

What is Torque Ripple and Cogging Torque in Electric Motors – Part 1

Agenda

1. Introduction
2. Torque in electric machines
3. What is torque ripple
4. Why we care about torque ripple
5. Measurement equipment for evaluating torque ripple

HBM

- eDrive motor analyzer
 - Accuracy & dynamic power
 - Expandable
 - Recorded data
 - High sample rate
 - Time alignment for mechanical and electrical measurements
- World class torque cells
 - Accuracy up to **.02%**
 - Bandwidth up to **6 kHz**
- **Combine eDrive & torque sensors for torque ripple analysis**
 - High accuracy torque cell shows small changes in torque
 - High bandwidth shows high frequency details
 - High sample rate and time alignment let you analyze the time and frequency data



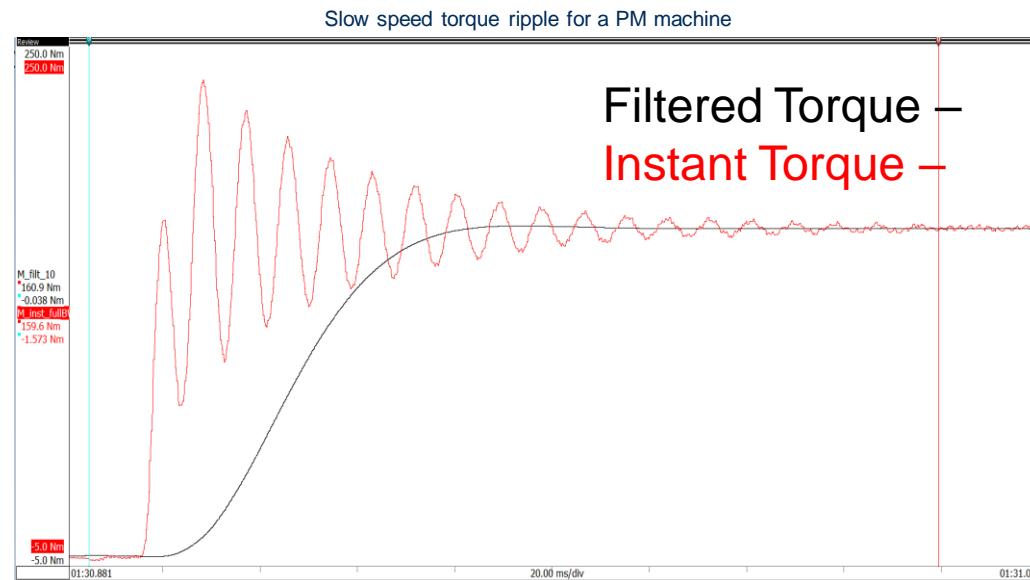
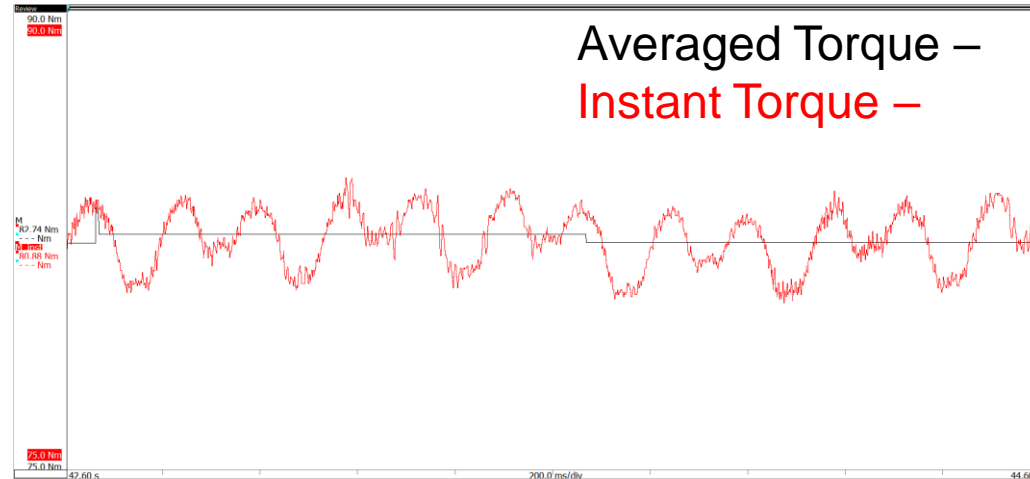
HBK products for torque and power

eDrive testing

What is Torque Ripple

Torque ripple is → periodic disturbances in torque

- Torque is not a static
- Torque has ripple from excitation and construction
- Many test stands show heavily filtered torque
- Torque ripple has a frequency and amplitude



Transient torque fluctuations and high speed torque ripple

Where does torque ripple come from?

Permanent Magnet

- Magnet interaction with stator slots
 - Cogging torque
- Cannot turn magnets off

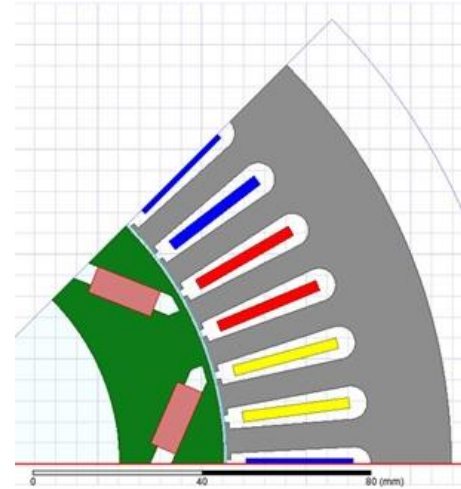
Switched Reluctance

- Pulsed current
- Hard torque pulses

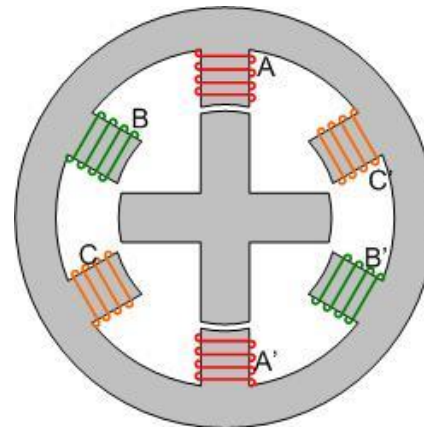
Induction Machine

- Magnets induced on rotor
- Bars interact with slots

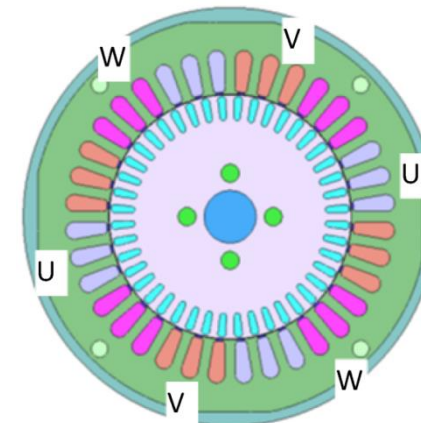
Permanent Magnet Motors



Switched Reluctance



Induction Machine

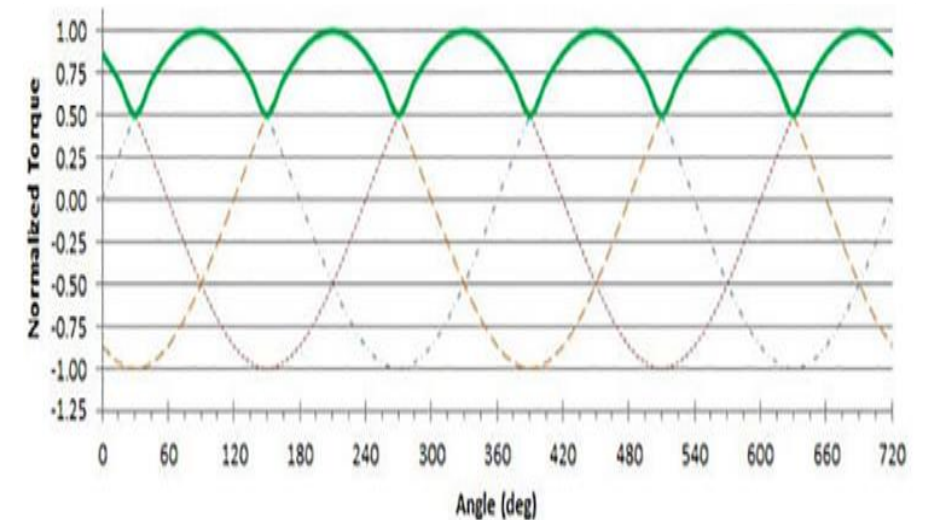
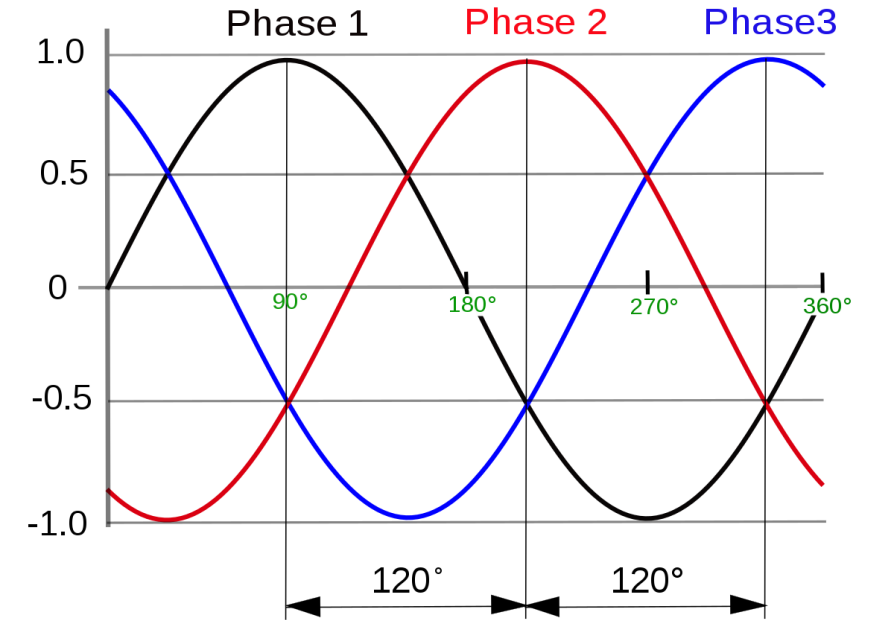


Different machine types will have different types of torque ripple

Where does torque ripple come from?

AC excitation

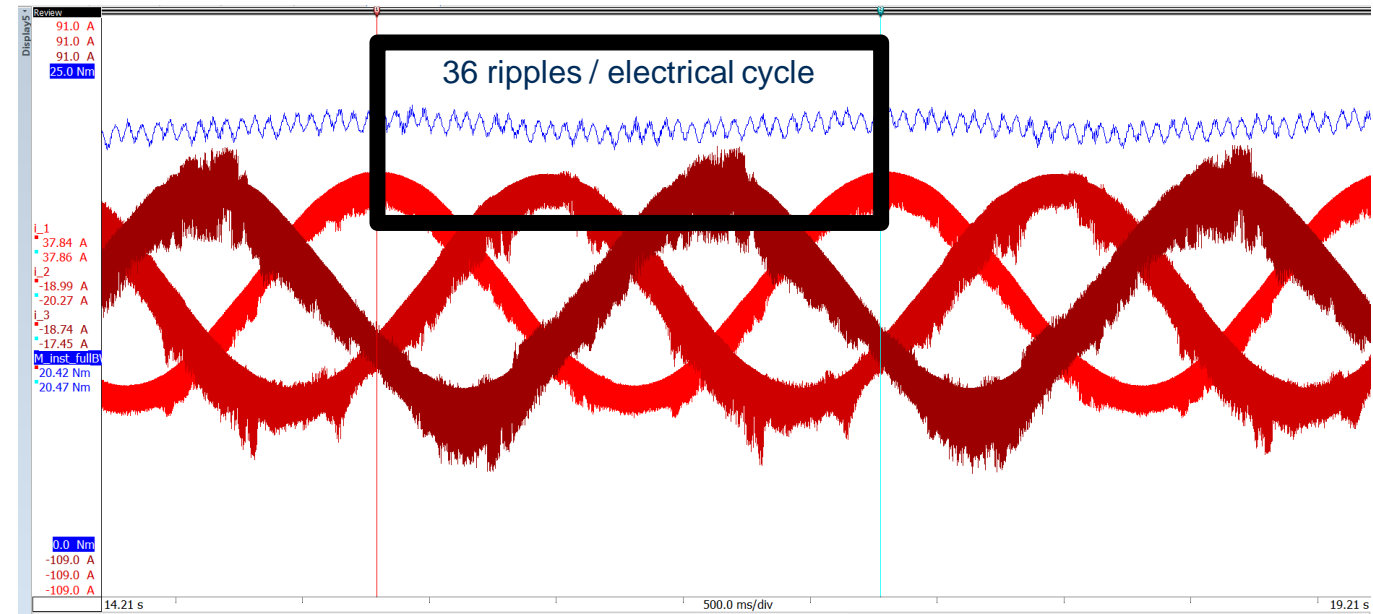
- Torque follows the peaks of the currents
- Influenced by the winding of the machine
- Responds to harmonics in the current
 - Control technique
 - Switching frequency
- Frequency and amplitude are proportional to phases and RPM



Three phase excitation and the resulting torque output

Torque ripple from PM motors

- Slow speed test
- Many ripples
 - Magnets interacting with stator slots
 - Excitation
 - Control technique
- Ripple is a function of construction
- Ripple is proportional to frequency



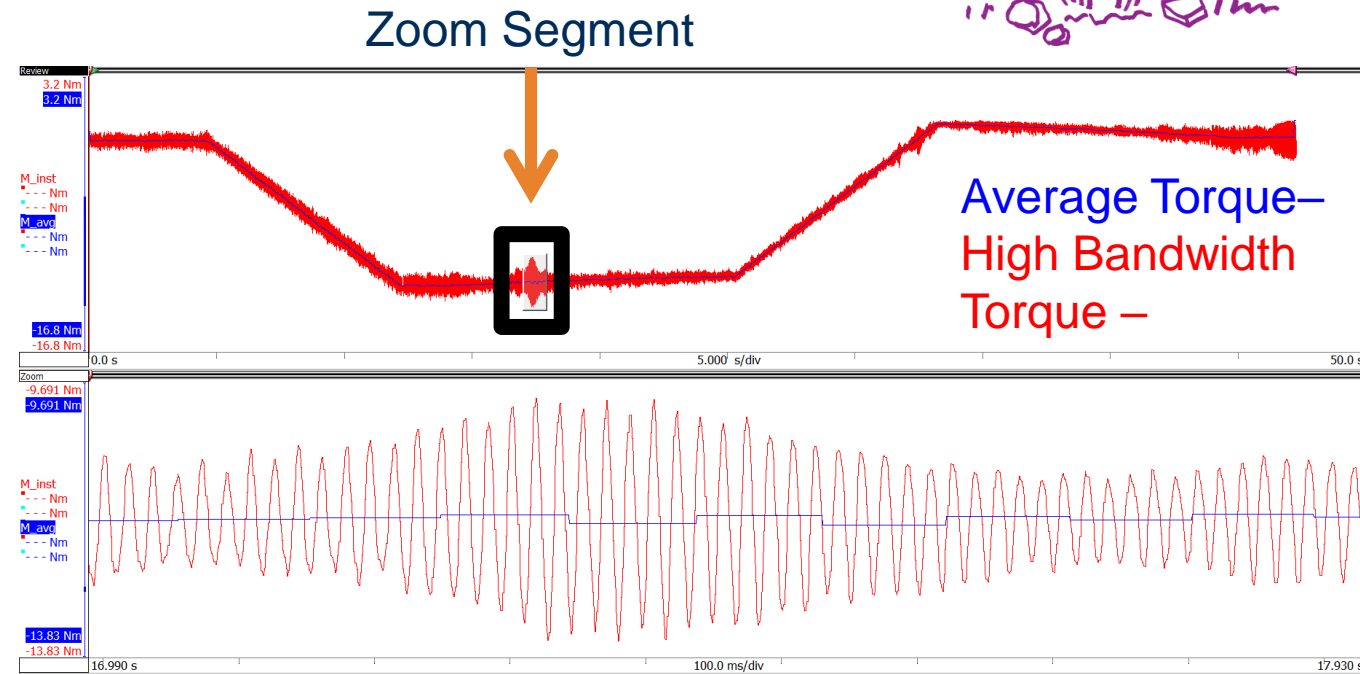
Three phase motor excitation in red and resultant torque ripple in blue

eDrive testing

Why we Care About Torque Ripple

Vibration, noise, and fatigue

- Torque ripple results in vibrations
 - Gear chatter in gear boxes
 - Lifetime and durability concerns
- Torque ripple can excite structures
 - Result in noise
 - Result in resonant vibrations
- Ripple frequency is proportional rotor construction and electrical frequency
 - Control technique
 - Ripple frequency * switches
- Motors spin at high speed



Why motors care about torque so much → Efficiency

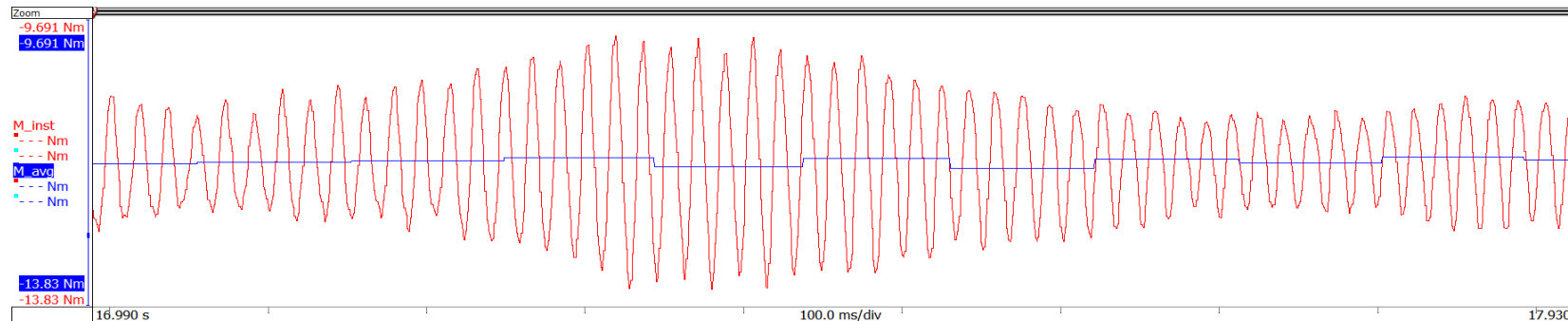
Internal Combustion Engine

- Engine efficiency 30-40%
- A 3% error in an engine gives 39% instead of 36%
- We believe this!

Electric Motor

- Motor efficiency 85-98%
- A 3% error in a motor gives 101% instead of 98%
- This is impossible!

- Need highly accurate torque and speed that accounts for **SMALL** disturbances in the average
- 80 kW @ 20k RPM → 2093 Rad/sec x 38.22 Nm → .25 Nm offset is 500 W → .625 %



User experience

- Sometimes you can feel torque ripple
 - Vehicle
- Sometimes you want to feel torque ripple
 - Drill clutch
- Vibration can be very hazardous
 - Vibration on a wing



Power tools and aircraft driven by electric machines

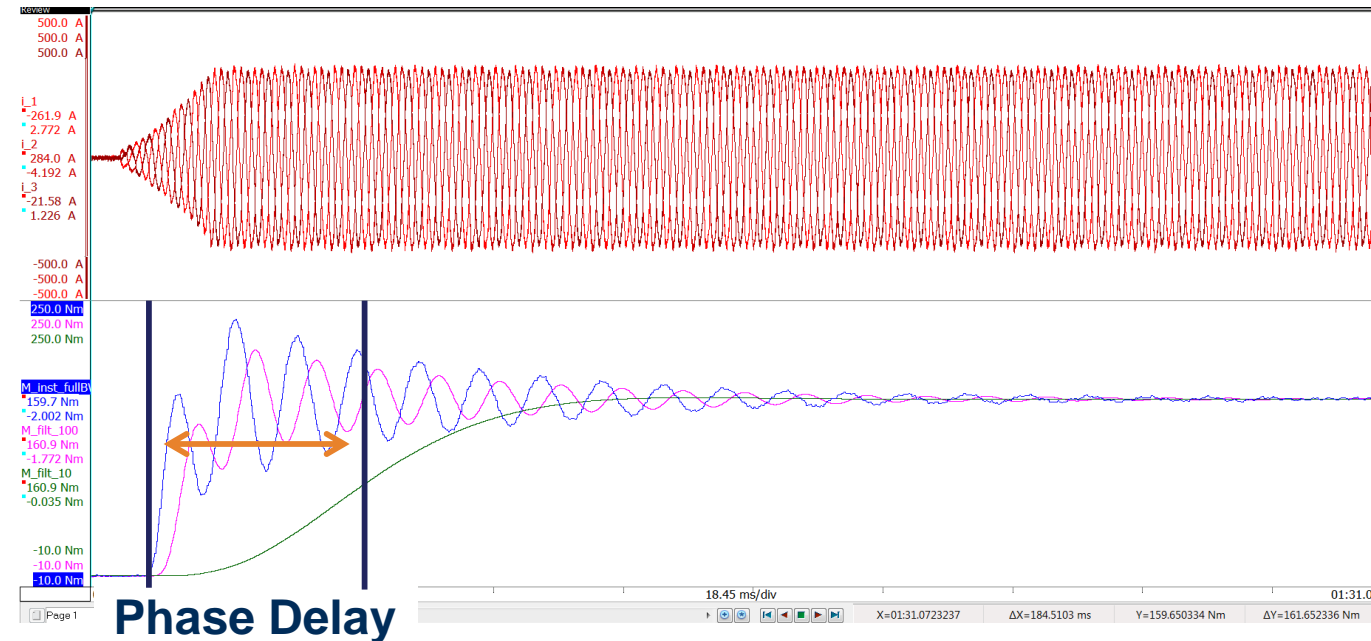
eDrive testing

Measuring Torque Ripple

Accuracy, Bandwidth & Time Alignment for Transients

- Test with load step
- Filtered version loses amplitude info and has phase delay
- Time alignment is necessary for control calibration
- Filters augment data used for efficiency
 - Results in very slow tests
 - Results in incorrect data

Full Bandwidth Torque –
100Hz Filtered Torque –
10 Hz Filtered Torque –



Top – three phase excitation for an electric machine with a load step
Bottom – cyclical torque with different filter rates

Equipment needed

- Torque sensor that has accuracy and bandwidth to observe bandwidth
- Noise immune torque communication
 - Analog signals are susceptible to noise in a PWM environment
 - HBM torque cells use a frequency output that reduces susceptibility to noise
- Acquisition system that records torque at a rate sufficient for bandwidth
- Acquisition system that correlates to other signals of interest
 - Electrical
 - Vibration



Questions?



Mitch Marks

Business Development at HBK -
Hottinger, Brüel & Kjær



HBK Electric Power Test

