Motor Performance Measurement Without a Dyno: A Portable Dynamometer

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Note: Sources for figure and citations listed at bottom of post as well as in the extended version of the article.

ABSTRACT

There are many scenarios where a quick, accurate validation of motor performance is valuable – R&D, vendor qualification, production, integration, commissioning, troubleshooting, or post-repair. Traditional methods for generating motor performance curves involve extensive time, effort, and resources for connection of the test motor to a loading device – which requires not only an alignment procedure but also significant infrastructure and resources to install, operate, and maintain the loading system. In the subject approach, none of the loading system infrastructure or resources are necessary. The results are quickly available after just a few uncoupled motor starts, including documentation of motor losses, in full compliance with IEEE and other standards, and the procedure is self-calibrating.

INTRODUCTION

The core idea of starting an uncoupled motor against only its own inertia is, of course, not new. Historical efforts have resulted in many publications from universities and even a few functional but short-lived commercial products. By and large, these commercial efforts suffered from a weakness of the "whole product" value proposition – i.e., the combination of initial price, required operator training, traceability, validation, calibration, and maintenance was inconsistent with industrial customer needs.

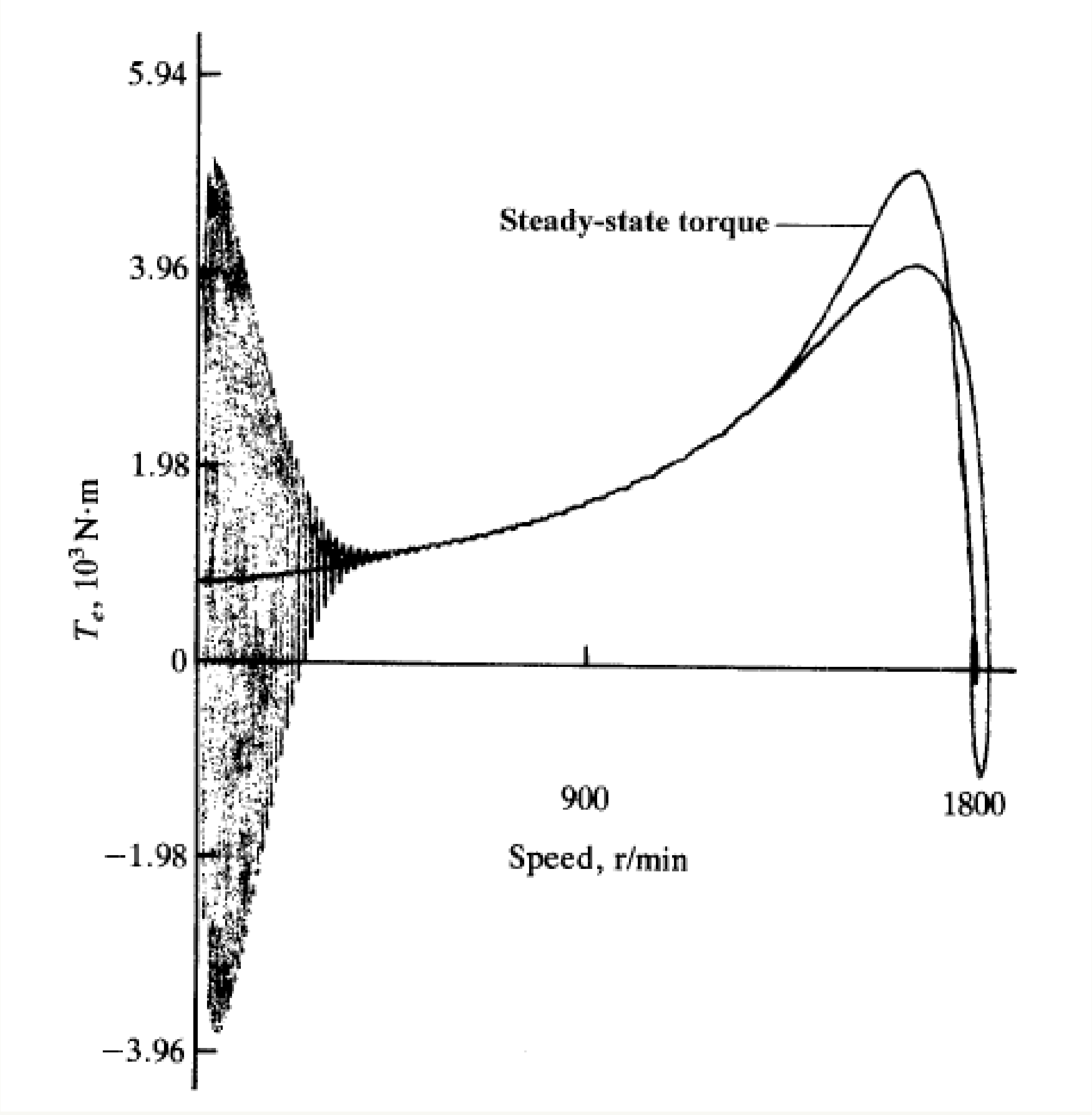
The resources required to perform the procedures described herein, consist of three main components. First, facilities to safely start and run a motor, even if at reduced or ramped voltage. Second, instrumentation and data collection equipment to properly record high-resolution current, voltage and rotor speed during a motor start. And third, a data analysis tool to convert raw data into the desired calibrated results in a format convenient for reporting and archiving in the end user's information environment. The first two of these are readily available as existing or easily-procured commercial tools from multiple suppliers. The focus of the work described herein is on the third core component, with special emphasis on compliance with industrial standards, results validation, commercial maintainability, and convenience for the end user.

BASIC PHYSICS BEHIND THE METHOD

To begin, recognize that saying that an uncoupled motor is "unloaded" is not correct. During a start, the load on an uncoupled motor contains inertia, friction and windage. Inertia is the physical mass property that resists speed change. Friction and windage are speed-dependent mechanical losses from shaft-attached cooling fans, air circulation in the air gap and stator cooling system, and bearings.

During startup, rotor inertia is the main "load" that resists speed change, requiring external (electrical) energy to change operation from any speed to a higher speed. As the motor speed increases, the internal friction and windage load increases. If there's no speed change, there's no *inertial* load, only friction and windage—hence the descriptive "full-speed, no-load" operating condition for an uncoupled motor.
A rotor has no kinetic energy at rest, and a fixed amount of kinetic energy at full speed. Input power is a measure of the *rate* of energy delivery to the motor required to overcome losses due to internal electrical and mechanical losses and change the speed of the rotating inertia. Power input can be measured, and if the losses are known, can be integrated to obtain rotor kinetic energy; and since speed is measured, the rotor inertia can be calculated directly.
Fig 0 shows the difference in torque-vs-speed results from a 500 HP induction motor comparing a transient start across the line, and a steady-state ramp from zero to full speed [3]. The three primary differences of note are:

1. Significant dynamic torque ripple occurs at line frequency, during an across -the-line start;
2. Breakdown torque is somewhat higher for the steady-state case; and
3. Overshoot and torque oscillation about the final operating point (full speed, no-load) during the transient start.



Credit: ***Paul Krause, Oleg Wasynczuk, Scott D. Sudhoff – Analysis of Electric Machinery and Drive Systems, 2nd Edition, Wiley/IEEE Press 2002, ISBN-13: 978-0471143260, ISBN-10: 047114326X***

Fig 0. Steady-state vs. across the line torque vs. speed result, 500HP/460V/4P induction motor [3]

Temperature change affects winding resistance (thus also current, torque and watts), friction and windage. The effect of temperature on inductance is usually ignored but could be included as required. If the motor start is fast enough, the effect of change in resistance can be ignored in these tests. In any case, winding resistance can be measured before and after a test to give a good indication as to the validity of a temperature change assumption. Note that IEEE 112 procedure [1] recommends a preliminary step of running an uncoupled motor at no load for sufficient time to reach stable temperature – which may be 30 minutes or more.

Testing at different voltages is necessary to separate and document the various energy loss mechanisms described above. The procedure for their separation is well-understood, built into the post-processing software, and described in the IEEE standards mentioned below.

COMPLIANCE WITH STANDARDS

IEEE 112 [1] contains published procedures for obtaining performance characteristics of polyphase induction motors using various test methods, including an inertial acceleration test. IEEE 114 has similar procedures for single-phase induction motors. These and BLDC motors also must of course obey basic and immutable laws of physics. The methods used in the proposed procedure and data processing, including documentation of all mechanical and electrical losses in the motor, are in full compliance with methods described therein.

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References/Citations:

1. ***IEEE 112-2017, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators, Pub 2018-02-14***
2. ***IEEE 114-2010 IEEE Standard Test Procedure for Single Phase induction Motors, Pub 2010-12-23***
3. ***Paul Krause, Oleg Wasynczuk, Scott D. Sudhoff – Analysis of Electric Machinery and Drive Systems, 2nd Edition, Wiley/IEEE Press 2002, ISBN-13: 978-0471143260, ISBN-10: 047114326X***
4. ***US Patent Smiley, R.G, 62/625,642; 02/02/2018,***