Application Note

Machine Diagnostics in SKF @ptitude Observer 9 – Private Rules

Introduction

When analysing a vibration frequency spectrum, it can be a difficult task to find out which machine part causes a particular frequency. To make the analysis easier, there are ready-made formulas called "*diagnosis*" in SKF @ptitude Observer. These formulas are executed automatically and preform an intelligent vibration analysis of the machine and its machine parts. These formulas link together specific machine frequencies and its harmonics, with the correct machine part and possible cause of defect.

There are two types of diagnostic rules:

- The rules defined by the **User** are called ***Private*** diagnosis rules, and these rules can be customized for a specific application on your machine.
- The rules defined by **SKF** are called ***Standard*** diagnosis rules; see Application Note **CM3203**, *Machine Diagnostics in SKF @ptitude Observer 9 – Standard Rules*.

Fig. 1 shows a vibration trend for a standard ENV3 (SKF Envelope 3 filter) diagnose for a defect generator bearing (6324 C4) on the driven side (DS) on a wind turbine. The red and yellow lines are showing the alarm and warning levels respectively.

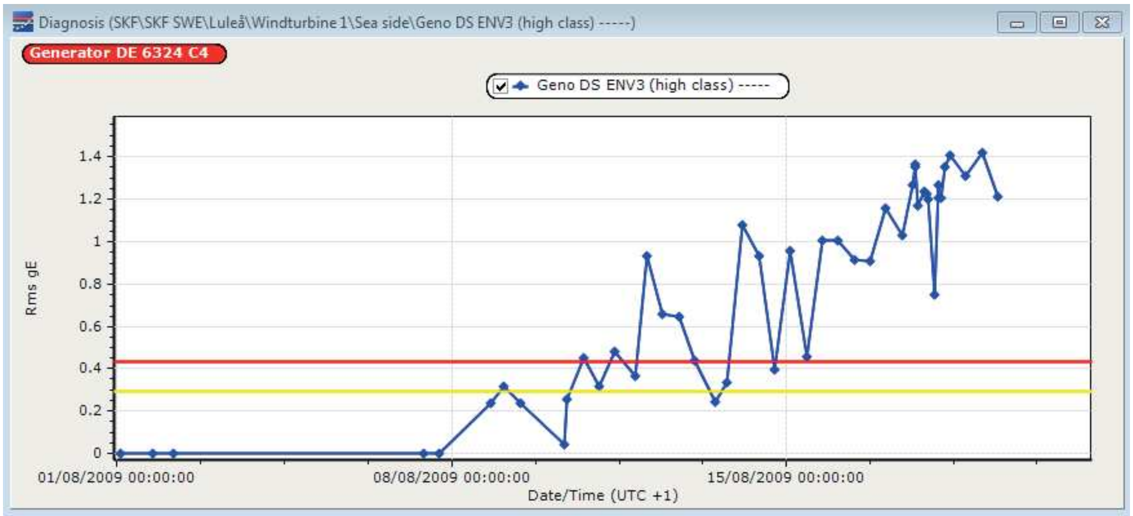


Fig. 1. An increasing ENV 3 diagnosis trend, for a defect outer race on a wind turbine generator bearing.

The Private diagnosis rules offer the SKF @ptitude Observer user an advanced toolbox when creating new diagnosis rules. This application note will in detail show two examples regarding how to create private diagnosis rules, based on the machine faults in **fig. 2** and **fig. 3a**.

Note: The machine parts tool has to be configured first, before creating the private diagnose rule. See application note **CM3213** for more information about how to create machine parts in SKF @ptitude Observer 9.

Wind turbine example

The SKF Envelope 3 vibration spectra in **fig. 2** shows a ball bearing with a damaged outer race. The bearing is located on the position "Generator NDE" on a wind turbine. The x-axis and y-axis are displayed in Hz and "gE PtP" respectively. The **red** arrows are pointing on the ball pass frequency outer race (BPFO) and some of its harmonics. The BPFO harmonics present in the lower part of the vibration spectrum indicate a bearing damage. Some of the harmonics to the BPFO are also sidebanded with the Fundamental Train Frequency (FTF), i.e., the bearing cage frequency, see the **blue** arrows in **fig. 2**. When the bearing wear progresses, the number of BPFO harmonics and FTF sidebands can increase. The bearing wear is now usually visible during a visual inspection of the bearing.

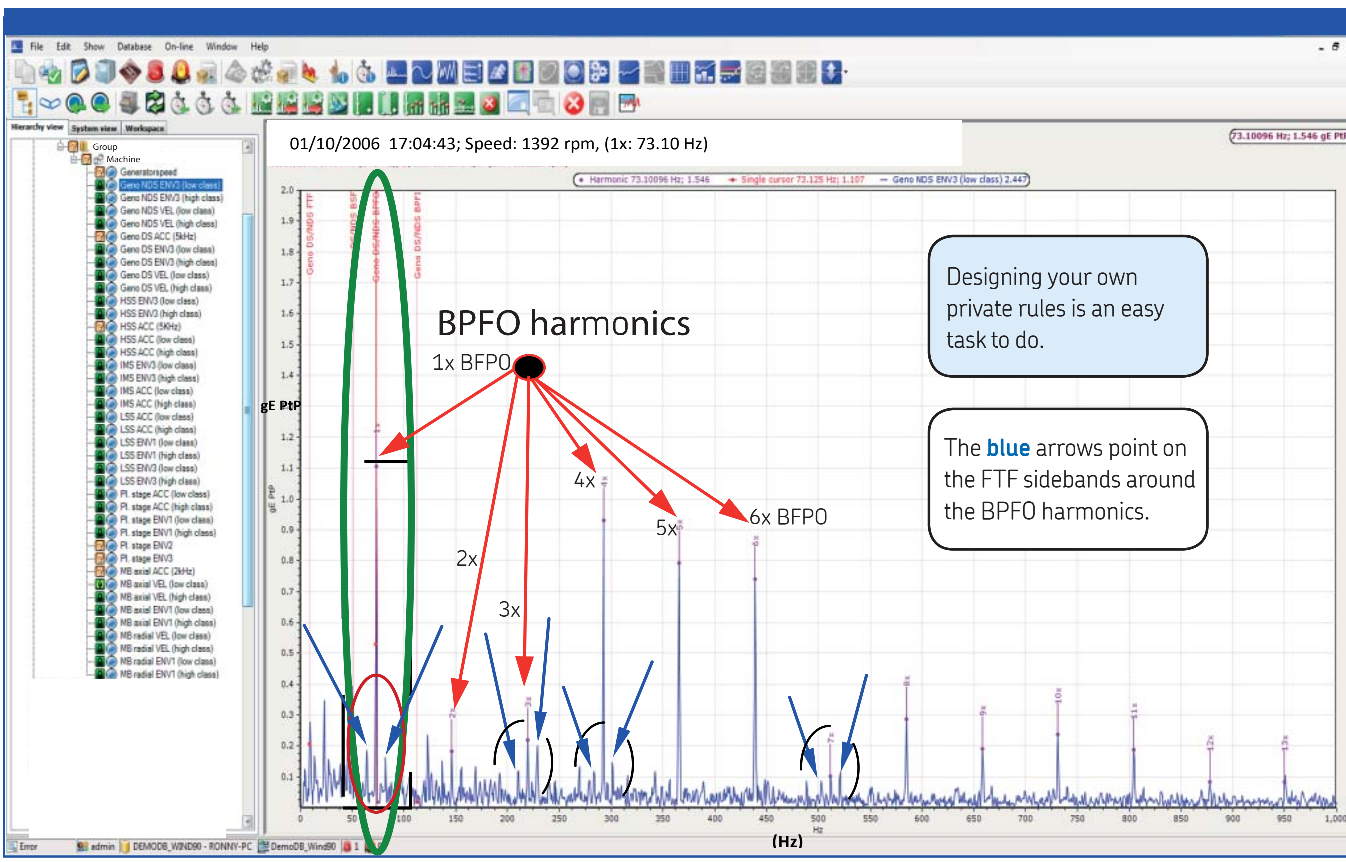


Fig. 2. An ENV 3 vibration spectra showing a generator bearing on a wind turbine with a severe outer race damaged, "BPFO" means "Ball Pass Frequency Outer race". The spectra time stamp is: 01/10/2006 at 17:04:43.

Underground mining haul truck example

During the analysis of the collected data, pinion bearing looseness and gear misalignment (2x Pinion GMF) was detected on a differential gearbox of an underground mining haul truck. See the vibration spectra in **fig. 3a**. The root cause of these faults was a too heavy load in the bucket of the truck when transporting the ore. This resulted in that the front differential and carrier assembly (→ **fig. 3b**), was repeatedly too heavy loaded. This overload resulted in several axle shaft breakdowns due to fatigue (→ **fig. 3c**). Visible wear marks due to bending of the axle shaft, including some surface fractures, could be seen on the axle shaft.

The sidebands around the second harmonic to the Gear Mesh Frequency (GMF) in **fig. 3a** are spaced with the **running speed** of the incoming cardan shaft to the gearbox. Gear misalignment will almost always excite the second order or higher GMF's, while bearing looseness normally produces many harmonics of the running speed of the shaft on which the bearing is mounted.

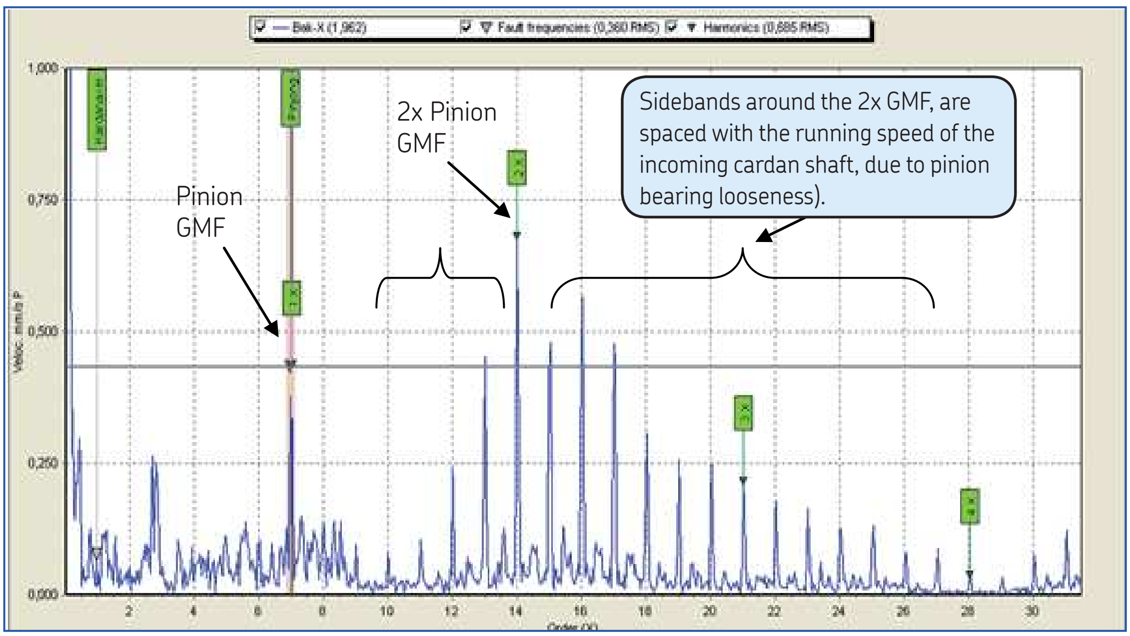


Fig. 3a. The vibration spectra is showing a gear misalignment and pinion bearing looseness on an underground haul truck. The X-axis is displayed in "Order" of the rotational speed of the cardan shaft, and the Y-axis is in "mm/s P".

The looseness in the pinion bearing increased over time, this finally caused the pinion gear to bend when the haul truck was fully loaded. This scenario resulted in misalignment between the pinion and the ring gear. The "bending" of the gear caused permanent damages on the gear teeth on the pinion and the ring gear due to fatigue (→ **fig. 3d**).

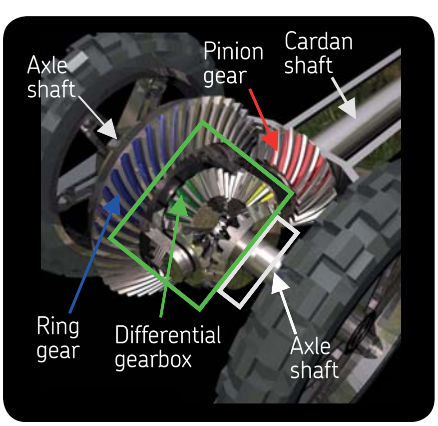


Fig. 3b. The front differential and carrier assembly on a haul truck.

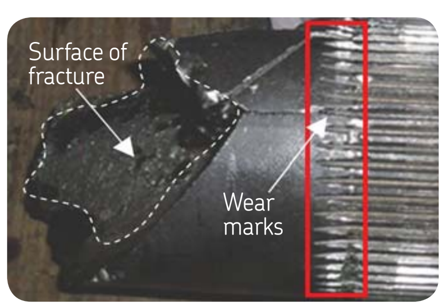


Fig. 3c. An axle shaft breakdown with visible wear marks from bending, due to repeatedly transporting a too heavy load in the bucket.

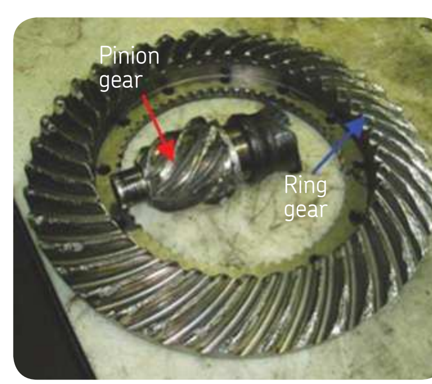
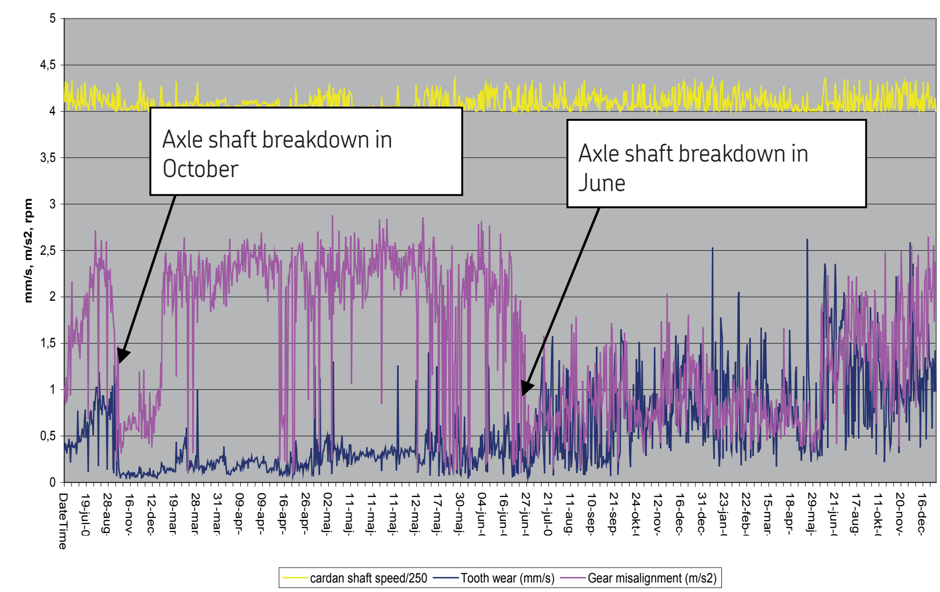


Fig. 3d. Severe damages on the pinion and the ring gear due to misalignment between these two machine parts.

Figs. 3e and **3f** show the vibration trend data for gear misalignment and tooth wear between the pinion and the ring gear on haul truck 1 and 2 respectively. The yellow line represents the running speed of the cardan shaft.

The time axis in the diagrams includes 2,5 years of measurement data. The measurement data in these figures have been exported from SKF @ptitude Observer to a Microsoft Excel diagram.

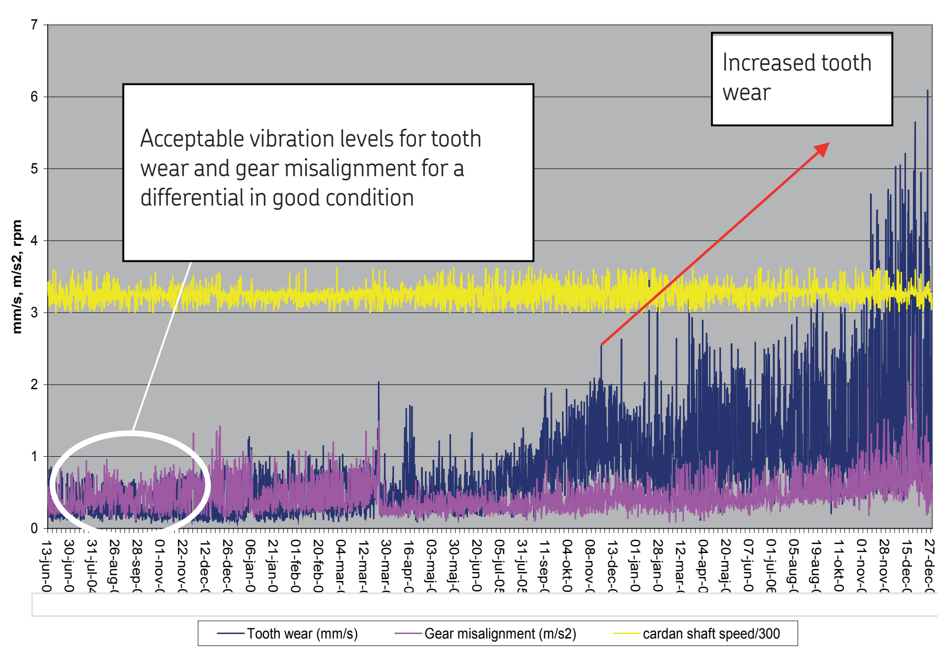


Yellow line = Cardan shaft speed/250

Blue line = Tooth wear in gearbox between the ring and pinion gear

Pink line = Gear misalignment between the pinion and the ring gear

Fig. 3e. Measurement point "Front axle" on haul truck 1 – the vibration trends for "tooth wear" and "gear misalignment between the pinion and the ring gear".



Yellow line = Cardan shaft speed/300

Blue line = Tooth wear in gearbox between the ring and pinion gear

Pink line = Misalignment between the pinion and the ring gear

Fig. 3f. Measurement point "Front axle" on haul truck 2 – the vibration trends for "tooth wear" and "gear misalignment between the pinion and the ring gear".

Procedure

There are three main steps for the user to create a private diagnose rule. You will now be guided on how to create the two private diagnosis rules for the machine faults in **fig. 2** and **fig. 3a**.

1 **Wind Turbine:** To create a diagnose rule called “BPFO FTF_sidebanded”, that calculates the number of cage frequency sidebands (**blue arrows**) around the harmonics to the BPFO, see **fig. 2**.
2 **Underground haul truck:** To create the diagnose rules called “Gear misalignment” (2xGMF) and “Bearing looseness”, see **fig. 3a**. This diagnosis rule calculates an RMS-overall vibration value for the frequency peaks in each rule.

Case 1: A wind turbine

To create a diagnose rule for the Wind Turbine, right-click on a machine in the hierarchy tree and select **Properties**, as in **fig. 4**. The **Machine properties** window in **fig. 5** opens.

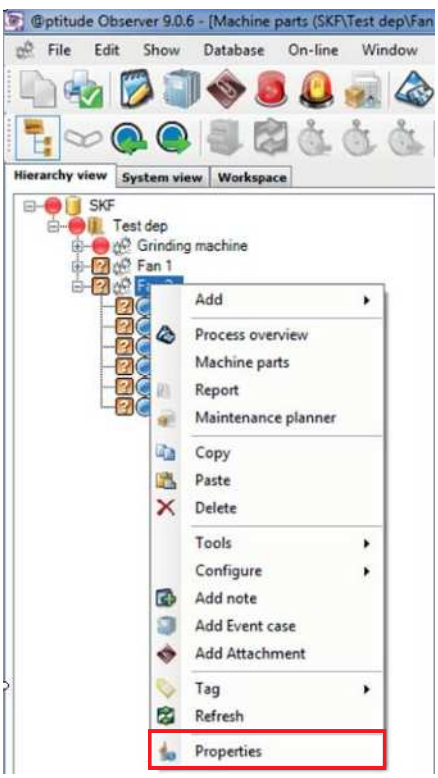


Fig. 4. Select “Properties” for the selected machine.

By clicking the **Attach** button in **fig. 5**, the window in **fig. 6** opens. In this window, you choose between attaching a "Standard" or a "Private" diagnose rule. To create a "Private" diagnose rule, click the **Create private diagnose** button in the same figure. The main interface for designing a "Private" diagnose rule opens (→ **fig. 7a**).

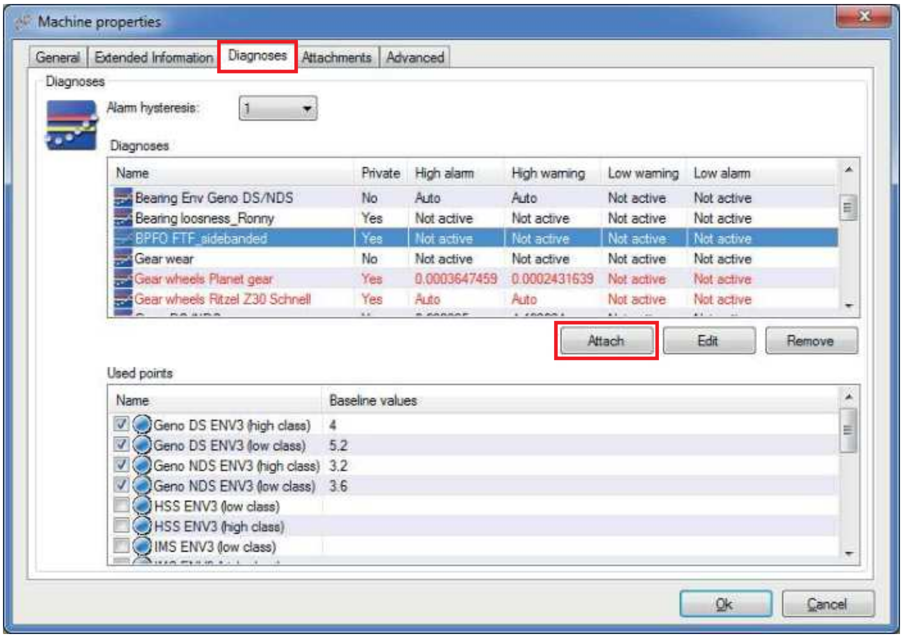


Fig. 5. The Machine properties window for adding new diagnosis rules to the machine.

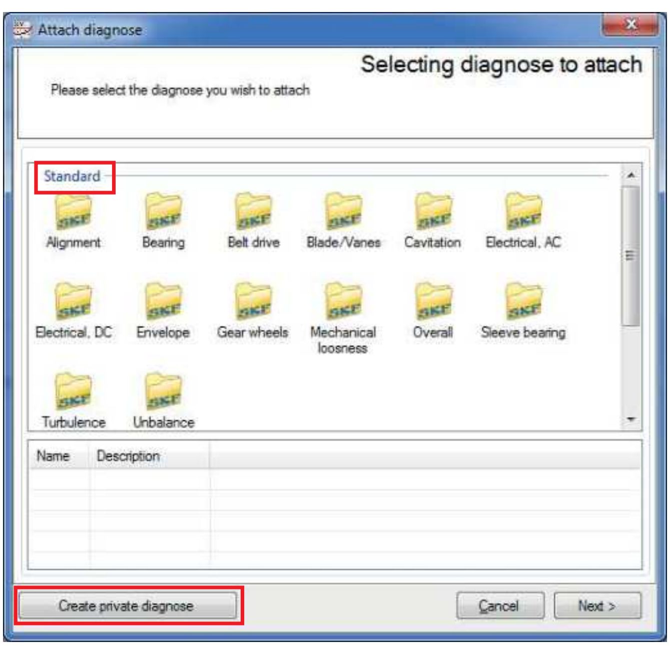


Fig. 6. Attaching a "Standard" or a "Private" diagnose rule to a machine.

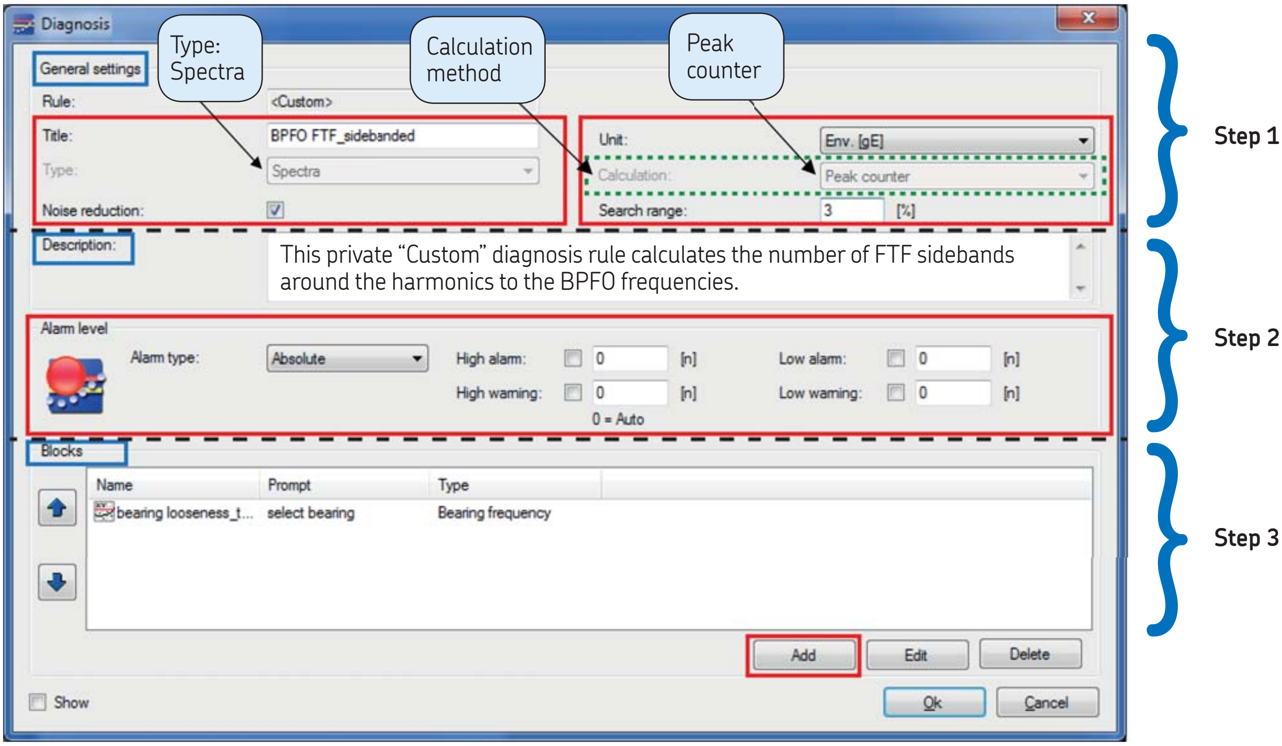


Fig. 7a. The interface for creating the private "Custom" diagnosis rule "BPFO FTF sidebanded" in fig. 2. In this case, no alarm levels are set.

The user configures the following to create a private diagnose rule:

- General settings
- Alarm type, and
- Blocks (specifies, for example, what type of frequencies to add or subtract from the rule)

The parameters for each step are explained for the creation of the new diagnose rule called "BPFO FTF_sidebanded" above. The user configures the "General settings", "Alarm level" and the building "Blocks" for the diagnose rule. The procedure for creating the diagnose in **fig. 7a** will be explained in **fig. 7b** to **fig. 10f**.

Note: What the diagnoses calculates is decided by the selected **"Calculation"** method. Since the diagnose rule in **fig. 7a** will calculate the **"no. of sidebands"** around the harmonics to the "BPFO", the option **"Peak counter"** was selected in this case.

Step 1 – General settings

- **Rule:** The rule is automatically set to “Custom” when adding a private diagnose (→ **fig. 7a**).
- **Title:** Select an appropriate title, in this case diagnose was called “BPFO FTF_sidebanded”.
- **Type:** The type can be set to “Spectra” or “Time waveform”.
- **Noise reduction:** Applies a filter that removes the noise from the spectra before the diagnosis calculation begins. Recommended to set to “On”.
- **Unit:** For an envelope diagnose, only two options are available (→ **fig. 7b**). In this case, “Env. [gE]” was selected.
- **Calculation** method and **Search range** will be explained separately below in **figs. 7c** and **7d**.

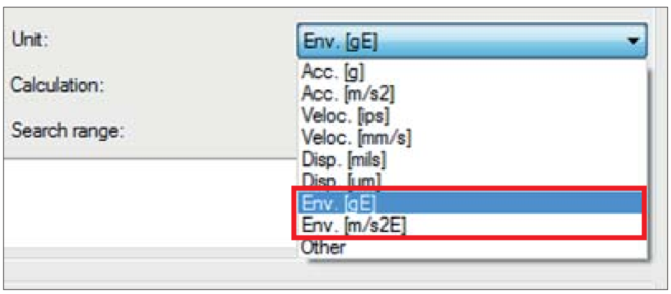


Fig. 7b. Select the engineering unit – “Env. [gE]”.

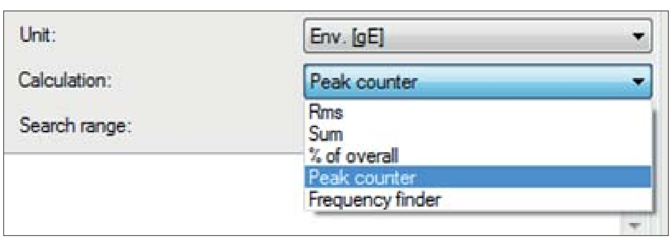


Fig. 7c. Select calculation method – “Peak counter”.

Calculation method:
In this case, the option “Peak counter” was selected, since the diagnose will count the number of sidebands around the harmonics to the “BPFO” frequency in **fig. 2**.

The other calculation methods in **fig. 7c** will do the following:

- **Rms** calculates the “RMS-value” for all the vibration peaks included in the rule.
- **Sum** calculates the “Sum-value” for all vibration peaks that are included in the rule.
- **“% of overall”** calculates the “RMS-value” of the selected frequencies and divides it by the “RMS-value” for the vibration spectra.

Note: The **“% of overall”** can, for example, make a more smoother vibration trend if the vibration levels vary a lot on the machine due to a varying “load”.

- **Frequency finder** finds the highest peak and trend its value.

- **Search range:** The diagnosis tool can, for example, calculate the number of sidebands around the BPFO frequency, based on the specified frequency band defined by the user. In this case, the frequency range “1 kHz” was selected and the “Search range” was set to 3% in **fig. 7a**.
  – **Calculation of the search range:** 3% out of 1 kHz is 30 Hz = 1 800 cpm (→ **fig. 7d**)

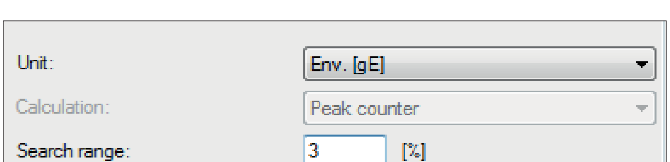


Fig. 7d. The search range is set in % and is calculated based on the frequency range for the vibration spectra.

Step 2 – Alarm type

There are two different types of alarms used for diagnosis trend, (→ **figs. 8a** and **8b**).

- **Absolute** means the alarm values are set in engineering units, like m/s^2 or mm/s.
- **Relative** means the alarm levels are set in percent (%) of a baseline level. The baseline level is calculated based on a number of historical values. This value can be recalculated at any time.
  Note: Relative alarm levels are the preferred way when viewing several trends in a diagram.
- **Alarm/Warning:** Setting the “alarm/warning” levels to “0” means that the “alarm/warning” levels will be automatically calculated when five consecutive vibration spectra measurements have been stored in the database (→ **figs. 8a** and **8b**). These alarm levels can at any time be edited by the user, by dragging and dropping the alarm levels in the diagnosis trend diagram.

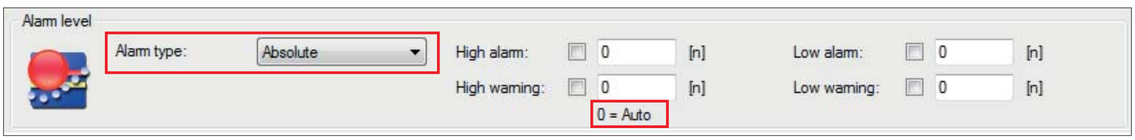


Fig. 8a. Alarm type – “Absolute”.

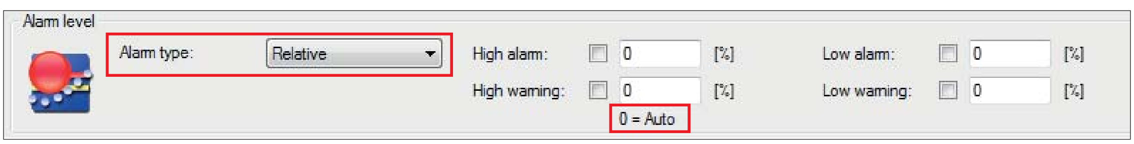


Fig. 8b. Alarm type – “Relative”.

The **warning level** is calculated as:

The **“average value”** for the measurements in the diagnosis trend + (plus) **“3x the standard deviation”** of the diagnosis trend.

The **alarm** level is calculated as:

1.5 x warning level (i.e., 50% higher than the warning level).

Step 3 – Adding blocks (i.e., building blocks)

“Blocks” are different types of frequencies used in the calculation of the diagnosis rule. A diagnose can consists of several “blocks”, where some “blocks” add frequencies and other “blocks” may subtract or “zero out” frequencies from the diagnose rule.

Each **“block”** includes specific frequencies from the machine, for example:

- A bearing frequency like “BPFO”
- The rotational speed of a shaft
- The number of blades on a fan wheel
- The number of teeth on a gear wheel

"Blocks" can also be configured by:

- Adding, subtracting or “zeroing out” frequencies, or editing and deleting existing “blocks”.

To add a new "Block", click the **Add** button in **fig. 9a**. The window in **fig. 9b** opens.

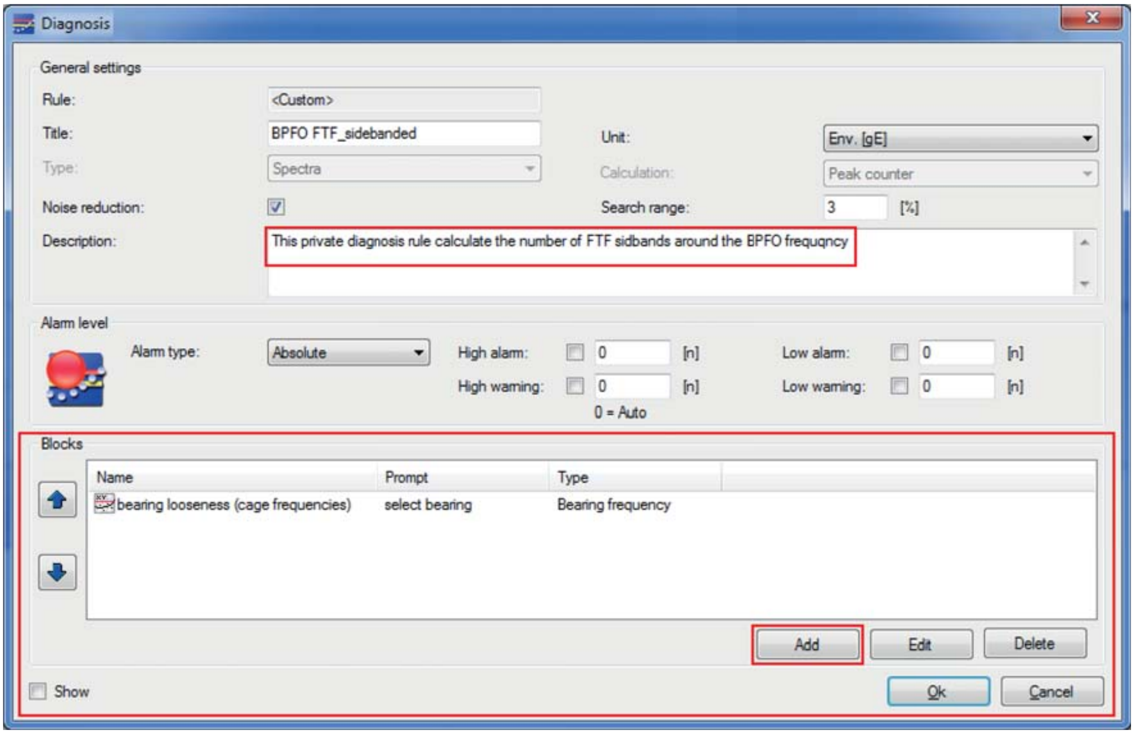


Fig. 9a. Adding a new block to the rule called "bearing looseness (cage frequencies)". This private diagnose calculates the number of FTF sidebands around the BPFO harmonics.

General settings (in fig. 9b)

- **Name** is the name of the block.
- **Prompt** is what to ask the user when attaching the diagnose. If the "Prompt" is the same on the other blocks, the user will be asked only once.

- **Calculation** can **add** or **subtract** frequencies from the diagnosis rule. "Zero out" will set the vibration amplitudes for the selected frequency to zero (see **fig. 11f**).
- **Type** is the selected type of frequency that will be used by the rule. Depending on the selection of "Type", different types of machine parts are selectable. In this case, the type "Bearing frequency" was selected in **fig. 9b**. The selection of bearings is limited to bearings added to the machine part tool for this machine.
  Note: See Application Note **CM 3213** for more information about the machine part tool.

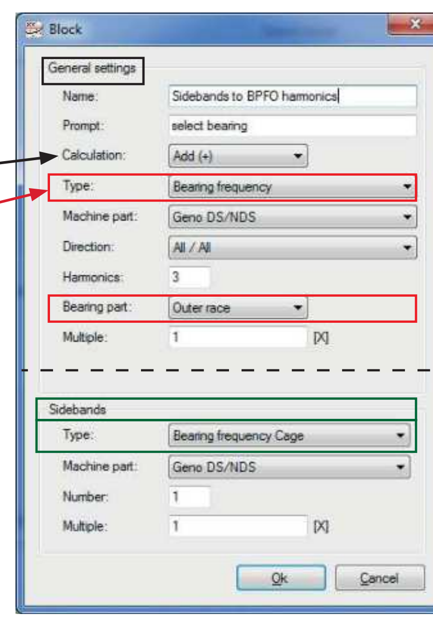


Fig. 9b. The building "Block" for the diagnose rule called "Example 1".

- **Direction** specifies in which direction the data will be calculated in, for example, horizontally, vertically or all.
- **Harmonics (Harm)** specifies the number of harmonics that shall be included in the calculation.
  Note: Harm.=0 includes only 1xBPFO, **Harm.=1** includes "1xBPFO and 2xBPFO", **Harm.=2** includes "1xBPFO, 2xBPFO and 3xBPFO", and so on.
- **Bearing part** specifies which machine part of the bearing to trend. In this case, the "Outer race" was selected.
- **Multiple** specifies the starting frequency for the "Harmonics". **Multiple 1** in combination with **three** "Harmonics" means that the diagnosis rule will include the frequencies 1xBPFO, 2xBPFO, 3xBPFO and 4xBPFO in the diagnose rule. If we, for example, select **"Multiple=2"** in combination with **three** "Harmonics", the rule will include the frequencies 2xBPFO, 4xBPFO, 6xBPFO and 8xBPFO in the diagnose rule.

Sidebands (in fig. 9b)

The “Type” of sidebands does also define the machine part to trend. Depending on your selection of “Type” in the “General settings”, different machine parts’ frequencies will be selectable as “Sidebands”. In this case, the type “Bearing frequency Cage” was selected, since the rule will calculate the number of sidebands around the BPFO harmonics.

Note: In each “Block” it is only possible to select one of the bearing parts that have been added to the machine parts tool interface.

Note: To add a second bearing frequency, a second block must be added to the rule. However, this is not recommended in this case.

When ticking the “Show” checkbox in **fig. 9c**, the frequency peaks that the diagnose includes in the calculation of the number of sidebands around the four BPFO harmonics are displayed in a spectrum. When calculating the **red dots** inside the **purple square**, the sum will be equal to 10 peaks. **Why is it 10 peaks instead of six peaks?** It is 10 peaks because the four harmonics to the BPFO frequency are also counted. **Fig. 9d** shows a close up of the result in **fig. 9c**.

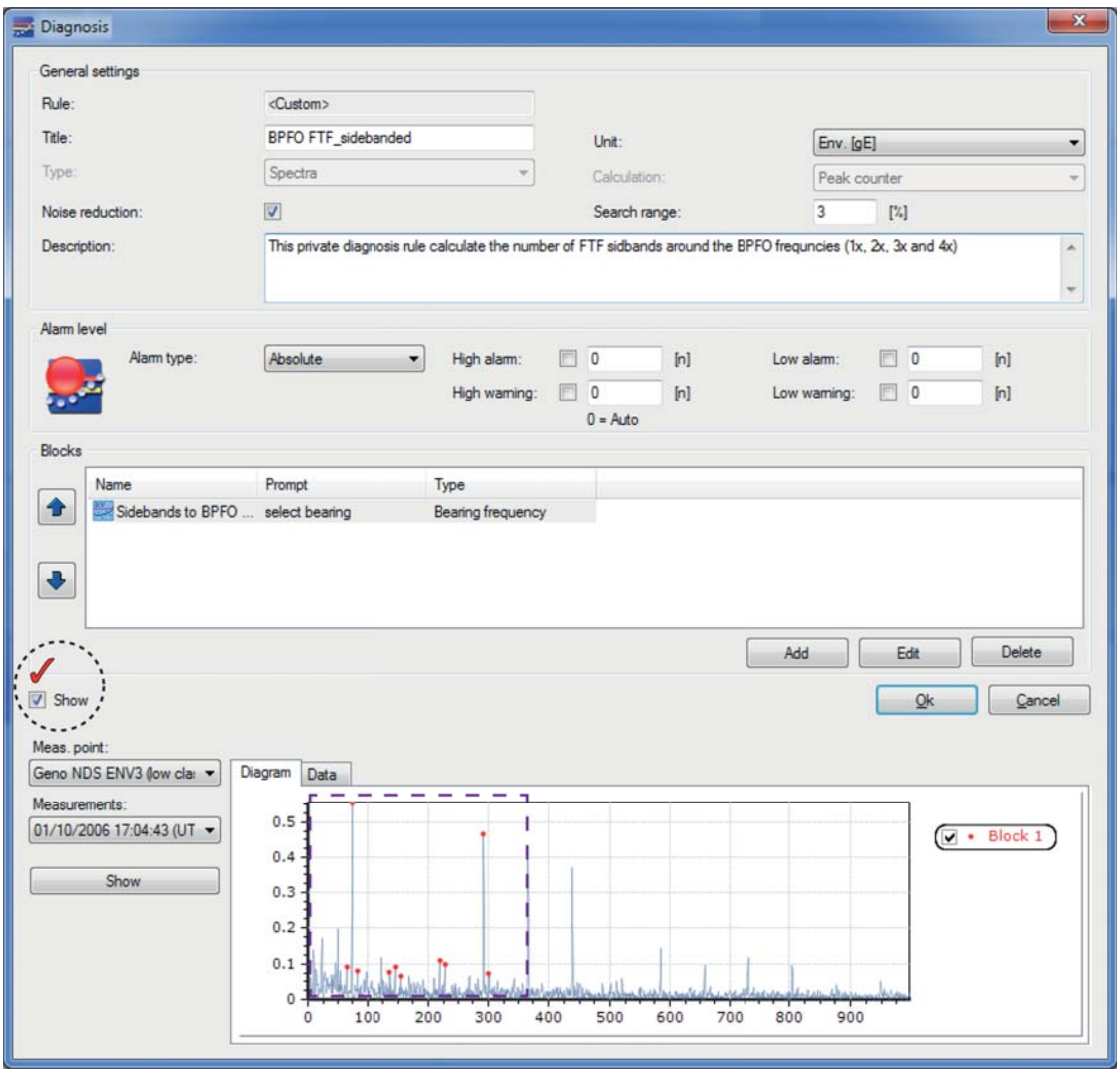


Fig. 9c. Viewing the result of the calculation of the number of sidebands around the four BPFO harmonics.

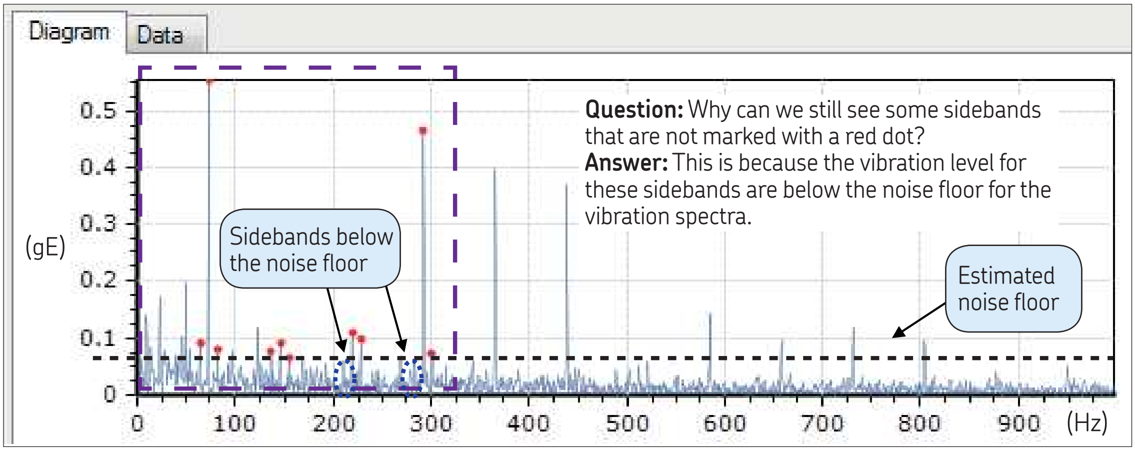


Fig. 9d. A close up of the vibration spectra in fig. 9c.

Fig. 9e shows a zoom in of the sidebands that are below the noise floor in **fig. 9d**. These two peaks are marked with a **dotted black circle**, and they will not be counted as sidebands in the diagnose rule. **Note:** The actual vibration level of the noise floor is not available for the SKF @ptitude Observer user. The dotted **black line** in **fig. 9e** is an estimation of the noise floor level (around 0.06 gE). The noise floor level is based on the sidebands that are marked with a dotted black oval circle, since they are below the noise floor.

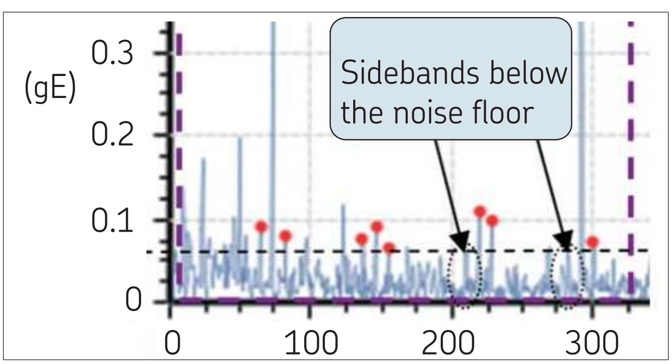


Fig. 9e. A close up of the sidebands that are below the noise floor.

Fig. 9f shows the diagnose trend for the number of sidebands around the BPFO frequencies for the diagnose “BPFO FTF_sidebanded”. The black circle shows the number of sidebands including the number of harmonics to the BPFO frequencies for the vibration spectra in **fig. 2**.

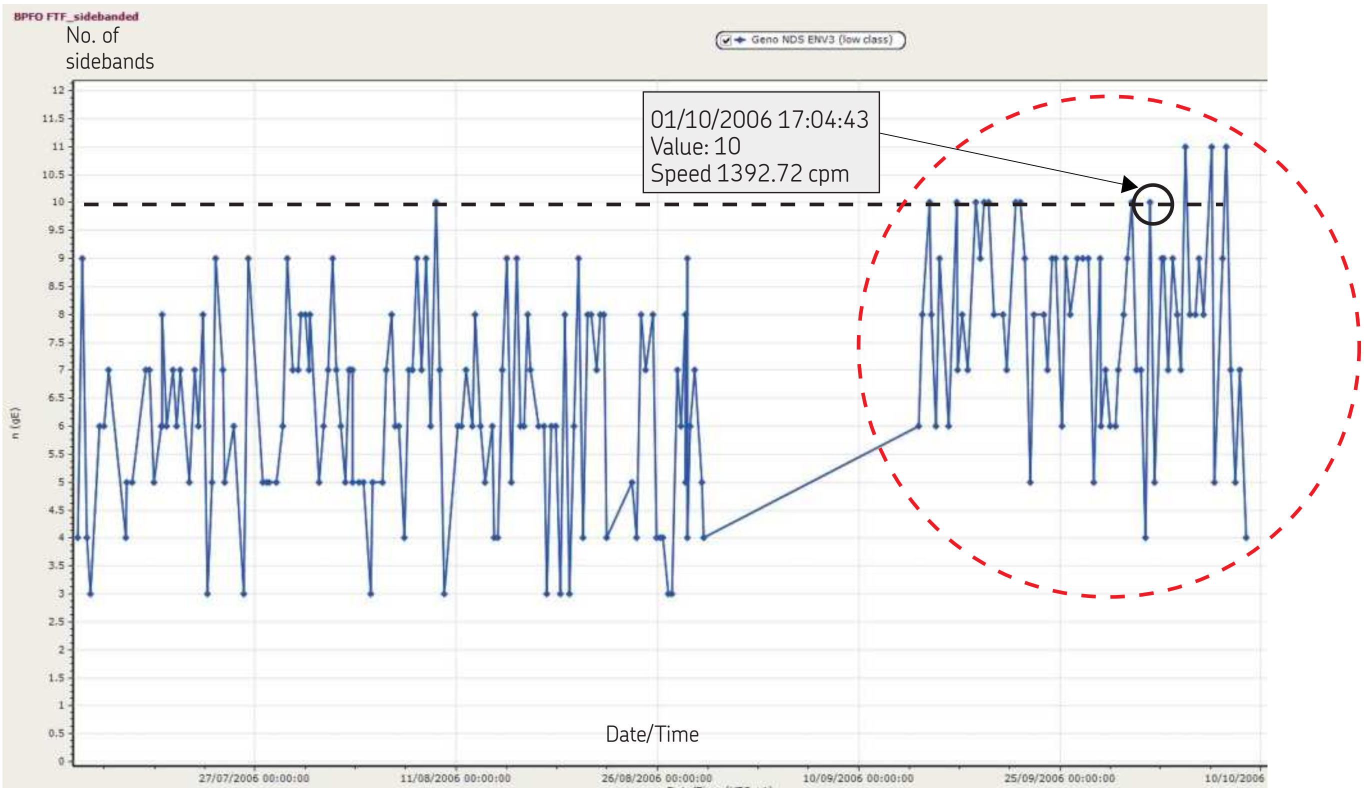


Fig. 9f. Displaying the number of sidebands around the 1xBPFO frequency from September 13 to October 10. Note: The harmonics to the BPFO are also counted as sidebands.

Fig. 9g shows a close up the marked area in **fig. 9f**. Both these figures are marked with the date when the vibration spectra in **fig. 2** was collected.

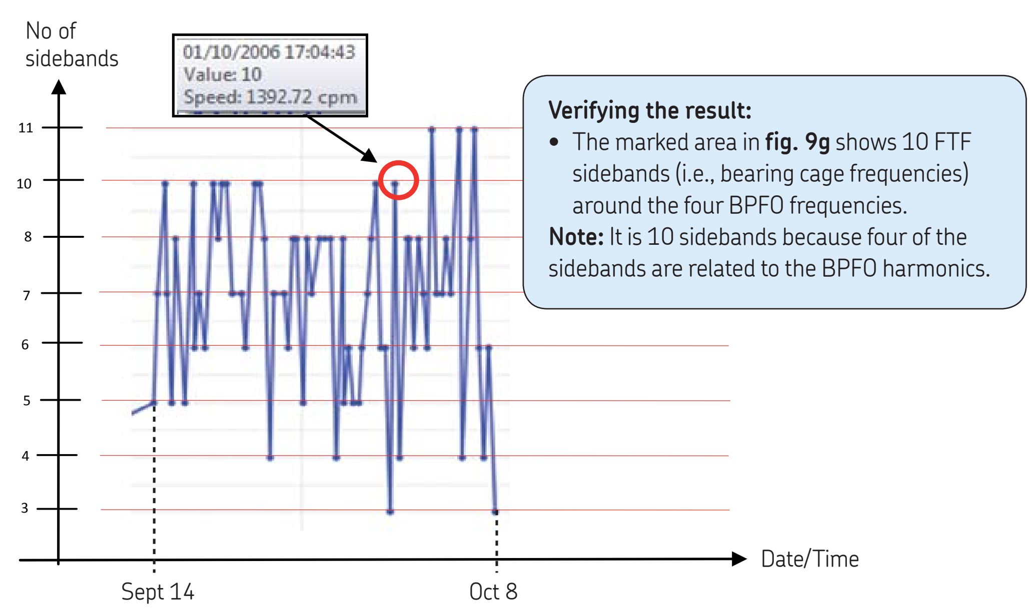


Fig. 9g. A close up of marked area in fig. 9f.

Calculating the true number of sidebands in fig. 2

In this example, the calculation of the true number of sidebands around the BPFO harmonics is explained. To do that, the harmonics to the BPFO has to be excluded from the vibration spectra when counting the number of sidebands.

By adding a second "Block" called "Remove BPFO harmonics" to the diagnose rule in **fig. 10a**, it will be possible to **subtract** the four BPFO harmonics from the vibration spectra. The improved diagnose rule will only calculate the number of the "FTF sidebands" around the BPFO harmonics. **Fig. 10b** shows a close up of the building "Block" that will remove the harmonics from the vibration spectra in **fig. 10a**.

Fig. 10a shows the same vibration spectra as we saw earlier in **fig. 9c**, but the difference between these two figures is that there are now two building "Blocks" in this improved diagnosis rule. This new "Block" is marked with a **blue** frame in **figs. 10a** and **10b**. **Fig. 10c** shows a close up of the vibration spectra in **fig. 10a**. The details for the two building blocks are displayed in **figs. 10d** and **10e**.

Conclusion: The improved diagnose "BPFO FTF_sidebanded" in **fig. 10f** is now showing the true number of sidebands around the four BPFO harmonics. The number of sidebands is equal to six sidebands.

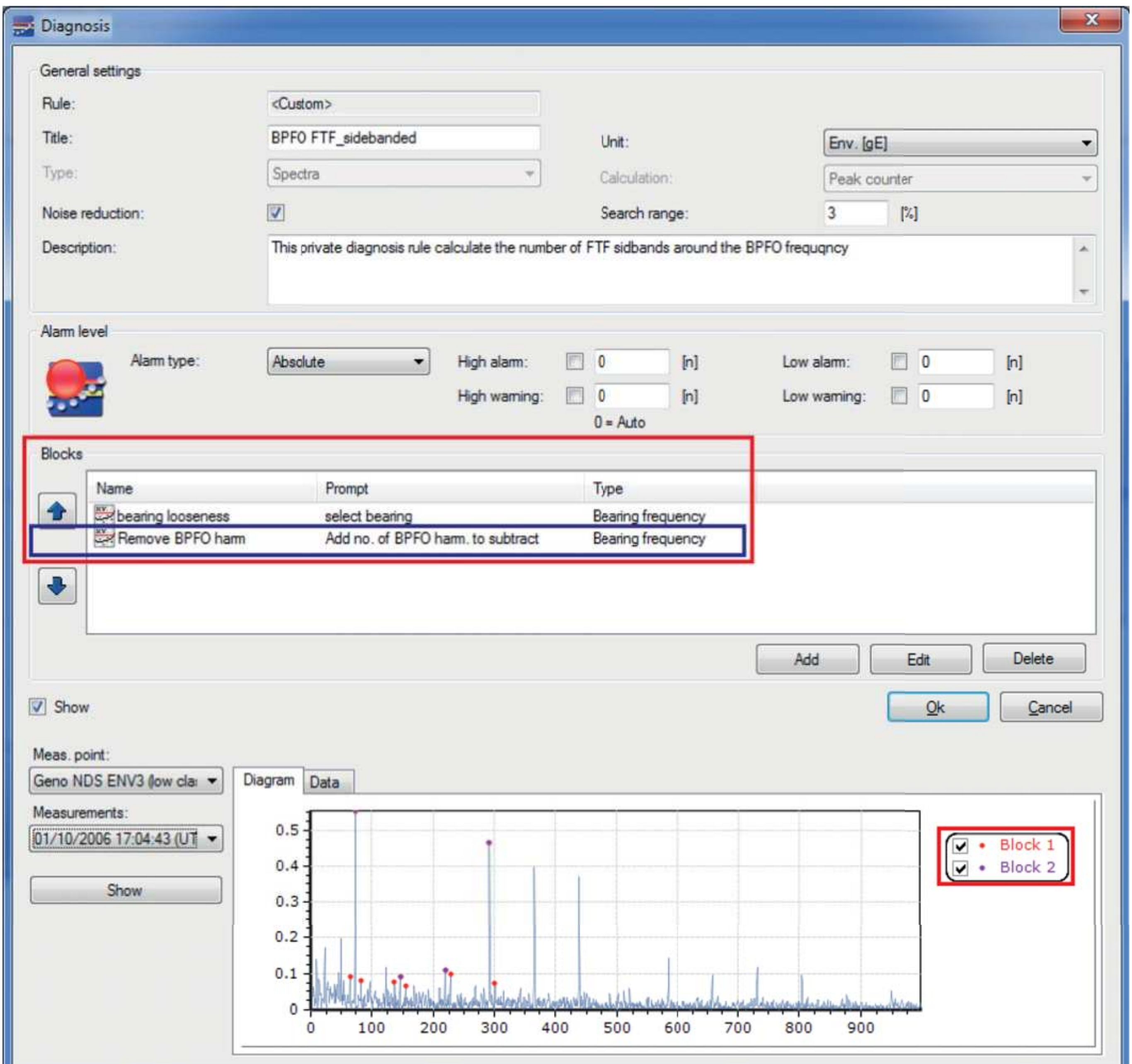


Fig. 10a. The diagnose rule in fig. 9a has been improved by subtracting the four BPFO harmonics before the calculation of the number of sidebands is executed.

Fig. 10b. A close up of the new building "Block" that will subtract the BPFO harmonics from the rule.

Note: When removing (subtracting) frequencies from a rule, the first "Block" in the rule has to be the "Block" that "Adds" frequencies.

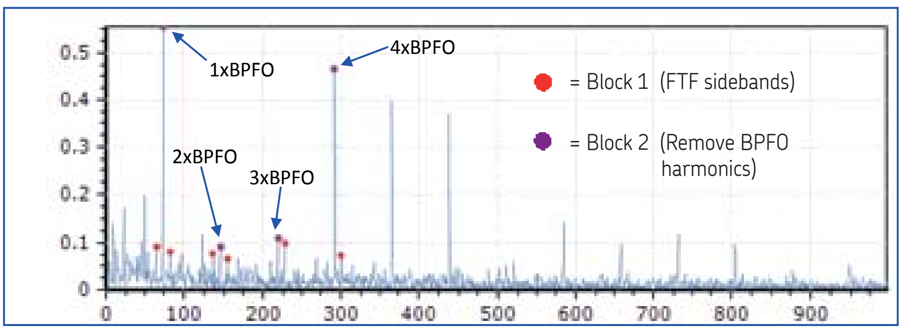


Fig. 10c. A close up of the vibration spectra in fig. 10a.

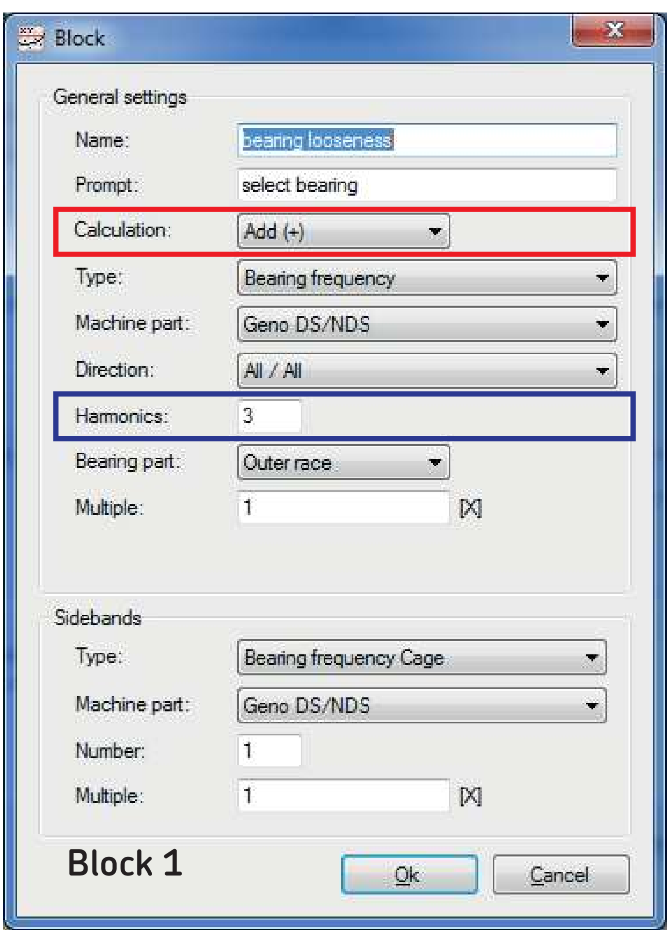


Fig. 10d. Block 1 includes all the four harmonics to the BPFO, including sidebands to the FTF frequency (i.e., cage frequency).

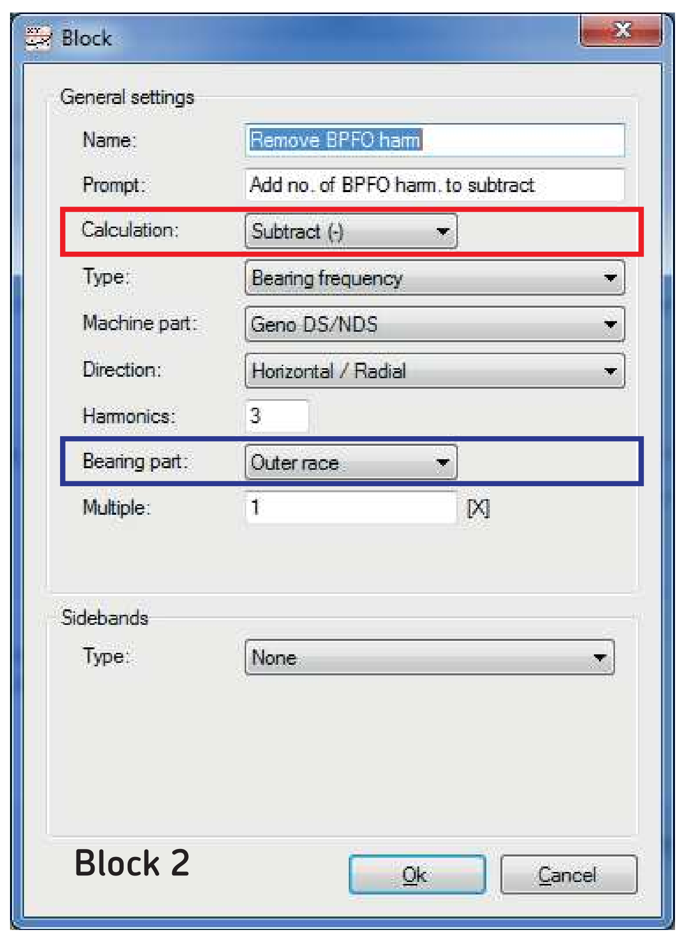


Fig. 10e. Block 2 subtracts the four BPFO harmonics from the rule. (Note: Harmonics=0 is equal to 1xBPFO.)

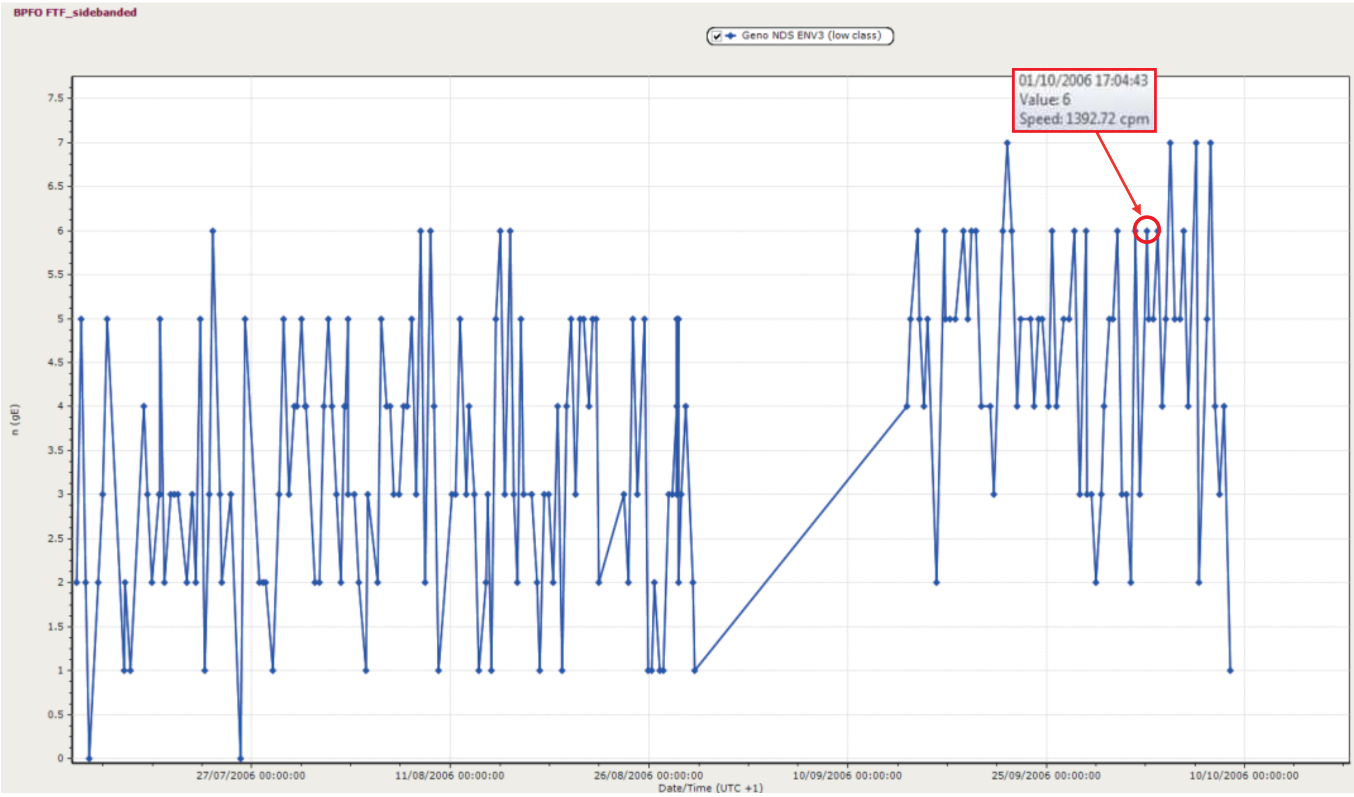


Fig. 10f. The improved diagnose "BPFO FTF_sidebanded" now shows the true number of sidebands around four BPFO harmonics on the position "Generator NDE ENV3". In total, six sidebands were detected.

Case 2: An underground haul truck

The two diagnosis rules below were created for an underground haul truck:

- Gear misalignment
- Pinion bearing looseness

Note: These examples are old cases, and we do not have access to the measurement data from the haul truck to be able to recalculate the diagnosis trends for these machine faults. However, the real diagnosis trends can be viewed in the Excel diagrams in **figs. 3e** and **3f**.

Gear misalignment

Fig. 11a shows the "General settings" for the diagnose rule called "Gear misalignment". A close up of the building block is shown in **fig. 11b**. **Fig. 11c** shows the detailed settings for the "Block". This rule will calculate an RMS-value in velocity (mm/s) for all vibration peaks that are included in the rule.

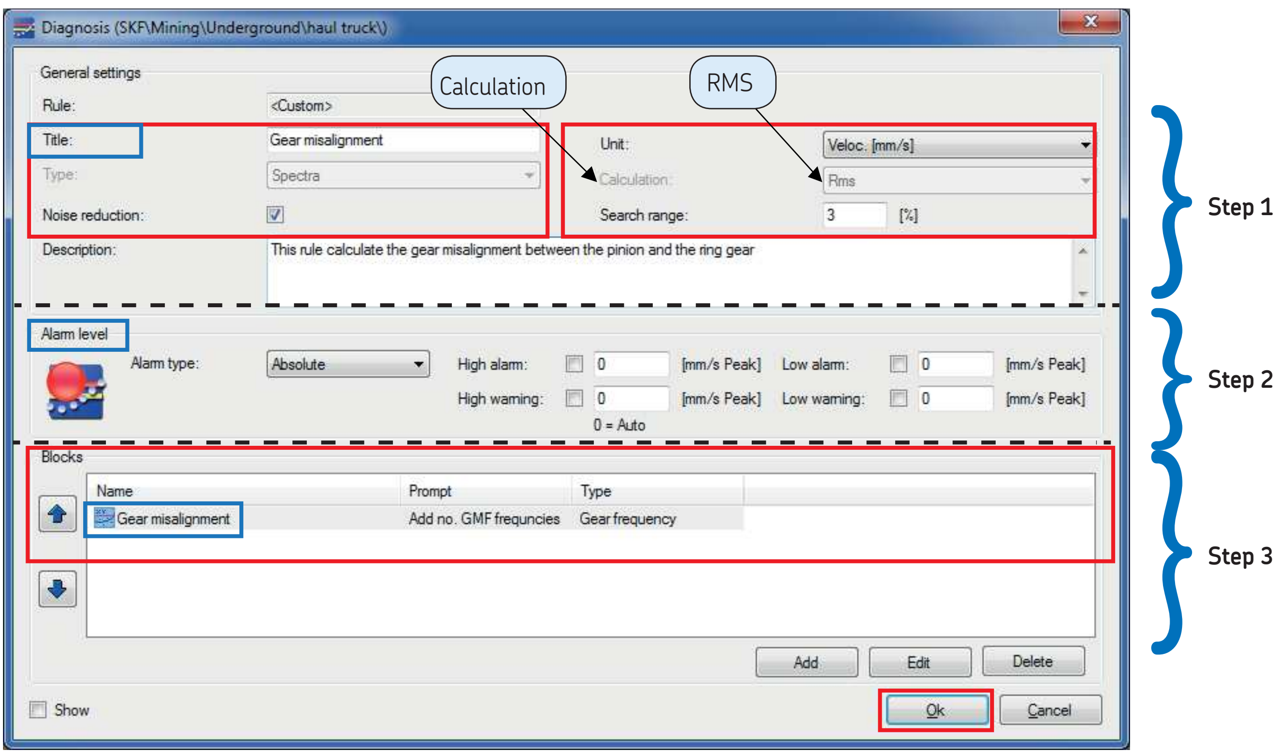


Fig. 11a. Designing a diagnose rule for gear misalignment between the pinion and the ring gear in fig. 3a. The engineering unit for the vibration level is velocity in (mm/s).

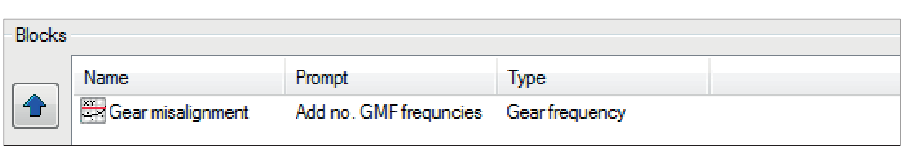
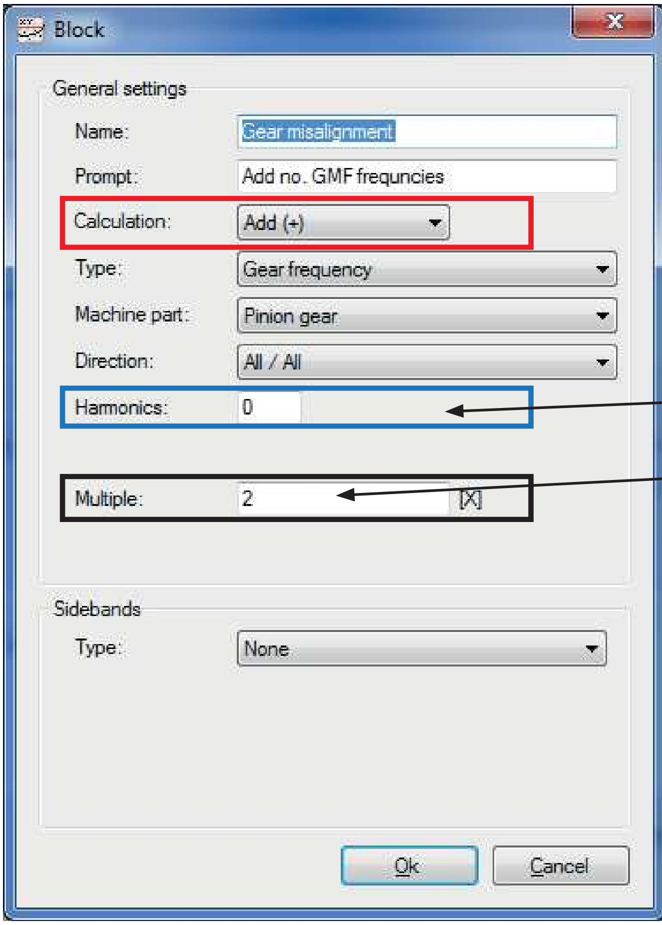


Fig. 11b. A close up of the building "Blocks" in fig. 11a.



Note:

Harmonics=0 will monitor the frequency "1xGMF".

Setting the parameter **Multiple=2** results in that the diagnose rule will calculate a diagnosis trend for the frequency "2xGMF".

Fig. 11c. The diagnose rule for calculating the gear misalignment between the pinion and the ring gear in fig. 3a.

Pinion bearing looseness

To calculate the diagnose rule for pinion bearing looseness, the frequency components for:

- Unbalance,
- Misalignment, and
- Pinion gear mesh frequencies

need to be eliminated from the vibration spectra in **fig. 3a**. All these frequencies are dependent upon the rotational speed of the cardan shaft. The general settings and the building “Blocks” for the diagnose rule is shown in **fig. 11d. Fig. 11e** shows a close up of the three building “Blocks” that will do the job. The diagnose rule will calculate an RMS-value in (g).

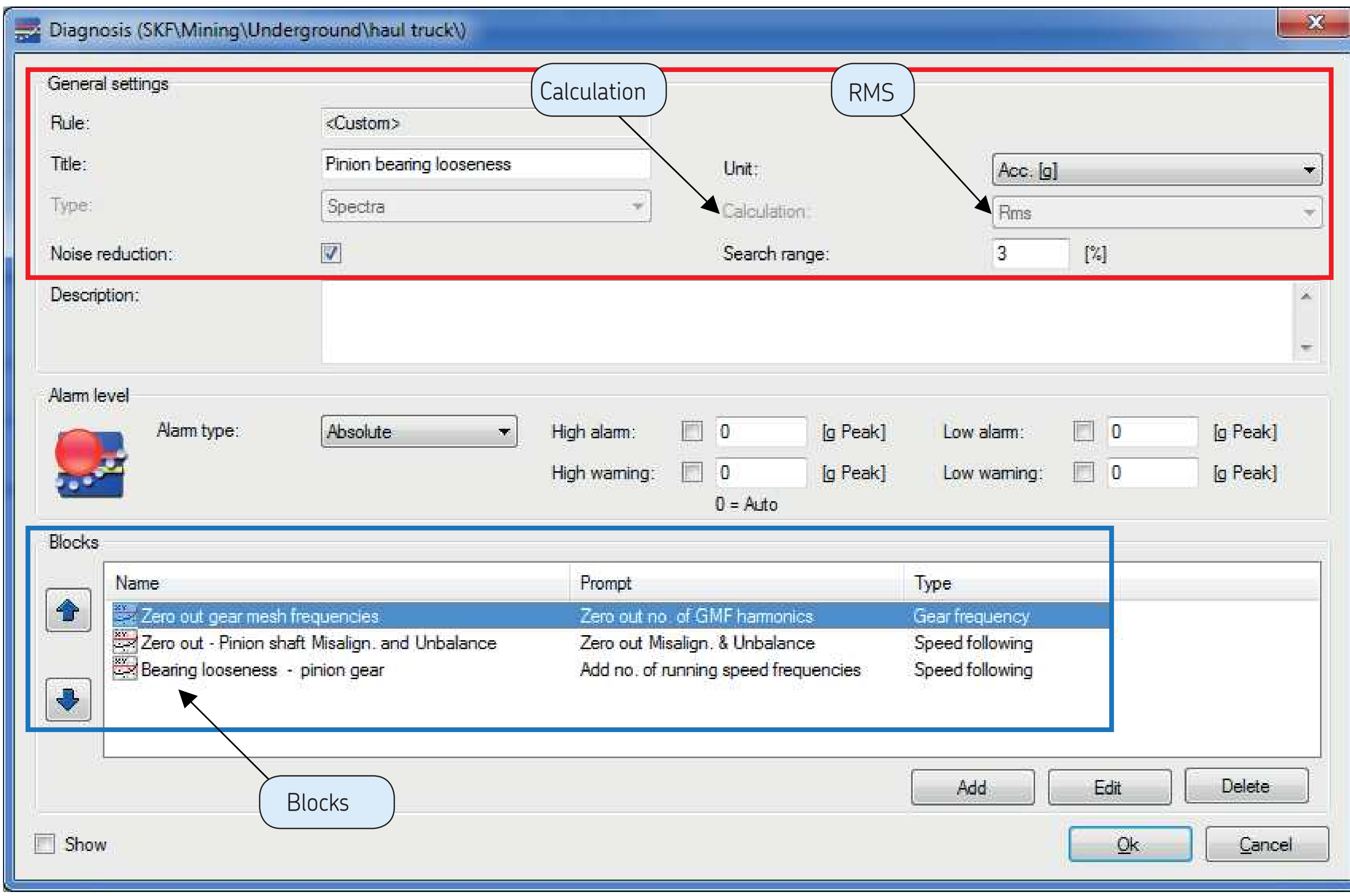


Fig. 11d. The “General settings” and the building “Blocks” for the diagnose rule “Pinion bearing looseness”.

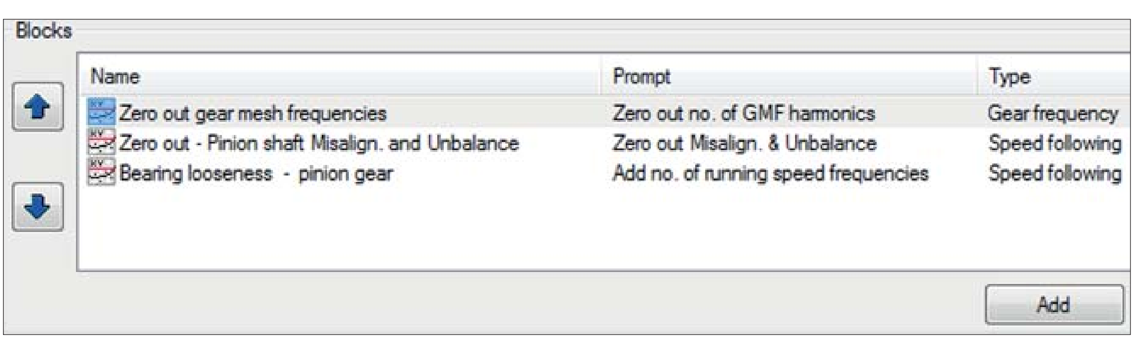


Fig. 11e. A close up of the building “Blocks” in fig. 11d for the diagnose rule “Pinion bearing looseness”.

In this case, the tool “Zero out” was used to eliminate the machine fault frequencies related to:

- The pinion gear mesh frequency and its harmonics,
- The unbalance component of the cardan shaft, and
- The misalignment component of the cardan shaft

from the vibration spectrum, before the calculation of the diagnose rule. The “Zero out” tool will automatically delete the center peak, including the two adjacent spectral lines on each side of the main peak. This will result in that the vibration amplitude for each frequency line (line 1 to 5) will be set to zero (→ **fig. 11f**). The details for each building block are displayed in **figs. 11g** to **11i**.

Note: The **“Zero out”** blocks in **fig. 11e** have to be the two first “Blocks” in the rule, since these “Blocks” will delete some frequencies from the vibration spectra before the diagnose rule “Bearing looseness – pinion gear“ is calculated.

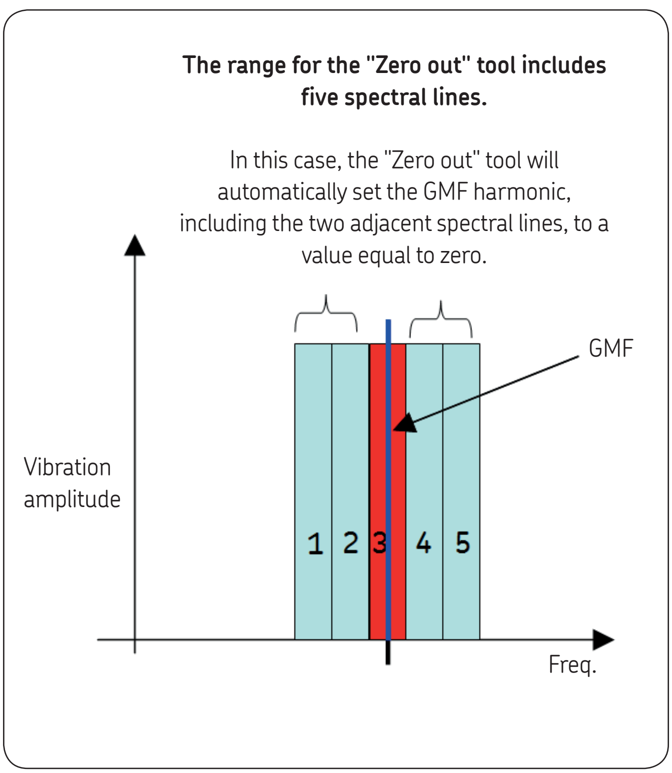


Fig. 11f. “Zero out” a frequency means that a vibration value for a specific frequency, in this case the GMF frequency (at line 3), will be set to “zero”, including the two adjacent spectral lines on each side of the center peak (line 3).

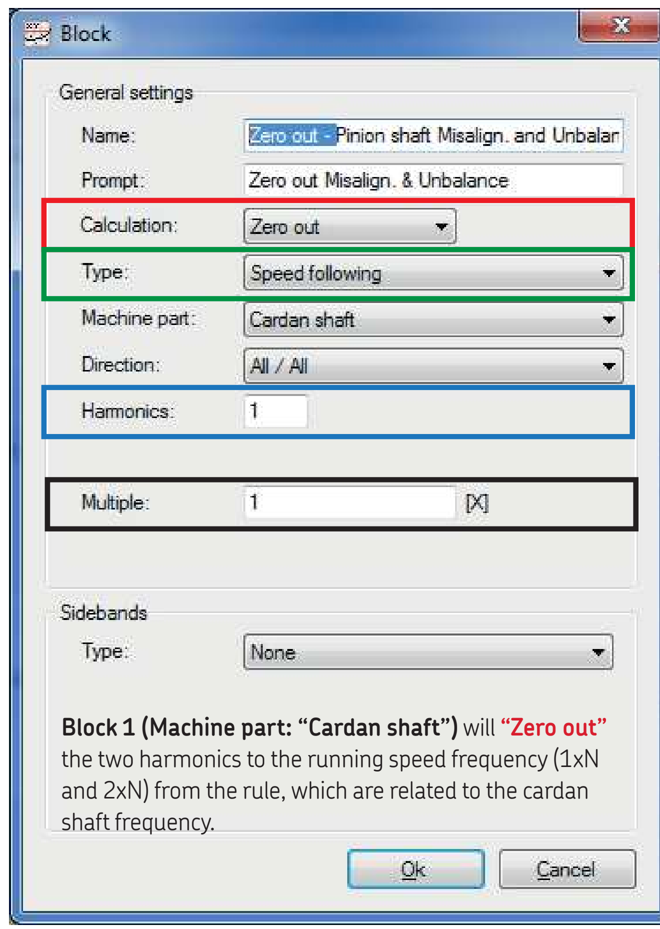


Fig. 11g. “Block 1” will “zero out” the frequencies for unbalance (1xN) and misalignment (2xN) in the vibration spectra.

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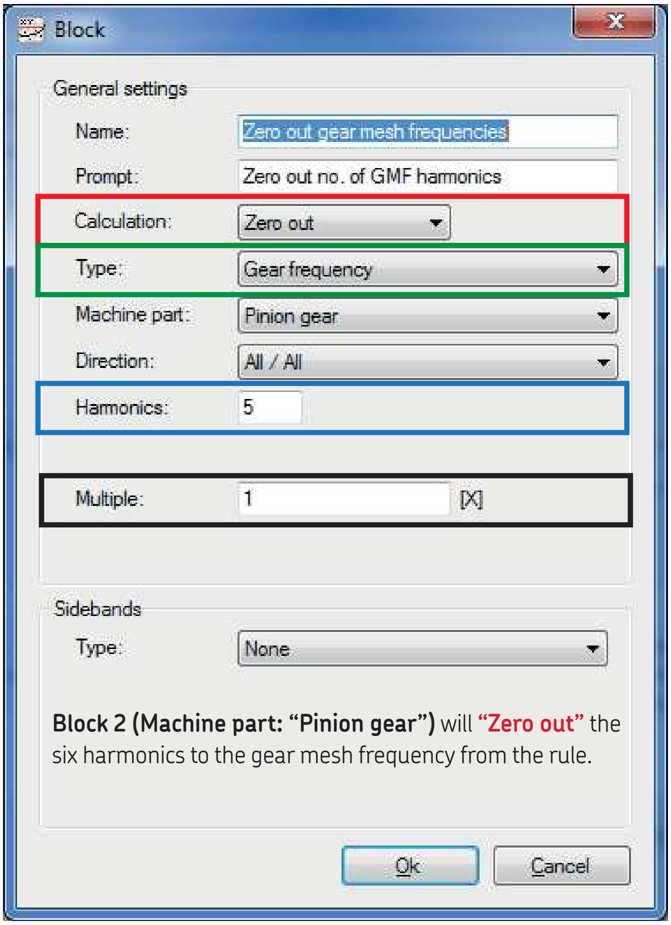


Fig. 11h. "Block 2" will "zero out" the six harmonics to the gear mesh frequencies in the vibration spectra.

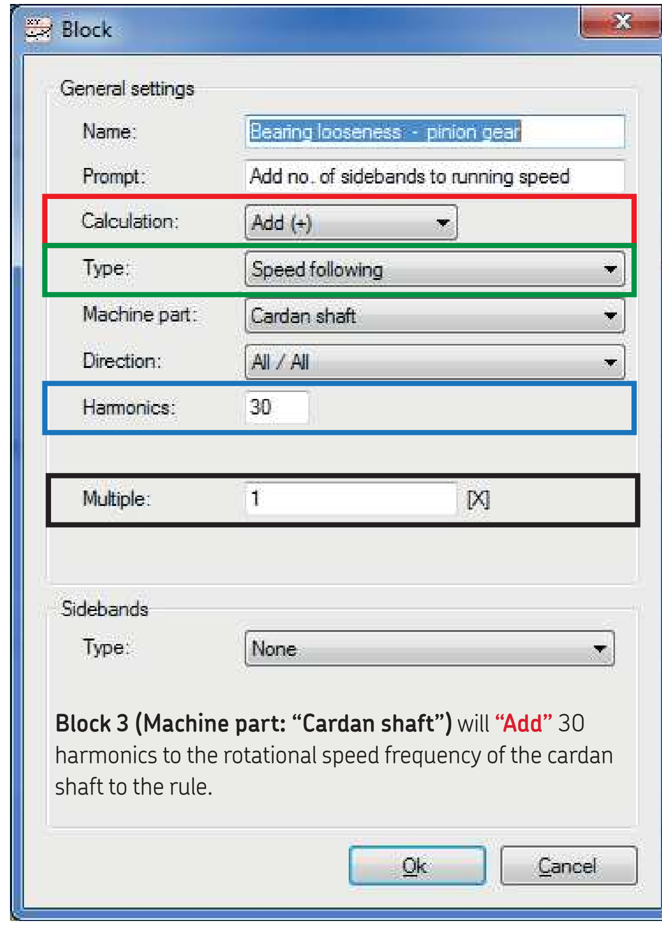
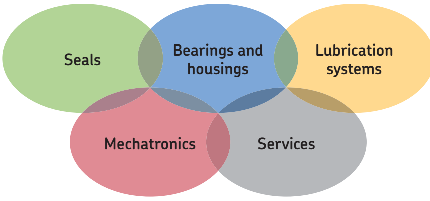


Fig. 11i. "Block 3" is adding 30 harmonics to the running speed of the cardan shaft to the rule, to calculate an RMS-value for the bearing looseness on the pinion gear including the GMF in fig. 3a.

Note: Please contact **ronny.sjoberg@skf.com** if you have any questions regarding how to create your private diagnosis rules.



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