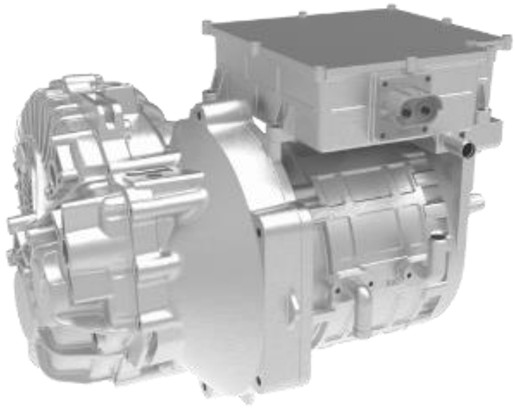
PLATO – NVH Measurement & Analysis of ePowertrains



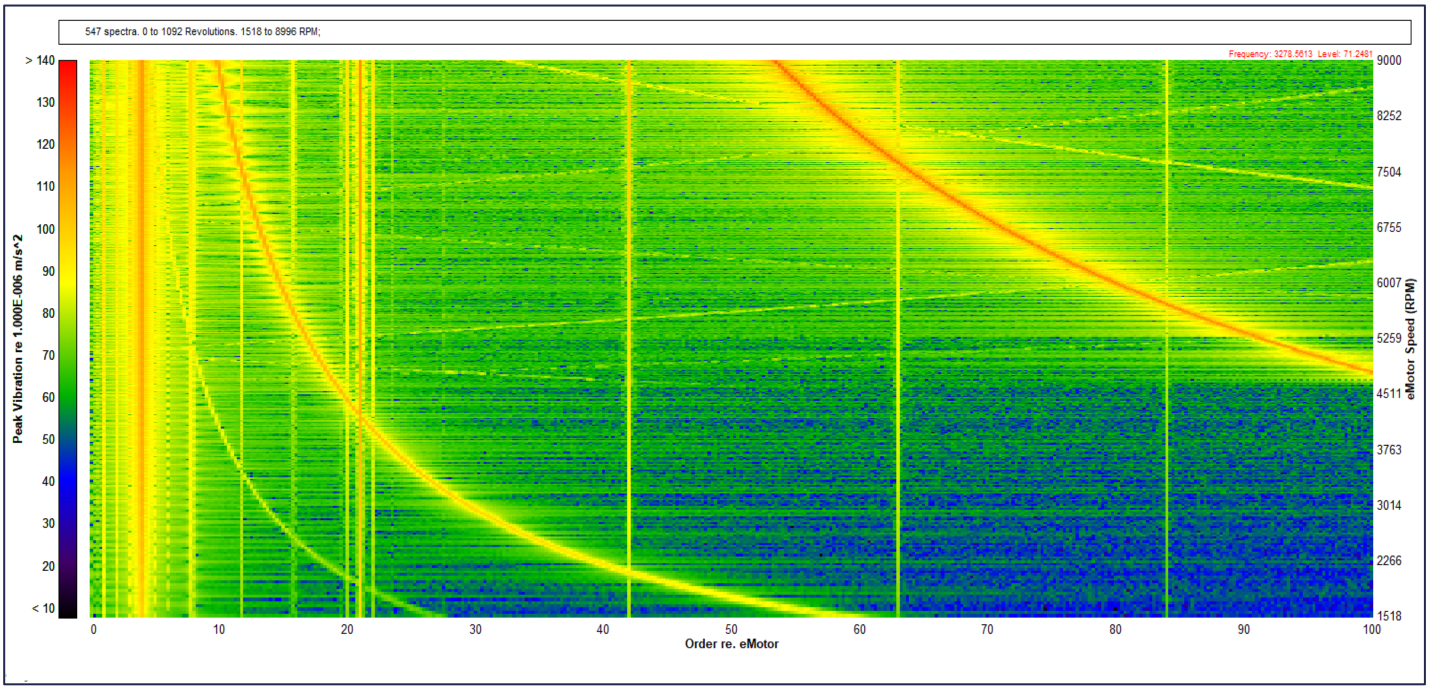
New technology – new approach

Automotive powertrain manufacturers worldwide are responding to market demands for electrified passenger and commercial vehicles. Many solutions are already in place and new technology is currently being developed for imminent deployment. The new technology includes high-power, high speed (rpm) electric motors (eMotors), often with integral control units (MCUs) / invertors coupled to mechanical gearsets and differentials. Overall reduction ratios are typically in the 10:1 to 16:1 range. NVH assessment of these products can use many of the same techniques developed over several decades for more traditional, mechanical-only, powertrain products, but the introduction of eMotors and associated control hardware requires additional measures to be assessed.

eMotor based automotive powertrains require a combination of NVH analysis techniques.

Higher speeds – higher frequencies

eMotors typically opeate at rotational speeds up to 30,000 rpm (500Hz). Rotor imbalance at a suitable speed up to 500Hz must be checked. No issue there, but eMotors include winding poles and stator/rotor interactions at pole count (and harmonics) which can be important contributors to user assessments of NVH. For example, a 12-pole eMotor has a basic interaction (vibrational disturbance), or socalled ´slot-frequency´ frequency of 6,000Hz at 30,000 rpm, with a high likelyhood of harmonic content at 12,000Hz and higher.



100-order analysis range (referenced to eMotor speed) is typically required. That´s an analysis range of 50kHz @ 30,000 rpm.

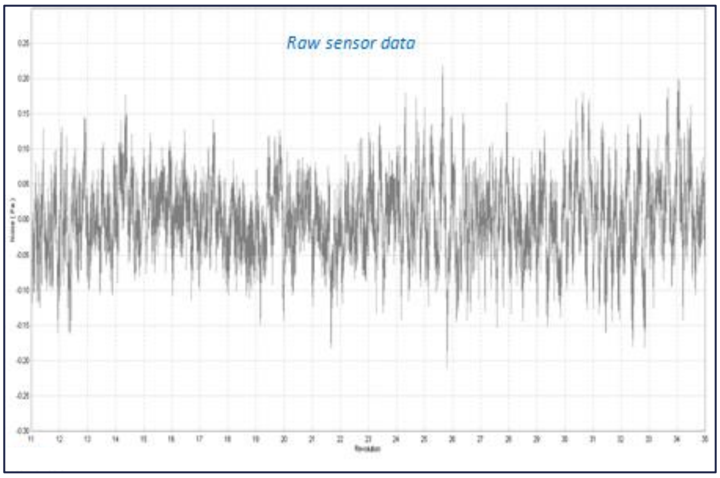
The high-speed nature of eMotors means that mechanical gearing is typically used to reduce shafts speeds down to those required for input to typical differential units. The input stages of that reduction gearing, by necessity, then include gears running at high rotational speeds. 20 to 30 teeth on the eMotor pinion is typical, allowing fundamental and harmonic orders to easily be encompassed within a 100-order analysis range, but at 30,000 rpm, fundamental gear mesh frequency for a 30-tooth gear is 15kHz.

ePowertrains with integral Motor Control Units (MCUs)/invertors, the so-called ´3-in-1 ePowertrains´, can also present their own NVH issues. PWM frequencies on typical invertors are around 8kHz (plus harmonics), so they, plus harmonics and speed related sidebands, must also be assessed, especially their interaction with gear-mesh orders.

Frequencies of interest as high as this also challenge the dynamic sensors used for more traditional NVH assessments.

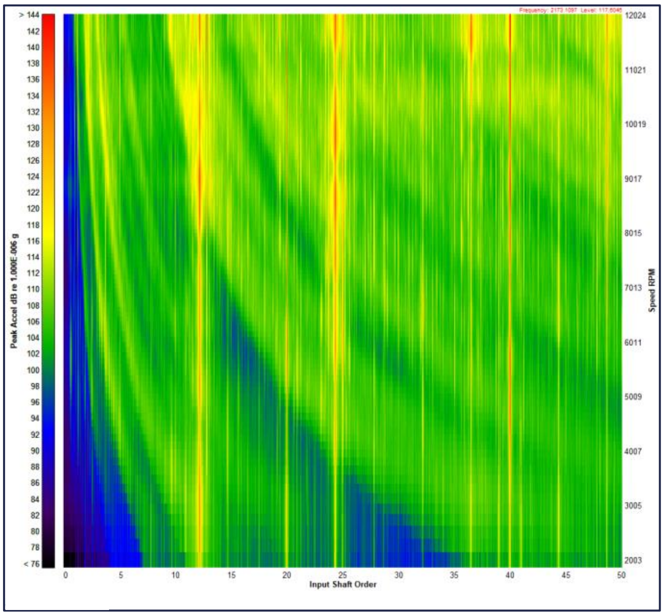
PLATO – "one stop shop"

PLATO from NVH International is a PC-based, multi-channel hardware/software system solution designed specifically for measuring noise/ vibration ("NVH") signatures from rotating machines such as automotive powertrain assemblies.



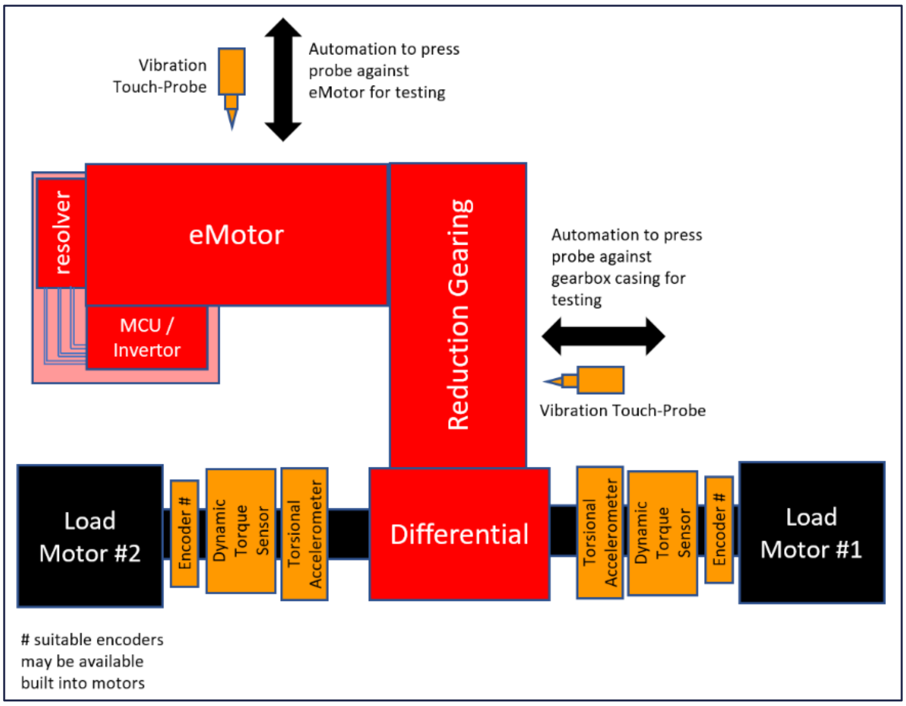
PLATO systems provide the **high raw data sampling rates** (up to 204.8kHz/channel) required for ePowertrain assessments linked to **precision frequency and order-locked analyses**. The software used for testing also provides in-depth interactive graphing / reporting when not in test mode.

And, to tailor each system to the exact requirements of each application and extend capability in specific analysis and/or application areas, a range of **add-on software modules** is also available. (Please refer to separate datasheet for overview of generic PLATO NVH measurement & analysis systems and datasheets on all available add-ons).



NVH sensors

The sensors typically used for ePowertrain NVH assessment using factory-based (end-of-line) testing with a test machine are shown generically in this diagram.



It is usual to measure **rotational** NVH energy at the ePowertrain´s outputs. For products that include a differential, it is usual to measure torsional acceleration and/or dynamic torque from both outputs by mounting suitable sensors within the output drivelines of the test machine.

The rotational sensors deployed should have the highest possible frequency response range.

Torsional accelerometers and dynamic torque sensors are available with up to 20kHz of measurement bandwidth. If dynamic torque measurement is selected in addition to, or instead of torsional acceleration measurement, dual-output torque sensors may be deployed to measure static torque and dynamic torque from a single sensor. Static torque measurements from both output drivelines is usually a control prerequisite for test machines of this type and PLATO also requires static torque values to check the consistency of test conditions run-to-run. Dual-output torque sensors can therefore be a very cost-effective solution since they remove the need for the output drivelines to be fitted with separate (static-only) torque sensors.

One or two vibration touch-probes (VTPs) are also typically used to measure eMotor and reduction gearset casing **linear** vibration. The VTPs are typically pressed against the ePowertrain under test using pneumatic actuators with a contact force in the range 10N – 20N. The VTPs deployed should have the highest possible frequency response range. Units are available with ´flat´ frequency responses (within ±3dB) up to 16kHz.

If budgets permit, laser-Doppler vibrometers (LDVs) may also be deployed in addition to, or in place of, VTPs. LDVs are available with measurement ranges up to 100kHz (although 25kHz is standard).

Some ePowertrains, particularly those with large airborne noise radiating surfaces may also be successfully tested by measuring an array of microphones (with stand-off distances of around 0.5m to 1.0m), but only if the test environment is quiet enough to allow the product noise to stand out above the background noise. (Contact NVH International for more information on using microphone arrays to successfully measure powertrain NVH).

Vibration sensor and microphone sensor powering & conditioning

The MC-103 sensor powering and conditioning module from NVH International is the ideal companion for IEPE-sensors (those with built-in electronics) such as vibration touch-probes (VTPs), accelerometers, and microphones etc.

The MC103 is available with any number of channels up to 8 and provides constant current power to the sensors before low-pass filtering prior to amplification.

Speed reference signal(s)

The order domain analyses within PLATO require a shaft speed reference signal to synchronise data resampling. For ePowertrain NVH testing, two options are typically available to obtain the speed refernce signal(s).

Option 1 – intercept eMotor resolver signals

The majority of automotive eMotors include a resolver to provide feedback to the MCU/invertor. If it feasible to access the resolver signals on a test-by-test basis, the **RSI-101 Resolver Speed Interface** module from NVH International provides a very cost-effective means to convert the resolver signals into a pulsetrain signal suitable for input as a speed reference signal to PLATO. Because the eMotor is (usually) the shaft with the highest rotational speed and it is common for resolvers to have up to 4-poles (or rotor lobes) per revolution, the signal derived from the RSI-101 provides a very high fidelity speed reference signal. (Contact NVH International for more information on the RSI-101).

Option 2 – use encoder signals from all outputs

For single output ePowertrains, the speed reference signal may be obtained from an encoder integral to the load motor (as used to provide feedback to the motor´s drive), or from a separate encoder mounted within the output driveline. The once-per-revolution marker signal can be used or any integer line-count value up to around 1024. For ePowertrains that include a differential gearset, and hence have two outputs, encoders on both outputs must be sampled by PLATO to ensure any speed differential in place is determined and compensated for in the analysis. When two encoders are used in this way, each encoder must output at least 500 pulses-per-revolution to ensure that any phasing errors at the start of the anlsyses are minimised on th elower speed shafts.

Channel counts and DAQ-hardware

Based on the above sensor recommendations, ePowertrain NVH measurement & analysis systems typically fall into either 8 or 16 channel count DAQ-systems as follows:

8-channel system

Channel	Measuring	DAQ-hardware
1	VTP#1 - eMotor casing linear vibration	National Instruments 8-channel PXIe-4492 (housed within suitable PXIe-chassis), 204.8kHz/channel 
2	VTP#1 – reduction gearbox casing linear vibration	
3	Torsional accelerometer #1 - left-hand output driveline	
4	Torsional accelerometer #2 - right-hand output driveline	
5	Static torque transducer #1 – left-hand output driveline	
6	Static torque transducer #2 – left-hand output driveline	
7*	Encoder #1 – left-hand output driveline	
8*	Encoder #2 – left-hand output driveline	

* or output of RSI-101 resolver speed interface (and one spare channel)

16-channel system

Channel	Measuring	
1	VTP#1 - eMotor casing linear vibration	National Instruments 16-channel PXIe-4497 (housed within suitable PXIe-chassis), 204.8kHz/channel 
2	VTP#1 – reduction gearbox casing linear vibration	
3	Torsional accelerometer #1 - left-hand output driveline	
4	Torsional accelerometer #2 - right-hand output driveline	
5	Dynamic torque sensor #1 - left-hand output driveline	
6	Dynamic torque sensor #2 - left-hand output driveline	
7	Spare #1	
8	Spare #2	
9	Spare #3	
10	Spare #4	
11	Spare #5	
12	Spare #6	
13	Static torque transducer #1 – left-hand output driveline	
14	Static torque transducer #2 – left-hand output driveline	
15*	Encoder #1 – left-hand output driveline	
16*	Encoder #2 – left-hand output driveline	

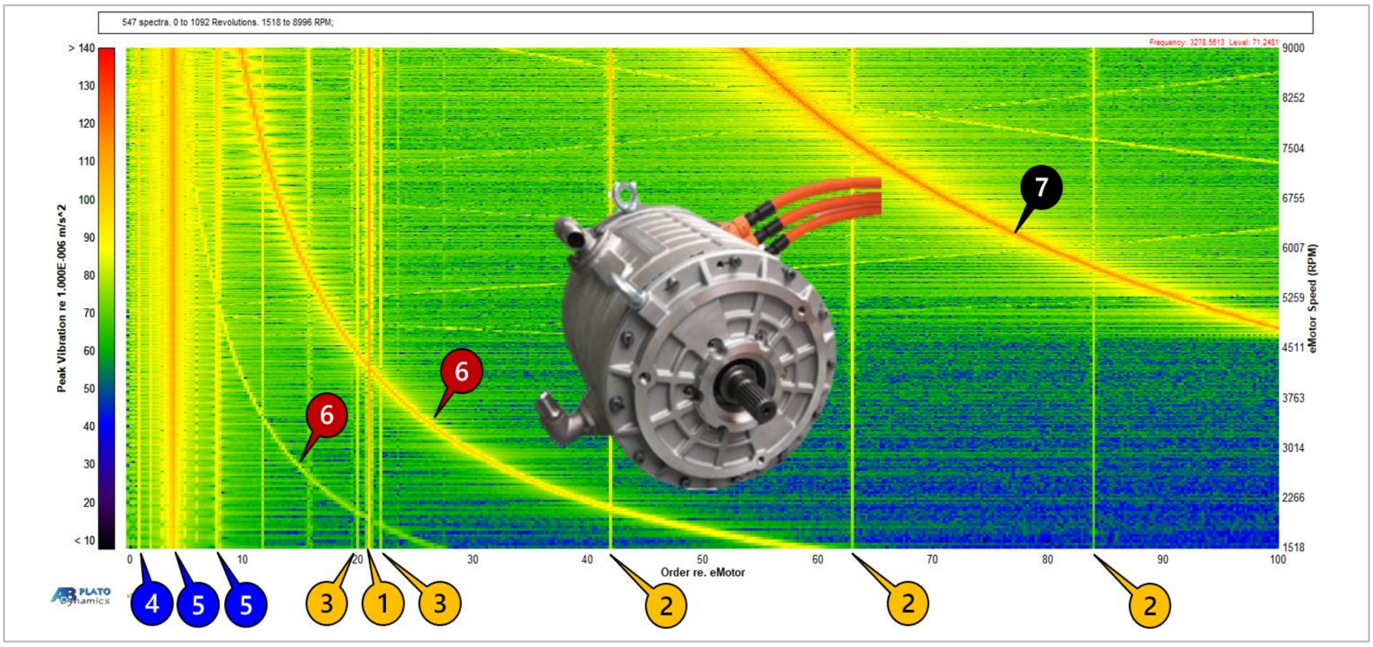
* Or output of RSI-101 resolver speed interface (and one more spare channel)

Operational envelope

	Order Range (re. eMotor)			
	50	100	200	400
PXIe-449x	96,000rpm	48,000rpm	24,000rpm	12,000rpm

NVH analyses

A 3-in-1 ePowertrain NVH (vibration) result may have the characteristics shown in the example spectrogram below.

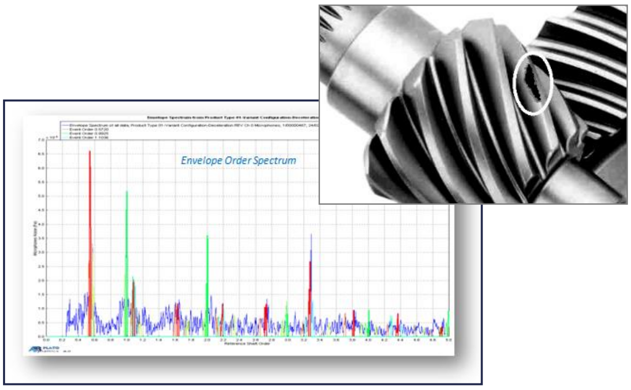
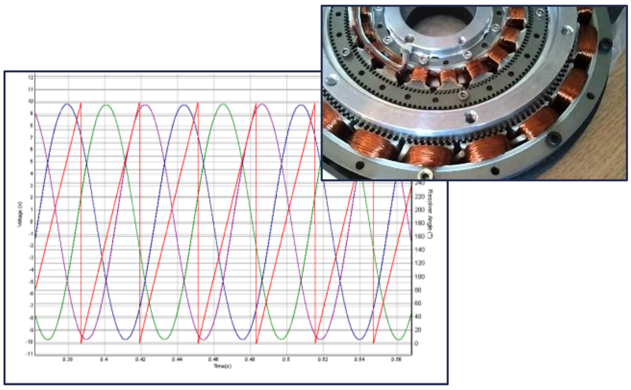


ePowertrain Feature	NVH Issue(s)	Method / Remarks
Reduction gears, differential	(1) Mesh orders (2) harmonics & (3) sidebands	Order analysis, at high rotation speeds (RPM)
E-motor	(4) Rotor imbalance (5) Slot orders & harmonics	
Bearings	Race and rolling-element defect, misaligned assembly	Speed synchronised envelope analysis (REVKIT)
Casing	(6) Structural resonance(s)	Frequency analysis
Invertor	(7) Base frequency e.g. 8kHz, sidebands and harmonics	Frequency & speed related analysis for sidebands

PLATO (with its add-on software option called REVKIT – see below) provides integrated analyses to assess all these characteristics.

Add-on options to extend ePowertrain testing capability

A range of sub-products can be added to a core PLATO system to enhance its capability and tailor each system solution to the exact requirements of the application. Add-ons particularly relevant to ePowertrain testing are:

REVKIT	Adds objective knock & click analysis to detect: ⊕ gear face defects ⊕ rolling-element bearing defects Primarily used to detect increases in energy but also includes a minimum acceptance level strategy to identify faults that are witnessed by less noise/vibration e.g. missing parts.	
eKIT	Adds Electric powertrain analyses: ⊕ resolver offset ⊕ resolver transformation ratio ⊕ eMotor back-EMF (pole/winding errors) 	

Please request/refer to separate brochures for each of the above areas.

Pedigree

Many vendors can supply NVH measurement & analysis systems, but PLATO from NVH International is designed, developed, and supported by engineers who:

- ⊕ consult with ePowertrain engineers, daily, worldwide
- ⊕ understand ePowertrain designs
- ⊕ understand the manufacturing processes involved
- ⊕ have first-hand experience of where manufacturing can go wrong and how this translates into noise/vibration output

Please ask for a copy of our PLATO installation reference list.

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+44 1225 970315
sales@nvhint.com
Eastern House, 15-16 Silver Street
Bradford-On-Avon, UK, BA15 1JZ