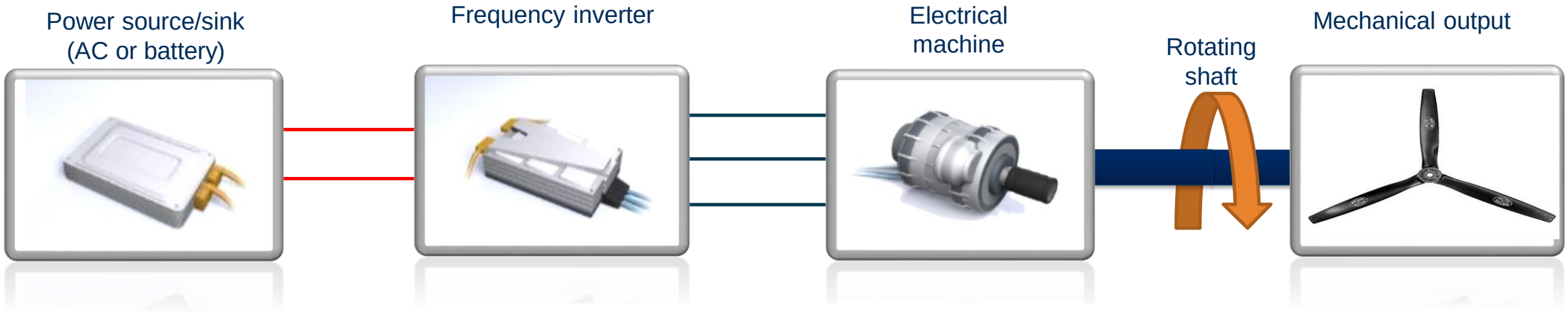
Introduction to Noise and Vibration in Electric Machines – Part 1

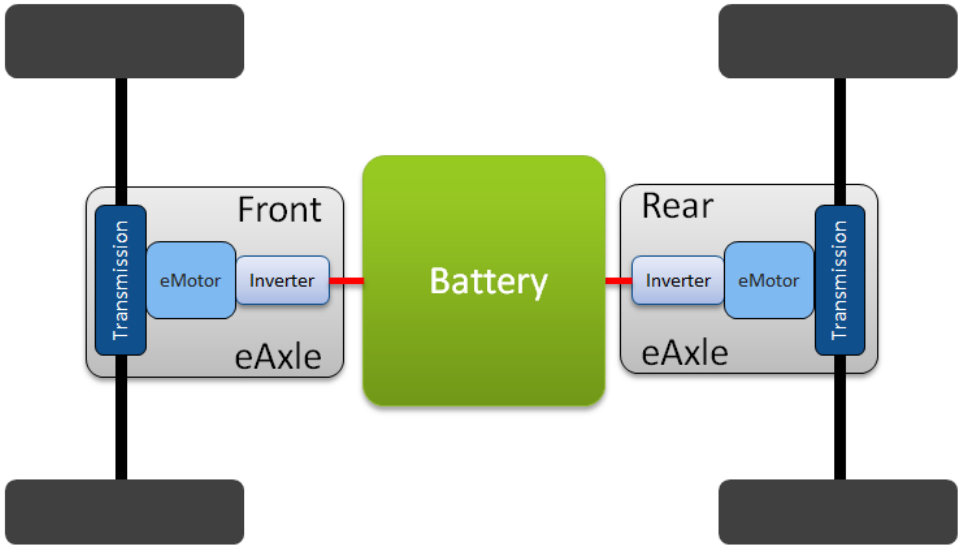
Agenda

1. Introduction to vibration in electric machines
2. Characterizing NVH in electric machines
3. Why test both
4. Case study
5. HBK eDrive solution

Introduction to Vibration In Electric Machines

Simple Measurement Chain - Electric & Mechanical Measurements





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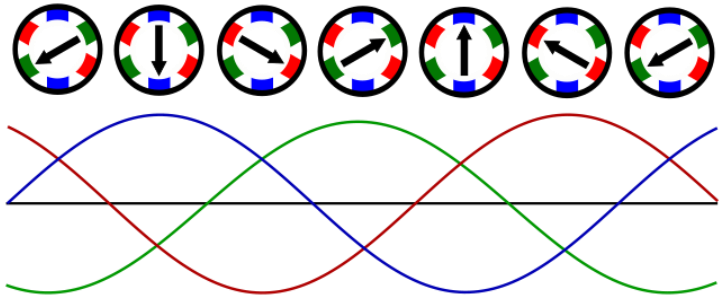
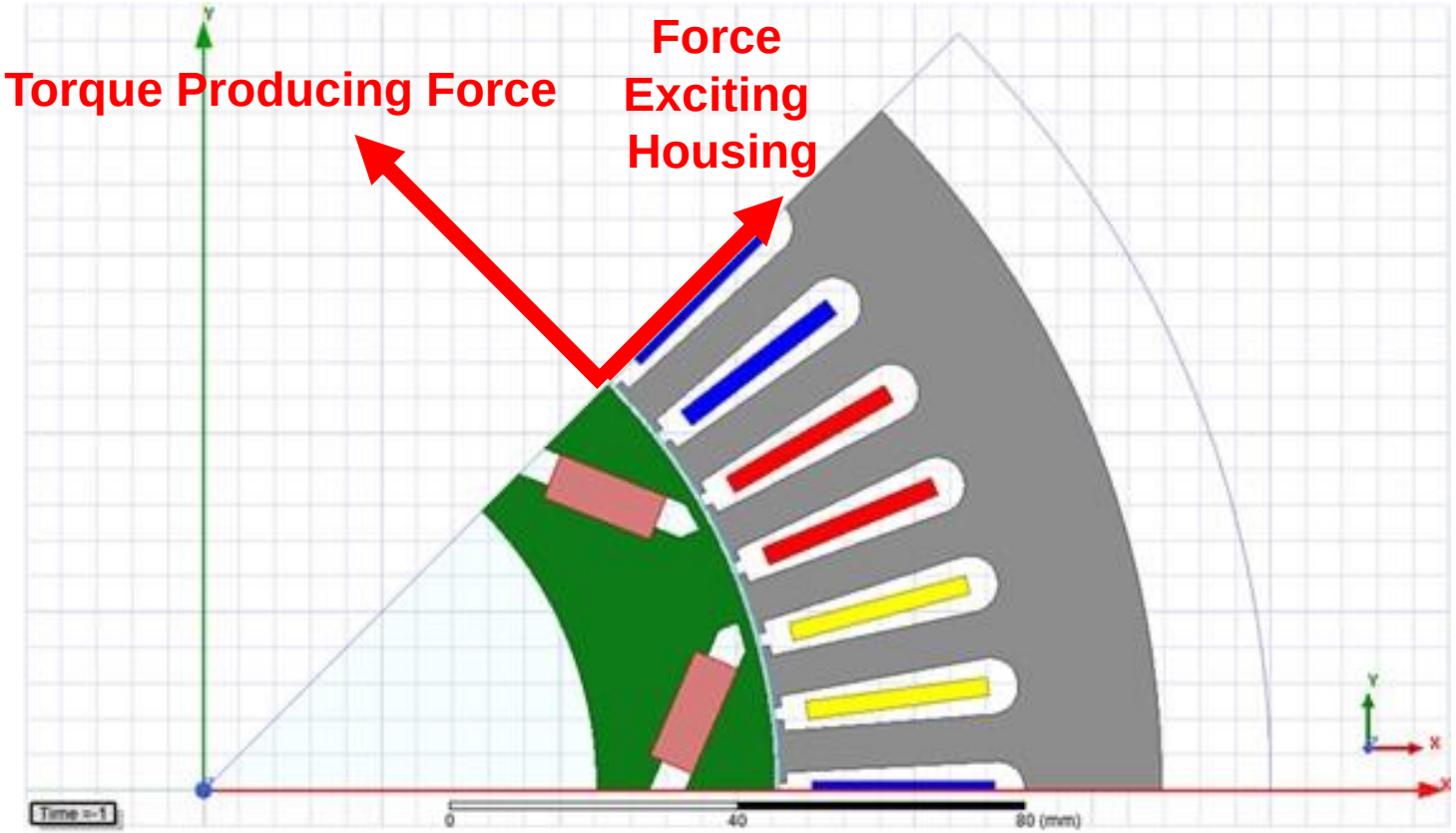
Motor construction – Sources of Vibration



- Torque follows the envelope of AC excitation
  - Slow speed ripple proportional to electrical frequency
  - Function of winding distribution
- Permanent magnets interact with slot teeth
  - Magnets want to stick to iron
  - Function of magnets
  - Function of slots
- Forces not in the direction of torque can excite housing

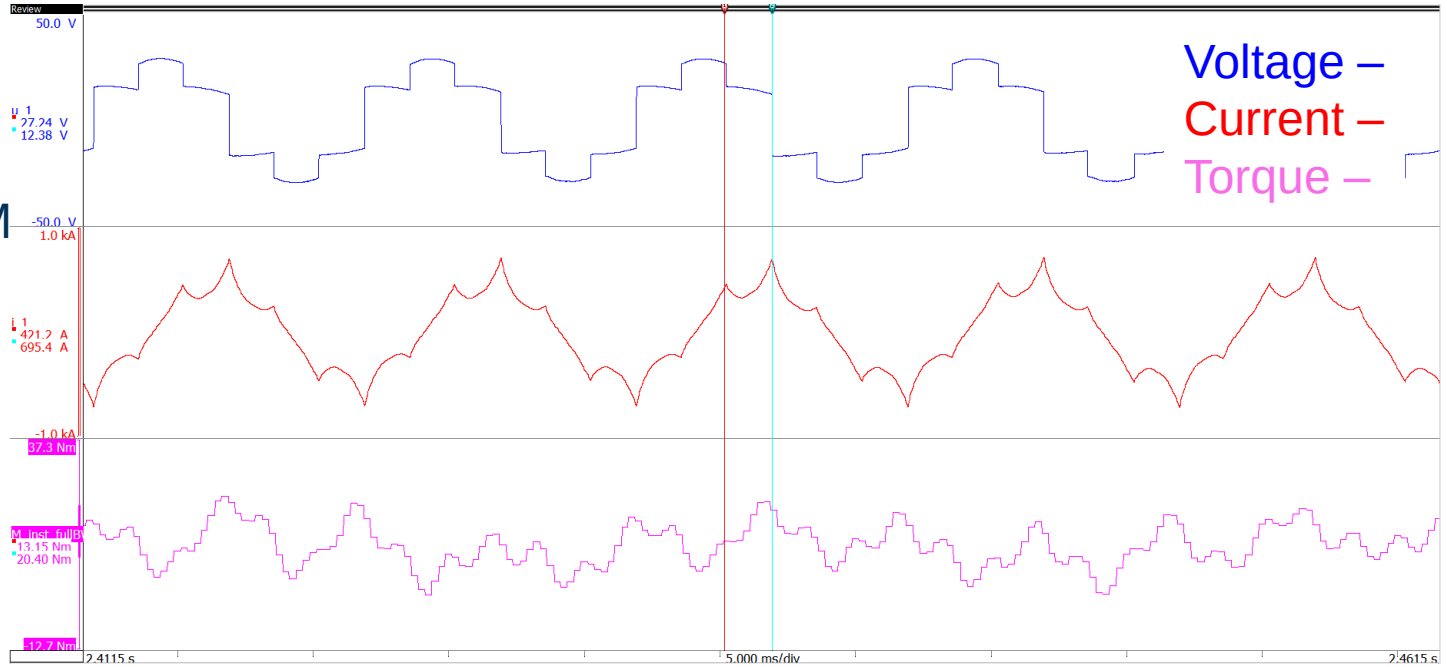


Single motor pole for a PM machine highlighting iron slots and widnings

Inverter operation

- Inverter often creates AC with a Pulse Width Modulated voltage
  - Pulses of different length create a sine wave
  - Unequally timed pulses result in multiple frequencies of NV
- PWM voltage → PWM current → PWM Magnet → PWM torque → PWM NV
  - Noise and vibration at switching rate
- Many more controls than PWM

PWM to Synthesize Sinusoidal Output



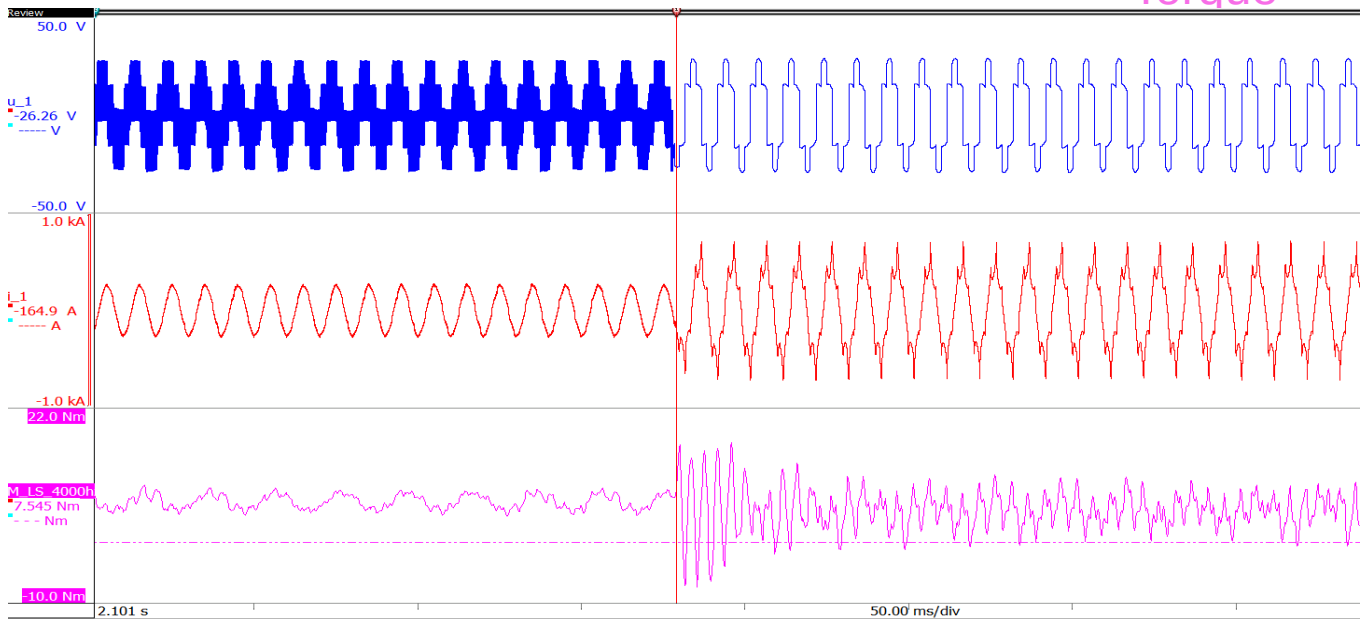
Voltage, current, and torque highlighting the correlation between the 3 values

Characterizing NVH for Electric Machines

Inverter Voltage Influence on Mechanical Torque

- Torque has frequency component
  - AC excitation
  - Slotting effects
- Control type effects torque
  - PWM excitation on the left
  - 6 step excitation on the right
- These effects will result in NV at the machine and down stream
- Inverter controlled torque ripple is being used for sound design

Voltage –
Current –
Torque –



Voltage, current, and torque for a control change in a 3 phase machine highlighting the dependence of torque on excitation

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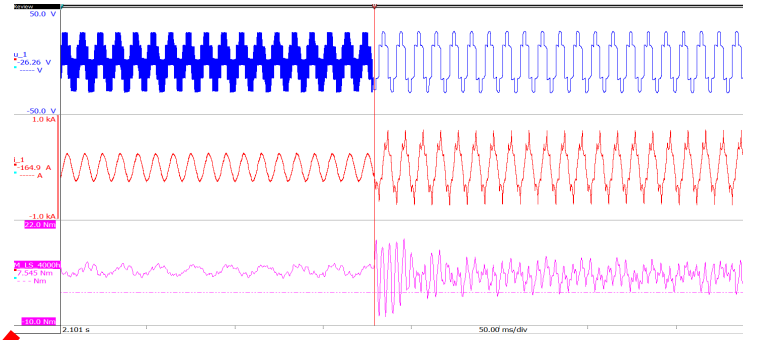
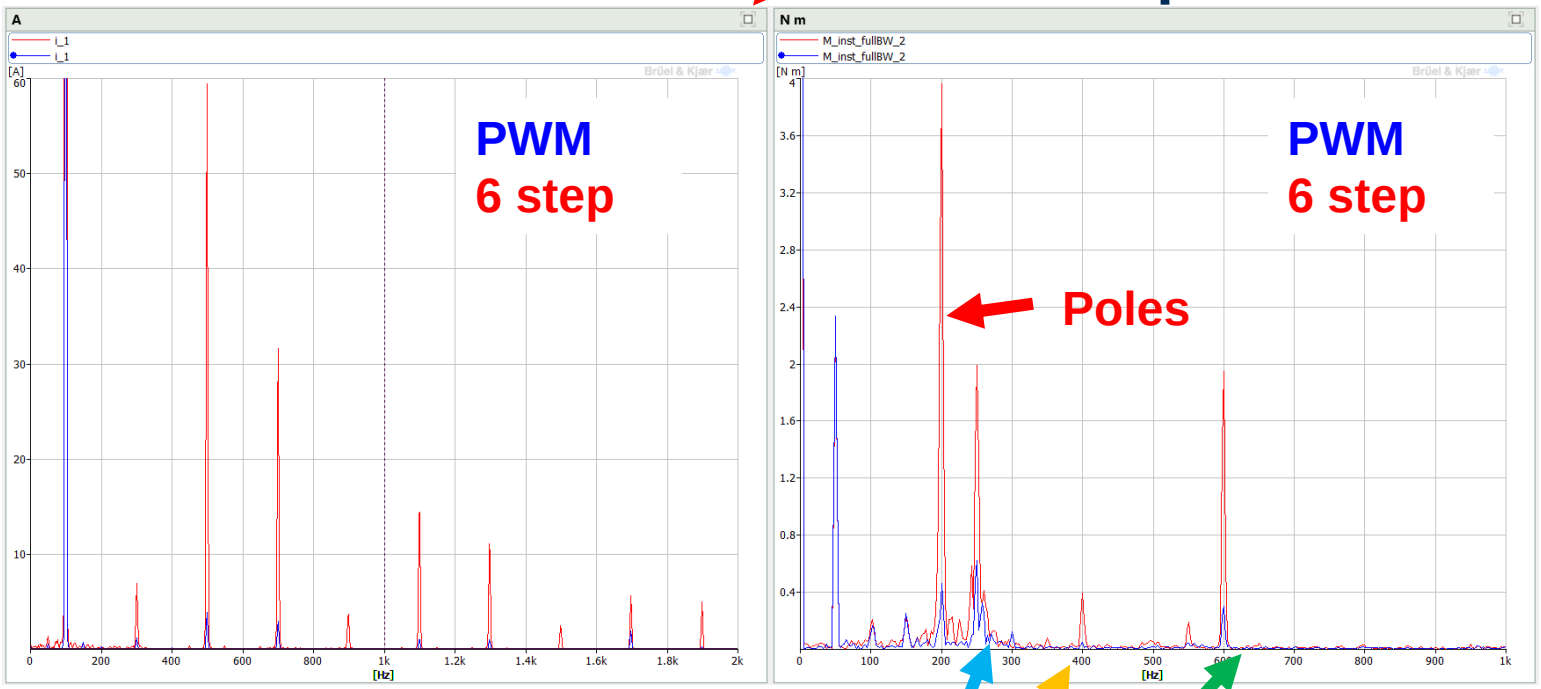
Voltage, Current, and Torque Frequency Content

- Fundamental and rotational current and torque are similar
- 6 step current has significantly more current harmonic content in PWM
  - 5^{th} , 7^{th}, 11^{th}, …
- Torque has significantly more harmonic content during PWM
  - 4x, 5x, 8x, 10x, 12x rotational frequency
  - Linked to current



Current **Torque**



Frequency spectrum comparing current and torque during PWM and 6 step operation

5^{th} electrical harmonic

Construction

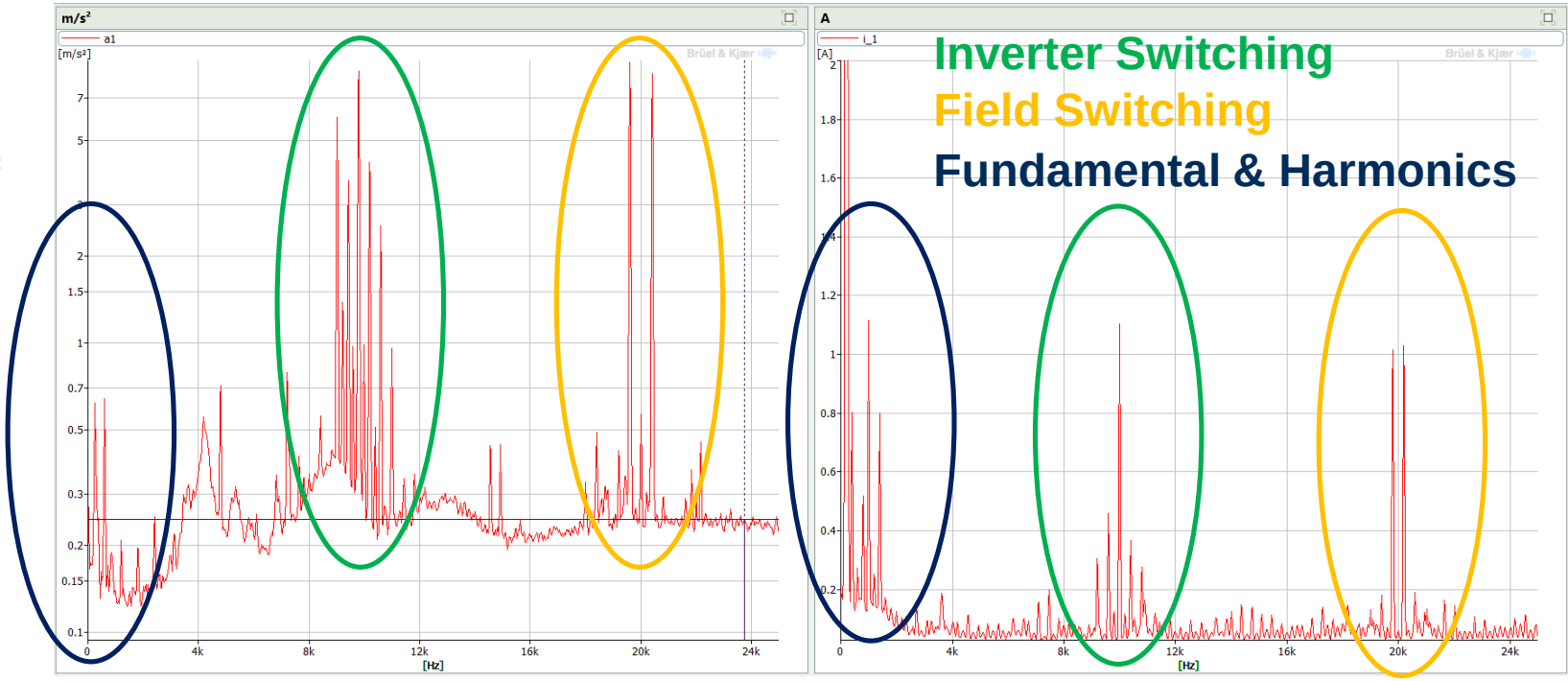
Switching

Current Causes Vibration

Field switching vibration and current do not perfectly align. It cannot be assumed that these are perfect correlations

Need to measure Both

- Some machine vibrations are caused by the current
- Rotational frequency shows vibration from the harmonics of the fundamental
- High frequency vibration from switching
- Torque sensors limited to 6kHz bandwidth → Accels are complimentary to torque measurement



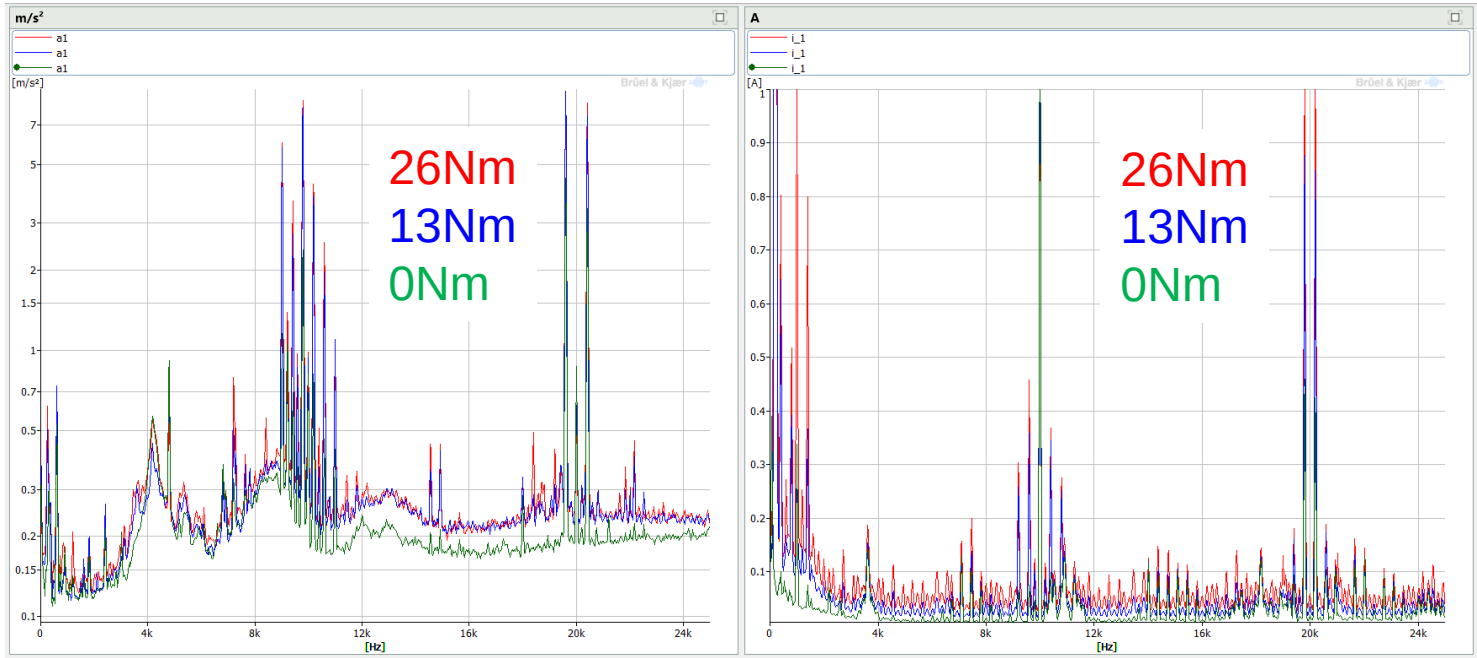
Frequency spectrum comparing current and vibration for a steady state machine operation

Torque Loading Influences Frequency Spectra

- Fundamental shows a torque dependence
- Inverter signature shows strong torque dependence
- Gear mesh orders also enhanced under high torque
- Switching is always there but has stronger presence with loading

Vibration

Current



Frequency spectrum comparing current and vibration for a steady state machine operation at 3 loading points

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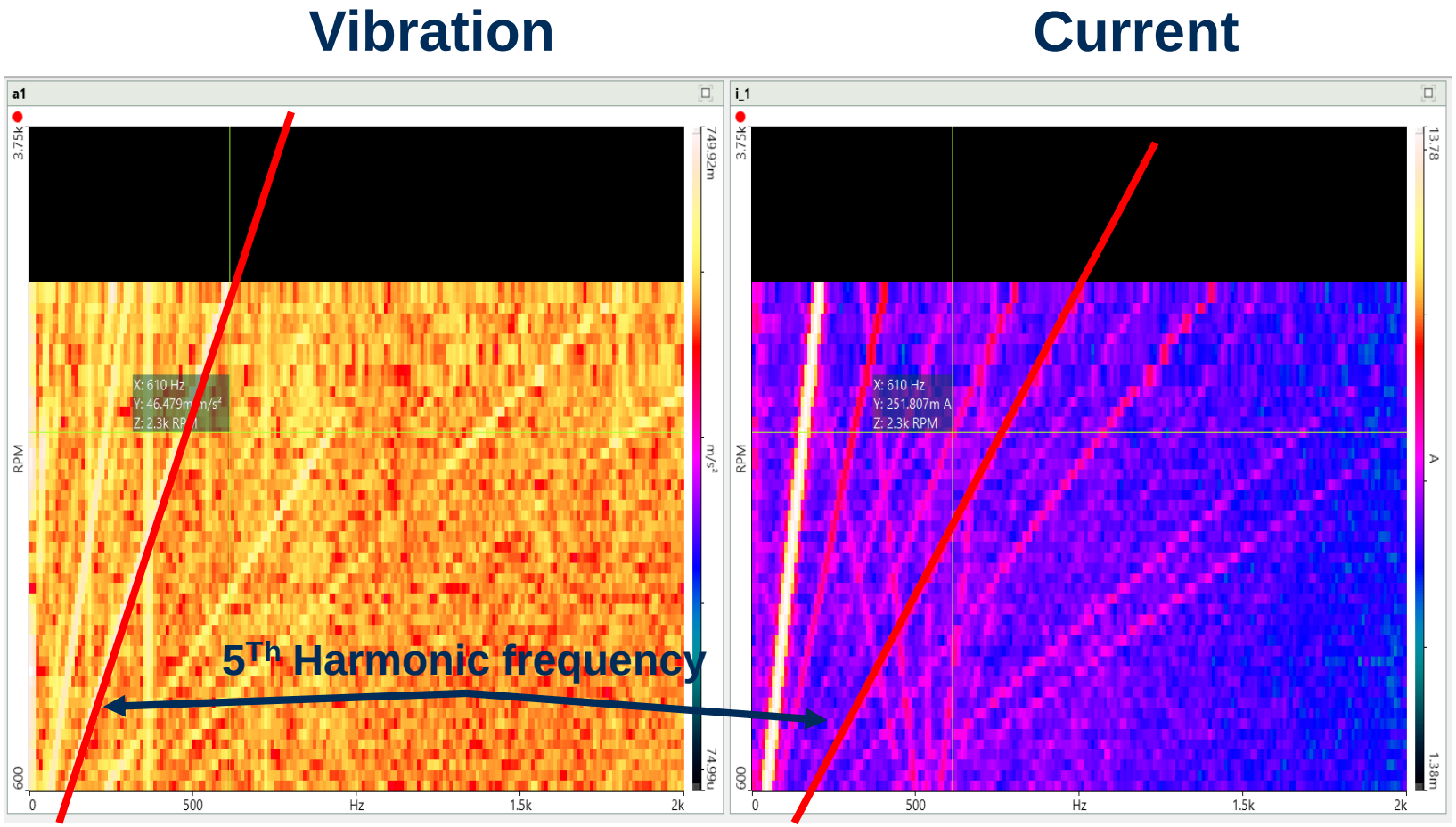
Ramps & Spectrum Plots

- Ramp up and down of speed at a given torque/ control
- Plot of amplitude (z), vs frequency (x), vs speed (y)
- Easy way to graphically see the influence of speed on current/vibration
- Follow fundamental & harmonics

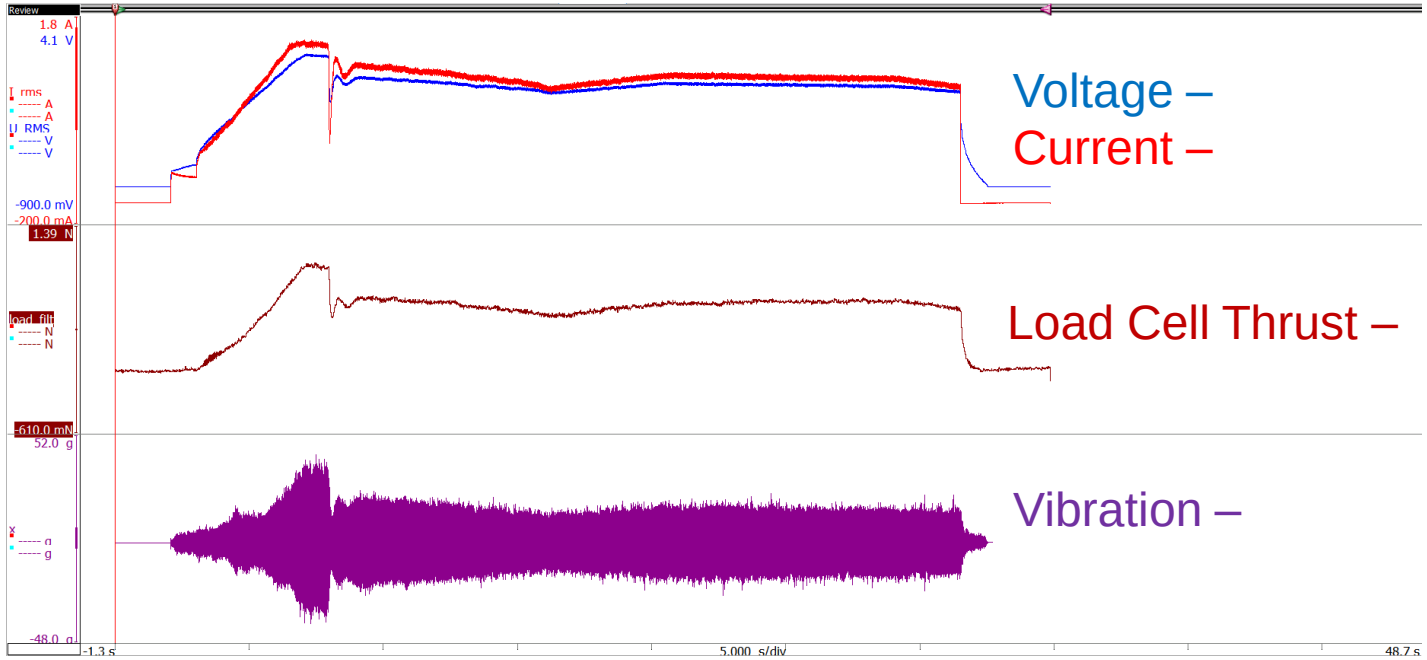


Spectrum graph showing vibration bands and current bands for the rotational frequency of a ramp test

Why Measure Both?

Benefits of combined testing

- Single test to do both
  - **Reduction costs**
- Communication between groups
  - **Faster development**
  - Easier communication to vehicle simulation
- Sound design
- Fatigue characterization
- Failure testing
- Resonance tracking
- End of line characterization



Propeller motor startup with load and vibration measurements

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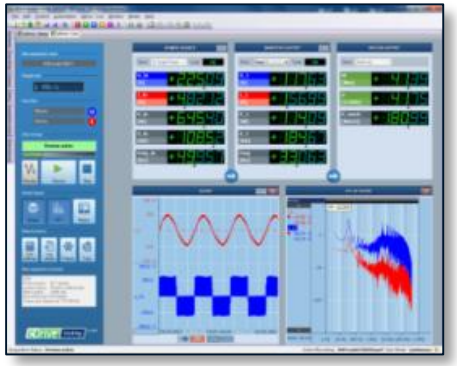
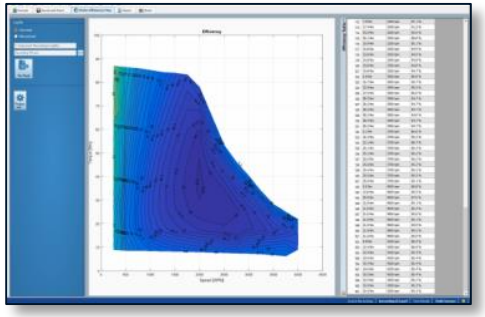
eDrive Solution

eDrive Value

- The HBK **eDrive solution** streamlines and simplifies data collection of electro-mechanical signals
- High accuracy power measurements
- Future proof your testing capabilities
- **Auditable Tests**
- Full data streaming / raw data collection – Know where your results came from
- Simplifies measurement chain
  - Sensors → Aquisition → Software





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Questions?

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HBK Electric Power Test