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Gas turbines — Acceptance tests

Turbines à gaz — Essais de réception

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 2314 was prepared by Technical Committee ISO/TC 192, *Gas turbines.*

This second edition cancels and replaces the first edition (ISO 2314 : 1973), of which it constitutes a technical revision.

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

International Organization for Standardization
Case postale 56 • CH-1211 Genève 20 • Switzerland
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Gas turbines — Acceptance tests

1 Scope and field of application

1.1 This International Standard specifies standard procedures and rules for the conduct and reporting of acceptance tests in order to determine and/or verify the power, thermal efficiency and other performance characteristics of gas turbine power plants. It defines standard conditions which should be used if no other conditions are agreed at the time of purchase.[1] This International Standard is not intended to provide a basis for the conduct of test work generally aimed at development or research.

The extent of acceptance tests that are carried out on the manufacturer's premises and at site respectively are to be agreed between the parties.

1.2 The acceptance requirements will have been satisfied if the mandatory tests given in 1.4 have been fulfilled under the procedures laid down.

Optional tests may, however, be included but should not be considered necessary unless specifically agreed upon by the parties to the test at the time of the purchase.

1.3 This International Standard applies to open cycle gas turbine power plants using normal combustion systems and also includes closed cycle and semi-closed cycle gas turbine power plants. In cases of gas turbines using free piston gas generators or special heat sources (for example chemical process, nuclear reactors, furnace for a supercharged boiler), this International Standard may be used as a basis but will need to be suitably modified.

1.4 The primary object of the acceptance (mandatory) tests is to determine

a) power under specified operating conditions (gas power, if only a gas generator is supplied);

b) thermal efficiency, heat rate or specific fuel consumption under specified operating conditions;

c) adequacy of essential protective devices as defined in 7.1.3.

1.5 Optional tests may also be included, provided that these are specifically agreed upon by both parties at the time of purchase. For example, such tests may include any of the following items or others specified by national or local requirements:

a) performance of the governing system and protective systems as given in 7.2.1 and 7.2.2;

b) handling characteristics (for example, starting characteristics, time of loading);

c) amplitude and frequency of vibration;

d) stack emission;

e) waste heat recovery evaluation;

f) noise level;

g) thermal discharges;

h) anti-icing system.

2 References

ISO 5167, *Measurement of fluid flow by means of orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full.*

ISO 6190, *Acoustics — Measurement of pressure levels of gas turbine installations for evaluating environmental noise — Survey method.*

1) Points on which an agreement between parties to the test is to be reached at the time of the purchase or prior to the test are indicated by a vertical line to the left of the relevant text.

IEC Publication 34-2, *Rotating electrical machines — Part 2: Methods for determining losses and efficiency of rotating electrical machinery from tests (excluding machines for traction vehicles).*

IEC Publication 46, *Recommendations for steam turbines — Part 2: Rules for acceptance tests.*

3 General definitions, description of terms and symbols

3.1 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1.1 gas turbine: Machine which converts thermal energy into mechanical work; it consists of one or several rotating compressors, thermal device(s) to heat the working fluid, one or several turbines, a control system and essential auxiliary equipment which allow the production of mechanical power in useful form. The gaseous working fluid passes continuously through the system, is compressed, heated and then expanded to develop useful mechanical power. Any heat exchangers (waste heat exchanger excluded) in the main working fluid circuit are considered to be part of the gas turbine.

3.1.2 gas generator: Combination of turbocompressor(s) driven by a turbine(s) with its combustion chamber, the whole providing hot gas under pressure. This combination may drive a separate power turbine, commonly having no compressor or combustion chamber.

3.2 Description of terms

3.2.1 Standard reference conditions

In cases where power, efficiency, heat rate or specific consumption refer to standard conditions, such conditions shall be:

a) for the intake air at the compressor flange (alternatively, the compressor intake flare) as detailed in 6.6.2 (see also figure 1):

- a total pressure of 101,3 kPa [1];
- a total temperature of 15 °C;
- a relative humidity of 60 %;

b) for the exhaust at turbine exhaust flange (or recuperator outlet, if recuperator cycle is used):

- a static pressure of 101,3 kPa [1].

An inlet water temperature of 15 °C shall apply if cooling of the working fluid is used. Except in the case where intercooling is involved, or where water spray coolers are used, the effect of humidity may generally be ignored.

In the case of the closed cycle, the standard conditions for the air heater shall be 15 °C and 101,3 kPa [1] for the ambient atmospheric air.

3.2.2 Power

Power may be expressed in terms of output at the turbine coupling, electrical power (see 8.1) at the generator terminals or gas power in the case of a gas turbine or gas generator producing gas or compressed air (bleed air from a circuit compressor).

3.2.3 Thermal efficiency and specific consumption of heat

Thermal efficiency or specific consumption of heat shall be based on the net specific energy, at constant pressure, of the fuel for either liquid, gaseous or solid fuel.

The specific energy used shall be based on a pressure of 101,3 kPa [1] and a temperature of 15 °C. Sensible heat above 15 °C shall be taken into account.

3.2.4 Cycle nomenclature

Figure 1 shows the basic nomenclature used in this International Standard. The station numbers refer to locations.

Ambient air conditions are read at station 1. Air conditions at the inlet of the compressor and leaving the compressor section

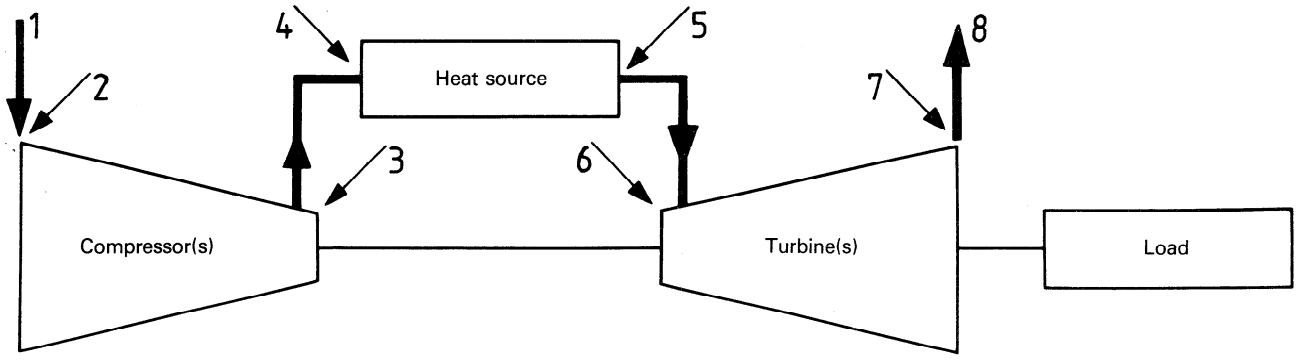

Figure 1 — Basic cycle nomenclature

1) 101,3 kPa = 1,013 bar ≈ 760 mmHg

are read at stations 2 and 3, respectively. In the event that there is more than one compressor section, the location for reading air conditions at the exit of the first compressor section is designated as station 2.1 and the inlet of the second compressor section as 2.2. Station 4 is the entrance to the heat source (after recuperation, if any). Station 5 is the exit from the heat source, and the inlet to the turbine is station 6. If there should be more than one turbine, the exit conditions from the first turbine would be read at 6.1 and the entrance conditions to the second turbine at 6.2, etc. However, if a reheater were used in the cycle, then it would be 6.1 for the exit from the first turbine stage, 6.2 into the reheater, 6.3 out of the reheater, and 6.4 at the entrance of the second turbine. Exhaust gas conditions leaving the turbine are taken at 7 and leaving the stack at 8. In the event that heat recovery equipment is employed in the cycle, the entrance conditions to this equipment would be read at 7.1 and the exit conditions at 7.2, etc.

In addition to this nomenclature, the following letters designate the type of fluid in various parts of the cycle:

f = fuel;

g = gas after the heat source;

a = air (or other working fluid);

w = water;

b = lubricating fluid.

Example: The temperature of the fuel at the entrance to the heat source would be designated as T_{f4}.

It is recognized that many different systems of station location designators are in use instead of those shown in figure 1.

3.3 Symbols

The symbols and their meanings used in this International Standard are given in table 1, together with the unit and reference clause in which they are covered.

4 Preparation for tests

4.1 The acceptance tests shall normally be carried out immediately after the completion of the setting-up period by the manufacturer and, in any event, within a period of three months, unless otherwise agreed by both parties. In any case, before the tests, the machine shall be placed at the disposal of the manufacturer for examination and cleaning.

4.2 If pipes or ducts are fitted for the purpose of by-passing any component, or if bleed-off is used for any service, any values in such ducts or pipes shall be set so as to produce conditions specified in the guarantee.

4.3 Dimensions and physical conditions of parts of the gas turbine required for calculations or other special purposes of the tests shall be determined and recorded prior to the tests. Serial numbers and data on name-plates shall be recorded to identify the gas turbine engine auxiliary equipment tested.

4.4 Preliminary tests may be run for the purpose of

a) determining whether the gas turbine and associated plant are in a condition suitable for conducting an acceptance test;

b) checking instrumentation;

c) familiarization with test procedure.

After a preliminary test is made, it may, by agreement between the purchaser and contractor, be deemed an acceptance test.

5 Test operating conditions

5.1 General

5.1.1 Every reasonable effort shall be made to run the test as close as possible to the reference operating conditions (standard conditions or other specified conditions agreed at the time of purchase). Fuel employed for test shall, wherever possible, be such as specified in the guarantee or substantially similar to it in properties. In case this is not possible, prior agreement shall be reached between the parties to the test as to the fuel to be used at an acceptance test and as to the interpretation of the results.

5.1.2 For convenience, thermal efficiency tests in dual fuel installations may be carried out with one fuel only, but only after agreement between the parties to the test.

5.1.3 Control settings for the gas turbine shall be established prior to the test. Special adjustments inappropriate for normal engine operation require written agreement.

5.1.4 The test observation records shall be entered on carefully prepared forms which constitute original logsheets to be authenticated by the observer's signature. The original sheets and recorded charts shall be such as to permit facsimile reproduction as, for example, by carbon copies or by photocopying process.

Hand copying is not permissible. For the acceptance tests, a complete set of unaltered logsheets and recorded charts will become the property of the parties to the test. The observations shall include the date and time of day. They shall be the actual readings without application of any instrument corrections. The logsheets and any recorded charts shall constitute a complete record.

5.1.5 If, during the conduct of a test or during the subsequent analysis or interpretation of the observed data, an obvious inconsistency is found which affects the validity of the results, every reasonable attempt shall be made to adjust or eliminate the inconsistency by mutual agreement. Failure to reach agreement will invalidate the run or test.

5.2 Operating conditions

5.2.1 Certain tests, for example those of 1.4a), b) and 1.5e), f), will normally be carried out at steady-state conditions.

Table 1 — Symbols

Symbol	Definition	Unit	Clause
c_{pc}	Specific heat of coolant	kJ/(kg·K)	8.5.7
h_{a0}	Specific enthalpy of air at the standard reference temperature	kJ/kg	8.5.1 8.6.1
h_{a1}	Specific enthalpy of air at temperature T_{a1} entering the control volume	kJ/kg	8.5.1
h_{a3}	Specific enthalpy of air at temperature T_{a3} leaving the compressor	kJ/kg	8.6.3
h_{a4}	Specific enthalpy of air at temperature T_{a4} entering the heat source (combustion chamber) and after any heat exchanger	kJ/kg	8.6.1
h_{ae}	Specific enthalpy of air at temperature T_e leaking from the control volume	kJ/kg	8.5.1
h_{f4}	Specific enthalpy of fuel at temperature T_{f4} entering the heat source (combustion chamber)	kJ/kg	8.2.1 8.5.1
h_{g0}	Specific enthalpy of combustion products at the standard reference temperature	kJ/kg	8.5.1
h_{g6}	Mean specific enthalpy of gases at temperature T_{g6} entering the turbine	kJ/kg	8.6.1
$h_{g6.1}$	Specific enthalpy of gas at temperature $T_{g6.1}$ leaving the turbine driving the compressor	kJ/kg	8.6.3
$h_{g6.2}$	Specific enthalpy of gas at temperature $T_{g6.2}$ entering the power turbine	kJ/kg	8.5.12
h_{g7}	Specific enthalpy of gas at temperature T_{g7} leaving the power turbine	kJ/kg	8.5.12
h_{g8}	Specific enthalpy of exhaust gases at temperature T_{g8}	kJ/kg	8.5.1
$h_{g,\,in}$	Specific enthalpy of gas at temperature $T_{g,\,in}$ and pressure $p_{g,\,in}$ entering the driven device	kJ/kg	8.5.11
$h_{g,\,out}$	Specific enthalpy of gas at temperature $T_{g,\,out}$ and pressure $p_{g,\,out}$ leaving the driven device	kJ/kg	8.5.11
h_0	Specific enthalpy of the fuel at 15 °C	kJ/kg	8.2.1 8.3.3e) 8.5.1
m	Rate of fuel consumption	kg/s	8.2.1
m_{a1}	Mass rate of air entering the control volume	kg/s	8.5.1
m_{a4}	Mass rate of air entering the combustion chamber	kg/s	8.6.1
m_c	Mass rate of coolant flowing through the lubricant cooling system	kg/s	8.5.1 8.5.7
m_e	Mass rate of sealing and/or extracted air leaving the control volume	kg/s	8.5.1 8.5.2 8.6.3
m_{f4}	Mass rate of fuel entering the control volume	kg/s	8.5.1 8.6.1
m_{g6}	Mass rate of gas at turbine inlet	kg/s	8.6.1 8.6.3
m_{g7}	Mass rate of gas leaving the turbine	kg/s	8.5.12
m_{g8}	Mass rate of exhaust gases leaving the control volume	kg/s	8.5.1
m_{in}	Mass rate of gas entering the load device	kg/s	8.5.11
m_m	Measured rate of fuel consumption	kg/s	8.3.3e)
m_τ	Mass of fuel used during period τ	kg	8.2.1
M	Torque	kN·m	8.1.1
n	Speed	r/min	8.1.1
n_0	Reference speed	r/min	8.3.3a)
n_t	Test speed	r/min	8.3.3a)
P	Net shaft power output	kW	8.2.2 8.2.3

Table 1 (*concluded*)

Symbol	Definition	Unit	Clause
P_c	Net corrected shaft power output	kW	8.3.3c)
P_{gr}	Gross shaft power output	kW	8.1.1
P_m	Measured shaft power output	kW	8.6.2
P_s	Shaft power output	kW	8.5.1 8.5.11 8.5.12
P_t	Test net shaft power output	kW	8.3.3c) 8.3.3e)
q	Heat consumption	kW	8.2.2 8.2.3
q_p	Heat rate	kW_{heat}/kW_{power}	8.2.3
q_r	Rate of heat consumption	kW	8.2.1
Q_{lo}	Net specific energy of the fuel at 15 °C and constant pressure	kJ/kg	8.2.1 8.3.3e) 8.5.1
Q_m	Mechanical losses	kW	8.5.1
Q_{mc}	Mechanical losses of the driven compressor, excluding the losses of speed changing, if used	kW	8.5.11 8.6.3
Q_{mt}	Mechanical losses of the power turbine, inclusive of speed changing gears, if used	kW	8.5.12 8.6.3
Q_r	Radiation and convection heat losses from the control volume	kW	8.5.1
Q_{rc}	Radiation heat losses from the driven compressor casing	kW	8.5.11
Q_{re}	Radiation and convection heat loss of the combustion chamber(s)	kW	8.6.1
Q_{rt}	Radiation and convection heat losses from the power turbine casing between temperature-measuring stations $T_{6.2}$ and T_7	kW	8.5.12
T_{a1}	Flow weighted average temperature of air entering the control volume	K	8.5.1
T_{a4}	Air temperature at the entrance of the heat source (combustion chamber)	K	8.6.1
T_{in}	Inlet temperature of the lubricant coolant	K	8.5.1
T_{out}	Outlet temperature of the lubricant coolant	K	8.5.1
$T_{out} - T_{in}$	Temperature rise of coolant through the oil cooler	K	8.5.7
T_{f4}	Temperature of fuel as it enters combustion chamber	K	8.6.1
T_{g6}	Reference turbine inlet temperature	K	8.6.1
T_{g8}	Flow weighted average temperature of gas leaving the control volume	K	8.5.1
T	Absolute reference temperature	K	8.3.3a)
T_t	Absolute test temperature	K	8.3.3b)
T_f	Temperature of fuel as it enters control volume	K	8.5.1
δ	The ratio of absolute ambient test pressure to the absolute ambient reference pressure	—	8.3.3c)
η_t	Thermal efficiency	—	8.2.2 8.3.3e)
η_{tc}	Combustion chamber efficiency	—	8.5.1 8.6.1
θ	The ratio of absolute ambient test temperature to the absolute ambient reference temperature	—	8.3.3a)
τ	Duration of test	s	8.2.1
ω	Angular velocity	rad/s	8.1.1

NOTE — Air or gas temperatures are assumed to be total temperature unless agreed upon by both parties.

5.2.2 Preparatory to any test, the gas turbine power plant shall be run until steady-state conditions have been established. Steady state is achieved when the key parameters associated with the objectives have been stabilized.

Stability will be achieved when continuous monitoring indicates that readings have been within the maximum permissible variation in accordance with 5.2.3 and table 2 for a period of time which is agreed upon by the parties to the test.

5.2.3 In determining the rated performance under any condition, evaluation of power and efficiency shall be carried out three times consecutively, the duration of each test being not less than 5 min and not longer than 20 min (i.e. a total period of not less than 15 min and not longer than 60 min). If the fuel flow is measured by weighing, the test period may be longer than 20 min in order to achieve adequate accuracy.

During evaluation, the load shall remain within ± 1 % while readings are taken. If this is not possible, at least five sets of readings spread over the period as stated above shall be taken for each evaluation and the results averaged. If the maximum fluctuation in load exceeds ± 2 %, the test shall be accepted only by mutual agreement.

Each observation of an operating condition during the overall period of the test shall not vary from the reported average for that operating condition by more than the amount shown in table 2, except by written agreement between the parties to the test.

NOTE — If the variations to be measured are rapid and irregular, the use of suitable instruments is to be preferred to directly observed readings. In cases which require each set of observations to be used for calculating a result, and where results are then averaged, simultaneous readings are required. If observations are made to determine rates by sums or differences, the exact time of making the observation is necessary.

6 Instruments and measurement methods

6.1 General

This clause describes the instruments, methods and precautions to be employed in testing gas turbine power plants and components in accordance with this International Standard. Where there is no specification in this clause concerning the instruments and the measurement method used, these shall be subject to agreement by the parties to the test.

Instruments and measurements shall be used in accordance with relevant International Standards, unless otherwise agreed.

Table 2 — Maximum permissible variations in operating conditions [1)]

	Variable	Variation of any observation from reported average operating condition during a test run
1	Speed of rotation of output shaft	± 1 %
2	Barometric pressure at test site	± 1 %
3	Temperature of working fluid at compressor inlet	± 2 °C
4	Specific energy of liquid fuel, per kilogram (gross and net specific energies)	± 2 %
5	Specific energy of gaseous fuel, per cubic metre (gross and net specific energies from continuous calorimeters) [2)]	± 2 %
6	Pressure of gaseous fuel, as supplied to the plant	± 1 % of absolute equivalent of average pressure
7	Temperature of fuel, as supplied to the plant [2)]	± 3 °C
8	Exhaust back pressure	± 1 % of absolute equivalent of average pressure
9	Working fluid inlet pressure	± 1 % of absolute equivalent of average pressure
10	Coolant temperature : inlet [3)]	± 3 °C
11	Coolant temperature rise [3)]	± 2 °C
12	Turbine exhaust temperature	± 2 °C

1) If acceptance tests are carried out during a ship commissioning of gas turbines used for propulsion, the parties may agree to special conditions.

2) For gaseous fuels other than natural gas, the allowable variation shall be specified by prior agreement.

3) Applicable where precoolers, intercoolers or aftercoolers are used.

6.2 Check list of equipment for mandatory tests

The following instruments and apparatus will be required:

a) Instruments to measure the power output of the gas turbine.

b) Apparatus for measuring fuel consumption of the gas turbine or the heat energy supplied to it.

c) Apparatus for determining the specific energy of the fuel, its ash content and composition.

Alternatively samples should be taken for tests in a laboratory agreed upon by both parties.

d) Instruments for determining the relative density (specific gravity) of the fuel.

Alternatively samples should be taken for tests in a laboratory agreed upon by both parties.

e) Manometers or pressure gauges for determining pressures and pressure differences at appropriate points on the gas turbine system (for pressure measurements affecting performance evaluation, liquid manometers or instruments with comparable accuracy shall be used).

f) Barometer.

g) Instruments needed for the indirect determination of the turbine inlet gas temperature (except in the case of closed cycle turbines).

h) Instrument(s) for determining the temperature at the compressor inlet.

i) Thermometers for determining the temperature of the fuel in the measuring tanks and circulating water in the coolers.

j) Speed of rotation indicators and manual or electronic revolution counters.

k) Master clock with synchronized signalling system, or, if this is not possible, synchronized watches or clocks.

l) Instruments for determining atmospheric humidity.

m) Instrumentation to determine gas turbine exhaust temperature.

6.3 Power measurement

6.3.1 Power measurement, mechanical

6.3.1.1 Torque mesurement

Either of the types of apparatus in 6.3.1.1.1 or 6.3.1.1.2 may be used to measure torques used in the derivation of the mechanical outputs of gas turbines.

6.3.1.1.1 Absorption dynamometers (mechanical, electrical or any fluid types, or a combination of any of these)

The dynamometer selected shall be chosen so that the minimum measured torque at any speed is at least 20 % of its normal maximum rated torque. Absorption dynamometers shall be so constructed that the cooling fluid enters and leaves in a plane through the axis so as to avoid tangential velocity components. Similar precautions shall also be taken regarding external windage. Hose connections, if used, shall impose no sensible tangential restraint. Dashpots, if used for damping oscillations, shall be demonstrated to impose equal resistance to motion in either direction. Effective radius arms of dynamometers shall be measured with an error not exceeding ± 0,1 %. A manufacturer's certificate may be accepted as sufficient evidence.

The force-measuring device shall be checked against certified weights in the directions of both increasing and decreasing load. The positive or negative error of the force-measuring device shall not exceed 0,1 % of the maximum load to be read in the test. The average of increasing and decreasing loadings shall be accepted as the calibration only if the difference remains within 0,3 % of the maximum test load.

Before and after acceptance tests, dynamometers shall be carefully examined and any imbalance of the arms determined. Tests shall be considered unsatisfactory should there be irregularities in the operation of the dynamometer, for example a period surging of load, such as might be due to the action of water in the dynamometer, or some resonant condition that produces pulsations of indicated torque in excess of ± 2 %.

6.3.1.1.2 Shaft torque meter

The shaft torque meter shall be calibrated before the test series. If the system is affected by temperature, it shall be recalibrated after the test at the temperature experienced during the test. Calibration shall be performed with the torsion-indicating means undisturbed from pre-test to the end of the post-test determination. In any case, observations shall be taken with a series of increasing loadings to a value above maximum test readings, followed by a series of decreasing loadings. Loadings shall always progress in one direction except at maximum value. The average of increasing and decreasing loadings shall be accepted as the calibration only if the difference is within 1 % of the maximum test load.

Dynamometer readings shall be taken with sufficient frequency that the average of all readings will not differ from the average of alternate readings (average value of even and uneven readings) by more than 0,2 %.

6.3.1.2 Speed measurement

An instrument of the speed-indicating type may be used for initial setting of the test speed and for checking constancy of speed during test periods. Each shaft of a multi-shaft engine shall be equipped with a speed-indicating device.

For checking constancy of speed during test periods, electronic pulse counter type speed indicators are recommended for visual readout as well as recording.

Either positively driven or no-contact type tachometers shall be used for all speeds. Hand-held tachometers are not recommended, because of the possibility of slip.

When mean rotative speed influences test results, an integrating type revolution counter, positively driven from the shaft, shall be used. Counting and time accuracy shall be such that error in mean speed does not exceed ± 0,25 %. Whenever electronic type pulse counters are used for power and efficiency determinations, readings shall be taken with sufficient