AUTOMATED, FULL LOAD MOTOR TESTING AT PRODUCTION SPEEDS

Abstract: Revolutionary test method coupled with innovative automation yields superior motor performance measurement data without sacrifice of production speed. This paper will discuss the methodology in detail, compare and contrast the methodology with traditional motor test methods and describe production applications wherein the method has been automated.

Introduction

Traditional electric motor performance test techniques fall broadly into three categories; no-load, signature and load tests. Each of these methods has serious limitations in its ability to detect manufacturing faults, time required to conduct the test, reliability and stability of the measuring instruments in a production environment and / or the usefulness of the test results beyond a mere pass or fail indication.

After several years of research wherein the goal was to develop a method with none of those limitations, the digital torque measurement method described herein was invented. The technique, later dubbed "Digitorque®", makes hundreds of torque, current and power measurements characterizing the entire motor performance curve from locked-rotor to full load in about 4 seconds.

Test equipment that applies this revolutionary method has been refined over the past few years so that it may be used in palletized handing systems as well as more traditional manually loaded test systems. Three applications in particular are discussed; a small, threaded-shaft motor, a threaded-shaft, two-speed pump motor application and a direct current automotive type starter motor.

Traditional Motor Performance Testing Techniques

The traditional methods of electric motor performance testing include no-load, signature and load test techniques. Each of these methods has advantages and disadvantages with respect to the others but none of these methods is completely satisfactory.

The induction electric motor performance parameters of greatest concern in most applications include locked-rotor current and torque, pull-up torque, breakdown torque and speed, and full load speed, current and power. These points are identified for reference in figure 1. One or several points along the torque / speed curve of DC permanent magnet and universal motors are typically of interest depending upon the application.

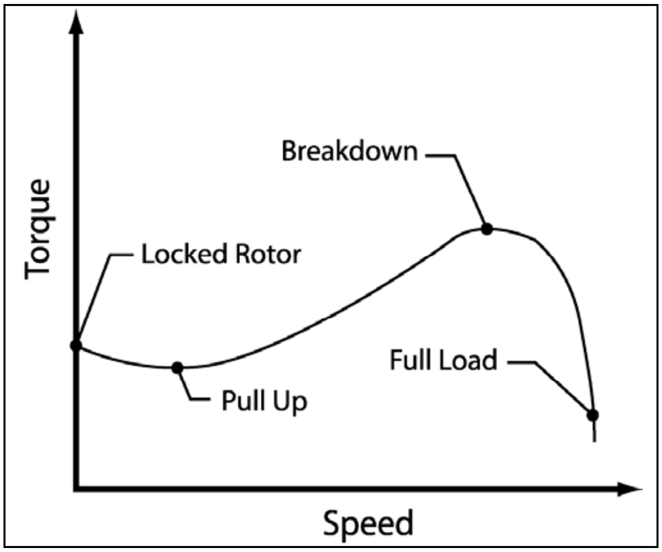

Figure 1: Typical Induction Motor Torque / Speed Curve.

With the exception of a load test, the traditional techniques are incapable of actually measuring any of these parameters. They, rather, measure one or more other characteristic of the motor under test and compare those measurement values to similar ones made on a "master motor" which displayed the desired locked-rotor, pull-up, breakdown and full load characteristics when tested off line usually with bench top instruments and a manually operated load. The result is a go / no-go test system which, by and large, produces data which cannot be directly related to any of the performance parameters of interest.

The simplest of these techniques is no-load testing. As the name implies, no-load motor performance testing consists of applying rated voltage to the motor with "no load" (nothing) coupled to the shaft. The resulting current and power are measured and compared to limits derived from "master motors" for acceptance. Additional external measuring devices are usually added to determine the speed and / or direction of rotation.

No-load test systems sometimes also include a "low-voltage start" test which is designed to detect (but not measure) low pull-up torque at the expense of additional test cycle time.

The major advantages of the no-load method are that the test system and instrumentation to implement it is about as simple as it gets and it can detect many gross manufacturing defects quickly enough that it can be used for 100 percent testing. For these reasons, the method is widely used in industry. However, many types of manufacturing defects simply cannot be detected by this method so it is typically augmented with lab load testing of so many per hour or per shift or per batch.

Signature testing is really an extension of no-load testing which utilizes faster measuring means, statistics and other theory to further refine the ability to quickly compare some measured characteristic of the motor under test to similar measurements made on a “master motor” found to perform as desired with respect to locked-rotor, pull-up, breakdown and full load when tested on a load test system. Like no-load testing, the signature method is typically fast enough for 100 percent production testing, however, the cost of the test system may be significantly greater. Although a great amount of research and development continues in this area, the existing techniques simply do not detect many types of common manufacturing defects. Furthermore, as with simple no-load testing, lab load testing is required to determine actual locked-rotor, pull-up, breakdown and full load performance of motors that pass or fail signature performance testing.

A load test system is a class of mechanisms which provide a specific torque load to the running motor under test and measure the resulting speed, current and power. They range from simple collections of bench top devices to computer controlled, fully automated systems.

Although superior to other traditional methods in that they can actually measure locked-rotor, pull-up, breakdown and full load motor parameters, load testers have a number of significant disadvantages. Some of the disadvantages of load testing as applied to electric motor performance testing are 1) the length of time it takes to make a single measurement, 2) problems related to torque measuring instruments and 3) the greater complexity of implementation as compared to no-load and signature methods.

Most load test systems employ either an eddy-current or hysteresis type of electromechanical brake to generate a variable rotating torque load. Some use a separate DC electric motor. In each case, the shaft of the load must be coupled to the shaft of the motor prior to test and uncoupled afterward. During testing, power to the load device is adjusted in order to apply the desired torque load to the motor under test. The motor, load and instrumentation must then be allowed to stabilize before speed, current and power can be measured. Once the measurements are recorded, the torque may be adjusted to the next point of interest and the process repeated. Although, the time it takes to collect each point varies with the level of sophistication of the electronics employed and / or the skill level of the operator, the motor will normally heat up significantly during the process of collecting locked-rotor, pull-up, breakdown and full load data. When measuring the higher-current points, such heating may become excessive and cause the motor to perform worse in testing than it would in the application. Therefore, the motor will often be allowed to cool between measurements made in the lab or, if in a production application, only one point, say full load or pull-up, will be measured.

Every load tester employees some sort of rotating or linear torque measuring transducer. Most such devices are based upon an electromechanical device known as a “strain gage” along with some mechanical interface to the rotating shaft or to the motor housing / test fixture. Such mechanisms are somewhat “involved” to calibrate requiring the use of precise levers and weights. Strain gages also tend to drift considerably over time and temperature changes resulting in the need for frequent calibration and / or the loss of accuracy. They also will measure any extraneous torque, such as vibration from adjacent machines, which may be applied to them however inadvertently resulting in additional measurement error. Finally, at least in the not too distant past, such devices have proven to be somewhat fragile for the typical manufacturing environment.

At this point, it is probably quite obvious that the implementation of the load test method to 100 percent production testing is much more involved than either no-load or signature testing would be. Coupling to every motor shaft, additional calibration and maintenance and potentially higher equipment costs all contribute to the complexity. The longer test time also is a consideration. None the less, test results data generated from load testing relates directly to locked-rotor, pull-up, breakdown and full load performance of the motor under test. Thus, 100 percent production testing on load testers does exist in the industry. Its primary role, however, remains as an audit or lab technique.

The Digitorque® Method

What began as a project to develop a better torque transducer / load test method soon developed into a rethinking of how torque is measured. As in all good research, the basic principles of physics were reexamined and, although all prior methods were studied, thinking was not allowed to simply begin where previous research had ended. The result was the invention of the digital torque measurement method. Now referred to as Digitorque®, this revolutionary method has all the advantages of load testing without its calibration / maintenance woes and typical slowness. Indeed, the Digitorque® method can measure hundreds of torque / speed points - enough to characterize the entire torque / speed curve including locked-rotor, pull-up, breakdown, and full load points - in just a few seconds; about the same amount of time most no-load and signature methods require. Simply put, this all-digital method renders laboratory results at production speeds.

The Digitorque® method is founded upon a basic physics principle: The torque applied to a rotating mass of known inertia can be calculated by measuring the change in speed over a fixed period.

$$\text{Torque} = \frac{\text{Inertial Load x change in speed}}{\text{time}}$$

Generally, this formula is used to determine the torque required of a motor to accelerate an "Inertial Load" from zero speed to full speed in a finite time. The Digitorque® method utilizes it to calculate torque.

In a system employing the Digitorque® method, the motor under test is mechanically connected to the test system via a test fixture consisting primarily of a rotating shaft supported upon high-quality bearings and a flywheel of known inertial and a high-resolution rotary digital encoder mounted on that shaft. A simplified fixture drawing is shown in figure 2.

The flywheel is used as an "inertial load." Its value is a constant in the above equation. The measurement time interval is also a fixed value generated by a crystal oscillator. Usually 16.67 ms, the period of one 60 Hz power line cycle, is used. Thus, the only remaining parameter required to calculate torque is the change in speed.

The change in speed is determined via the digital encoder which, together with support electronics, is capable of resolving as little as 0.0072 degrees of angular displacement. This resolution permits speed changes as small as 0.07 RPM to be measured in the 16.67 ms period.

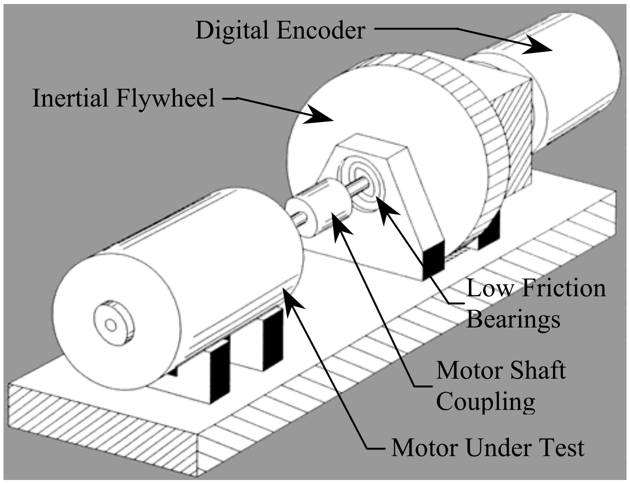

Figure 2: Simplified Digitorque® Fixture.

Torque and speed are computed using this method for each 16.67 ms period from the time power is applied to the motor until it reaches its maximum "no-load speed." The flywheel size is selected so it will take about 4 seconds for the motor to accelerate to that speed from a standstill. The exact time is not critical. The result is, of course, that about 240 torque and speed measurements are made during this acceleration time. This is more than enough points to accurately describe the entire torque / speed curve of the motor from locked-rotor to full load.

In practice, motor power and current are also measured during each 16.67 ms period and both are plotted along with torque versus speed in real time. The test system computer then employs algorithms to instantly pick out each specific point of interest (locked-rotor torque and current, pull-up torque, breakdown torque and speed, full load speed, current and power for induction motors) from the curves.

A sample curve created by Digitorque® may be found in Figure 3:I.

Torque Ripple and Switch Speed

Because of the high resolution with which the torque / speed curve is measured, additional information about the motor's performance can be determined from it at no additional cost in terms of cycle time. Torque ripple and governor switch speed are examples of such information.

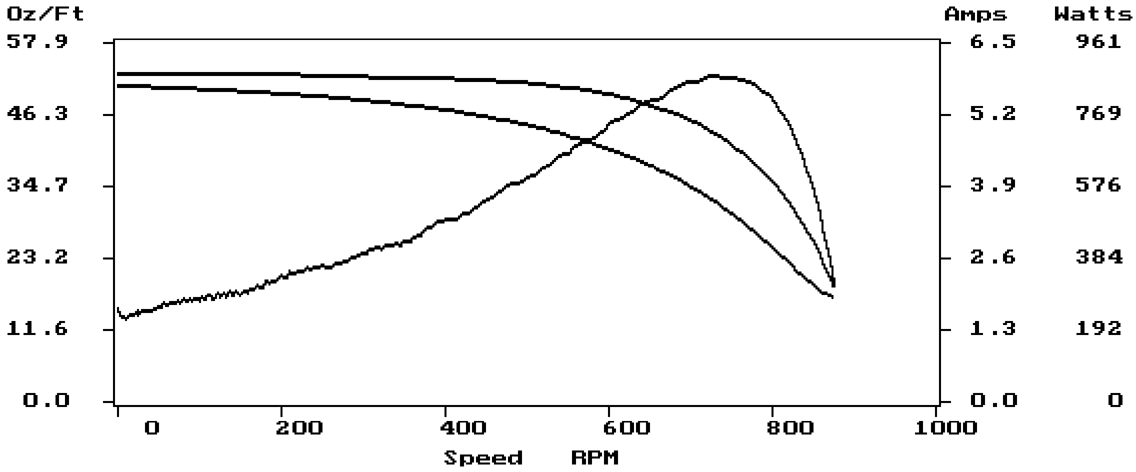

Figure 3: I Typical Digitorque® Graph of a PSC Motor.

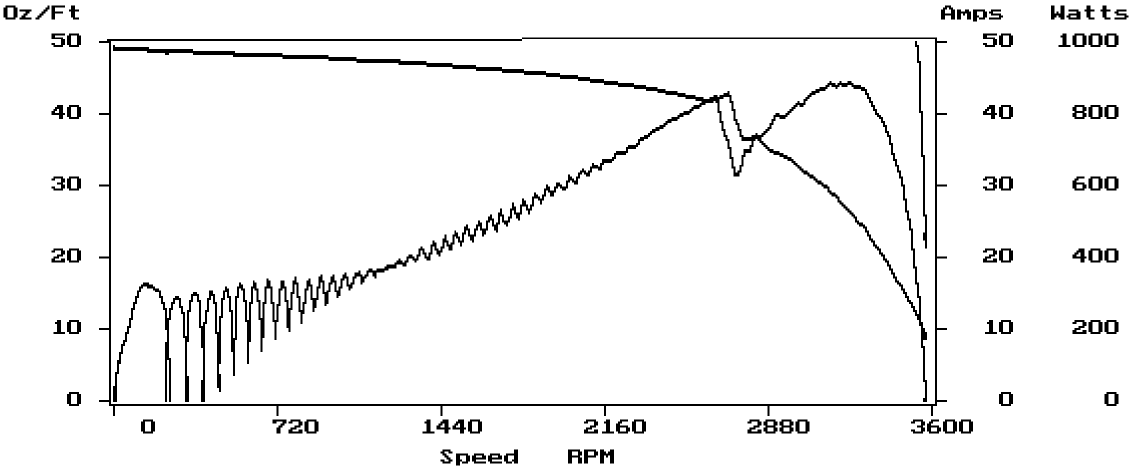

Figure 3: II Extreme Example of Torque Ripple – Caused by a Rotor Hit.

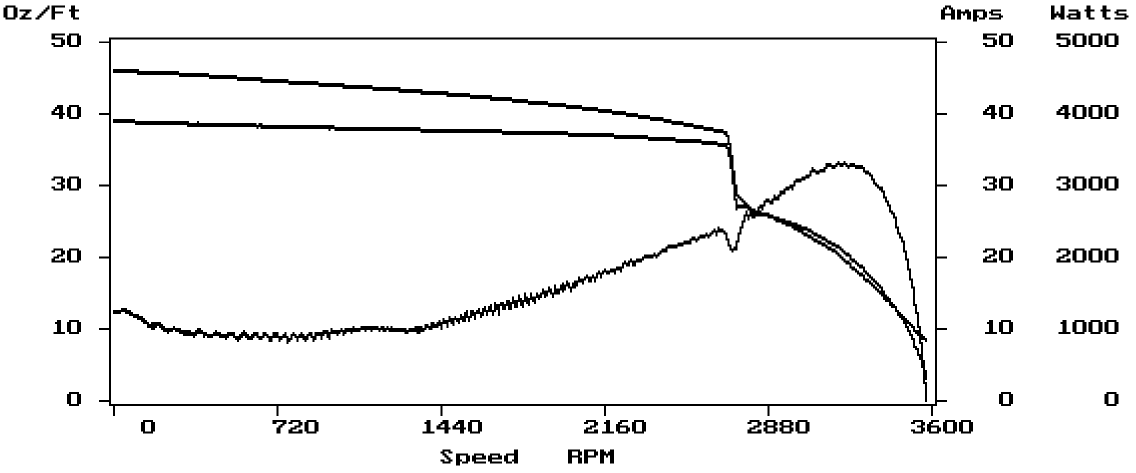

Figure 3: III Example Digitorque® Graph of a Governor Switched Motor.

Torque ripple, as the name implies, is oscillation or ripple on the torque curve which can be easily seen on the graph generated by Digitorque®. An algorithm calculates a ripple torque value which may then be compared to limits for test acceptance. Torque ripple can be indicative of a number of manufacturing and material defects such as bad bearings, a bent shaft, a non-uniform air gap, rotor out of balance, rotor hits and open rotor bars. Most of these defects are not even detectable using the traditional test methods. A drastic example of torque ripple caused by a rotor hit (which previously passed a no-load test) may be found in Figure 3:II.

The speed at which the governor switch transitions power from the start winding to the run winding is an important design parameter in motors so equipped. That switch speed is an obvious feature on the Digitorque® graph. An algorithm determines the switch speed from the graph which may then be compared to limits for test acceptance. An example of a Digitorque® graph of a governor switched motor may be found in Figure 3:III.

Friction Torque Measurement

Excessive friction torque in a motor is typically due to some defect in the bearing system; defective or incorrectly installed bearings, damaged shaft, etc. Sometimes it is a characteristic of the bearing system which will not affect performance after a few minutes of run time in the application. In other applications, friction torque may be a cause for rejecting the motor. In either case, the Digitorque® method is used to measure the torque applied to the test fixture shaft by the friction of the bearings. That measurement may then be compared to limits for test acceptance or the entire torque / speed graph may be adjusted to compensate for the friction torque.

Coupling to the Motor Shaft

There should be little doubt by this point that 100 percent production testing using the Digitorque® method is desirable. One concern that remains, however, is the shaft coupling requirement. Although it is a fairly simple matter to accomplish in a manually loaded test fixture, coupling to a motor shaft in an automated test system may be less straight-forward. The following examples illustrate how the automated coupling issue has been dealt with effectively in fully automated test systems.

The first example is a small, low-power motor with a threaded shaft. In this application, a small portion of non-threaded shaft was available for clamping to via a collet. The motors were located in nests, shaft-up on an indexing table top. The test fixture assembly, consisting of a centering mechanism, the collet mechanism, shaft, flywheel and encoder was lowered from above. See figure 4.

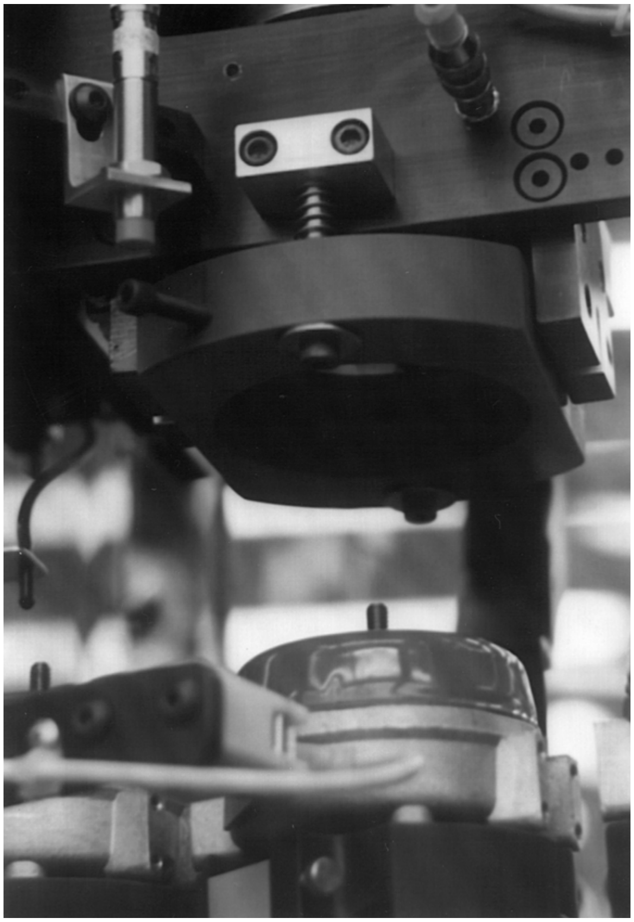

Figure 4: Coupling to motor from above using a collet.

The next example is an automotive-type DC starter motor. The motors were mounted on pallets, shaft / gear end down, during the assembly process. When they arrived at the test station, the pallets were clamped in place and the fixture assembly consisting of a mating gear, shaft, flywheel and encoder was raised into position from below. When the motor was energized, the drive mechanism caused the gears to engage similar to the way it would in the application. This method had the added advantage that it verified proper operation of the drive mechanism as well as tested the motor under load. See figure 5.

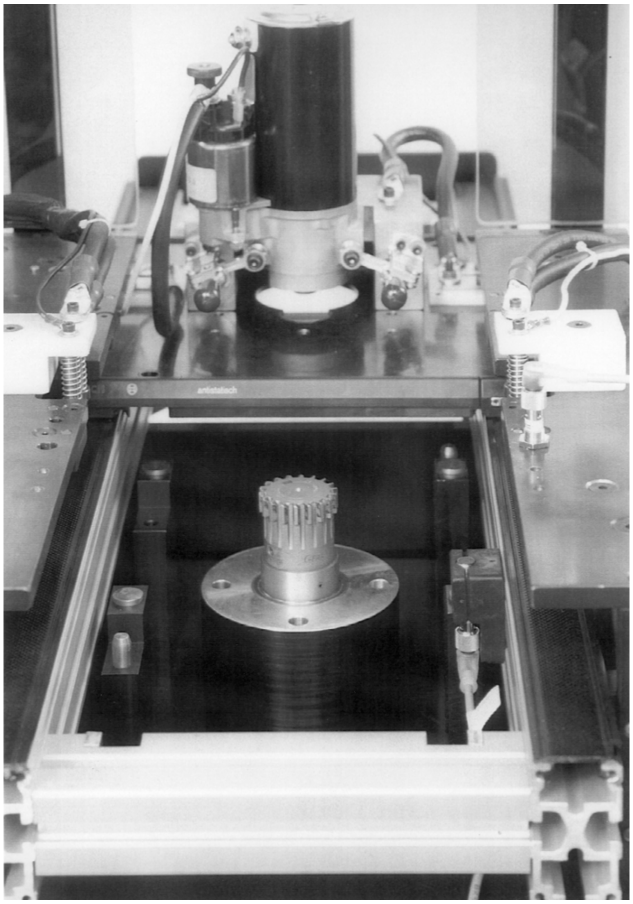

Figure 5: Coupling to a DC starter motor from below via a gear that mates with that of the starter motor's drive.

Yet another example of automated coupling is a one to two horsepower governor switched pump motor with a threaded shaft. As with the DC starter application, the motors traveled on pallets throughout the assembly process and the test station fixture assembly was raised into position from below. Instead of using a collet or similar clamping device, a unique application of unidirectional clutch bearings was employed.

Prior to the automation, during assembly of the pump motor, plastic caps had been placed on the shaft over the threads to protect them from damage. Prior to packing, each shaft was checked with a thread gage to verify the correct shaft had been used and that the threads were indeed not damaged. When the automated system was designed, protection and thread gage were combined into case hardened, coupling adapters the outside diameter of which matched the clutch bearing shaft specifications.

When the pallet arrived at the test station, before it was clamped into place, the fixture assembly raised from below and a taper guided the coupling adapter on the motor shaft into the mating bearings. The pallet was then clamped in place, the motor held from above and testing proceeded. To insure that the motor shaft and fixture shaft could not rotate individually, two unidirectional clutch bearings were used; one was installed to stop rotation in the clockwise direction and the other to stop rotation in counter-clockwise direction. At the end of the test, the fixture assembly retracted downward pulling the bearing assembly off the coupling adapter. See figure 6.

Conclusions

The Digitorque® method for motor performance testing is far superior to traditional methods. It provides real performance data including locked-rotor torque and current, pull-up torque, breakdown torque and speed and full load torque, power and current in about 4 seconds. In addition, the high resolution Digitorque® graph provides the ability to monitor torque ripple and governor switch speed helping to uncover many manufacturing and material defects that went undetected using traditional methods. Bearing friction torque may also be measured using the Digitorque® method. A broad variety of automated shaft coupling applications were presented to illustrate that the method is applicable to 100 percent production testing even in a fully automated test station.

The implications of this technology to the electric motor manufacturing industry are numerous. It is now possible to monitor every critical motor design parameter on every motor manufactured at a rate compatible with production lines. This alone could result in the elimination of many manufacturing and material defects which currently go undetected by traditional test techniques only to manifest themselves in a poorly performing motor once installed in the customer's application.

However, because torque ripple, switch speeds and bearing friction can now me monitored at the same time, the opportunity now exists to detect more subtle material and manufacturing problems as well. The result will, no doubt, be a higher quality product and happier customers.

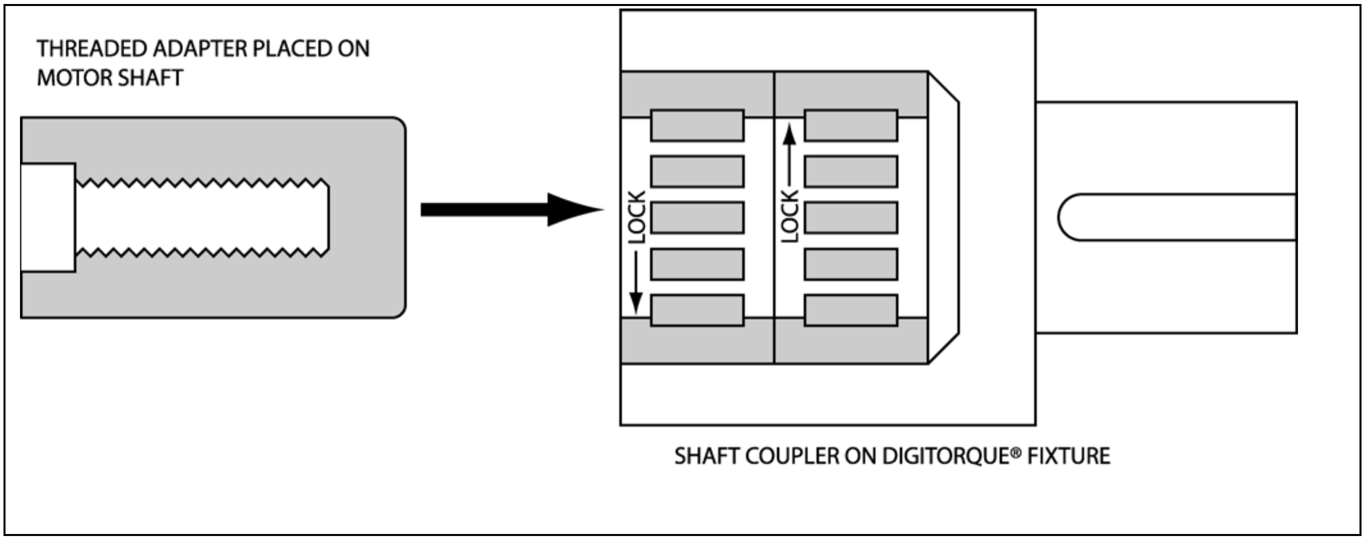

Figure 6: Cut away view of threaded adapter and shaft coupler which, as shown, utilizes two unidirectional clutch bearings to insure the motor and test fixture shafts do not turn independently in automated coupling application.

Beyond these more apparent yet retroactive implications are some very interesting possibilities. Statistical quality control methods may be automated and applied to real performance data allowing a manufacturer to begin to reign in processes. Close monitoring of parameters which affect energy efficiency would be a logical application as this becomes more and more necessary. If required, a manufacturer could provide graphical and numerical proof of design conformance for every single motor delivered. Digitorque® is certainly a tool for the future.