Tool for the generation of mechanical vibration signatures
Matlab documentation

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Version 1.0
Last update: Sep 2018

This is a tool for the generation of synthetic mechanical signatures of faulted gears and bearings operating in non-stationary conditions. The main goal of this tool is to supply to the scientific community a standard tool for the generation of synthetic mechanical signatures. The tool is provided under Creative Commons license and it allows to simulate different possible situations: from the basic case of a single bearing fault to the case of a multi-stage gearbox having either a localized fault and a distributed REB fault. Among several features, the proposed tool could take also into account variable speed profiles of the input shaft, cyclostationary contributions and effects of LTI systems.

Please, cite us!

If you have used this tool in a scientific publication, we would appreciate citations to the following paper:

M. Buzzoni, G. D'Elia and M. Cocconcelli, "A tool for comparing signal processing techniques applied to machine diagnosis", Mechanical System and Signal Processing, 2018, *Submitted*.

Thanks.

Installation

This tool can be ran by means of the following steps:

1. unpack the .zip file that contains the launcher and the core files
2. open Matlab and set as working path the folder in which the launcher (`Mech_sign_gen_tool.m`) is contained
3. run the launcher `Mech_sign_gen_tool.m`

This tool works properly only if the user avoid to run commands through the command window. In case of errors or bugs, quit Matlab and repeat the previous steps.

Compatibility

This tool has been developed with Matlab 2017a and tested with Matlab 2016a and 2017a. The authors do not guarantee the compatibility by using Matlab versions different from Matlab 2017a.

Theoretical principles

All the theory in which the tool is rooted can be found at the following reference:

[1] M. Buzzoni, G. D'Elia and M. Cocconcelli, "A tool for comparing signal processing techniques applied to machine diagnosis", Mechanical System and Signal Processing, 2018, *Submitted.*

In this documentation, many equations deriving from Ref. [1] have been mentioned. Therefore, it is strongly suggested to read carefully Ref. [1] before the use this tool.

Main menu

The main menu is the menu that appears just after running the launcher called `Mech_sign_gen_tool.m`. It consists of 5 modules:

Module 1: allow to define of the speed profile.

Module 2: allow to set the parameters of the gear fault signature.

Module 3: allow to set the parameters of the bearing fault signature.

Module 4: allow to set the parameters of the stationary background noise.

Module 5: generate and save the signal in .mat format.

Speed profile module

The speed profile module allows to define two kind of speed profiles: a predefined speed profile and an arbitrary speed profile. Note that all the speed profiles are expressed in the angle domain. The predefined speed profile menu enables you to set the following parameters:

- the sampling frequency of the desired simulated signal in Hz;
- the number of points per revolution;
- the starting carrier frequency fc1 in Hz;
- the final carrier frequency fc2 in Hz;
- the frequency deviation fd in Hz;
- the value of the frequency modulation fm.

Note that all these parameters are referred to the input shaft. For the sake of clarity, these parameters refer to the following equation:

$$f_r[\theta] = \theta \left(\frac{f_{c2} - f_{c1}}{2\pi N_{rev}} \right) + f_{c1} + f_d \cos\left(f_m \theta\right) \tag{1}$$

An arbitrary speed profile can be used as well. The dedicated menu allows to load an arbitrary speed profile that must be a vector in .mat format. In this case, the following parameters can be set:

- the sampling frequency of the desired simulated signal in Hz;
- the number of points per revolution related to the loaded speed profile.

In both the menu, the user can visualize the speed profile through the button "plot and check".

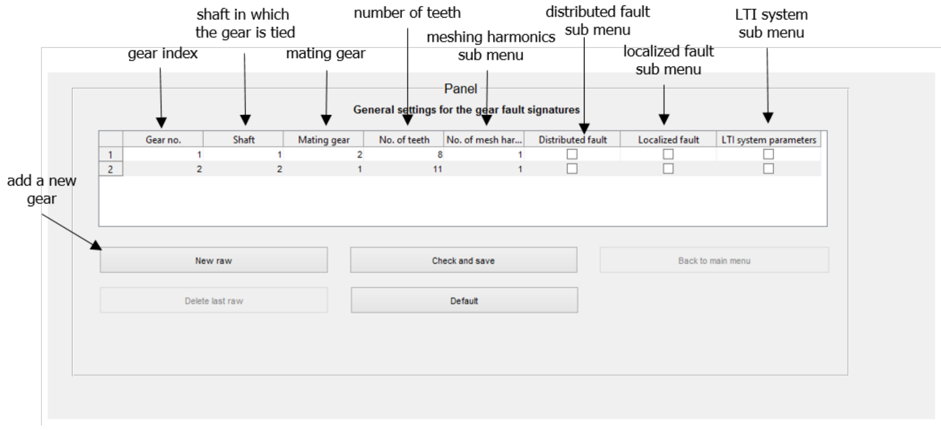

Figure 1: Description of the gear fault menu.

Gear fault module

In this module it is possible to replicate a synthetic vibration response of a (fixed axis) multi-stage gearbox with arbitrary localized and/or distributed faults. The main panel is depicted in Figure 1. Each row of the main panel refers to a specific gearbox shaft. In each row, the following parameters can be defined:

- the shaft number where the gear is tied (note that the shaft no. 1 is the input shaft);
- the mating gear (the user must refer to the Gear. no that is uniquely defined for each gear).
- the number of teeth.

There are also 4 sub-menus:

- "No. of mesh harmonics" (see Figure 2) allows to set the number of the sinusoidal mesh harmonics with their amplitude and phase;
- "distributed fault" (see Figure 3) allows to set the parameters of the simulated distributed faults that can be realized by phase/amplitude modulations and second order cyclostationary contribution as well;
- "localized fault" (see Figure 4) allows to set the parameters of the simulated localized faults that can be realized by phase/amplitude local modulations and pure impulsive contributions;
- "LTI" allows to set the parameters of the effect of LTI systems modeled as single-degree-of-freedom systems.

Figures 2 to 4 help the reader to make a connection between the equations in which this tool is rooted and the interface. Note that Ref. [1] is pivotal for a full comprehension of the equations reported in Figures 2 to 4.

Bearing fault module

In this module it is possible to replicate a synthetic vibration response of faulty rolling element bearings. The main panel is depicted in Figure 1. Each row of the main panel refers to a specific gearbox shaft. In each row, the following parameters can be defined:

- the shaft number where the bearing is tied (note that the shaft no. 1 is the input shaft);
- the geometrical parameters of the bearing such as rolling element number, bearing roller diameter, pitch circle diameter and contact angle

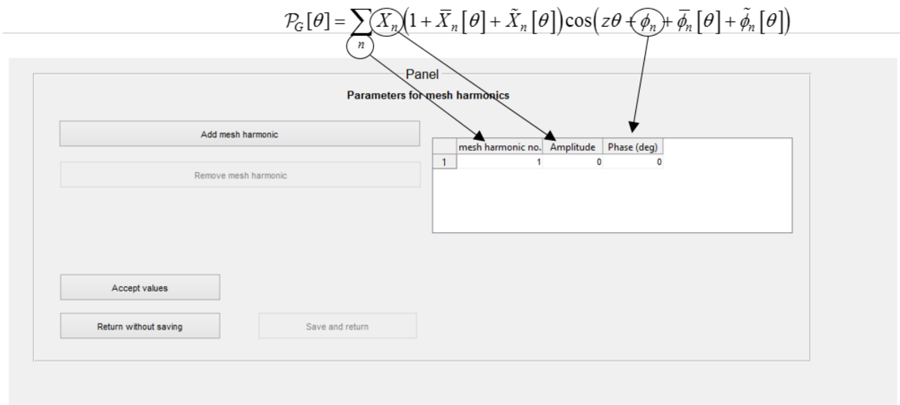

Figure 2: Description of the gear mesh sub-menu.

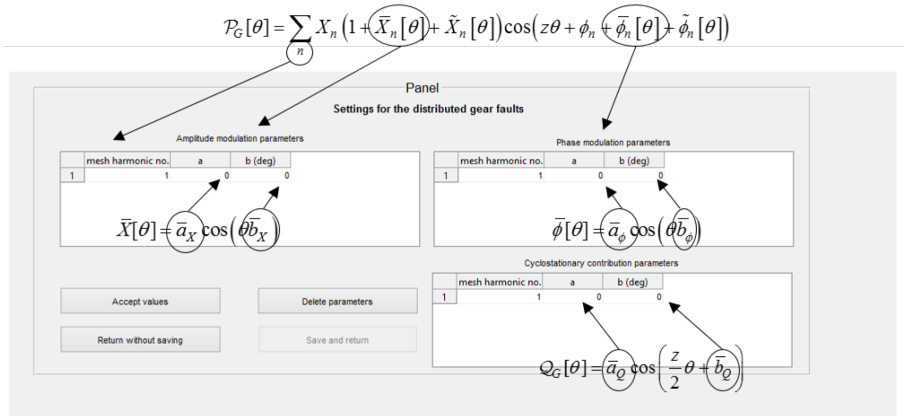

Figure 3: Description of the distributed gear fault sub-menu.

Furthermore, there are 2 sub-menus:

- "distributed fault" (see Figure 5) allows to set the parameters of the simulated distributed faults that can be realized by periodic contributions and/or (pure) second order cyclostationary contributions as well;
- "localized fault" (see Figure 6) allows to set the parameters of the simulated localized faults that can be realized by amplitude modulations and (pseudo) second order cyclostationary contribution as well;

Figures 5 and 6 help the reader to make a connection between the equations in which this tool is rooted and the interface. Again, note that Ref. [1] is pivotal for a full comprehension of the equations reported in Figures 5 and 6.

Background noise module

In this module it is possible to add stationary Gaussian background noise by defining its mean and variance. Furthermore, it is possible to convolve the background noise with a given Impulse Response Function modeled as a Single-Degree-of-Freedom system (see [1]) which can be useful for testing blind separation and blind deconvolution techniques.

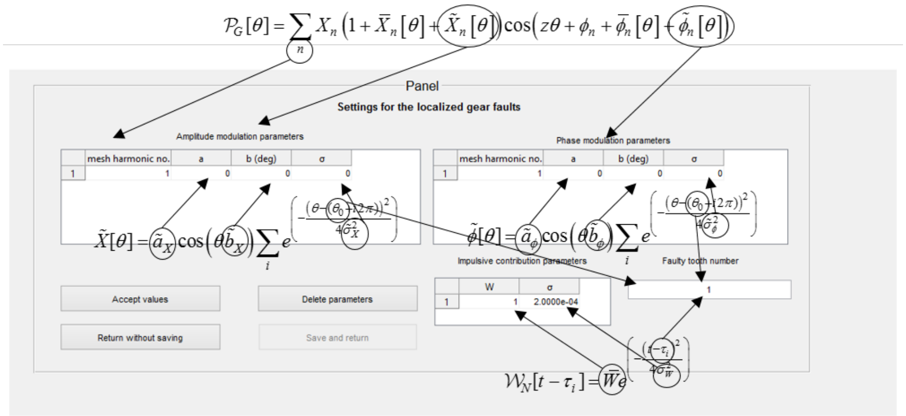

Figure 4: Description of the localized gear fault sub-menu.

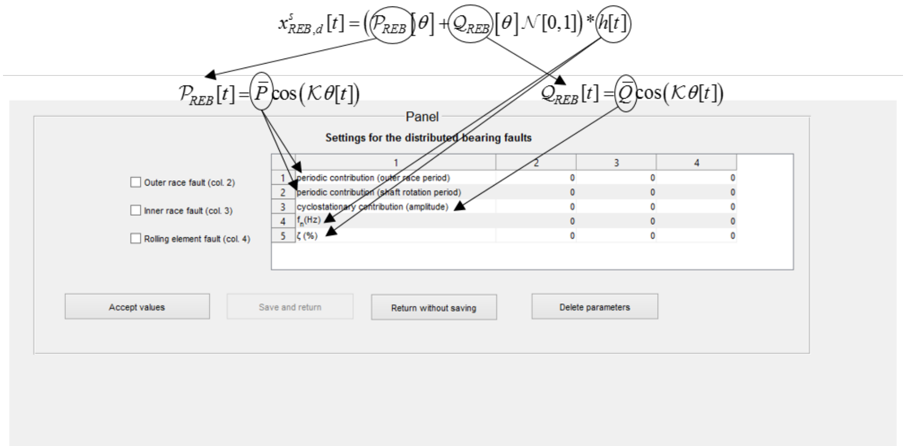

Figure 5: Description of the distributed bearing fault sub-menu.

Signal generation module

Once set all the parameters, the signal can be generated and then saved through this module. The signal is saved as .mat file and the following variables will be provided:

- a vector variable that contains the simulated signal, called `simulatedSignal`
- a vector variable that contains the response of the gear contributions only neglecting the background noise, called `gearResponseOverall`
- a vector variable that contains the response of the bearing contributions only neglecting the background noise, called `bearingResponseOverall`
- a cell variable called `gearfrTime` that contains the instantaneous speed (in the time domain) of each shaft of the simulated gearbox;
- a cell variable called `bearingfrTime` that contains the instantaneous speed (in the time domain) of each simulated bearing fault;
- a vector variable called `tau` that contains the transmission ratios of the simulated gearbox
- a vector variable called `estFaultFreq` that contains the characteristic bearing fault orders that have been simulated
- a variable called `fs` that expresses the sampling frequency

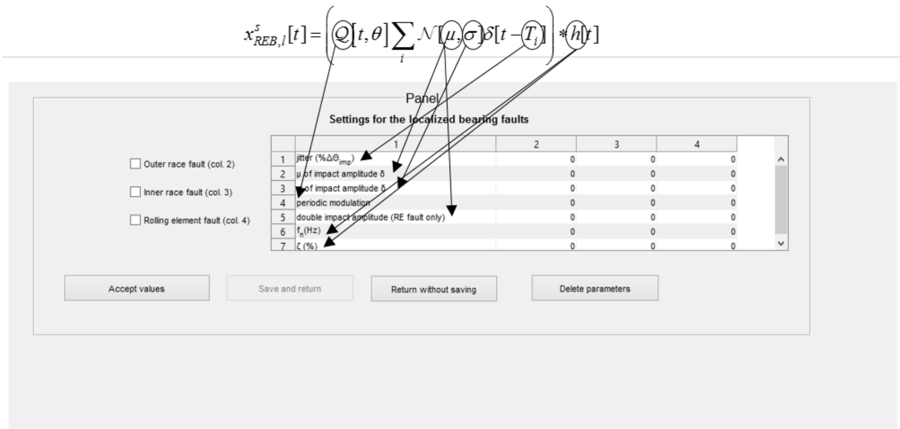

Figure 6: Description of the localized bearing fault sub-menu.

Known bugs

1. In the bearing fault module, if the user simulate more than one fault in the same raw (i.e. in the same shaft), the tool produces a fatal error. A possible work around is to simulate multiple bearing faults in the same shaft by adding one row each bearing fault.