DIGITAL PROCESSING METHODS IN EDDY-CURRENT FLAW DETECTION

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Abstract: The application of digital processing methods improving the identification of useful signal in case of great noise is presented.

When inspecting the surface of real objects, the output signal from the probe usually comprises a low frequency component – a trend, with the duration much longer than the width of the topography of magnetic field from a defect. Further analysis of the magnetic field from the defect with the trend can dramatically decrease the reliability of inspection. The quality of the trend rejection from the signal is determined by the ratio between the signal duration and the width of the magnetic field topography from defect. In general the trend from a signal measured is interpolated by a polynomial of *K* power (usually $K \leq 2$).

To reject random noise from signal we use digital filtering methods that lead to high accuracy and noise immunity of equipment. The main aspect when using digital filtration is the choice of a window function which is employed for spectrum analysis of signals. Processing with windows is used for controlling effects caused by side lobes in spectrum. Designing of the optimal window function for different tasks instead of choosing one from available functions is highly advisable.

The application of correlation processing where theoretical defect model is used as a reference signal allows to increase essentially the signal-noise ratio.

The above digital processing methods have proved to be decisive and have successfully been applied in eddy-current flaw detectors VD-12NFP that are manufactured by JSC “RII-Spectrum”.

Introduction: Test of real objects by eddy-current technique is connected with the need to eliminate interfering parameters which are caused by the surface under test. In this case we have magnetic field distorted and this decreases dramatically the reliability of test. That is why we need special processing of signal to exclude random noise, constant components and restore initial signal.

Discussion: In the signal obtained there is a low frequency component (trend) with duration much longer than the topography of magnetic field from defect. This confuses the determination of the signal from defect. In general, the trend $H_T(x)$ of the measured signal can be presented as a polynomial of *K* power:

$$H_T(x) = \sum_{k=0}^{K} B_k x^k. \quad (1)$$

Coefficients B_k in (1) are determined by least-squares technique based on minimization of

$$F = \sum_{i=1}^{N} \left(H_z^{И}(x_i, z) - H_T(x_i) \right)^2, \quad (2)$$

Where $H_z^{И}(x, z)$ - magnetic field from defect; N- number of measurements.

The quality of restoration of initial signal from defect is determined by the duration of the signal to the topography of magnetic field ratio. Fig. 1 shows the defectogram taken by eddy-current flaw detector VD-89NFP before and after we exclude the polynomial trend of the 4th power.

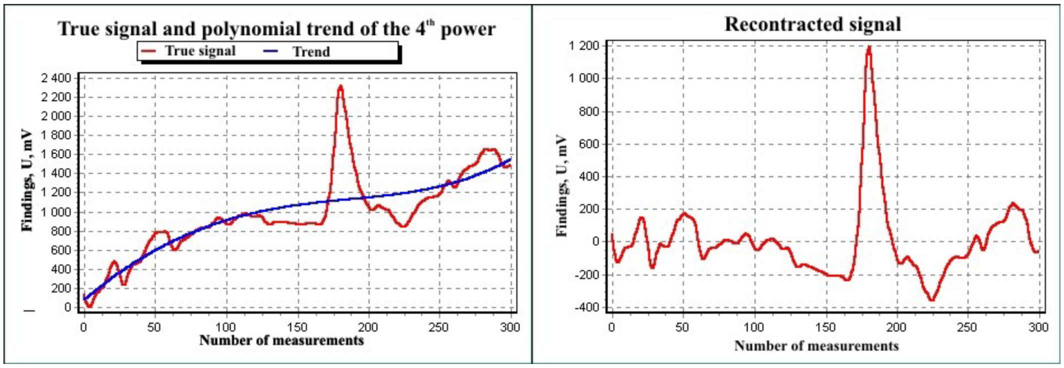

Fig. 1. Signal (a) before and (b) after we deleted the polynomial trend of the 4th power

Fig. 1 shows that the exclusion of the trend leads to the form of the signal which is more convenient for further processing.

The signals of short duration (comparable with the topography of magnetic field from defect) the exclusion of the trend of the 2nd power results in a close form between the trend and the signal.

In the magnetic field from defect $n \in [165..203]$ in fig.1 the trend is nearly linear (see fig. 2):

$$H_T(x) = H_z^{\text{И}}(x_1, z) + \frac{H_z^{\text{И}}(x_N, z) - H_z^{\text{И}}(x_1, z)}{x_N - x_1}(x - x_1). \quad (3)$$

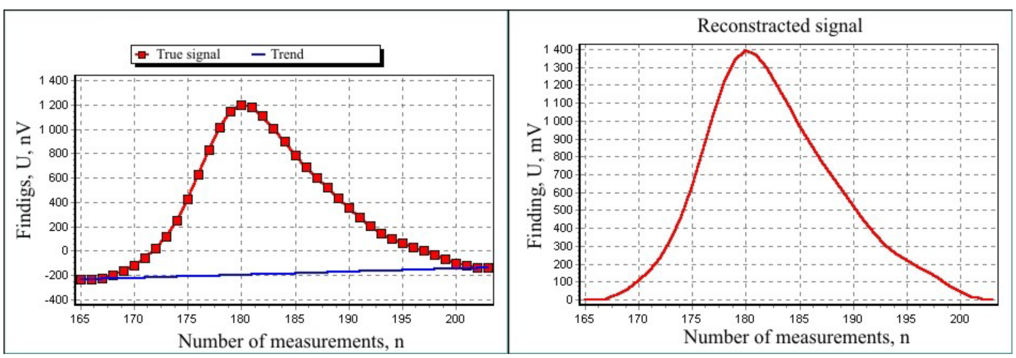

Fig. 2. Signal (a) before and (b) after the exclusion of the linear trend

To eliminate random noise from the measured signal, techniques of digital processing are the most promising, which on the one hand provides high accuracy and noise-immunity and on the other hand allows to use digital filters based on microprocessors.

The choice of window functions is an important point when using digital filtration. The window functions are used for spectrum analysis of signals. The processing by window functions is used to control the influence of side lobe in spectrum. That is why the resulting signal will depend on the window function and will differ from the initial one.

Our experience shows that the construction of an optimal window function is the most advisable to solve a particular task instead of choosing the function among given. The most effective function for investigation of magnetic fields is a parameter window function which can be obtained from the analytic form of magnetic field from internal defect. The current model in this form consists of two currents directed opposite:

$$w(x) = \frac{H_z(x, z)}{H_{zm}(x, z)} = \left[\frac{p_1}{(x - \Delta x)^2 + p_1^2} - \frac{p_2}{(x - \Delta x)^2 + p_2^2}\right]\frac{p_1 p_2}{p_2 - p_1}, \quad (4)$$

where p_1, p_2 – depth of occurrence of currents ($p_1 < p_2 \neq 0$); Δx – coordinate of location of currents. Changing the parameters p_1 and p_2 of the window function (4) we may significantly change their characteristics and get an optimal result in elimination of random noise.

Fig. 3 shows the result of digital filtration with the use of parameter window function when some random noise is applied.

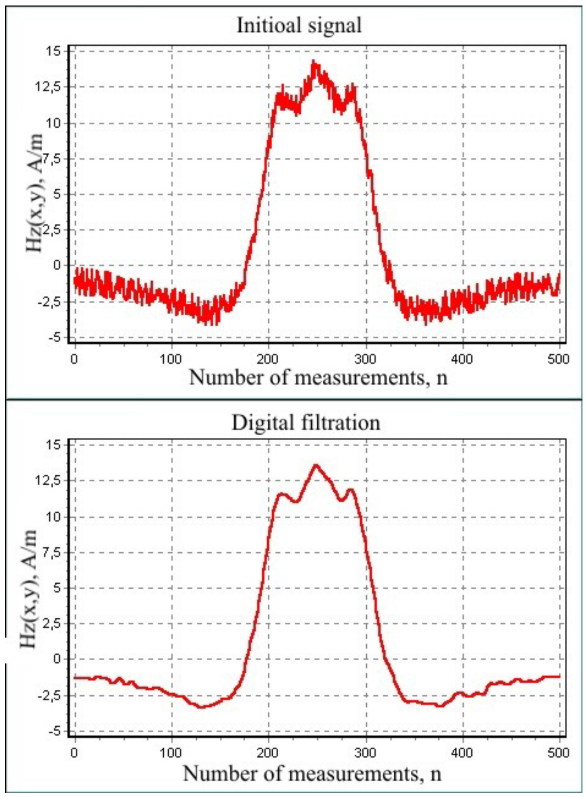

Fig. 3. Initial signal when random noise is applied (a) and its digital filtration (b)

Digital filtration as shown in fig. 3 provides satisfactory results for the restoration of initial signal. Some problems arise while measuring magnetic field from defect with lift-off (see fig. 4). In this case there is little difference between the spectrum of noise and spectrum of useful signal, and base techniques cannot give acceptable results.

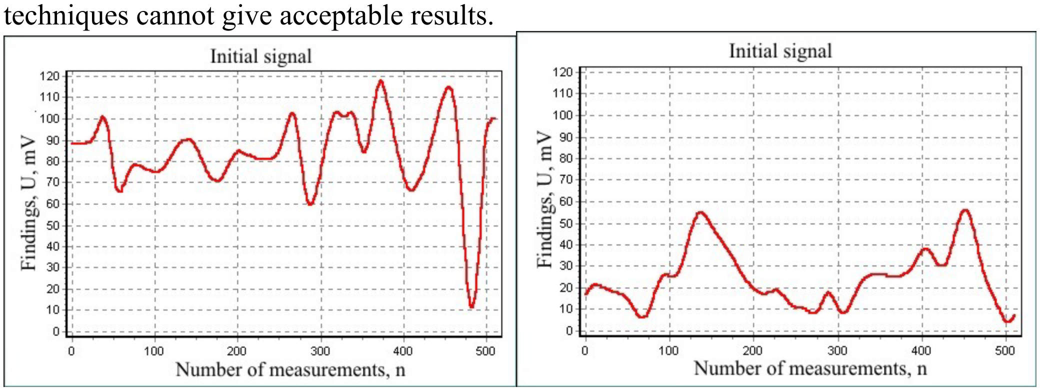

Fig. 4. Defectogram from plumping rods

(a) sample with 3 surface defects, (b) free of defect sample

One of the way out of this problem is the application of correlation processing together with digital filtration where the theoretical model of defect is used as a reference signal. To adjust to scale both reference and measured signal we use normalization. On the base of normalized signal we use the correlation function:

$$\rho = \sum_{i=1}^{N} H_{z\ норм}^{O}(x_i, z) H_{z\ норм}^{И}(x_i, z), \quad (5)$$

where $H_{z\ норм}^{O}(x_i, z)$ – reference signal; $H_{z\ норм}^{И}(x_i, z)$ – measured signal; N – number of measurements.

Amplitude-duration processing allows to increase dramatically the signal noise ratio and, as a result, reliability of distinguishing of signal from noise (see fig. 5).

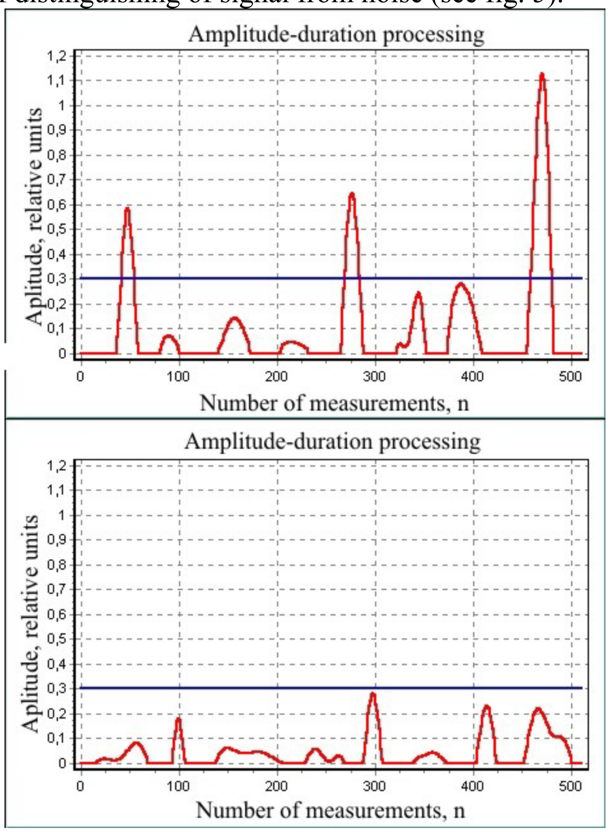

Fig. 5. Amplitude-duration processing
(a) sample with 3 surface defects, (b) free of defect sample

The above methods of digital processing have been successfully used in the eddy-current flaw detectors VD-12NFP manufactured by JSC "Spectrum-RII".

The eddy-current flaw detector VD-12NFP (see fig. 6) is intended to detect surface cracks in objects made of ferromagnetic and non-magnetic steels and alloys.

Fig. 6. Eddy-current flaw detector

The eddy-current flaw detector VD-12NFP features microprocessor system for data collection, storing and processing. It also features the possibility to display the signal itself on the screen (see fig. 7) that makes the process of calibration easier and increase the reliability of test. Also the up-to-date circuit technology is used there.

Fig. 7. Display

The device is provided with three probes with diamond spar in the top that increases their durability and can be used for test of rough surfaces with Rz≤320. The device reveals the defects at lift-off up to 3 mm between the surface and the probe on the surfaces with curvature up to 30 radian. Sound and light alarm systems signal about defect. The device can also estimate how risky the defect is comparing with artificial defects on reference samples. There are 5 modes in the device to store the calibrations, the type of probe connected to the device detects automatically and sets the parameters for test. The VD-12NFP has a build-in memory to store the test results and transfer them to PC by IR-channel and then to print out the report. If the device is used for continuous testing, the data to PC can be transferred on-line.

Specification: Threshold of sensitivity (surface artificial defect of hairline type in reference sample made of ferromagnetic material)

- at Rz≤320 and lift-off≤3 mm:
  - depth of defect 3,0±0,1
  - width of defect 0,1…0,3
- at Rz≤1,25 and lift-off≤0,5 mm:
  - depth of defect 0,5±0,05
  - width of defect 0,05…0,15

Threshold of sensitivity (surface artificial defect of hairline type in reference sample made of non-magnetic material)

- at Rz≤160 and lift-off≤0,2 mm:
  - depth of defect 1,5±0,1
  - width of defect 0,05…0,15
- at Rz≤1,25 and lift-off≤0,2 mm:
  - depth of defect 0,5±0,05
  - width of defect 0,05…0,15

Limits of allowable basic absolute error for depth 0,5…3,0 mm is not more than $\Delta=\pm(0,1+0,3X)$, where x – depth to be estimated

Speed of scanning, m/sec	0,02…0,1
Power supply	4 batteries of AA type
Temperature range, ^{0}C	-10…+40
Dimensions, mm	
Electronic unit	190 x 150 x 70
Probe (diameter, length)	20 x 30
Weight, kg	0,9

The VD-12NFP is certified and included into trade register as the flaw detector to apply for Railroad enterprises.