

Instantaneous Torque as a Predictive Maintenance Tool for Variable Frequency Drives and Line Operated Motors

Abstract

Despite the growing number and importance of VFD motor/machine systems in industrial applications, predictive maintenance professionals aren't often aware of what is necessary to identify faults to avert catastrophic motor failures. The complexity of the symptoms exceeds commonly-used RMS hand-held instruments, many of which cannot even discern symptoms, never mind root causes. This paper presents a pair of VFD applications, problems associated with those applications, and diagnoses from the use of modern field instrumentation.

Introduction

The focus of plant operations and maintenance management is shifting from an overall expense viewpoint to expenses per product or value as a measurement metric [1-3]. In spite of this, when it comes to electric motor and motor/machine system maintenance, the prevailing management mode for plant operation is "run to failure." The negative consequences of this reactive approach are compounded by a lack of knowledge of how to properly install variable frequency drive motors. This often results in additional failures due to faulty installations. Such basic instructions, though time-consuming, include how to properly install fusing, wiring and motor lead length, practices which go a long way toward reduction of drive system failures [4].

A trend to adopt modern asset management practices is helping. Predictive maintenance conferences are now focusing more on managerial education and the tactical steps required to follow through with this approach [3,5,6].

This management shift from expense reduction to efficiency improvement is changing the maintenance professional's perspective from a reactive "replace the broken" to a more proactive root-cause analysis approach that improves identification of problems prior to failure. Leading manufacturers have identified that electrical component replacement (motors and drives) is the third highest operational expense, behind wages and energy, and are consequently investing in training and equipment to reduce costs of reactive management.

A variable frequency drive exposes a motor to millions of impulses, which in turn requires proper installation and maintenance of both motor and drive [7]. Protective devices such as line and load reactors, line traps and MOV Surge Arrestors [8] are necessary even if their return on investment is not immediately apparent. Tools available to field maintenance electricians are often limited to RMS current and voltage meters, which are inadequate when it comes to diagnostics of a given VFD's variable operation in a motor-load system.

While there are a few articles on debug and root-cause analysis of VFDs, authoritative and comprehensive technical references for analysis of VFD-related problems are not so readily available. The transient nature of VFDs, which interact dynamically with the motor and load system components, severely limits the usefulness of standard RMS and waveform types of instrumentation [14]. This paper presents two case studies that exemplify how VFD motor load system diagnostics can be adequately performed with modern instrumentation.

A case of thermal overload: Identifying the need for VFD tuning

Maintenance professionals at a timber mill in the state of Washington discovered abnormally high operating temperatures of a VFD motor at its facility. This motor, a 10-year old Design B, 460V 60hp, TEFC 6-pole motor, was at the heart of a critical system the plant – and the company – depended upon for revenue generation (a conveyor for transporting cut logs to a saw).

The established rule of thumb regarding motor insulation life is that for every 10° Celsius above a motor's rated operational temperature, the life of the motor's winding insulation drops by half (Figure 1).

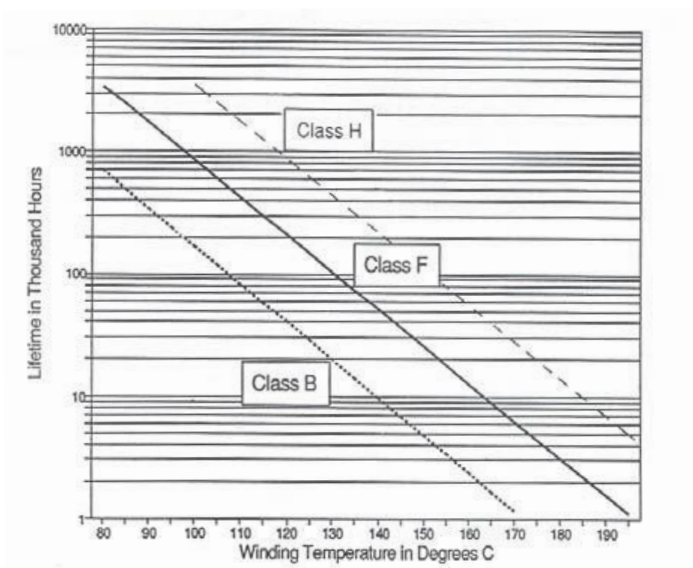


Figure 1: Winding temperature vs. lifetime for insulation classes B, F & H

To apply this concept, a motor operating at 30° C above its insulation's rated temperature reduces the motor's normal life expectancy of 20 years to just 2.5 years. In the case of this company's VFD motor, it drove a log transport conveyor belt in an operation involving three steps. First, when a log is not in close proximity to the saw, the motor operates at a relatively fast pace. When a log nears the saw, the motor decelerates to a pre-set cutting speed. Finally, once a log exits the saw, the motor accelerates again to the faster setting. In this particular case, the system is designed so that a log reaches the saw every 15 seconds. The company depends upon the VFD's ability to dynamically change the speed of the belt for efficient operation of this band saw.

Standard approaches to identifying causes of thermal overload include an assessment of environmental factors such as inordinate amounts of motor contamination (e.g. accumulated sawdust) or external sources of heat imposed upon the system. Maintenance personnel typically inspect the motor and system to ensure windings are inverter rated, and that HVF (Harmonic Voltage Factor) guidelines have been met. In this case, it was determined that ambient temperature was below 25° C and the motor's vents were not clogged with pulp or other contaminants.

Figure 2 reveals a partial cycle (in blue) of the motor's speed for 7.5 seconds. At the beginning of the cycle the motor is running at 1200 rpm. After one second, deceleration occurs, taking just 0.7 seconds to reach cutting speed, where it remains constant for two seconds. At 2.7 seconds, the drive accelerates and returns to 1200 rpm in just one second, where it remains for the rest of the cycle.

The timber mill's VFD motor system was first tested with RMS (root mean square) analyzers and other types of waveform

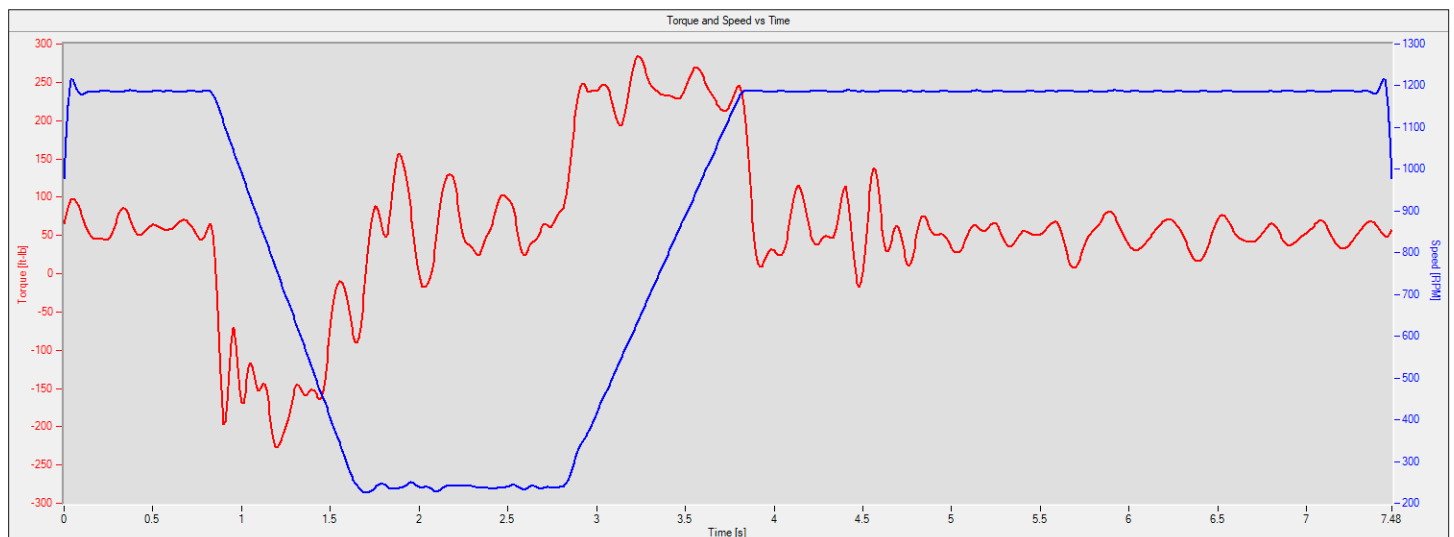


Figure 2: Torque (red) and speed (blue) vs. time

instrumentation [12-14]. None could identify that a problem existed, never mind the cause. The VFD output voltage level during the longest constant period was rated line-to-line at 460V, which was the desired voltage for the highest speed of operation (60Hz). The voltage level during the second constant speed operation of 12Hz was 90V, which was also correct. The two continuous operation states were compliant with the motor's nameplate voltage, and current ratings were in line with the V/f control expectations. Handheld multimeters are the tool of choice for performing line operation motor debugs, but they aren't capable of testing a VFD's two remaining operational modes: acceleration and deceleration.

To address this, it was necessary to connect a modern motor test instrument capable of monitoring VFD applications – and these two additional modes.

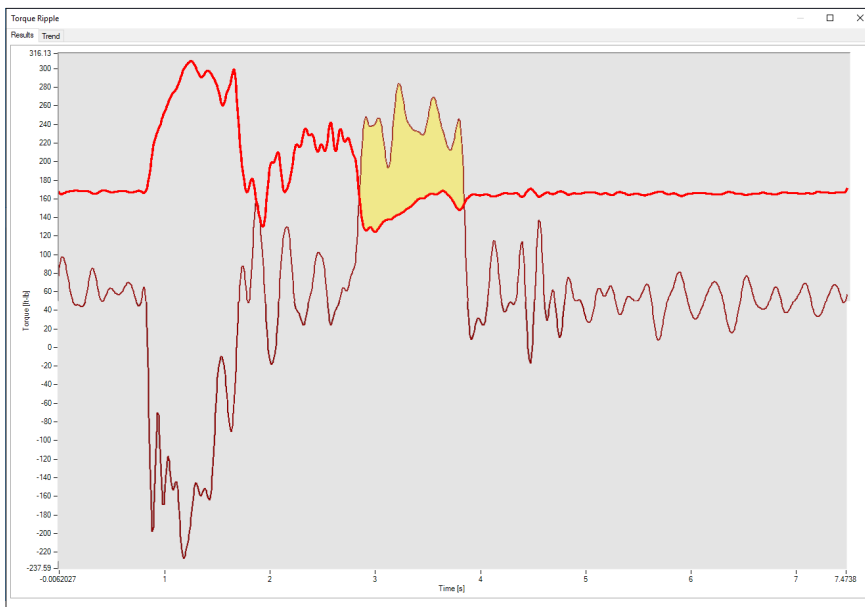


Figure 3: Torque (brown) and equivalent rated torque (red) vs. time

Figure 2 and Figure 3 are screen captures from the display of a Baker EXP4000 dynamic motor analyzer [16] or the associated Surveyor EXP AC desktop software. The red trace in Figure 2 displays torque versus time. Average torque during the first second of operation is 100 Nm, which is approximately a third of the rated torque for the motor. The torque for the low- speed operation reveals a similar average, which is common for conveyor belt applications. Both torque figures during deceleration appear to be roughly constant. These data points adequately correspond with the programmed rate of conveyor deceleration (and negative, which shows that the motor operates as a generator when actively braking). Finally, the monitor shows acceleration exerts a higher torque than the constant speed torque, which is necessary to accelerate the conveyor bearing the

weight of each log. In this case, overall deceleration took 0.7 seconds; acceleration, one second.

Figure 3 shows instantaneous torque versus time, and the red line within captures the equivalent rated torque. The motor analyzer calculated this with a motor model that incorporates voltage level, frequency, torque, and nameplate information as input variables. The goal of the model was to find thermal equivalent stress relative to rated operation, and for multiple operating frequencies and voltages. The model implemented displayed the torque so that the motor rotor's I²R losses are identical to those for full-load operation. This estimation neglects the reduced cooling achieved by shaft-mounted fans when they are operated at lower RPM. Observe that between seconds three and four, instantaneous torque is significantly higher (300Nm) than the equivalent rated torque (200Nm). (This region is highlighted in yellow

for this paper.) This calculates to approximately 150% of full thermal loading, and happens every 15 seconds. This is what is causing the motor to overheat.

Even though modern VFD systems report motor torque, it's usually averaged over time, and so this repetitive transient heating event would have been missed without the use of the EXP4000 analyzer.

With the knowledge that this was the problem, the solution involved reducing the requisite torque during conveyor acceleration by a third. The one-second acceleration time was slowed to 1.5 seconds. This slowed production by 0.5 seconds for every 12 seconds, or 2 minutes per hour, which was acceptable to operations.



Figure 4: The Baker EXP4000 Dynamic Motor Analyzer

The VFD could now handle the new high-speed setting (changed from 60Hz to 66Hz) with no thermal impact on the motor, and still complied with NEMA Part 31 guidelines for VFD operation of standard motors [15]. These changes actually increased productivity by half an hour per shift, while averting premature failure of the motor and any consequential downtime.

As a bonus, the EXP4000 analyzer revealed a second potential fault during the investigation. The VFD motor/load system was consistently oscillating (or “hunting”). Figure 3 clearly reveals the oscillation in the last 1.5 seconds of instantaneous torque, where about five cycles of the oscillation occurs. After identification of the frequency, maintenance personnel noticed the repetitive load variation could be heard at the motor during periods of continuous operation. This oscillation did not noticeably degrade the electrical system, but the mechanical system (from conveyor belt to motor bolts) was under unnecessary stress. With help from the vendor’s field support the VFD’s PID parameters were tuned and provided a much smoother operation, which reduced the audible vibration sound and maintained a comfortable class F temperature range for the VFD/motor/load system.

Case study: VFD control board malfunction

Another example that underscores the need for advanced dynamic motor monitoring involved a critical VFD (driven by two 1 hp VFD-driven 4-pole motors) in a South Korean electronics manufacturing plant. Each motor operated a chain-gear reduction mechanism that slowly spins a stirrer to keep 2,000 gallons of molten glass in constant motion. A failure of just one of the stirrers could compromise an entire batch of expensive high quality molten glass, and in turn, cause a costly disruption in production.

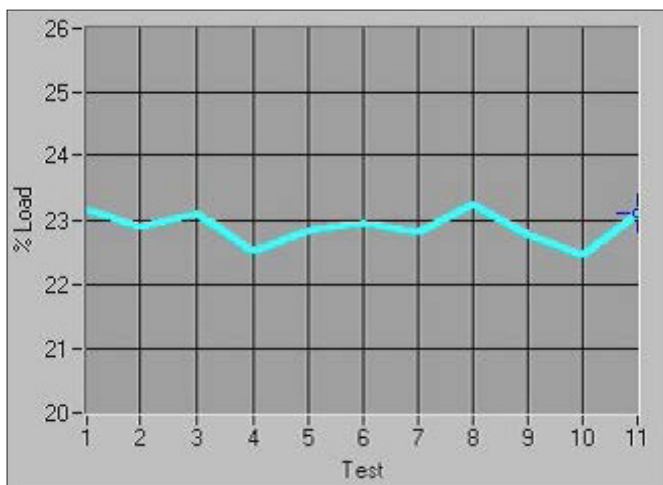


Figure 5: Estimated % load vs. test number

These critical 1-hp motors are monitored 24/7, and warranted the installation of the means to log A-phase state current levels. One of the stirrers, however, experienced an increase in the motor stator’s current over the last two days prior to the check. In order to avoid unplanned downtime and costly loss of production, the root cause of the problem needed to be found as quickly as possible. Both stirrers were analyzed with a Baker Explorer dynamic motor analyzer. Initial considerations made the likely source of the problem related to the load of stirrer No. 2. Figure 5 displays the load condition of stirrer No. 2, and reveals a constant load level between 22.5% and 23.2% load for 11 subsequent tests. Stirrer No. 1 was also checked, yielding similar results.

This low load is advantageous to the operation because the VFDs were installed 20 feet above the open batch of molten glass. Ambient temperature exceeds 60° C, which required running both motors and the VFD under low load to avoid overheating.

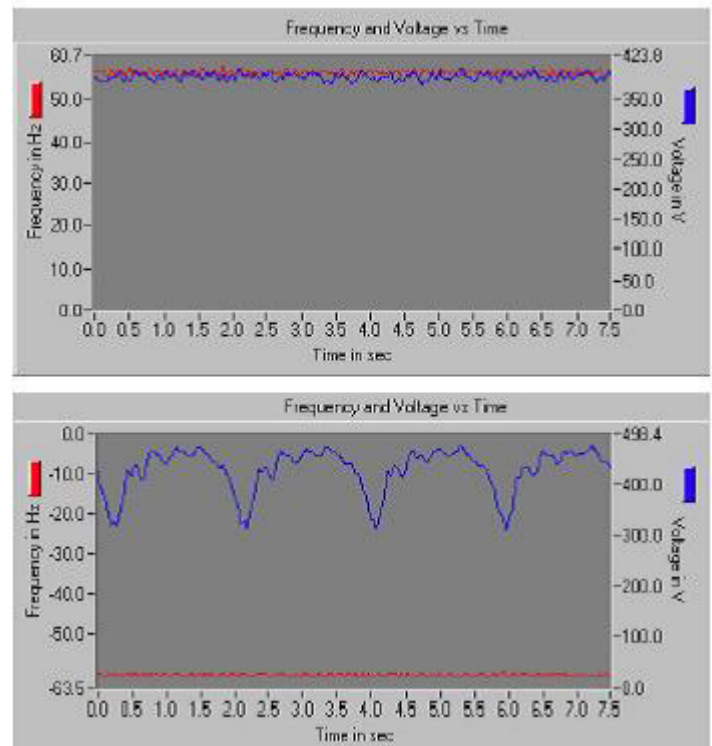


Figure 6a (top): Frequency and voltage vs. time, stirrer No. 1

Figure 6b: (bottom): Frequency and voltage vs. time, stirrer No. 2

Figure 6 compares other operational values for both VFDs. Figure 6a displays an expected constant frequency of 56Hz for stirrer No. 1 along with a constant voltage level. Figure 6b shows stirrer No. 2 data. A negative frequency of roughly 56Hz is recorded. This negative sequence indicates that stirrer No. 2 was operating in the opposite direction of stirrer No. 1, which is needed to meet the best stirring practice of the molten glass. However, the voltage level varied between 470V and 300V. Since the load does not change, these

abrupt voltage collapses cause the stators current to rise. The single-horsepower VFD's control board was not properly regulating the output voltage, and thus the root cause of this symptom was determined to be a faulty VFD. The scheduling of maintenance allowed for an exchange of the VFD when the batch was empty. The flow of production was not impacted, and the cost of repair was minimal.

The high temperature environment the VFD operated under may have precipitated the failing control board. If a pattern of failure emerges for this critical application, then it might necessitate relocating the VFDs further from the molten glass.

Conclusions, future work

Today's predictive maintenance professional has to solve more problems that involve VFDs than ever before. However, the most common field test instruments are not adequate for this task. The cases in this paper underscore how RMS type or waveform display and harmonic analyzers are not reliable when it comes to finding these dynamic, hard-to-discern problems. The inherent variability of frequency and dynamic changes in operating conditions can create other dynamic disturbances conducive to faults, which need to be identified and corrected to avert any unplanned downtime.

VFD/motor/machine systems introduce a number of challenges that, for many organizations, will cause system failures until they adopt modern dynamic motor monitoring tools. However, the VFD is too attractive to ignore in terms of the benefits they afford, such as power savings, greater control, and report generation for industry. Currently, 28% of new motors are controlled by a variable speed drive, with growth potential substantial. In the coming years, non-linear loads such as VFDs and AC servo controllers will account for at least 50% of the power produced [20]. Research the available dynamic motor monitoring and test equipment available today to be sure you can confidently identify and resolve problems with VFD/motor/machine systems.

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