FilterEvaluation Users Guide

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Introduction

The *FilterEvaluation* utility allows the user to generate test data with specific signals in order to evaluate the inspection software's ability to filter the test data. One observation, particularly noticed when writing this utility, is how vague the various options provided by the inspection software can be. Using this utility allows a better understand the capability of the inspection software and the impact of various filter settings.

In the early days of CMM's it was common to find problems with inconsistent fitting of basic geometry such as circles, spheres, and planes. To address the problems standards were created and now organizations such as PTB or NIST provide services to validate that any CMM inspection software can acceptably fit basic geometry. Unfortunately the current validation scope does not extend to any interpretation of data so some items must be validated by the end user. For basic dimensions such as the distance between two features it is relatively easy to validate but when dealing with something like a filter then validation by the end user ranges from difficult to practically impossible.

Overview of Filters

Filters remove undesired elements. In the case of a CMM the item that is filtered is measurement data and the undesired elements are components of the data that does not represent the measured artifact.

The source of the undesired elements contained within the measurement data vary depending on the situation. Most CMM's that are capable of scanning use an analogue probe resulting in friction from the machine dragging the stylus over the inspected surface resulting in one or more undesired signals. Properties of the surface finish or other surface defects may also contribute to noise in the measurement. Servo tuning and other characteristics of the machine can introduce anomalies in the data, especially when using an analogue probe, as the CMM axis motion is not constant particularly when scanning round features. External vibration can also be a source of noise in the measurement data. Sensor resolution and various other hardware limitations may contribute to unwanted signals in the measurement. There are likely many other contributing signal sources not described above which affect the measurement data. The ultimate goal would be to remove everything that does not represent the measured artifact.

Most inspection software use a weighted average from a sample of data points for the filter but other methods to handle filtering exist so the filter is more an implementation detail than anything else. Regardless of the method used by the inspection software it is expected that the characteristics of the filter will match those defined in standards such as ISO/IEC 11562. For example, it is expected that the amplitude of the data at the cutoff frequency is reduced to 50% of the unfiltered version according to ISO/IEC 11562.

The following is an example of data filtering. The waveform shown in illustration 1 is the product of three signals that have the same amplitude with the middle signal at the cutoff frequency:
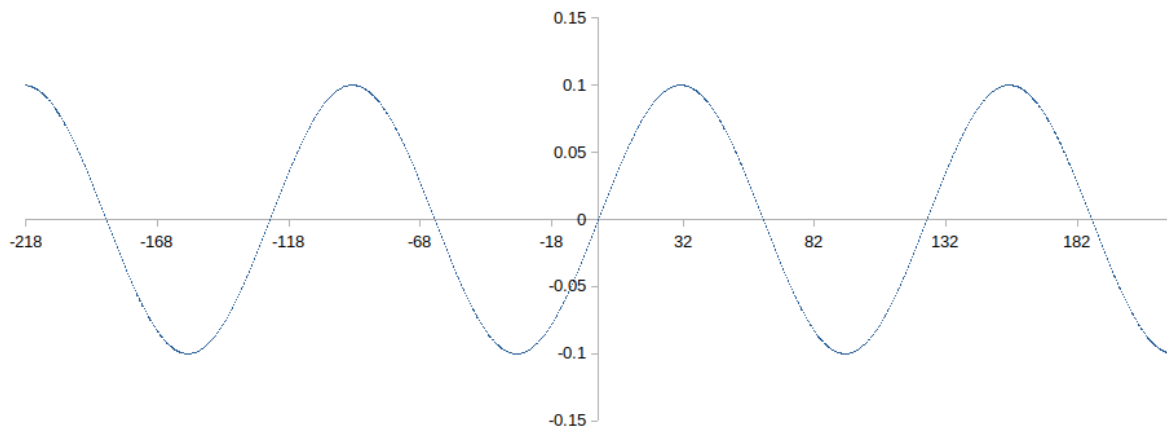
Any complex waveform can be described by a series of sine waves at specific frequencies with relative phase offsets and varying amplitudes.
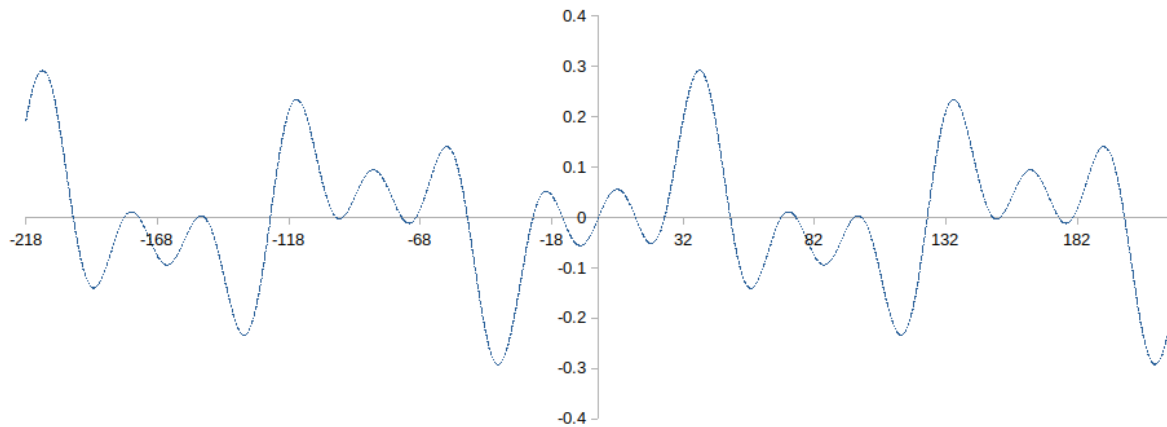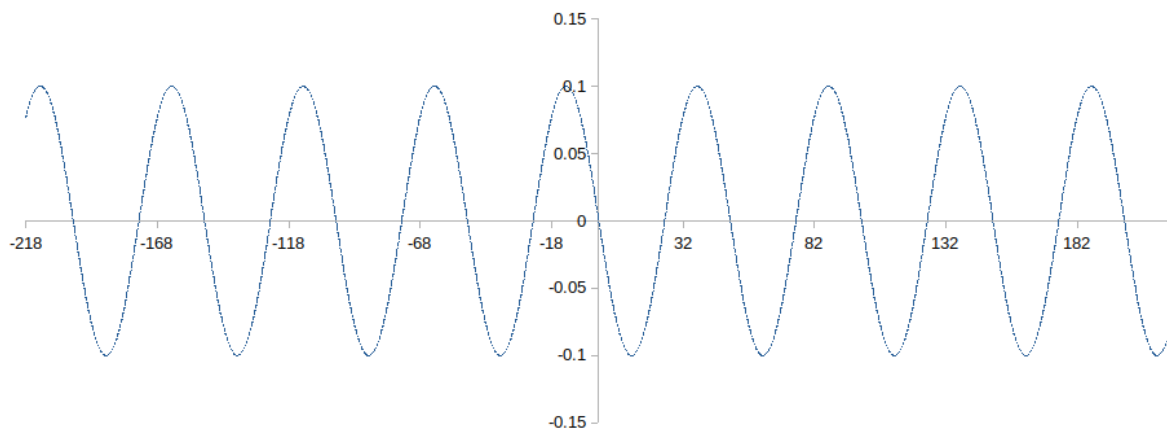
Illustration 1: Unfiltered waveform. This is the combined result from the low, middle, and high frequency signals shown below.

Illustration 2: low frequency signal.

Illustration 3: Middle frequency signal. This is also the cutoff frequency for this example.
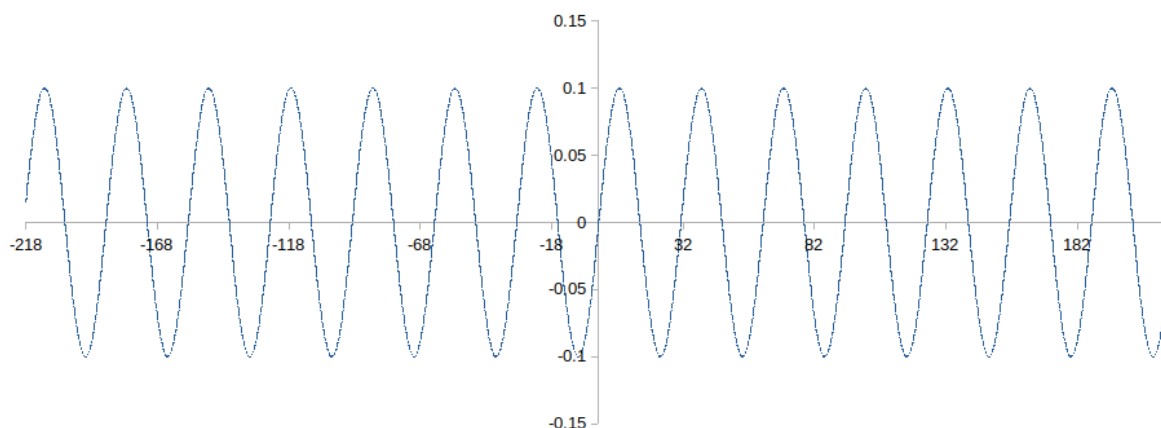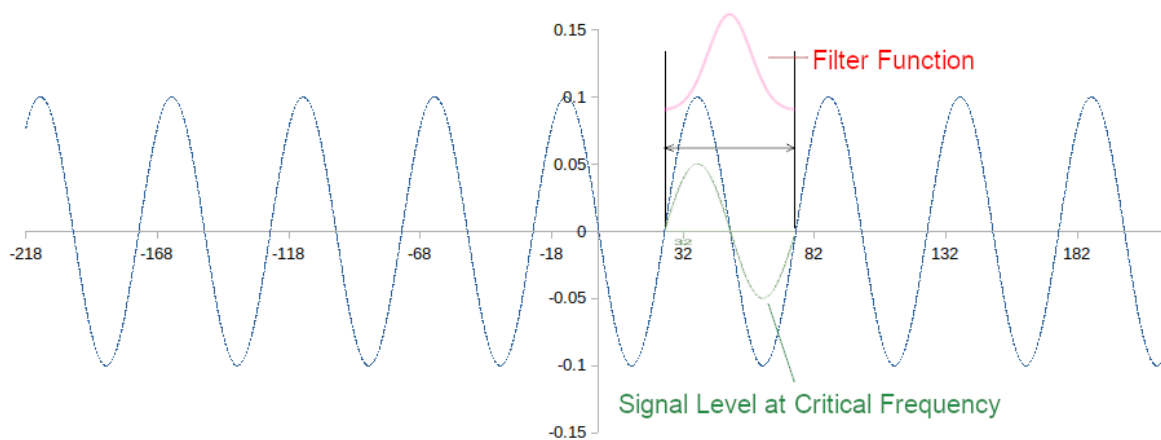
Illustration 4: High frequency signal.

Illustration 5: Application of the filter function. A weighted filter is used and drawn above of one cycle of the middle or cutoff signal.
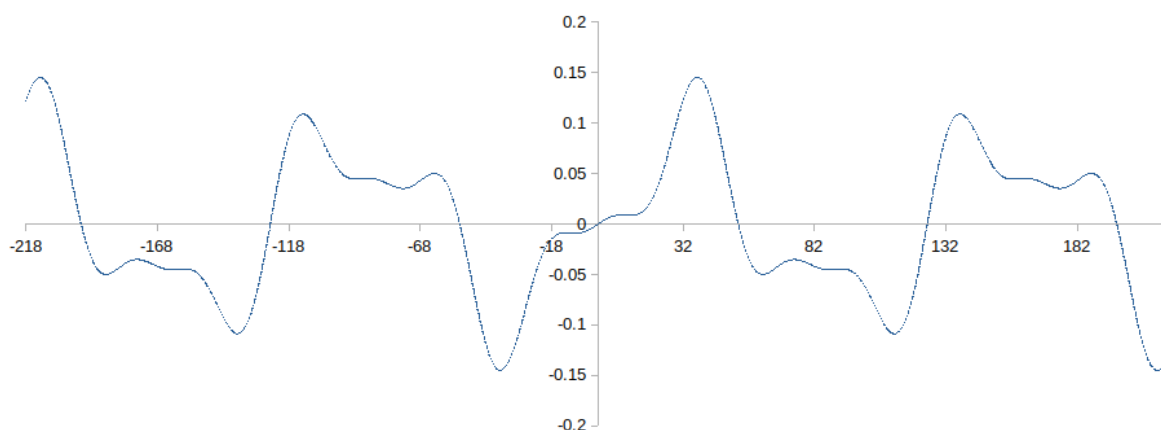

Illustration 6: Filtered waveform.

Applying the filter function to one full data cycle at the cutoff frequency results in a 50% reduction in amplitude and, ideally, no phase shift. Data with higher frequencies will be reduced by more

than 50% and lower frequency signals will be reduced by less than 50% with the amount of signal amplitude change based on the roll-off characteristics of the filter.

The roll-off characteristics are logarithmic. For any given cutoff frequency analyzing the impact of signals at half and double that of the cutoff signal frequency would be a good indication of the roll-off. To see this properly the graph needs to display the frequencies with a logarithmic scale.

Key points in the filtered data should be done as a bode plot which identifies intersection points of the straight line segments.

Overview

The *FilterEvaluation* utility users interface is shown in illustration 7:
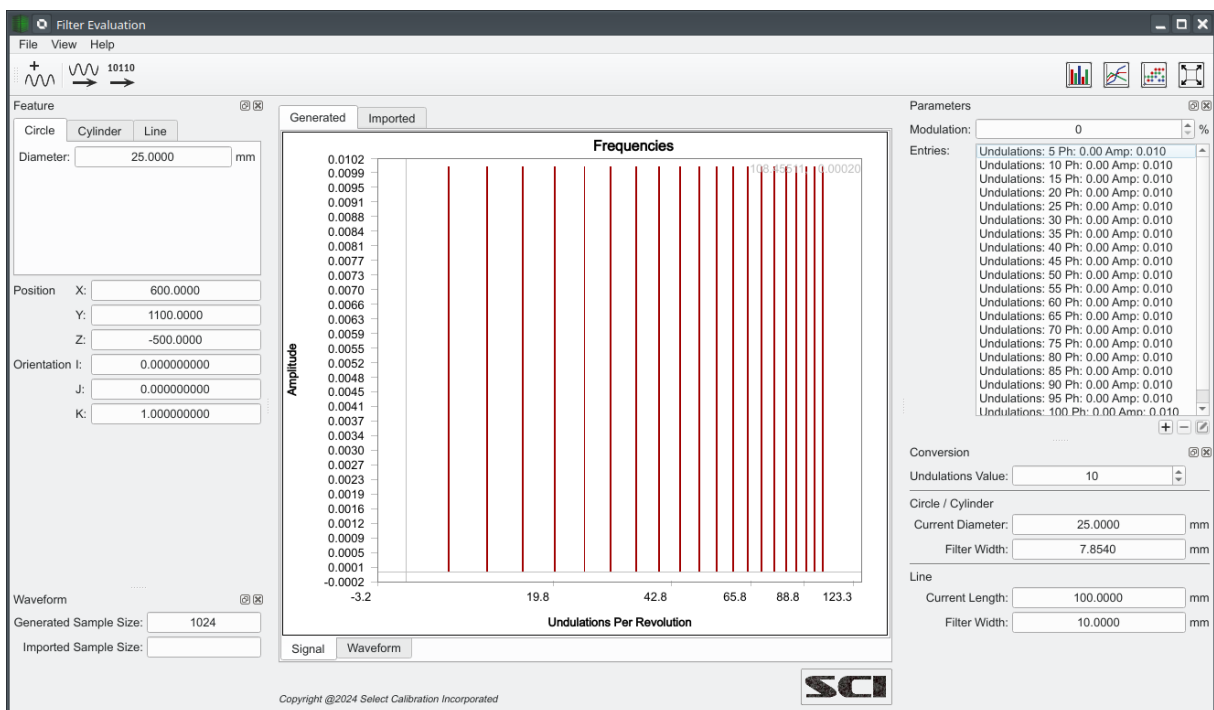

Illustration 7: Filter Evaluation main window.

The utility contains five sub sections. Four of the five sections are panels attached to the left and right of the main view that can be detached, moved, or hidden. The central view is one of four graphs showing the frequency and waveform information for the generated or imported data.

The signal data displayed in illustration 7 starts at 5 undulations and each subsequent signal is 5 undulations higher than the last. Since the horizontal axis is logarithmic the data on the right side appears more compressed than the data on the left side.

Features Panel

The features panel allows selection of the type of feature to be created for evaluation. Currently test data can be generated for circles, cylinders, and lines. Features such as planes and spheres may be added to a future version of the *FilterEvaluation* utility if an acceptable method is found to represent those features.

The data generated for cylinders assumes the 2D shape is the same throughout the length. It is a reasonable assumption in most cases. The data generated for cylinders is a spiral pattern and not circular cross section measurements.

Features such as a plane or sphere involve too many points to be practically evaluated by most inspection software. Ideas such as boundary lines for a plane or circular cross-sections of a sphere were considered but this is subjective. It is unknown if any inspection software can actually filter those kinds of features directly which defeats the purpose of generating test data.

Illustration 8: Features panel.

Illustration 8 shows an example of the features panel. The upper section allows the selection of the feature type along with specific attributes where the lower section contains the location and orientation of the feature.

All features types can be created at any location and in any orientation. For lines and circles the orientation should be restricted to one of the inspection software's working planes as these are typically treated as 2D features. For lines the signal direction (the normal vector of the touch points) is automatically set by the *FilterEvaluation* utility.

When generating a signal or DMIS program the active feature selected determines the type of output.

Parameters Panel

The parameters panel allows the creation of the signals that will be used to generate the test data. A signal is simply a sine wave with a specific frequency, amplitude, and phase shift on top of the nominal data. The number of signals, signal amplitude, and phase shift for each entry can be set as required.

Some evaluations of the test data can be performed completely within the inspection software. For example, if a circle is generated with a single 50 UPR signal and the inspection software filters that data using a comparable 50 UPR setting the resulting form error should be reduced to 50% of the unfiltered version. Using multiple signals allows a more complete evaluation of the filter characteristics but this kind of evaluation must be done by the *FilterEvaluation* utility or some equivalent utility in order to extract all the individual signals from the data.

When using a wide range of signals the reduction at the cutoff frequency can be evaluated provided that enough signals exist on the low side of the cutoff frequency.

The terminology used for the signals is undulations per revolution (circles, cylinders) or undulations per length (lines, planes). Depending on the inspection software it may be necessary to convert this to a filter window size (see *Conversion Panel* section for details).
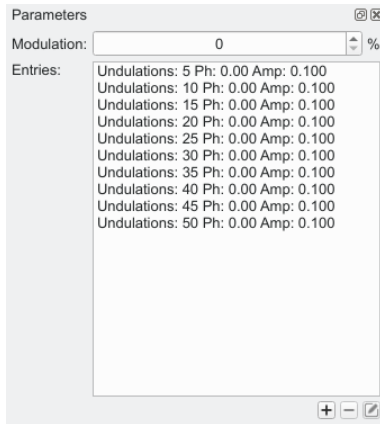
Illustration 9: Parameters panel.

The spacing of the generated point data can be modulated up to +/- 1 degrees for circular features (modulation setting of 100%). The modulation mimics the effect of measuring a circle that is offset from the nominal location. This kind of modulation happens in almost all cases with the common exception being situations where the test feature is also used as a datum or origin. Even in the best possible scenario the positioning accuracy of the CMM performing the measurements may add a random modulation of the data depending of how precisely it can position. Illustration 10 shows an example that the modulation of the point spacing when measuring a circle from an offset location.
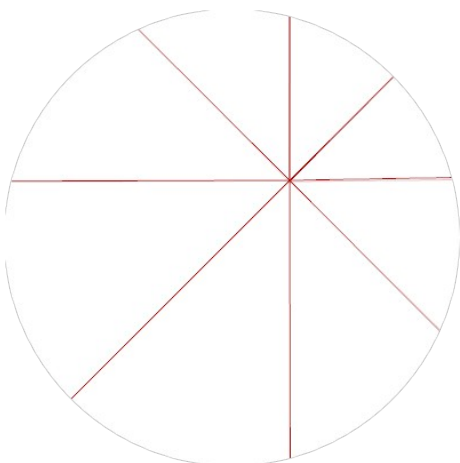
Illustration 10: Modulation example. Points measured from a center that is not the true center of the feature.
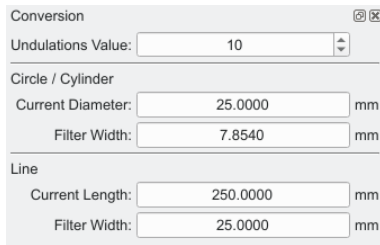
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Conversion Panel

The conversion panel returns the width of a comparable filter window in metric based on a user defined undulation value and characteristics of the current features.

The *FilterEvaluation* utility uses Undulations Per Revolution for round features or Undulations Per Length for linear features. If the inspection software uses a filter window with specific dimensions then the dimensions of that window can be calculated using the conversion panel. Illustration 11 shows an example of the conversion panel with values for circular or linear features.
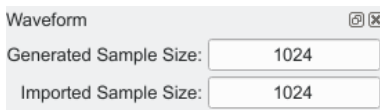

Illustration 11: Conversion panel.

Using the example shown in illustration 11 the width of a filter window should be 25 mm in order to filter a signal of 10 undulations per length from a line with a length of 250 mm.

Using Undulations Per Revolution (UPR) for circular features is common but without specifying the feature diameter the value has little meaning. Filtering a circle using 50 UPR will show very different results if the diameter is 10 mm vs 500 mm. Most CMM's with analogue probes will scan at a set data rate regardless of the feature size.

Waveform Panel

The waveform panel shows the sample size of the exported and imported data. The idea is to make sure the data used for the comparisons represent a set of signals over a specific, common, length and, in cases where the size does not match, comparisons of the data may not be possible.

Illustration 12: Waveform panel.

The generated data is always padded with an additional 31 points from what is shown in the waveform panel. For example, if the measurement window size is 64 points then the generated file will have 126 points where almost half of the data is for padding. The inspection software can throw out whatever it wants at the beginning or end of the data provided it leaves at least 64 samples when done with it. When imported any remaining padding points that were not discarded by the inspection software are removed. When too many points are discarded by the inspection software then the sizes will not match and that can be a problem when performing a comparison.

Clipping ends of the data is a safe way to deal with problems related to the beginning or end of a sample but some software seems to clip more than others. In theory, clipping the ends is not necessary if the filter parameters are dynamic but this is an implementation detail.

The nominal waveform size is from the number 2 raised to an integer power no less than 6. Window sizes can be 64, 128, 256, 512, 1024, or higher. The upper size is determined from the

entries in the parameters panel.

Parameters Editing

The parameter can be modified by using the add, remove, or edit buttons at the bottom of the entry list. The editing functions were optimized in order to allow easy additions or changes to groups of entries. For example, adding multiple signals can be done without having to repeatably click on the *Add* button. Changes to a group of entries can be performed without having to individually edit each item. Illustration 13 show the parameter editor dialog when configured to add points.
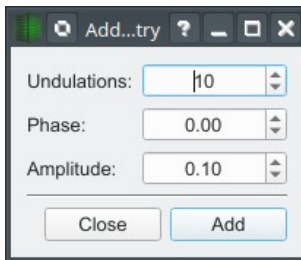

Illustration 13: Parameter editor dialog.

For modifications of a group of entries only the phase and amplitude inputs can be changed.

Graph Views

The graph section displays a representation of the generated or imported data. Each category has a subsection showing the signal or waveform view. The signal view shows the set of frequencies and amplitude contained within the data where the waveform shows the appearance of the data.

The signal view of the data can be viewed as a bar graph (default), line graph, or point graph. The waveform view is always shown as a line graph and cannot be changed.

Table 1: Graph Toolbar Options

Icon	Description
	Display signal data as a bar graph (default).
	Display signal data as a line graph.
	Display signal data as points.
	Scale to fit.

Menu Options

Table 2: Menu Options

Options	Description
File – Import Signal	Load a signal file. This is the format of data that the test inspection software would need to recreate in order for the *FilterEvaluation* utility to analyze the data.
File – Export Signal	Create a signal file using current settings and based on the selected feature.
File – Export DMIS	Create a DMIS program that can be imported into any CMM software that supports DMIS. The file contains a set of points (along with padding points) that can be used to construct the selected feature.
File - Quit	Close the *FilterEvaluation* utility.
View	Allows showing or hiding the various panels.
Help - About	Displays information about the *FeatureEvalutation* utility.

Signal File

The signal file is a format defined by SCI for use by the *FilterEvaluation* utility. The contents of this file is essentially a set of data points for either a circle or line cross section regardless of the feature type. In order to evaluate the inspection software a signal file with the filtered point data is required.

The contents of a typical signal file are shown below:

```
Filter_Evaluation_Signal_Data:Version=1:Type=Signal_Data

# First line must start with 'Filter_Evaluation_Signal_Data'
# 'Version=<n>' is the revision of this file
# The value of Type must be 'Signal_Data'.  Other options may be added in the future.

# Data is grouped in pairs <desc>_Begin: and <desc>_End:

# Position and Orientation entries must exist.
# For circular features the diameter must also exist.

# Signal type can be either 'Circle' or 'Line'.

# Start and end of the data is extended or padded.

Signal_Type:Line
Position:0.00000,0.00000,0.00000
Orientation:1.00000,0.00000,0.00000
Signal_Axis:0.00000,1.00000,0.00000

Data_Begin:
-246.09375,0.00618,0.00000
-242.18750,0.00904,0.00000
```

```
-238.28125,0.00883,0.00000
-234.37500,0.01037,0.00000
-230.46875,0.02066,0.00000
…
230.46875,-0.02066,0.00000
234.37500,-0.01037,0.00000
238.28125,-0.00883,0.00000
242.18750,-0.00904,0.00000
Data_End:
```

The generated signal files from the *FilterEvaluation* utility include comment lines that describe the requirements. The comment lines can be deleted if necessary.

Only two categories of signal files are currently supported; circle or line. When dealing with features such as a cylinder then only one cross section of the data is expected and when dealing with a plane feature then only one measurement line would be expected from the data.

DMIS File

The DMIS file is the data that the inspection software is expected to import and filter. The contents of a typical DMIS file generated by the *FilterEvalution* utility are shown below:

```
$$ filterevaluation DMIS file
DMISMN/'filterevaluation.dms' 04.0
FILNAM/'filterevaluation.dms'
$$
UNITS/MM,ANGDEC
D(MC_CSY)=DATSET/MCS
MODE/MAN
$$
$$ Increase the display precision to 5 decimal places minimum.
DECPL/ALL,5
$$
MODE/PROG,MAN
$$
F(LN_1_PAD)=FEAT/POINT,CART,444.72656,1099.94985,-
500.00000,0.000000000,1.000000000,0.000000000
MEAS/POINT,F(LN_1_PAD),1
    PTMEAS/CART,444.72656,1099.94985,-500.00000,0.000000000,1.000000000,0.000000000
ENDMES
$$
F(LN_2_PAD)=FEAT/POINT,CART,445.70313,1100.02280,-
500.00000,0.000000000,1.000000000,0.000000000
MEAS/POINT,F(LN_2_PAD),1
    PTMEAS/CART,445.70313,1100.02280,-500.00000,0.000000000,1.000000000,0.000000000
ENDMES
$$
…
$$
F(LN_210)=FEAT/POINT,CART,648.82813,1100.00365,-
500.00000,0.000000000,1.000000000,0.000000000
MEAS/POINT,F(LN_210),1
    PTMEAS/CART,648.82813,1100.00365,-500.00000,0.000000000,1.000000000,0.000000000
ENDMES
$$
F(LN_211)=FEAT/POINT,CART,649.80469,1099.97646,-
500.00000,0.000000000,1.000000000,0.000000000
MEAS/POINT,F(LN_211),1
```

```
      PTMEAS/CART,649.80469,1099.97646,-500.00000,0.000000000,1.000000000,0.000000000
ENDMES
$$
...
$$
F(LN_317_PAD)=FEAT/POINT,CART,753.32031,1099.97461,-
500.00000,0.000000000,1.000000000,0.000000000
MEAS/POINT,F(LN_317_PAD),1
      PTMEAS/CART,753.32031,1099.97461,-500.00000,0.000000000,1.000000000,0.000000000
ENDMES
$$
F(LN_318_PAD)=FEAT/POINT,CART,754.29688,1099.97720,-
500.00000,0.000000000,1.000000000,0.000000000
MEAS/POINT,F(LN_318_PAD),1
      PTMEAS/CART,754.29688,1099.97720,-500.00000,0.000000000,1.000000000,0.000000000
ENDMES
$$
ENDFIL
```

The generated DMIS file for any feature type will start with a series of padding points. All data should be used when applying a filter if the inspection software clips the ends of the data. In cases such as a circle where the features is closed (start point is the end point) then the padding points should be ignored. Following filtering the data must be exported to a *signal* file for importing into the *FilterEvaluation* utility for analysis.

The type of target feature and function of each point is included in the DMIS feature name. For example, F(LN_211) is for a signal point from a line feature where F(LN_318_PAD) is a padding point from a line feature.

Circle Filter Example

The following shows an example for filtering a circle with a diameter of 25 mm.

The test signal generated by the *FilterEvaluation* utility spans from 5 to 100 UPR at an increment of 5 UPR with all signals having an amplitude of 0.01 mm. Illustration 14 shows frequency vs amplitude view of the generated test signal. The waveform data was exported to a DMIS file.
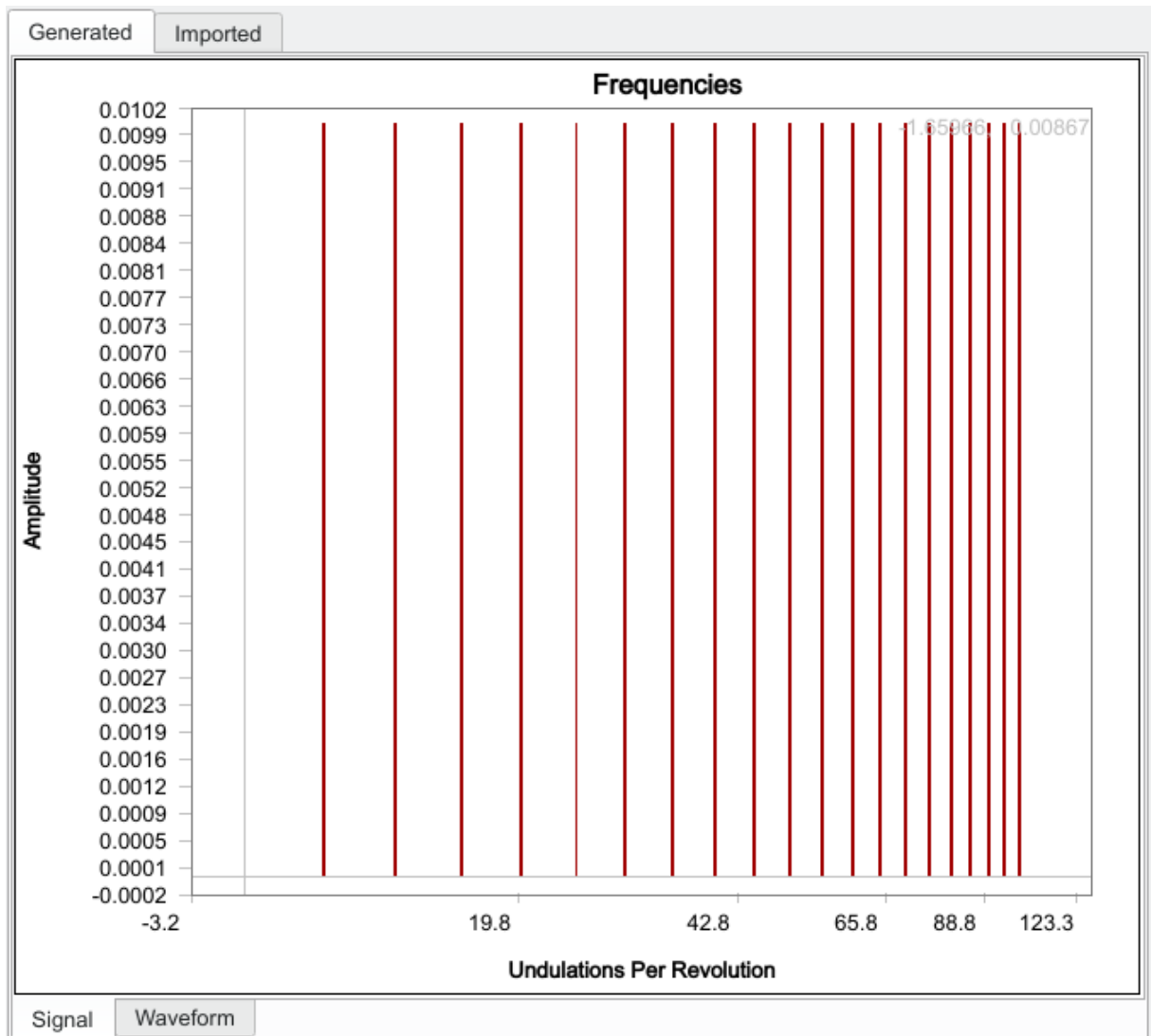
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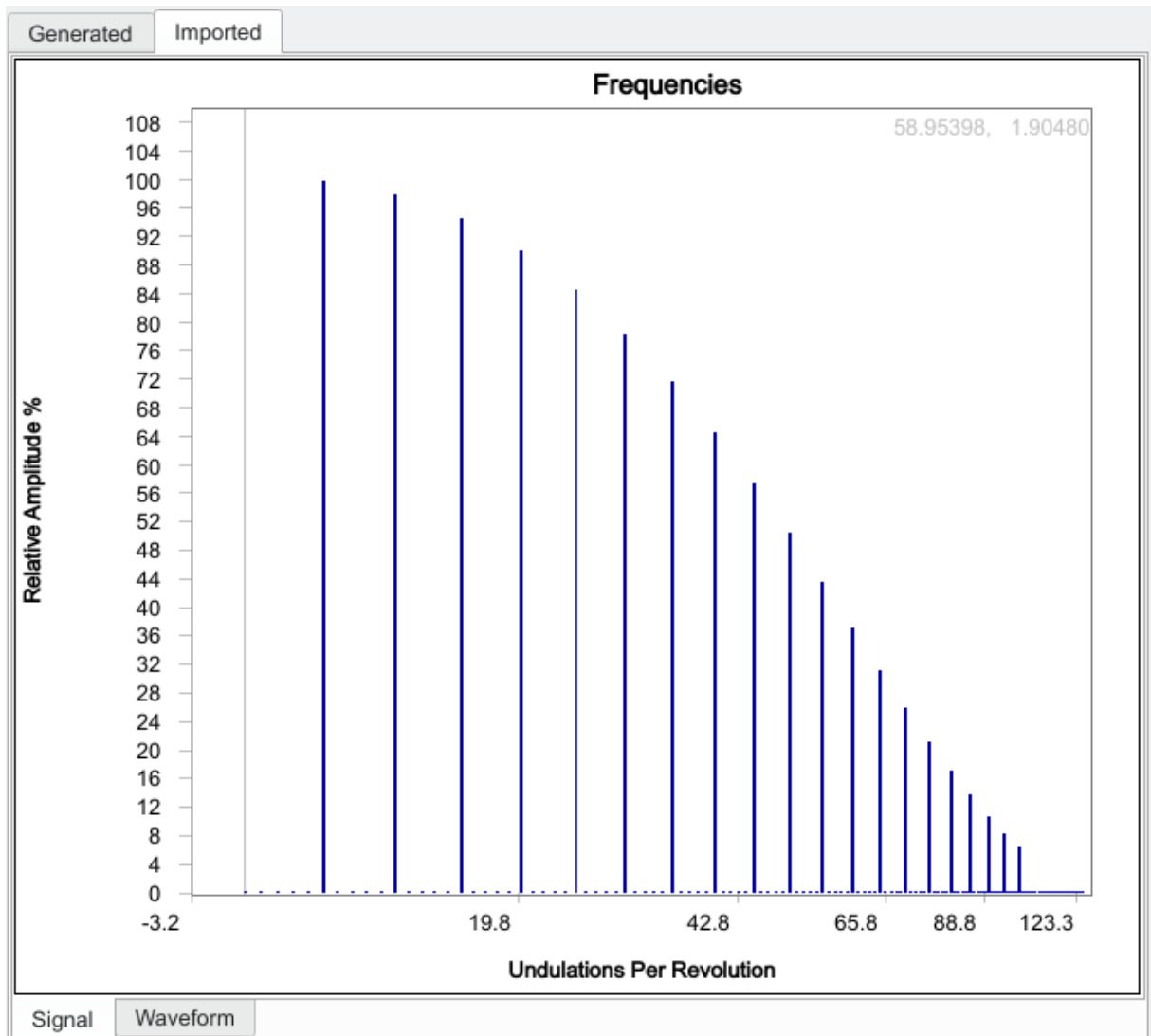*Illustration 14: Graphical view of the generated signals.*

Illustration 15: Graphical view of the signals following filtering of the circle.

The DMIS program was imported into the inspection software. A circle was constructed from all the points and a 50 UPR filter was applied at the same time. Illustration 15 shows the frequency spectrum of the filtered data.

The expected results is that the signal level at 50 UPR would be reduced to 50% of the original amplitude. The signal level at 25 UPR should be around 80% and 20% at 100 UPR.

Line Filter Example

The following shows an example for filtering a line with a length of 250 mm.

The test signal generated by the *FilterEvaluation* utility spans from 5 to 100 UPL at an increment of 5 UPL with all signals having an amplitude of 0.01 mm. Illustration 16 shows frequency vs amplitude view of the generated test signal. The data was exported to a DMIS file in order to be processed by the inspection software.
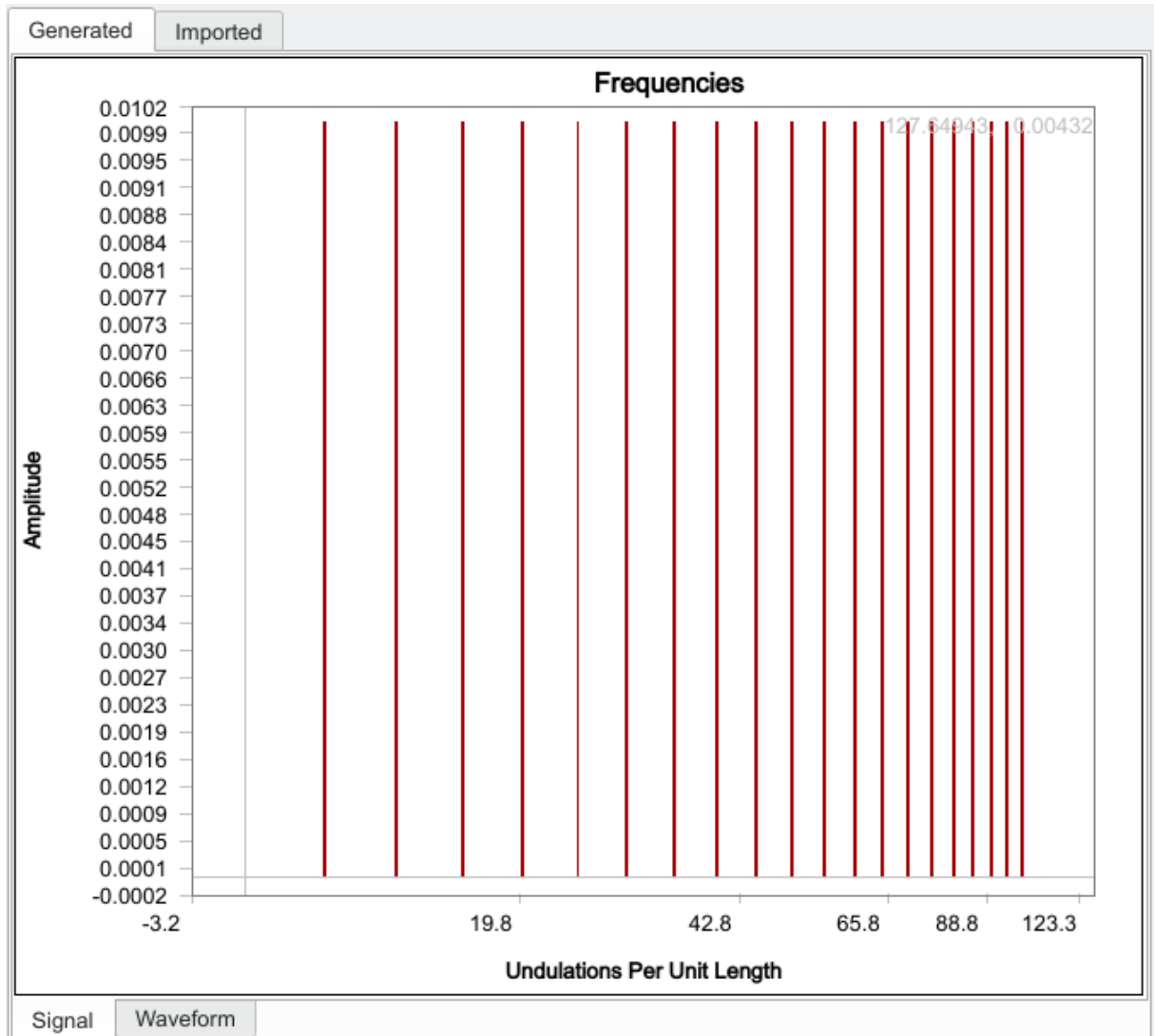
Illustration 16: Graphical view of the generated signals.

Unlike the circle example the inspection software expects a filter window length and not an undulation per unit length when dealing with lines. The conversion function of the *FilterEvaluation* utility shows that a 5 mm filter window is appropriate for the desired cutoff frequency of 50 UPL of a line with a length of 250 mm.

When filtering data knowing the type of input is critical. In this particular case the inspection software tested used a combination of undulations per revolution for circles and filter length for lines.
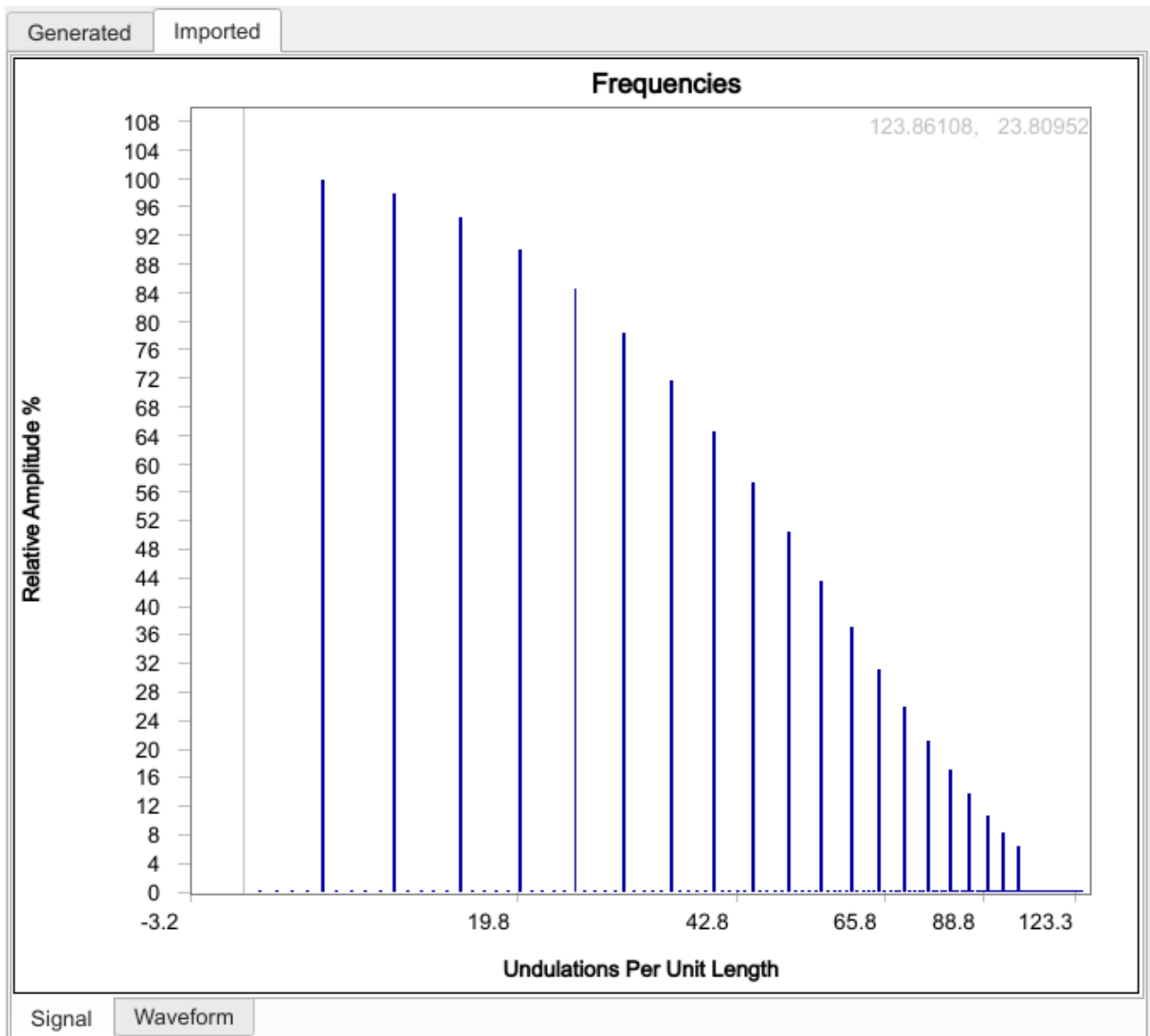
Illustration 17: Graphical view of the signals following filtering of the line.

The DMIS program was imported into the inspection software. A line was constructed from all the points and a filter with a width of 5 mm was applied at the same time. Illustration 17 shows the frequency spectrum of the filtered data.

The expected results is that the signal level at 50 undulations per unit length would be reduced to 50% of the original amplitude. The signal level at 25 undulations per unit length should be around 80% and 20% at 100 undulations per unit length.

Revision History

Date	Version	Changes
Feb 16, 2024	1.0	New Program