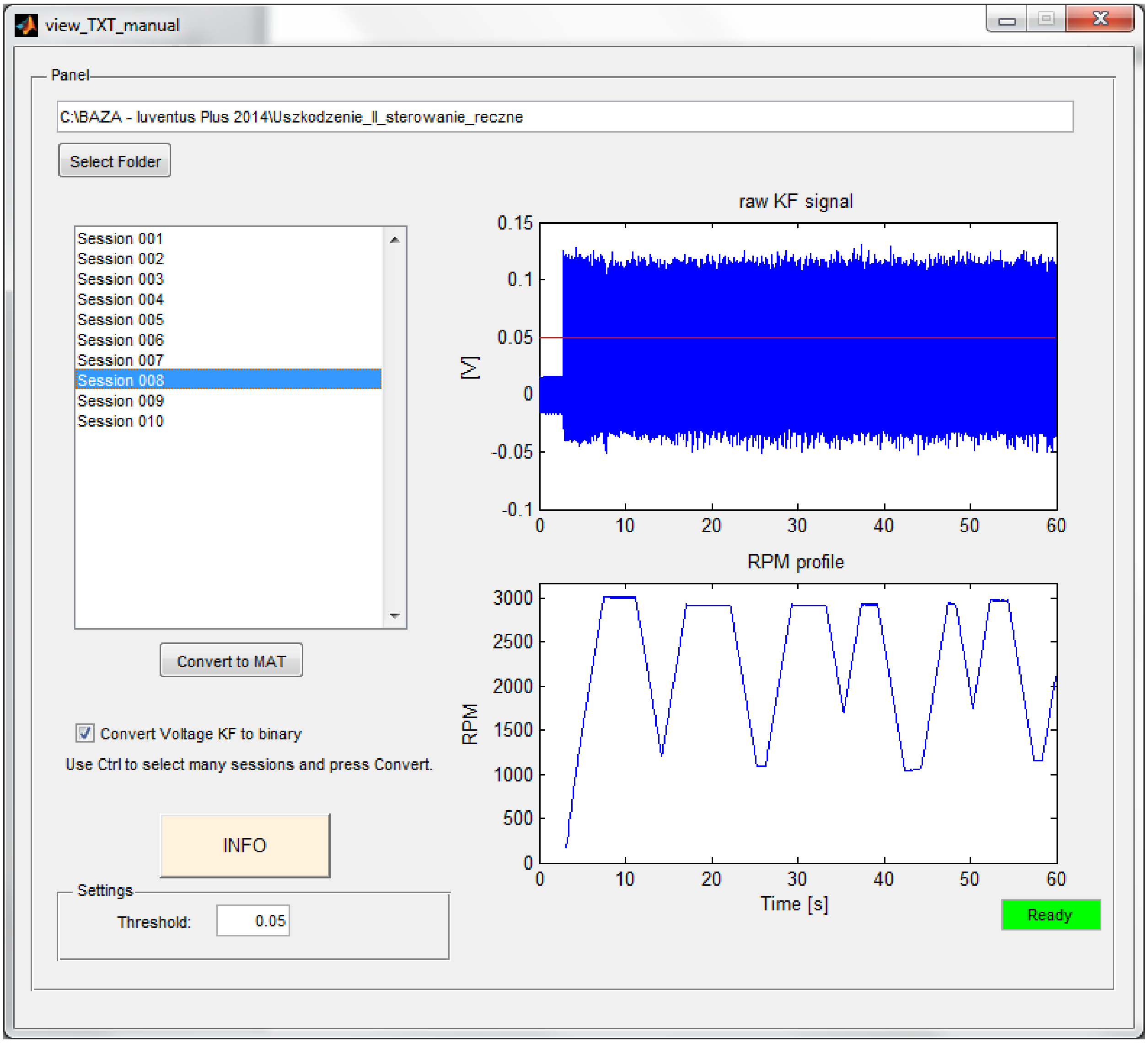

Figure Appendix A 1. Session 008

The Session 008 has been accepted for analysis.

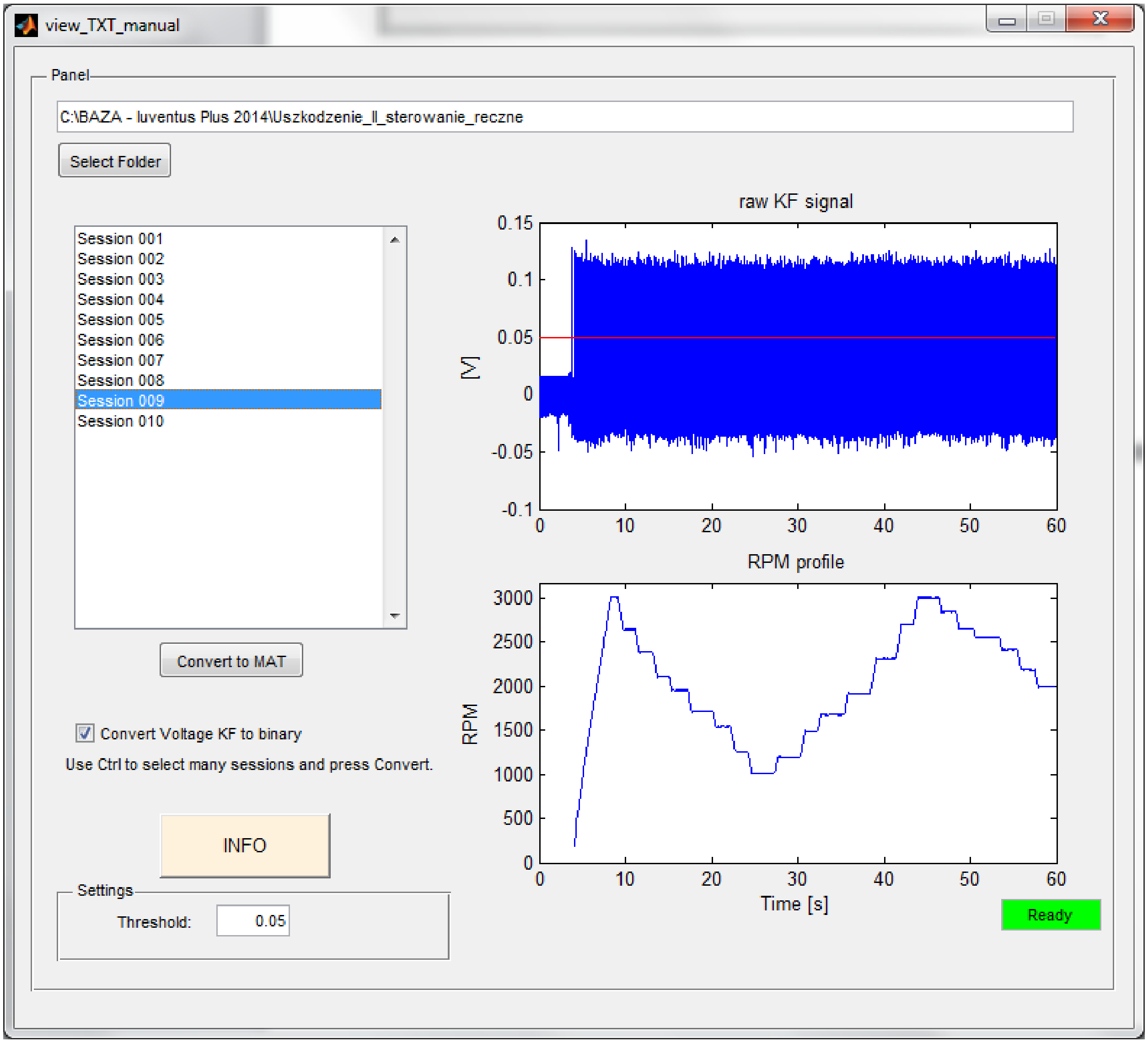

Figure Appendix A 1. Session 009

The Session 009 has been accepted for analysis.

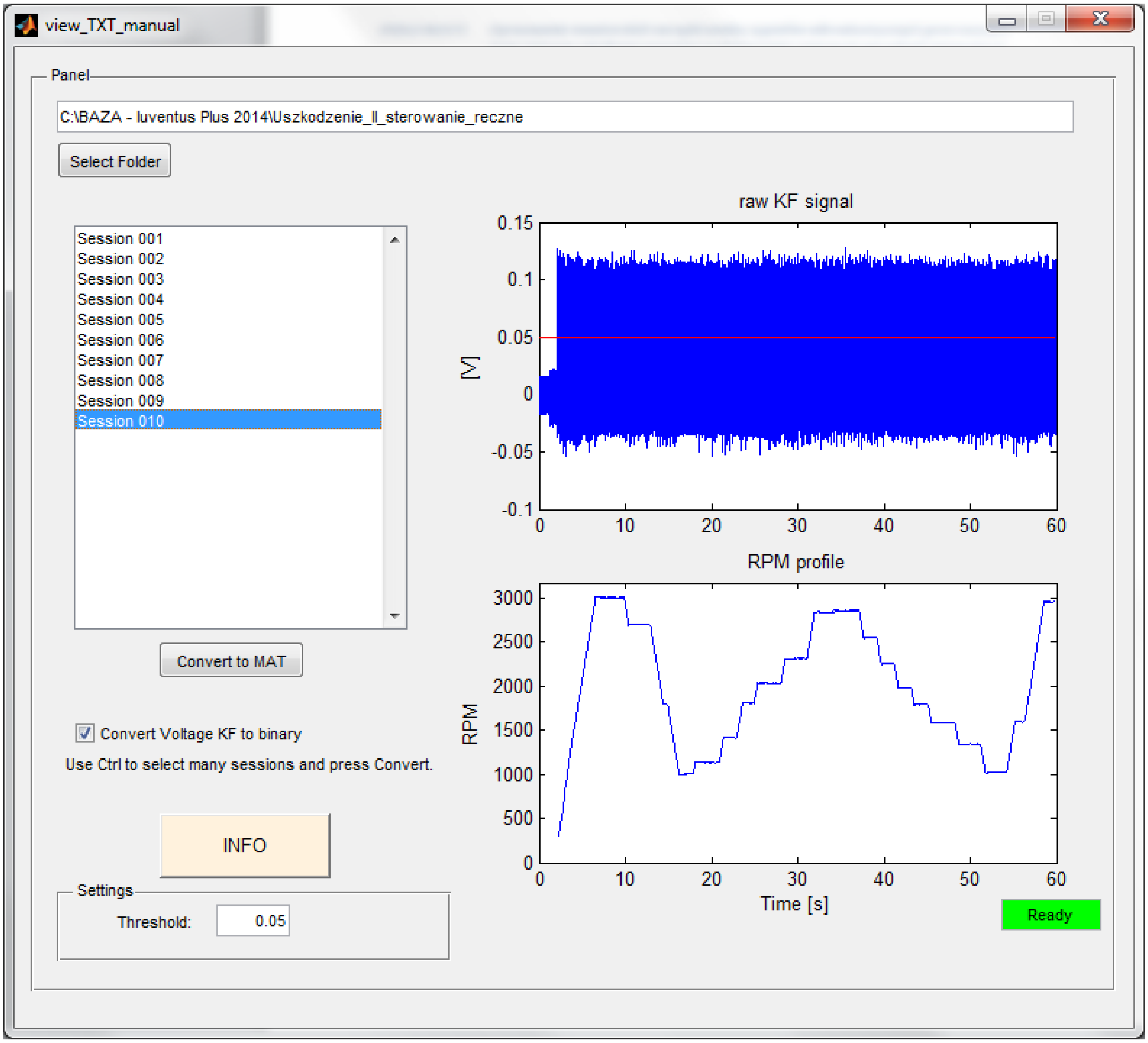

Figure Appendix A 1. Session 010

The Session 010 has been accepted for analysis.

7 Appendix B – Sessions with a damaged bearing and imbalance

The Appendix A illustrates 10 sessions controlled manually supplementary to Appendix A and figure 1.

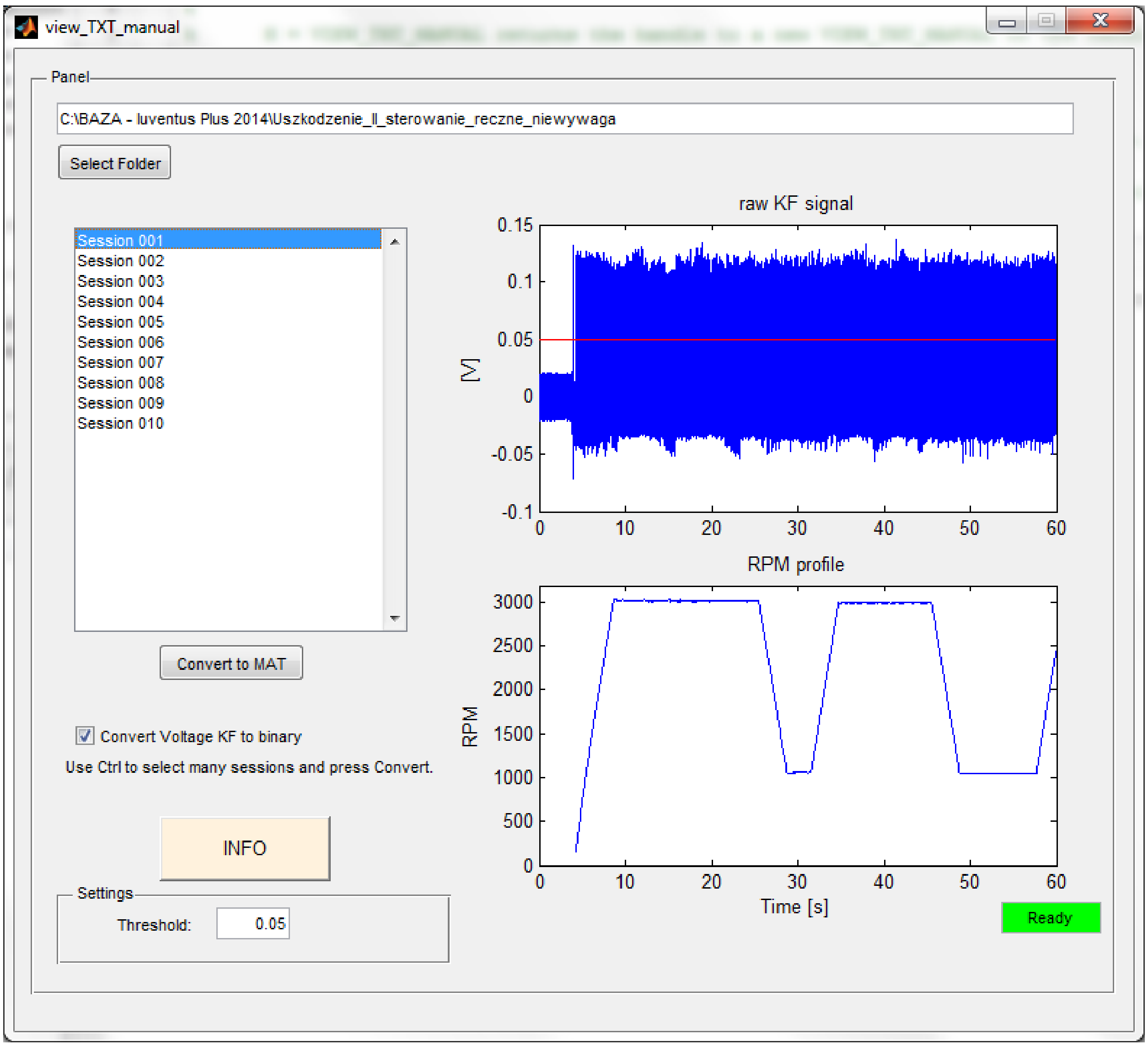

Figure Appendix B 1. Session 001

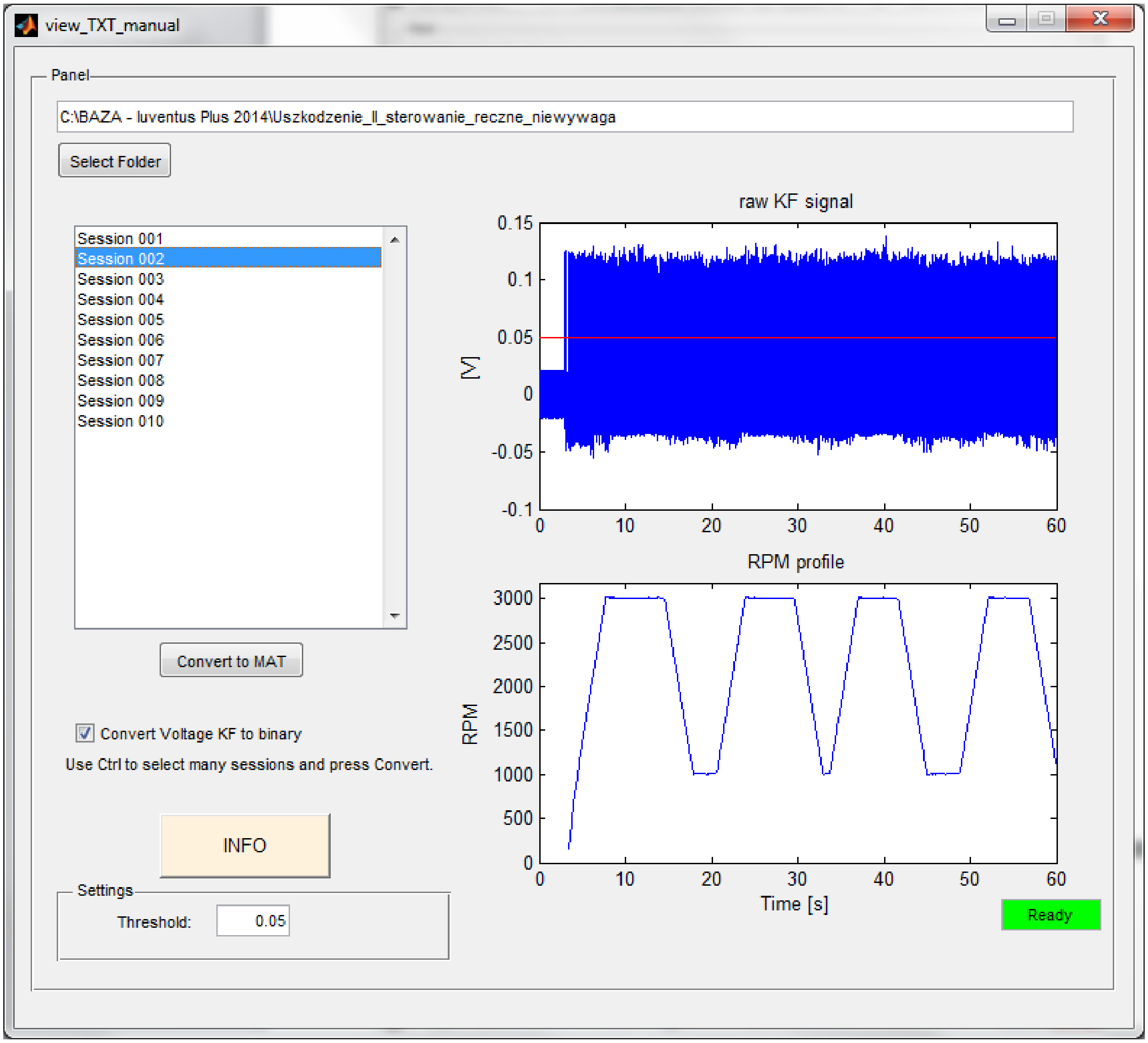

Figure Appendix B 1. Session 002

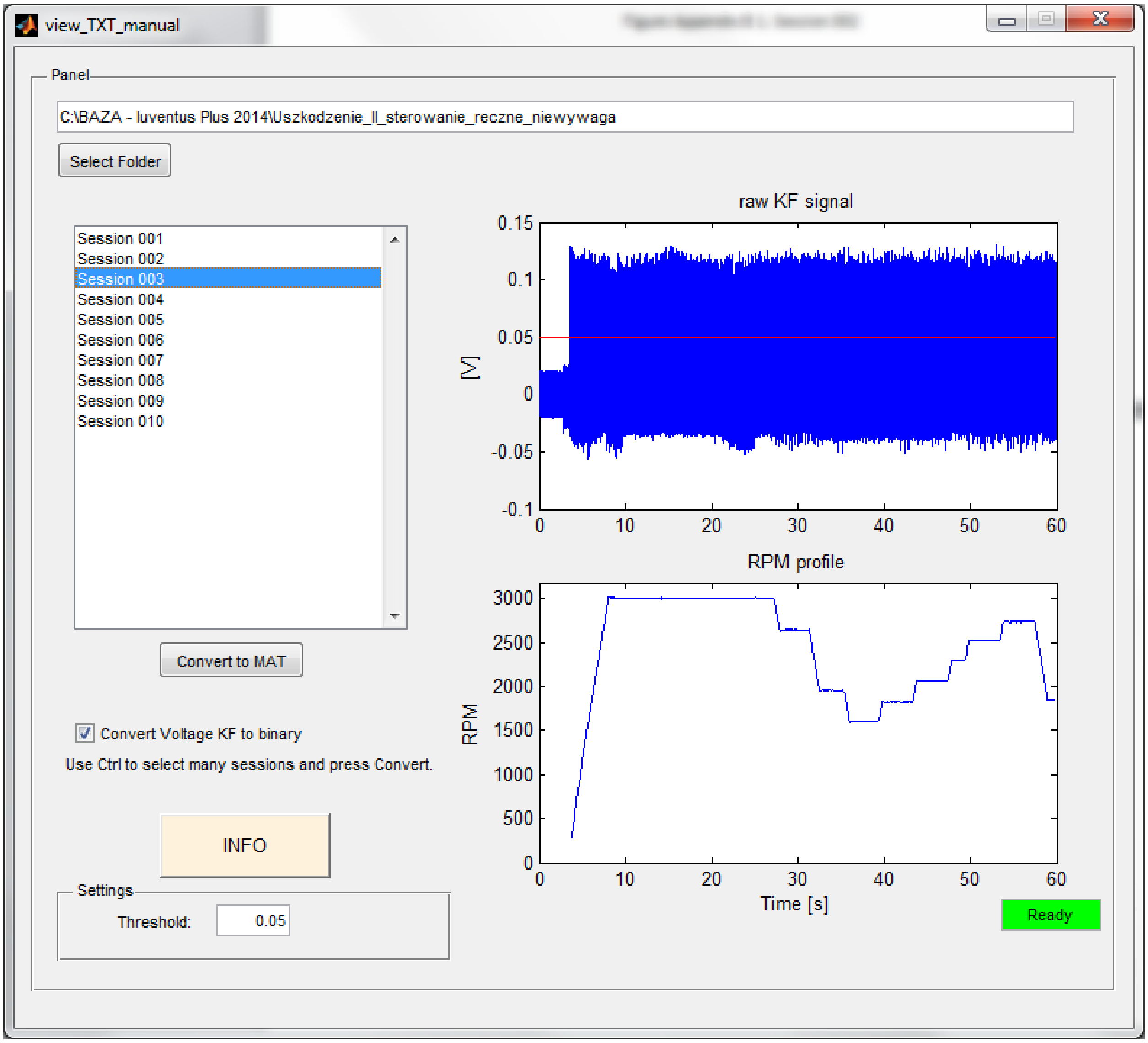

Figure Appendix B 1. Session 003

The Session 003 has been accepted for analysis.

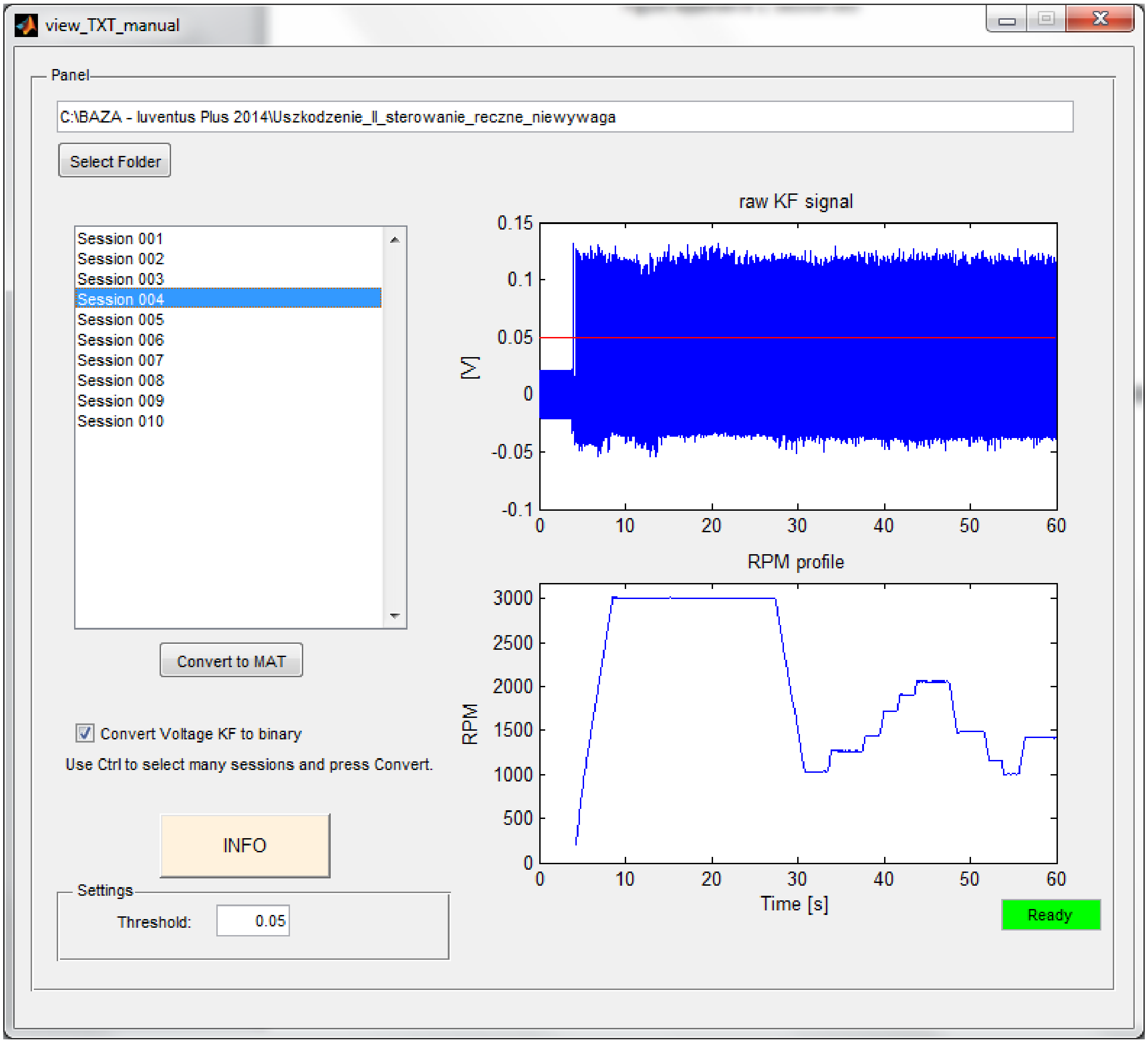

Figure Appendix B 1. Session 004

The Session 004 has been accepted for analysis.

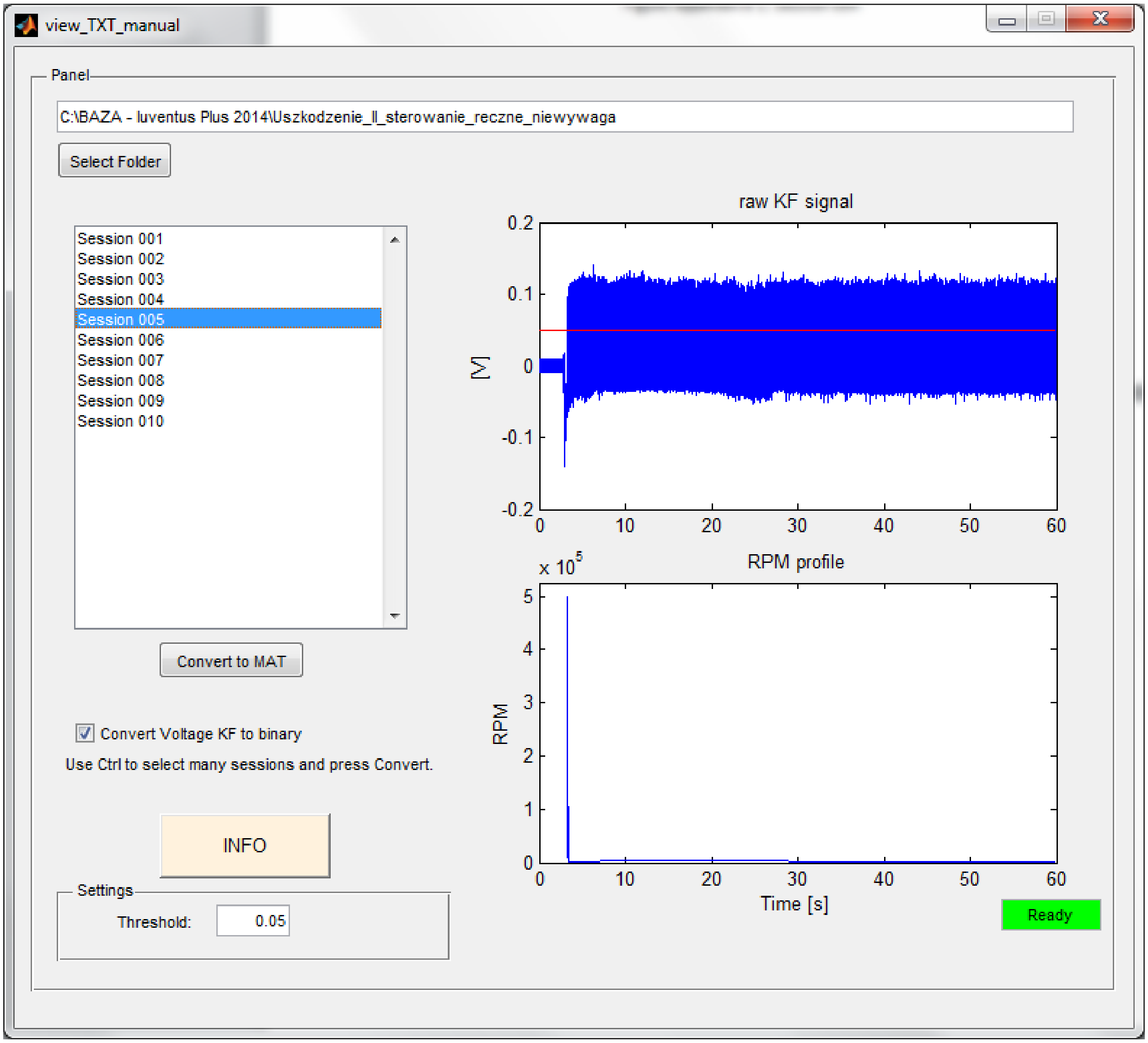

Figure Appendix B 1. Session 005

The Session 005 has been rejected for analysis due to improper phase marker readings.

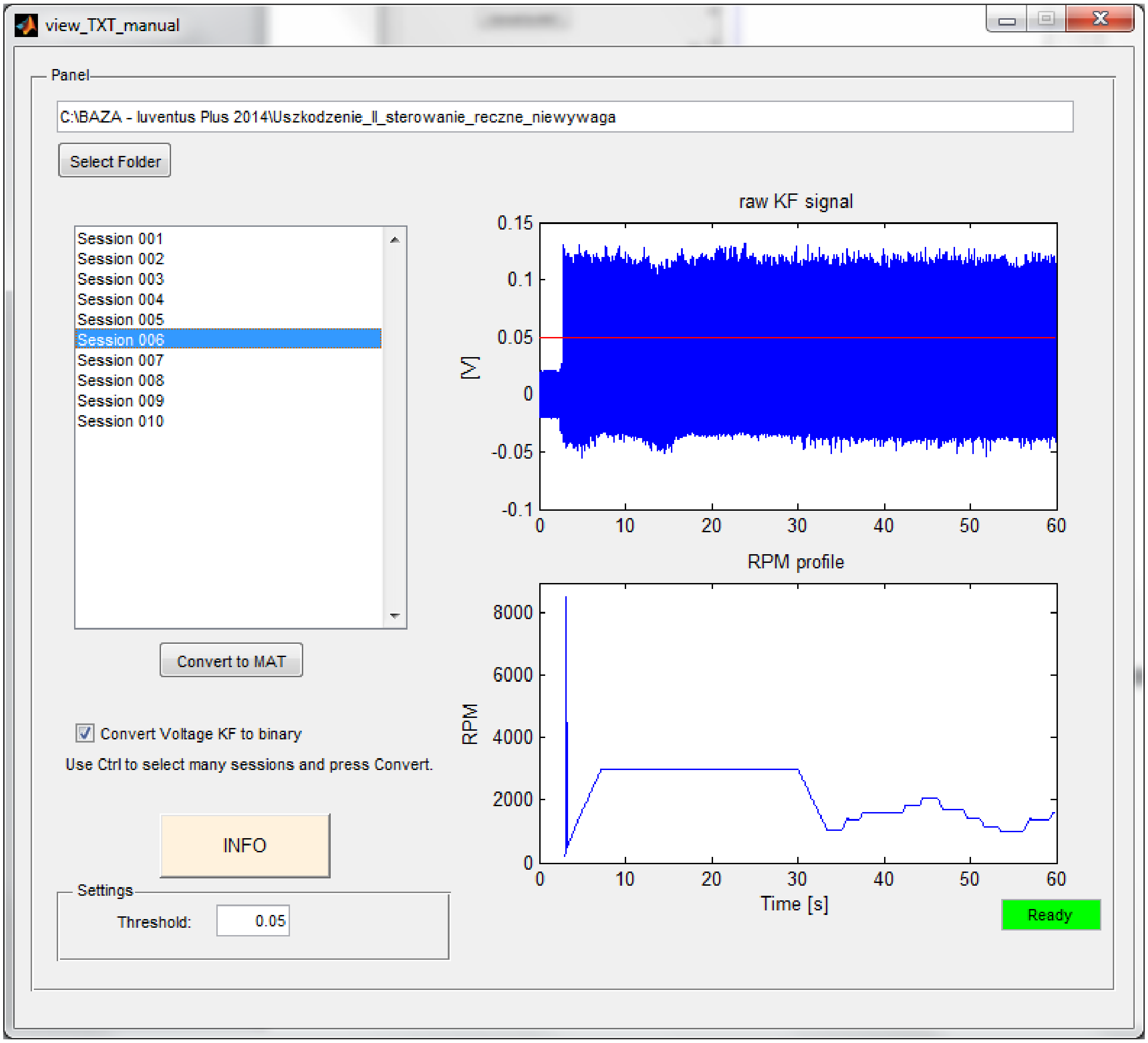

Figure Appendix B 1. Session 006

The Session 006 has been rejected for analysis due to improper phase marker readings.

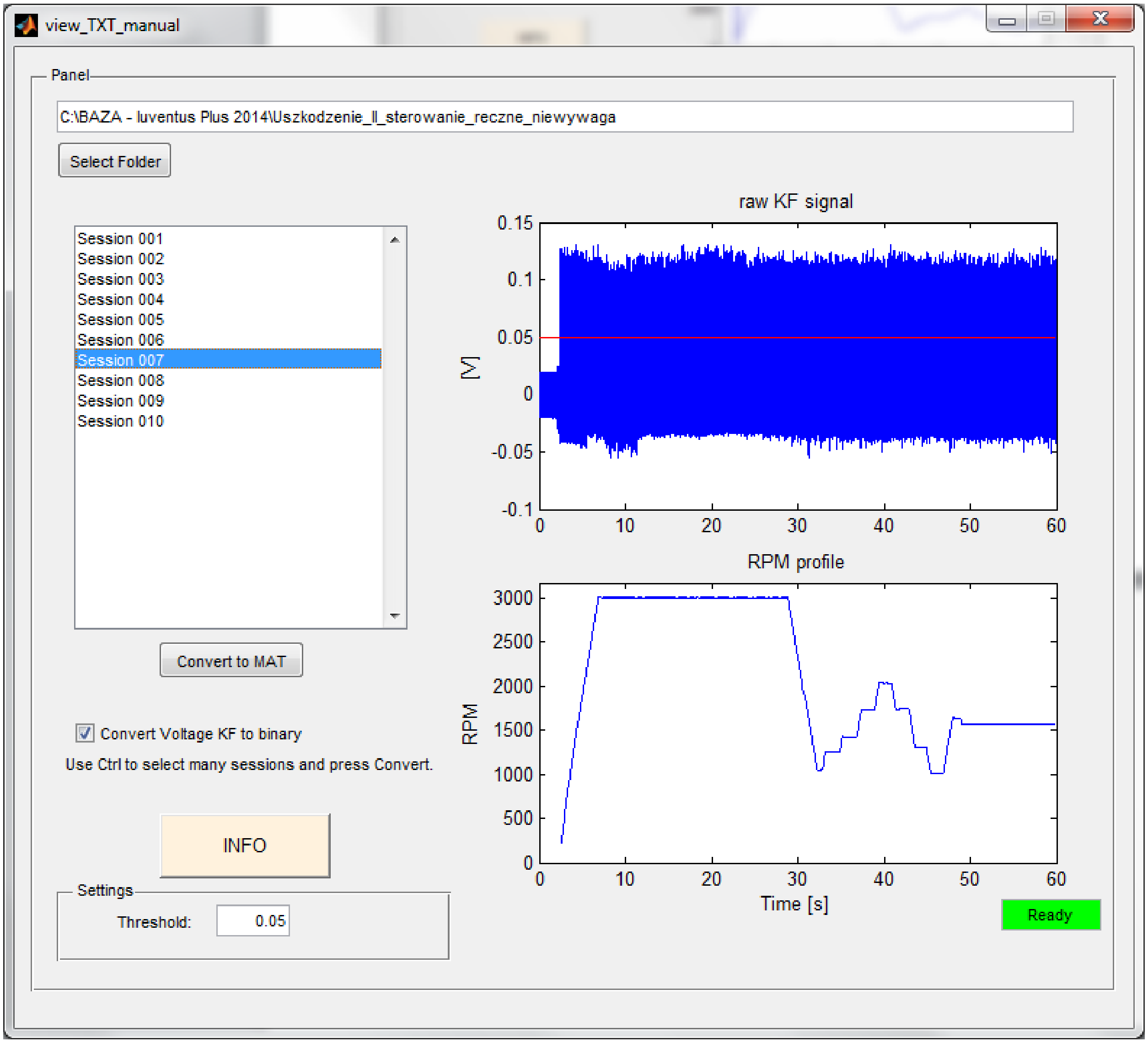

Figure Appendix B 1. Session 007

The Session 007 has been accepted for analysis.

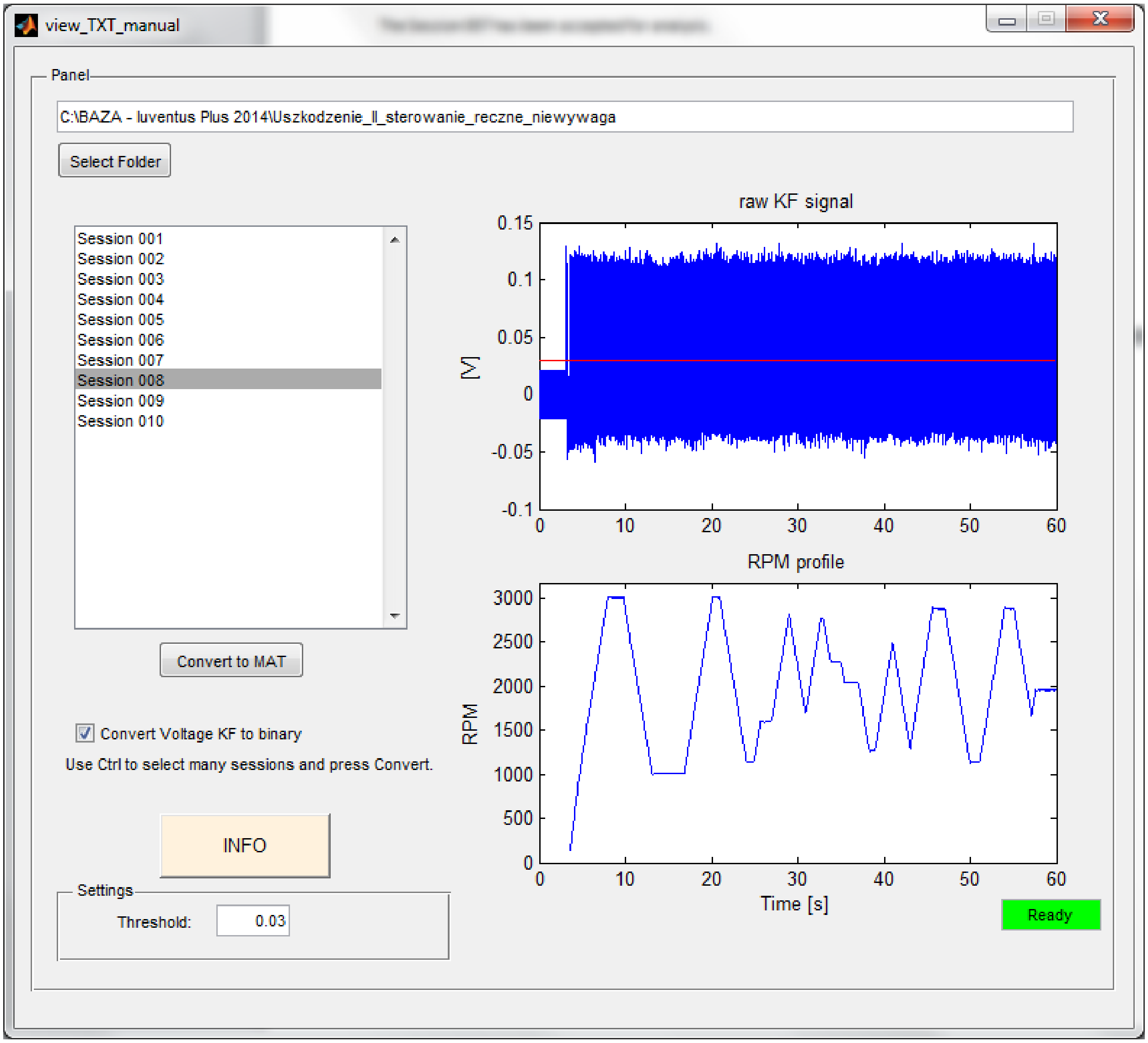

Figure Appendix B 1. Session 008

The Session 008 has been accepted for analysis after a modification of threshold equal to 0.03.

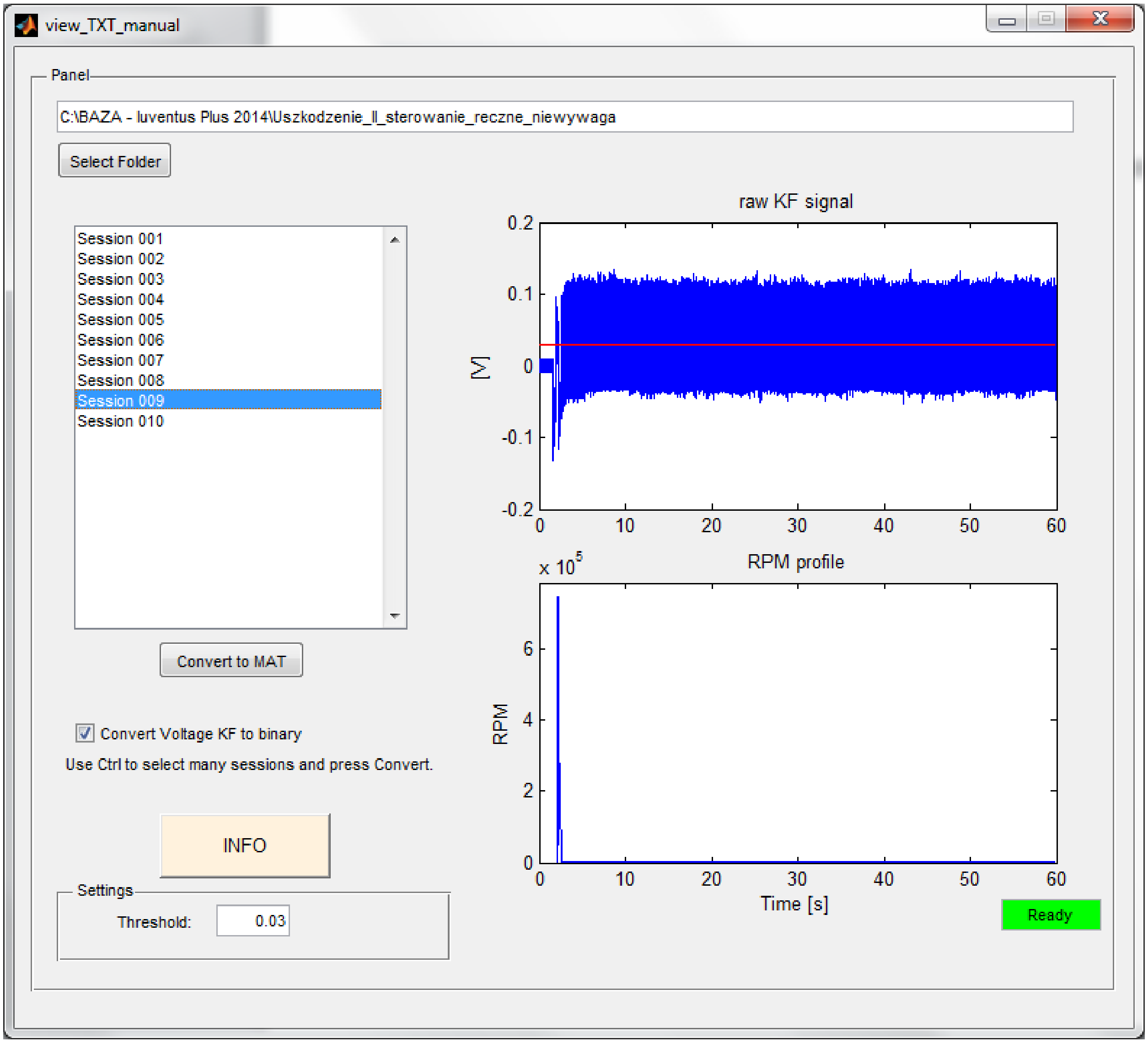

Figure Appendix B 1. Session 009

The Session 009 has been accepted for analysis. The Session 010 has been recorded improperly and is unavailable for opening due to corrupted data files.

8 Appendix D – Abstracts

The appendix contains abstracts of four publications submitted to the 4th International Conference on Condition Monitoring of Machinery in Non-Stationary Operations (CMMN0'2014) will be held in Lyon (France) during the 15th, 16th and 17th of December 2014.

Application of angular-temporal spectrum for detection of rolling-element bearing faults operating under varying speed regime

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Vibration-based condition monitoring of rotor machinery develops towards application for highly non-stationary operational conditions. Namely, rotational speed and load. If speed and load varies during the acquisition of vibration signal both, instantaneous amplitudes and instantaneous frequencies of signal components will vary accordingly. That causes a strong demand for novel signal-processing approach suitable for analysis of such processes. In this paper, the angular-temporal spectrum is introduced as a practical solution for analysis of such signals. The tool bases on well-established principles of angular-temporal determinism and allows for representation of energy of analyzed signal on bi-frequency plane related to angular and temporal properties of the underlying process.

Additionally, the proposed approach includes amplitude normalization technique in order to give more interpretable representation of instantaneous amplitude related to varying speed and load. The paper gives overall description of the proposed tool as well as its intuitive explanation from the perspective of signal generation mechanism. Additionally, it is shown that for signals generated by machinery operating under stationary regime, the proposed tool takes form of a cyclic modulation spectrum previously proposed for the analysis of cyclostationary signals originated from mechanical sources. Angular-temporal spectrum is presented using generated signal as well as vibration signal measured on lab test-rig operating with damaged bearing during run-up process.

Blind separation of vibration components for rotor machinery operating under highly non-stationary regime

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The paper undertakes the problem of unsupervised decomposition of vibration signals generated by machinery operating under highly varying speed and load. Proposed method decomposes a signal into two contributing parts. Namely: components related directly to shaft rotation and components that manifests themselves as a periodic excitation of structural resonances with periods length depending on instantaneous rotational speed of the machine. The method uses short time Fourier transformation as a basis for estimation of the transfer function used for decomposition. However, due to high degree of non-stationarity, it is crucial to transform the analyzed signal, so it could be represented as a sum of periodic and random components. For this purpose, a novel transformation based on angular resampling and instantaneous amplitude normalization is introduced. After decomposition, separated components are back-transformed to their original domains, in order to preserve its non-stationary properties.

In the paper, the method is explained and each step of the algorithm is visualized using simulated signals. Additionally, simulated signal is used for analysis of estimation error.

Finally, the proposed method is evaluated in practice using signal measured on the test rig operating with unbalanced shaft and faulty rolling element bearing, during a controlled run-up. Individual components resulted from the proposed separation technique are visualized in both, time and time-frequency domains.

Varying-coefficient based modeling of wind turbine vibration features and its application to condition monitoring

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Wind turbines belong to the wide group of machines operating under highly varying operational conditions experiencing non-linear relationship between them. Rotational speed and mechanical load applied to the drive train vary significantly because of continuously changing wind speed and varying demand for electrical power. In addition, the exposure to rough weather and temperature changes often causes accelerated wear of rotating elements. As a consequence, vibration-based condition monitoring systems are currently installed on virtually all wind turbines with nominal power above 1MW. It has been shown in literature that there is a substantial association between the operational conditions and the vibration features leading to the observations collected over extended periods of time exhibiting large variability. Although industrial practice proposes classification of vibration data based on operational states, this concept has not reached a quantitative benchmark hitherto, which results in significantly different approaches recommended by different manufacturers of condition monitoring systems(e.g. load-based classification vs. speed/load classification).

This observation makes classical threshold-based fault detection methods relatively difficult to apply and very often unreliable. As a novel developments, we propose a method that promisingly accounts for non-stationary load and rotational speed when modeling the features of the vibration signals. In this paper, we employ varying-coefficient models to estimate the normal-technical-condition coefficients which are then used as a reference. This method is introduced and described from the perspective of practical vibration-based condition monitoring. Presented approach is applied to the dataset containing long-term observations of root-mean-square (RMS) features of wind turbine during the period of development of the generator bearing fault.

Modeling of rotating machine vibration signals operating under highly varying speed and load

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Vibrations generated by different rotating elements could be precisely modeled under assumption of stationary or quasi-stationary operational conditions of the modeled object. Vibro-acoustical behavior of common mechanical parts, like shafts or gearboxes, are often modeled as a sum of sine/cosine waves with frequencies related to rotational speed of the machine. On the other hand, signals originated from elements like rolling element bearings or pistons are described by either cyclostationary or more precisely, angular-temporal deterministic processes. However, it is still unclear how to include the influence of simultaneously varying rotational speed and load while staying close to the well-established principles of aforementioned modeling techniques.

The following paper gives overall view on modeling of machine vibration signals generated under highly varying operational conditions based on the generalized principles of cyclostationarity and angular-temporal determinism. Signals are modeled as random processes driven by two independent external functions. Namely, time-dependent rotational speed together with time-dependent load of the modeled object. The mathematical model that includes signals originated from two shafts and rolling element bearings is presented. Additionally, it is shown that in case of constant operational conditions the model takes the form of well-known cyclostationarity-based model, which proves its universality.

Relation of amplitudes and fundamental frequencies of modeled signals to operational conditions is determined based on the data collected in the laboratory test-rig experiment.