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EMC of vehicle, reverse tractive current, STFT and CWT method

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REVERSE TRACTION CURRENT MEASUREMENT AND EVALUATION USING MODERN SIGNAL PROCESSING METHODS

The actual problems solved for Czech Railways by Railway Research Institute are described in this paper. It deals with an evaluation of the interference influence of the electrical engines which adversely effects on the other railway equipment, above all the communication and signalling and interlocking devices, what can negatively affect fluency and safety of the railway's transport. It was decided to utilize for innovation the modern methods of the digital signal processing – STFT and CWT.

SZACOWANIE I POMIAR POWROTNEGO PRĄDU TRAKCYJNEGO Z WYKORZYSTANIEM NOWOCZESNYCH METOD PRZETWARZANIA SYGNAŁU

W referacie opisywane są bieżące problemy Republiki Czeskiej, rozwiązywane przez Instytut Badawczy Kolejnictwa. Traktuje on o wpływie zakłóceń silników elektrycznych, które oddziałują negatywnie na pozostałe wyposażenie kolejowe, przede wszystkim na urządzenia łączności i sygnalizacji oraz blokady, co może negatywnie wpływać na płynność i bezpieczeństwo transportu szynowego. Zdecydowano się na wykorzystanie dla celów innowacyjnych nowoczesnych metod cyfrowej obróbki sygnałów– STFT i CWT.

1. INTRODUCTION

Prerequisite for the safety assurance of railway transport is error free and reliable operation of interlocking devices. Using interlocking devices increases railway transport safety to such level, that it is, according to long-term statistics, the safest transport together with air transport. Therefore it is inevitable to exclude any possibility of negative interference of the correct operation of interlocking systems. Electrical engines with modern means of traction control are one of the main sources of interference, first of all due to interfering effects of the reverse tractive current. The reverse tractive current flows from the electrical engine back to the power supply, where the rails are exploited as the path. The working signals of the other railway systems are however also transmitted in this environment and

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therefore it is necessary to measure parameters of this current, whether do not contain components, which could affect adversely their function. Ones of the mostly endangered interlocking devices are the track circuits (TC), due to the fact that they share a transmission environment (the rails) just with the reverse traction current. The TC continue to be the most widely used interlocking device for the train location detection on Czech Railways. That is why their correct function has direct influence on railway transport safety and why this research work was just focused on them. It was carried out in cooperation with workers of Railway Research Institute in Prague, who carry out the own measurement and evaluation of the reverse tractive current in practice. This problem is examined already from the start of the electrical engines operation at the end of the 1960s.

Target of this research work was to propose possibilities of innovation of the reverse tractive current measurement and evaluation methodology. Existing procedure, used method and equipment are tributary to time of their creation, which is already relatively distant and do not match the present possibilities.

1.1 TRACK CIRCUITS AND REVERSE TRACTIVE CURRENT

The fundamental purpose of TC is a safe detection of presence or on the contrary absence of the train in a given track section. It means, that the whole line is divided into individual sections guarded by TCs. Number of the different TC types exists, but the most widely used is so-called parallel TC. Parallel TC consists of the signal transmitter and receiver, that are linked by the track section (the rails) and signal current flows through the circuit. If there is not train in the section, receiver is excited by the current and signalizes clear track section. When the axles of passing by train conductively connect the rails, the receiver will stop being excited and that means the section is occupied. From the TC working principle is evident, that the individual TCs have to be separated from each other, in order not to influence each other. This separation must not however inhibit the flow of the reverse tractive current, how is apparent from Fig.1. The several ways exist to achieve that and, according to it, the TCs are divided in the various types. From the description is also obvious, that another current flowing through the rails could falsely influence the TC receiver, which could for example signalize section clearance even during the train presence. This would be dangerous state, which could lead to the railway accident. Therefore it is necessary to prevent this TC interference by all the available resources. These precautions can be done partly on the side of the own TCs and partly on the side of the interference sources, which is generally more efficient and mostly easier.

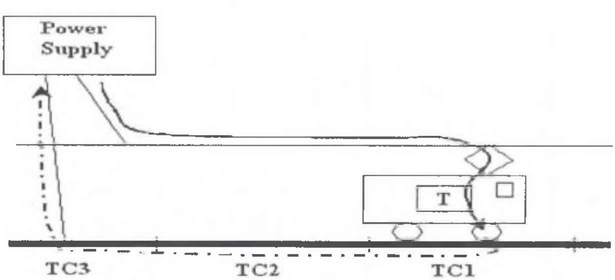

Fig.1. Scheme of engine power supply, T – engine traction, TCx – track circuit, dash-dotted line – reverse tractive current, full line – supply current

One of the main precautions against their interfering effects is the TC operation on different frequencies, than normally occur in the reverse tractive current. Czech Railways use two tractive systems, d.c system and a.c system - 50 Hz. That is why the most widely used working frequencies of the TCs are nowadays 75 and 275 Hz and the TC receiver obviously has to be frequency selective. The standards, which reserve these bands for TC and set maximum acceptable interference limits to occur in it, indeed exist. Briefly said, in reserved bands 68 – 82 Hz and 268 – 282 Hz the railway vehicles must not, even at any power supply failure in view, be source of interfering current, whose value would exceed 100 mA on time longer than 100 ms. Time 100ms was set, because it is the excitation response time of the most widespread TC receiver - electromagnetic relay of DSŠ type.

1.2 PRESENT METHOD OF REVERSE TRACTIVE CURRENT ANALYSIS

The measurement methodology of the reverse tractive current covers conditions and methods of the own data acquisition, measurement chain configuration as well as evaluation methods of the measured values. This work has been focused first of all on innovation of the last two mentioned fields.

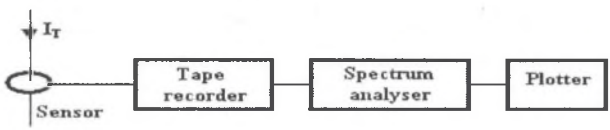

Fig.2. Present measurement and evaluation instrument chain

The present measurement chain configuration is on Fig.2. The reverse tractive current is scanned either on the TC receiver or right on the engine, by means of current measurement transformer, and recorded on measurement tape-recorder. Finally, it is in laboratory replayed from the tape-recorder and analyzed by the analog spectrum analyser and time behaviour of the individual spectral components printed on the co-ordinate plotter.

The disadvantages of this measurement and analysis method consist in real constructional qualities of the measurement tape-recorder and spectrum analyser, resulting among others from their age. The main problem is analog data storage (degradation), insufficient time resolution and small accuracy of frequency component amplitude determination, which makes it impossible to accurately evaluate parameters of the short-term events in signal. Next there is the big time consumption of the analysis and impossibility of the overall signal spectrum overview.

2. PROPOSED SOLUTIONS OF INNOVATION

The innovation proposal of the measured data processing is based on the fact that real-time operation is not demanded and, on the contrary, the financial resources allotted on the measurement are considerably limited. The own innovation then consists in replacement of the present analog processing of the measured signal, done by the measurement instruments, by digitizing of the signal and its subsequent digital processing by means of the available software on the powerful desktop computer.

2.1 MEASUREMENT CHAIN INNOVATION

The two versions of the new measurement and evaluation chain configuration were proposed.

The first version consists in the computer connection to the measurement tape-recorder instead of the present spectrum analyser by means of measurement or sound PC card. The scanning and primary storage of the signal in analog form remains unchanged. The advantage of this version is its relative economic unpretentiousness and possibility of the parallel processing of the measured data by old and new method with their results comparison, which is though possible only in limited scale due to the method differences.

In the second proposed version even the measurement tape-recorder is removed and the data from the sensor are directly digitized. The advantage is removal of the analog signal storage, which is redundant at subsequent digital processing. The relative disadvantage is impossibility to carry out measurement evaluation by the present method, but above all higher economic heftiness of this solution. The portable computer (notebook), with PCMCIA measurement card, or industrial PC is needed for digitizing and data storage, because of the limited space and conditions, when measuring on the engine. And most likely once again the need of the powerful desktop computer for additional detailed analysis, because the data processing by the proposed methods is very demanding for computing power and memory size.

2.2 NEW SIGNAL PROCESSING METHODS

The aim at evaluation of the reverse tractive current is to find out magnitude of its components occuring in bands reserved to the operation of the TCs. The problem is, that it is so-called non-stationary signal, which means that its parameters significantly change in time. These changes happen for example during accelerating period of the engine or its tractive mode changes. So, the time behaviour of given frequency components of the current is the main object of interest. Regarding to the to standard requirements, mentioned in chapter 1.1, it would be necessary to achieve time resolution better than 100 ms, in order to be possible distinguish between interfering influences, which can and those that cannot, influence the TC receiver. The amplitude resolution should be tens, better however ones, of mA to distinguish, whether the component magnitude is bigger or smaller than 100 mA.

The new methods for the reverse tractive current parameters evaluation had to be chosen with reference to signal character and desired results. Two methods for non-stationary signal analysis, Short-Term Fourier Transform (STFT) and Continuous Wavelet Transform (CWT), were chosen for their features examination, whether they are suitable for this application or not. STFT is modification of the well-known Discreet Fourier Transform (DFT), which is not suitable for non-stationary signals. The CWT is one variation of the general Wavelet Transform, which nowadays finds still wider use at processing of all sorts of the signal, because it has very convenient characteristics for some applications.

2.3 PRINCIPLE OF STFT AND CWT

STFT is based on DFT analysis of short signal intervals consecutively, which is carried out by shifting of so-called window (or weighting) function. The information about the frequency components present in signal in a given time interval is obtained by this process.

The desired time frequency overview of the signal originates by the composition of the all results. The time and frequency resolution of STFT is invariable for entire analysis and is dependent on window length, number of points of DFT and sampling rate selected in advance.

The principle of Wavelet Transform, illustrated on Fig.3, rests in the fact that the time weighted information from signal ***s(t)*** around the time ***b*** is obtained by means of function $\psi_{b,a}(t)$. The mutual correlation among signal and variously outstretched (parameter ***a***) and in time shifted (parameter ***b***) versions of so-called mother wavelet function Ψ is computed.

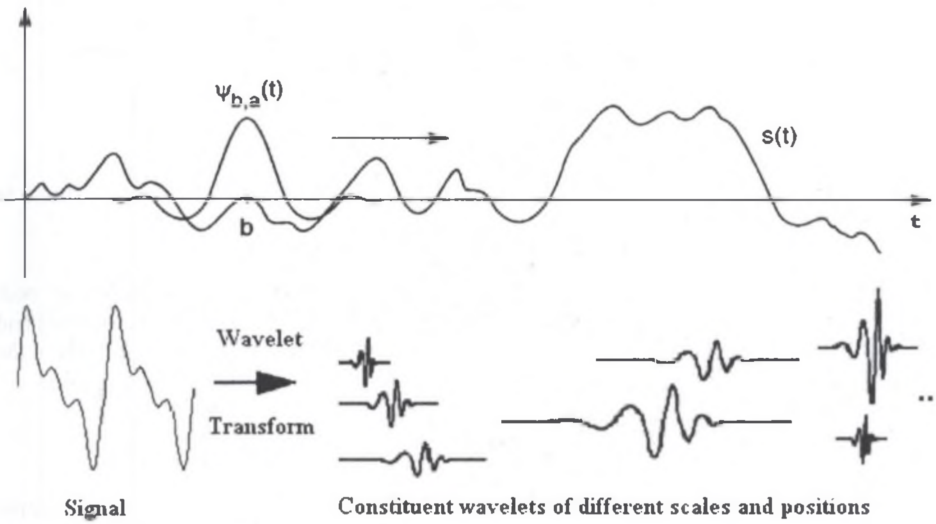

Fig.3. Principle of Wavelet Transform

The main diversity of WT against FT (STFT) can be seen from Fig.3, and rests in the shape of the constituent functions, the signal is decomposed on. The fundamental of FT is the signal decomposition on harmonic functions with various frequencies, whereas WT decompose signal on shifted and extended or compressed versions of the basic mother wavelet. The WT constituent functions have effectively limited time duration, zero mean value and have tendency to be irregular and asymmetrical in contrast to the FT constituent functions, which have infinite time duration, are smooth and have deterministic shape. The different characteristics of WT result from this difference. At look on these pictures it is intuitively evident, that the local signal characteristics may be better described by wavelets, which have also local scope and also makes sense, that fast changes in signal can be better analyzed by irregular and often sharply varying wavelets than by smooth harmonics. There is bigger quantity of different WT constituent functions with different characteristics. For more info about WT, see [1], [2], [3].

The WT presents improved access, compared to STFT, in effort to obtain time and frequency information contained in signal. Essentially, it is the window technique with variable region size, which results in flexible changes of time and frequency resolution according to what frequencies are analyzed, what is often convenient. In direction to higher frequencies frequency resolution is decreasing and time resolution on the contrary is rising. This described difference between them is illustrated on Fig.4.

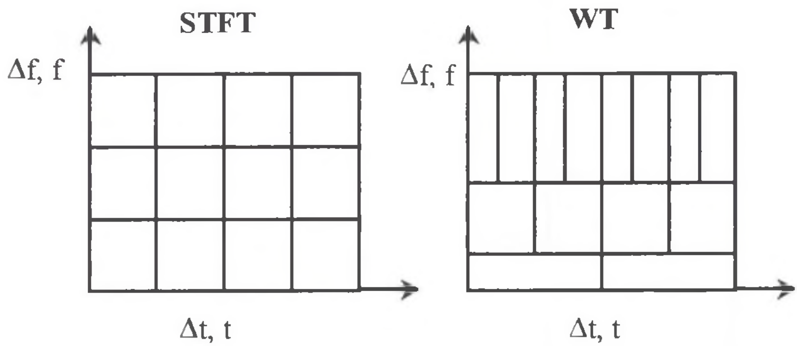

Fig.4. Differences in time resolution Δt and frequency resolution Δf

Both methods however underlie the Heisenberg uncertainty principle, which is generally expressed by formula:

$$\Delta f * \Delta t = const.$$

This formula says, that it is not possible to achieve arbitrarily small values of both resolutions at once. In other words, when time resolution is made smaller (i.e. improved) and is thus more precisely identified the moment, when the given event occurred, then the accuracy of the frequency determination, the event appeared at, is reduced and vice versa.

2.4 BRIEF DESCRIPTION OF MATLAB PROGRAM

The program Matlab, version 6, was selected for processing and analysis of the acquired data. It is very well known as universal and powerful mathematic system. It can be used in many application areas, because to the own program kernel, which is able, above all, to carry out operations and calculations with matrices, are, in addition, available specialized application toolboxes. For signal processing there is available Signal Processing Toolbox (includes function for STFT computation) and also Wavelet Toolbox for the WT execution.

A lucidity of the results display of these time-frequency transforms is generally problematic, because the spectrum forms generally 3-D structure with axes: time, frequency and amplitude of the particular spectrum components. Matlab offers wide possibilities of results visualization, including 3-D diagrams. Nevertheless for complicated spectrum, it is naturally difficult the mere orientation in 3- D diagram, let alone the measurement of required parameters. However, there exist possibilities how to improve this lucidity even in Matlab, e.g. by various types of 2-D diagrams with third proportion expressed e.g. by colour. The various spectral cuts are also very useful at the spectrum parameters examination.

2.5 ILLUSTRATION OF ANALYSIS RESULTS

The reverse tractive current analysis results are shown for illustration here, using both methods, for d.c. traction engine. STFT analysis results are on Fig.5. The overall signal spectrum is on the left lower part of the figure and the time behaviour of the spectral components 75 and 275Hz is on the right.

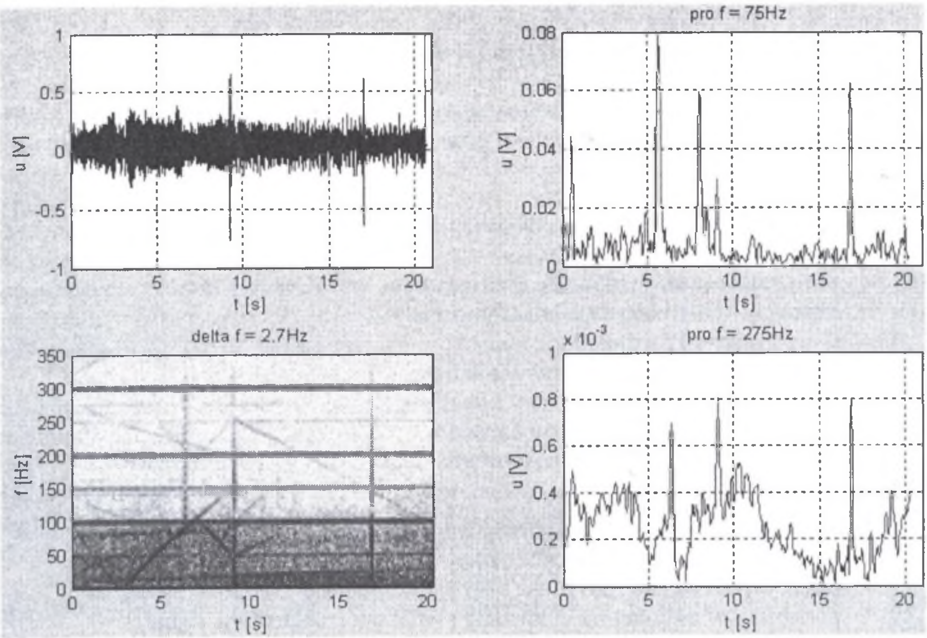

Fig.5. Analysis results using STFT

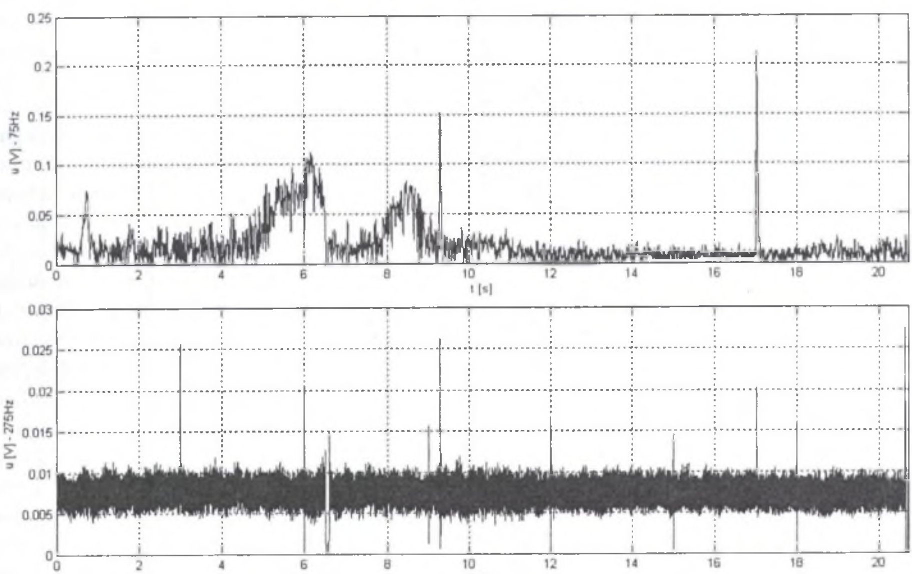

Fig.6. Time behaviour of the two spectrum components using CWT

The time behaviour of the spectrum components 75 and 275Hz obtained by CWT are shown for comparison on Fig.6.

2.6 BOTH METHODS FEATURES SUMMARY

An analysis of the testing and also real signals proved that non-stationary signals can be analyzed by both methods, but both of them have its benefits, disadvantages and limitations.

STFT:

+ computation speed, memory demandingness
+ line spectrum (in ideal case)
+ time and frequency resolution relation can be set in certain limits
+ relatively non-problematic broadband analysis
+ d.c. component computation
- not completely sufficient time resolution
- inaccurate spectrum component localization in time
- spectrum "truncation" in time domain
- always analysis of the whole spectrum range, till the Nyquist frequency

CWT:

+ time resolution, magnitude determination accuracy
+ signal changes determination accuracy
+ possibility of the analysis of the only partial frequency range of the signal
+ possibility of the analysis of the only partial time range of the signal
- computation speed, memory demandingness
- overlap of the neighbouring components, necessity of the signal filtration
- unsuitability of the broadband analysis
- impossibility of the d.c. component computation
- necessity of dividing of the longer signal on shorter parts
- more complicated analysis procedure

The main examined parameters of these methods were an accuracy of the signal component amplitudes determination and maximum attainable time and frequency resolution in the bands of our interest, as was described in chap.2.3. Using STFT it is possible to achieve time resolution about 300ms with required frequency resolution at least 3Hz, accuracy of amplitude determination achieves only about 90% of actual value. These values are invariable for the entire spectrum. When using CWT, on the contrary, both resolutions change according to analyzed frequency and at search of its time resolution limit we had to, in compliance with theory, focus on the lowest frequencies. It can be claimed, that for band of our interest (from 50Hz above) is the CWT time resolution better than 100ms. The CWT frequency resolution, unlike the STFT, where it is possible to set arbitrarily by ratio of sampling rate and of the number of points calculated by DFT, decreases approximately logarithmically with growing analyzed frequency. It cannot be influenced by any way, but it resulted that it is sufficient minimally up to the 500Hz. This problem can be eventually solved, for signals containing only relatively narrow band of the high frequencies, by conversion to the lower band using digital mixing. The CWT amplitude determination accuracy can be basically achieved 100%. The CWT is from standpoint of the main parameters more suitable method for the reverse tractive current analysis. It has however other inconvenient characteristics, which make its usage more difficult. STFT has on the contrary some substantial benefits. Therefore the combination of both methods with utilization of their strong features appears as optimal for analysis, with mutual results comparison and verification in maximum ratio, as possible.

STFT can be utilized for obtaining of quick overview spectrum image and long-term components detection, whereas CWT for detailed analysis of the chosen critical signal parts.

The comparison of computational demandingness between STFT and CWT is surely on behalf of STFT. Thanks to much greater demandingness of CWT it is necessary to divide longer signals and analyze it in parts. Obviously, the demandingness is affected by required analysis punctuality and the range of the frequencies, for which is the analysis done. This can be in part compensated by utilization of benefits of WT local operation, when can be analyzed only interesting part of signal, as in time, as well as in frequency area, without results distortion increase or resolution decrease. Second aspect is considerable memory demandingness, which partly also is connected with used program Matlab. In this program every real number occupies 8 Bytes of memory and complex then 16 Bytes. Both methods of analysis, but firstly CWT, come up with considerably big matrices of resulting coefficients.

The inconvenient STFT feature is the time shift of the computed spectrum to the left, i.e. some spectrum "advancing " in time, caused by that first window is symmetrical around the time 0s. The related problem is the time spectrum truncation compared to the original signal. The spectrum truncation is because the last spectrum point can be computed, once the window end reaches the signal end. Both problems are related to the selected duration of the weighted window and partial elimination of them both rests in an extension of the signal duration by the zero values completion on its beginning and end.

Next disadvantage of CWT is its unsuitability for broadband analysis in one computation run (over 3 decades and more), otherwise said for large range of the scales $\boldsymbol{a}$. The reason is, that it is necessary to choose small step of the computed scales sequence to get reasonable analysis punctuality on high frequencies (within the scope of available frequency resolution). Matlab allows to choose only linear sequence with invariable step, which means that for low frequencies is the analysis too much detailed. This uselessly lengthens out computation and very much increases results file size and also memory demandingness for processing. So, it is suitable to divide the band of interest on subbands and for each of them choose suitable step, in order to the analysis was appropriately detailed. This procedure on the other side somewhat complicate the results processing and display.

A "wave" generation in spectrum is the next inconvenient CWT feature. Spectrum is not line as with FT, because it is in principle computation of correlation of the analyzed signal with the given wavelet. That is why the Wavelet spectrum is not line even for sine signal (as with FT), but some "wave" with maximum, which matches the frequency and amplitude of existing component. It was proved, that the big signal component creating big "wave" will cover eventual near small component, that would be however distinguished without its presence. This behaviour is inadmissible for our application, where one of the measurement and analysis difficulties is very big ratio between current working component amplitude (d.c. or 50Hz) and interfering components amplitudes. The d.c. component cannot be in principle computed using WT because of the temporary duration of common wavelet function. It would mean the infinite wavelet dilatation alias computation for scale $a = +\infty$, which is not possible. Nevertheless it was proved, that its presence in signal unaffects the correct computation of the other spectrum components. But the signal filtration is necessary when tractive current working component is 50Hz. From performed analyses, it resulted that after removal dominant frequency component, it can be determined amplitude as well as time behaviour of the originally covered component. This filtration need is inconvenient from standpoint of the possible signal parameters affection nevertheless it can be done very well thanks to the possibility of the digital processing and not in real-time.

3. RESEARCH WORK RESULTS

The two versions of the measurement and evaluation chain configuration innovation were proposed. At this moment, the first version appears as most suitable thanks to compatibility with existing method. Second version can, under certain conditions, become suitable solution in the future thanks to some its described benefits. The main obstruction of its usage now is its economic demandingness and incompatibility with present method.

The main focus and result of this work is however pieces of knowledge summary resulting from performed detailed feature analysis of the chosen modern methods of non-stationary signal analysis - STFT and CWT. The comparison of their characteristics and their convenience for this application was done, see chap. 2.6. The practical procedure of acquired data analysis with Matlab utilization, including obtaining required results in comprehensible form, was also worked-out. The own application, in form of graphical user interface (GUI) of Matlab, was written for easier data evaluation and results processing, because it did not exist for STFT and existing GUI for CWT turned out to be insufficient for this application. This GUI creation allows to perform the data analysis faster, and basically even without knowledge of the Matlab program control, which was before unavoidable.

This work is not the end of innovation of the reverse tractive current measurement methodology, because is it long-term process, even only thanks to substantial touch of the railway transport safety. It is necessary to obtain more and more experience with real data evaluation before possible replacement of the existing methodology. Finally, the modification of relevant standards will also have to be implemented.

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