The HBM eDrive solution:
The next generation power analyser / DAQ for electric and hybrid test rigs
eDrive testing – presentation topics

- Current motor testing limitations
- State of the art technical requirements
- Testing of an electromechanical system involving pressure, displacement, flow and temperature
- Actuator Testing
- Dynamic efficiency testing
- Dynamic control analysis
- Large system testing with many motors and converters
- Failure and fault analysis for motors
- Real time test system feedback
- Summary & Questions
Introduction
Mitch Marks

- BSEE, MSEE – Electrical Engineering
  University of Wisconsin – Madison WEMPEC

- Managed Power Lab
  - Traction motors
  - MicroGrids
  - Batteries
  - EV

- Previous positions in motor manufacturing, controls, and testing

- Current Motor Testing Specialist at HBM
Major Motor Projects

Prime Mover Emulator for Grid Research

Wound Field Traction Machine

Variable Magnetization State PM

Electric Truck
Limitations of Current Test Systems
DAQ requirements on electric drive train

Power source/sink (AC or battery)

Frequency inverter

Electrical machine

Rotating shaft

**Power source output**
- Voltages
- Currents
- Temperatures
- Electric power $P_{in}$

**Inverter output**
- n-phase Voltages, modulated
- Currents
- Temperatures & CAN
- Electric power $P$ & PF

**Electric machine output**
- Torque, Speed, and position
- Displacement & Acceleration
- Temperatures & Vibration
- Mechanical power $P_{mech}$

Inverter Efficiency

Motor Efficiency

Electric Drive Efficiency
Testing electric drives – the typical method

Battery voltage and current
Various slow speed measurement types, i.e. just using DMM’s

Frequency inverter output
Power analyzer and scope

Electrical machine output
Torque transducer and DAQ system for torque, angle and speed

Problems:
1. Limited understanding of the application -- Not designed for motor testing
2. No raw data available for verification or analysis – Disconnect of high and low sampling rates
   1. Difficult time synchronization between different systems
   2. Data storage (limited) in different systems & different formats
   3. Power meters deliver few calculations only and are not reliable in dynamic load change situations
   4. Limited or difficult system integration possibilities
   5. Difficult for future expansion

User comment:
“Sometimes we measure efficiency larger than 1. We can’t believe that, but we can’t analyze further as we have no raw data.”
State of the Art Requirements
New Electric Motor Requirements

- Accurate power measurement in dynamic load changes
- Testing of machines with > 3 phases or multiple machines
- Noisy DC bus
- Torque Ripple
- Testing of complex systems like hybrids or actuators
- Acquisition of all signals with only one system
- Shortest possible test cycles per set point (~ms)
Introduction

Designed for motor testing and analysis. eDrive has made the topics covered in this presentation possible.

EtherCAT®

CAN FD
eDrive testing

Testing of an Electromechanical System
Torque Ripple

- Instantaneous and averaged torque
- High sampling rate acquires full bandwidth of a torque cell
- Identify and analyze ripple
Torque Ripple from PM Motors → control change
Dynamic Torque Measurement

- 10000 RPM Test with 100kW Load Step
eDrive: Airgap torque estimation

- From the currents and with some formulas, you can compute the torque in the airgap of the machine.
- Thus you can estimate (1-3% accurate) the torque generated without measuring it.
Actuator Testing
Research on Actuators

- Testing thermal characteristics
- Efficiency & Power Flow
- Comparing EHA & EMA
- Mechanical Behavior
- Control for best response
Mechanical Velocity and Displacement

- Measurement using displacement sensors and commanded values
- Time alignment is necessary for knowing delay in controller
- Want to minimize overshoot and rise time
- Use feedback/feed forward in controls to accomplish acceptable response
- There is no steady state
Regenerative DC Bus

• Power flow monitoring during step commands

• End up with Regen on the DC bus

• Current research into AC component of DC bus
Frequency Response – Light Loaded Failure testing

- Increase displacement command frequency and monitor current and temperature
- Eventually things break down
- Monitor limits of system and their coupling
Cycle Detect
Making dynamic testing possible
Dynamic Testing ➔ Cycle detection

- To compute any power result the “cycles” of the signals are needed
- Detecting the cycles via zero crossings is difficult due to noise
- Allows for dynamic power measurements
eDrive: Cycle detect verification
In Vehicle Testing
Cycle Detect

- Currents for a Chevy Bolt
- Driving around parking lot
- Cycle detect functioning with changing frequency and amplitude
Dynamic Efficiency Testing
Accelerated efficiency mapping

- Raw data is stored per set point in real time
  - 293 set points
    - 20 different speed values
    - 17 different torque values
  - Each set point:
    - 100 ms recording
    - 400 ms pause, then next torque step
    - After full torque ramp, a few seconds pause before next speed step

- During test result table with P, P_mech, M, n, η... is created in real time

- Finally: Post run map creation (in MATLAB or other drawing sw)

- Complete mapping can be done in a few minutes
Drive Cycle Testing

World Harmonized Light Vehicles Test Cycle (WLTC)

Motor Losses

Winding Temperature

Magnet Temperature

Fixed MS<sub>e</sub>

Variable MS<sub>e</sub>

Motor Losses

Winding Temperature

Magnet Temperature
Calculations are done on a per cycle basis.
Dynamic Control Analysis
Monitor Control Changes

- Voltage and Current from Customer
- Voltage Transition from PWM to 6-Step to increase speed
- Current changes from Pure Sinusoid to jagged
- Control Changes highlighted in Space vector and DQ0
- DQ0 shown in different reference frames
Space Vector Transformation During a Control Transition

- Space Vector $\alpha$ and $\beta$
- Confirm control behavior
- Visualize control path during transitions
Watching \( I_d \) and \( I_q \) during a Magnetization change

**Transitions:**

MS change for increasing and decreasing \( M S_e \) level combinations at 2000 rpm, over a range of torque conditions

- 60% => 100% \( M S_e \)
- 100% => 60% \( M S_e \)
- 60% => 80% \( M S_e \)
- 80% => 60% \( M S_e \)

Disturbances outside the desired control circle

Map control path correlated to Torque disturbances

Time [s]

\( T \) [Nm]
Having controller and physical signals in one location

- $I_d$ – Direct Axis (field)
- $I_q$ – Quad Axis (Torque)
- $V_d$
- $V_q$
- $I_q^*$ - Estimated
- $I_d^*$ - Estimated
- $J$ – Magnetization State
- Angle of Rotor
Large System Testing
Efficiency testing on multi level inverter

- More power channels needed
- Special formulas needed for efficiency
New challenges: > 3 ph motors

- More power channels needed
- Formulas for total power are different from "standard" 3 ph

Example formulas:

<table>
<thead>
<tr>
<th>P_L1</th>
<th>@CycleMean (RTFormulas.p_1 : RTFormulas.Cycle_Master)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P_L2</td>
<td>@CycleMean (RTFormulas.p_2 : RTFormulas.Cycle_Master)</td>
</tr>
<tr>
<td>P_L3</td>
<td>@CycleMean (RTFormulas.p_3 : RTFormulas.Cycle_Master)</td>
</tr>
</tbody>
</table>

The sum of the active power per phase gives the total active power:

| P_tot  | RTFormulas.P_L1 + RTFormulas.P_L2 + RTFormulas.P_L3 |

User entered formulas for 5ph real power:
Electrical four wheel drive tested with a single eDrive system

Motor 1
- 3 currents from CT’s (via MCTS and HBR)
- 3 voltages (via star adapter)
- 2 x M / 2 x n from Txx level converter

Motor 2
- 3 currents from CT’s (via MCTS and HBR)
- 3 voltages (via star adapter)

Motor 3
- 3 currents from CT’s (via MCTS and HBR)
- 3 voltages (via star adapter)
- 2 x M / 2 x n from Txx level converter

Motor 4
- 3 currents from CT’s (via MCTS and HBR)
- 3 voltages (via star adapter)

AuSy with EtherCAT

GEN DAQ eDrive System with EtherCAT

Windows PC with Perception Software
Electrical four wheel drive tested with a single eDrive system
Failure and Fault Analysis
eDrive: Durability testing

- Tests according to Chinese standards GB/T 29307-2012, GB/T 18488.1-2015 and 18488.2-2015
- Defines at least 400 h of continuous testing, 1000 h recommended
- Last 30 minutes should be kept in circular buffer to analyse failures
  - This sums up to about 10-25 GB of data

- GEN DAQ offers unique „Circular recording“ option with full disc pretrigger

- Powerful trigger capabilities on all input signals incl temp & vibration
  - Side note: HBM patent on fast display used in Perception:
  10 GB are shown in review in 4 s

- So power values are streamed to ECU (using EtherCAT to CAN gateway) while raw data is kept in circular buffer
FFT of the voltage

- FFT can show information on test
- Unexpected FFT can indicate issues
- Increase of certain harmonics over time can indicate issues
- Use FFT to see torque ripple beyond resolution of sensors
- High Sample rate and Raw data necessary for long term failure testing
Battery Control & Lifetime Testing

- Batteries used in automotive need to be verified and tested

- As they are charged and discharged using inverters with (small) DC link capacitors, high frequency components in the charging currents need to be detected and minimized

Charging currents before (yellow) and after optimization (red)
Real Time Feedback
In a Test system
eDrive: Interfacing with the GENxt products – RPC & EtherCAT

**Test cell**

- Input signals: Voltage, Current, Torque, Speed, Angle, Temperature, Vibration, CAN…..

**Control room**

- Automation system (Windows or Linux)
- Setup and Remote control
- PC running Perception
- EtherCAT – 1000 results/s
- COM / RPC

**GENxt mainframe (Linux RT)**

**PNRF database**

- PNRF reader

**Other analysis software:**

- MATLAB, LabView, DIAdem, FlexPro, FAMOS, jBEAM, GlyphWorks
Advantages:

1. Synchronous acquisition of all data in one file & format, with higher channel count and temperatures / vibration / CAN

2. Continuous recording or snapshots per set point for verification, analysis and motor mapping

3. Real time power calculations per cycle, plus user formulas

4. Advanced analysis capabilities like space vector, dq0 transformation or airgap torque

5. Real time data transfer to automation system
eDrive: The HBM components for advanced power analysis

- GEN DAQ configurable, expandable mainframes
  - Up to 51 channels for power measurements (102 U&I)
  - Continuous streaming or storage per set point in real time
  - Support for up to 6 torque transducers (12 as special)

- 6 channel input card (= 3 power channels)
  - Voltage up to +/- 1000 V, current via CT’s or clamps
  - Sample rate 1 MS/s @ 18 bit, typ. power accuracy 0.02%
  - Option: 5 kV_{rms} differential probe, 0.1% accurate
  - Plug-in artificial star adapter, cascadable
  - Burden resistors for CT usage
  - On board user programmable math

- High accuracy HBM torque transducer (with speed)
  - Accuracy 0.02%

- Options
  - EtherCAT interface for real time data transfer to automation
  - Temperature satellite, 1 kV isolated, 8 channels
  - CAN input
  - Various inputs for strain, vibration, temp....
    …and also “scope cards” up to 250 MS/s
Like other power analyzers, the HBM eDrive computes power values and efficiency and displays these in real time.

Unlike other power analyzers, the HBM eDrive can store a variety of signals & raw data - like a high end DAQ - for review, verification and advanced analysis such as efficiency mapping or dq0 transformation.

Thus it does not only give you “efficiency”, but it also helps you to improve the efficiency.

It also offers a complete solution acquiring more than 3 phases, complex setups, temperatures, CAN and vibration as well.

For system integration, it offers modern integration tools including real time result transfer and accelerated motor mapping capabilities to save test time.

Note: eDrive is a strategic target market area for HBM.
Thanks for your time – Any Questions?

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