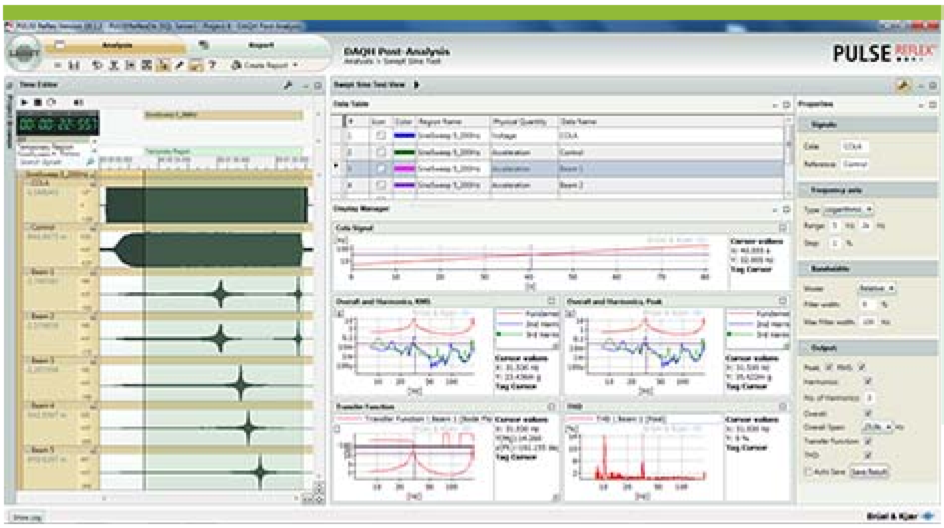
APPLICATION NOTE

Brüel & Kjær

PULSE Reflex Sine Processing

The basic principles behind the software



Sine Processing is a Brüel & Kjær software application available with PULSE Reflex™.

It comes as part of the DAQ-H based Satellite Qualification Test System (SQTS), which is an integrated solution for vibration, shock and acoustic-fatigue testing for satellite mechanical qualification and acceptance testing.

Description and Methodology

Introduction

The ability to accurately extract amplitude, frequency and phase information from a sinusoidal signal is important to provide leakage-free response spectra. This Application Note provides a description of a method to post-process recorded vibration test data to accurately extract sine data.

Analysis Methodology

Sine processing is used to identify and analyze natural frequencies in structures by exciting the structure at a single frequency that is varying (sweeping) up or down with time.

Vibration signals from accelerometers and force transducers mounted on the structure are measured together with sweep frequency, and are then analyzed (post-processed) to provide the structure's response to the controlled sinusoidal excitation at different qualification levels.

Output from sine processing is in the form of overall vibration levels, harmonic components, transfer functions and total harmonic distortion.

The COLA (constant output level amplitude) signal from the vibration controller is used as the frequency reference for the analysis, see Fig. 1. This method accurately extracts the frequency of the COLA signal for each time-sample acquired, see Fig. 2.

Fig. 1 *Typical system*

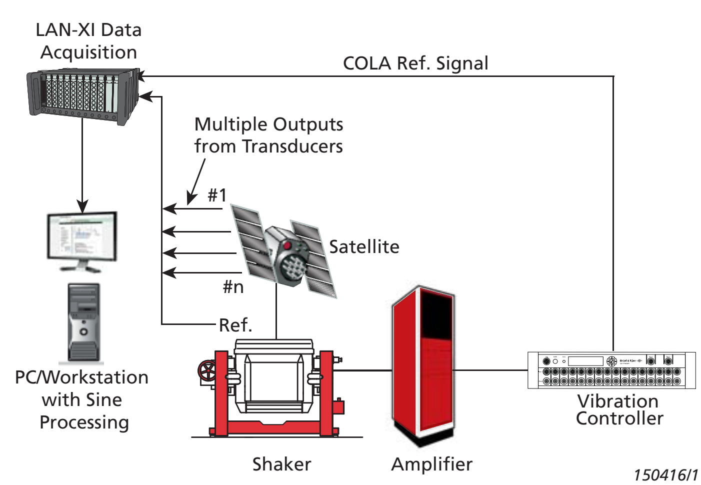
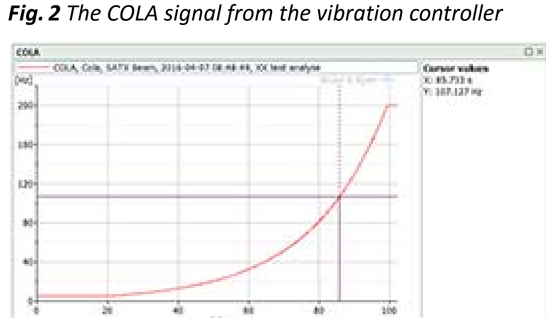


Fig. 2 *The COLA signal from the vibration controller*



It also extracts (and narrow-band filters) the fundamental and its harmonics, so that the structural behaviour of the satellite is well known at different excitation levels.

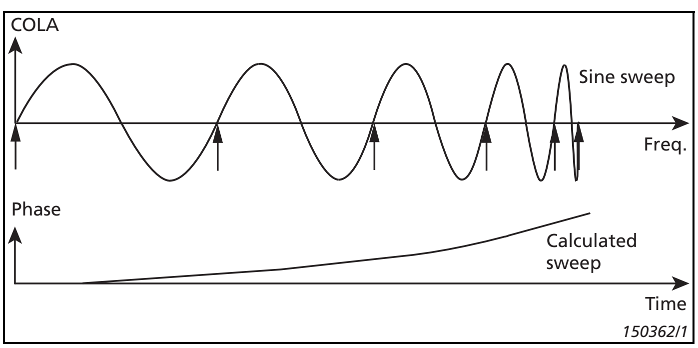
The following analyses are performed as functions of the excitation frequency:

- Detection of amplitude, frequency and phase of the vibration reference
- Extraction of harmonic components (Peak and RMS) of all measured signals
- Extraction of the overall broadband signal (Peak and RMS) level of all measured signals
- Post-processing of the extracted data to obtain the transfer function (FRF, coherence, etc.) and the total harmonic distortion (THD) between the reference signal and any point measured on the satellite

Detection of COLA Signal

The analysis determines the phase and frequency of the COLA signal as reference for the sweep. In order to get a good estimate it is important to have a very high precision of phase and frequency as a function of time. This is achieved by detecting the absolute time for each period of the COLA signal. Each period is an increment, in phase, of 2π. The frequency is 1/Period Time. After detecting all periods in the signal a model of the COLA signal is created (see Fig. 3).

***Fig. 3** COLA signal and calculated phase*



The sweep can be modelled by one of the following approaches:

- A second order model, used when:
  - The acceleration is constant in each period
  - The frequency is linear – which means the phase is parabolic
- A logarithmic model, used when:
  - log (acceleration) is constant
  - log (frequency) is linear – and the phase has the form phase(t) = a^t +b

The result is an accurate sweep frequency for each measured sample.

Calculation of the Fundamental and its Harmonics

Having determined the COLA signal, you now need to calculate the fundamental and its harmonics for the reference signal and each of the response signals.

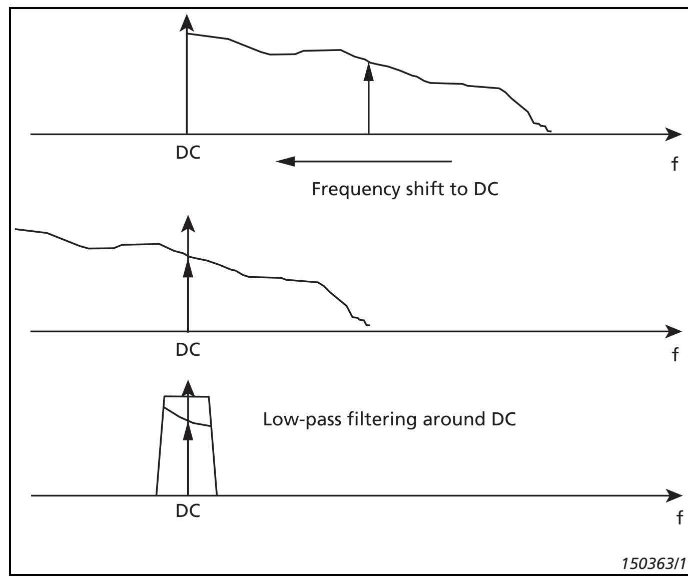
All harmonics are calculated in the time domain using two steps:

1. Frequency shifting the signal component down to DC using the phase information from the COLA signal:
   - y(t) = ($e^{j2\pi k}$phaseCOLA(t))signal(t), where k is the harmonic number

   After the frequency shifting, the harmonic component can be found at 0 Hz in the time signal
2. Extracting the harmonics by low-pass filtering to the specified bandwidth (as defined in the Sine Test Setup properties panel, see Fig. 6) using either:
   - Fixed bandwidth filter, or
   - Relative bandwidth filter

     For the relative bandwidth the filter bandwidth is controlled by the COLA frequency:
     - FBW = (bandwidth_percentage/100) FCOLA

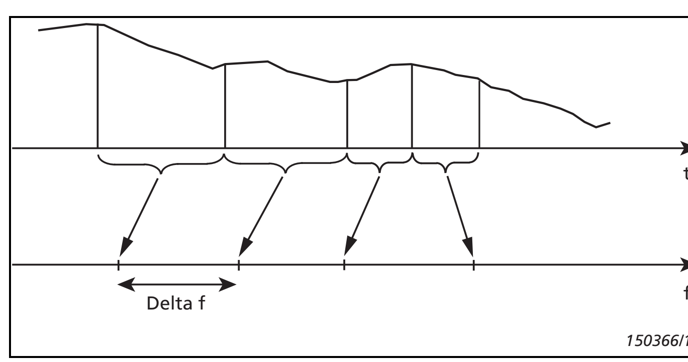
***Fig. 4** Frequency shift and low-pass filtering*



The outputs from the filters are complex harmonic signals, where phase is the phase of the harmonic relative to the COLA signal.

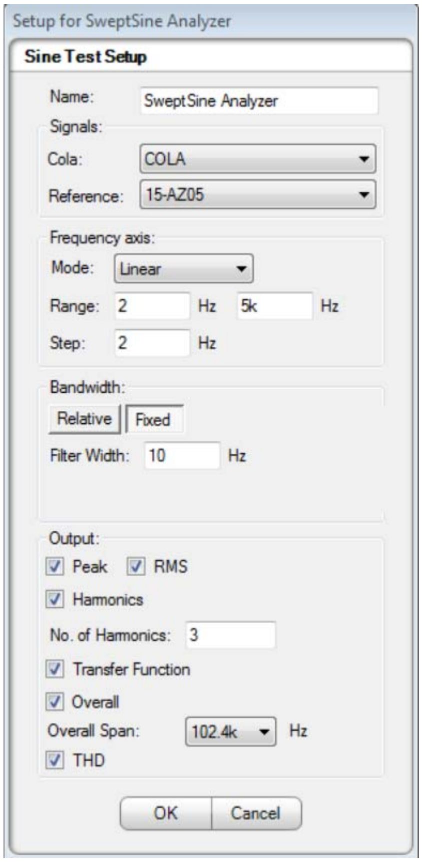
The filtered output is in the time domain, and this can be mapped to a frequency axis defined by the COLA excitation signal (see Fig. 5).

***Fig. 5** Time axis converted to a frequency axis using averaging*



The frequency axis can be either linear or logarithmic. Resolution of the frequency axis can be defined (via the Sine Test Setup properties panel, see Fig. 6) and each filter output value can be placed on the frequency axis.

Fig. 6 *Typical properties panel for PULSE Reflex Sine Processing*



Samples mapped to the same frequency point are averaged together.

Calculating Functions for Each Harmonic

For each harmonic, the following functions are calculated for each delta frequency (frequency band) in the resulting spectrum:

- The normalized mean complex value of the complex values (defines the phases)
- Power mean value (this can also be shown as RMS)
- Peak value: the sample with highest magnitude is stored for each frequency band

Calculating Overall Signals in Time Domain (Broadband Level)

Overall signals are then calculated in the time domain:

- A Hilbert transformation is used to produce the analytic signal
- The magnitude of the analytic signal is the overall value as a function of time

Calculating Overall Metrics

Overall metrics are calculated within each frequency band in the resulting spectrum:

- Mean power value
- Peak value: The sample with highest magnitude is stored for each frequency band

Calculating Basic Spectra

The following basic spectra are calculated:

- 1...n harmonic real power
- 1...n harmonic phase (relative to the COLA signal)
- 1...n harmonic complex peak
- Real overall power
- Real overall peak

Calculation of Functions

The following specific functions are calculated from basic functions:

- Relative phase is calculated by subtracting the reference phase from the phase signal
- Phase assigned spectrum is calculated as the real power spectrum added to the relative phase
- Frequency response is calculated as real mean spectrum divided by the real mean spectrum of the reference signal added to the relative phase
- THD is calculated as:

$$\mathrm{THD} = \frac{(\text{Overall Mean Spectrum} - \text{Fundamental Mean Spectrum})\,100\%}{\text{Overall Mean Spectrum}}$$

About PULSE Reflex and Satellite Qualification Test System (SQTS)

PULSE Reflex

PULSE Reflex Sine Processing is an application running on PULSE Reflex, see BP 2258. PULSE Reflex provides real-time and fully integrated post-processing and reporting. The innovative and intuitive GUI delivers genuine ease-of-use through a workflow concept that is easy to learn and consistent across applications.

SQTS

The DAQ-H based SQTS is an integrated solution for vibration, shock and acoustic fatigue testing for satellite mechanical qualification and acceptance testing. The system comprises a complete suite of test application for data recording, acoustic fatigue, transient, random and swept sine testing. See BU 3086.

Results

The sine processing software can calculate and display a number of analyses as functions of the excitation frequency.

Typical results from swept sine measurements are shown in Fig. 7 to Fig. 9.

Fig. 7 Data comparison on a typical test

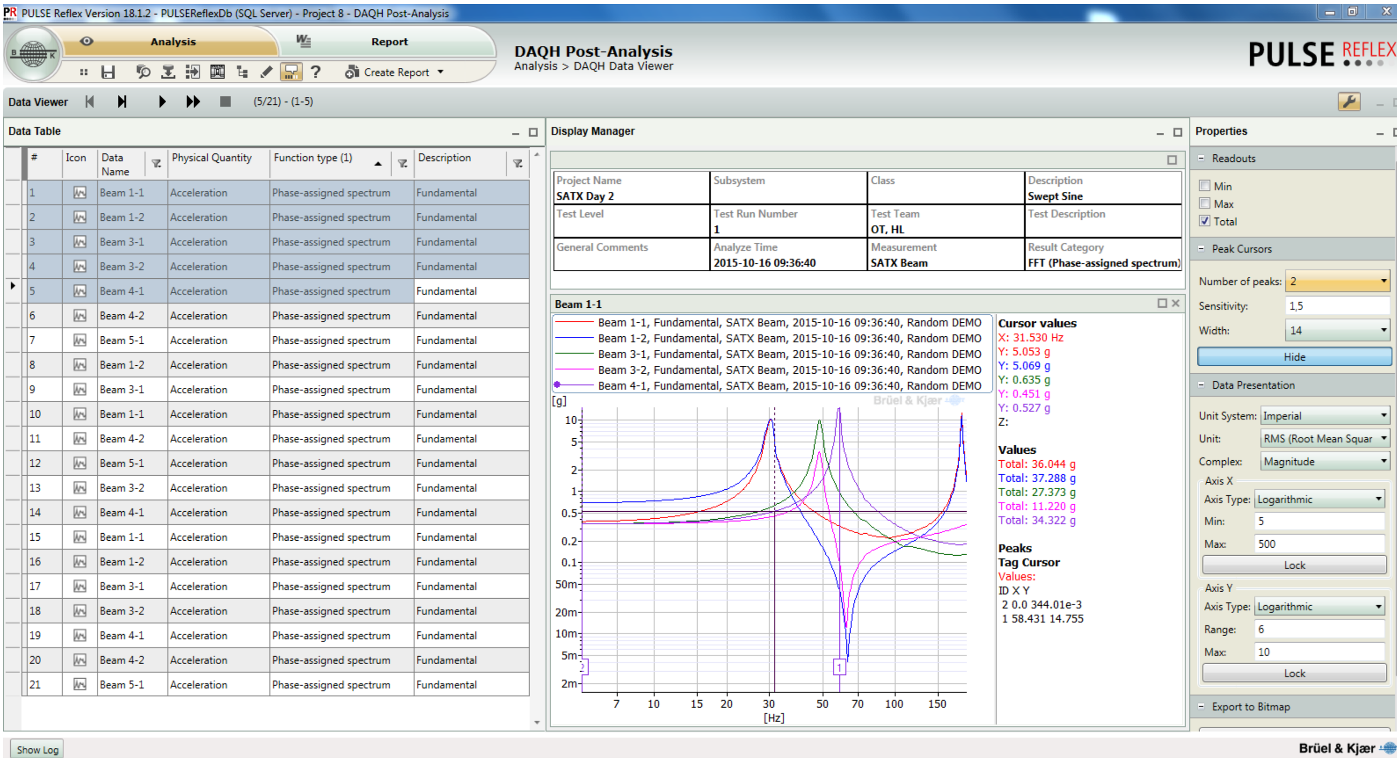


Fig. 8 Calculating the fundamental signals and harmonics

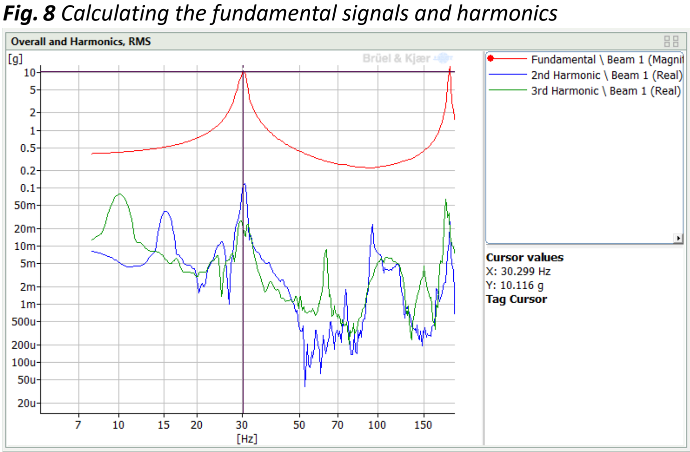
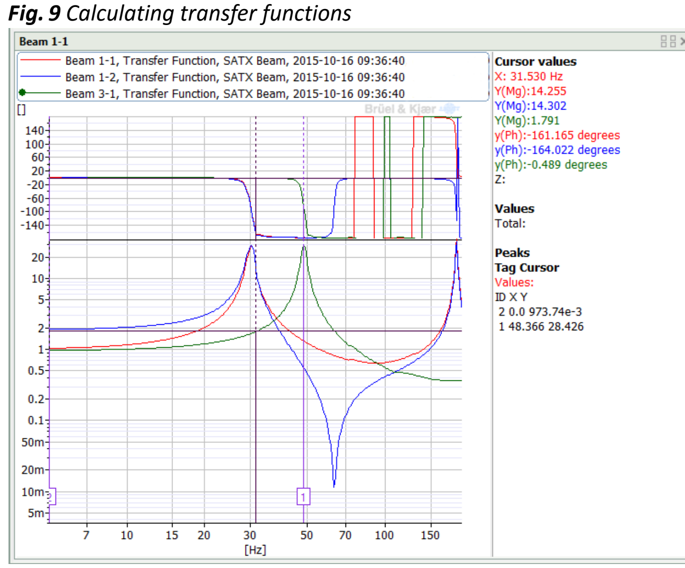


Fig. 9 Calculating transfer functions



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