TEST EQUIPMENT FOR DETERMINING PERFORMANCE OF ELECTRIC MOTORS

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ABSTRACT

Large quantities of electric power are used by electric motors in the production and processing of food, feed, and fiber. The literature indicates many individuals responsible for the selection and application of motors have a limited knowledge of motor performance characteristics - specifically, efficiency and power factor. To enhance student understanding of these concepts, two motor testing stations were assembled. A manually operated motor testing station provides students an opportunity for hands-on laboratory exercises in determining efficiency and power factor. A computer-assisted motor testing station allows students to experience a complete motor test, described by the IEEE Standard 114-1982, using a menu-driven interface to computerize the data collection process. Motor performance data is graphically represented on a monitor, printer, or plotter. Instructors and students have expressed that using those state-of-the-art stations enhances instructional effectiveness and student learning.

INTRODUCTION

Electric motors provide one of the principal means of converting electrical energy into mechanical energy, which then may be used to drive household appliances, modern machine tools, fans or blowers for central heating systems and other equipment. During the period from 1960 to 1975, electric motors, particularly those in the 0.75 to 186 kW (1 to 250 hp) range, were designed for minimum first cost with little attention given to motor efficiency or power factor (Andreas, 1982). Yet, a 1980 U.S. Department of Energy study reported that the total number of all electric motors, between 0.75 and 93 kW (1 and 125 hp), used in the U.S. was 71 million in 1977. The study also reported 60% of all electricity used in the U.S. was consumed by electric motors (EPRI, 1986). Since 1975, electric motor manufacturers have focused attention on improving electric motor performance to save electrical energy. Two important performance characteristics have included motor efficiency and power factor. Many motors are oversized, resulting in reduced efficiency and power factor. In many cases, electric motors have been selected and applied by engineers or other personnel who have a limited knowledge of electric motors, particularly a lack of understanding of power factor, efficiency, and associated energy economies (Andreas, 1982).

Motor efficiency is the ratio of mechanical energy output to electrical energy input. Thus, the only power absorbed by the electric motor is the loss incurred in making the conversion from electrical to mechanical energy. These losses consist of stator, rotor, magnetic core, and friction and windage losses (Andreas, 1982). These losses must be minimized to increase motor efficiency (EPRI, 1986).

Power factor is related to motor efficiency and can be defined as the ratio of true power (watts) to apparent power (volts x amperes) (Gustafson, 1988). The power factor of a single-phase induction motor is usually between 0.30 and 0.90 (Bear et al., 1983). Electric power suppliers prefer to have a power factor as close to 1.00 as possible to maximize system efficiency. A low power factor reduces system efficiency, since the current increases with the total apparent power and must be supplied by the electric utility. However, since consumers generally pay only for true power, most electric utilities impose a penalty or charge in their industrial and commercial rate structure for low power factors. The use of power capacitors to supply the required leading reactive power is a popular method of improving the power factor on low voltage distribution systems. When improving motor performance, it is important to recognize that if efficiency is increased, power factor will tend to decrease (Andreas, 1982; Veinott, 1970).

While there is no single method for evaluating motor efficiency levels, one of the most often used references is standard 112-1978 of the Institute of Electrical and Electronics Engineers (IEEE) (EPRI, 1986). This standard provides instructions for a complete motor test which includes obtaining data for determining efficiency and power factor.

As stated earlier, the concepts of motor efficiency and power factor are not understood by many individuals who work with motors on a routine basis. One method to overcome this dilemma is to provide individuals with hands-on laboratory exercises which would enhance their understanding of these concepts. Contained in this article is the description of a manually operated motor testing station which is used to enhance student understanding of efficiency and power factor in an educational environment. Additionally, the article contains the description of a computer-assisted motor testing station to determine efficiency and power factor. It is the author's intent to describe the operation and application of the two unique motor testing stations. The data acquisition program used with the computer-assisted equipment is described by Wagner et al. (1989).

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OBJECTIVE

The objective of this project was to develop and assemble manual and computer-assisted equipment for determining electric motor performance in teaching, extension, and research environments. The specific objectives were to

1. Assemble a manual motor testing station that illustrated the required components and procedures for determining power factor and efficiency.
2. Assemble a computer-assisted motor testing station to determine power factor and efficiency that: interfaced a microcomputer with the required components; used menu-driven software; output data as ASCII files; and graphically represented data on a monitor, printer, or plotter.

DESCRIPTION OF TESTING STATIONS

MANUAL MOTOR TESTING STATION

The manual motor testing station was assembled to increase student understanding of motor performance, with primary emphasis on efficiency and power factor. The testing station was assembled by constructing a 1.2m x 0.91m (4 ft x 3 ft) display panel, which contained a schematic of the components used to determine motor efficiency and power factor. The schematic was designed to illustrate the relationship of each component to motor performance testing. The display has 115 VAC connected in parallel to an analog voltmeter and in series to an analog ammeter so the apparent power supplied to the motor can be calculated. An analog wattmeter was connected in the circuitry to display the actual power used by the motor. The display was designed so a Clark-Hess* Model 256 digital Volt-Amp-Watt (V-A-W) meter could be connected into the circuitry to compute and display the power factor of the motor under various load conditions. Load is applied to the motor using a Go-Power, Model MD 80-friction brake dynamometer. An Ametek-Model 1736 digital tachometer displays the speed of the motor shaft. A schematic and picture of the manual motor test station is shown in Fig. 1. The station has the capability of testing single-phase motors up to 0.37 kW (0.5 hp). The total cost for assembling the manual motor test station was approximately $3,500.

COMPUTER-ASSISTED MOTOR TESTING STATION

The computer-assisted motor testing station was assembled to accomplish two objectives. One objective was to computerize the data collection process of a complete motor test (IEEE, 1982) using a menu-driven interface. A second objective was to further enhance student understanding of motor performance characteristics, including power factor and efficiency, by providing an instantaneous graphical representation of motor performance data. These objectives were accomplished using a Tecmar LabMaster data acquisition system with a Zenith 158, IBM-PC compatible computer, which is described by Wagner et al. (1989). Instrumentation consisted of a Magtrol, Model HD-700-8 electric motor dynamometer for up to 0.37 kW (0.5 hp) motors; a Clark-Hess, Model 256 digital V-A-W meter; and thermocouples. The Magtrol dynamometer is a hysteresis

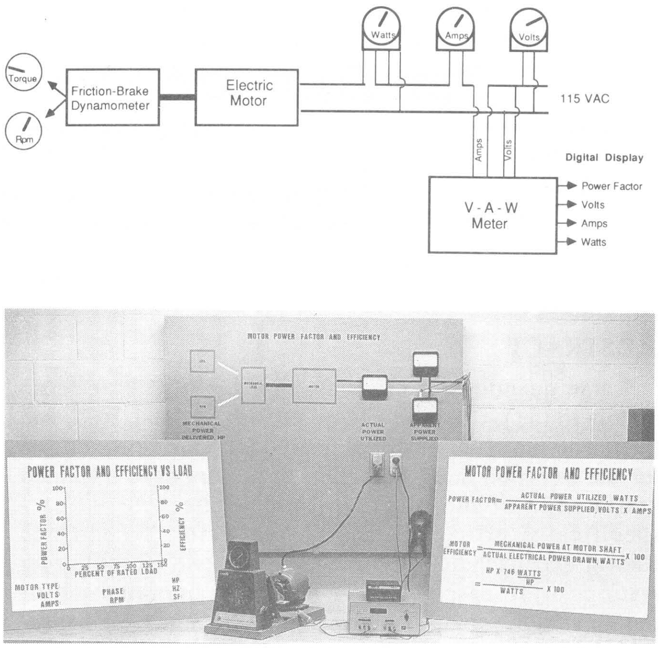

Figure 1–Schematic and picture of manual motor test station.

type and provides 1) a speed signal of 60 low-voltage pulses per revolution, and 2) an analog torque signal from a load cell. The V-A-W meter was purchased with options that enabled the computer to switch functions and read a 0-1 VDC signal proportional to the displayed value. A schematic and picture of the computer-assisted motor testing station is shown in Fig. 2. The total equipment cost was approximately $7,500.

A data acquisition program, written in the C programming language, was developed specifically for this application (Wagner et al., 1989). A commercial library package, 'Windows for Data', was used to construct the menu system, input forms, choice lists, and the on-line context-sensitive help system. The data acquisition routines controlling the Tecmar LabMaster functions were developed in the Agricultural Engineering Department at Kansas State University (Wagner, 1988).

The main menu consists of four menu options and an exit command (Fig. 3) which are described as follows.

1. **Calibration Option.** This allows the user to adjust the calibration scale factors for the input readings obtained by the data acquisition system. These inputs are the excitation voltage driving the dynamometer load cell; dynamometer torque and speed signals; V-A-W meter readings of amperes, volts, power, power factor; and thermocouple readings.
2. **Test Configuration Option.** This main menu option allows the user to select the output ASCII data file names and provide input forms for entering information about the motor and other pertinent test information. It also allows the user to specify the V-A-W switch settings not controlled by the computer.

The last option under the configuration menu is the setup menu. This submenu allows the user to define data collection parameters, such as the number of collected and averaged samples per data point stored and the time interval between each sample collected. Other default parameters may also be reconfigured for each instrument. Examples include the analog to digital channels and

*Mention of tradenames does not imply endorsement of a product or criticism of similar products by the authors or Kansas State University.

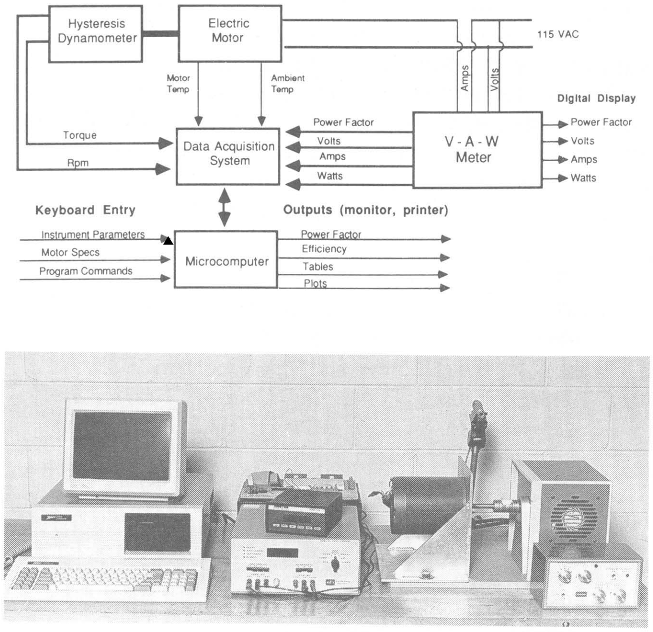

Figure 2–Schematic and picture of computer-assisted motor testing station.

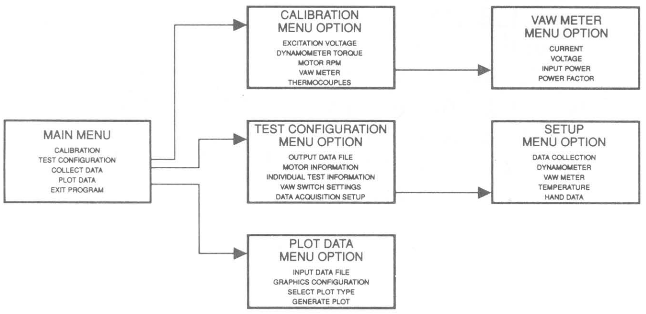

Figure 3–Basic flow diagram of dynamometer data acquisition program.

amplifier gain settings, TTL-level ports and their I/O configurations, and counter/timer configurations necessary for each instrument.

3. **Collect Data Option**. This main menu option initiates the data collection sequence. The program will continuously monitor and display the sampled data in Continuous Data Monitor windows (Fig. 4). Pressing the return key records a data collection cycle, while pressing

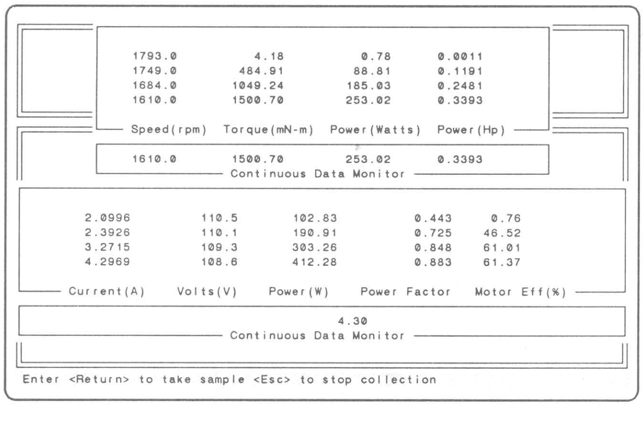

Figure 4–Typical data collection screen display.

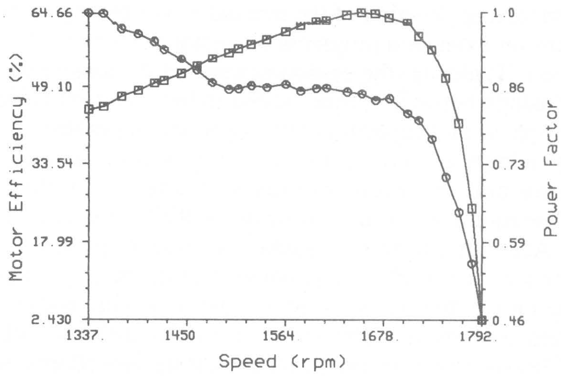

Figure 5–Sample graphical representation of collected data from a 0.20 kW (0.25 hp) permanent-split capacitor motor.

the escape key stops the data collection sequence and returns the user to the main menu. Scrolling windows display the previously recorded data samples, providing the operator with a visual record of progression into the current test sequence. The visual display of the collected data also helps the operator verify the validity of the data already collected. A typical data collection screen is shown in Fig. 4.

4. **Plot Data Option**. This main menu option allows selection of the input data file, the output graphics device, drawing resolution for that device, and the type of graph to generate. The graph then can be generated on the selected device. An example of graphical output is shown in Fig. 5.

Application and Utilization of Test Stations

The manual motor testing station is used for teaching and extension programs. It is transportable and can be used off-campus. The computer-assisted motor testing station is primarily used in the teaching and research programs.

Students utilize the manual testing station in laboratory exercises. They place a motor under various load conditions and record the motor nameplate information, shaft speed in revolutions/minute, amperes drawn by the motor, volts supplied to the motor, watts consumed by the motor, and power factor of the motor. Motor efficiency is calculated as follows:

$$\%\ \text{Efficiency} = \frac{\text{Mechanical Power Output}}{\text{Electrical Power Input}} \times 100$$

Power factor is calculated using the following equation and compared to the power factor displayed on the Clark-Hess V-A-W meter:

$$\text{Power Factor} = \frac{\text{Watts}}{\text{Amperes x Volts}}$$

To improve student understanding of power factor, calculations are then performed to determine the amount of capacitance needed to correct the power factor of a motor or series of motors. The appropriate amount of capacitance is installed, and the corrected power factor data is collected and recorded. Students' confidence in the equations, the meters, and procedures for measuring power factor and efficiency improve after completing hands-on exercises.

A second application of the manual motor testing station is its use in extension programs on motor performance and selection. Typically, the station is used to demonstrate the relationships between torque, speed, power, and efficiency of split-phase and capacitor-start, capacitor-run motors.

The computer-assisted motor testing station is used in teaching and research programs. Students conduct a complete motor test as described in the IEEE Standard 114-1982. According to this standard, a complete test involves obtaining data for efficiency, power factor, starting torque, pull up torque, breakdown torque, rated-load slip, and rated load temperature rise. This station provides students with a visual image of motor performance testing procedures and interpretation of data. A second application of the computer-assisted motor testing station is testing the performance of motors from livestock building ventilation fans.

SUMMARY

As a result of using the manual and computer-assisted motor testing stations in educational settings, instructors believe students are more knowledgeable about electric motor performance—specifically, efficiency and power factor. Students have indicated that using the testing stations aids significantly in their understanding of motor efficiency and power factor. Similarly, instructors have expressed that the motor testing stations require a minimal amount of set-up time and their instructional effectiveness is improved, since students participate in hands-on exercises. The authors believe the correct application of electric motors can be enhanced through this multi-faceted approach to increasing student understanding of motor performance.

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