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MEASUREMENT OF QUASISTATIONARY RANDOM SIGNAL ENVELOPE

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Abstract: Signals of quasistationary nature are often met in diagnostics and NDT systems. In the paper model for quasistationary signals with periodically varying deviation is proposed. Procedures for wide band quasistationary signal envelope detection are analyzed and tested using both simulated signals and records of Barkhausen noise. Accuracy and speed of detection of these procedures are estimated using digital signal processing techniques.
Keywords: quasistationary signals, Barkhausen noise, envelope detection.

1 INTRODUCTION

Quasistationary random signals are often met in systems of technical diagnostics and non-destructive testing [1]. The feature of their nature is much slower changes of statistical characteristics compared to the considered signal. Examples of such a signals are:

- mechanical vibrations of friction pairs with periodic movement,
- mechanical vibrations of cutting process (drilling, grinding and etc.),
- signals induced in the receiver by the acoustic noise source, that changes position relative to the receiver,
- magnetic noise of Barkhausen effect, caused by periodic magnetization of ferromagnetic materials [2] and other.

Quasistationary signals must be processed and their essential parameters extracted to apply them to a decision making units.

Paper considers procedures of the envelope detection (EDP) of wide band quasistationary signals. The task of the work is to choose procedures for envelope detection and estimate them in respect to precision and speed.

2 MODEL OF QUASISTATIONARY SIGNAL

In this paper we consider wide band quasistationary random signals with periodically varying deviation. We assume the start moment of the period is precisely known and necessary number of periods may be reproduced. These processes sometimes are called cyclostationary. Model of the process within a period could be described

$$b(t_i) = E(t_i) \cdot n(t_i), \tag{1}$$

where $E(t_i)$ - slowly varying envelope, $n(t_i)$ - wide band noise. For the quantitative comparison of the envelope detection procedures test signals with predefined $E(t_i)$ and $n(t_i)$ as a Gaussian moving average process with frequency band 10kHz..100kHz, zero mean and deviation equal to 1 were simulated [3]. Simulation error of the $n(t_i)$ deviation does not exceed $\varepsilon = 0.05$.

3 ENVELOPE DETECTION PROCEDURES

It is clear from (1) that in our approach envelope is treated as a sequence of instant values of standard deviation. Thus, envelope detection procedure (EDP) may proceed in one of the following ways:

1. Directly estimate $\hat{\sigma}_b(t_i) = \hat{E}(t_i)$ using std statistics expression;
2. Transform process b in to process d and then estimate a parameter $\hat{P}_d(t_i)$, that is related to $\hat{\sigma}_b(t_i)$. In this work we use nonlinear transformation $d = |b|$.

Considered statistical estimates of b and d process parameters involve mean, deviation and median.

EDP could be separated according to the number of envelope $\hat{E}(t_i)$ samples N_e compared to the number of observation $b(t_i)$ samples N:

1. Downsampling $N_e < N$,
2. Retaining the number of samples $N_e = N$.

A principle possibility to use downsampling exists because the bandwidth of the envelope *0..F_{MAX}* is located much lower on the frequency axis compared to the $b(t_i)$ bandwidth $F_1..F_2$. Reduction of the number of samples S times in the interval *0..NDt* is equivalent to the reduction of the sampling frequency S times. In order not to violate requirements of Naiquist's law S should not exceed

$$S_{MAX} = \frac{F_S}{2F_{MAX}}, \qquad (2)$$

where F_S is sampling frequency. We will call ratio $s = S / S_{MAX}$ relative step width.

A concept of an aperture a is used through the calculations of the time estimates of process parameters (mean, deviation, median). Aperture defines the number of adjacent samples used in parameter statistics expression at the considered point. In order to encounter all samples of $b(t_i)$ in EDP, it is required that $S \le a$.

Envelope detection procedures are listed in table 1.

Table 1. Envelope detection procedures

Name of EDP	$\hat{E}(t_i)$ expression	Optimal parameter values	
		s	a
Direct	$F\{M[D\{b(t_k)\}]\}$	0.2	S
Simple detection	$F\{M[\lvert b(t_j)\rvert]\}$	-	-
Median	Scenario 1: $F\{M[med\{\lvert b(t_k)\rvert\}]\}$ Scenario 2: $F\{med\{M[\lvert b(t_k)\rvert]\}\}$	0.2	S
Smoothing	$M[sg\{\lvert b(t_k)\rvert, p, a\}]$	0.05	5
TSSA	$F\{M[M\{\lvert b(t_k)\rvert\}]\}$	0.2	S

Notations in table 1:

$M[\ ]$ - synchronous averaging,

$D\{\ \}$, $med\{\ \}$ - respectively deviation and median estimates at the time moment t_k calculated from samples $b\left(t_{k-a/2 \cdots k+a/2}\right)$,

$\lvert b(t_k)\rvert$ - absolute value of $b(t_k)$,

$F\{\ \}$ - linear filtering,

$sg\{\ \}$ - Savitzki-Golay polynomial smoothing filtering with parameters p as polynomial order and a as aperture width in samples [4],

TSSA – Time Segment Synchronous Averaging.

Optimal values of the s and a parameters were selected from S_e curves, that are not presented in the paper. Filtering $F\{\ \}$ was not temporarily used during selection of optimal s and a values. Later on, during comparison of different EDP procedures, lowpass 3[rd] order FIR Baterworth digital filter with cutoff frequency $F_{LF} = 2F_{MAX}$ was used. Filter transfer function values at the specific points are $K(F_{MAX}) = 0.992$, $K(F_{LF}) = 0.707$. In order to avoid influence of signal delays caused by lowpass filtering zero-phase forward and reverse digital filtering was used [4].

4 COMPARISON OF ENVELOPE DETECTION PROCEDURES

EDP accuracy was investigated by means of computer simulation. To describe the error of EDP total relative error estimate was used

$$S_e = \frac{\sum_{j=1}^{N_e} \left| E(t_j) - \hat{E}(t_j) \right|}{\sum_{j=1}^{N_e} \left| E(t_j) \right|}, \qquad (3)$$

where N_e - number of envelope samples, $N_e \le N$, N - number of $b(t_i)$ series samples. $E(t_j), j = \overline{1, N_e}$ is predefined envelope used to generate test series according to model (1).

$$\hat{E}(t_i) = K \cdot \hat{E}'(t_i), \qquad (4)$$

where $E'(t_j)$ is envelope estimate by any EDP from table 1, and K is a constant coefficient dependant from particular random process. transformation in EDP algorithm [5].

Test signal simulation followed by envelope detection and error S_e estimation were repeated 10 times and average $\bar{S}_e$ as well as its confidence level $\Delta\{\overline{S_e}\}$ at probability p=95% were achieved. During computer simulation sampling frequency was assumed to be $F_S = 1MHz$ and length of every $b(t_i)$ series consisted of $N = 10000$ samples. Two types of original envelope $E(t_i), i = \overline{1, N}$ shape were considered - square and sinusoidal, both with the maximum frequency F_{MAX}. In the case of square envelope $E(t_i)$ was simulated by filtering square impulse with 3rd order Baterworth filter with cut-off frequency F_{MAX}.

Figure 1. presents comparison of the error of investigated EDP as a function of the number of averaged series. Figure 2. shows S_e dependence from the number of averaged series for sinusoidal and square envelopes with different F_{MAX}, when Simple Detection EDP was considered.

For quantitative comparison of EDP speed and error the following criterion could be used

$$I = {S_e}^2 \cdot T_m \qquad (5)$$

where T_m - is measurement time:

$$T_m = N_s \cdot T + C(N_s) \qquad (6)$$

where T - is duration of cycle period, $C(N_s)$ - time interval necessary to process N_s series stored in memory. Let us assume digital processing is carried out with a TMS320C31 DSP. Its processor cycle is equal to 40ns. Multiply, sum and absolute value operations are carried out in one processor cycle, while division in approximately five processor cycles. In addition for every arithmetical operation processor reads operands from and writes results to RAM. $C(N_s)$ depends from particular method, i.e. number of mathematical operations. Figure 3 presents ${S_e}^2$ and T_m relationship, where $a = S$, $S_{OPT} = 200$, $e = 4$, $N_s = 10$, $N = 10000$.

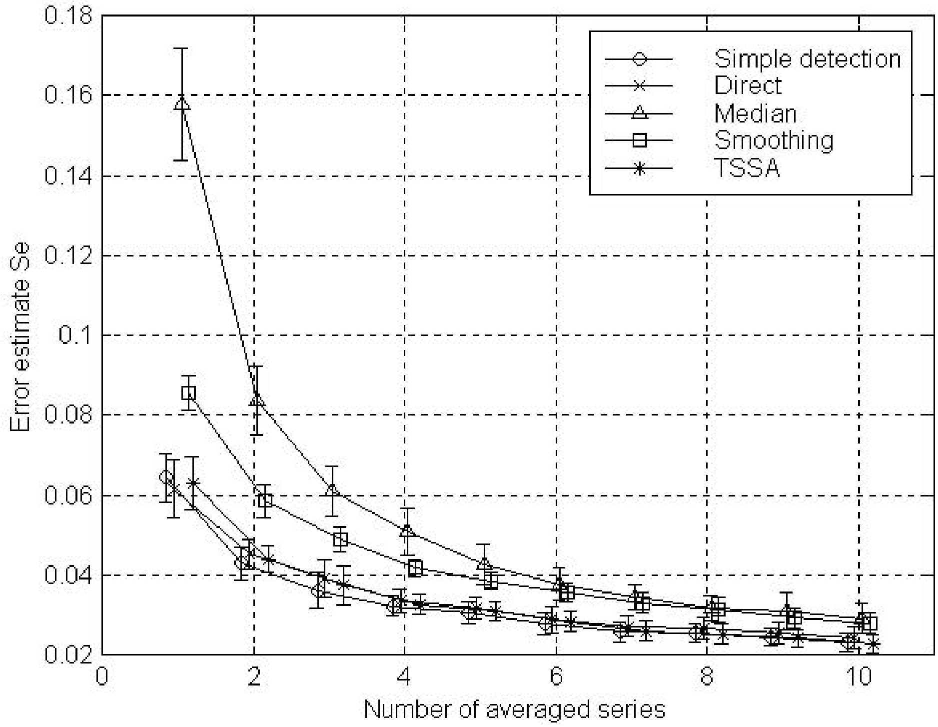

Figure 1. Comparison of the total relative error of EDPs.

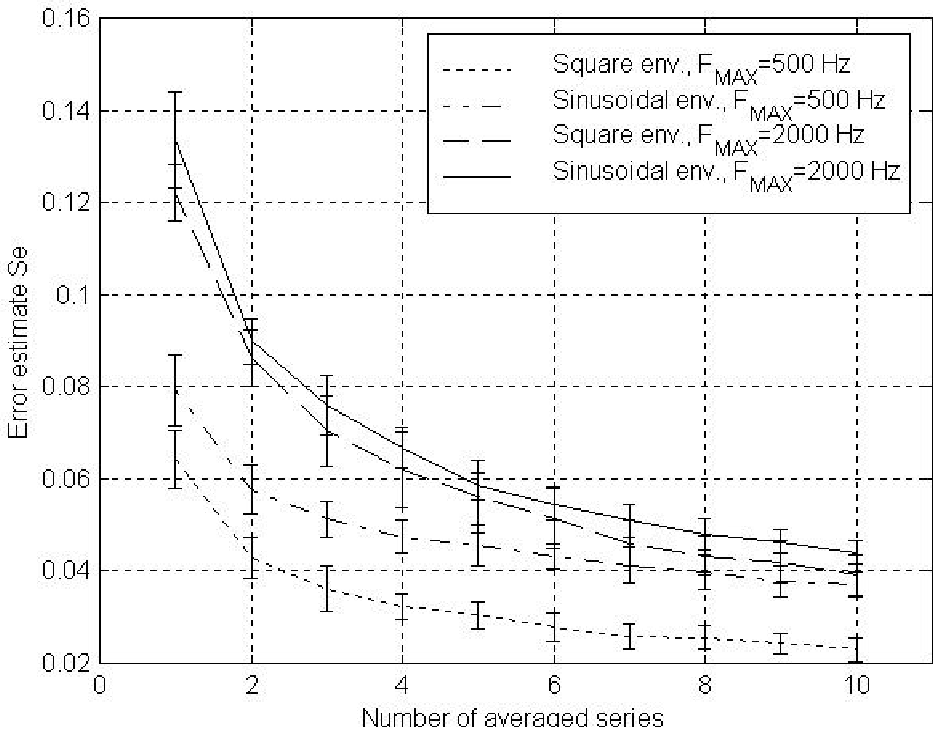

Figure 2. Total relative error of Simple Detection procedure.

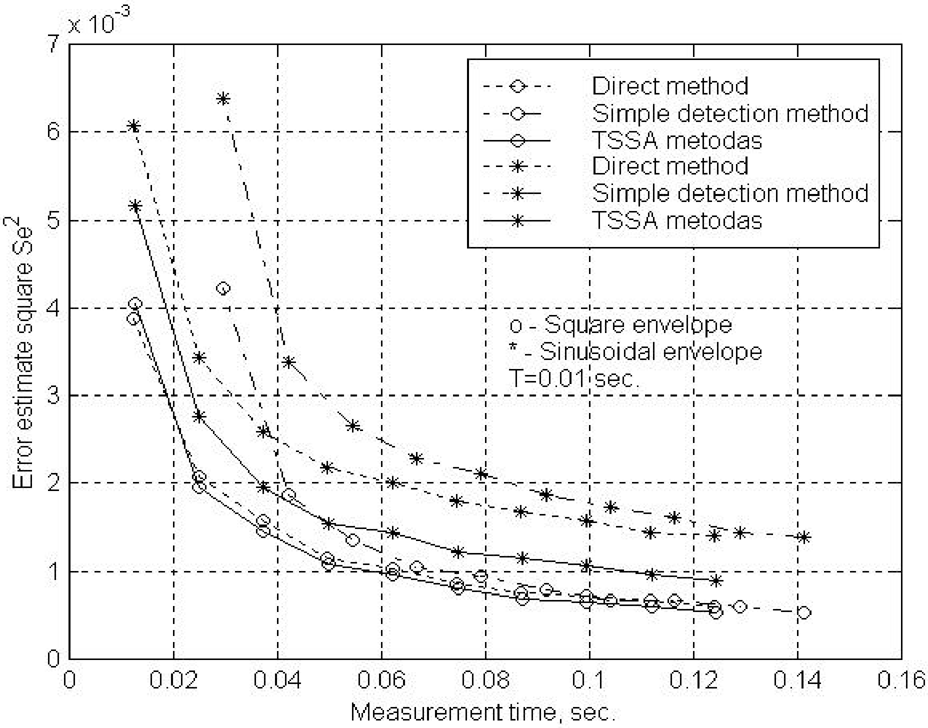

Figure 3. Comparison of EDP speed and error.

5 APPLICATIONS

Discussed EDP were applied to recorded series of magnetic Barkhausen noise (BN) induced in sample tapes of ferromagnetic material. Width of a tape is 18mm, thickens 0.2mm. It is known that BN intensity is sensitive to the stresses , material microstructure, irregularities [2] and etc. In Figure 4 BN series and detected envelopes at three different stress values are shown.

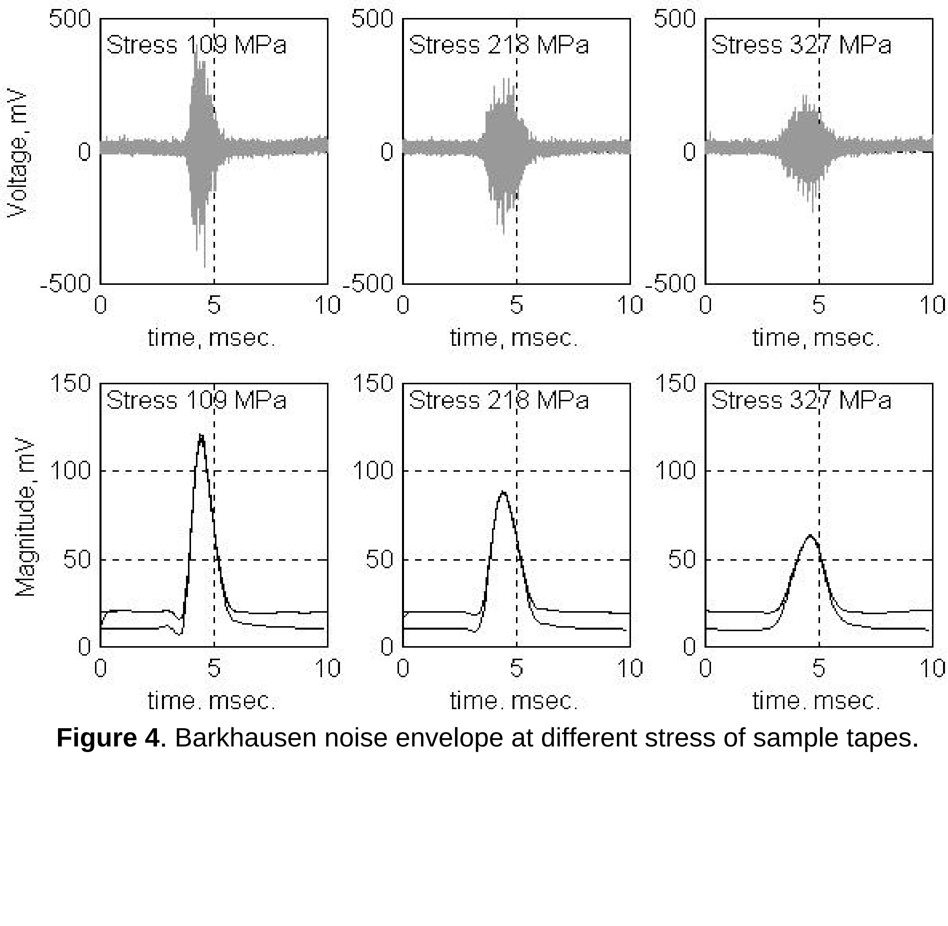

Figure 4. Barkhausen noise envelope at different stress of sample tapes.

It is evident that not only intensity of the BN changes dependant to stress, but also position of the maximum of envelope as well as its shape and width at different threshold levels. This opens new possibilities for improvement of BN method applications in stress measurement.

6 CONCLUSIONS

Total relative error of wide band quasistationary random process envelope detection procedures depends not only from the envelope's bandwidth but also from its shape. Because apriori information about the shape of really measured signals usually is not available, therefore error of EDP could be described with the upper bound. Computer simulation results indicate that the largest total relative error corresponds to the sinusoidal envelope with the frequency equal to the upper bandwidth frequency of an envelope.

In the downsampling EDP optimal value of relative step . When estimate of the std at the given moment is made from small number of samples, which causes large deviation of the envelope estimate. When, error increases because the process itself is averaged and detected envelope does not trace the original one.

Time Segment Synchronous Averaging, Simple Detection and Direct envelope detection procedures ensure smaller total relative error compared to Median and Smoothing EDP. If detection speed is also an important parameter, the TSSA method is the most preferable.

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