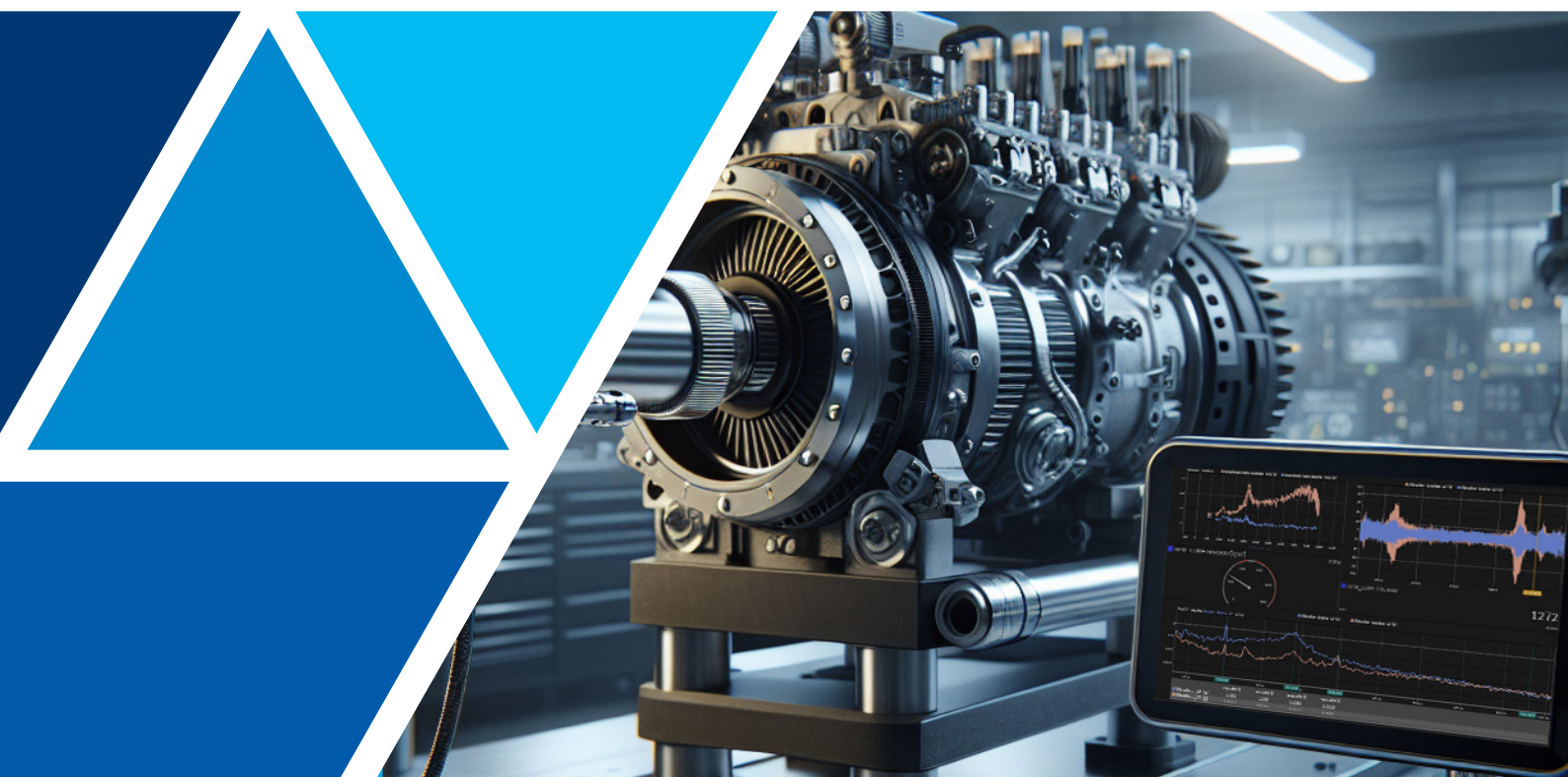


APPLICATION NOTE

MEASURING THE TORQUE RIPPLE

WITH DEWETRON HARD- AND SOFTWARE



DEWETRON

ABSTRACT

This application note examines the critical role of torque ripple in electric motors and underscores the importance of precise torque measurement. It explores the causes and effects of torque ripple, detailing its impact on motor performance and longevity. The document provides an example of torque measurement analysis, demonstrating how to calculate torque ripple and its correlation with other key factors, such as motor sound and temperature. At DEWETRON, we are dedicated to offering innovative solutions that empower engineers to optimize electric motor performance. Our comprehensive data analysis tools, capable of integrating measurements from various sensors as well as direct voltage and current readings, provide a holistic perspective on motor functionality. This enables more efficient issue identification and resolution, ensuring the highest quality standards.

INTRODUCTION

In the rapidly evolving world of electric motor technology, one parameter that has gained significant attention is torque ripple. It is a periodic variation in the torque produced by an electric motor that lead to undesirable effects such as noise, vibration, and reduced motor lifespan. Therefore, accurate measurement of torque ripple is crucial for the development, testing, and quality control of electric motors.

This application note provides an exemplary guide on how to measure torque ripple using DEWETRON hardware. We will explore the causes and effects of torque ripple, discuss the importance of its accurate measurement, and provide an example of how to quantify fluctuations in torque and further analyze the result.

Whether you are a motor designer looking to optimize your designs, a quality control engineer ensuring the highest standards, or a researcher exploring new motor technologies, this application note can help to improve your understanding and hand a possible solution how to acquire and analyze torque ripple.

WHAT IS TORQUE RIPPLE?

It refers to the variation or pulsation in the torque produced by an electric motor during one rotation. It's a key performance parameter impacting motor efficiency and smooth operation. It's calculated using this formula:

$$T_{\text{ripple}} [\%] = \frac{T_{\text{max}} - T_{\text{min}}}{T_{\text{avg}}} \times 100$$

Equ. 1: Torque ripple calculation

Torque ripple can be caused by factors like cogging torque, mutual inductance variations, and harmonic currents, leading to uneven magnetic fields within the motor. High levels of it can increase noise and vibration, reduce motor efficiency, cause premature wear on mechanical components, and decrease positional accuracy in precision applications. It's important to note that torque ripple is not a static value. It has a frequency component and an amplitude component, caused by excitation and construction. Torque is often misunderstood because it is looked at when heavily filtered. Even a little filtering can distort the torque ripple signal and cause missed information.

Cogging Torque is caused by the attraction between the rotor's permanent magnets and the stator's steel teeth. This can be felt as a "jerking" motion when rotating the shaft of a conventional brushless motor. Slotless motors do not exhibit this property.

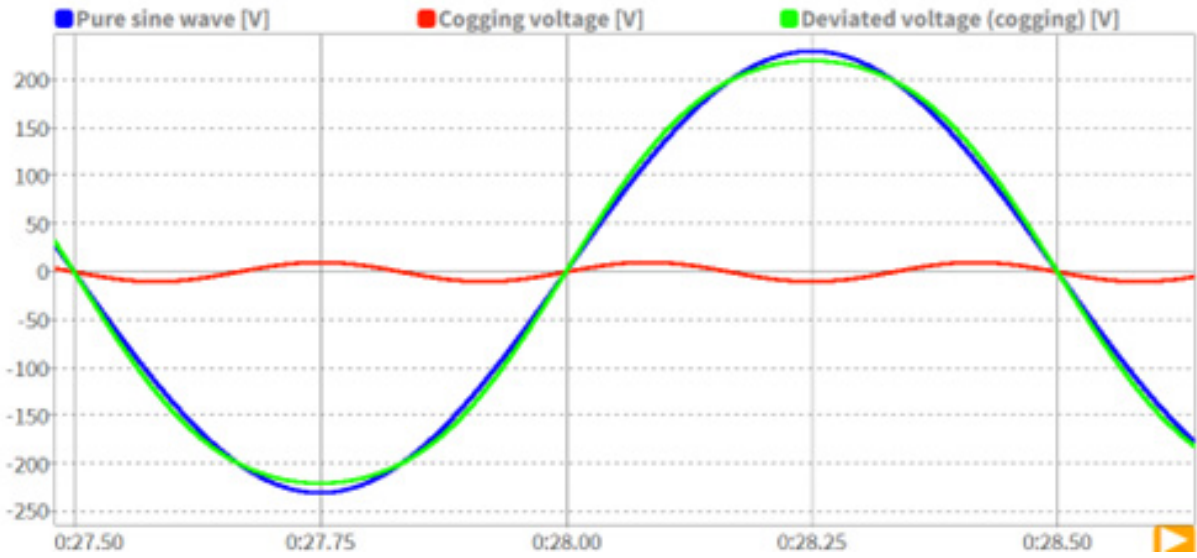


Fig. 1: Example for cogging voltage and its effect on the motor excitation

In applications requiring high torque and smooth motion at low speeds, engineers face a dilemma. Conventional brushless motors with a slotted lamination design can achieve maximum available torque and torque density but inherently exhibit cogging torque. Slotless motors are not subject to cogging torque but may still exhibit torque ripple when energized and cannot deliver the same torque per volume as conventional motors. These slotless motors still follow the AC excitation envelope and thus have an inherent torque ripple.

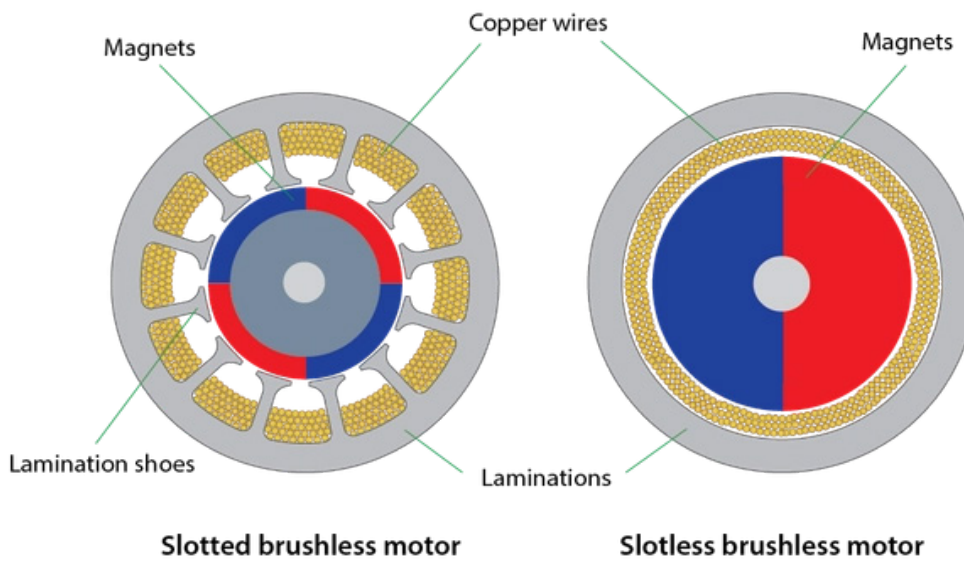


Fig. 2: Comparison slotted vs slotless motor (Image credit: [Copyright Lin Eng. Inc. 2024](#))

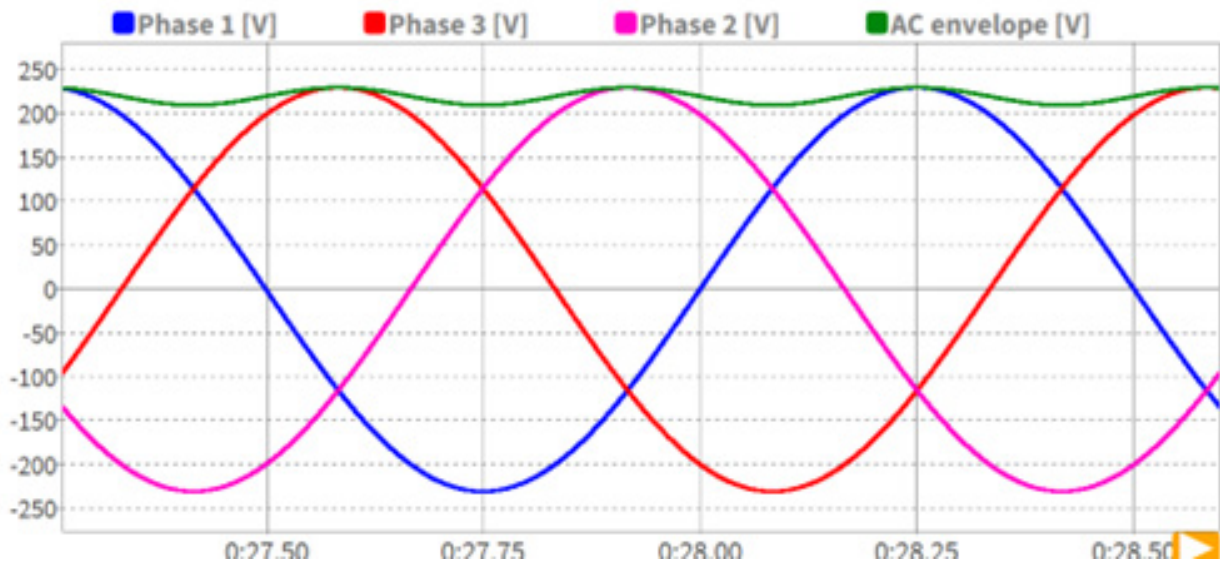


Fig 3: AC excitation envelope induces torque ripples in slotless motors

Accurate measurement of torque ripple is crucial for motor design, testing, and quality control. By identifying and quantifying torque fluctuations, engineers can optimize motor performance and ensure high quality. A common target in many applications is to keep the torque ripple below 5 %.

▼ HOW TO MEASURE TORQUE RIPPLE WITH DEWETRON HARDWARE

To measure the engine parameters following DEWETRON hardware was used:

DEWE3-A4:

- ▶ TRION3-1810M-POWER – for acquisition of voltages and current
- ▶ XR-TH8-S extension – for acquisition of engine temperature with thermocouples
- ▶ TRION3-1820-MULTI-4-D – for acquisition of sound and vibration

The acquisition of speed and torque was done via the counter inputs that are integrated into the DEWE3-A4 chassis. The time base of the counter channels is 100 MHz which allows input frequencies up to 10 MHz. Typ. 2 ppm (max. 10 ppm) time base accuracy ensures highly precise measurement results for both torque and speed.

▼ MEASUREMENT EXAMPLE

The measurement data of an engine runup and coast down can be easily analyzed in OXYGEN. Either create the statistics before the measurement or after the measurement. The next figure shows a comprehensive overview of measured parameters such as torque, angle, sound and temperature.

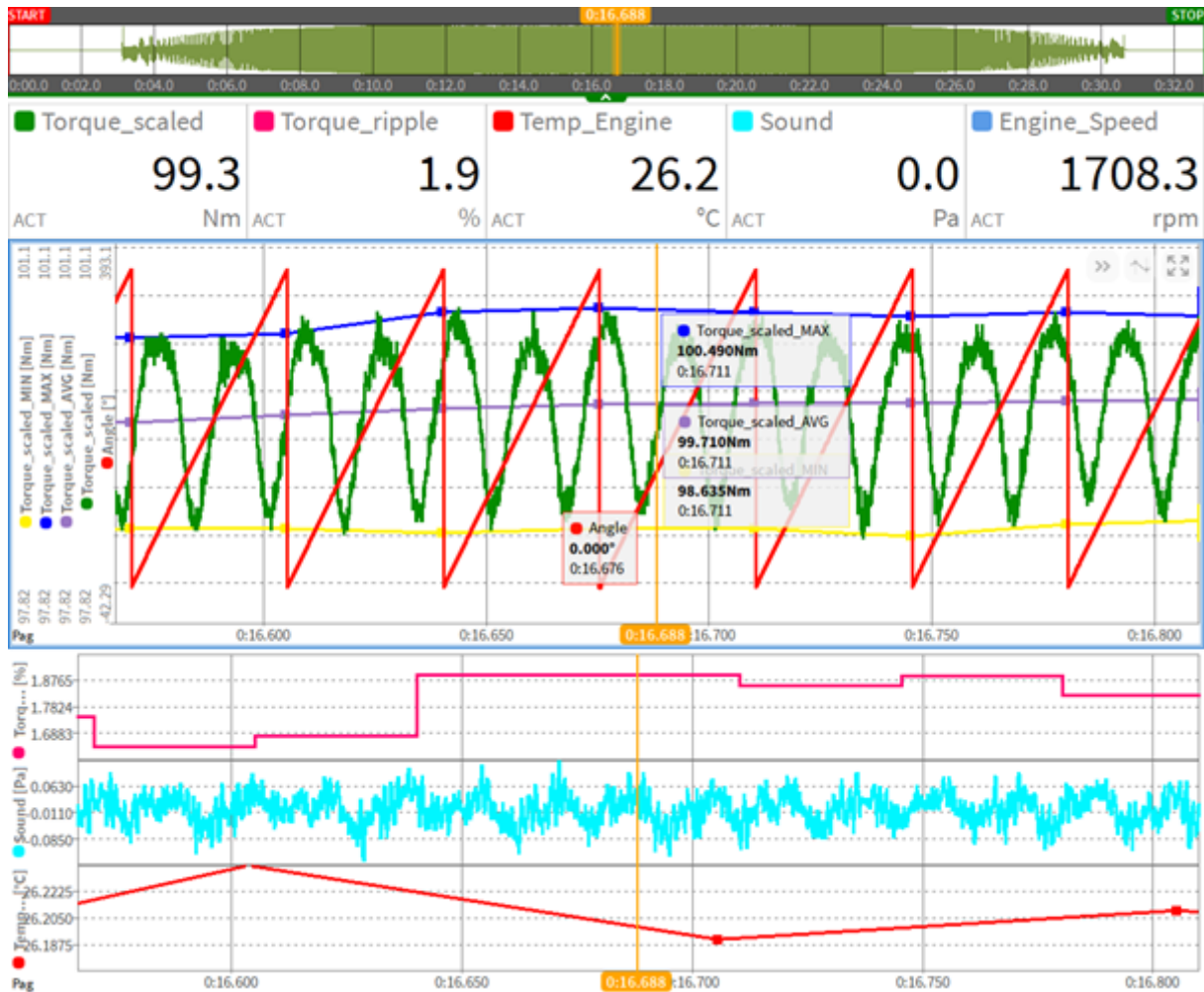


Fig. 4: Overview of measurement, torque, sound, torque ripple and angle.

By statistically evaluating the torque fluctuations over one rotation the torque ripple can be calculated and further compared to other parameters.

Fig. 5 shows the torque over one rotation in green. The statistical calculations are set to be triggered by the falling edge of the angle signal. To calculate the torque ripple, the maximum, minimum and average torque for one rotation is calculated. In this example, the maximum (blue), minimum (yellow) and average (purple) can be seen to reflect the measured torque value.



Fig. 5: Detail view of torque over one revolution.

With these values the torque ripple can be calculated continuously:

$$Torque\ ripple[\%] = \frac{Torque_{max} - Torque_{min}}{Torque_{avg}} \times 100$$

Equ. 2: Continuous calculation of the torque ripple

Torque [Nm]	Torque ripple [%]	Engine temperature [°C]	Sound [Pa]	Engine Speed [rpm]
100.2	1.9	26.2	-0.1	1723.7

Tab 1: The torque, torque ripple, temperature, sound and speed parameters Fig. 5

Torque ripple triggered statistics setup

The next figure shows how the triggered statistics calculations can be done in OXYGEN. Triggered by the falling edge of the angle signal at 150°, the time frame is set and after surpassing 350° the next trigger can be activated. This was done for the maximum, minimum and average torque.



Fig. 6: Triggered statistics for torque ripple calculation.

Finally, these three values are computed as described in formula (1), by maximum minus minimum divided by the average torque.

Torque ripple vs engine speed

The torque, torque ripple and engine speed of the measurement example are displayed in Table 2, where the speed is runup to ~1700 rpm and the coast down. From this table it's easy to see the correlation between a stable speed and a low torque ripple.

Time [s]	Torque scaled [Nm]	Torque ripple [%]	Engine Speed [rpm]
10.00	61	4.0	1052
12.00	82	2.5	1412
14.00	99	1.8	1708
16.00	100	1.8	1716
18.00	100	1.8	1717
20.00	100	1.8	1719
22.00	91	2.2	1568
24.00	70	3.0	1212
26.00	50	5.1	855

Tab. 2: Snapshot values every 2 seconds of engine runup and coast down (10 s to 26 s)

As described before, the torque ripple is very dependent on the engine speed, because the calculation principle averages the torque change over one rotation.

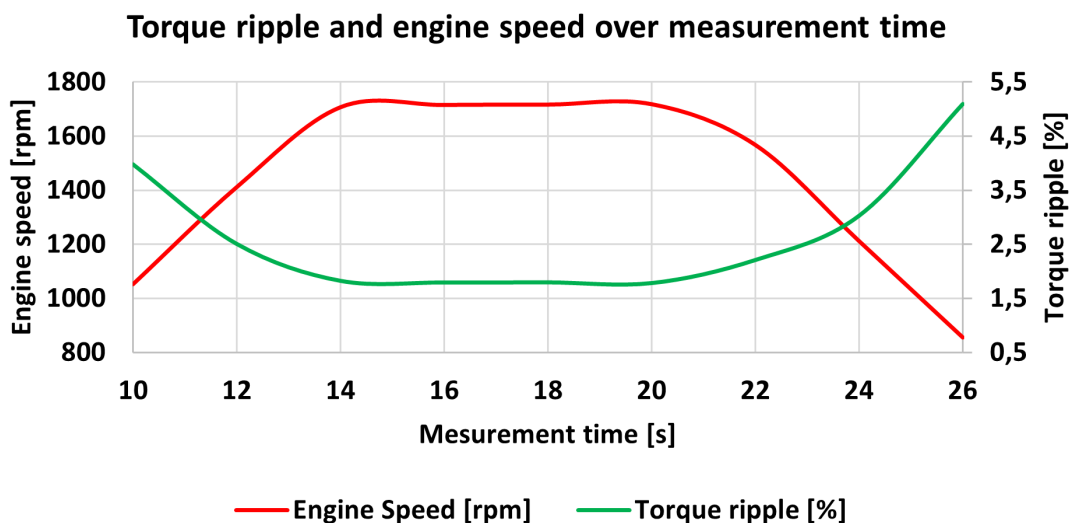


Fig. 7: Dependency of low torque ripple on stable engine speed

Torque ripple vs engine speed

To find correlations to reduce torque ripple, the possibility to compare other factors such as sound, temperature or vibration are a valuable tool in the process of optimizing motor efficiency.

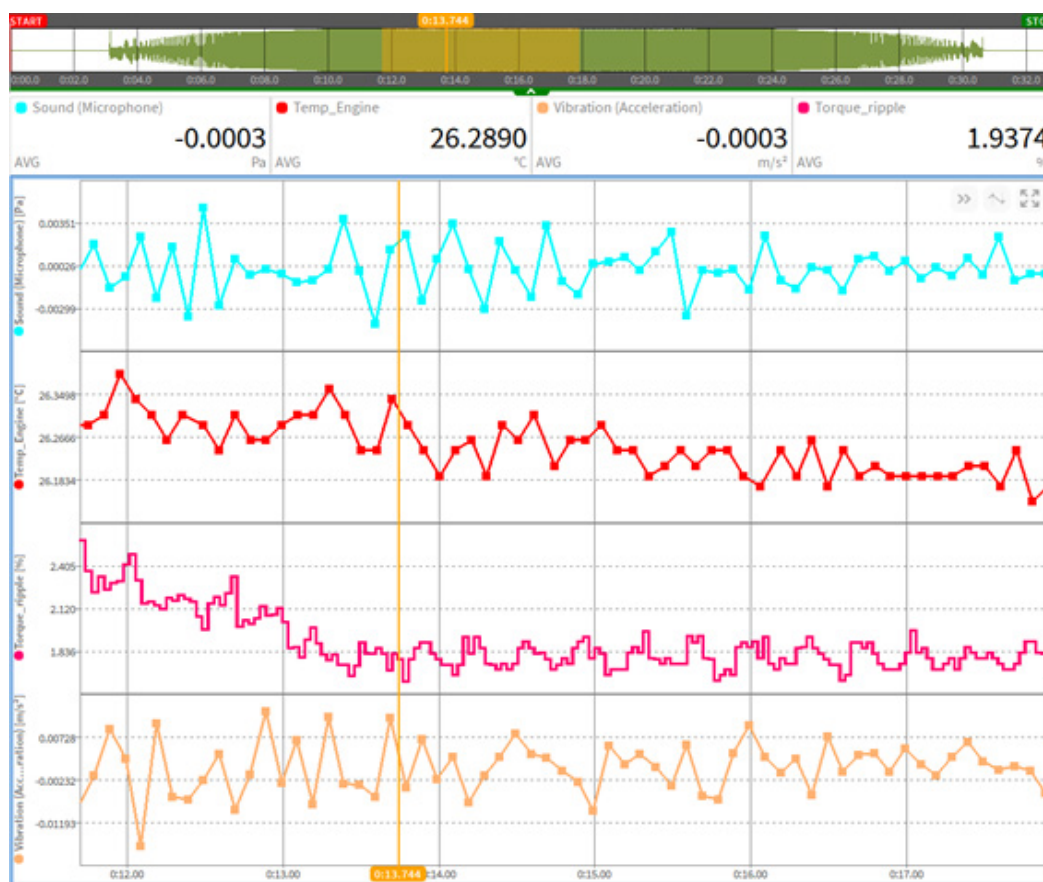


Fig. 8: Comparison of sound [PA], sound level [dB(A)], engine temperature [°C] and torque ripple [%]

▼ CONCLUSION

In this application note, we have explored the critical aspect of torque ripple in electric motors and the importance of its accurate measurement. We have discussed the causes and effects of it, and how it can impact the performance and lifespan of electric motors.

The application note showed an example of how to analyze a torque measurement and calculate the torque ripple. Subsequently, it can be related to other factors, such as the sound of the engine or its temperature.

At DEWETRON, we are committed to providing innovative solutions that help engineers optimize electric motor performance and ensure the highest standards of quality. By straight forward data analysis and the possibility to measure data from multiple types of sensors in addition to directly measure voltages and currents, we offer a holistic view of motor performance, enabling more effective identification and resolution of issues.

For more information about our [products and services](#), please visit our [website](#) or [contact](#) our technical support team.

▼ AUTHOR

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Thomas Klug has a background in natural sciences and materials science from his studies at Graz University of Technology. During his bachelor studies he specialized in geophysics and solar cells, while in his master studies he focused on semiconductors and bio-based materials. During his studies, he worked at AVL List GmbH and the Virtual Vehicle Research Center. After graduating in 2023, he began his career at DEWETRON as an application engineer for industrial manufacturing and software interfaces as well as general test and measurement solutions.



About DEWETRON

DEWETRON is a manufacturer of precision test & measurement systems designed to help our customers make the world more predictable, efficient and safe. Our strengths lie in customized solutions that are immediately ready for use while also being quickly adaptable to the changing needs of the test environment and sophisticated technology of the energy, automotive, transportation and aerospace industries.

More than 35 years of experience and innovation have awarded DEWETRON the trust and respect of the global market. There are more than 25,000 DEWETRON measurement systems and over 400,000 measurement channels in use in well-known companies worldwide.

DEWETRON employs over 120 people in 25 countries and is part of the TKH Group, a global corporation, that specializes in the development and supply of innovative solutions worldwide.

DEWETRON's quality is certified in compliance with ISO9001 and ISO14001. The high integrity of the measurement data is guaranteed by our own accredited calibration lab according to ISO17025.

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