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Test Report: Impact On Low Voltage Motor Performance with Zeus PEEK Insulation Products

Increasing motor efficiency: saving energy, cost, and improving reliability.

ABSTRACT

This test report reviews the results of common and routine performance testing carried out on an electric motor before and after rebuilding the motor with Zeus-manufactured products including crystalline PEEK-coated magnet wire and PEEK Lay-Flat® tubing used as insulating material. Motor performance using the originally installed industry standard products and materials including standard magnet wire, Nomex®, Nomex® laminate, and Dacron®-Mylar®-Dacron® (DMD) insulation materials was compared to performance using Zeus products after rebuild. Evaluation was performed using Electrical Signature Analysis (ESA) and Motor Circuit Analysis (MCA). Additional high voltage testing was done to include high potential testing, surge comparison, and surge partial discharge as outlined in IEEE Std 1415-2006. The rebuilt motor using Zeus-manufactured products showed improvements in Q factor, capacitance, and partial discharge compared to the originally installed motor components. Additionally, the Zeus-rebuilt motor exhibited lower leakage, shorter absorption times, and appeared to operate with greater efficiency compared to the original motor.

What performance factors are affected through improved motor insulation?

How can these factors influence motor system efficiency.

INTRODUCTION

The motor used for this evaluation was a small 0.75 horsepower, 4-pole, 460 volt, AC induction motor. The motor's original insulation system was a typical Class 155C (Class F) material with a light varnish coating and Class F lead wire. The original wire in the motor was 24 AWG standard magnet wire (MW) 35 (**Fig. 1**, *left*). Following initial testing, the original wiring and insulation system were removed from the motor and replaced with Zeus-manufactured products: PEEK magnet wire, PEEK lead wire, PEEK Lay Flat® tubing used as both the slot liners and phase insulation. The new insulation system was a Class 180C (Class H) material and used polyester resin trickle varnish impregnation (**Fig. 1**, *right*). Testing was done before and after motor rebuild. Testing was also done before and after trickle varnish impregnation with respect to the Zeus insulation system. Evaluation of the motor was performed using an ALL-TEST PRO 5™, an ALL-TEST PRO OL™, an Amprobe® AMB55 high voltage insulation resistance tester, and an Electrom iTIG 12D before and after rebuild. The testing revealed differences in the insulation resistance curve and capacitance before and after the addition of trickle varnish for the Zeus-rebuilt motor (see below). All other tests were within expected limits. At the same time, electrical signature analysis showed that the motor had a severe imbalance and misalignment as well as eccentricity of the rotor in the air gap between the rotor and stator. These are not factors when considering the insulation system alone.

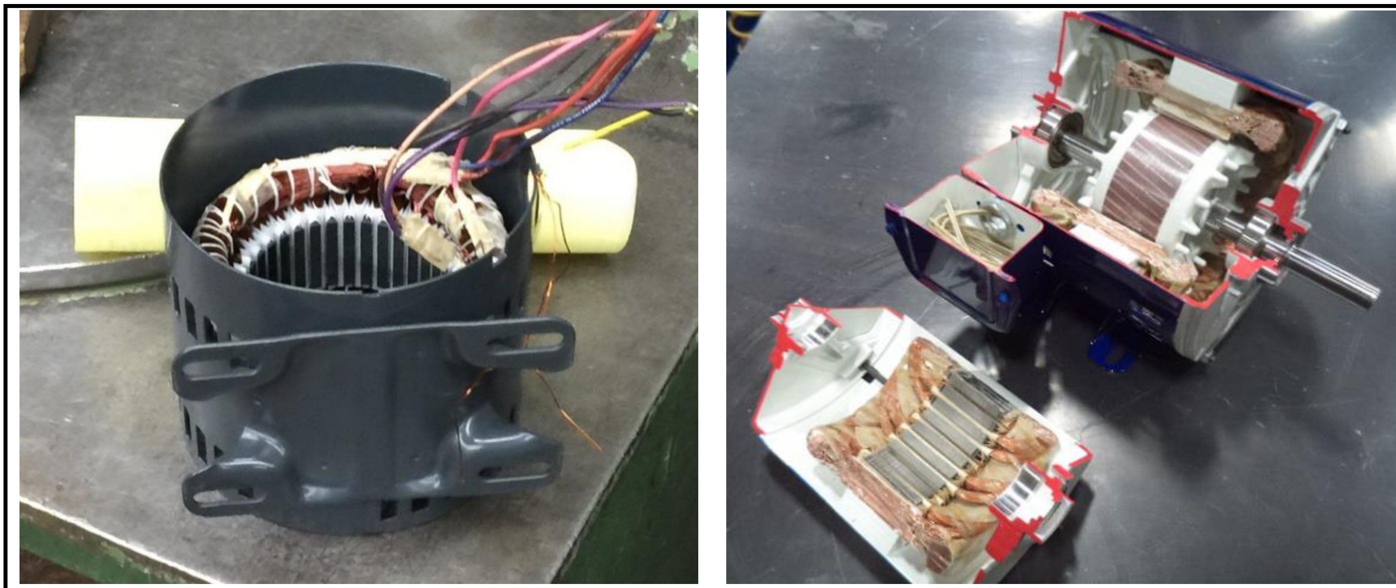

Figure 1: Test motor used for evaluation of Zeus PEEK insulation products: *Left* Original stator prior to head removal and stripping. *Right* New insulation system cut-away.

EVALUATION WITH ALL-TEST PRO 5

The ALL-TEST PRO 5 (ATP5) is a low voltage motor circuit analyzer which measures circuit and insulation-to-ground capacitance to identify insulation defects prior to motor failure. The motor with original insulation system and then later with Zeus products were tested using the ATP5 for low ohm resistance, inductance, impedance, capacitive phase angle, current/frequency (I/F) response, insulation to ground, and capacitance to ground (**Table 1**).

Table 1: Test results for low ohm resistance, inductance, impedance, capacitive phase angle, current/frequency (I/F) response, insulation to ground, and capacitance to ground for original motor and motor rebuilt with Zeus-manufactured products.

Test	Original Motor	Zeus Materials
Resistance	37.7 Ohms	38.0 Ohms
Inductance	159 mH	159 mH
Impedance	106 Ohms	107 Ohms
Phase Angle	68.8 degrees	68.6 degrees
I/F	-47%	-46.9%
Insulation Resistance	>1 GigOhm	>1 GigOhm
Capacitance	<2 µF	<2 µF

Tests showed that the motor using Zeus products displayed nearly identical outputs as the original motor with respect to the tested parameters. Slight electrical differences are typical when multiple motors of the same design are compared. Additionally, each phase was balanced in both the original and the Zeus motor indicating that the Zeus-rebuilt motor will electrically operate as designed.

EVALUATION WITH THE AMPROBE® AMB55

The AMB55 high-voltage industrial insulation tester was used to generate insulation resistance curves to assess differences between the original motor and the motor rebuilt using Zeus products. The resistance curves were measured in accordance with IEEE Std 43-2013 Annex D or insulation resistance profile (IRP) testing. The motor with the original insulation produced an as-expected polarization index curve showing that the insulation system absorption current dropped to zero during the ten-minute test (**Fig. 2A**).

IRPs were next tested on the Zeus-rebuilt motor before and after the addition of trickle varnish insulation resin. Before the addition of the resin, the insulation polarized to 1 TeraOhm in 12 s (**Fig. 2B**). After the addition of the trickle varnish, the insulation polarized to 1 TeraOhm in 5 s (**Fig. 3**). Both of these IRP's demonstrate that the Zeus motor polarized rapidly providing negligible absorption current. Furthermore, the leakage current shown for the Zeus motor, measured at 1 TeraOhm, was far lower than in the original machine which measured >10 GigaOhms.

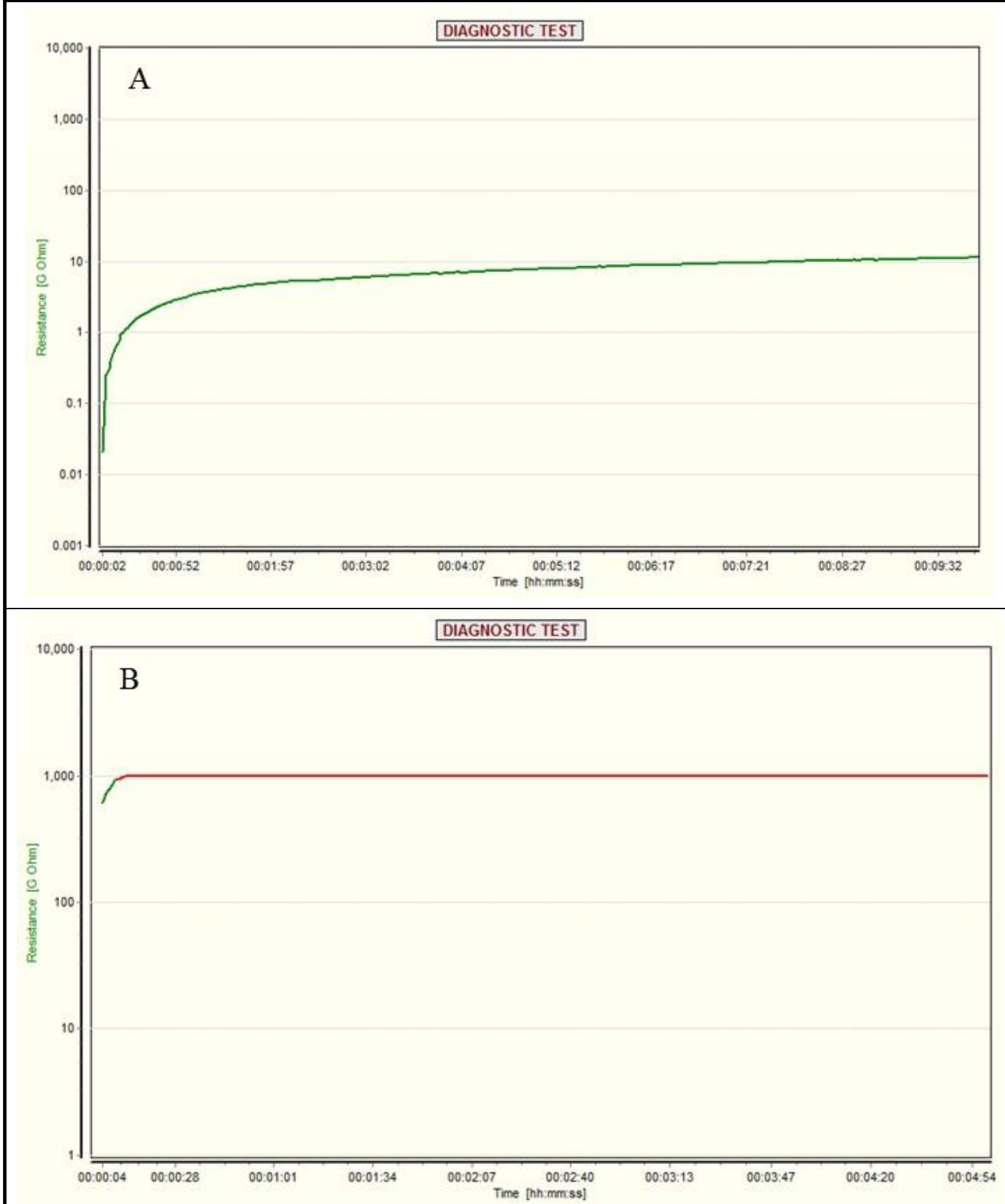

Figure 2: Motor insulation polarization indices. (**A**) Insulation resistance profile (IRP) of the original motor insulation system. (**B**) Insulation resistance curve before the addition of trickle varnish showing that the insulation polarized to 1 TeraOhm in 12 seconds.

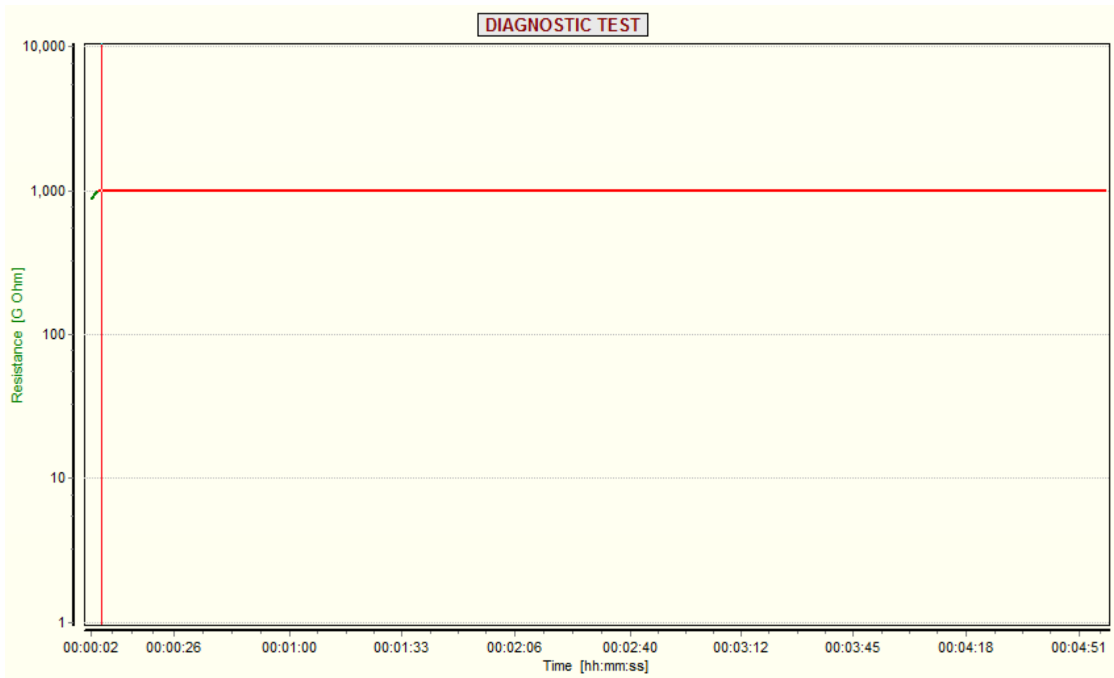

Figure 3: Motor insulation polarization index for the rebuilt motor after trickle varnish impregnation showing that the insulation polarized to 1 TeraOhm in 5 seconds.

ELECTROM iTIG D12 LOW AND HIGH VOLTAGE TESTING

The Electrom iTIG D12 provides a set of low and high voltage motor winding tests to determine the condition of an insulation system. These tests include resistance, insulation resistance, dielectric absorption, polarization index, high potential test, and surge comparison. Surge partial discharge tests can also be done to detect voids in the insulation system which could generate insulation failure in variable frequency drive (VFD) applications. Low voltage tests include capacitance (C), dissipation (D) factor, inductance (L), impedance, phase angle (Ø), and quality (Q) factor.

Initial testing with the iTIG D12 revealed that the original insulation system was susceptible to winding failure in VFD applications showing a substantial partial discharge of 668,070 pC (**Fig. 4A**). Partial discharge was also evaluated for the Zeus-rebuilt motor. The Zeus motor showed a partial discharge of 703 pC which was nearly three orders of magnitude less than the partial discharge observed in the original motor (**Fig. 4B**). The partial discharge shown in the Zeus motor increased slightly following the application of the trickle varnish impregnation (data not shown). The low partial discharge was also determined at a higher voltages suggesting that the Zeus motor was in superior operating condition than the original motor. These results also suggest that the motor built with Zeus components had far less potential for winding failure if subjected to VFD applications.

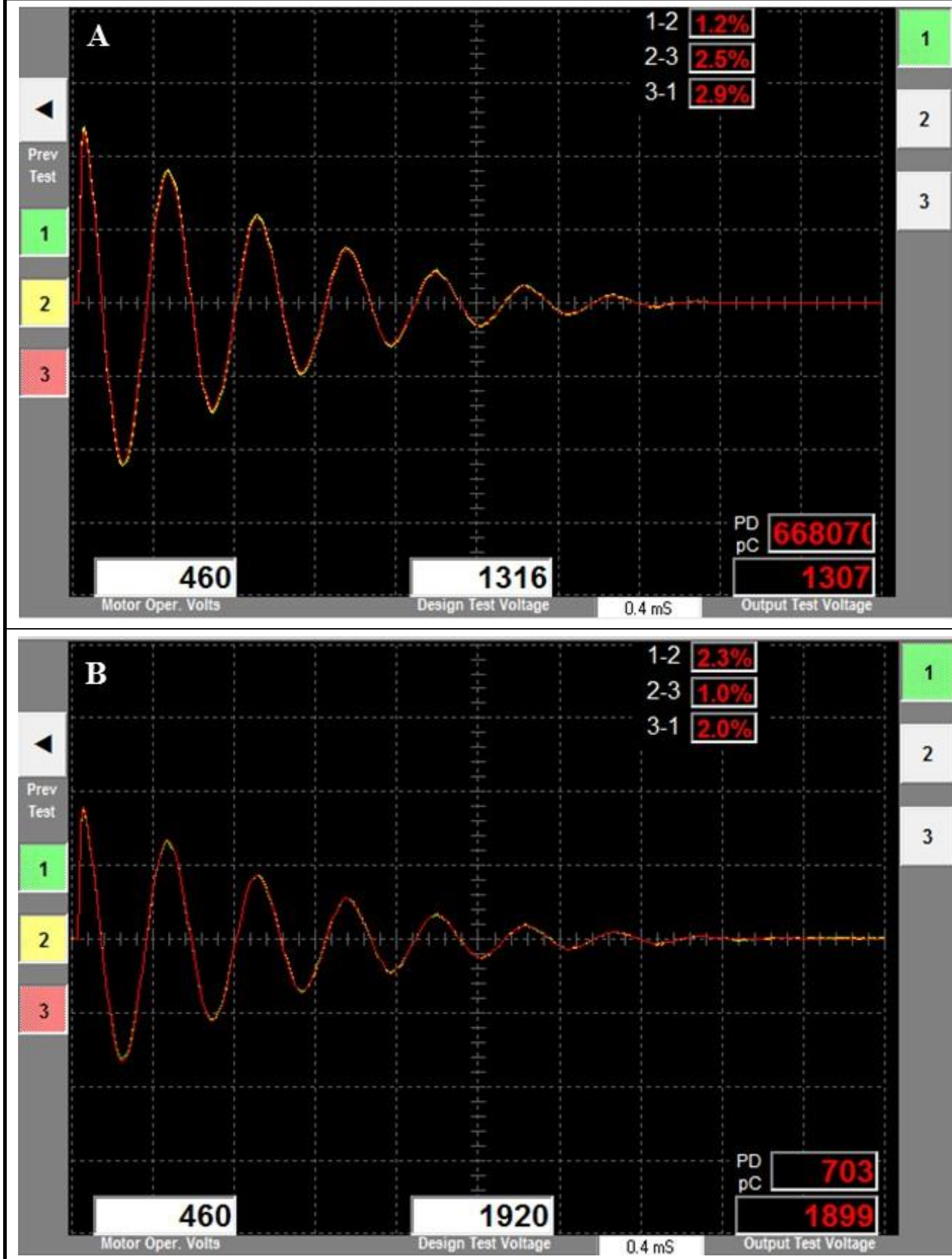

Figure 4: Partial discharge tests for the OEM and rebuilt motors. (**A**) Original insulation system showing partial discharge of 668,070 pC at 1316 V test voltage. (**B**) Zeus-rebuilt insulation system showing partial discharge of 703 pC at 1920 V test voltage.

Testing also showed that the windings for the original insulation system motor and for the Zeus motor were very similar. However, for the Zeus motor, the Q factor, D factor, and capacitance were all improved compared to the originally built motor (**Table 2**): the Q factor was reduced by ~1 for the Zeus motor compared to the original motor for each of the three lead configurations; the D factor was reduced by 0.001, or ~8.3%, for the Zeus motor; and the capacitance was improved in the Zeus motor by 0.01, or ~7.3%, compared to the original motor.

Low Voltage C/L/Z Test Data

	C (nF)	D Factor	L (mH)	Impedance	Ø Angle	Q Factor
Lead 1-2	0.137	0.012	153.930	969.40	86.1	14.59
Lead 2-3			153.640	967.60	86.1	14.52
Lead 1-3			154.120	970.60	86.1	14.51
Balance			0.3%	0.3%	0.0%	0.6%

Low Voltage C/L/Z Test Data

	C (nF)	D Factor	L (mH)	Impedance	Ø Angle	Q Factor
Lead 1-2	0.147	0.011	153.690	968.30	85.8	13.53
Lead 2-3			153.890	969.50	85.8	13.54
Lead 1-3			153.460	966.80	85.8	13.64
Balance			0.3%	0.3%	0.0%	0.8%

Table 2: Results of low voltage testing for capacitance (C), dissipation (D) factor, inductance (L), impedance, phase angle (Ø), and quality (Q) factor: *Top* original motor insulation system; *Bottom* Zeus insulation system.

ELECTRICAL SIGNATURE ANALYSIS WITH ALL-TEST PRO OL

The motor was next placed on a dynamometer to test motor efficiency at specific values and to identify significant electrical or mechanical conditions which may be of interest. The motor was first tested with the original insulation system and then retested following rewind and rebuild with Zeus products.

For the original insulation system, the RPM at 80% load was 1715 RPM; this value was less than the 1725 RPM indicated on the nameplate of the motor (**Fig. 5A**). The Zeus insulation system motor, however, showed a 79.8% efficiency [measured using Oak Ridge Motor Efficiency and Load software (ORMEL ′96)] at the same load except that the motor ran at 1746 RPM (**Fig. 5B**). Secondly, measuring the voltage and current harmonics, the Zeus motor showed that the current total harmonic distortion (THDC) was 3.8% and the voltage total harmonic distortion (THDV) was 2.4%. For the original motor insulation system, the THDC was 2.4% and the THDV was 1.3%. The increased current and voltage harmonics typically observed for the Zeus motor typically indicate a negative effect on efficiency. However, because the Zeus-rebuilt motor operated at a higher RPM (1746 compared to 1715) than the original motor under the same load, the overall consequence was that motor efficiency was effectively higher in the new Zeus insulation system motor.

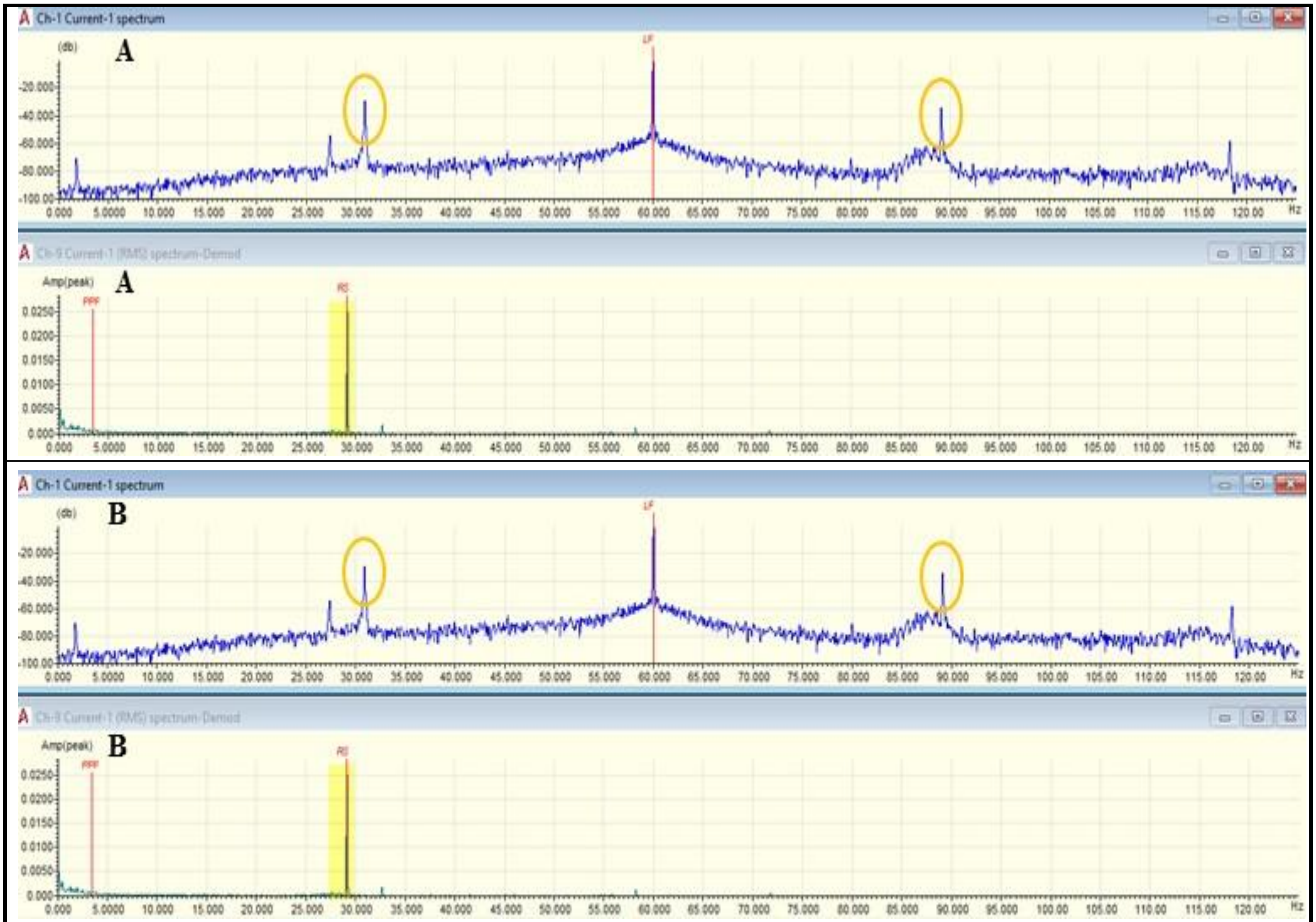

Figure 5: Dynamometer and motor efficiency test results. (**A**) Unbalance and misalignment (circles) detected in original motor. (**B**) Unbalance and misalignment (circles) detected in the new insulation motor.

CONCLUSION

The Zeus products performed at a superior level compared to the OEM-installed insulation and winding material in a number of areas. Improvements were found in the Zeus system including Q factor, D factor, capacitance, partial discharge, and stiffness of the windings compared to the original motor insulating system. The partial discharge results particularly imply that the Zeus motor is more likely to survive if used in an inverter application than the original motor. Further testing at varying temperatures and conditions would be required to quantify this advantage. Additionally, the very low leakage current and absorption times shown in the Zeus motor were superior to the original motor and insulation materials. Finally, the Zeus motor appeared to function with greater machine efficiency as a result of reduced insulation system related losses.

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