FFT Basics
The basics of signal processing

OROS Webinar

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Application Engineer, OROS Americas

8/27/2020
About your presenter

Nick Hoffman

Joined OROS Americas May 2020. Responsible for supporting US users and sales team. Recent graduate, worked NVH support from 2015 and consultation from 2017.
About your presenter

⇒ Please write your questions in the Q&A area
⇒ We will take time to answer at the end of this webinar

Corentin Lecoq

Corentin joined the customer care department of OROS in 2014. Since 2016, he has held the position of application engineer and has been responsible for supporting users on advanced projects, sales and validating OROS solutions.
Webinar Recorded!

YES, YOU’LL BE ABLE TO REPLAY THIS WEBINAR
Contents

> OROS Introduction
> Signal types
> Digitization Process
> FourierTransform (FFT)
> Weighting windows
> Averaging
> Overlapping
Made for Your Demanding World

Industrial Sectors
Automotive
Aerospace
Energy and Process
Marine
Precision Machining and Process

Product Life Cycle
R&D
Acceptance
Diagnostics

Applications
Noise
Rotating
NVH
Structural Dynamics
Quality Process and Control
OROS – Noise and Vibration Testing and Analysis Solutions

**Full Software suite**
- Comprehensive
- Application oriented
- Rotating
- Structural Dynamics
- Data Acquisition and Signal Processing
- Acoustics

**Services**
- Customer Support
- Consulting & Coaching
- Customization & Integration

**State-of-the-art Instruments**
- From 2 to 32 channels
- Distributed up to 1000+
- DataCare®
- Flexible
- Made for any testing environment
Signal processing
Where to find Vibration? Acoustic?

Noise
- Building acoustics
- Sound power
- Source localization
- Psychoacoustics & sound design

Structural Dynamics
- Operating Deflection Shape - ODS
- Bump test
- Modal analysis
- Building vibration

Rotating
- In-flight test
- Jet engine test
- Factory acceptance test
- Maintenance Repair Overhaul - MRO
- On-site commissioning / troubleshooting diagnostic
- Rotordynamics & balancing
Where to find Vibration? Acoustic?

Quality & process control
- Microelectronics production equipment
- End of line production test
- Machine tool fine tuning

NVH
- In-vehicle test
- EV / HV
- Cabin noise and acoustic comfort
- Prototype validation
- TPA - Transfer Path Analysis
- Powertrain test
Signal types

Stationary
Constant with time

Determinist
Forecastable with math. models

Periodic
Repeated pattern

Random
Forecast impossible in time domain ➔ Statistical observation
Random noise

Example: white noise

Time history

Statistical observation: Averaging of 400 spectra show an homogeneous distribution of frequency

Narrow band spectrum

Value?

46 mV RMS
Signal types

- **Non Stationary**: No statistical observation
- **Transient**: Transient conditions
- **Shocks**: Very short time (~ms)
Signal Types

> Shock signal is characterized by a short time impulse.
> Example: Laplace transform of a Dirac impulse $\delta$

This property is used for modal purpose to excite the whole frequency range (bump test)
Shocks analysed in time domain

Time indicators: Pk-Pk, RMS, Kurtosis, crest factor, ...

⇒ Statistical analysis on time signal

<table>
<thead>
<tr>
<th>TimeVw [1]</th>
<th>DC Unit</th>
<th>RMS Unit</th>
<th>Min Unit</th>
<th>Max Unit</th>
<th>Ktsis Unit</th>
<th>Pk Unit</th>
<th>Pk-Pk Unit</th>
<th>CrFact</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01 m/s²</td>
<td>8.55 m/s²</td>
<td>-53.24 m/s²</td>
<td>75.67 m/s²</td>
<td>7.68 m/s²</td>
<td>75.67 m/s²</td>
<td>128.91 m/s²</td>
<td>8.85</td>
<td></td>
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</tbody>
</table>
Signal types

Non Stationary
- No statistical observation

Transient
- Transient conditions

Shocks
- Very short time (~ms)

Variable conditions
- short or mid time (~s or ~mn)
FFT Basics & Signal processing

- Signal types
- **Digitization Process**
  - FourierTransform (FFT)
  - Weighting windows
  - Averaging
  - Overlapping
Acquisition flow chart

1. **Physical quantity**
2. **Sensors**
3. **Conditioning**
4. **Processing**
5. **Digitizing**
6. **Analog Filter**
Signal Conditioning

> How to prevent inputs overload?

Signal Range < Analyzer range peak

Otherwise → input will be overloaded and peaks will be cut → risk of damage for analyzer integrity
Signal Digitizing

Analog Signal

Digitizing

Digitized Signal

Sampling  Quantization
Sampling

Pick up samples every T-time
T-time is the sampling period $T_s$

Sampling frequency $F_s$ means how many samples are picked up per second
Discretization in magnitude: closest discrete value of the analog value will be held.
The dynamic range is given by the number of bytes, according to the following formula:

$$N \text{ Bits} = 2^N$$

For 24 bits, equal to $2^{24}=16.8$ Billons points are spread on the selected peak range.
The digitized signal is a values serie
FFT Basics & Signal processing

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- Overlapping
Time domain to Frequency domain

> Time view

FFT

> Spectral view
Time domain to Frequency domain

Time view of a pure sine

Frequency spectrum of a pure sine
> Fourier Theorem: All continuous signal can be decomposed with Fourier series, as a sum of sines

In 1810 Fourier created the Imperial Faculty of Grenoble where he became rector.
Shannon’s theorem

Fe > 2,56 Fmax

Fmax corresponds to the frequency range
Time and frequency resolution

Time history of signal

Time block for FFT analysis

FFT spectrum

\[
time\_block\_duration = \frac{\text{spectral\_lines}}{\text{Freq\_range}}
\]

\[
\text{Delta}_F = \frac{\text{Freq\_range}}{\text{spectral\_lines}}
\]
FFT Basics & Signal processing

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Windowing

FFT process can be applied only on finite durations such as periodic signal. This is rare to satisfy this condition so windowing is often used to force signal to be a periodic one.

Sharp shape in the signal can create high calculation errors.
Windowing process

To transform a non-periodic signal into periodic signal, time weighting is applied. Hence, the time block starts and ends by zero

Example: Hanning window is used in this example:

- raw trigger block
- weighting block
FFT processing

Instantaneous Spectrum
FFT Basics & Signal processing

- Signal types
- Digitalisation Process
- Fourier Transform (FFT)
- Weighting windows
- Averaging
- Overlapping
Averaging purpose

- Raw result from FFT module is an instantaneous spectrum. It represents a weak duration of signal.

- Averaging allows analyzing a larger portion of signal to improve the real energy of the signal (below comparison between 1 single result and 100 FFT’s result).
Averaging purpose

- Instantaneous spectrum is computed from one time block. Averaging leads to get a better estimation of the real vibration energy.
- How to average spectrum each other?
- Linear or Exponential?

Sketch for exponential averaging

<table>
<thead>
<tr>
<th>Inst. Spectrum</th>
<th>SP1</th>
<th>SP2</th>
<th>SP3</th>
<th>SP4</th>
<th>SP5</th>
<th>SP6</th>
<th>SP7</th>
<th>SP8</th>
<th>SP9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Averag Spect 1</td>
<td>1</td>
<td>0.6</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Averag Spect 2</td>
<td>1</td>
<td>0.6</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Averag Spect 3</td>
<td>1</td>
<td>0.6</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
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LINEAR stops after the avg time ➔ used for stationary conditions

EXP never stops ➔ used for monitoring and transient conditions
Time or Spectral averaging?

Spectral domain averaging

Time domain averaging

In time domain, a phase reference is requested (keyphasor)
FFT processing: linear Averaging, Size 3
Due to the windowing, area at the time block ends are not taken into account as the central area of the time block.

Overlapping allows to minimize the windowing effect
The table below gives the advised value for the usual windows, in percentage.

<table>
<thead>
<tr>
<th>Weighting window</th>
<th>Theoretical values</th>
<th>Usual values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hanning</td>
<td>66</td>
<td>50/75</td>
</tr>
<tr>
<td>Flat Top</td>
<td>50</td>
<td>50/75</td>
</tr>
<tr>
<td>Uniform</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Overlap

Without overlap

With overlap

Sampled data

Sampled data

Processed data with no overlap

Processed data with 66 % overlap

66 % overlap
And much more …

- Cross spectrums, FRF and Coherence
- Waterfall and 3D results
- Envelope analysis
- Frequency synchronous averaging

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