An oscillograms processing algorithm of a high power transformer on the basis of experimental data

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Abstract. The paper presents the studies on digital processing of oscillograms of the power transformer operation allowing determining the state of its windings of different types and degrees of damage. The study was carried out according to the authors' own methods using the Fourier analysis and the developed program based on the following application software packages: MathCAD and Lab View. The efficiency of the algorithm was demonstrated by the example of the waveform nondefective and defective transformers on the basis of the method of nanosecond pulses.

1. Introduction
One of the causes of damage is effects of short circuit currents, resulting in the displacement of turns in the windings of the high power transformer [1]. Capacitance and inductance of deformed elements are changed according to the degree of deformations. This leads to a change in the vibration frequency that can manifest itself in the waveform of pulsed currents and voltages [2]. Thus, the development of simulation algorithm processes in the high power transformer for diagnosis is an important problem.

2. Research method
The voltage pulse applied to the matched load was exhibited by an oscilloscope 'Tektronix-TDS2012' using the standard probe of the P2220 type applied to the oscilloscope with a bandwidth of 200 MHz.

A winding turn is presented by an equivalent circuit in Figure 1, where L – leakage inductance coil, considering mutual inductance between the coils, C_1 – capacitance between the turns, C_2 – capacitance between the coil and the grounded part of the transformer, R – resistance of windings.

The flow diagram of the procedure sequence of the high power transformer oscillograms is shown in Figure 2. The efficiency of the developed algorithm was proved by the example of two pulses read under the matched load.

The pulse of the nondefective transformer obtained by connecting the output of the generator with resistance $R = 50$ Ohm is shown in Figure 3 (curve 1). The pulse obtained by short circuit turns taken in comparison with the pulse previously discussed (curve 2).
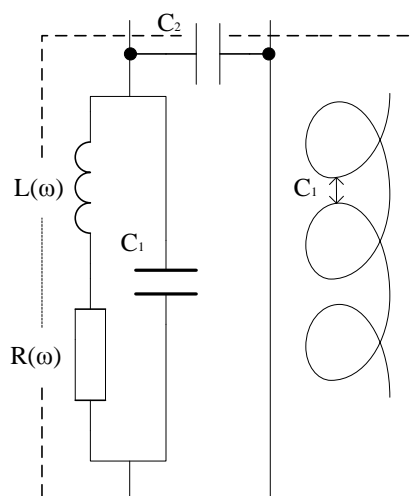
Figure 1. The equivalent circuit of a power transformer winding turn.

The condition of the developed program in the Lab View software program is the *same sample rate condition* of processed pulses [3, 4]. In our case time step was estimated as $h = 4 \cdot 10^{-10}$ ns. Time step can be expressed as:

$$h = t_{11} - t_{12}, \qquad (1)$$

where t_{11} and t_{12} − the first column of the first and second rows, accordingly. The original data are similar to other pulses. A coefficient must be brought in the box 'Step, s'.

3. An experimental part

Then the processing of the signals must be tested in order to compare two signals (Figure 4). For example, one waveform might be subtracted from another, provided that sharp rises in both oscillograms are set both at the same moment. The procedure for the above-mentioned example is feasible *after setting simultaneous starting time* of oscillograms having an arbitrary offset relative to each other and receiving pulses difference in a separate box.

The number of entries K must be calculated in order to set simultaneous starting time, which is required to equalize the processed oscillogram relative to the standard sample and enter the coefficient in the box "Number of entries". Number of entries can be expressed as:

$$K = \frac{(t_{11} - t_{21})}{h} . \qquad (2)$$

In our case the coefficient was estimated as $K = 110$. Thus, time shift was equal to $t_0 = 44$ ns.

The pulses comparison is given in Figure 4, which justifies that the pulses vary notably. A detailed analysis is required for more thorough comprehension.

After processing (2) the digital data are saved automatically in extension txt.

The study was carried out in the MathCAD software program using the Fourier analysis method for an objective pulses comparison. The method justification is that the discrete Fourier transform allows obtaining the required results quickly and with sufficient accuracy.

The pulse was decomposed into Fourier series F components in the MathCAD software program (Figure 5) [5]:

$$F = FFT(U), \qquad (3)$$

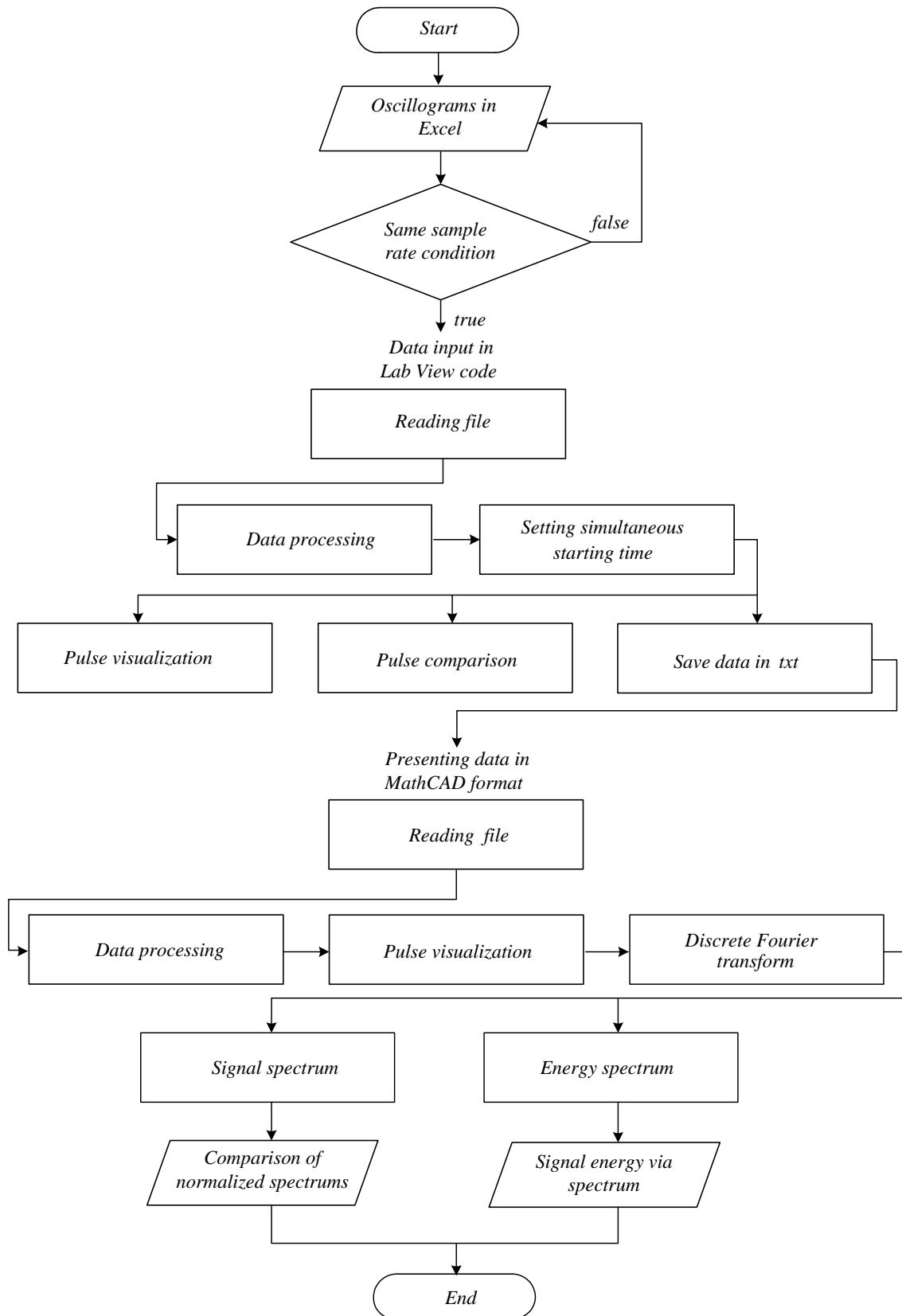where U − instant voltage value on the matched load at the generator exit.
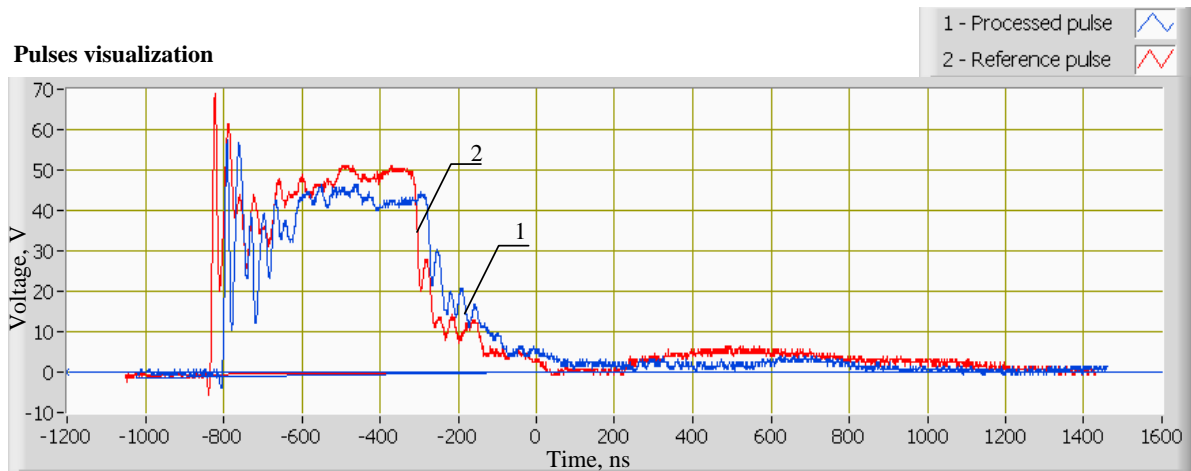
Figure 2. A control-flow chart

Pulses visualization

Figure 3. Pulses visualization.
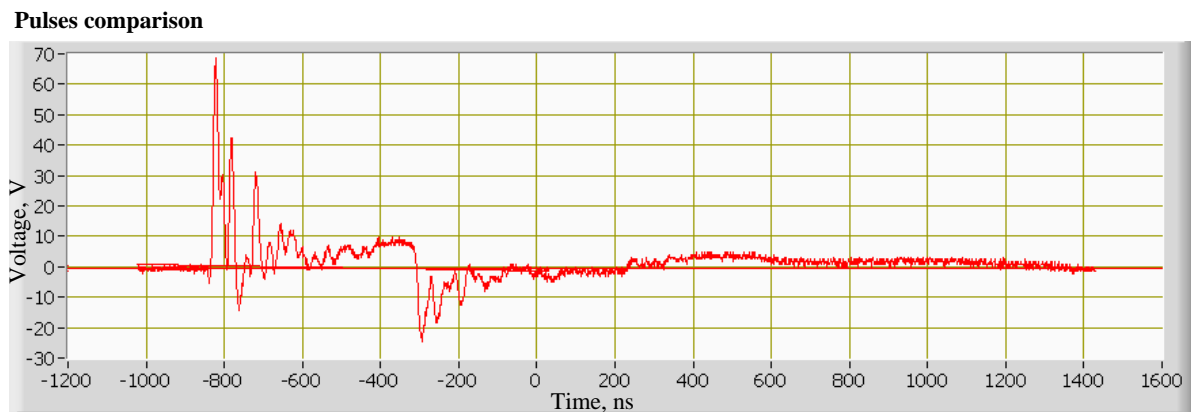
Pulses comparison

Figure 4. Pulses comparison.

All pulses were normalized by amplitude to unity before Fourier series expansion. The signal of each spectrum was equal to 1 nominal unit. This allows making a comparison of normalized spectrums of different pulses.
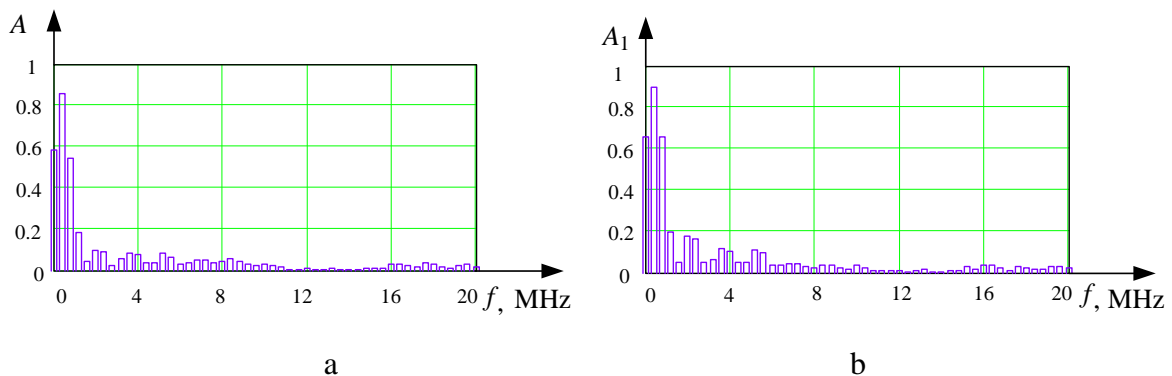

Figure 5. The signal spectrum: *a* – a nondefective transformer; *b* – a defective transformer with short circuit.

Visually the signal spectrums differ from each other a little bit (Figure 5a). Therefore, we suggest comparing the signal spectrums in the form of normalized spectrums of relative divergence (5).

The pulses signal of spectrum *A* can be expressed as double discrete Fourier function (1) [6, 7]:

$$A_j = \left| F_j \right| \cdot 2, \tag{4}$$

where $j = 0 - 50$ – harmonic order, $A_0 = \dfrac{A_0}{2}$ – steady component amplitude.

A comparison of normalized spectrums ΔA_j can be expressed as:

$$\Delta A_j = \frac{A_j}{A_{1_j}}, \tag{5}$$

where A_j and A_{1_j} – the signal spectrum values of the nondefective and defective transformers accordingly, $n = 2^{10} = 1024$ – the number of points.
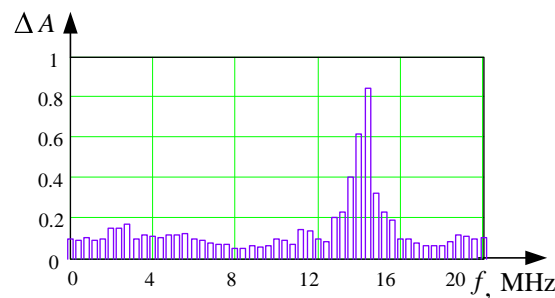

Figure 6. The comparison of normalized spectrums.

The large peak in the latter spectrum demonstrated a lot to the high-frequency components. This indicates obvious damages in the transformer windings, in particular, short circuit.

Analyzing the frequency range it can be concluded that the work of the transformer at frequencies $(12.89 \le f \le 15.71)$ MHz can lead to a breakdown and serious damage of the transformer, period was equal $T = 2.48$ μs , basic frequency was equal $f = 0.4$ MHz.

The total spectrum energy can be expressed as:

$$W = \sum_{j=1}^{n-1} \left| F_j \right| \cdot 2^{\,2} + \frac{\left| F_0 \cdot 2 \right|^2}{2}, \tag{6}$$

where $\left| F_j \right| \cdot 2^{\,2}$ – harmonic energy using (3), $F_0 = \dfrac{F_0}{2}$ – coefficients of the constant component of Fourier series.

Using (6) the total spectrum energy value nondefective transformer was estimated as $W = 898.6$ J and the total spectrum energy value of the defective transformer was estimated as $W_1 = 1121$ J. The large peak in the latter spectrum contributed a lot to the total energy. It gives a physical and numerical concept of the processes.

The direct physical voltage signals were used for test of the algorithm in addition to the experimental data decomposition in Fourier series. The instantaneous experimental values were recorded in the files and then processed and used as an input in the Lab View software program.

This algorithm can be used to simulate the defects of the windings and generate reference signals for various fault operations of the tested equipment.

4. Results
Thus, the proposed algorithm will significantly increase the speed of processing and comparison of the oscillograms while examining transformers by nanosecond pulses. The waveform visualization and a

technique, allowing the comparison of pulses by means of Fourier series and the comparison in relative terms of the spectra of initial pulses, have been presented.

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