Phase analysis of interference currents of railway vehicles

Petr Hloušek[1]

[1]University of West Bohemia, Dept. of Applied Electronics and Telecommunications, Univerzitni 8, 306 14 Pilsen, Czech Republic
hlousek@kae.zcu.cz

***Abstract* – Problems with evaluation of phase relations of reverse tractive current produced by railway driving vehicles are described in this article. This evaluation is newly required in innovated standard ČSN 34 2613. The possibilities and problems of phase analysis with usage of STFT method are discussed.**

INTRODUCTION

Disturbance of railway signalling devices, first of all track circuits (TC), due to reverse tractive current generated by driving vehicles became very actual during last ten years thanks to the new drive generation of these vehicles. These new vehicles with asynchronous drives, due to the principle of their control, generate interference signals in broad spectrum of frequencies, which may intervene in bands reserved for transmission of TC signals. It can cause potential violation of the TC function, so the safety of railway's transport is fundamentally endangered. Mutual interaction is caused by the fact that the rails serve for both the flow of reverse tractive current and the TC signal transmission. These interferences cannot be simply suppressed directly near the sources (on vehicle). The development also proceeds on the side of TC in an effort to improve their immunity, e.g. the new TC receiver - EFCP.
These problems projected also in the legislative area, when innovation of standard ČSN 34 2613 [1], which deals with track circuit and conditions for its correct operation, took place. One of things newly introduced in this standard, is the request to evaluate a phase (no)steadiness of interfering signal (threatening current i_{TDS}). Purpose of this requirement is potential possibility to increase the tolerable value of interference current magnitude. This idea is based on fact that TC receivers are phase-sensitive, so the activation of receiver happens only if the two input signals are phase offset by specific angle (typically 90°) during all the time of excitation. Real receiver can be excited also at different angle, but the amplitude of signals must be higher, growing very steeply with increasing deviation. As a result the sufficient phase unstability of interference current would entitle higher tolerable interfering signal magnitude while a safety is still preserved.

MEASUREMENT OF REVERSE TRACK CURRENT

A measurement of interference influences of reverse tractive current has been carried out since the end of 1960s, when first problems with vehicles using thyristor regulated drives were detected [2]. The new problems, detected in 1990s, also led to innovation of measurement, both the technical equipment and methodology. One of the main changes was move of measurement place from the end of TC onto driving vehicle, so the total current is measured, before it divides into individual vehicle chassis, see fig. 1. An advantage of this arrangement is measurement of real tractive current magnitude and better coverage of entire speed-tractive-effort curve.

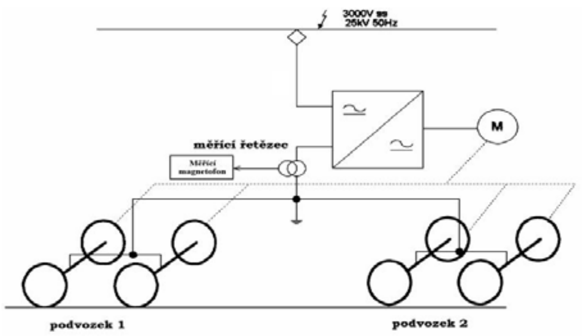

Fig. 1 Place of current measurement

Next important innovation, which was enabled by technical progress, was change from analog measuring equipment to digital, even if not yet completely at present, how can be seen from fig.2.

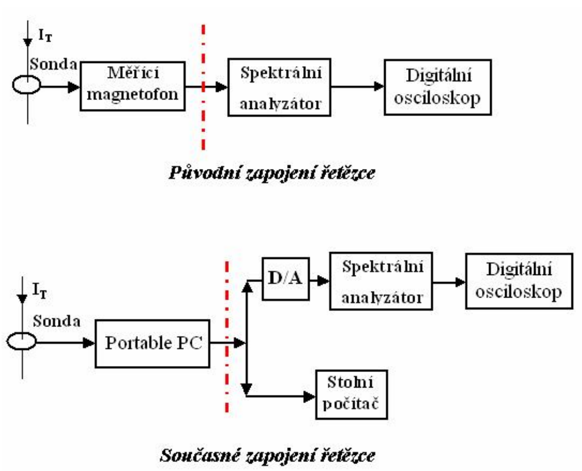

Fig. 2 Interconnection of instrumentation

Signal is presently digitized just behind current sensor by means of measuring PC card by National Instruments using portable PC.

MEASUREMENT EVALUATION

Fig. 2 also shows that equipment innovation enabled also innovation of measured values evaluation methodology. An analysis of measured signal was originally carried out only in time domain. The special-interest frequencies, e.g. 75Hz, were selected from signal by means of narrow-band filter and their time behaviour was examined using oscilloscope. Measurement digitization enabled to use other computationally demanding methods of signal processing in frequency domain even using the common PC, because processing can be proceeded offline. Considering that the signal is non-stationary, methods for time- frequency analysis – Short Time Fourier Analysis (STFT) and Continuous Wavelength Transformation (CWT) were chosen, for more detail see [3, chap. 4]. A Matlab application - **Signal Analysis** was developed for easy use of these methods, see fig. 3.

ANALYSIS OF SIGNAL PHASE

An innovation of this application to version 2.1 was made on the basis of new requirement from standard ČSN 34 2613. Calculation of phase spectrum by STFT method, including visualization of results, was added. It enabled to carry out analyses to discover possibilities and problems of phase analysis of non-stationary signal. The most interesting achieved results are shortly described bellow.

As an introduction into the problems let us explain the principle of STFT method, which rests in shift of chosen type window along the signal in time. The convolution of window function with signal is performed for every shift and Fourier transform is calculated for the result to obtain spectrum for each given signal section, see fig. 4. It makes possible the changes in signal to be displayed as spectral changes. The window duration can be chosen and holds that the shorter window, the better time resolution, but on the contrary the frequency resolution deteriorates.

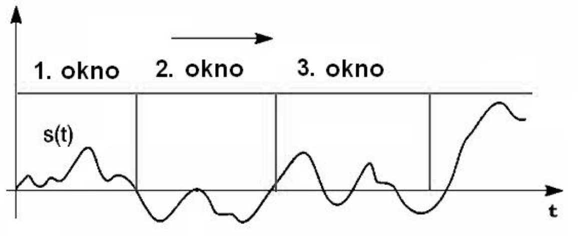

Fig. 4 STFT principle

First conclusion that can be made on the basis of analyses is that the phase analysis is generally more complicated than amplitude one. It applies also to evaluation and interpretation of results.

First complication is a necessity to choose the window duration from very limited set of options otherwise the correct analysis is not possible. The window duration has to be chosen as an integer multiple of period duration of given special-interest signal components.

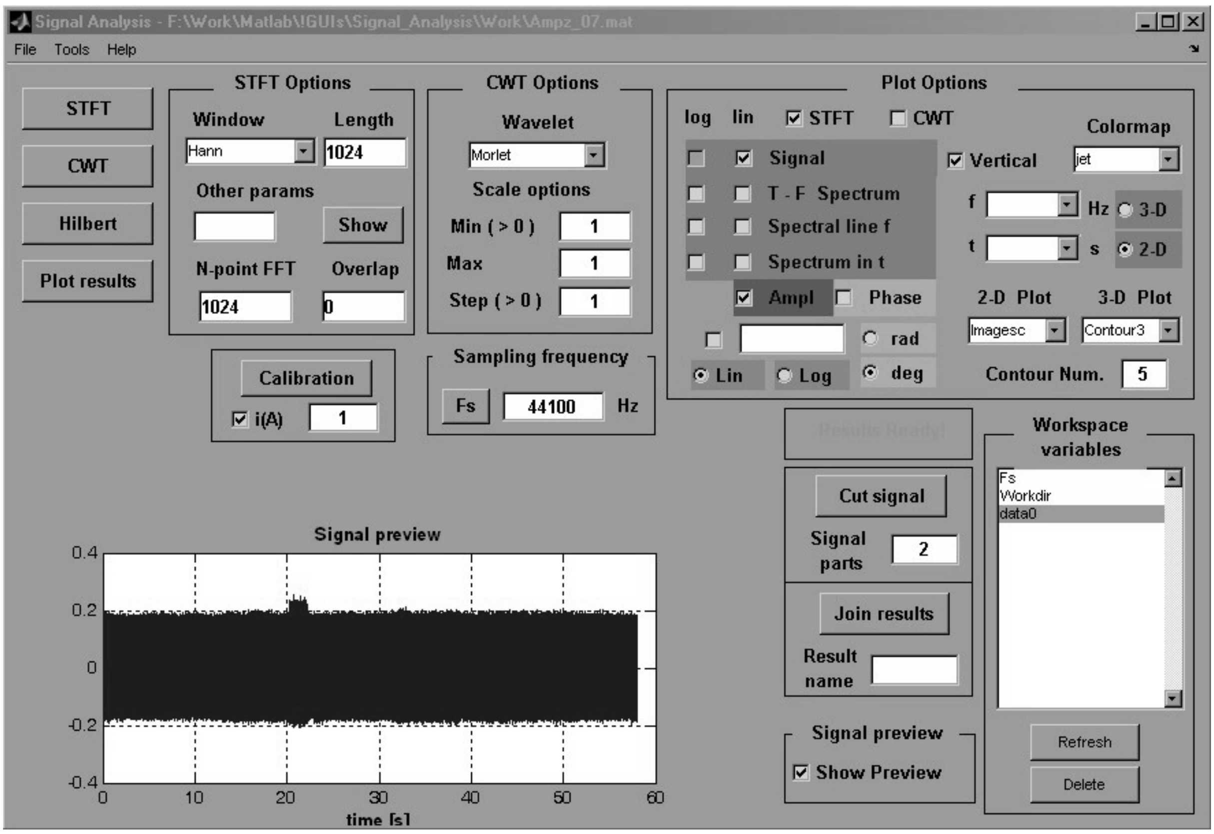

Fig. 3 Signal Analysis application

If this is not kept, more or less fast change phase, eventually sudden phase “jump”, happens to even ideal signal in accordance with deviation size. Following figures 5, 6 and 7 illustrate this situation. The ideal signal seemingly looks like phase unstable.

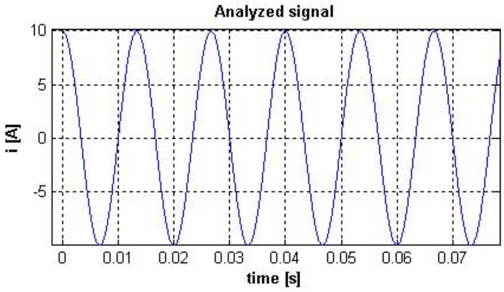

Fig. 5 Harmonic signal time behaviour

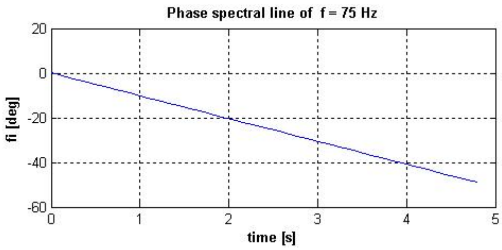

Fig. 6 Phase time behaviour - small deviation

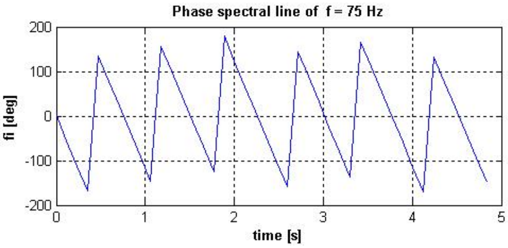

Fig. 7 Phase time behaviour - large deviation

The result is that the for reverse tractive current signal, where are the main special-interest components on frequencies 50Hz, 75Hz and 275Hz is necessary to choose the window duration according to the table 1.

Time resolution	Freq. resolution	Number of period		
		50Hz	75Hz	275Hz
40ms	25Hz	2	3	11
80ms	12,5Hz	4	6	22
120ms	8,33Hz	6	9	33

Tab. 1 Possibilities of window duration choice

The time resolution can be further deteriorated by 40ms steps towards the better frequency resolution. Practical tests showed that the shortest time resolution is totally unusable. The reason is demonstrated on the following signal:

$$x(t) = 1 \cdot \cos(2 \cdot \pi \cdot 50 \cdot t) + 0.001 \cdot \sin(2\pi \cdot 75 \cdot t) + 0.05 \cdot \cos(2\pi \cdot 275 \cdot t) \quad (1)$$

An analysis results with time resolution of **40ms** are on fig. 8 and 9. The amplitude and phase do not comply with formula (1), because the small 75Hz component is affected by big 50Hz component.

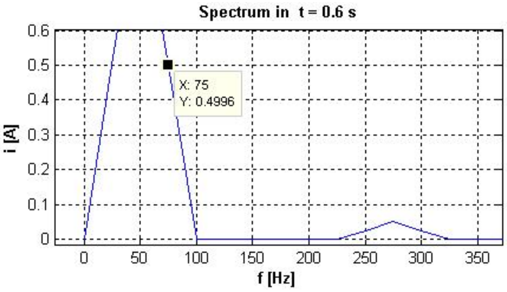

Fig. 8 Amplitude spectrum

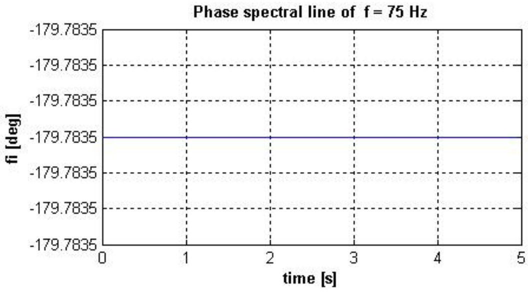

Fig. 9 Phase time behaviour of 75Hz

Analysis results with time resolution **120ms** are on fig. 10 and 11. The amplitude and phase correspond with the reality very well.

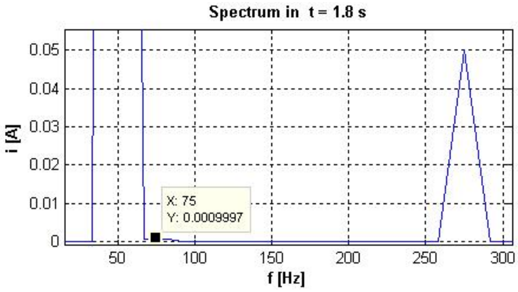

Fig. 10 Amplitude spectrum

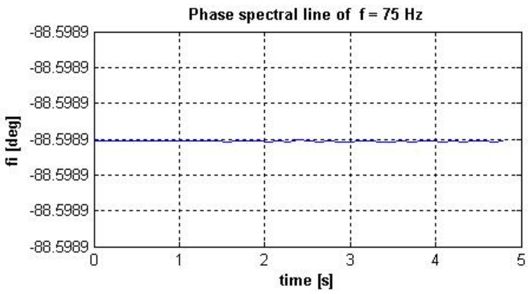

Fig. 11 Phase time behaviour of 75Hz

ANALYSIS OF REAL SIGNAL

The analyses were performed on the signal sensed during accelerating period of driving vehicle. Its time behaviour is shown on fig. 11. Phase spectrum as the result of analysis using time resolution of **120ms** is plotted on fig. 12. The phase of 50Hz component relatively slowly changes, i.e. relatively is stable according to expectation, whereas phase of 75Hz and 275Hz components is very variable.

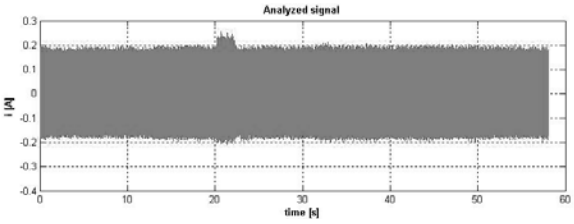

Fig. 11 Real signal time behaviour

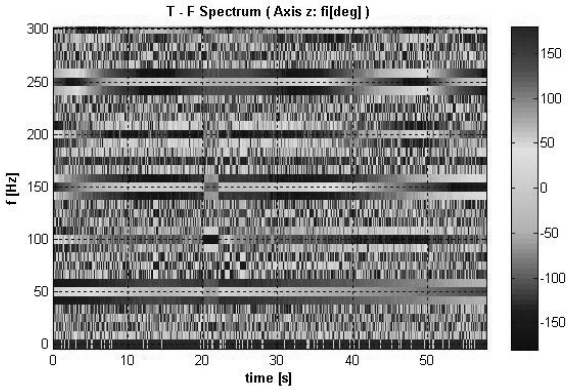

Fig. 12 Phase spectrum - $\Delta t = 120ms$

The phase time behaviour of 50Hz component using time resolution $\Delta t = 120ms$ is plotted on fig. 13.

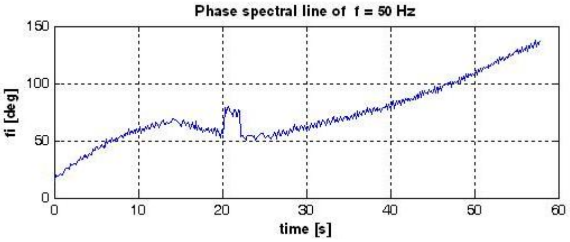

Fig. 13 Phase of 50Hz spectral component

The effect of incorrect window duration setting for the same signal is demonstrated on fig. 14. The time resolution of **66,6ms** was chosen, which is not integer multiple of 50Hz component period. This component now evidently looks like having phase totally unstable.

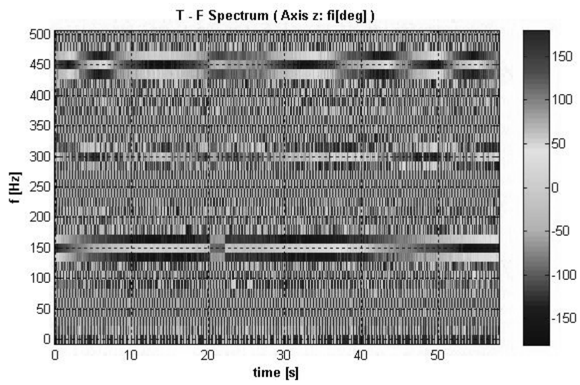

Fig. 14 Phase spectrum - $\Delta t = 66{,}6ms$

Figures 15 and 16 reflect next very important fact. Despite that the 75Hz signal component phase globally looks very unstable, it is possible to find sections with good phase stability, lasting for approx. **600ms** in this particular case. It significantly exceeds an activation time of TC receiver.

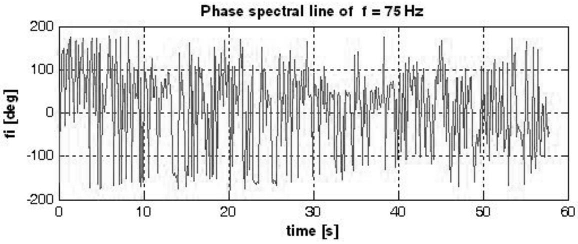

Fig. 15 Phase time behaviour of 75Hz

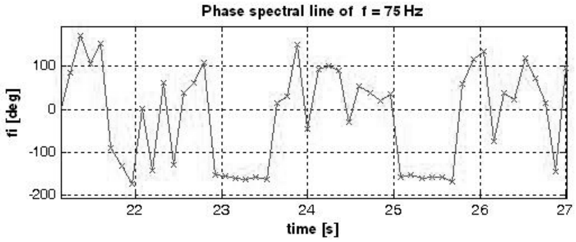

Fig. 16 Phase time behaviour of 75Hz – detail

SUMMARY OF PHASE ANALYSIS RESULTS

Present phase analyses result in these findings:

1) bigger intricacy of analysis setting and results interpretation,
2) phase unstability cannot be proved.

Complication with analysis of real signal rests in limited choice of transformation window duration, to be compatible with multiples of periods of all special-interest spectral components. Nevertheless, the interference current can look like phase unstable „virtually", if its actual value of frequency differs from the theoretic one. It would be necessary to determine very precisely the frequencies of analysed spectral components for real signal, which is very problematic task.

Conclusion from present results is that the phase spectrum does not seem to bring any additional valuable information and that the evaluation could be simple. The proof of phase unstability of disturbing components cannot be done with sufficient confidence. In addition, the standard does not specify how big phase stability is tolerable. The worst possible case must be taken in consideration, regarding philosophy of signalling systems, that the interfering signal can be phase steady enough regarding the activation time of the TC receiver.

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