y(k)e^{-j\omega kT}\right|^2. \quad (14)$$

3. Method of determining the standard deviation of the amplitude is based on calculating the standard deviation *s[u(t)]* values of instantaneous amplitude *u(t)*, obtained by Hilbert transformation.

Table 1

	HHT		
	The amplitude of the baseband signal demodulation method	The spectral power density spectrum Hilbert	The standard deviation of the amplitude
	|a|	*W*	*s(u)*
SIGNAL_1	0,0014489	0,0000162	0,0018404
SIGNAL_2	0,0028693	0,0000547	0,0034982
SIGNAL_3	0,0035904	0,0000775	0,0043536
SIGNAL_4	0,0037882	0,0000867	0,0045380

Below is a table detailing the wavelet coefficients calculated using a multiple scale analysis (MSA). Orthogonal basis expansion MSA is formed based on Daubechies wavelet fourth. Decomposition of the test signal is carried to the 3rd level. Then the calculated standard deviations detailing factors at all levels of decomposition: cD1 - standard deviation detailing the coefficient of the first level of decomposition, cD2 - the second level of decomposition, etc.

Table 2

	Wavelet coefficients		
	cD1	*cD2*	*cD3*
SIGNAL_1	0,0048410	0,0105530	0,0306110
SIGNAL_2	0,0063770	0,0208370	0,0569860
SIGNAL_3	0,0068790	0,0232930	0,0648030
SIGNAL_4	0,0071410	0,0242060	0,0646650

Table3

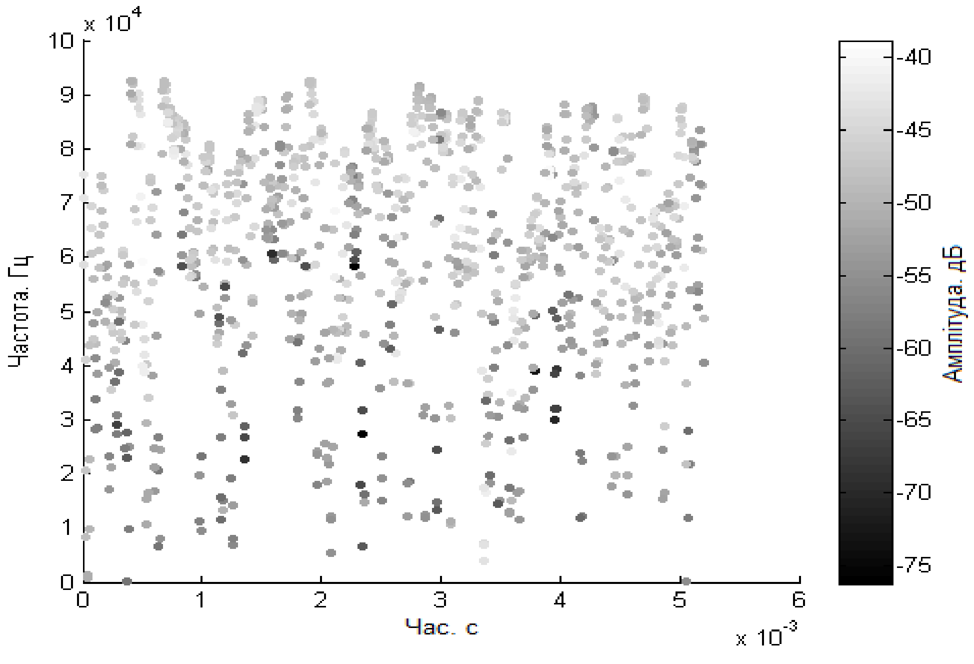
	Power density wavelet coefficients		
	W_cD1	*W_cD2*	*W_cD3*
SIGNAL_1	0,0000074	0,0000352	0,0002964
SIGNAL_2	0,0000129	0,0001372	0,0010292
SIGNAL_3	0,0000151	0,0001716	0,0013284
SIGNAL_4	0,0000162	0,0001853	0,0013232

Based on the parameters listed in Tables 1 - 3, the following conclusions:

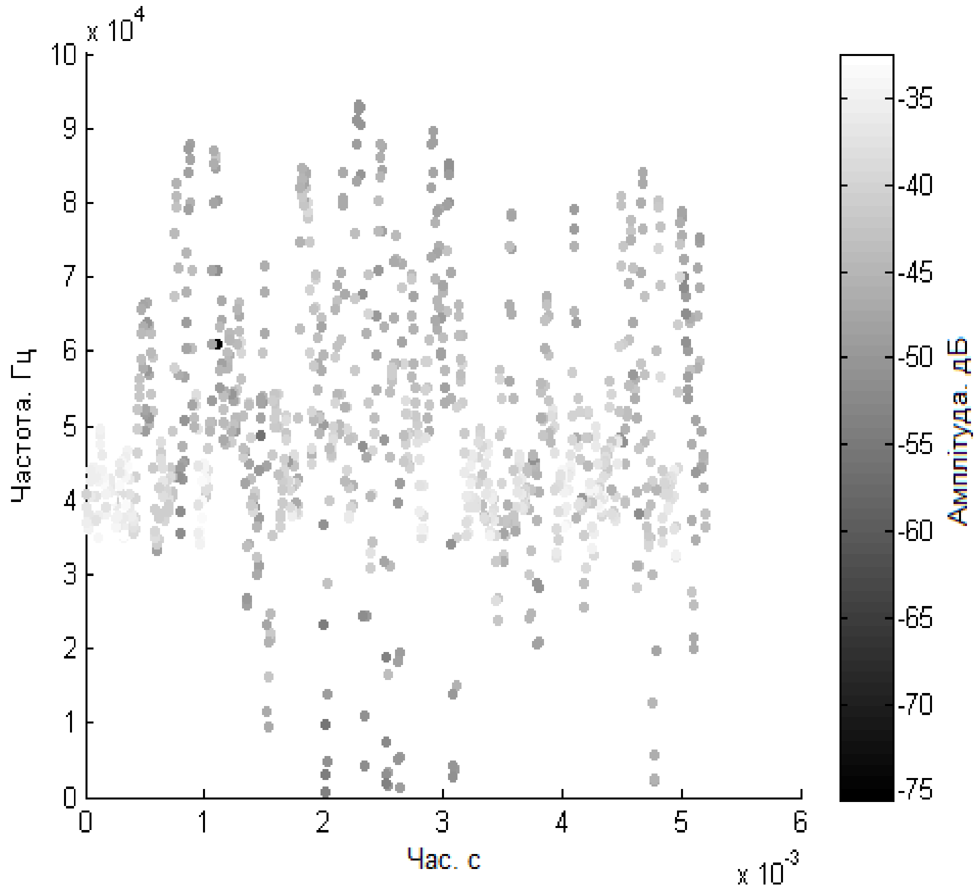
Alert «SIGNAL_1» Out of aviation hub at the time when he was in good condition. The remaining signals are removed from the site in time periods that corresponded to TC with varying degrees of failure:

1. «SIGNAL_2» - signal corresponds to the smallest degree of injury.
2. «SIGNAL_3» - signal corresponds to the average degree of damage.
3. «SIGNAL_4» - signal corresponds to the degree of damage.

For a visual representation of the analysis results shows graphs Hilbert spectra for SIGNAL_1and SIGNAL_4.



Picture 1 – Hilbert spectrum signal SIGNAL_1



Picture 2 – Hilbert spectrum signal SIGNAL_4

Comparing the two is a graph can even visually notice that the energy exceeds the energy SIGNAL_4 SIGNAL_1. This fact confirms the conclusions drawn on the basis of estimated parameters in the above table.

At the same time, it should be noted that all conclusions are merely the assumption of TC node. However, the actual file SIGNAL_i = $\overline{1,4}$ reflect the following:

1. «SIGNAL_1» - modified algorithm of node.
2. «SIGNAL_2» - part replaced.
3. «SIGNAL_3» - вузол node has completed more than 100 hours.
4. «SIGNAL_4» - one defective part.

In turn, comparing the actual TC with predictable based on an analysis of the above methods, we can say that these methods allow to determine the times of occurrence of defects and technical trends in the state of aviation hub in general.

To confirm the findings apply rolling window method to calculate the expectation and variance of the coefficients of wavelet analysis and HHT, calculated for a sequence of signal samples aviation hub. The sequences were previously obtained by moving a window of a given length of the signal. This overlap of neighboring windows was 50%. The length of the window meets the fundamental period - time interval during which the analyzed system passes all its states and returns to its original. Expected value and variance calculated in this manner will also display the TC site. The value of these estimates should be increased due to deterioration of the TC, as this trend is the fluctuation amplitude. The results of calculations are documented.

Table 4

	Mathematical expectation HHT		
	The amplitude of the baseband signal demodulation method	The spectral power density spectrum Hilbert	The standard deviation of the amplitude
	|*a*|	*W*	*s(u)*
SIGNAL_1	0,0014620	0,0165380	0,0018590
SIGNAL_2	0,0029210	0,0560050	0,0035600
SIGNAL_3	0,0035700	0,0779270	0,0043080
SIGNAL_4	0,0038860	0,0903880	0,0046600

Table5

	Mathematical expectation wavelet coefficients		
	cD1	*cD2*	*cD3*
SIGNAL_1	0,004905	0,010668	0,029986
SIGNAL_2	0,006382	0,020949	0,056394
SIGNAL_3	0,006902	0,023008	0,064091
SIGNAL_4	0,007250	0,024447	0,064523

Calculated expectation, as expected, increases with worsening TOR node.

Table6

	Dispersion HHT		
	The amplitude of the baseband signal demodulation method	The spectral power density spectrum Hilbert	The standard deviation of the amplitude
	|*a*|	*W*	*s(u)*
SIGNAL_1	3,32E-10	1,4E-07	4,91E-10
SIGNAL_4	9,62E-09	1,28E-05	1,31E-08
SIGNAL_3	1,54E-08	1,64E-05	2,05E-08
SIGNAL_2	1,55E-08	1,34E-05	2,09E-08

Table 7

	Dispersion of wavelet coefficients		
	cD1	*cD2*	*cD3*
SIGNAL_1	1,34E-09	1,03E-08	3,48E-07
SIGNAL_2	3,46E-09	4,85E-08	5,69E-07
SIGNAL_3	3,80E-09	5,27E-08	8,36E-07
SIGNAL_4	5,26E-09	7,78E-08	6,99E-07

On the other hand, the calculated dispersion parameters HHT only partially confirms the assumptions made. For example, the variance of the signal SIGNAL_1 (modified algorithm of node) is much less variance other signals. However, if we compare the dispersion signal SIGNAL_2 (part replaced) and SIGNAL_4 (one defective part), it turns out that SIGNAL_4 less SIGNAL_2, although logically should be the opposite. Differences are also among the indicators HHT, namely SHP Hilbert spectrum worse than all others (amplitude envelope signal demodulation method, the standard deviation of the amplitude) reflects the TS engine. This is due to the fact that periodohramnyy method is not able to estimate SHP as the variance of such estimates can be compared with its expectation [5]. With increasing length of the analyzed signal value SHP starts faster change. Accordingly, if we replace periodohramnyy calculation method for JVT more effective, such as Welch's method [5], the error variance significantly reduced.

Comparing the values given in Tables 6 and 7, we can say that the variance parameters of wavelet transform as opposed to HHT does not go beyond theoretical assumptions (TS deterioration leads to an increase in variance). The most obvious reasons for this discrepancy following:

1. The signal is noise components. Since the wavelet transform is characterized filtering noise reduction property [6], then it is not affected, in contrast to the HHT, which does not have data properties.
2. The lack of a priori information about signal causes analyze only the first component of mode conversion Huang. This component in addition to the information component also contains noise, due to the properties of this transformation [7]. The remaining modal signal components are less noisy, but can not be taken into account in the analysis. As a result, there is error variance parameters HHT.

Conclusions

These results suggest that the Hilbert-Huang transform and wavelet decomposition can be used as a basis for effective methods of diagnosing aircraft gears. Moreover, these methods have several advantages that can be the basis of their combined use. Refers to the properties of wavelets ability to suppress noise and HHT method to analyze non-stationary signal components. Thus, if the analyzed signal has noise components and contains transient components using the proposed combined method makes it possible to carry out his analysis without loss of information.

In turn, it is interesting also that the trend change indicators Hilbert-Huang and wavelet analysis of TS aviation hub is the same as the analysis engine capacity of 2.2 kW [1]. This is a typical consequence of increased power vibrator object of study for defective.

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