APPLICATION NOTE

TESTING OF SIX-PHASE MOTOR SYSTEMS

INNOVATIVE CONTROL SOLUTIONS FOR NEXT-GENERATION ELECTRIC DRIVE APPLICATIONS

DEWETRON

ABSTRACT

This application note outlines a testing solution for six-phase motor systems, which are increasingly used in automotive and aerospace applications due to their high performance, reliability, and reduced noise.

It highlights key challenges such as increased measurement channels, signal synchronization, efficiency calculation, and high-frequency harmonic analysis, as well as the need for multi-motor and multi-phase testing.

A modular solution with advanced power analyzers and software is presented, enabling precise measurements, flexible configurations, and integrated analysis of electrical, thermal, and mechanical data. This approach improves accuracy and reliability in testing next-generation electric drive systems.

INTRODUCTION

As technology matures and continues to evolve, motor drives are being increasingly used in fields such as automotive electronics and aerospace. Due to their performance characteristics, six-phase motor control systems have also been gaining wider adoption in recent years. For example:

- BYD announced on October 31, 2024, a patent titled “Six-phase motor control method, device, storage medium, and vehicle” (No. CN117526808B) and plans to promote this technology in future products.
- Mercedes-Benz EQS uses a six-phase motor controller and dual-motor drive technology.
- Volvo B5 hybrid bus uses an AC six-phase motor.
- ZF’s six-phase electric power steering system.
- Marelli Formula racing applications use dual inverters and six-phase motor drive technology.
- Jing-Jin Electric’s six-phase drive motor technology.
- EMOSS E-DRIVE 200 series six-drive motors.

ADVANTAGES OF SIX-PHASE MOTORS

- Capable of achieving high power output at low voltage.
- Redundant phase count ensures high reliability.
- Increase in pole pairs leads to an increase in spatial harmonic orders, resulting in an increase in torque pulsation frequency but a decrease in amplitude, thereby reducing noise and vibration caused by torque pulsation.
- Vector space decoupling enables decoupling of fundamental and harmonic components. By controlling the harmonic sub-plane components, dead zone compensation and asymmetric compensation can be achieved; overmodulation and parameter identification can also be realized through harmonic injections.

CHALLENGES IN SIX-PHASE MOTOR TESTING

1. How to handle the increased number of current and voltage measurement channels?
2. How to measure speed and torque for multiple motors?

3. How to deal with high-frequency harmonics caused by multiple pole pairs and high speeds?
4. How to ensure full synchronization between six-phase voltages and currents?
5. How to avoid efficiency deviation caused by combining two three-phase systems?
6. How to generate efficiency maps for six-phase systems?
7. How to synchronously measure harmonics, phase and symmetrical components?
8. How to ensure fault tolerance in complex testing?
9. How to achieve multi-point temperature synchronous testing of the motor?
10. How to locate vibration and noise source from the motor during fault diagnosis?
11. Can vibration and noise be measured simultaneously with electrical parameters?

Reference Standard

IEC TS 60034-25; IEC/TS 60034-2-3; IEC 60034-1:2022; IEC 60034-18; IEC 60034-29:2019

DEWETRON SOLUTIONS

In the following sections, DEWETRON will explain why each challenge exists and present the corresponding solution offered by DEWETRON products.

1. How to Handle the Increased Number of Current and Voltage Measurement Channels

For a traditional 3-phase motor and controller, testing requires 1 DC channel plus 3 AC channels, i.e. 4 current/voltage channels. A 6-phase motor requires 1 DC and 6 AC channels, i.e. at least 7 current/voltage channels.

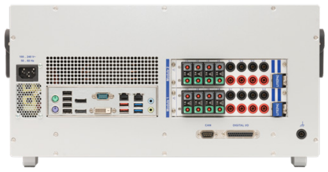
During the actual research and development process, to further improve the efficiency of the 6-phase driver, merely testing the input direct current and the output 6-phase alternating current is not sufficient. It is also necessary to conduct tests on many intermediate links of the motor and the controller, is it the high switching loss, or the high conduction loss, or is it the harmonics that cause the loss in the form of heat?

Intermediate Test Point	Measured Parameters	Value for Efficiency Improvement
Across DC-link capacitor	Voltage ripple, current ripple	Determines if the DC-link capacitor is adequate. Excessive ripple increases switching device stress and harmonic losses.
Drain-source (or collector-emitter) of power devices (MOSFET/IGBT)	On-state voltage Vds(on), switching waveforms (rise/fall time, ringing)	Core loss source: conduction loss (I^2*Rds(on)) and switching loss (overlap area). If switching edges are too slow or ringing is severe, adjust gate resistance or PCB layout.
Gate drive signals	Gate voltage amplitude, rise/fall time, dead time	Insufficient drive keeps devices in linear region (excessive heating). Excessive dead time reduces output voltage utilization (increases harmonics).
Phase current waveforms (all 6 phases simultaneously)	Current THD, phase current balance	In 6-phase motors, phase imbalance directly causes additional copper loss and torque ripple. Ideal THD < 5%
DC bus current (high-frequency components)	Amplitude of switching frequency components	Indicates risk of shoot-through or insufficient high-frequency impedance of DC-link capacitor.

Tab. 1: Intermediate Stages Inside the Controller

It can be seen from the above table that for the R&D test of the 6-phase motor controller, in order to improve the efficiency, more test channels are needed to be tested synchronously, which is used to analyze the specific reasons affecting the efficiency. DEWETRON power analyzers use a modular design based on 4-voltage + 4-current power cards, enabling configurations of 4 V+4 I, 8 V+8 I, 16 V+16 I, and more. This meets the requirements of multi-channel test configurations.

4V/4I



8V/8I

16V/16I

Fig. 1: Available configurations

2. How to Measure Speed and Torque for Multiple Motors?

For a 6-phase motor controller with a dual-motor design, at least 2 pairs of speed and torque – i.e., 4 speed/torque channels – are required.

DEWETRON integrated devices come standard with 4 CNT channels, which can connect encoders or frequency signals. In addition, the device can be expanded with 6 additional CNT channels for speed/torque signals.

Fig. 2: Speed / torque x 6 (CNT1 through CNT6)

3. How to Deal with High-Frequency Harmonics Caused by Multiple Pole Pairs and High Speeds?

Motor controllers invert DC signals into AC signals to drive the motor. The higher switching frequency and high-frequency harmonics in the PWM modulation process are the main causes of reduced efficiency, vibration, and heat generation. Compared to 3-phase motors, 6-phase motors have even higher switching frequency control and produce twice as many high-frequency harmonics.

DEWETRON power analyzers achieve a sampling rate of 10 MHz with a bandwidth of 5 MHz, effectively covering high-frequency components. A measurement accuracy of 0.03 % is guaranteed for fundamental frequencies from 0.1 to 10 kHz. Traditional power analyzers typically guarantee accuracy only at 50 Hz (typical value).

OXYGEN software can perform real-time FFT analysis on harmonics, fully covering the functions of a spectrum analyzer.

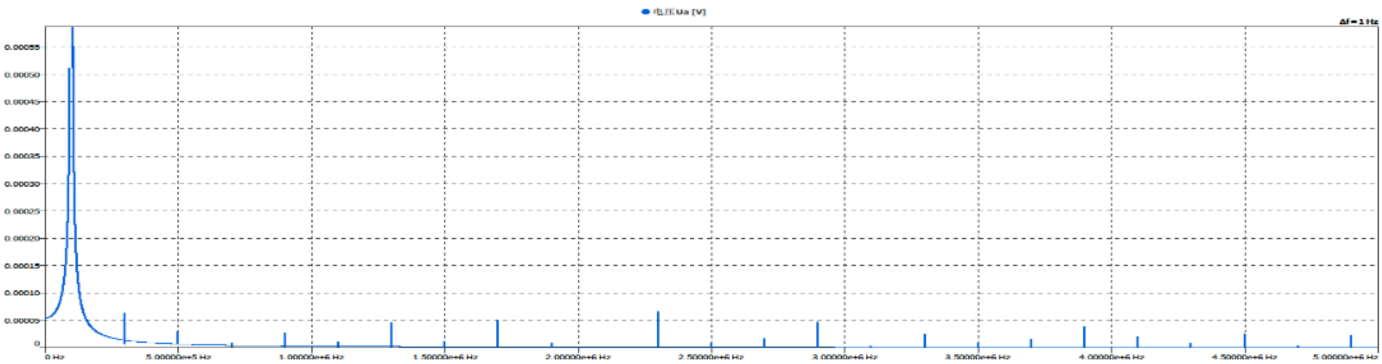


Fig. 3: Real-time spectrum analysis of a 5 MHz bandwidth signal

4. How to Ensure Full Synchronization Between Six-Phase Voltages and Currents?

The synchronization between current and voltage determines the phase angle and power factor. If the current lags the voltage by 10 µs at a frequency of 400 Hz, the resulting power factor errors would be:

Target PF	Actual PF	Absolute Error (PF)	Relative Error
0.98	0.9748	-0.0052	-0.53 %
0.8	0.7846	-0.0154	-1.93 %
0.1	0.0747	-0.0253	-25.3 %

Tab. 2: Error under different PF with a 10 µs delay

DEWETRON devices achieve a current-voltage synchronization accuracy of <250 ns. With this value at 400 Hz, the resulting power factor errors would be:

Target PF	Actual PF	Absolute Error (PF)	Relative Error
0.98	0.97996	-0.00004	-0.004 %
0.8	0.79936	-0.00064	-0.08 %
0.1	0.09984	-0.00016	-0.16 %

Tab. 3: Error under different PF with a 250 ns delay

5. How to Avoid Efficiency Value Deviations Caused by Combining Two Three-Phase Systems?

Most traditional power analyzers support three-phase star and delta wiring. When testing 6-phase motors, two power groups must be created separately, then mathematically summed in post-processing. The difference in calculation synchronization between the two groups can cause minor deviations in power and efficiency values — a problem that traditional power analyzers cannot resolve.

DEWETRON's OXYGEN software POWER function natively supports 6-phase motor wiring and can add a DC group for controller efficiency calculation, eliminating deviations caused by split-group calculations.

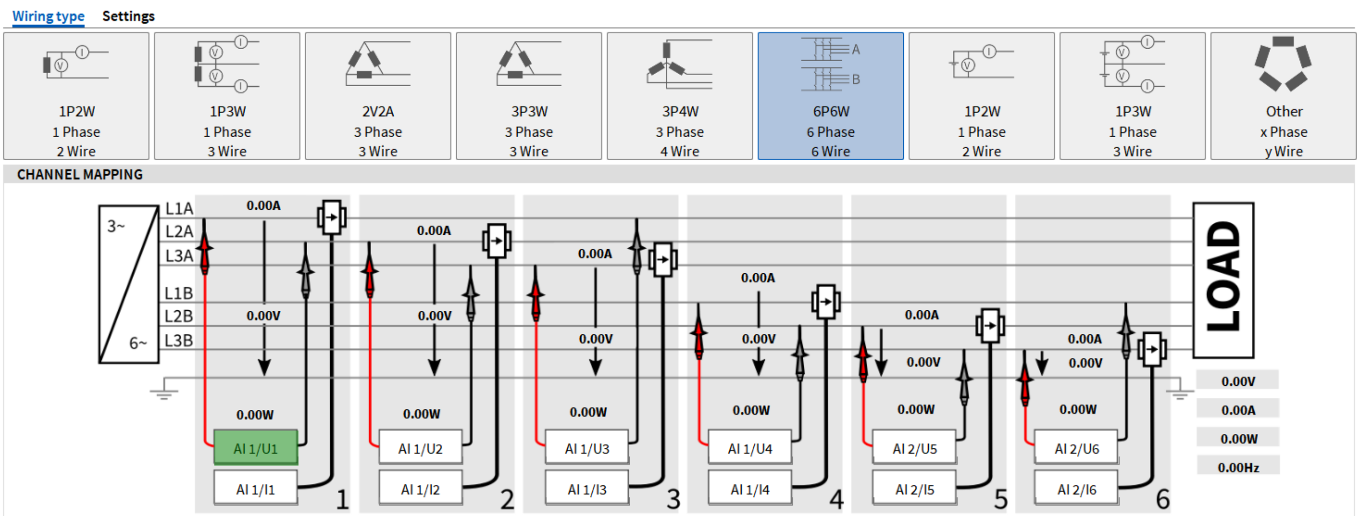


Fig. 4: 6-Phase Motor Wiring Power Sets

6. How to Generate Efficiency Maps for Six-Phase Systems?

Many power analyzers can calculate and plot motor efficiency maps. However, when dealing with a 6-phase motor, or a 6-phase motor controller driving two sets of 3-phase motors, calculating efficiency and plotting the efficiency map becomes an unsolvable challenge for conventional tools.

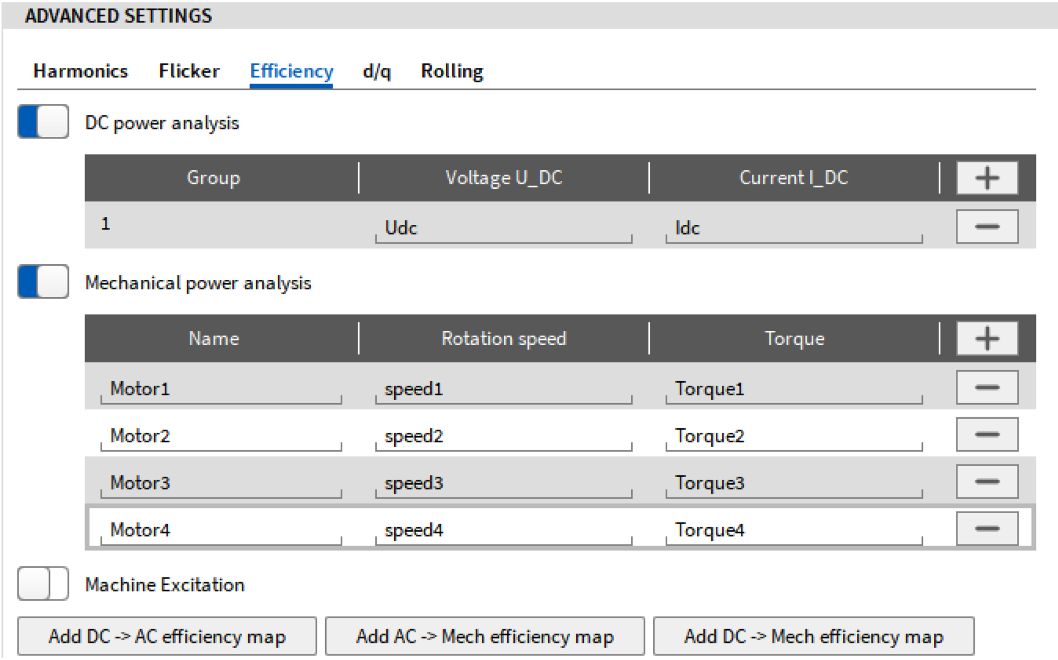


Fig. 5: DC/AC Efficiency and Mechanical Efficiency added (supports 4-wheel-drive)

DEWETRON OXYGEN can add a DC group and up to 4 motor groups on top of the 6-phase motor setup, enabling efficiency calculation across the entire DC → AC → drive motor energy chain, and plotting the corresponding efficiency maps (supports 4WD configurations).

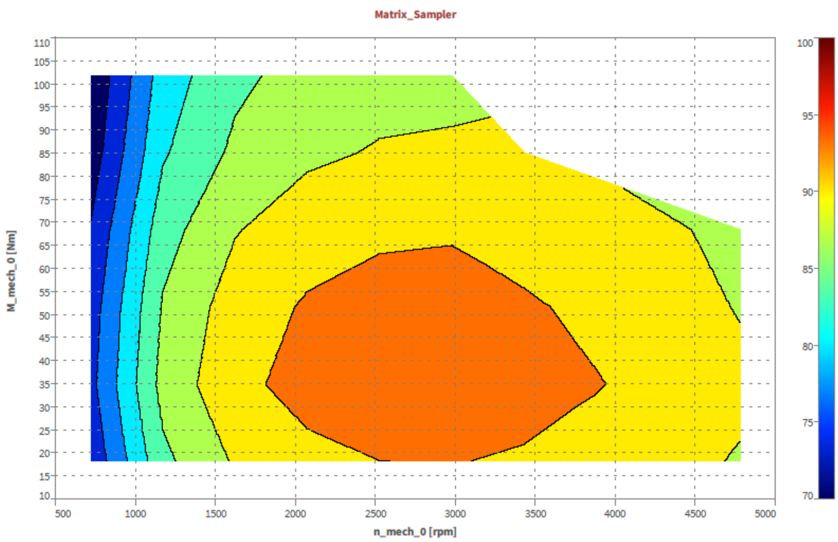


Fig. 6: Mechanical Efficiency Map

7. How to Synchronously Measure Harmonics, Phase and Symmetrical Components?

It is necessary to obtain harmonics, phases information and symmetrical components synchronously in addition to measuring RMS/P/Q/S and efficiency of motor.

Harmonics can reveal waveform distortion and additional losses, locate controller dead zone effects, evaluate modulation algorithm quality, identify specific 6-phase circulations, etc. An incorrect setting of the dead time can lead to distortion of the zero-crossing point of the current, resulting in the generation of 5th, 7th, and other low-order harmonics. IEC/TS 60034-2-3 (P5) states that “The additional harmonic losses determined by use of this technical specification are for comparison of different motor designs”.

Phase testing is used to ensure the continuity of torque output, and it can verify the control algorithm, diagnose sensor faults, and evaluate the fault-tolerant operation capability.

Symmetrical components are the essence for diagnosing system imbalance. Positive sequence component represents the energy that generates effective torque. Negative sequence component represents the reversed rotating magnetic field. Zero sequence component represents leakage current or circulating current.

The harmonic, phase and symmetrical components must be analyzed simultaneously in the motor test. The imbalance in the time domain and the distortion in the frequency domain are uniformly mapped into positive, negative and zero sequence components, to accurately locate the root causes of loss, vibration and circulation.

DEWETRONs powerful OXYGEN-Power can record raw data and analyze all these parameters mentioned above synchronously or offline to help developers conduct in-depth analysis of the motor.

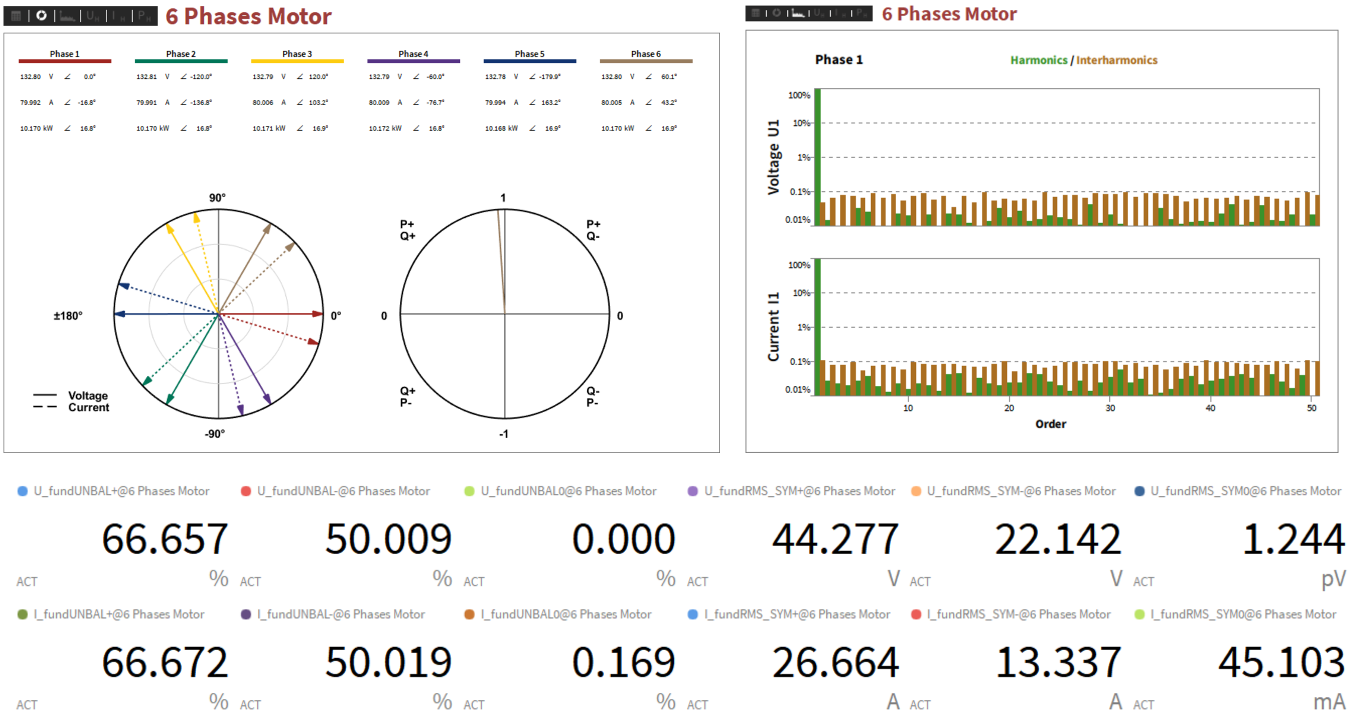


Fig. 7: Phases / Harmonics / Symmetrical Components for 6-Phase Motors in OXYGEN

8. How to Ensure Fault Tolerance in Complex Tests?

Six-phase motor testing uses many measurement points and sensors, making it prone to phase sequence errors, current sensor direction reversals, and other configuration mistakes. Traditional power analyzers only record post-calculation results such as RMS values, power, and efficiency. Once an error is discovered during data analysis, it cannot be corrected — the test must be repeated.

DEWETRON OXYGEN stores the raw current and voltage values and performs all calculations in real time from these values. When an error is found during data analysis, offline mathematical operations can be used to reassign or modify the data. As long as the user has stored 6 voltages and 6 currents, any subsequent modifications and recalculations can be performed freely.

9. How to Achieve Multi-Point Temperature Synchronous Testing of the Motor?

The lifespan and reliability of a motor‘s insulation system are critically dependent on its operating temperature. Measuring temperature during testing is essential to prevent premature failure and ensure safe operation. In IEC 60034-1:2022 (Chapter 8), the temperature rise limit, thermal stability condition, temperature measurement method and other requirements are specified. Motor manufacturers need to interpret the results obtained from the heat resistance test in accordance with the relevant sections of IEC 60034-18. IEC 60034-29:2019 specifies the methods for measuring the losses and temperature rise of variable-frequency motors.

Motor and controller development requires monitoring rotor and circuit board temperatures. There are many temperature measurement points, and high voltage isolation levels are required in energized environments. Traditional power analyzers cannot provide this extended functionality.

DEWETRON devices can expand temperature acquisition channels via CAN bus or RS485 bus, with an expansion capacity of up to 200 channels. Multiple types of thermocouples and platinum resistance thermometers (RTDs) are supported, with an isolation voltage of up to 1500 V.

Fig. 8: XR-TH8-S

10. How to Locate Vibration and Noise Source from the Motor During Fault Diagnosis?

Does the vibration and noise of the motor arise from shaft-end imbalance? Or from mechanical resonance? Or from unstable rotational speed? Or from high-frequency harmonics of the electric drive? A single device alone cannot accurately determine the cause.

Since DEWETRON captures both speed and vibration/noise signals, order analysis can be performed on the motor. Comparing this with the motor harmonic analysis allows determination of whether the source of vibration and noise is due to the motor's structural characteristics or the harmonics from the electric drive signal. This is highly valuable for in-depth fault diagnosis and product performance improvement.

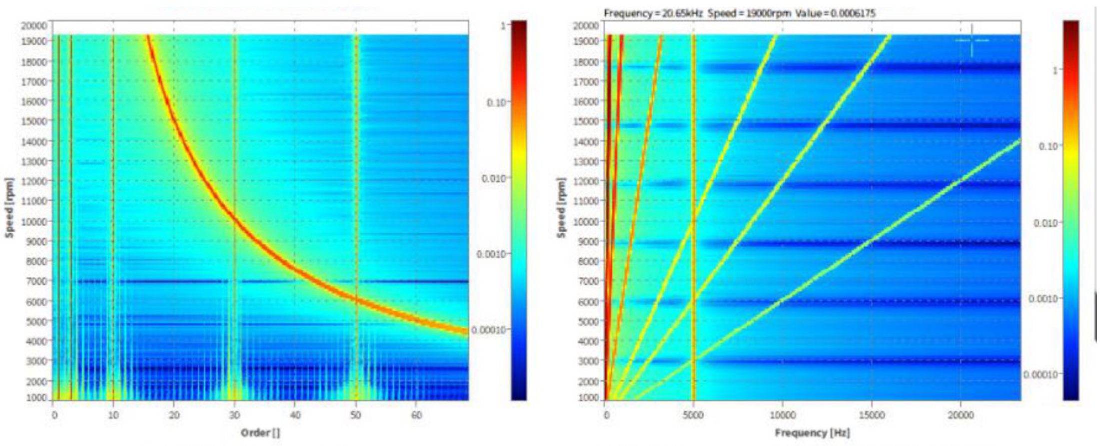


Fig. 9: Order Analysis in OXYGEN

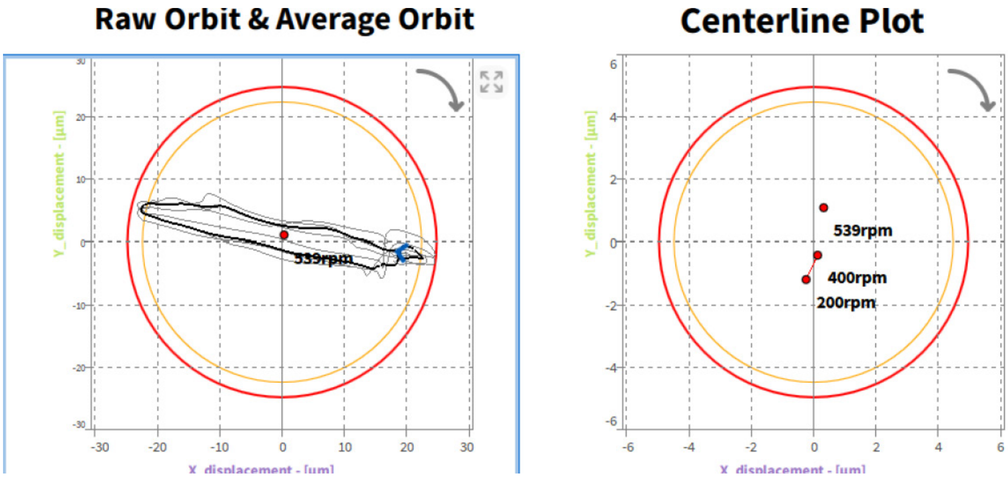


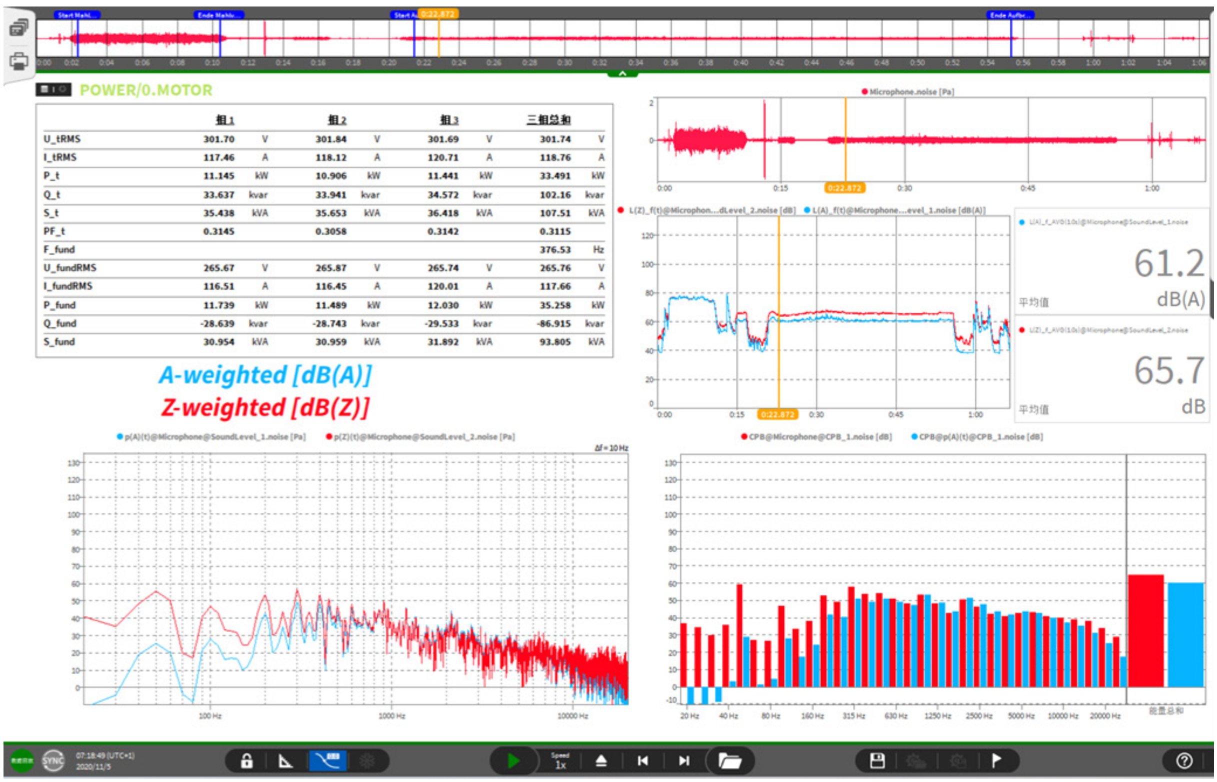
Fig. 10: Orbit in OXYGEN

11. Can Vibration and Noise Be Measured Simultaneously with Electrical Parameters?

Electric vehicles, having no combustion engine, have stricter NVH requirements. The drive motor, as the main power source of an electric vehicle, produces vibration and noise due to its high-speed operation, affecting NVH performance. Traditional power analyzers require adding separate vibration/noise analysis or NVH analysis equipment when testing electrical parameters — this approach makes data merging impossible and cannot guarantee data synchronization.

The testing methods and importance of vibration and noise tests are elaborately described in detail in Chapter 6 of Standard IEC TS 60034-25-2022 chapter 6. A similar description can be found in chapter 6 GB/T 21209-2017.

DEWETRON OXYGEN's POWER function supports 6-phase motor wiring and can add a DC group for controller efficiency calculation, avoiding power and efficiency deviations from split-group calculations. The same system simultaneously captures and analyzes vibration and noise data in full synchronization with the electrical measurements.



	相1		相2		相3		三相总和	
U_tRMS	301.70	V	301.84	V	301.69	V	301.74	V
I_tRMS	117.46	A	118.12	A	120.71	A	118.76	A
P_t	11.145	kW	10.906	kW	11.441	kW	33.491	kW
Q_t	33.637	kvar	33.941	kvar	34.572	kvar	102.16	kvar
S_t	35.438	kVA	35.653	kVA	36.418	kVA	107.51	kVA
PF_t	0.3145		0.3058		0.3142		0.3115	
F_fund							376.53	Hz
U_fundRMS	265.67	V	265.87	V	265.74	V	265.76	V
I_fundRMS	116.51	A	116.45	A	120.01	A	117.66	A
P_fund	11.739	kW	11.489	kW	12.030	kW	35.258	kW
Q_fund	-28.639	kvar	-28.743	kvar	-29.533	kvar	-86.915	kvar
S_fund	30.954	kVA	30.959	kVA	31.892	kVA	93.805	kVA

Fig. 11: Synchronous Acquisition and Analysis of Electricity Power and Noise

SUMMARY

In conclusion, six-phase motor technology offers significant advantages in performance, reliability, and efficiency, making it increasingly relevant for advanced electric drive applications. However, these benefits come with greater testing complexity, requiring precise measurement, synchronization, and comprehensive data analysis. The presented solution demonstrates how modular hardware and integrated software can effectively address these challenges, enabling accurate, flexible, and scalable testing. By combining electrical, mechanical, thermal, and NVH analysis in a unified framework, it not only improves measurement reliability but also enhances diagnostic capabilities. Overall, this approach provides a solid foundation for the efficient development, validation, and optimization of next-generation six-phase motor systems.

AUTHOR

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Steven Duan is the Technical Director of DEWETRON China and a Senior Mechatronics Engineer. He holds a Master of Engineering from the Hebei University of Technology and a Bachelor of Engineering from the Taiyuan University of Technology. With three years of experience in the wind power industry and over 13 years at DEWETRON, he brings strong theoretical and practical expertise across automotive, renewable energy, and mechanical structural system testing, particularly in the design and implementation of complex test and measurement solutions.

ABOUT DEWETRON

DEWETRON is a manufacturer of precision test and measurement systems and part of the globally operating Anritsu Group. Our reliable measurement data help customers worldwide make processes more predictable, efficient, and safer.

Our strength lies in customized measurement solutions: ready to use right away while remaining flexible to adapt to dynamic testing requirements in the energy, automotive, transportation, and aerospace industries.

More than 35 years of experience and innovation have made DEWETRON a trusted partner in the global test and measurement market.

More than 25,000 DEWETRON measurement systems and over 400,000 measurement channels are in continuous use at leading companies worldwide.

DEWETRON's quality is certified according to ISO 9001 and ISO 14001.
The high integrity of the measurement data is guaranteed by our own accredited calibration lab according to ISO 17025.

THE MEASURABLE DIFFERENCE.

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