Internal Identifier: OPMO.PLUS

D1.1. An installation and operating instructions, product description and example of use case

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Content

1. Introduction

Ore processing machines operating in mining industry are very specialized and rare in the broad scope of industrial machinery. In opposition to very common and well-known devices such as electric motors, mineral processing machines such as crushers or sieving screens are characterized with complex behavior, which translates into complicated structure of data measured on such machines. In the age of industry 4.0 utilizing technologies such as internet of things (IoT) and multichannel data acquisition systems, technical capabilities to construct very potent system for monitoring and diagnostics is relatively easy to construct, and data analysis can provide information as never before. Especially in the areas where machines are difficult to be diagnosed in a non-desctructive and non-obstructive manner, extensive data collection and analysis can help solving many problems. For this reason, diagnostics and condition monitoring in general can require dedicated analytical approach. In this report we present the application prepared especially for the data analysis and diagnostics of crushing and sieving machines.

First part is the instruction manual for the user of the program. It contains step-by-step description of all the actions that user can take in order to properly navigate and use the application.

Second part describes the example of workflow of analysis that can be performed for the analysis of the data from crushing machine, and the third part presents a similar example for sieving screen.

2.   Instruction

This document is a user manual containing instructions how to use the application. The program is intended to be used for the analysis of data related to ore crushers and sieving screens, that are a part of technological chain of the mining industry. Most of the functionality is designed to be used for vibration data analysis (especially orbit analytics or spectral analytics). However, one can process any types of signals (i.e. temperature), especially with functionality such as time-varying statistics or long-term analytics, where the functionality does not strictly require a particular type of data (i.e. two-channel orthogonal vibration measurement for orbit diagnostics).

The application generates intermediate files (text files and images) that are used to compile a report. Every tab of the program contains buttons allowing to add a particular content to the report. For every tab except the Start tab, adding content to report translates into saving all the plots to image files, and all the relevant information (i.e. about used variables, obtained diagnostic decisions etc.) to the text file. On the Start tab, there are separate buttons that allow to add information about input data file, additional images and so-called "profile" that contains technical information present on the Start tab. It is important to remember that all buttons adding content to report (with the exception of button adding the profile) allow to do it multiple times, i.e. when user wishes to analyze multiple different signals, or one signal with different parameters etc. If user wishes to do so, multiple cases will appear in the report in the section describing a particular used functionality. Information about multiple used input files can be also sent to report multiple times, in case that user wishes to analyze data from multiple files within one report.

3. Register form for OPMO.PLUS application and login to the cloud.

3.1. OPMO.PLUS Analyzer hardware specification

OPMO.PLUS Analyzer can be installed for customers as a standalone-application on the dedicated, provided by the WUST, open-source Linux environment.

The minimal requirements, enabling to implement software on a user's computer, are presented below:

- processor, 4 cores – above 5000 points in PassMark CPU MARK (cpubenchmark.net/)
- memory – 8 GB RAM
- storage – 60GB

The provided software will be preconfigured and ready to install on a customer device.
After the installation, there is an *'OPMO PLUS ANALYZER'* icon created on the desktop, clicking of which allows for quick initialization of the application.

3.2. OPMO.PLUS Analyzer cloud resource

OPMO.PLUS Analyzer is provided as a Software-as-a-Service (SaaS). The configured solution is stored on a public cloud provider repository. Thanks to that, the availability of software is significantly increased and reduces the configuration of the environment by the customer to a minimum. Before started, the user should fill-up the registration form on http://dmc.pwr.edu.pl/index.php/opmo-plus-register-form/

Figure 1 Online register form – Case description

In the registration form Please, provide the following information:

- First and last name,
- Email address,
- Public IP address (if you do not have a static IP address enter 0.0.0.0).

All the fields marked with an asterisk symbol are needed for the service-related identification.

Additionally, when filling the registration form, data regarding the inspected machine mechanical components (bearings, springs) and orbit tolerances being a basis of the springs' work analysis can be inputted. It is, however, not compulsory, since the mentioned parameters can be also inputted in the starting window of the *OPMO.PLUS Analyzer* application. The fields, which are filled optionally during the registration are presented in the figure below.

Figure 2 Online register form - Technical information

Then login details will be sent to the user's email address provided in the registration form. Additional information about public IP address is needed to configure the cloud environment for an end-user correctly. If a user does not possess a static IP public address, please enter the value 0.0.0.0. On this webpage: https://whatismyipaddress.com/ an IP address can be checked.

Login details and .rdp file will be sent to the user's email inbox.

The desktop remote connection can be set via the Windows' **'Remote Desktop Connection'** application, which is to be found with the use of the *search* bar (if it is hidden - can be activated by pressing and holding/right-clicking the taskbar and selecting *Search > Show search box*. The application can be also initialized from the **Control Panel > All control Panel Items > RemoteApp and Desktop Connections**. An .rdp icon, that can be created to quickly run a configured remote desktop connection is presented below.

Figure 3 Remote desktop icon

The connection interface with the cloud-stored OPMO.PLUS Analyzer is presented in the screenshot below.
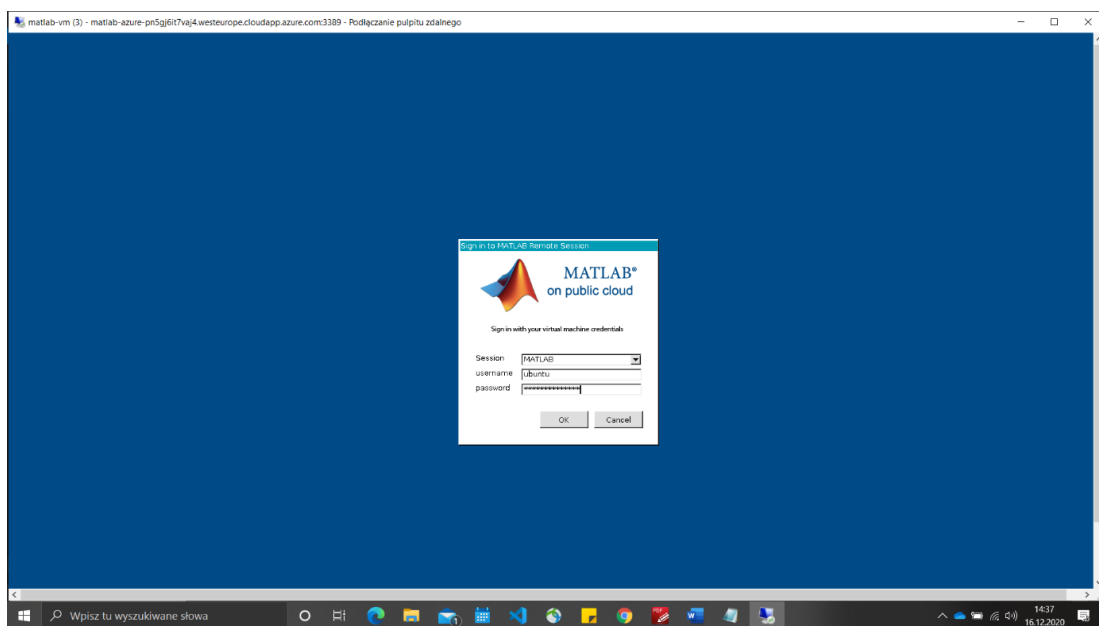
Figure 4 Session login screen

In this window, the credentials received by the user in an email sent after filling the registration form have to be inputted. After that a Linux based operating system can be seen. On the desktop the *'OPMO.PLUS ANALYZER'* application shortcut can be found.

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3.3. Data structure

User is able to load input data file in Matlab data file '.mat' format, or comma-separated values file '.csv' format. The application performs all the necessary steps to properly read data from files, however user needs to prepare them according to the conventions described in the following sections.

3.3.1. Input file
3.3.1.1.   Matlab data files

In Matlab data file, each variable has to be stored either separately as column vectors, or in the form of multi-column matrices (it is possible to select the column of the matrix in the program when user selects the variable for the particular analysis).

The value of sampling frequency for the signals can be stored as a single-value numeric variable, or provided manually in the program if it is not stored in the file. If the variable is named "fs", "Fs", "SamplingFrequency" or "samplingfrequency", program will detect and assign it automatically. If the variable is named otherwise, user can select it from the list.

3.3.1.2.   CSV files

In CSV file, that should consist of one sheet only, the header (first line of the file) needs to contain names of the variables separated by the commas. From the second row onwards, file should contain the values of samples from the respective variables, also separated by commas. This way, each variable should be represented by its label in the header and column vector of values . The decimal delimiter for numeric values should be a dot ("."). Since variables are defined by their labels, one label describes one variable, so this convention does not support variables represented as matrices.

3.3.2. Profile data

User can load the profile from file. The profile contains all the information visible on the input tab of the program. The profile file can be created by the program by saving the currently filled information. User can also prepare the profile manually by creating Matlab data file containing the following structure:
Profile
-.Orbit
--.Theta [deg deg]
--.Length [mm mm]
--.Width [mm mm]
-.Spring
--.MeanDiameter [mm]
--.WireDiameter [mm]
--.NOfCoilings [int]
--.NOfSprings [int]
--.MassOfScreen [kg]
--.FillCoeff [0-1]
--.SpringLength [mm]

--.ShearModule [MPa]

--.Pitch [mm]

-.Machine

--.Name [string]

--.Type [string]

--.Model [string]

--.Element [string]

--.ElementModel [string]

--.LastRepair [dd-mmm-yyyy]

--.Installation [dd-mmm-yyyy]

--.Operator [string]

--.Commissioner [string]

--.FailCause [string]

-.Bearing

--.BPFO [Hz]

--.BPFI [Hz]

--.BSF [Hz]

--.FTF [Hz]

--.D1 [mm]

--.D2 [mm]

--.Bd [mm]

--.Nb [int]

--.Beta [deg]

--.RPM [rpm]

3.3.3. Archive data

Archive is a data structure used, created and updated in the long-term statistical analysis tab. It consists of two variables. First variable called "Archive" is a matrix of size Nx12, where N is the amount of records. The matrix contains values of 12 statistics calculated for the analyzed signals, one set of 12 values per record. The second variable called "Time" is a vector of dates corresponding to the records. The dates are stored as "datetime" values. They do not have to be saved in a chronological order (program sorts the data before plotting), but the order has to correspond to the order of records in the "Archive" matrix.

3.4. Tutorial

3.4.1. Start tab
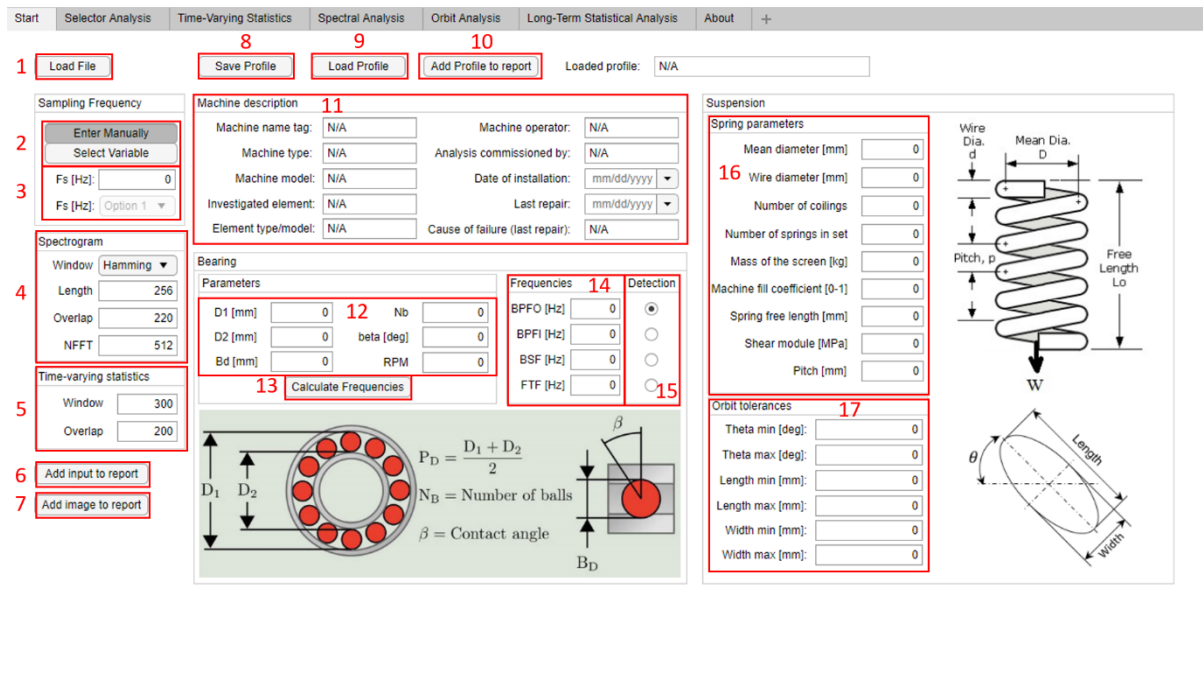
Figure 5 Starting tab

To start the preparation of a report, a Matlab or CSV data file has to be loaded by clicking the *'Load File'* button (1) (more details about accepted data structures and readable files are to be found in Section 3.3). If the data structure in the file loaded is correct, all the fields for input data are filled automatically. Sampling frequency can be set manually by clicking the *'Enter Manually'* (2) button or selected – choosing the *'Select Variable'* (2) option if more variables have been identified as possible sampling frequencies. The sampling frequency will appear in the field (3) automatically if it has been identified in the loaded file.

Spectrogram settings, like the type of the window, its length, the overlap of the windows, and Fast Fourier Transform size (NFFT) are initially established in section (4) and can be manually adjusted by the user to fit the particular case.

Settings of the time-varying statistics functionality are to be done in section (5), which includes window size and overlap for the calculation of variance, kurtosis or root mean square (RMS).

To attach the sampling frequency, spectrogram settings, and parameters used for time-varying statistics to a report, the user has to click the *'Add input to report'* button (6). Additionally, supplementary images like for instance pictures of the machine, layout of sensors, and others can be added to a report by selecting the *'Add image to report'* option (7). Program supports '.jpg' or '.png' file extensions.

All the machine identification-related data is either automatically displayed in section (11) - if the data related to a previously diagnosed machine has been loaded to the workspace by selecting the *'Load Profile'* option (9) and correctly identified, or has to be manually inputted. All the fields in this section are not compulsory to proceed to further functions, however, it is highly recommended to input as much information as it is possible

to facilitate the reporting process. The machine's identification data can be saved to file by clicking the button *'Save Profile'* **(8)**.

Bearing parameters, such as outer diameter (in millimeters), inner diameter (in millimeters), ball's diameter (in millimeters), number of balls, number of balls, contact angle (in degrees), and rotational speed (revolutions per minute) have to be inputted in the section **(12)**. The abovementioned data serves to calculate the ball pass frequency multiplier of the outer race (BPFO), ball pass frequency multiplier of the inner race (BPFI), Ball Spin Frequency (BSF), and the fundamental train frequency (FTF) by clicking the *'Calculate Frequencies'* button **(13)**. The calculated frequencies are displayed in section **(14)**, where they can be also manually set if a particular, known frequency is known and sought in the diagnostic data. The frequency of interest (manually set or calculated based on bearing parameters) can be marked in the *'Detection'* section **(15)** to be forwarded to the Selector Analysis and Spectral Analysis.

Section **(16)** – 'Spring Parameters' is used to introduce following data:

- mean diameter (in millimeters),
- wire diameter (in millimeters),
- number of coilings,
- number of springs in the set,
- mass of the screen (in kilograms),
- machine fill coefficient (a float value from the threshold of 0-1 with a dot separator),
- spring free length (in millimeters), shear module (in megapascals), and pitch (in millimeters).

The data is automatically filled if identified in the loaded file.

In section **(17)** orbit tolerances data used in the *'Orbit Analysis'* functionality are displayed. They can be manually set if lacking, or changed by the user. All the parameters in sections **(16)** and **(17)** are compulsory for the orbit analysis. To add the information displayed in the fields in sections **(11)**, **(12)**, **(14)**, **(16)**, and **(17)** to the report, the user has to select the *'Add Profile to report'* option **(10)**.

3.4.2. Selector analysis tab
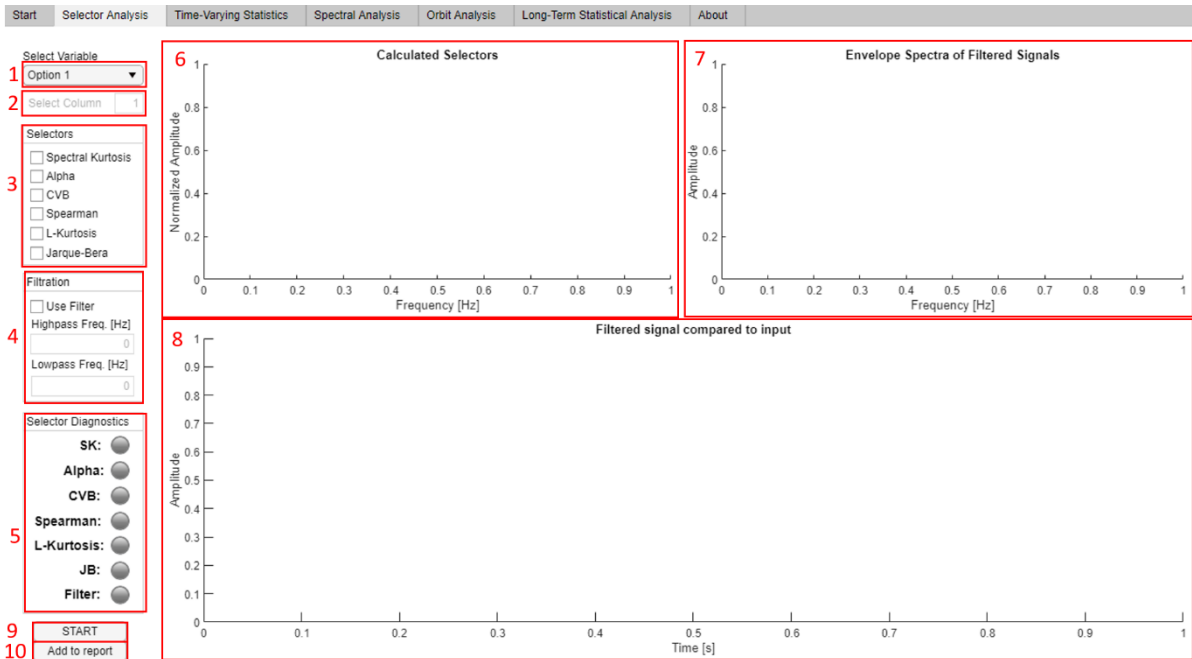
Figure 6 Selector analysis tab

To perform the selector analysis the variable of interest has to be selected in the field (**1**). If the variable has been saved in the form of a matrix, in the second field from the top in the upper right corner (**2**) user can select the column containing the data of interest by clicking or manually inputting the column's number. In the next field below entitled 'Selectors' (**3**), one or more selectors have to be chosen by marking them in respective boxes. Available types of selectors are:

- Spectral Kurtosis,
- Alpha selector,
- Conditional-Variance based selector,
- Spearman selector,
- L-Kurtosis,
- Jarque-Berra selector.

After clicking the *'START'* button the calculated selectors in the form of normalized amplitude as the function of frequency are displayed in the field (**6**) in different colours assigned to each selector (the same colours correspond to particular selectors on other plots).

Filters can be set in the section entitled *'Filtration'* (**4**), where after selecting the box 'Use Filter' lowpass, highpass, bandpass, and bandstop filters can be used. The filters are set as follows:

- A lowpass filter is established by inputting the frequency value (in Hz), below which the signal is allowed to pass in the *'Lowpass Freq.'* field. The *'Highpass Freq.'* field ought to be left blank, or the 0 value should be inputted.

- A highpass filter is established by inputting the frequency value (in Hz), above which the signal is allowed to pass in the *'Highpass Freq.'* field. The *'Lowpass Freq.'* field ought to be left blank, or the 0 value should be inputted.
- A bandpass filter is set by inputting the highest and the lowest frequency (in Hz) of interest in the *'Highpass Freq.'* field and *'Lowpass Freq.'* field - respectively.
- A bandstop filter is set by inputting the higher frequency value (in Hz) in the *'Lowpass Freq.'* field, and the lower value in the *'Highpass Freq.'* field. The data with frequencies from the threshold between these values are going to be filtered out from the input signal.

Envelope spectra of the signal after filtering is displayed on the chart in the upper right corner **(7)** in the form of amplitude as the function of frequency. If more selectors have been chosen, the spectra for each selector are going to be plotted in the same colors as assigned in the field **(6)**. If damage has been diagnosed by any of the chosen selectors the circular field next to the selector's name is highlighted in red. If no malfunctions are detected by the particular selector, the circular field is green.

The filtered signal obtained after using the selectors chosen in the field **(3)** and the filters set in the field **(4)** compared to input data is displayed on the largest plot **(8)**. All the plots visible in the workspace are added to a report by clicking the *'Add to report'* button.

3.4.3. Time-varying statistics tab
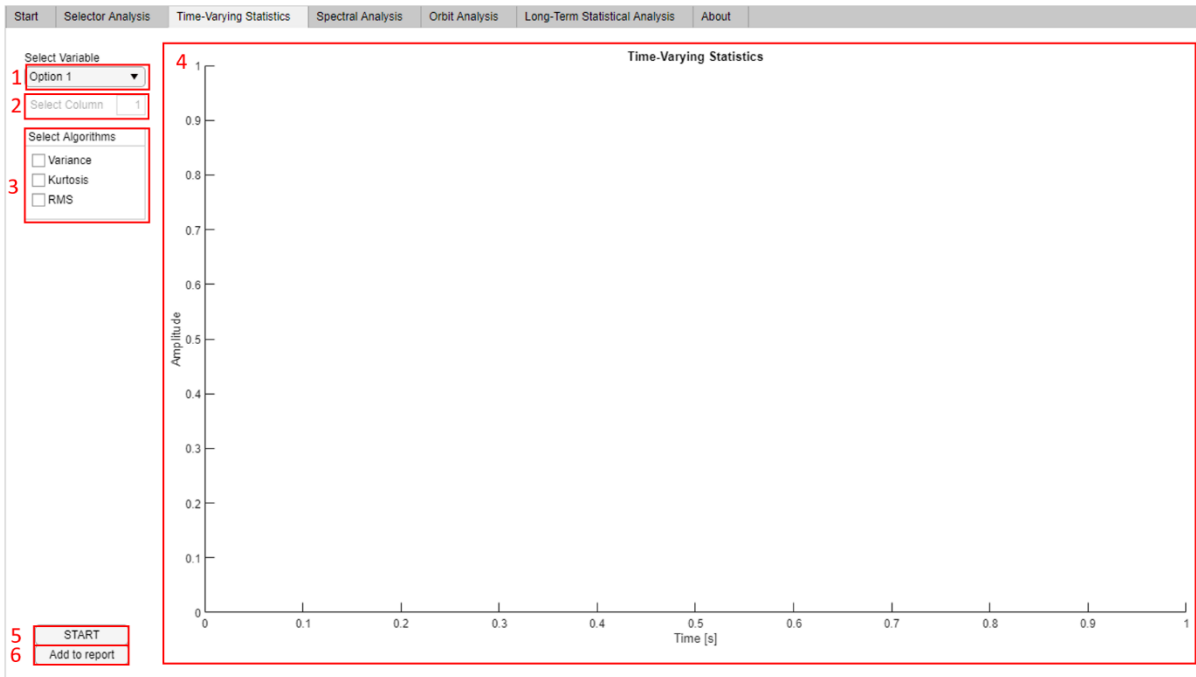
Figure 7 Time-varying statistical analysis tab

In the *'Time-Varying Statistics'* tab variance, kurtosis, and root mean square (RMS) of the analyzed signal can be plotted. Firstly, a variable of interest has to be chosen in the field **(1)**, where the variables identified in the loaded file are displayed. If a variable has been saved in the form of a matrix, the column containing the data of interest can be chosen in the field **(2)** by clicking or manually inputting the column's number . To calculate one or more statistics and display them on the plot **(4)**, the user has to select the statistics in the *'Select Algorithms'* field **(3)** and initialize calculations by clicking the *'START'* button in the lower-left corner. To attach the plot from field **(3)** to a report, a user has to click the *'Add to report'* button **(6)**.

3.4.4. Spectral analysis tab

Figure 8 Spectral analysis tab

To calculate and plot the spectrum and the spectrogram of the loaded signal, firstly the user has to select an appropriate variable from the list appearing after clicking the top-right field with a black down arrow entitled *'Select Variable'* (**1**). If a variable has be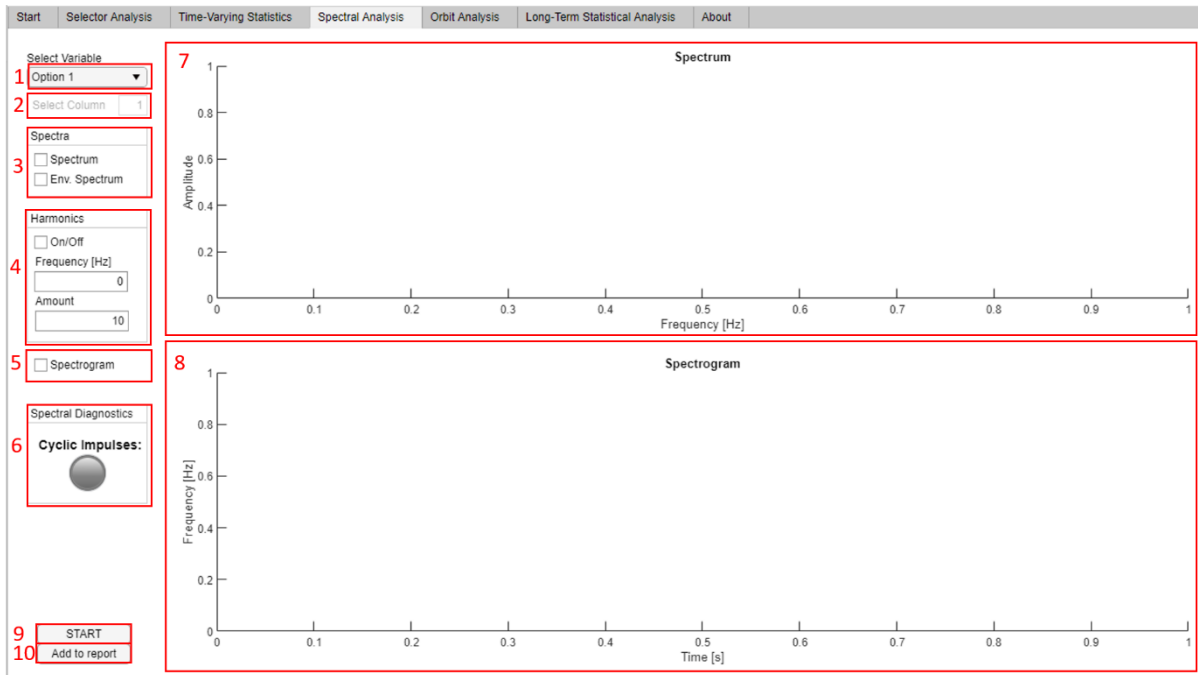en saved in the form of a matrix, the column containing the data of interest can be chosen in the field (**2**) by clicking or manually inputting the column's number. The type of spectrum to be calculated has to be chosen from two options (Spectrum or Envelope Spectrum) in the field (**3**) entitled *'Spectra'*. The spectrum is plotted in the field (**7**) entitled *'Spectrum'*. To mark harmonics on the spectrum plot, a user has to select this option by clicking the selection box *'On/Off'* in the field (**4**), input their fundamental frequency in the field below the box and define the number of harmonics to be marked in the textbox *'Amount'*. The harmonics are marked with a small red circle on the amplitude-frequency plot in the field (**7**). User has to initialize calculations by clicking the *'START'* button in the lower-left corner. If cyclic impulses have been detected, the circular icon entitled *'Cyclic Impulses'* is highlighted in green. To attach the plot from field (**3**) to a report, a user has to click the *'Add to report'* button (**6**).
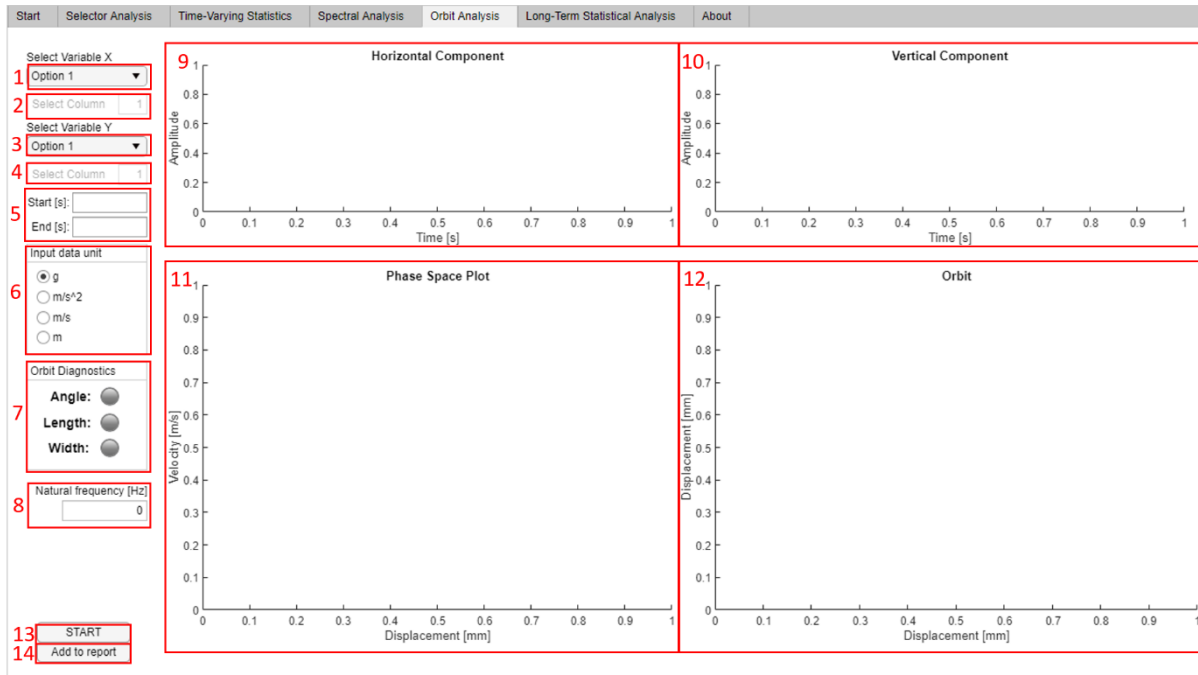
3.4.5. Orbit analysis tab

Figure 9 Orbit analysis tab

In the 'Orbital Analysis' tab, both signals measured perpendicularly to each other can be plotted (amplitude as a function of time) together with a phase-space plot (graph of the velocity as a function of the displacement), and an orbit plot showing the dynamic motion of the spring. Firstly, a user has to select the variable of interest, measured in one direction from the list appearing after clicking the top-right field with a black down arrow entitled 'Select Variable' (1). If a variable has been saved in the form of a matrix, the column containing the data of interest can be chosen in the field (2) by clicking or manually inputting the column's number. Then the variable, measured in perpendicular direction has to be chosen in the same way as the previous one in fields (3) and (4). In the next step, the timespan of the orbit analysis has to be defined in the field (5). The starting time of the analysis is to be defined in the textbox entitled 'Start' by inputting the value in seconds, using a dot separator. The end time of the analysis is to be defined in the textbox entitled 'End' by inputting the value in seconds, using a dot separator. It is necessary to correctly define the unit (whether it is given in g, m/s2, m/s, or m) of the input data in the field (6) entitled 'Input data unit' by selecting one of the options by clicking the options button corresponding to an appropriate unit. To start the diagnostics, a user has to click the 'START' button (13). By comparing the orbit tolerances set in the starting window the program outputs the information regarding angle, length, and width of the orbit in the 'Orbit Diagnostics' field (7). The parameters of the orbit which meet the criteria (do not exceed the established tolerances) are highlighted in green in the circular icons. In the case when a given tolerance is exceeded the circular icon is highlighted in red. Additionally, the natural frequency of the machine is computed based on the spring parameters introduced in the starting window in the 'Suspension' section and outputted in the 'Natural frequency' field (8). To attach the plots from fields (9), (10), (11), and (12), orbit diagnostics, and natural frequency outputs to a report, a user has to click the 'Add to report' button (14).
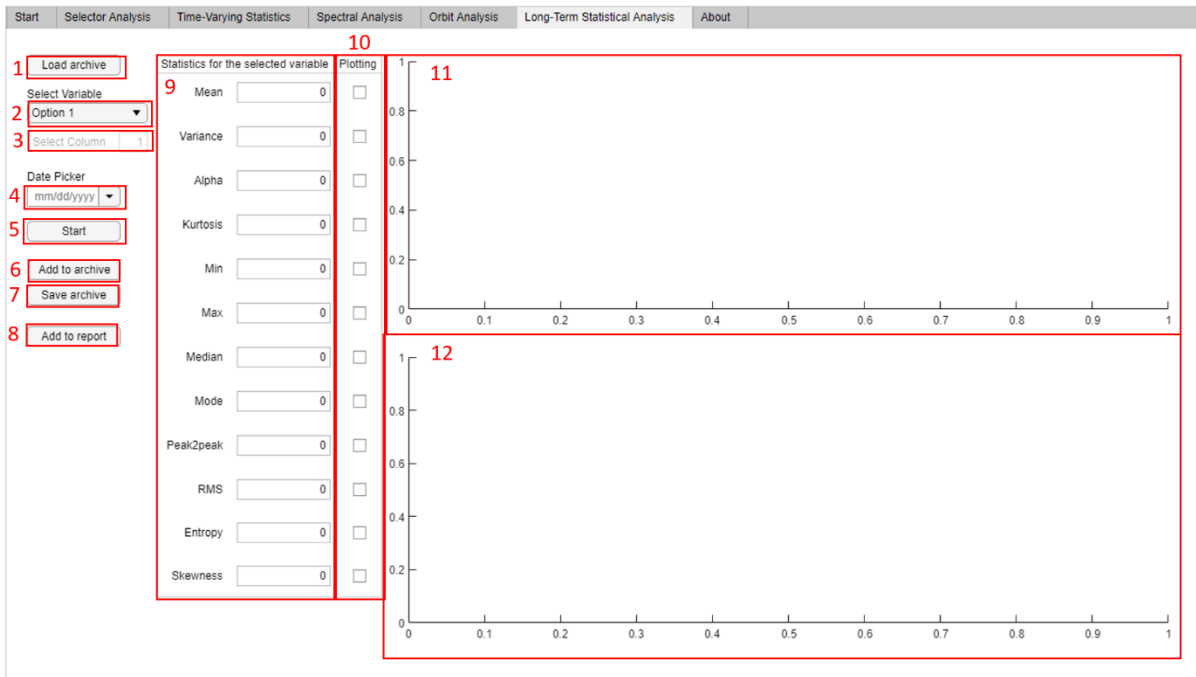
3.4.6. Long-term statistical analysis tab

Figure 10 Long-term statistical analysis tab

In the *'Long-Term Statistical Analysis'* tab, the historical data regarding machine's diagnostics can be displayed after loading archival files and compared with the calculated statistics for a given variable. Firstly, the data has to be loaded by clicking the *'Load archive'* button **(1)**. A user has to select the variable of interest from the list appearing after clicking the top-right field with a black down arrow entitled *'Select Variable'* **(2)**. If a variable has been saved in the form of a matrix, the column containing the data of interest can be chosen in the field **(3)** by clicking or manually inputting the column's number. The date of the acquisition of the data loaded to the workspace has to be introduced in the *'Date Picker'* field **(4)**. After clicking the *'START'* button **(5)**, statistics calculated for the selected variable are outputted in the *'Statistics for the selected variable'* field **(9)**. The calculated statistics can be added to an existing archive file by clicking the *'Add to archive'* button **(6)** or saved as a separate archive file by clicking the *'Save archive'* button **(7)**. To plot particular statistics and compare them with the historical data, they have to be chosen by clicking in the selection box in the *'Plotting'* field **(10)**. The historical data is plotted on the graphs in fields **(11)** and **(12)**. To attach the plots from fields **(11)**, and **(12)**, and the statistics calculated for the selected variable, outputted in the field **(9)** to a report, a user has to click the *'Add to report'* button **(14)**. Additionally after selecting the *'Add to report' option*, the historical data from the plots are added to the report in the tabular form.

4. Funcionality description in case of hammer crusher machine

First of all the Registration form has to be completed. The figures below presented the completed form for hammer crusher and the e-mail sent to user after registration.

OPMO.PLUS Register form

Your Name*

Jacek Wodecki

Your e-mail adress*

wodecki.jacek@gmail.com

Public IP address (if you do not have a static IP address enter 0.0.0.0)*

0.0.0.0

Machine name tag*

CrusherZWR

Machine type*

Hammer Crusher

Machine model*

KR1

Investigated element*

Bearing

Element type/model*

23264CCK_W33

Machine operator*

ZWR

Date of installation*

02-Nov-2020

Date of last repair*

18-Nov-2020

Cause of failure (last repair)*

Inner race crack

File* (.zip, max 25MB)
Choose File example1.zip

Figure 11 Example of filled registration form for crusher use case

Bearings
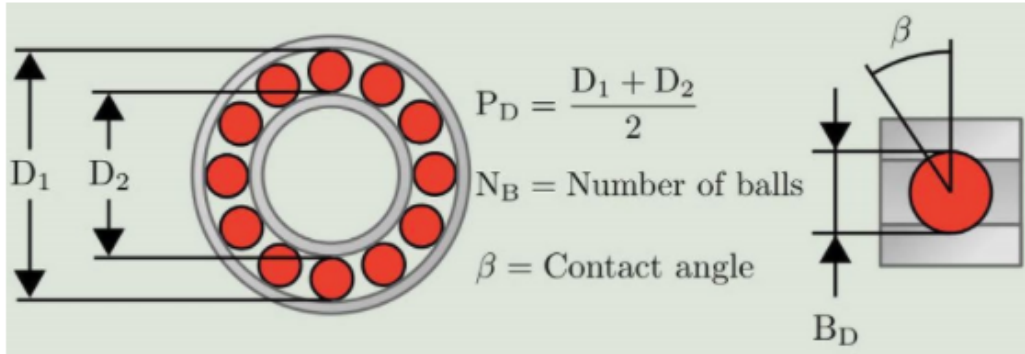
$$P_D = \frac{D_1 + D_2}{2}$$

$N_B = $ Number of balls

$\beta = $ Contact angle

D1 [mm]

493

D2 [mm]

382

Bd [mm]

55.5

Nb

19

beta [deg]

53

RPM

180

BPFO [Hz]

26.32

BPFI [Hz]

30.68

BSF [Hz]

11.76

FTF [Hz]

1.385

Figure 12 Example of filled registration form for crusher use case - part 2

Digital Mining Center: OPMO.PLUS Registration ⊃ Odebrane x **Projekty KIC/OPMO x**

Digital Mining Center <wordpress@dmc.pwr.edu.pl>
do mnie ▾

文A angielski ▾ › polski ▾ Przetłumacz wiadomość

OPMO.PLUS registration form.

Name: Jacek Wodecki
E-mail address: wodecki.jacek@gmail.com
Machine name tag: CrusherZWR
Machine type: Hammer Crusher
Public IP address: 0.0.0.0
Machine model: KR1
Investigated element: Bearing
Element type or model: 23264CCK_W33
Last repair: 18-Nov-2020
Date of installation: 02-Nov-2020
Cause of failure (last repair): Inner race crack
Machine operator: ZWR
Analysis commissioned by: Jacek Wodecki
D1 [mm]: 493
D2 [mm]: 382
Bd [mm]: 55.5
Nb: 19
beta [deg]:53
RPM: 180
BPFO [Hz]: 26.32
BPFI [Hz]: 30.68
BSF [Hz]: 11.76
FTF [Hz]: 1.385
Mean diameter [mm]:
Wire diameter [mm]:
Number of coilings:
Number of springs in set:
Mass of the empty screen [kg]:
Machine fill coefficient [0-1]:
Spring free length [mm]:
Shear module [MPa]:
Pitch [mm]:
Theta min [deg]:
Theta max [deg]:
Length min [mm]:
Length max [mm]:
Width min [mm]:
Width max [mm]:

File: example1.zip

The information regarding logging into cloud service containing the analyzer will arrive in the next message.
--
This e-mail was sent from a register form the OPMO.PLUS Application on Digital Mining Center (http://dmc.pwr.edu.pl)

Figure 13 Example of e-mail notification

4.1. Selector Anaylsis output

In the figures below, the output of the selector analysis is presented. After choosing a variable to be subjected to the analysis, setting the selectors, configuring the filtration, and initializing the analysis, the following plots are generated.
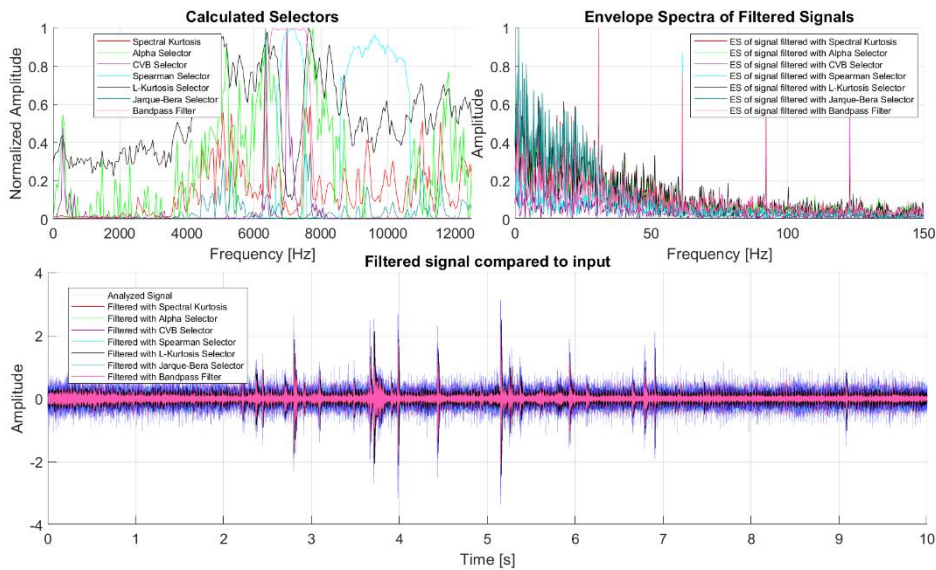

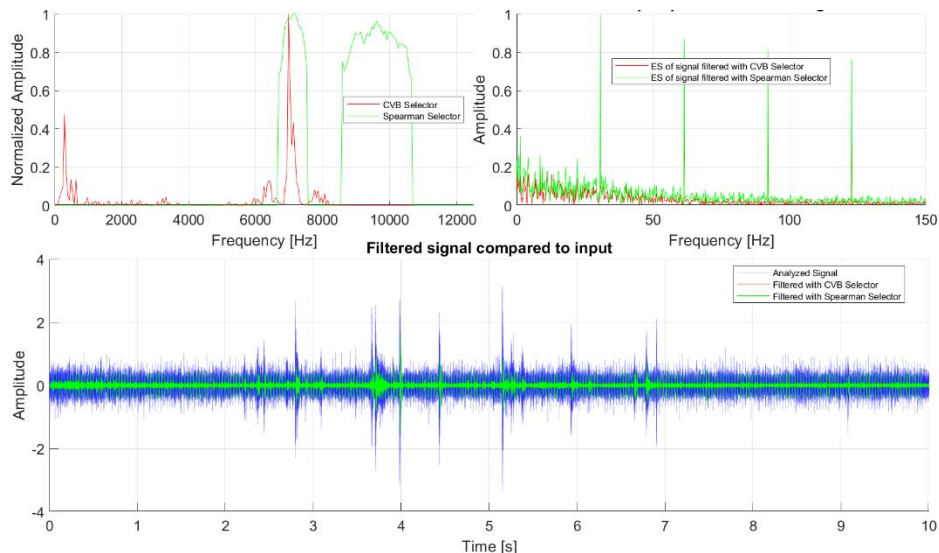Figure 15 Example of selector analysis - all selectors

Figure 14 Example of selector analysis - only 2 selectors chosen

The first set of graphs presents the output obtained when selecting: Spectral Kurtosis, Alpha Selector, Conditional-Variance Based Selector (CVB), Spearman Selector, L-Kurtosis, Jarque-Berra Selector, and configuring a bandpass filter. Calculated selectors are plotted on the upper-left chart in the form of normalized amplitude as the function of frequency. A legend, which allows distinguishing particular selectors appears on the plot. On the upper-right plot, envelope spectra of filtered signals are displayed, with a legend. Colors on

the plots are constant for a given selector chosen. On the plot below the two mentioned above, the signal filtered with the use of each of the chosen selectors is plotted together with the raw signal, which allows for their comparison. The output of the same type, but for two selectors only – CVB and Spearman is presented in the second figure below.

4.2.   Time-Varying Statistics output

In the figures below, the output of the Time-Varying statistics is presented. After choosing a variable to be subjected to the analysis, selecting the algorithms (types of the statistics to be used: Variance, Kurtosis, Root Mean Square), and initializing the calculations, the following plot is generated.
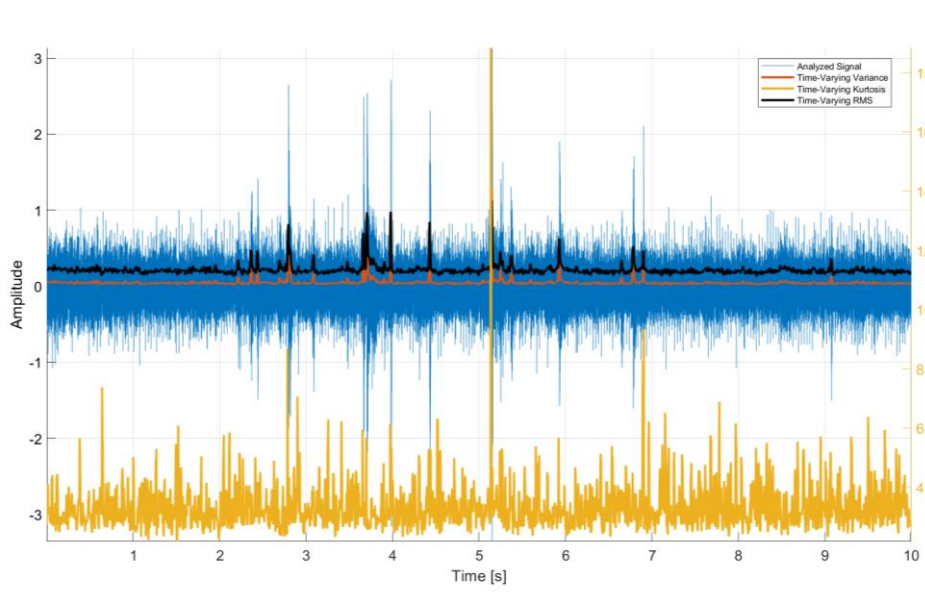

Figure 16 Example of time-varying statistical analysis

The graph presents plotted statistics in the case when a user selects all the possible algorithm options to be used. There is a separate scale for the Kurtosis marked in yellow on the right-hand side of the graph. The raw analyzed signal is presented in blue.

4.3. Spectral Analysis output

In the figures below, the output of the Time-Varying statistics is presented. After choosing a variable to be subjected to the analysis, selecting the spectrum type, turning the *'Harmonics'* option on, defining the number of harmonics to be marked, marking the and *'Spectrogram'* selection box, and initializing the calculations, the following graphs are displayed.
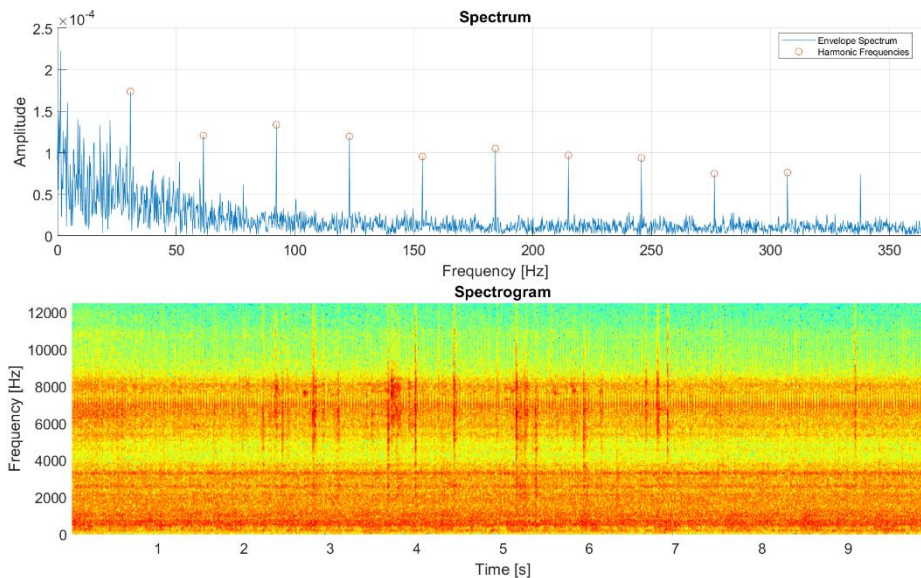
In the figure above, the case in which the envelope spectrum has been chosen by the user is presented. The harmonics with frequencies defined by the user exist and have been marked correctly on the consecutive peaks of the amplitude-frequency function. Below the spectrum plot, the spectrogram is displayed, which allows the user to analyze the data with an insight into an additional dimension. It represents the frequency and amplitude of the signal in time, with the amplitude represented by the color scale (the maximum value is red; the color mapped to the minimum value is blue). High energetic impulses can be seen in the spectrogram in the form of vertical red narrow lines.

The figure above presents the situation in which the user selected the standard spectrum option. The harmonic frequencies defined by the user do not exist in the spectrum of the signal analyzed. The red circles do not correspond to any repetitive peaks of the amplitude in the graph above. However, on the spectrogram, the
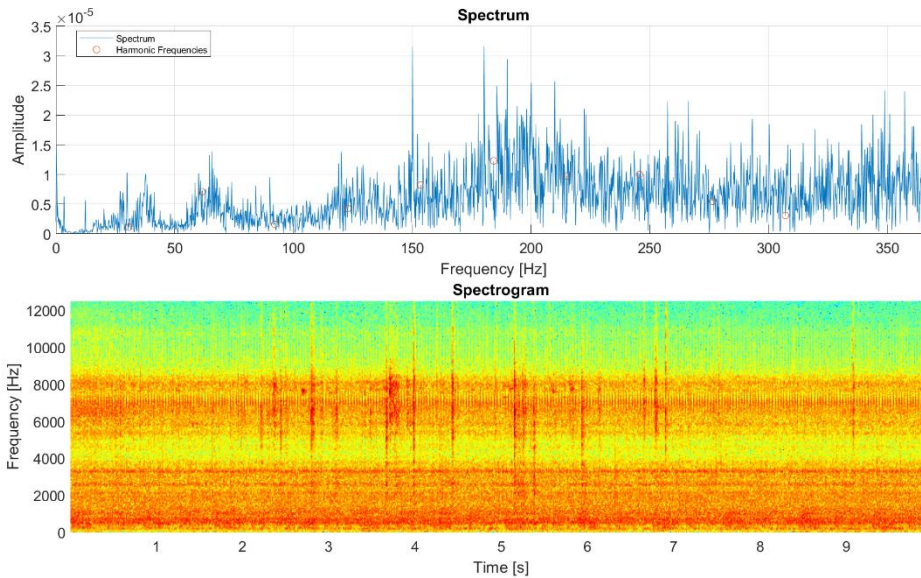
Figure 18 Example of spectral analysis with ordinary spectrum

user can still notice some high-energetic impulses in the form of red narrow lines that may be related to a normal operational state or characterize other types of malfunctioning.

4.4.   Long-Term Statistical Analysis output

In the figures below, the output of the long-term statistical analysis is presented. After loading an archive, selecting a variable for which statistics are to be calculated, choosing a date of the variable's registration, and initializing the calculations the following graphs are displayed.
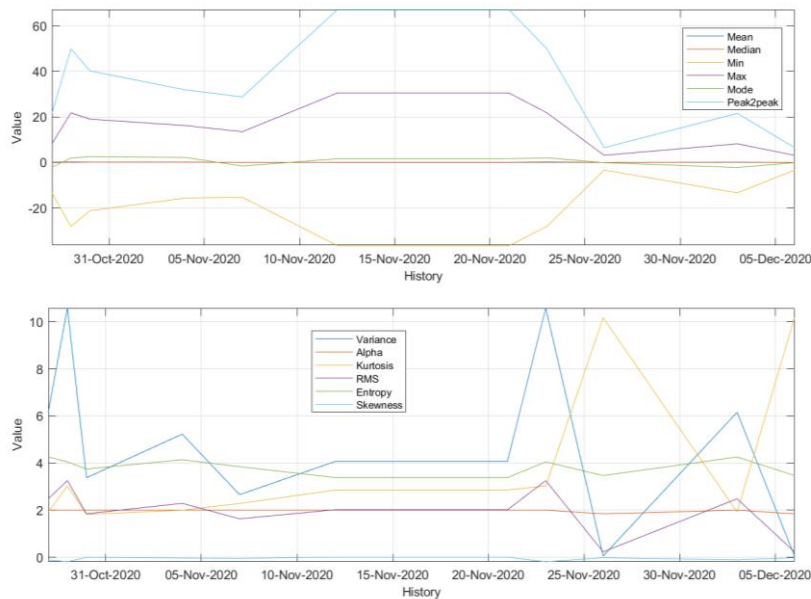

Figure 19 Example of long-term analysis - all statistics

25

The figure below presents the output of the long-term statistical analysis in the case when all of the possible statistics for a given variable have been chosen by the user. For better readability, two separate graphs with the same time-scale are used to depict different statistics for the analyzed variable. In the case presented below only four different statistics have been chosen by the user, hence two of them are displayed per one graph.

Long-term statistics presented in the figures above are displayed in both – graphical and tabular form if added to a report.
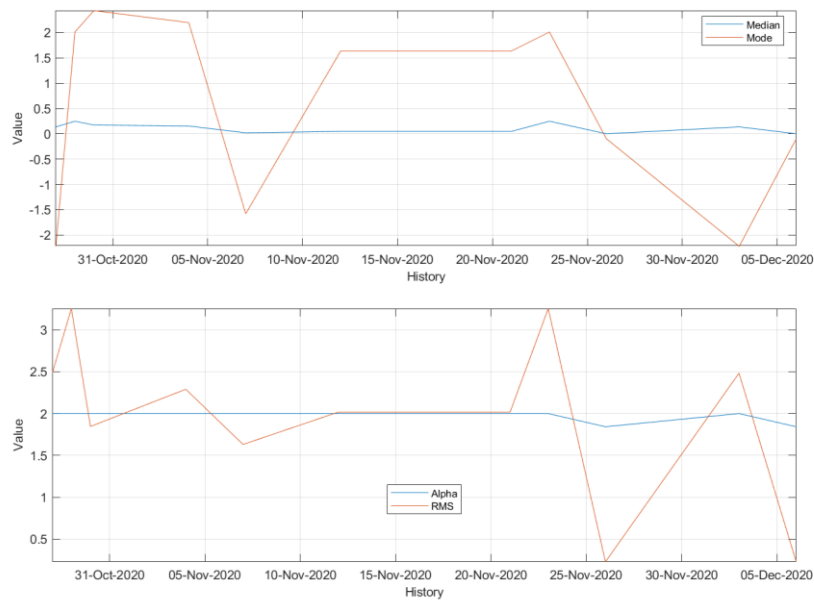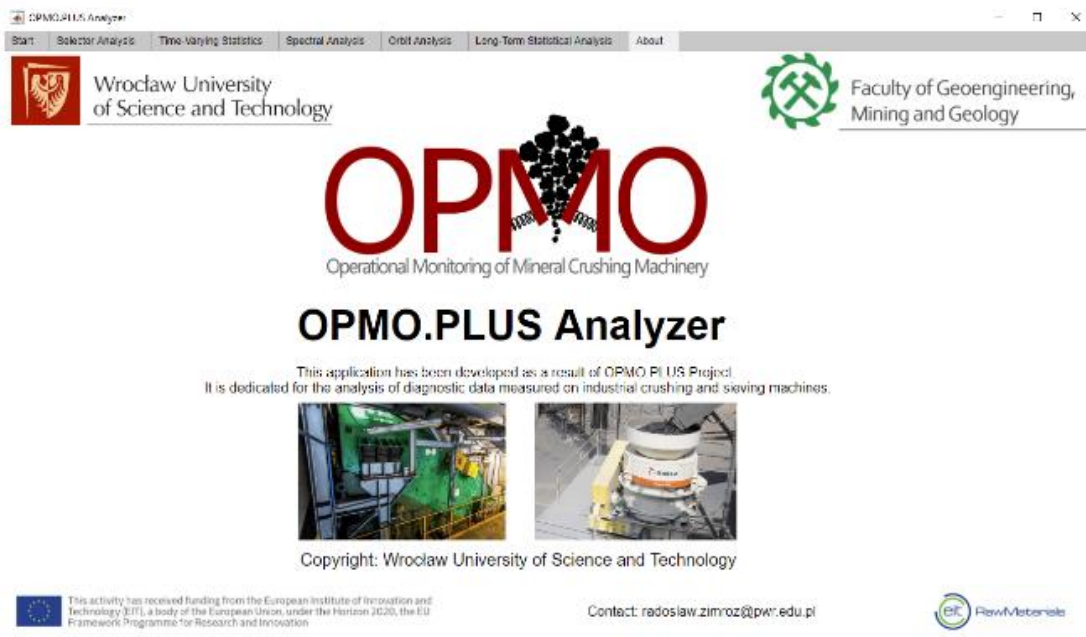

Figure 20 Example of long-term analysis - only 4 statistics selected

OPMO.PLUS Diagnostic Report

Copyright: Digital Mining Center
December 21, 2020

Machine name tag:	CrusherZWR
Machine type:	Hammer Crusher
Machine model:	KR1
Investigated element:	Bearing
Element type\model:	23264CCK_W33
Last repair:	02-Nov-2020
Date of installation:	18-Nov-2020
Cause of failure (last repair):	Inner race crack
Machine operator:	ZWR
Analysis commissioned by:	HQ
Analysis performed by:	Jacek Wodecki
Analysis verified by:	Anna Michalak

OPMO.PLUS Analyzer

This application has been developed as a result of OPMO.PLUS Project.
It is dedicated for the analysis of diagnostic data measured on industrial crushing and sieving machines.

Copyright: Wrocław University of Science and Technology

Contact: radoslaw.zimroz@pwr.edu.pl

Contents

1 Input profile

The following data describes hardware profile set in the "Start" tab of the application.

Loaded profile: `23264CCK_W33_kr1.mat`

Bearing parameters:

- D1 [mm]: 493
- D2 [mm]: 382
- Bd [mm]: 55.5
- Nb: 19
- β [deg]: 53
- RPM: 180

Bearing frequencies:

- BPFO [Hz]: 26.32
- BPFI [Hz]: 30.68
- FTF [Hz]: 11.76
- BPFO [Hz]: 1.385

Spring parameters:

- Mean diameter [mm]: 0
- Wire diameter [mm]: 0
- Number of coilings: 0
- Number of springs in set: 0
- Mass of the empty screen [kg]: 0
- Machine fill coefficient [0-1]: 0
- Spring free length [mm]: 0
- Shear module [MPa]: 0
- Pitch [mm]: 0

Tolerances for orbit parameters:

- Θ [deg]: $0-0$
- Length [mm]: $0-0$
- Width [mm]: $0-0$

2   Input data

2.1   Data 1

File name: `uszk_30hz.mat`

Variables present in the file:
    fs: 1x1 double
    signal: 1x250001 double

Sampling frequency: 2.5e+04

2.2   Uploaded photo

Figure 1: Uploaded image file.

2.3   Uploaded photo

Figure 2: Uploaded image file.

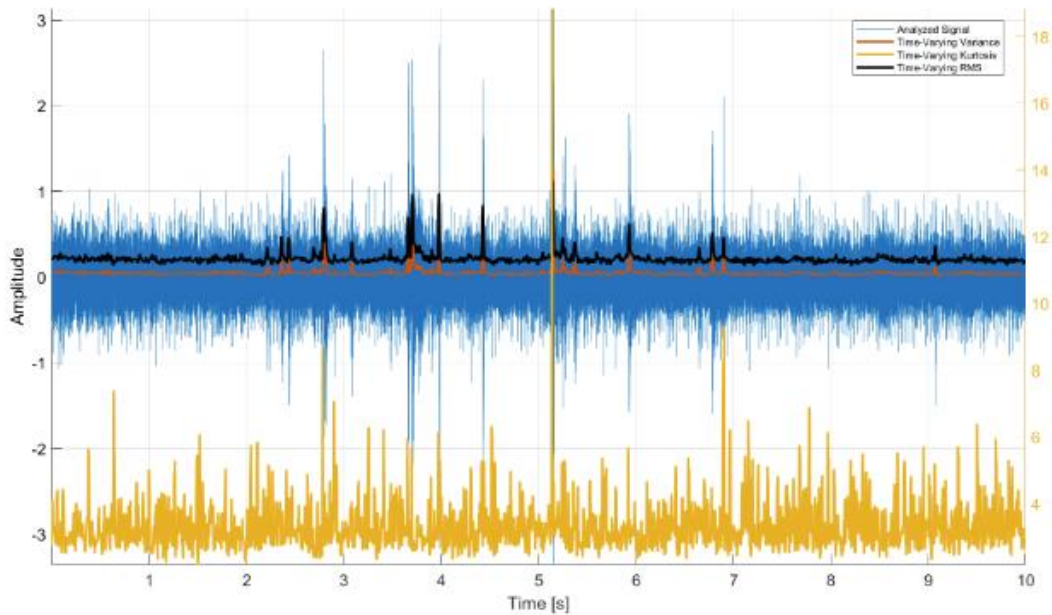# 3 Time - varying statistics

3.1 Case 1

Figure 3: Time - varying statistics, case 1.

The following time-varying analysis has been performed for the variable `signal` and the following parameters:

- Window: 300 samples
- Overlap: 200 samples

Time-varying statistics of the signal presented in Fig 3:

- Time-Varying Variance
- Time-Varying Kurtosis
- Time-Varying RMS
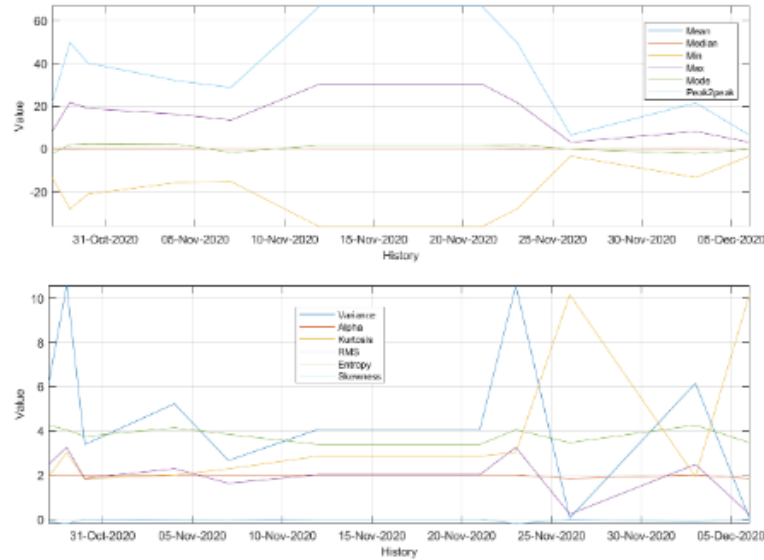
6

4 Long term statistical analysis

4.1 Case 1

Figure 4: Long term statistical analysis, case 1.

The following long-term analysis has been performed for the variable `signal`.

Long-term statistics of the signal arepresented in Fig 4. In the table below the currently analyzed long-term archive is listed.

Table 1: Long-term varying statistics

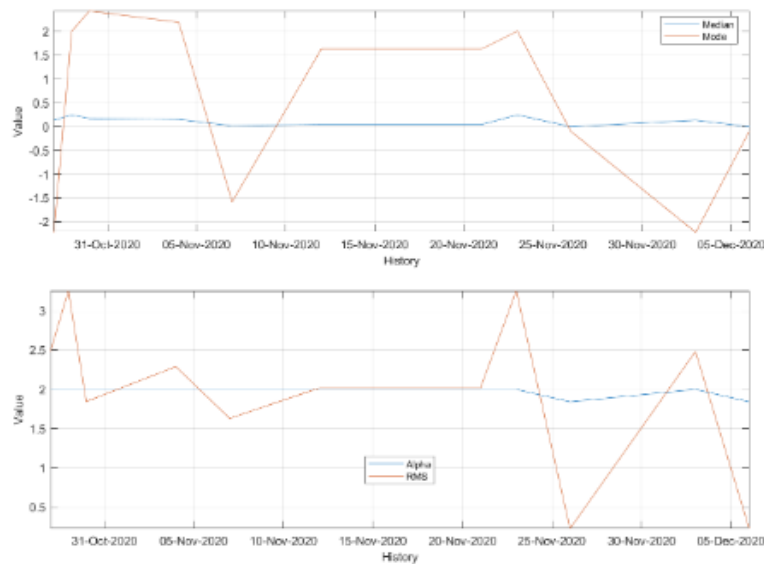| Dates	Mean	Var	α	Kurt	Med	Min	Max	Mode	P2P	RMS	Entropy	Skewness
02-Nov-2020	0.064	6.2	2	1.9	0.14	−13	8.2	−2.2	22	2.5	4.3	−0.11
03-Nov-2020	0.092	11	2	3	0.25	−28	22	2	50	3.3	4.1	−0.19
04-Nov-2020	0.16	3.4	2	1.8	0.17	−21	19	2.4	40	1.8	3.7	−0.007
09-Nov-2020	0.13	5.2	2	2	0.15	−16	16	2.2	32	2.3	4.1	−0.036
12-Nov-2020	0.012	2.7	2	2.3	0.019	−15	13	−1.6	29	1.6	3.8	−0.048
17-Nov-2020	0.012	4.1	2	2.9	0.048	−37	30	1.6	67	2	3.4	−0.00085
26-Nov-2020	0.012	4.1	2	2.9	0.048	−37	30	1.6	67	2	3.4	−0.00085
28-Nov-2020	0.092	11	2	3	0.25	−28	22	2	50	3.3	4.1	−0.19
01-Dec-2020	$-8.9E-07$	0.051	1.8	10	0.00054	−3.4	3.1	−0.097	6.5	0.23	3.5	−0.024
08-Dec-2020	0.064	6.2	2	1.9	0.14	−13	8.2	−2.2	22	2.5	4.3	−0.11
11-Dec-2020	$-8.9E-07$	0.051	1.8	10	0.00054	−3.4	3.1	−0.097	6.5	0.23	3.5	−0.024

4.2 Case 2

Figure 5: Long term statistical analysis, case 2.

The following long-term analysis has been performed for the variable `signal`.

Long-term statistics of the signal arepresented in Fig 5. In the table below the currently analyzed long-term archive is listed.

Table 2: Long-term varying statistics

Dates	Mean	Var	α	Kurt	Med	Min	Max	Mode	P2P	RMS	Entropy	Skewness
02-Nov-2020	0.064	6.2	2	1.9	0.14	−13	8.2	−2.2	22	2.5	4.3	−0.11
03-Nov-2020	0.092	11	2	3	0.25	−28	22	2	50	3.3	4.1	−0.19
04-Nov-2020	0.16	3.4	2	1.8	0.17	−21	19	2.4	40	1.8	3.7	−0.007
09-Nov-2020	0.13	5.2	2	2	0.15	−16	16	2.2	32	2.3	4.1	−0.036
12-Nov-2020	0.012	2.7	2	2.3	0.019	−15	13	−1.6	29	1.6	3.8	−0.048
17-Nov-2020	0.012	4.1	2	2.9	0.048	−37	30	1.6	67	2	3.4	−0.00085
26-Nov-2020	0.012	4.1	2	2.9	0.048	−37	30	1.6	67	2	3.4	−0.00085
28-Nov-2020	0.092	11	2	3	0.25	−28	22	2	50	3.3	4.1	−0.19
01-Dec-2020	$-8.9E-07$	0.051	1.8	10	0.00054	−3.4	3.1	−0.097	6.5	0.23	3.5	−0.024
08-Dec-2020	0.064	6.2	2	1.9	0.14	−13	8.2	−2.2	22	2.5	4.3	−0.11
11-Dec-2020	$-8.9E-07$	0.051	1.8	10	0.00054	−3.4	3.1	−0.097	6.5	0.23	3.5	−0.024

5 Selector analysis

In this section the analysis based on the selectors of the chosen variable are presented, with the frequency (in Hz) analyzed given in **bold** (see the first sentence in each of case). These selectors, which enable detection of the target frequency, are written in red (fault detected), whereas the ones, which can not identify the cyclic component of the given frequency are written in green (no fault detected).

The selectors, which can be chosen in the application are presented in the following list:

1. Spectral Kurtosis

2. Alpha Selector

3. CVB Selector

4. Spearman Selector

5. L-Kurtosis Selector

6. Jarque-Bera Selector

7. Custom Filter (bandpass, bandstop, highpass, lowpass – depending on the settings in the program)
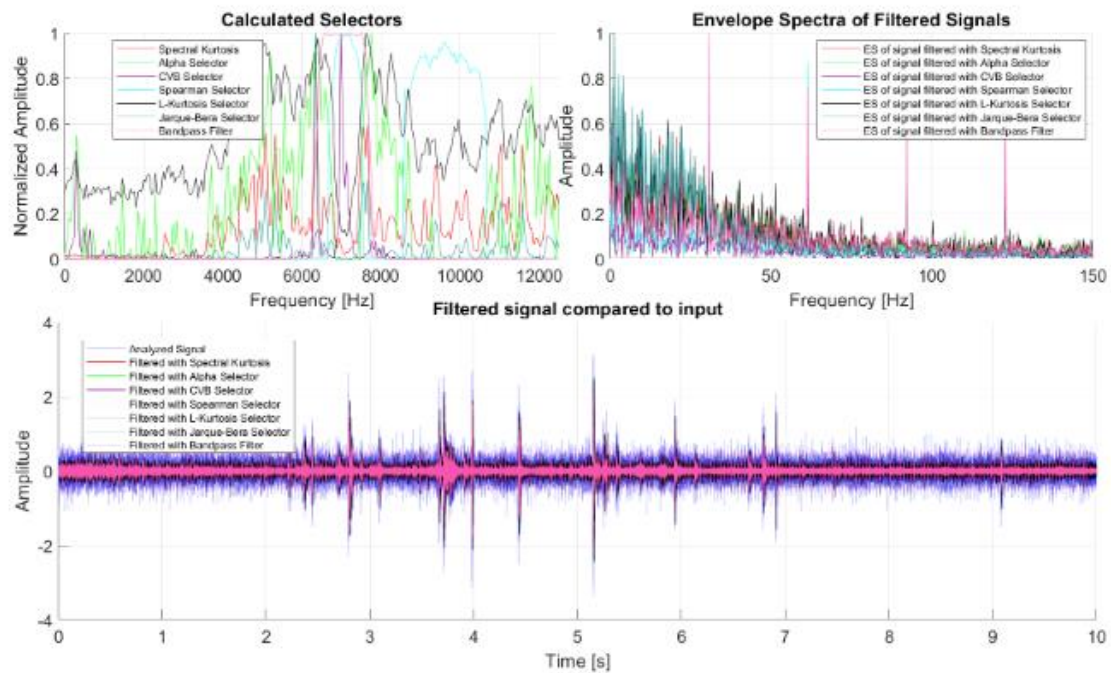
5.1 Case 1

Figure 6: Selector analysis, case 1.

The following selector-based analysis has been performed for the variable `signal` in search of the fault at frequency **30.68 Hz**.

Selectors presented in left top panel of Fig 6:
Spectral Kurtosis
Alpha Selector
CVB Selector
Spearman Selector
L-Kurtosis Selector
Jarque-Bera Selector
Bandpass Filter

Obtained envelope spectra are presented in right top panel.
The filtered signals are presented in the bottom panel.

Based on the analysis the following methods show that cyclic impulses are present in the data:
CVB Selector
Spearman Selector
Bandpass Filter

However, the following methods cannot detect cyclic component:
Spectral Kurtosis
Alpha Selector
L-Kurtosis Selector
Jarque-Bera Selector

5.2   Case 2

The following selector-based analysis has been performed for the variable `signal` in search of the fault at frequency
30.7 Hz.

Selectors presented in left top panel of Fig 7:
CVB Selector
Spearman Selector

Obtained envelope spectra are presented in right top panel.
The filtered signals are presented in the bottom panel.

Based on the analysis the following methods show that cyclic impulses are present in the data:
CVB Selector
Spearman Selector

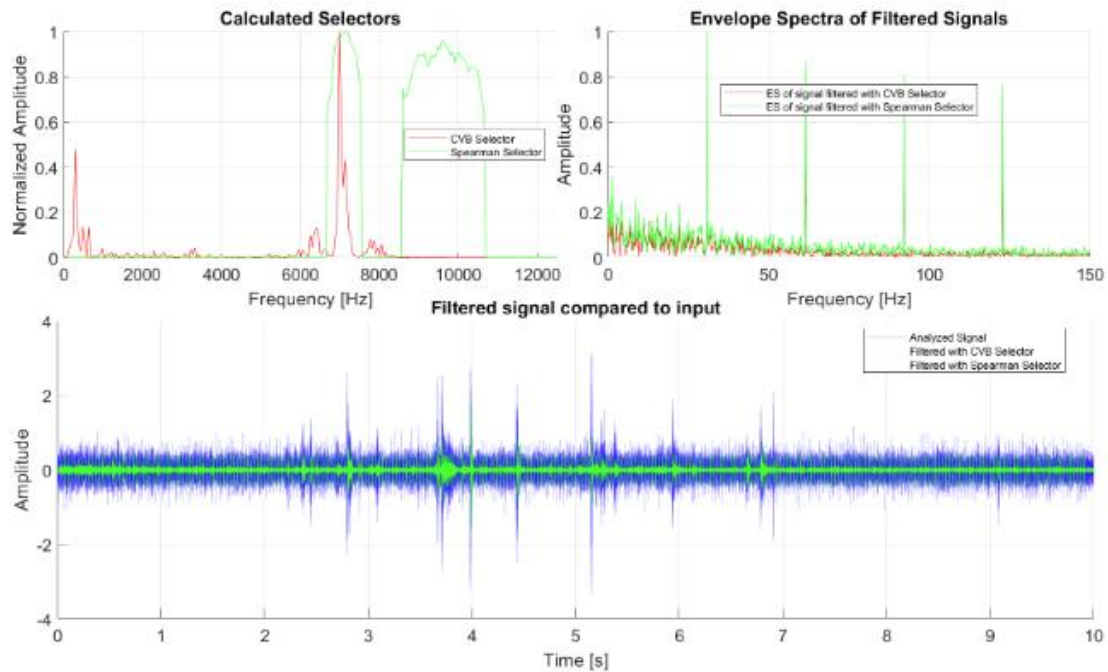However, the following methods cannot detect cyclic component:

Figure 7: Selector analysis, case 2.

6   Spectral analysis

In this section the spectral analysis of the chosen variable are presented. For calculation of the Spectrogram (time-frequency representation) in user can select a few parameters in the starting tab of the application - window type, window length, overlap and nfft. The following window types can be selected:

1. Hamming

2. Kaiser

3. Bartlett

4. Blackman

5. Chebyshev

6. Hann

Moreover, user can input the fundamental frequency and the number of harmonics (they will be marked by the red circle in the top panel of the figure). Finally the diagnosis is written in red (fault detected in defined frequency) or in green (no fault component detected in defined frequency).

6.1   Case 1

The following spectral analysis has been performed for the variable signal.
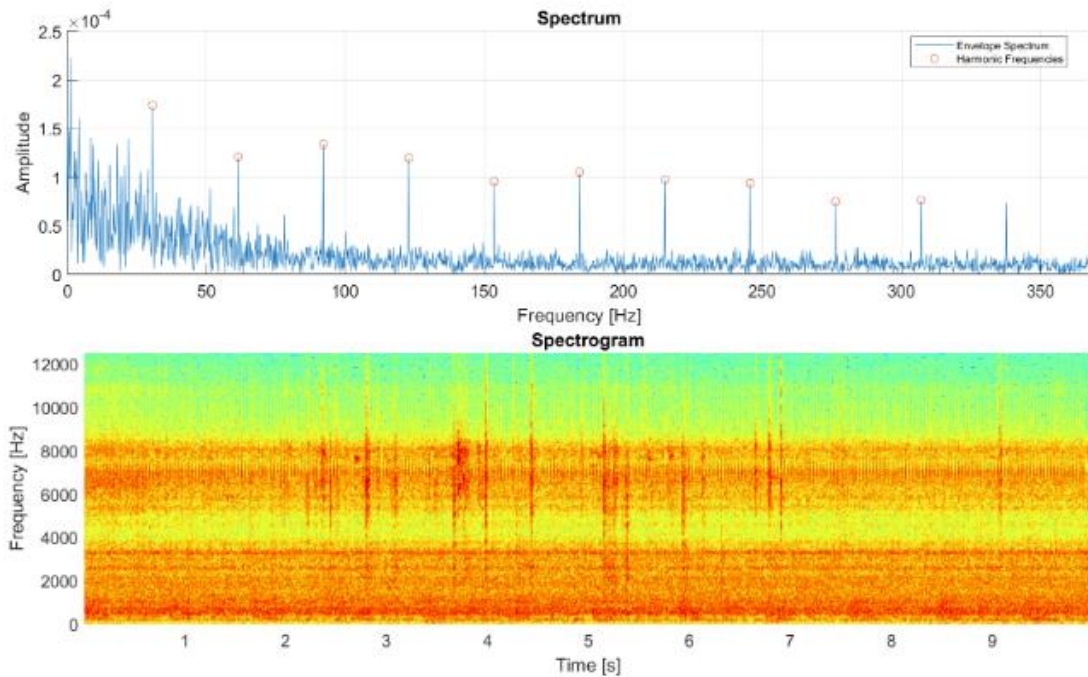
Figure 8: Spectral analysis, case 1.

Spectra presented in top panel of Fig 8:
Envelope Spectrum

Indication of 10 harmonic components for fundamental frequency of **30.7 Hz** has been engaged.

Spectrogram is presented in top panel of Fig 8 and has been calculated with the following parameters:
- Window type: Hamming

- Window length: 512

- Overlap: 220

- NFFT: 512

Diagnosis: Fault detected at 30.7 Hz.

6.2 Case 2

The following spectral analysis has been performed for the variable `signal`.

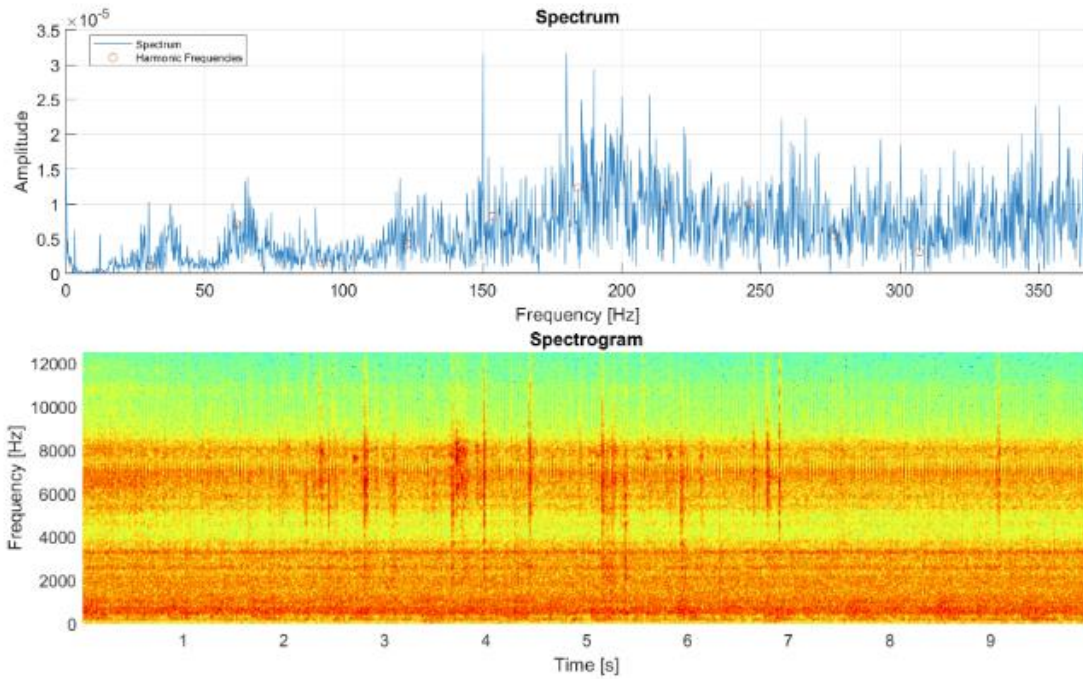Spectra presented in top panel of Fig 9:
Spectrum

Figure 9: Spectral analysis, case 2.

Indication of 10 harmonic components for fundamental frequency of **30.7 Hz** has been engaged.

Spectrogram is presented in top panel of Fig 9 and has been calculated with the following parameters:
- Window type: Hamming

- Window length: 512

- Overlap: 220

- NFFT: 512

Diagnosis: Fault detected at 30.7 Hz.

5. Funcionality description in case of sieving screen machine

First of all the Registration form has to be completed. The figures below presented the completed form for sieving screen and the e-mail sent to user after registration.

OPMO.PLUS Register form

Your Name*

Jacek Wodecki

Your e-mail adress*

wodecki.jacek@gmail.com

Public IP address (if you do not have a static IP address enter 0.0.0.0)*

0.0.0.0

Machine name tag*

ScreenZWR

Machine type*

Sieving Screen

Machine model*

SW3

Investigated element*

Spring

Element type/model*

N/A

Machine operator*

ZWR

Date of installation*

02-Nov-2020

Date of last repair*

18-Nov-2020

Cause of failure (last repair)*
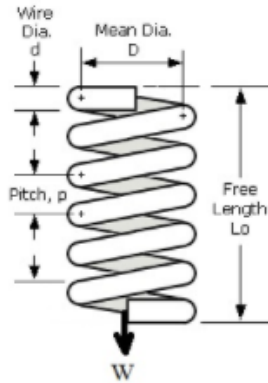
Crack

File* (.zip, max 25MB)

[Choose File] example1.zip

Figure 21 Example of filled register form for screen use case

40

Springs

Mean diameter [mm]

180

Wire diameter [mm]

30

Number of coilings

10

Number of springs in set

12

Mass of the screen [kg]

15230

Machine fill coefficient [0-1]
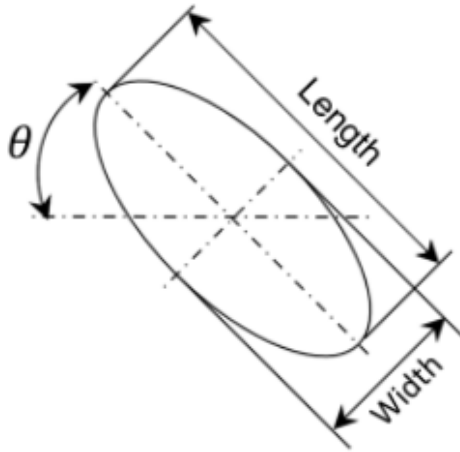
0

Spring free length [mm]

410

Shear module [MPa]

8000

Pitch [mm]

40

Figure 22 Example of filled register form for screen use case - part 2

![EIT RawMaterials - Connecting matters]

Orbit

Theta min [deg]:

40

Theta max [deg]:

50

Length min [mm]:

6

Length max [mm]:

12

Width min [mm]:

0

Width max [mm]:

5

SUBMIT

Figure 23 Example of filled register form for screen use case - part 3

RawMaterials
Connecting matters

Digital Mining Center: OPMO.PLUS Registration ⟩ Odebrane x **Projekty KIC/OPMO x**

Digital Mining Center <wordpress@dmc.pwr.edu.pl>
do mnie ▾

文A angielski ▾   ⟩   polski ▾   Przetłumacz wiadomość

OPMO.PLUS registration form.

Name: Jacek Wodecki
E-mail address: wodecki.jacek@gmail.com
Machine name tag: ScreenZWR
Machine type: Sieving Screen
Public IP address: 0.0.0.0
Machine model: SW3
Investigated element: Spring
Element type or model: N/A
Last repair: 18-Nov-2020
Date of installation: 02-Nov-2020
Cause of failure (last repair): Crack
Machine operator: ZWR
Analysis commissioned by: Jacek Wodecki
D1 [mm]:
D2 [mm]:
Bd [mm]:
Nb:
beta [deg]:
RPM:
BPFO [Hz]:
BPFI [Hz]:
BSF [Hz]:
FTF [Hz]:
Mean diameter [mm]: 180
Wire diameter [mm]: 30
Number of coilings: 10
Number of springs in set: 12
Mass of the empty screen [kg]: 15230
Machine fill coefficient [0-1]: 0
Spring free length [mm]: 410
Shear module [MPa]: 8000
Pitch [mm]: 40
Theta min [deg]: 40
Theta max [deg]: 50
Length min [mm]: 6
Length max [mm]: 12
Width min [mm]: 0
Width max [mm]: 5

File: example1.zip

The information regarding logging into cloud service containing the analyzer will arrive in the next message.
–
This e-mail was sent from a register form the OPMO.PLUS Application on Digital Mining Center (http://dmc.pwr.edu.pl)

Figure 24 Example of e-mail notification

5.1. Time-Varying Statistics output

In the figures below, the output of the Time-Varying statistics is presented. After choosing a variable to be subjected to the analysis, selecting the algorithms (types of the statistics to be used: Variance, Kurtosis, Root Mean Square), and initializing the calculations, the following plot is generated.
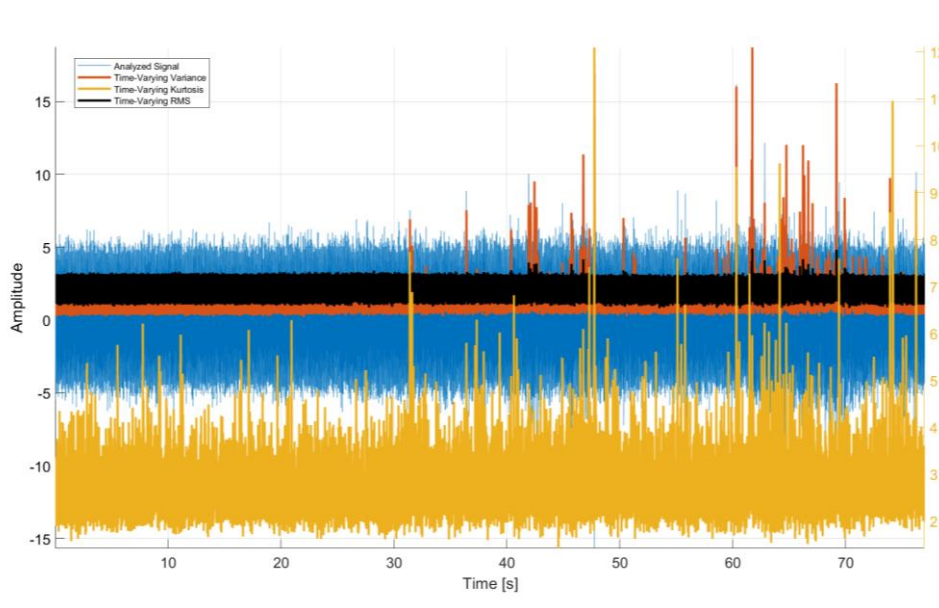

Figure 25 Example of time-varying analysis

The graph presents plotted statistics in the case when a user selects all the possible algorithm options to be used. There is a separate scale for the Kurtosis marked in yellow on the right-hand side of the graph. The raw analyzed signal is presented in blue. It has to be highlighted, that the output of the time-varying statistics utility is depending on the window size and the overlap configured by the user in the *'Time-varying statistics'* field in
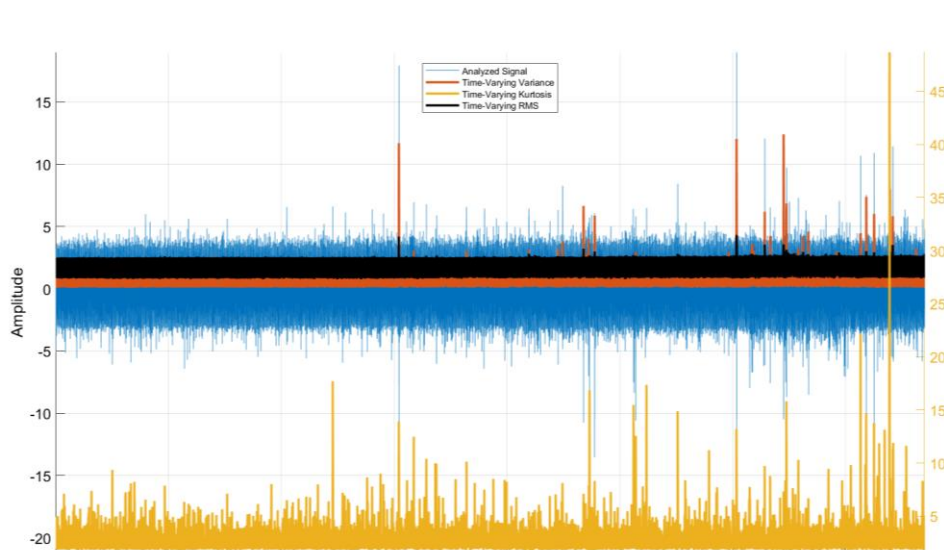

Figure 26 Example of time-varying analysis - different window of analysis

44

the application's starting tab. The example presented in the figure above corresponds to the analysis of the vibration data measured in vertical direction. In this case the window size has been set for 300 samples and the overlap – for 200 samples. The figure below presents similar example (the same configuration of the window size and overlap) of the time-varying statistics functionality, with the analysis' output of the inertial variable measured in horizontal direction.

In the figures below, the time-varying statistics utility's outputs are presented for the same variables measured in as follows: horizontal direction and vertical direction with the window size for the calculation of statistics set as equal to 2500 samples and the overlap of 200 samples.
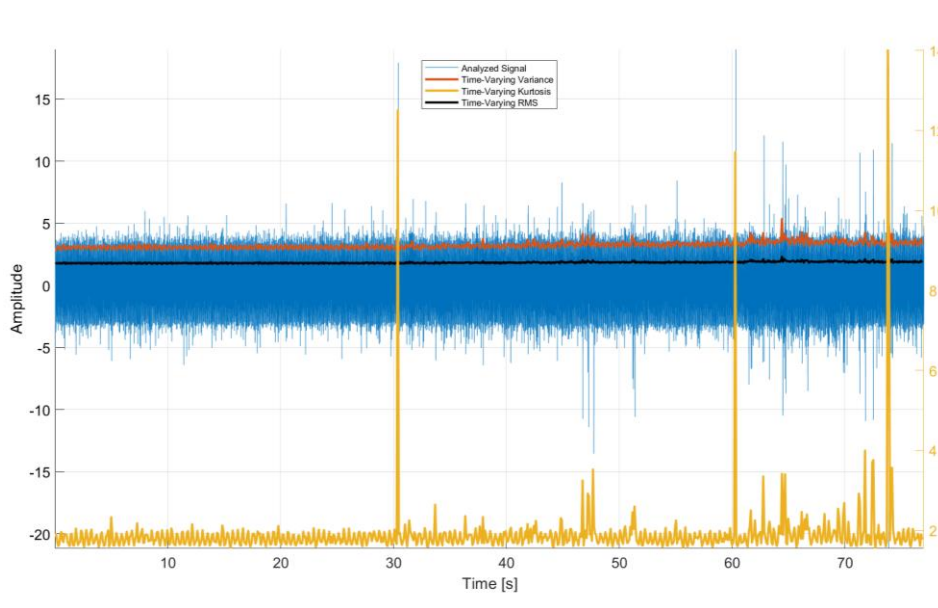

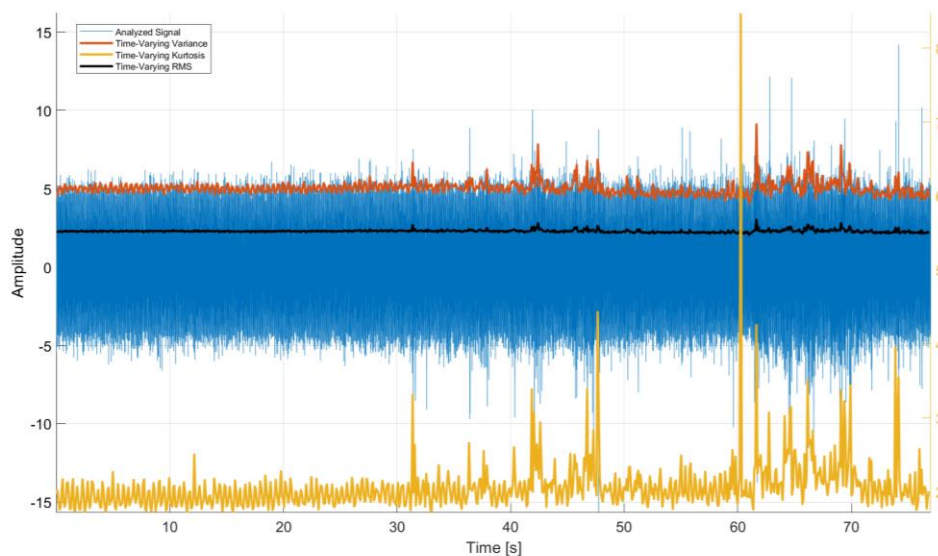Figure 27 Example of time-varying analysis - long window, horizontal direction

Figure 28 Example of time-varying analysis - long window, vertical direction

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5.2.   Spectral Analysis output

In the figure below, the output of the Time-Varying statistics is presented. After choosing a variable to be subjected to the analysis, selecting the spectrum type, defining the number of harmonics to be marked, and *'Spectrogram'* selection box, and initializing the calculations, the following graphs are displayed.
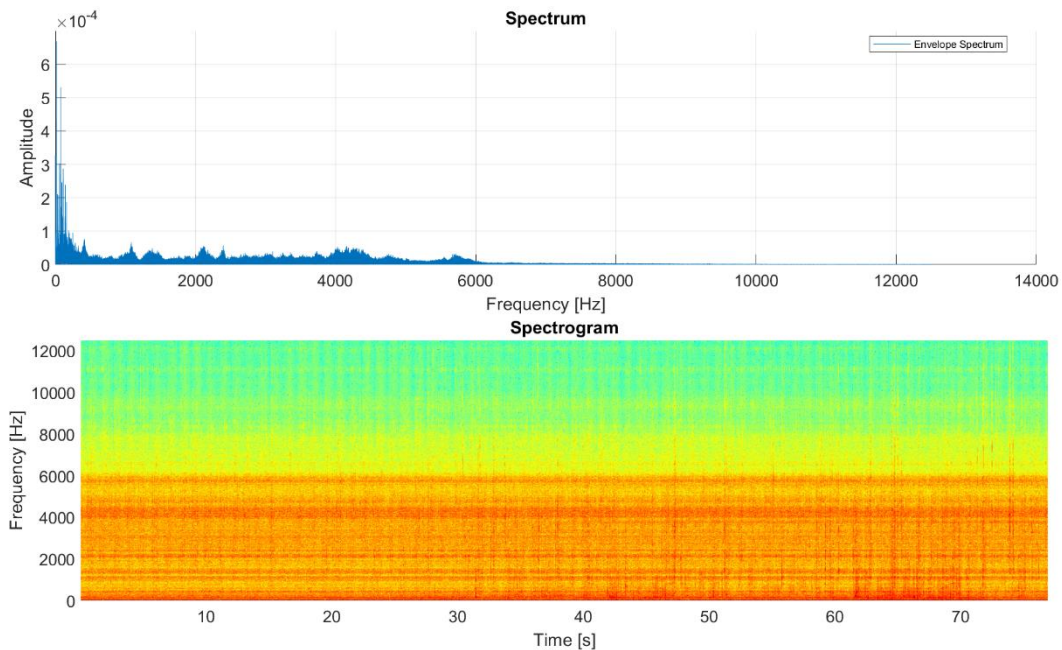

Figure 29 Example of spectral analysis

In the figure above, the case in which the envelope spectrum has been chosen by the user is presented. Below the spectrum plot, the spectrogram is displayed, which allows the user to analyze the data with an insight into an additional dimension. It represents the frequency and amplitude of the signal in time, with the amplitude represented by the color scale (the maximum value is red; the color corresponding to the minimum value is blue). High energetic impulses can be seen in the spectrogram in the form of vertical red narrow lines.

The figure below presents the situation in which the user selected the envelope spectrum option as in the previous case, but additionally turned the *'Harmonics'* option 'On' to display the markers on the defined fundamental frequency and its higher-order harmonics. The harmonic frequencies defined by the user exist in the spectrum of the signal analyzed and have been marked correctly on the consecutive peaks of the amplitude-frequency function. The red circles correspond to any repetitive peaks of the amplitude in the graph below. Moreover, on the spectrogram, the user can notice some high-energetic impulses in the form of red narrow lines that may be related to a normal operational state or characterize some types of malfunctioning.
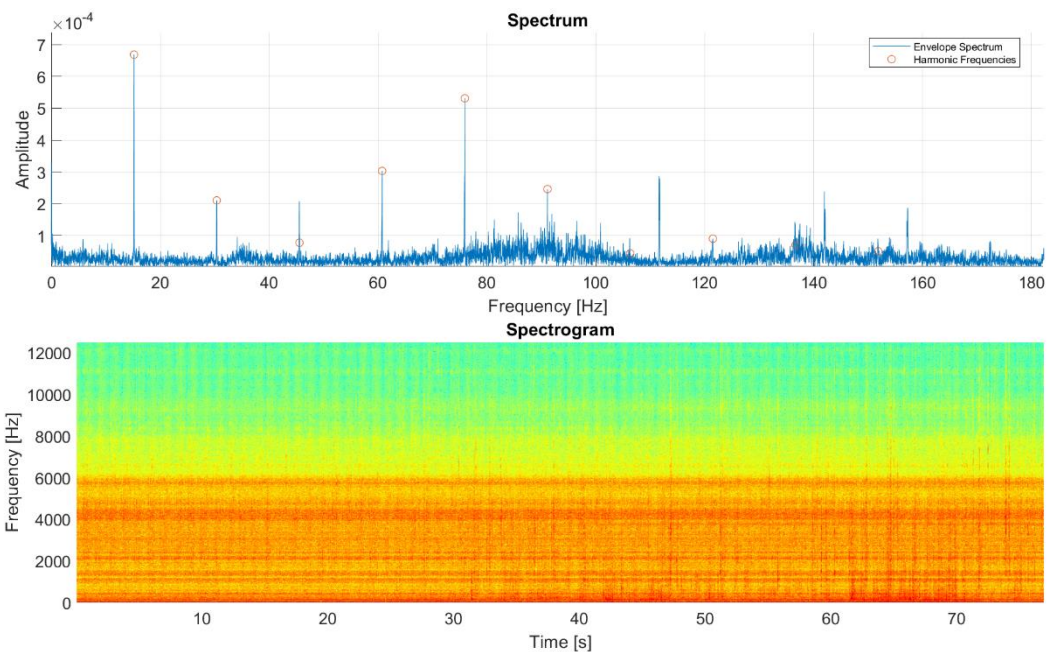
Figure 30 Example of spectral analysis with envelope spectrum zoomed on relevant components

5.3. Orbit Analysis output

In the figure below, the output of the orbit analysis functionality is presented. After choosing a variable of interest (two perpendicular components of the vibration have to be selected), defining the start- and end-time of the analysis, choosing the proper unit, in which the analyzed variable is expressed, and initializing the analysis the following graphs are displayed. The following plots are generated:

- the horizontal component of the analyzed variable - upper-left graph,
- the vertical component - upper-right graph,
- the phase space plot - lower-left graph,
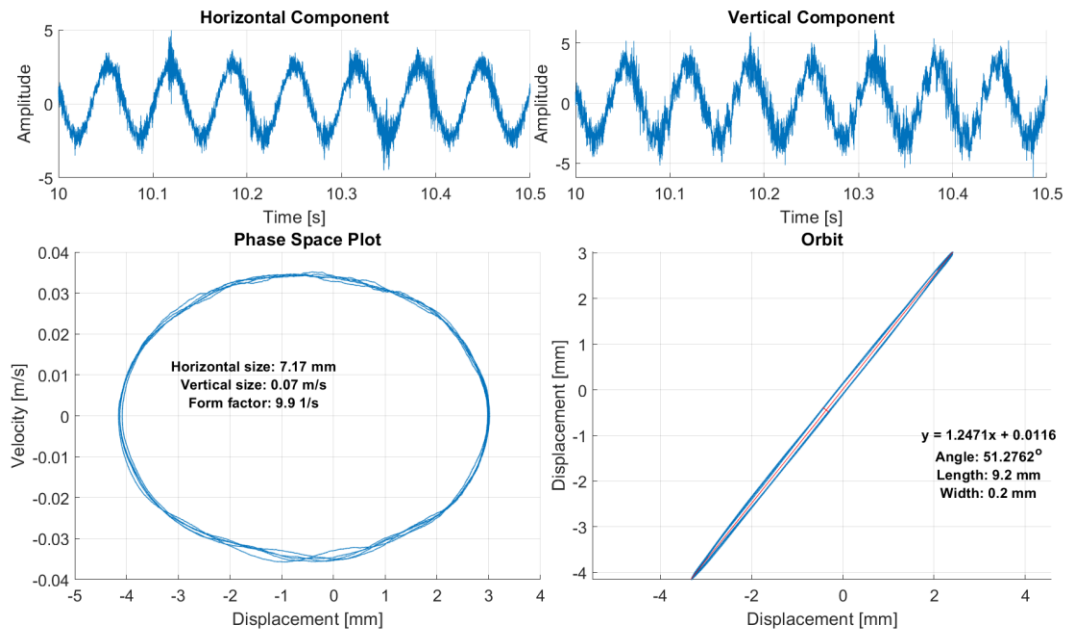- the orbit plot - lower-right graph.
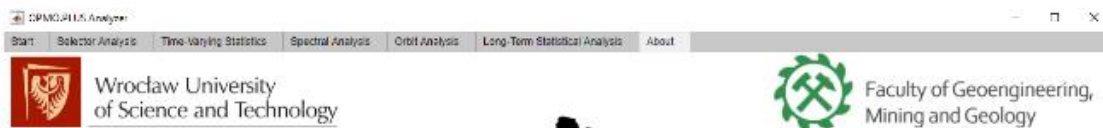
Figure 31 Example of orbit analysis

The example presents an orbit analysis performed for a 0.5-second long data series. As it can be seen - the orbit and phase space plot parameters calculated on the basis of springs parameters defined in the starting window of the application (the *'Suspension'* section) are presented on their corresponding plots. For the phase space plot, the parameters calculated are: horizontal size, vertical size, and form factor – the values are displayed on the graph with a legend. In the orbit's case: angle, length, and width – all displayed on the graph

OPMO.PLUS Diagnostic Report

Copyright: Digital Mining Center
December 21, 2020

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Machine name tag:	ScreenZWR
Machine type:	Sieving Screen
Machine model:	SW3
Investigated element:	Spring
Element type\model:	N/A
Last repair:	02-Nov-2020
Date of installation:	18-Nov-2020
Cause of failure (last repair):	Crack
Machine operator:	ZWR
Analysis commissioned by:	HQ
Analysis performed by:	Jacek Wodecki
Analysis verified by:	Anna Michalak

Wrocław University of Science and Technology

Faculty of Geoengineering, Mining and Geology

OPMO.PLUS Analyzer

This application has been developed as a result of OPMO PLUS Project
It is dedicated for the analysis of diagnostic data measured on industrial crushing and sieving machines.

Copyright: Wrocław University of Science and Technology

Contact: radoslaw.zimroz@pwr.edu.pl

1

Contents

1   Input profile

The following data describes hardware profile set in the "Start" tab of the application.

Loaded profile: `screen_SW3.mat`

Bearing parameters:

- D1 [mm]: 0
- D2 [mm]: 0
- Bd [mm]: 0
- Nb: 0
- β [deg]: 0
- RPM: 0

Bearing frequencies:

- BPFO [Hz]: 0
- BPFI [Hz]: 0
- FTF [Hz]: 0
- BPFO [Hz]: 0

Spring parameters:

- Mean diameter [mm]: 180
- Wire diameter [mm]: 30
- Number of coilings: 10
- Number of springs in set: 12
- Mass of the empty screen [kg]: 1.523e+04
- Machine fill coefficient [0-1]: 0
- Spring free length [mm]: 410
- Shear module [MPa]: 8000
- Pitch [mm]: 40

Tolerances for orbit parameters:

- Θ [deg]: $40 - 50$
- Length [mm]: $6 - 12$
- Width [mm]: $0 - 5$

3

2 Input data

2.1 Data 1

File name: RU_08.mat

Variables present in the file:
    B_RDV_08: 1x1925000 double
    B_RUV_08: 1x1925000 double
    Fs: 1x1 double
    S_RDH_08: 1x1925000 double
    S_RDV_08: 1x1925000 double
    S_RUH_08: 1x1925000 double
    S_RUV_08: 1x1925000 double
    TSC_08: 1x1925000 double

Sampling frequency: 2.5e+04

2.2 Uploaded photo

Figure 1: Uploaded image file.

3   Time - varying statistics

3.1   Case 1

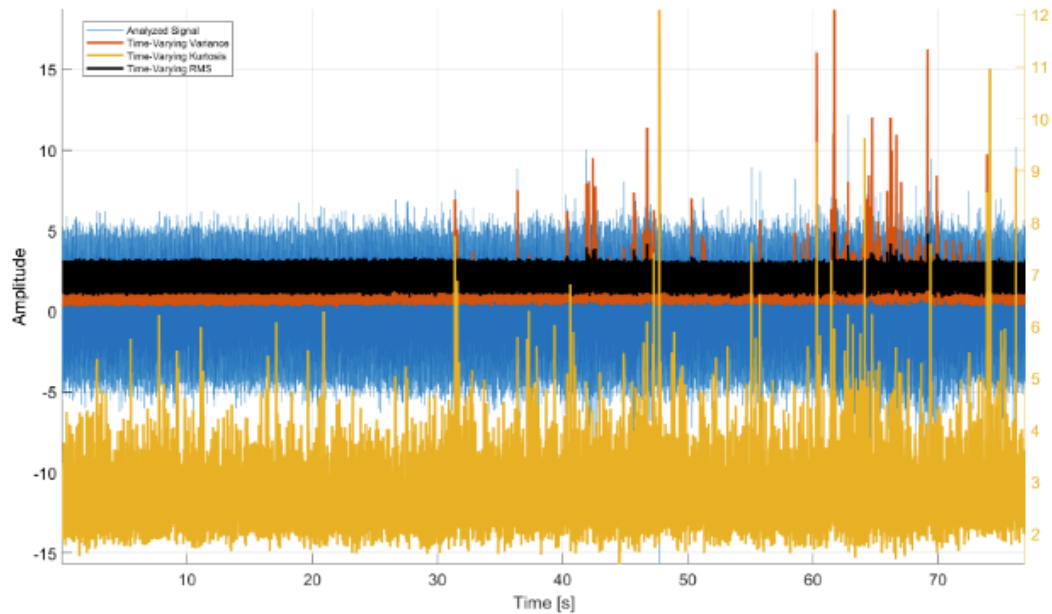
Figure 2: Time - varying statistics, case 1.

The following time-varying analysis has been performed for the variable S_RDV_08 and the following parameters:

- Window: 300 samples
- Overlap: 200 samples

Time-varying statistics of the signal presented in Fig 2:

- Time-Varying Variance
- Time-Varying Kurtosis
- Time-Varying RMS

5

3.2 Case 2

Figure 3: Time - varying statistics, case 2.

The following time-varying analysis has been performed for the variable S_RDH_08 and the following parameters:

- Window: 300 samples
- Overlap: 200 samples

Time-varying statistics of the signal presented in Fig 3:

- Time-Varying Variance
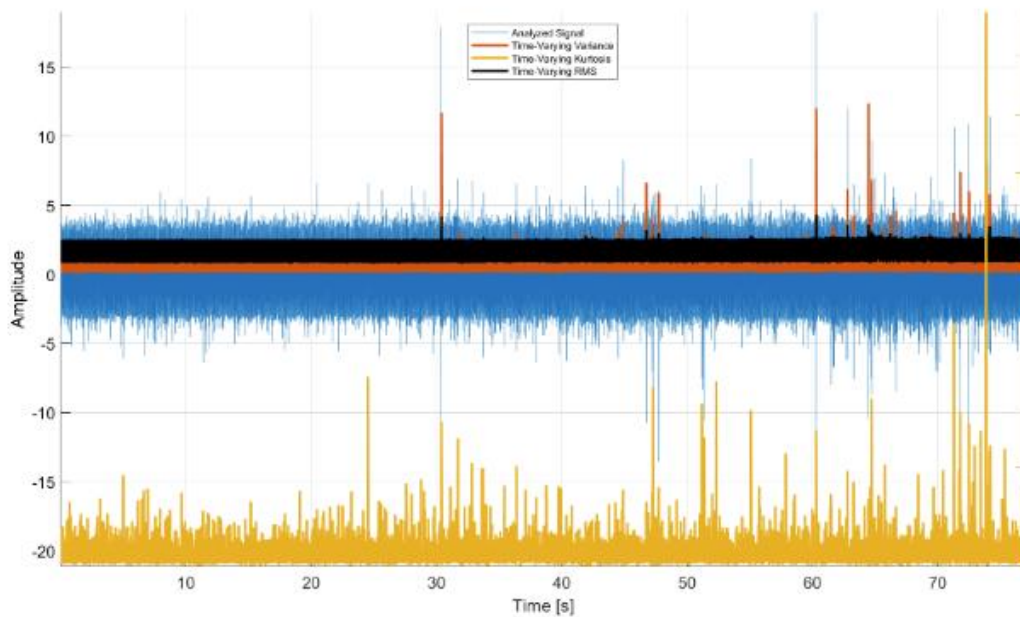- Time-Varying Kurtosis
- Time-Varying RMS

3.3 Case 3

Figure 4: Time - varying statistics, case 3.

The following time-varying analysis has been performed for the variable S_RDH_08 and the following parameters:

- Window: 2500 samples
- Overlap: 200 samples

Time-varying statistics of the signal presented in Fig 4:

- Time-Varying Variance
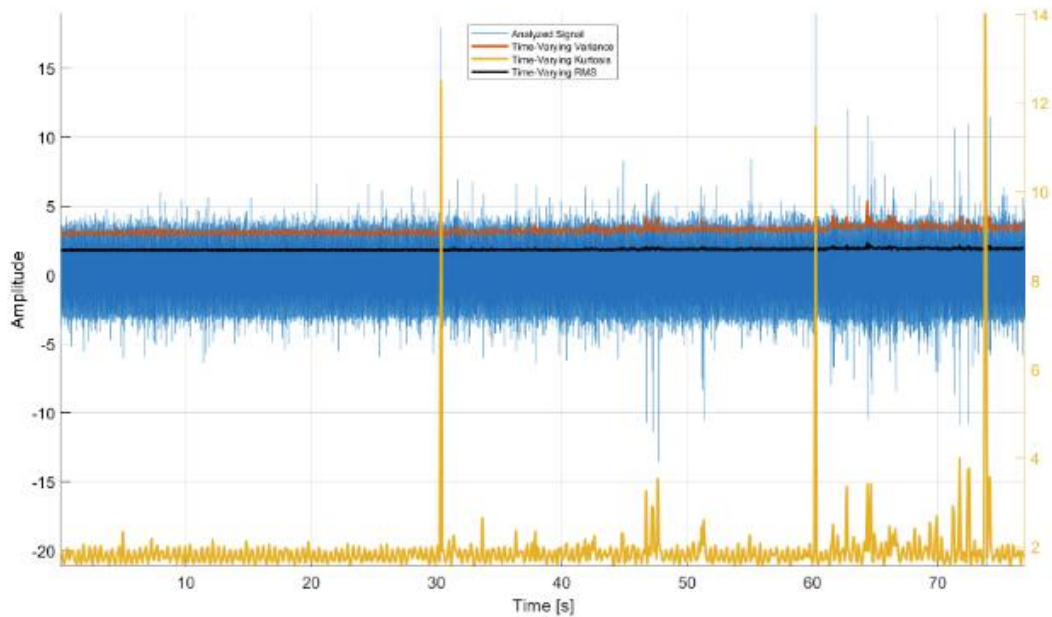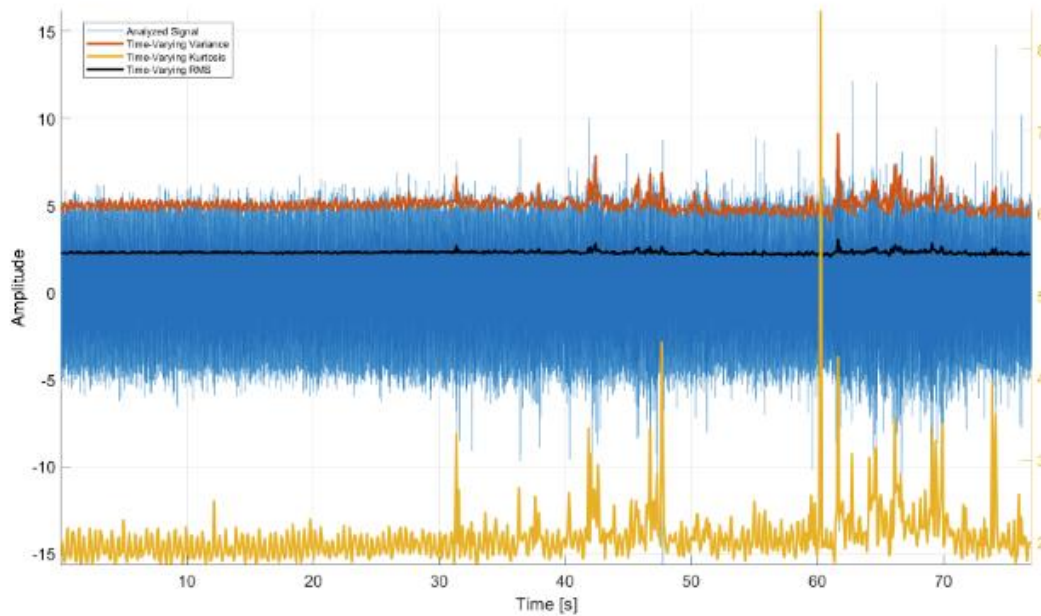- Time-Varying Kurtosis
- Time-Varying RMS

3.4   Case 4

Figure 5: Time - varying statistics, case 4.

The following time-varying analysis has been performed for the variable S_RDV_08 and the following parameters:

- Window: 2500 samples
- Overlap: 200 samples

Time-varying statistics of the signal presented in Fig 5:

- Time-Varying Variance
- Time-Varying Kurtosis
- Time-Varying RMS

4   Spectral analysis

In this section the spectral analysis of the chosen variable are presented. For calculation of the Spectrogram (time-frequency representation) in user can select a few parameters in the starting tab of the application - window type, window length, overlap and nfft. The following window types can be selected:

1. Hamming

2. Kaiser

3. Bartlett

4. Blackman

5. Chebyshev

6. Hann

Moreover, user can input the fundamental frequency and the number of harmonics (they will be marked by the red circle in the top panel of the figure). Finally the diagnosis is written in red (fault detected in defined frequency) or in green (no fault component detected in defined frequency).

4.1   Case 1

Figure 6: Spectral analysis, case 1.

The following spectral analysis has been performed for the variable S_RDV_08.

Spectra presented in top panel of Fig 6:
Envelope Spectrum

Spectrogram is presented in top panel of Fig 6 and has been calculated with the following parameters:

- Window type: Hamming

- Window length: 1024

- Overlap: 220

- NFFT: 1024
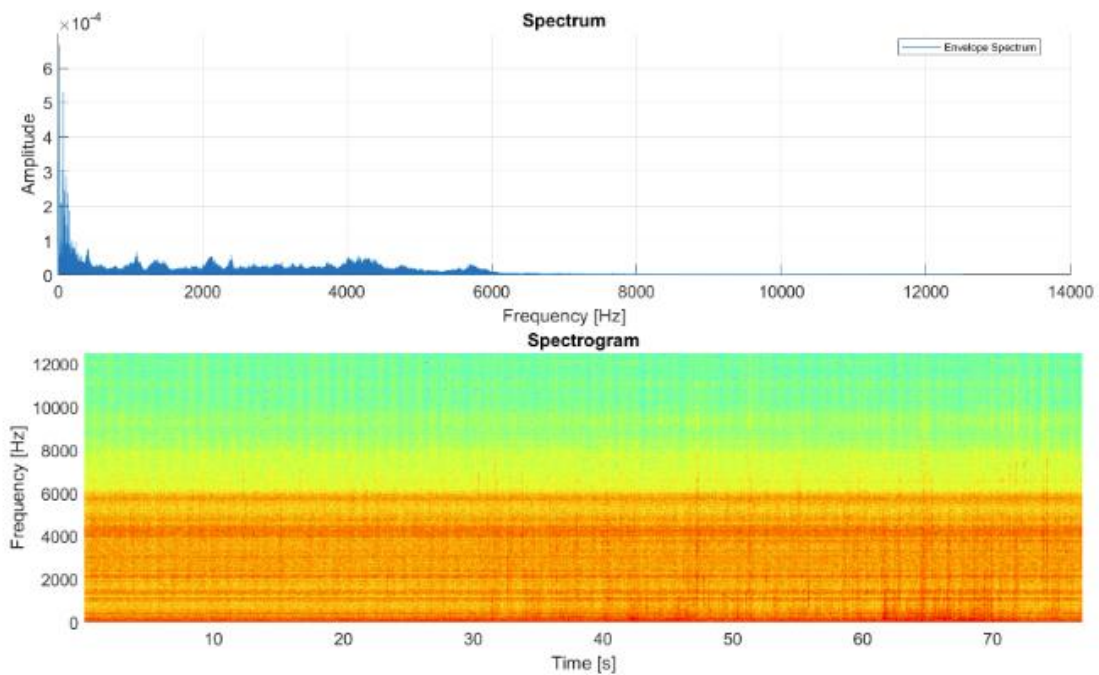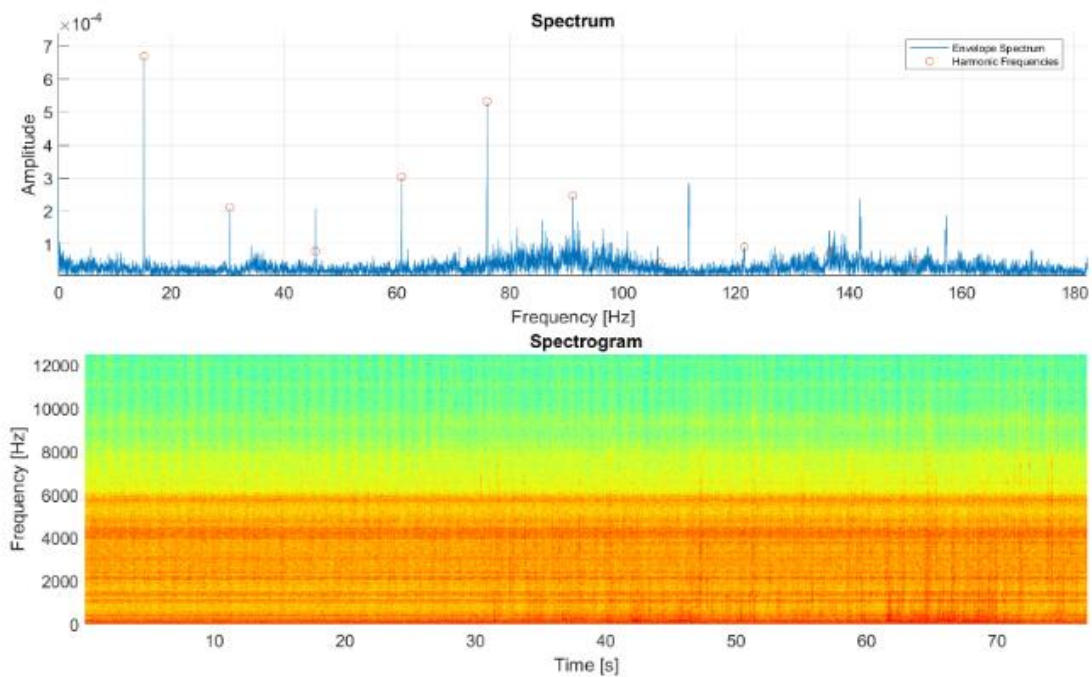
Diagnosis: No Fault detected at 0 Hz.

4.2 Case 2

Figure 7: Spectral analysis, case 2.

The following spectral analysis has been performed for the variable S_RDV_08.

Spectra presented in top panel of Fig 7:
Envelope Spectrum

Indication of 10 harmonic components for fundamental frequency of **15.19 Hz** has been engaged.

Spectrogram is presented in top panel of Fig 7 and has been calculated with the following parameters:

10

- Window type: Hamming

- Window length: 2048

- Overlap: 500

- NFFT: 2048

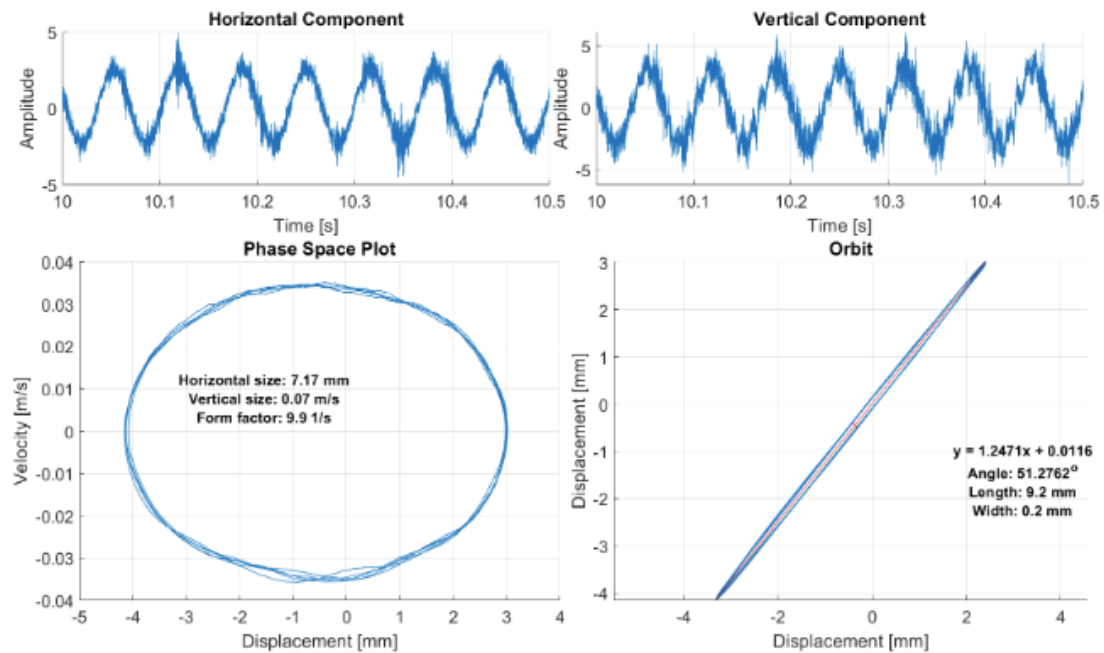Diagnosis: **No Fault detected at 15.19 Hz.**

5 Orbit analysis

5.1 Case 1

Figure 8: Orbit analysis, case 1.

The following orbit analysis has been performed for the horizontal variable "S_RDH_08" and vertical variable "S_RDV_08". Time period for orbit calculation has been selected from 10 seconds to 10.5 seconds. Source components for orbit calculation are presented in top panels of Fig 8. Orbit plot is presented in bottom-right panel of Fig 8. Phase space plot is presented in bottom-left panel of Fig 8.

Calculated orbit parameters:

- Angle: 51.28°

- Length: 9.177 mm

- Width: 0.1768 mm

Calculated phase space plot parameters:

- Horizontal size: 7.172 mm

- Vertical size: 0.07084 m/s

- Form factor: 9.877 1/s

Orbit diagnostics.

- Angle: Out of tolerances.
- Length: Within tolerances.
- Width: Within tolerances.

6. Conclusions

Condition monitoring of industrial machinery requires an extensive knowledge about the particular machine and processes that exist when the machine is in operation. Especially in case of the machines dedicated to processing of mineral raw materials, where operating conditions themselves are a factor making the analysis of acquired data more difficult In this report, we present a dedicated software package prepared for the analysis of signals registered on such type of machinery, for which high-energy disturbances in noise and vibration data make condition monitoring, and particularly damage detection, especially difficult.

It is prepared in a way to accommodate the most important techniques for the analysis of vibration data measured on crushers and sieving screens. It allows for investigation in frequency and time-frequency domain, custom filtration using state-of-the-art collection of selectors, time-varying analysis, long-term historical analysis or even assessment of dynamic motion especially useful for machines mounted on a flexible suspension, such as sieving screen. The program allows to read multiple data files, perform the same type of analysis multiple times which generates separate cases in the report each time it is done, include additional images to the report (i.e. photographs of an investigated machine or the layout of the sensors used), create and save hardware profiles, upload historical data for long-term analysis - all in a systematic manner so as to facilitate the inspection- and maintenance-related work.

The application can be used in three ways:
- as a standalone desktop application (user is provided with an installation package), as a cloud service (user can login to the server instance where the application can be used via cloud),
- as a service without user involvement (user uploads data file and all the required information via online form,
- as the report of the analysis is provided to the user shortly after that).