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Expanding Maintenance Technologies

Electrical Motor Diagnostics in Hybrid and Electric Vehicles

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Introduction

Most of the first automobiles produced in the 19th Century were all-electric. The primary reason was the amount of instantaneous power and torque provided and other advantages. However, the batteries limited the distance that the vehicles could travel resulting in the use of the combustion engine in which lighter fuel could be carried giving the vehicle a much greater range. For the greater part of a century the internal combustion engine (ICE) held dominance, an infrastructure was built around the use of gasoline, and the automotive industry focused on customer requirements of size and power.

Following the 1973 Oil Embargo on the USA, and the near-forgotten lines at gas stations, a hardy few realized that the flow of oil would not last forever. In addition to alternative fuels, battery and hybrid/electric research was initiated by governments, automotive companies, universities, independent research facilities and individuals in an effort to return to the original concept of an electric vehicle. The first modern production electric vehicle produced was the General Motors EV1, which was first released in 1996 and ran for three years on a lease-only, 3 year, 30,000 mile warranty. With a total population of 2,234 EV1's built at the GM Lansing Craft Centre in Lansing, Michigan, the vehicle was an engineering and marketing evaluation in California and Arizona only. At the end of the run, the EV1 was pulled out of production and almost all vehicles recovered by GM due to problems with expected advancements in battery technology.

Most automotive manufacturers made the decision to focus on hybrid technology while working towards all-electric powertrains, with the exception of Tesla Motors® who have focused, and released, all-electric sports cars in the $105,000+ range. One of the first hybrids to market was the Toyota Prius which instilled the concept that a fuel efficient vehicle must be small in order to obtain good mileage and fuel range. General Motors, Ford, and Chrysler focused their primary work related to hybrids on their better selling, more profitable larger vehicles with an assortment of SUVs and pickup trucks now being available and all-electric production vehicles being made available by 2010.

Figure 1: GM 2Mode Hybrid Transmission

General Motors and Chrysler partnered on the development of the 'heavy hybrid' two-mode transmission, which is the subject of the tests in this article. The transmission, as shown in Figure 1, is in direct line with the combustion engine and contains two powerful electric motors driven by two variable frequency drives under the hood which is supplied by a 300 volt battery pack under the rear passenger seats. In the two-mode full-sized SUVs and trucks, the ICE is: a GM Active Fuel Management® Vortec®

engine; and, a displacement on demand Hemi® for Chrysler. The transmissions are 4-speed with the electric motors assisting, which provides for an infinite variation in speeds, resulting in an extremely versatile transmission which, combined with the ability to vary the ICE between 4 and 8 cylinders, increases the fuel efficiency of the vehicles by more than 50%. The 300 volt system operates in both motoring and regeneration mode, meaning that in addition to operating as an electric motor, the machines also act to generate power for the battery as well as are used as part of the braking system. The result is an even and very fast braking through the transmission. The combination of increased power over an ICE-only SUV and braking capability that outperforms most passenger vehicles in acceleration and deceleration. Because of the additional weight of the hybrid powertrain, many of the components, such as the rear hatch, are aluminum versus steel, which lowers the center of gravity and allows for exceptional handling in all weather conditions.

The challenge: can modern maintenance testing technologies be used to evaluate the electric motors in an electric or hybrid machine? What can they tell us?

Evaluation

Within the challenge was also the challenge of obtaining information from an Electric Signature Analyzer (ESA), or Motor Current Signature Analyzer (MCSA). Because of specific interlocks within the variable frequency drive system in the vehicle, and the fact that we were using an AllAmericanHybrid.com™ owned vehicle for the experiment, we determined that the best approach would be to take current-only readings. Data would have to be taken while the vehicle was in motion and in hybrid or electric-only mode (less than 15 mph) so we had to decide whether or not we would use a device that required intrusive modifications to the vehicle, such as putting a hole through the firewall. The result was the selection of the ALL-TEST Pro, LLC, ATPOL II ESA device which can be communicated with via Bluetooth. This allowed us to mount the data collector under the hood (Figure 2) while an engineer operated a laptop within the truck to take data (Figure 3) and the driver controlled the SUV to keep it at a steady speed and in electric motor mode.

Figure 2: Data Collector Under Hood

Figure 3: Data Collection Computer

The vehicle used was a 2008 four-wheel drive GM hybrid Tahoe manufactured in March, 2008, in Arlington Texas, using the Baltimore Powertrain (GM/Allison Transmission) manufactured 2-mode transmission, which is similar to the Allison Transmission, LLC, Indianapolis hybrid bus transmission. For the purpose of the test, all work was performed by SUCCESS by DESIGN® personnel at the GM Tech Center in Warren, Michigan. The Tahoe was operated in two-wheel drive mode for the duration of the tests which were performed in drive at 10mph, in reverse at 5mph, and in drive at variable speeds. The vehicle, itself, has been used to evaluate such things as mileage which has ranged from 19.8mpg to 26.1mpg, depending on driving and weather conditions, and with just over 12,000 miles at the time of this study. Specific data on the components of the transmission were provided to SUCCESS by DESIGN® personnel for purposes of evaluation.

Test Results

One of the concerns was whether or not we could obtain data through the shielded cables that led from the drives to the transmission. The other primary concern was what the current data would look like as the motors were inverter-fed. The cables related to the low-speed motor were identified and a one-thousand amp clamp connected to one lead. As the Tahoe was backed out of the garage it was observed that both concerns were unfounded as we were drawing well over 100 Amps that remained steady on the digital readout. Unfortunately, the ATPOL II does not display the spectra of the motor diagnostics nor allow the operator to watch real-time data and capture just the area of interest, so the testing and data capture was performed and the results provided after.

The evaluation required a steady speed at about 10mph for about 1 minute in the forward direction, and then about 5mph in the reverse direction in a remote empty parking lot, then 1 minute at varying speeds back to the garage. The data was analyzed and all involved were impressed with the current and spectral data, which showed virtually no noise as compared to the noise generated in a commercial drive/motor combination.

In the drive mode at 10mph, the results appeared as shown in Figures 4, 5 and 6. In Figure 5, there are line frequency side bands around the line frequency and multiple harmonics of twice line frequency in demodulated current, as shown in Figure 4. Upon review, we were able to determine that these were most likely the other motor in generating mode as the engine was running to charge the batteries. In Figure 6, we were able to determine that there were peaks with line frequency sidebands at a multiple of 60 times running speed. We were able to determine the source and will continue monitoring in order to see if there are any changes associated with age. At an average of 38 amps steady, the harmonic content, as shown in Figure 7, was null.

Figure 4: Low Frequency Data

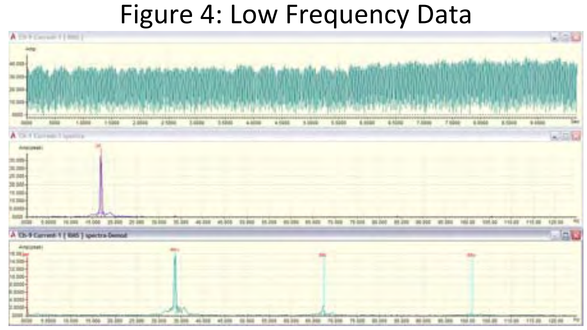


Figure 5: Low Frequency Data Sidebands

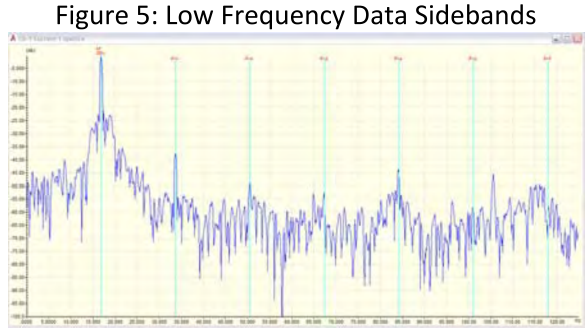
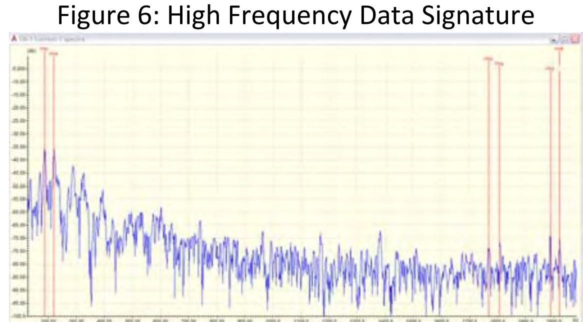


Figure 6: High Frequency Data Signature



In reverse at about 5mph, the results appeared as shown in Figures 8 and 9. The current was much higher, drawing over 100 amps during the test, with relatively small variations in speed (5 to 8 mph). The results also showed the same 60 times running speed signature with harmonics. The harmonic current content was similar to that in Figure 7.

Figure 7: Harmonics

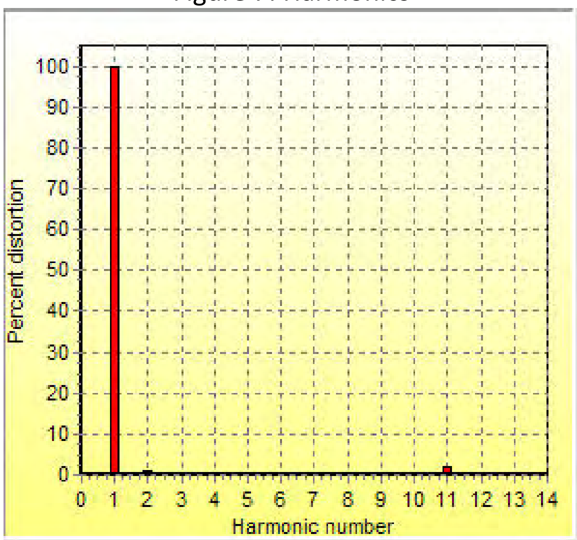


Figure 8: Reverse Low Frequency Data

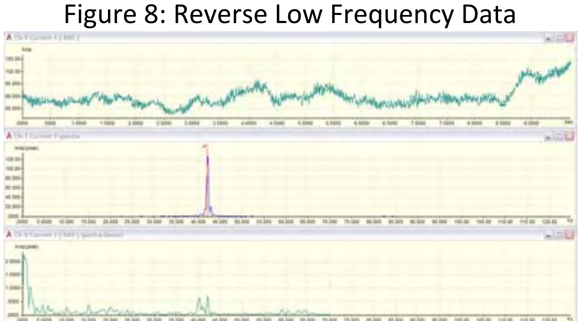
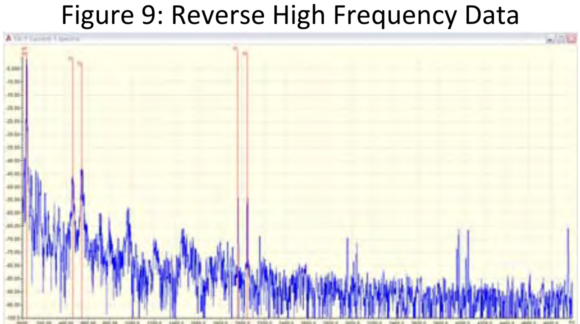


Figure 9: Reverse High Frequency Data



At varying speeds during the return to the garage, the results were as shown in Figures 10 and 11. The data was much more difficult to evaluate and the harmonic content increased, as shown in Figure 12. This data was much more difficult to analyze and the results were questionable.

Figure 10: Variable Speed Low Frequency

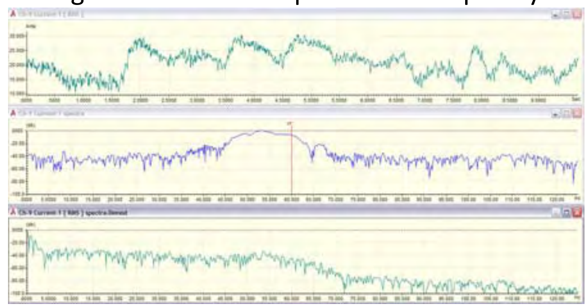


Figure 11: Variable Speed High Frequency

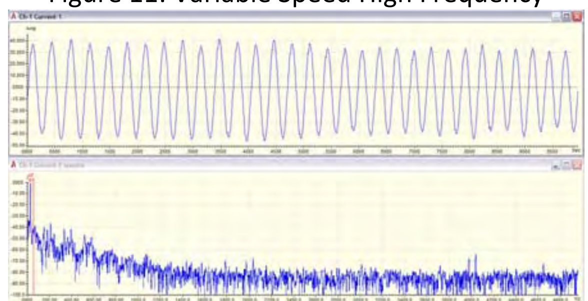
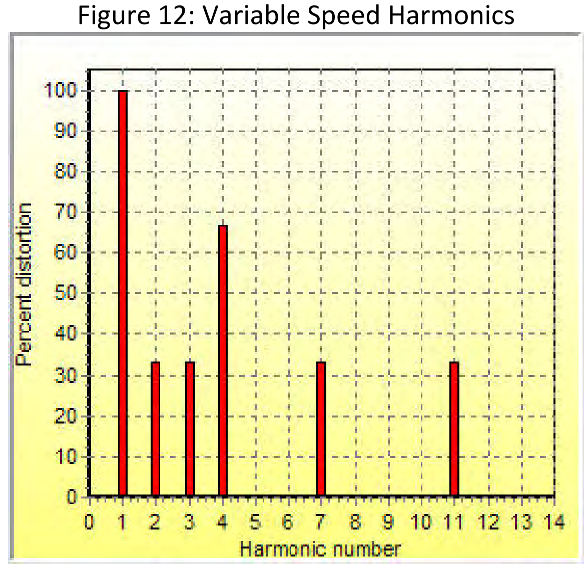


Figure 12: Variable Speed Harmonics



Conclusion

The use of the ESA/MCSA data collector provides an excellent view as to the condition of the electric motors and transmission in the two-mode hybrid Tahoe. The initial concerns about whether or not data could be collected and in a non-intrusive manner, were resolved through the use of the ATPOL II Bluetooth data collector and the collection of useful data. Challenges, such as the ability to watch real-time data for collection do need to be overcome and the ability to operate the machine at a steady speed either on a dynamometer or flat stretch of road is required. As with industrial machinery, the usefulness of the data for analysis is dependent upon the information provided on the electric machine and the components attached to it. However, we now know that it is feasible for purposes of research and servicing of modern hybrid and electric vehicles.

About the Author

Howard W Penrose, Ph.D., CMRP is the President of SUCCESS by DESIGN® Reliability Services and Publishing, President of AllAmericanHybrid.com™, Editor in Chief of the Institute of Electrical and Electronics Engineers, Inc. Dielectrics and Electrical Insulation Society (IEEE-DEIS) Web and eZine, and the Founding Executive Director of the Institute of Electrical Motor Diagnostics, Inc. He is a member of the National Writers Union (UAW Local 1981) and International Federation of Journalists and author of such books as "Physical Asset Management for the Executive – Caution: Do Not Read This on an Airplane," and, "Electrical Motor Diagnostics: 2nd Edition." For more information, please feel free to contact Dr. Penrose at howard@motordoc.com.