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Standard Test Method for Measuring Electrical Energy Requirements of Processing Equipment[1]

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1. Scope

1.1 This test method covers the determination of the energy and power requirements of processing equipment using an electrical metering system.

1.2 This test method can be used to measure energy and power requirements of processing equipment driven by an electrical motor operating on alternating current.

1.3 This test method includes instructions for installation and checkout of the energy metering system, procedures for measuring and recording energy usage, and methods for calculating the average gross power, average freewheeling power, and average net power requirements of processing equipment.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For hazard statements, see Section 6.

2. Terminology Definitions

2.1 *electrical metering system*—a system composed of current and potential transformers and a wattmeter electrically connected in such a manner so as to measure the energy usage of a piece of equipment driven by an electric motor.

2.2 *freewheeling condition*—a piece of equipment under an unloaded condition wherein the electrical energy is dissipated due to friction and windage.

2.3 *freewheeling power*—power requirement of a piece of equipment under unloaded, or freewheeling, conditions.

2.4 *gross energy*— energy usage of a piece of equipment operating under loaded conditions as measured using an electrical metering system.

2.5 *gross power*— power requirement of a piece of equipment under loaded conditions.

2.6 *loaded condition*— equipment doing processing work on solids, liquids, or gases, or all of these, (for example, moving material, changing its characteristics, or separating it into different streams).

2.7 *net power*—the difference between gross power and freewheeling power; net power is the power required for processing.

2.8 *specific energy*— energy consumption expressed on the basis of unit mass of throughput.

2.9 *unloaded condition*—equipment not doing processing work (for example, moving, changing the characteristics of, or separating materials), but operating in a freewheeling, or idling, condition.

3. Summary of Test Method

3.1 An electrical metering system is installed and checked.

3.2 The metering instrumentation and processing equipment is allowed to warmup.

3.3 Using the electrical metering system, the energy used by the processing equipment under no-load and loaded conditions is measured and recorded.

3.4 The average gross power, average freewheeling power, and average net power required by the equipment is calculated.

4. Significance and Use

4.1 Energy usage and power requirements of processing equipment are important from the standpoint of determining if equipment is operating within specification and meeting performance criteria.

4.2 Having determined the energy usage and power requirements of the processing equipment using this method, specific energy may be calculated, with the use of system throughput, and used as one criterion to compare the performance of similar pieces of equipment operating under similar operating conditions.

4.3 Measurements of energy usage can be used for the purpose of identifying inefficient electrical motors and processing equipment.

5. Apparatus

5.1 *Calibrated Watthour Meter*.

5.2 *Volt-Ammeter*.

5.3 *Stopwatch*, accurate to 0.1 s.

5.4 *Incandescent Lamps*, for use as a known load.

5.5 *Current Transformers* (CTs).

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[1] This test method is under the jurisdiction of ASTM Committee D34 on Waste Management and is the direct responsibility of Subcommittee D34.06 on Recovery and Reuse.

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Watthour Meter	Serial No.	Type	Class	K_h	Accuracy	Date Calibrated

Current Transformer	Serial No.	Type	Ratio	Accuracy Class	Date Calibrated

Potential Transformer	Serial No.	Type	Ratio	Accuracy Class	Date Calibrated

FIG. 1 Electrical Metering System Installation Form

5.6 *Potential (Voltage) Transformers* (PTs).

6. Hazards

6.1 When installing metering equipment always de-energize the load side of the processing equipment by locking out the main switch on the electrical control panel.

6.2 Dangerous high voltage results from open current transformer secondaries. Therefore, to avoid equipment damage and electrical shock, use circuit-closing devices or equipment to short circuit the secondaries of current transformers.

6.3 Always observe the polarity markings of current and potential transformers during their installations to ensure proper connection of the metering equipment. These polarity markings are usually denoted on the transformers as white dots, blocks, or "HX" marks.

6.4 Closely observe polarities, and check connections of instrument transformers to the watthour meter.

7. Equipment Calibration

7.1 Calibrate all meters and instrument transformers used for energy measurements in accordance with standard practice of calibration.[2,3,4,5] The accuracy of the meters and transformers shall be duly noted on the Electrical Metering Service Installation Form, see Fig. 1.

8. Procedure

8.1 *Meter Installation*:

8.1.1 For the piece of equipment to be tested, determine the type of electrical service (for example, single-phase two-wire, three-phase three-wire), voltage requirements, full load power, and current rating of the motor from the motor nameplate or manufacturer's specifications. For the purpose of meter selection and installation, it can be assumed that 1 hp = 1 kW = 1 kVA. Select the metering system that is compatible with the type of electrical service and with the load on the motor.

8.1.1.1 Self-contained single phase watthour meter can be used when the load is less than 48 kVA.

8.1.1.2 Self-contained polyphase meters can be used when the load is less than 96 kVA (except 480 V delta).

8.1.1.3 Above 48 or 96 kVA, respectively, for single and polyphase loads, use transformer type watthour meters.

8.1.2 For any meter installation, do not exceed the meter's overload capability listed as follows:

8.1.2.1 *Class 10*—Nominal 2.5-A meter, 10-A overload capability.

8.1.2.2 *Class 20*—Nominal 2.5-A meter, 20-A overload capability.

8.1.2.3 *Class 60*—Nominal 15-A meter, 60-A overload capability.

8.1.2.4 *Class 100*—Nominal 15-A meter, 100-A overload capability.

8.1.2.5 *Class 200*—Nominal 30-A meter, 200-A overload capability.

8.1.2.6 *Class 320*—Nominal 50-A meter, 320-A overload capability.

8.1.3 *Instrument Transformers*—For meter installations requiring instrument transformers (that is, when the primary current or voltage, or both, exceed the operating specifications of the watthour meter), use current and potential (voltage) transformers. Select current and potential transformers with an accuracy class rating of 0.3 (0.3 %) and compatibility with the primary electrical service. If transformers with an accuracy class of 0.3 are not available, substitute another accuracy class and note on the Electrical Metering System Installation Form (Fig. 1).

8.1.4 *Current Transformers*—Calculate the current transformer ratio (CTR) using the following definition.

$$\text{CTR} = \text{Primary Current/Watthour Meter Nominal Current Rating} \tag{1}$$

Generally, current transformer ratios are denoted such that the secondary current will be 5 amperes when rated amperes are flowing in the primary circuit.

8.1.5 *Potential Transformers* — Potential transformers are used with watthour meters where the primary circuit voltage exceeds the rating of the meter, generally above 480 V and frequently above 240 V. The potential transformer ratio (PTR) can be calculated using the following definition.

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[2] *Meter and Instrument Transformer Application Guide*, 5th Edition, Westinghouse Electric Company, Raleigh, NC.

[3] *Metermen's Handbook*, Duncan Electric Company, Lafayette, IN, No. 5M, April 1976.

[4] *Electrical Metermen's Handbook*, Edison Electric Institute, New York, NY.

[5] *Guide for Installing General Electric Watthour Meters*, General Electric Company, Somersworth, NH, April 1976.

$$PTR = \text{Primary Voltage/Watthour Meter Nominal Voltage Rating} \quad (2)$$

8.1.6 Phase relations will be retained if the polarity markings are observed and the current in the potential circuit is considered to flow in on the primary terminal polarity mark and out on the corresponding secondary terminal polarity mark.

8.1.7 The Electrical Metering Service Installation Form (Fig. 1) is recommended for documenting the equipment used for the test.

8.1.8 Mount instrument transformers and watthour meters in an upright position and in a area free from heavy vibration.

8.2 *Checking Meter Installation*:

8.2.1 Check meter installations for correct connections as soon as the wiring is completed. For installation of self-contained watthour meters this is comparatively simple. It is only necessary to see that line and load wires, and potential taps where required, are connected to the proper points. A quick check on the operation under load conditions may be made to see that the meter is rotating in the proper direction and at approximately the right speed.

8.2.2 Where instrument transformers are used, the installation is more liable to incorrect connections and should, therefore, be checked carefully. It is possible to have incorrect registration even with proper connections, due to a wrong transformer polarity marking, a reversed meter coil, incorrect transformer ratio marking, etc. It is generally not possible to completely check all of these items in the field; however, by making several of the tests listed in Annex A1, it will be possible to determine most of the inconsistencies or incorrect connections that might occur.

8.3 *Measurements*:

8.3.1 After installation and check-out of the energy metering equipment, measure and record the energy used by the equipment under no-load and loaded conditions in order to determine the average gross and freewheel power requirements of the equipment.

8.3.2 Determine the average freewheeling power of the equipment to be tested by measuring the energy usage of the motor under no-load conditions over a specified time interval. After a suitable warm-up period, time ten disk revolutions to establish the freewheel energy usage at the beginning and end of the test. Prior to taking the first measurement for determining the freewheel energy usage, take two preliminary freewheel energy measurements (10 disk revolutions) approximately 5 min apart. If the preliminary readings differ by more than 10 % or more, extend the warm-up period until two consecutive preliminary measurements fall within 10 % of one another.

8.3.3 After the suitable warm-up period, take and record three initial disk timings of ten revolutions each. Likewise, after the conclusion of the load tests, take and record three final disk timings of ten revolutions each. An Energy Measurement Data Sheet for recording the freewheeling energy measurements is given in Fig. 2. The freewheeling power calculations are described in Section 9.

8.3.4 Determine the gross energy usage (E_g) of the equipment undergoing testing by calculating the difference in the register readings or by counting the number of disk revolutions of the watthour meter while operating the processing equipment under loaded conditions for a suitable measuring period. A suitable measuring period consists of a time span that is long enough to attain at least one disk revolution or at least one complete rotation of the least significant register dial, whichever applies to the particular test situation.

8.3.5 An Energy Measurement Data Sheet for recording the measured data from the tests conducted under loaded conditions is given in Fig. 2. The calculations for determining power demand under loaded conditions are described in Section 9.

8.3.6 *Alternative Procedure for Constant Load Power Measurements*—If the processing equipment exhibits a constant load as evidenced by power fluctuations of less than ±10 % of the average reading (that is, as may be the case for a conveyor or blower, etc.), a clamp-on wattmeter, an analog wattmeter, or recording wattmeter can be used to measure power if the metering equipment and electrical service can be made compatible with one another. For this procedure, power measurements for both unloaded (freewheeling) and loaded conditions should be made in sufficient numbers so that a reliable average reading can be calculated. The power requirement is read directly from the instrument. The measurements may be recorded on the Gross and Net Power Data Sheet, Fig. 3.

9. Calculation

9.1 *Average Freewheeling Power Requirements*:

9.1.1 Calculate freewheeling power (P_{fw}), in kilowatts, as follows:

$$P_{fw} = 600\,(Kh)(CTR)(PTR)/t \quad (3)$$

where:

Kh = disk constant of the watthour meter (kWh/disk revolution),
CTR = current transformer ratio,
PTR = potential transformer ratio, and
t = time duration for 10 disk revolutions (minutes).

9.1.2 Average the three initial freewheeling power measurements and the three final measurements to give the average initial freewheeling power ($\bar{P}_{fw_i}$) and final freewheeling power ($\bar{P}_{fw_f}$). Then average the average values ($\bar{P}_{fw_i}$ and $\bar{P}_{fw_f}$) and use as the average freewheeling power requirement $\bar{P}_{fw}$ of the equipment corresponding to the interval of gross energy measurement. Record the average value for the freewheeling power in the column titled "Average Freewheel Power" of the Gross and Net Power Data Sheet (see Fig. 3).

9.1.3 Calculate average initial freewheel power ($\bar{P}_{fw_i}$) as follows:

$$\bar{P}_{fw_i} = (P_{fw_a} + P_{fw_b} + P_{fw_c})/3 \quad (4)$$

where:

P_{fw_a}, P_{fw_b}, and P_{fw_c} are the three initial freewheeling power measurements.

9.1.4 Calculate average final freewheel power ($\bar{P}_{fw_f}$) as follows:

$$\bar{P}_{fw_f} = (P_{fw_x} + P_{fw_y} + P_{fw_z})/3 \quad (5)$$

CTR: ___ PTR: ___

Test No.	Watthour Meter Reading		Time Interval (Min)	Disk Revolutions (n)	Kh (kWh/rev.)	Gross Energy (kWh)
	Initial (kWh)	Final (kWh)				
Loaded Condition 1						
2						
3						
4						
5						
6						
7						
No-load Condition (Freewheel)						
Initial (P_{fwi}) 1						
2						
3						
Average Initial ($\bar{P}_{fw)i}$						
Final (P_{fwf}) 1						
2						
3						
Average Final ($\bar{P}_{fwf}$)						

Average of Average Initial and Average Final Freewheeling Power: ___

FIG. 2 Energy Measurement Data Sheet

where:

P_{fw_x}, P_{fw_y}, and P_{fw_z} are the three final freewheeling power measurements.

9.1.5 Calculate average freewheel power as follows:

$$\bar{P}_{fw} = (\bar{P}_{fw_i} + \bar{P}_{fw_f})/2 \quad (6)$$

9.2 Determine the gross energy (E_g) usage of the equipment undergoing testing by calculating the difference in the register readings (Case 1) or by counting the number of disk revolutions of the watthour meter after a suitable measuring period (Case 2).

9.2.1 For Case 1, calculate the gross energy (E_g) as follows:

$$E_g = (R_f - R_i)(PTR)(CTR) \quad (7)$$

where:

R_f = final meter reading (kWh),
R_i = initial meter reading (kWh),
PTR = potential transformer ratio, and
CTR = current transformer ratio.

9.2.2 For Case 2, calculate the gross energy (E_g) as follows:

$$E_g = 60\, n\, (Kh)(PTR)(CTR)/t \quad (8)$$

where:

n = number of disk revolutions (rev.),
Kh = disk constant of the watthour meter (kWh/r),
PTR = potential transformer ratio,
CTR = current transformer ratio, and
t = time in minutes.

9.3 *Average Gross Power Requirement*—Calculate the average gross power requirement ($\bar{P}_g$) for the equipment under load using the calculated value of gross energy and the length of the time interval over which the gross energy usage was measured:

$$\bar{P}_g = 60E_g/t \quad (9)$$

where:

$\bar{P}_g$ has units of kW,

E_g = gross energy (kWh) measured during the timing interval, and
t = time in minutes.

CTR:___
PTR:___

Test No.	Gross Energy (E_g) (kWh)	Time Interval (t) (Mins.)	Average Gross Power ($\bar{P}_g$) (kW)	Average Freewheel Power ($\bar{P}_{fw}$) (kW)	Average Net Power ($\bar{P}_n$)

FIG. 3 Gross and Net Power Data Sheet

9.4 *Average Net Power Requirement*—Calculate the average net power requirement ($\bar{P}_n$) as follows:

$$\bar{P}_n = \bar{P}_g - \bar{P}_{fw} \quad (10)$$

where:

$\bar{P}_n$, $\bar{P}_g$, and $\bar{P}_{fw}$ have units of kW.

9.5 A gross and net power data sheet for recording the data and results is included in Fig. 3.

10. Precision and Bias

10.1 *Precision*—The precision of this test method has not been established.

10.2 *Bias*—The bias of this test method has not been established. As a guideline, the accuracy of watthour meters is estimated to be 98.0 to 99.5 %. The accuracy of potential and current transformers (0.3 accuracy class) is 99.7 %. The accuracy of clamp-on wattmeters is typically 5 % of full-scale deflection.

ANNEX

(Mandatory Information)

A1. PROCEDURES FOR CHECKING METER INSTALLATIONS

A1.1 Single Phase

A1.1.1 For single phase meter installation, it is sufficient to see that the line and load conductors are connected to the proper terminals of the meters. A very rough but quick check is to turn on a load and see that the disk rotates in the correct direction. A more careful check (usually unnecessary on single-phase) is to connect a known load and time the revolution of the disk.

A1.2 Three-Phase, Three-Wire

A1.2.1 *Cross-phase Check*—Interchange top and bottom line side potentials. Meter should stop on balanced load regardless of power factor.

A1.2.2 Open common or number two potential. Meter should run at half-speed on balanced load.

A1.2.3 Read current in each lead. On three-phase, three-wire installations using two current transformers, all leads should read the same on balanced load. This will give a check on connections and comparative ratio of transformers.

A1.2.4 Determine relative speed and direction of stators when power factor is known.

A1.3 Three-Phase, Four-Wire Delta (Two Stators)

A1.3.1 Check one stator at a time. Speed of meter should be the same for each stator on balanced load regardless of power factor.

A1.3.2 On unbalanced loads, when the approximate three phase and single-phase loads are known, check each stator at a time. The top stator measures half of the three-phase load.

A1.4 Three-Phase, Four-Wire "Y" (Two Stators)

A1.4.1 *Cross Phase Check*—Interchange top and bottom line potentials. Meter should stop on balanced load regardless of power factor.

A1.4.2 Open common potential. Meter should run at half-speed on balanced load. The No. 2 current does not affect this check.

A1.4.3 Check one current at a time with normal potential on each stator. Meter should run at same speed at balanced load for each current regardless of power factor.

A1.4.4 Determine relative speed and direction of stators when approximate power factor is known.

A1.4.5 Read current in each lead. On balanced load, the three line currents should be the same and the neutral current should be zero.

A1.5 Time Load Method (Not to be used for calibration)

A1.5.1 This method of checking the accuracy of a watthour meter consists of connecting a known load to a two-wire watthour meter in the conventional manner, and timing the disk for a desired number of revolutions. (Be sure that loads other than those being considered are not connected to the meter at the time of the check.) One of the most consistent and readily available loads is a standard incandescent lamp. Lamp wattage can, if desired, be pre-checked in the shop before use in the field. However, the actual load is usually close enough to the watt rating at rated voltage for making approximate field checks of meter accuracy. The accuracy of the field check can be materially improved by measuring the service voltage in each case and adjusting the "known" wattage accordingly. For voltages within plus or minus 10 volts of lamp rating (which is usually well within the variation found in service), the watt load of the lamp will increase or decrease 1½ % for each 1 % of voltage above or below the voltage rating of the lamps.

A1.5.2 The disk should be timed for a convenient number of revolutions depending on the rating of the meter and the load used. It is usually desirable to run meters for about one minute or over to minimize errors in reading time. It is preferable when timing the disk to use a stop watch or timing device with a second hand. When a pocket or wrist watch without a stop second hand is used, hold the watch in front of the disk so that both the second hand on the watch and the meter disk can be seen at the same time and repeat the time trials until consistent results are obtained.

A1.5.3 The required number of seconds for a given num ber of revolutions of the disk in an accurately calibrated meter measuring a known watt load is given by the equation:

$$\mathrm{Kh} \times 3600 \times R/W = t \tag{A1.1}$$

where:

Kh = watthour (or disk) constant (watthours for one revolution),
3600 = 60 min × 60 s = 1 h (used in equation to convert watt-hours to watt-seconds),
R = revolutions of meter disk for time of test,
W = watt load on meter, and
t = time of test in seconds.

A1.5.4 The watthour or disk constant (Kh) will be found on the nameplate of all modern meters; for some older types it is marked on the disk. In any cases of doubt, constants of any meter may be obtained from the manufacturer if the rating, type, and serial number of the meter is given.

A1.5.5 In checking three-wire meters, load should be applied to both current coils. This may be done by dividing the load between the two live conductors and the neutral, or connecting to first one side and then the other.

A1.5.6 For checking 15 ampere (TA 15) three-wire meters, it is usually desirable to use at least 600 watts or about 20 % of rated capacity. A light load check may be made with 300 watts or 10 % load. In some cases, particularly when the normal load is small (below the light load calibration point of 10 percent) it is desirable to also make a check below the 10 % point. There are some rare cases where a meter is improperly calibrated on light load and may be out considerably more at extremely light loads. If such a case is found the meter should, of course, be tested with a rotating standard or equivalent method and recalibrated.

A1.5.7 A Time-Load chart for use in this method of checking is given in Table A1.1.

A1.5.8 The accuracy of the Time-Load method of checking should not be expected to be better than two percent.

TABLE A1.1 Time-Load Chart for Watthour Meter

Meter Rating	Manufacturer-Type	Disk Constant (Kh)	Rev. (R)	Required Time for Known Load		Load Ws = 3600 Kh (R)
				Watts (W)	Seconds (S)	
5-ampere	Duncan MF, MD; Westinghouse C,	1/3	15	300	60	18000
2-wire	OC, OB; Sangamo HF, HC	1/3	3	60	60	3600
120-volt	G.E. I-50, I-30, I-20, I-16	0.6	10	300	72	21600
	Sangamo J	0.6	2	60	72	4320
15-ampere	Duncan MF, MD; Westinghouse	1	10	600	60	36000
	C-OC-OB; Sangamo HF-HC					
2-wire	G.E. I-30	1.5	8	600	72	43200
120-volt	G.E. I-50, I-20, I-16, Sangamo J	1.8	6	600	64.8	38880
	Duncan MK, MQ Westinghouse D, D-2					
	Sangamo J-2, J-3	3.0	4	600	72	43200
15-ampere	Duncan MF, MD; Westinghouse	2	5	600	60	36000
3-wire	C-OC-OB; Sangamo HF-HC					
	G.E. I-30	3	4	600	72	43200
240-volt	G.E. I-55, I-50, I-20, I-16; Sangamo J. Duncan MK, MQ, Westinghouse D, D-2	3.6	3	600	64.8	38880
	Sangamo J-2, J-3	6.0	2	600	72	43200
30-ampere	Duncan MF, MD; Westinghouse	6–2/1	5	2000	60	120000
3-wire	C-OC-OB; Sangamo HF-HC					
240-volt	G.E. I-50, I-30, I-20, I-16; Duncan MK, MQ, Sangamo J, J-2, J-3	12	3	2000	64.8	129600
50-ampere	Duncan MK, MQ	12	3	2000	64.8	129600
3-wire	G.E. I-60	7.2	5	1800	72	129600
240-volt	Westinghouse D, D-2;	7.2	5	1800	72	129600
	Sangamo J-2, J-3	12	3	2000	64.8	129600