IS 12306 (1987): Methods of test for direct arc melting furnaces [ETD 17: Industrial Electroheating Equipment]

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Indian Standard

METHODS OF TEST FOR DIRECT ARC FURNACES

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BUREAU OF INDIAN STANDARDS

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NEW DELHI 110002

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Indian Standard

METHODS OF TEST FOR DIRECT ARC FURNACES

0. FOREWORD

0.1 This Indian Standard was adopted by the Bureau of Indian Standards on 23 December 1987, after the draft finalized by the Industrial Electroheating Equipment Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 This standard has been formulated with a view to standardize the arc furnace test conditions and methods to determine the main parameters and technical operating characteristics.

0.3 These furnaces are intended for melting of ferrous metals and non-ferrous metals. They may also be used as holding furnaces for a liquid charge to superheat and to maintain the temperature before tapping.

0.4 All the electrical terms exclude the influence of equipment for reactive power compensation and/or voltage stabilization. Should it not be feasible to switch off such apparatus during testing, the terms stated in the standard are applicable in respect of the main electrical circuit (*see* **2.16**) only with due indication of simultaneous operation of the apparatus. Figures resulting from the influence of such apparatus and valid for the supply network may be shown additionally.

0.5 This standard does not cover all the possible test methods which may be carried out for technical and economical assessment of arc furnaces.

0.6 In preparing this standard, assistance has been derived from IEC publication 676 (1980) 'Test methods for direct arc furnaces', issued by the International Electrotechnical Commission (IEC).

0.7 In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS : 2-1960*.

*Rules for rounding off numerical values (*revised*).

1. SCOPE

1.1 This standard covers the service conditions and design features of three-phase direct arc melting furnaces for steel scrap of nominal capacities between 2 tonnes and 50 tonnes.

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions in addition to those given in IS : 1885 (Part 51/Sec 1)-1979* and IS : 12188-1987† shall apply.

2.1 Arc Furnace — Furnace in which a 3-phase ac electric arc is the main source of heat.

2.2 Direct Arc Furnace — Arc furnace in which the electric arc is generated between the electrodes and the charge.

2.3 Direct Arc Melting Furnace Installation — Furnace assembly with complete set of electrical equipment including furnace substation with furnace transformer reactor (where applicable), switchgear, automatic electrode regulator, furnace control instrument panel/desk, signalling devices, busbars, interconnecting cables, pneumatic, hydraulic and cooling water circuits, etc, but excluding the following:

a) Fume extraction equipment,

b) Ventilation equipment,

c) Power factor correction and reactor power compensation equipment,

d) Harmonic filters, and

e) Other auxiliary operation equipment such as charging buckets, ladles, slag pots, cooling circulating system, compressor plant, etc.

2.4 Furnace Body — Refractory lined shell with refractory lined roof with openings for operating, slagging off, tapping and top charging.

2.5 Rated Volume of the Furnace — Total internal volume of the furnace body as defined by the inner surface of the specified shell lining. (The volume between the upper level of the shell and the underside of the roof is not included in the rated volume).

*Electrotechincal vocabulary: Part 51 Industrial electroheating, Section 1 General terms.

†Specification for electric direct arc melting furnaces.

2.6 Rated Capacity of Furnace — Calculated capacity in tonnes of liquid metal for which the furnace has been designed, built and marked. This capacity is defined with specified shell lining at 50 mm below sill level and considering the density of liquid metal as 7 kg/dm^3.

The volume between the sill level and the liquid metal which is 50 mm below sill level is allowed for the slag.

2.7 Minimum Bulk Density of Scrap for the Single Complete Maximum Charge of the Furnace (t/m) — Ratio of the furnace rated capacity to its rated volume.

2.8 Furnace High-Voltage Switch — High-voltage switch which is used for switching on and off the furnace transformer under load in accordance with the operating requirements.

2.9 Arc Furnace Transformer — The transformer feeding the arc furnace from the high voltage network and providing a voltage range suitable for the furnace operation.

2.10 Rated Power for Furnace Transformer — Maximum admissible continuous apparent power (in kVA) of furnace transformer (without time limitation) at the specified voltage tappings.

2.11 Meltdown Power of Furnace Transformer — Maximum admissible apparent power (in kVA) as per load cycle.

2.12 Reactor — Reactor used in the arc furnace installations with the object of ensuring the stability of the electric arc and limiting the short circuit current during the operation.

2.13 Arc Furnace Electrode — Current carrying column, in general, made up of graphite sections, intended to supply power to the charge material contained in the furnace body and to maintain the electric arc.

2.14 Electrode Clamp — A device for clamping the electrode in a given position and for supply of current to the electrode.

2.15 Heavy Current Line — Assembly of series connected elements of the secondary circuit comprising electrodes and secondary voltage busbar system (electrode clamps, busbar system of electrode arms, flexible cables and transformer secondary busbar connection) intended to carry the required electrical power from the transformer to the charge material contained in the furnace body.

2.16 Main Electrical Circuit of Arc Furnace Installation — The part of the arc furnace installation which include the high-voltage equipment (reactor when used) furnace transformer, heavy current line, arc and charge.

2.17 Assymmetry Factor on Primary Side (Percent) — Percentage ratio of the difference between the maximum and the minimum phase impedance including the furnace transformer and the heavy current line, to the mean impedance of all the phases:

$$K_{as} = \frac{Z_{max} - Z_{min}}{Z_{mean}} \times 100 \text{ percent} \quad (1)$$

where

Z_{max} = maximum phase impedance,

Z_{min} = minimum phase impedance, and

Z_{mean} = Arithmetic mean value of all the phase impedances.

The calculated assymmetry factor is determined for the furnace current corresponding to the rated power of the furnace transformer.

Measurement of the actual asymmetry factor should be carried out according to the data of the short-circuit test when the currents are close to rated secondary current (*see* **2.10**).

NOTE — With prior mutual agreement between the manufacturer and the user, a detailed measure of the assymmetry factor can be developed by using the components (*R*, *X*) of the impedance (*Z*). In case furnace manufacturer provides this data, it is not necessary to make these measurements.

$$K_{as-r} = \frac{R_{max} - R_{min}}{R_m} \times 100 \text{ percent} \quad (1A)$$

$$K_{as-x} = \frac{X_{max} - X_{min}}{X_m} \times 100 \text{ percent} \quad (1B)$$

where

R_{max} = maximum phase resistance,

R_{min} = minimum phase/resistance,

R_m = arithmetic mean value of all the phase resistances,

X_{max} = maximum phase reactance,

X_{min} = minimum phase reactance, and

X_m = arithmetic mean value of all the phase reactances.

2.18 Active Power of Furnace Installation (kW) — Total active power of the three phases of the main electrical circuit of the arc furnace installation.

NOTE 1 — Instantaneous value of active power of the furnace may be measured at any moment, simultaneously on the three phases.

NOTE 2 — Mean value of active power of the furnace within a definite time interval, for example, within the melt-down period, may be obtained as a result of division of consumed electrical energy measured in kWh by the duration of the time it is switched on, measured in hours.

2.19 Specific Electrical Energy Consumption for Melt-Down (kWh/t) — Quantity of electrical energy measured in kWh, consumed by the main electrical circuit of an arc furnace installation for the complete melting of one tonne of liquid metal from a specified furnace charge.

NOTE 1 — For the end of melt-down period, *see* **2.21**.

NOTE 2 — The energy consumed by the furnace installation does not include power factor correction capacitor and other auxiliary equipment including those given in **2.3**.

2.20 Specific Melt-Down Rate (t/h) — Total quantity of liquid metal measured in tonnes, divided by net melt-down time measured in hours.

2.21 Melt-Down Time — Melt-down time is a period elapsed from the moment of switching on after the first charging to the moment of complete melt-down of the charge, with subtraction of the time lost for the switch off duration arising out of one additional back charge and emergency disconnection due to charge collapse or any other operational interruption.

NOTE — The end of melt-down period to be reckoned when no unmelted piece of scrap exists within the molten bath having a temperature of 1 520°C for mild steel when measured with a dip type thermocouple near the slag door. No consideration is given for the charge scrap hanging on the banks in unmelted stage.

2.22 Power Factor of Main Electrical Circuit of Arc Furnace Installation (cos ϕ) — The approximate value of the power factor is determined from the following formula:

$$\cos \phi \approx \frac{P}{\sqrt{P^2 + Q^2}}$$

where

P = active power, and

Q = reactive power.

NOTE 1 — Because of the possible presence of harmonics, the measurement of the power factor is not necessarily correct.

NOTE 2 — The instantaneous value of the furnace installation power factor may be obtained by simultaneously measuring the active and reactive power at any moment.

NOTE 3 — The value of the furnace installation power factor over a definite period of time, for example, during the melt-down period, may be obtained from the following formula:

$$\cos \phi \approx \frac{E_P}{\sqrt{E_P^2 + E_Q^2}}$$

where

E_P = active electrical energy measured for a definite period of time, and

E_Q = reactive electrical energy measured for the same period of time.

2.23 Cooling Water Consumption (m³/h) — The total cooling water consumption is usually subdivided as follows:

a) Consumption for the furnace proper including secondary voltage busbar systems; and

b) Consumption to cool the furnace transformer.

2.24 Operational Short Circuit — Electrical contact of one, two or three live electrodes with solid or liquid charge.

2.25 Cold State of Arc Furnace Installation — State of furnace and its installation when the temperature of all its parts equals the ambient temperature.

2.26 Hot State of Furnace — Thermal state of furnace defined after 48 hours of normal and continuous operation.

3. GENERAL CONDITIONS FOR PERFORMANCE OF TESTS

3.1 The general conditions for performance of the tests shall be in accordance with IS : 9021-1978*.

3.2 The furnace shall be prepared for tests and put into operation at the purchaser's site in accordance with the service instructions and the requirements for its safe working.

3.3 The mains supplying the furnace installation during tests shall ensure a symmetry of voltages between the separate phases.

3.4 The mains supply voltage level at the transformer primary should be within ± 5 percent. Voltage levels outside these limits may be admitted in the tests by agreement between the manufacturer and the user. In any case, the test results shall be converted to the reference rated voltage value.

4. TESTS

4.1 The tests are recommended to be carried out in two categories:

a) Routine tests, and

b) Type tests.

4.1.1 *Routine Tests*

a) Measurement of electrical insulation of the heavy current line (**4.2**),

b) Measurement of cooling water consumption (**4.3**),

c) Check of the rated capacity of the furnace (**4.5**),

d) Specific electrical energy consumption during melt-down period (**4.8.2.1**),

e) Specific melt-down rate (**4.8.2.2**),

*General test conditions for industrial electro-heating equipment.

f) Approximate power factor (**4.8.2.3**), and

g) Net melt-down time (**4.8.2.4**).

4.1.2 *Type Tests/Special Tests*

a) Determination of the electrode motion regulation system characteristics (**4.4**),

b) Short circuit test during normal operation (**4.6**),

c) Determination of the assymmetry factor on primary side (**4.7**), and

d) Determination of the mains operating characteristic during the melt-down period (**4.8**).

NOTE 1 — Normally, only routine tests are recommended to be carried out on every installed or reconstructed furnace.

NOTE 2 — The type tests may not be carried out if the corresponding data are given in the technical documentation of arc furnace. Subject to prior mutual agreement, these tests can be carried out.

4.2 Measurement of Electrical Insulation of Heavy Current Line — Two tests shall be carried out on the de-energized furnace with the electrodes completely mounted and passing through port holes in the roof of an empty furnace in the following order:

a) In the cold state, on complete furnace installation without water; and

b) In the hot state, on complete furnace installation with water.

4.2.1 *Measurement of Electrical Insulation Resistance of Heavy Current Line of the Furnace in Cold State* — The test of the furnace in the cold state shall be carried out by means of a 1 000 V dc megohmmeter:

a) In the test on the furnace installation without flexible cables, the measurement of the insulation resistance value shall be carried out separately between each phase and the earthed steel structure of the furnace.

b) In the test on the furnace installation without flexible cables, the measurement of the insulation resistance shall be carried out between all the three electrically connected phases and the earthed metal body of the furnace. Before this test is carried out, any protective devices connected to earth such as electrostatic earthing device should be disconnected.

4.3 Measurement of Cooling Water Consumption — The purpose of this test is to check the cooling water consumption as foreseen by the manufacturer during the normal operation.

The test shall be carried out when the furnace is in the hot state (*see* **2.26**) during the melt-down period. The pressure, temperature and properties of the cooling water shall correspond to the requirements given in the technical documentation by the furnace manufacturer. The temperature of outlet water should be measured every 15 minutes by means of a thermometer scaled from 0 to 100°C.

The cooling water consumption is determined from the formula:

$$Q = \frac{Q_m}{t} m^3/h$$

where

Q_m = quantity of water measured (m^3), and

t = period of time during which the quantity of water flows through a separate cooling branch (h).

Prior to the test, it is desirable to determine the cooling water properties (hardness, quantity of suspended particles, etc) and compare them with the manufacturer's recommendations.

4.4 Determination of Electrode Motion Regulating System Characteristics

4.4.1 *Measurement of Speed of Electrode Motion* — The measurement shall be made with manual control of the driving power for movement of the electrode in two directions. The measurement of the speed of motion is carried out separately on each electrode and then on all the three together by means of a stop-watch, noting the distance covered by the electrode arm relative to its fixed support.

4.5 Check of the Rated Capacity of the Furnace — The furnace, lined according to the manufacturer's requirements, shall be charged with scrap the quality of which is agreed between the manufacturer and the user. The quantity of the scrap charged shall be such as to obtain a quantity of the liquid metal equal to the rated capacity. The charge shall be melted, refined and slagged off according to a procedure agreed between the manufacturer and the user. The volume of slag shall conform with the required (*see* **2.6**). The total quantity of liquid metal which is tapped when completely emptying the furnace, should not be less than the rated capacity of the furnace.

4.6 Carrying out Short-circuit Test During Normal Operation — This test can be carried out subject to prior agreement between the supplier and the purchaser. However, it will not be mandatory on the furnace manufacturer to demonstrate this.

4.6.1 *General* — To obtain the values of the resistance, reactance and assymmetry factor of the heavy current line and of the arc furnace installation, the measurements are performed on the primary side of the transformer and the results converted, to give the required values.

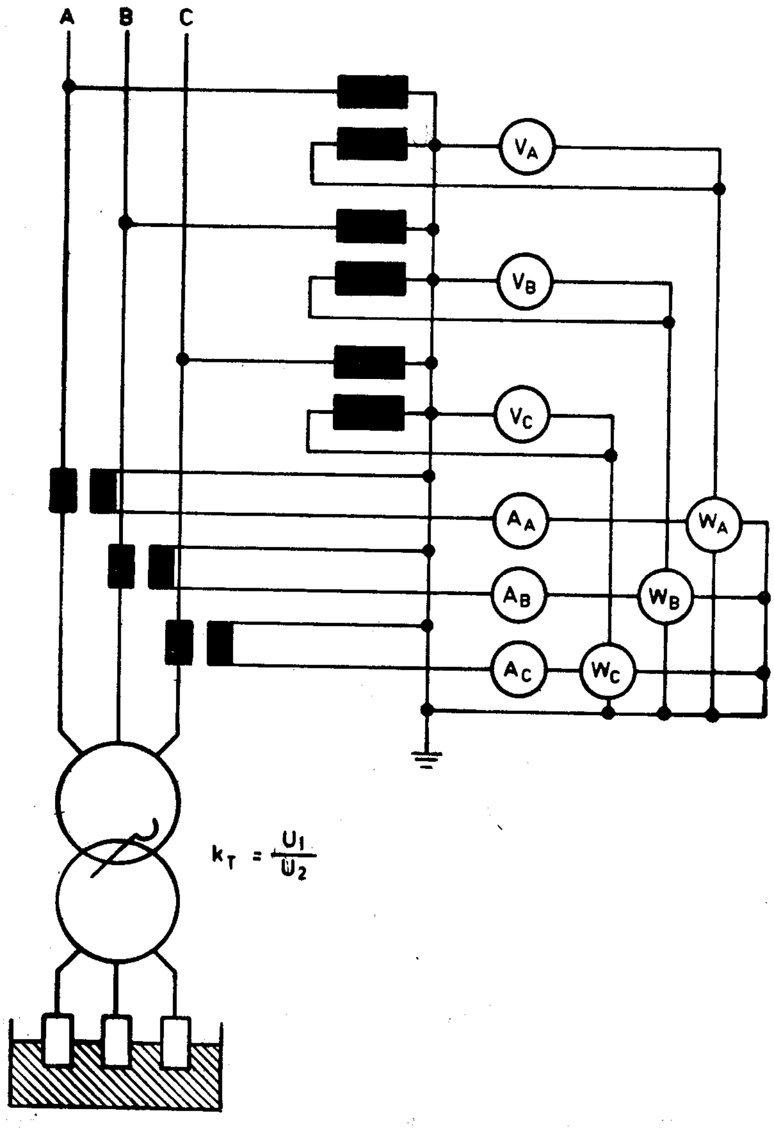
4.6.2 *Determination of Resistance and Reactance of the Heavy Current Line*

4.6.2.1 *Measuring conditions* — The measurements shall be made during a three-phase short-circuit during normal operation under sinusoidal voltage at the primary side not influenced by other furnaces. The furnace currents, voltages and power losses shall be determined after meltdown and/or after superheating. The test circuit shall be as shown in Fig. 1.

NOTE 1 — The current circuit of meters and the equipment/apparatus connected to the current transformers, in the circuits of which are also inserted meters used for the short-circuit test, can be shunted before the test when the load of the current transformers is exceeded. During the test, the clamps of all the three furnace electrodes shall be placed at the same height, preferably as low as possible. The measuring instruments used may not be lower than Class 0·5 (wattmeters must be calibrated at low power factor).

NOTE 2 — In the case of out-of-balance (value k_{as} > 10 percent), the individual values of the three phases are only applicable for determining the approximate average value of the three phases for each. Test condition for determining the individual approximate values of each phase including the case of out of balance (value k_{as} > 10 percent), are under consideration.

4.6.2.2 *Test procedure* — Before the test, the arc furnace transformer shall be switched on a suitably low tapping and the reactor inserted to ensure that the furnace current under the three-phase operational short-circuit conditions will be as close as possible to the rated secondary current of the furnace. The electrodes shall then be lowered to dip their ends into the liquid metal to a depth allowing for a complete short-circuit



A, B, C = symbols for 3 different phases

V_A, V_B, V_C = voltmeter or voltage recorder for U_{1A}, U_{1B}, U_{1C}

A_A, A_B, A_C = ammeter or current-recorder for I_{1A}, I_{1B}, I_1C

W_A, W_B, W_C = wattmeter or active power-recorder for P_{1A}, P_{1B}, P_{1C}

k_T = ratio of primary to secondary voltages for the tap on which the test was performed

FIG. 1 WIRING DIAGRAM FOR MEASUREMENT OF THE REACTANCE OF THE HEAVY CURRENT LINE

(usually to half or to two-thirds of electrode diameter) and fixed.

The measuring instruments shall be read after the swings of the needles have steadied down.

The tests shall be carried out at least twice. For every test, the resistance and the reactance of each phase of the arc furnace installation is derived from the following formulae:

Measurement on primary side: I_{1A}, I_{1B}, I_{1C}, U_{1A}, U_{1B}, U_{1C}, P_{1A}, P_{1B}, P_{1C}

Calculations of primary values:

$$R_{1A} = \frac{P_{1A}}{I_{1A}}; \quad R_{1B} = \frac{P_{1B}}{I_{1B}} \quad R_{1C} = \frac{P_{1C}}{I_{1C}}$$

$$Z_{1A} = \frac{U_{1A}}{I_{1A}}; \quad Z_{1B} = \frac{U_{1B}}{I_{1B}}; \quad Z_{1C} = \frac{U_{1C}}{I_{1C}}$$

$$X_{1A} = \sqrt{\left[\left(\frac{U_{1A}}{I_{1A}}\right)^2 - R^2_{1A}\right]^{\frac{1}{2}}};$$

$$X_{1B} = \sqrt{\left[\left(\frac{U_{1B}}{I_{1B}}\right)^2 - R^2_{1B}\right]}$$

$$X_{1C} = \sqrt{\left[\left(\frac{U_{1C}}{I_{1C}}\right)^3 - R^3_{1C}\right]^{\frac{1}{2}}}$$

Furnace transformer voltage ratio:

$$R_T = \frac{U_1}{U_2}$$

$$R_{2TA} \approx R_{2TB} \approx R_{2TC} \approx R_{2Tm} = \frac{P_{CUT}}{3 \times I^2_2 T}$$

$$X_{2TA} \approx X_{2TB} \approx X_{2TC} \; X_{2Tm}$$

$$= \sqrt{\left[\left(\frac{U^2_{2T} \times u_{k\ Tm}}{100 \times S_T}\right)^2 - R^2_{2Tm}\right]^{\frac{1}{2}}}$$

Heavy current line (secondary voltage):

$$R_A \approx \frac{R_{1A}}{k^2_T} - R_{2Tm}$$

$$R_B \approx \frac{R_{1B}}{k^2_T} - R_{2Tm}$$

$$R_C \approx \frac{R_{1C}}{k^2_T} - R_{2Tm}$$

$$X_A \approx \frac{X_{1A}}{k^2_T} - X_{2Tm}$$

$$X_B \approx \frac{X_{1B}}{k^2_T} - X_{2Tm}$$

$$X_C \approx \frac{X_{1C}}{k^2_T} - X_{2Tm}$$

$$Z_A = \sqrt{R^2_A + X^2_A} \quad Z_B = \sqrt{R^2_B + X^2_B}$$

$$Z_C = \sqrt{R^2_C + X^2_A}$$

where

I_{1A}, I_{1B}, I_{1C} = currents measured on primary side by the ammeters A_A, A_B, and A_C during the test;

U_{1A}, U_{1B}, U_{1C} = phase-voltages measured on primary side by the voltmeters V_A, V_B and V_C during the test;

P_{1A}, P_{1B}, P_{1C} = phase-powers measured on primary side by the wattmeters W_A, W_B and W_C during the test;

R_{1A}, R_{1B}, R_{1C} = phase-resistance of main electrical circuit of the arc-furnace installation on primary side during the test;

X_{1A}, X_{1B}, X_{1C} = phase-reactance of main electrical circuit of the arc-furnace installation on primary side during the test;

Z_{1A}, Z_{1B}, Z_{1C} = phase-impedance of main electrical circuit of the arc furnace installation on primary side during the test;

K_T = voltage ratio of transformer for the tap on which the test was performed;

P_{CUT} = transformer load losses for the tap on which the test was performed;

I_{2T} = rated secondary transformer current for the tap on which the test was performed;

U_{2T} = rated secondary transformer voltage for the tap on which the test was performed;

S_T = rated apparent power of transformer for the tap on which the test was performed;

U_{KT} = rated percentage impedance voltage of transformer for the tap on which the test was performed;

R_{2TA}, R_{2TB}, R_{2TC} = secondary phase-resistances of transformer for the tap on which the test was performed;

R_{2Tm} = mean secondary phase-resistance of transformer for the tap on which the test was performed;

X_{2TA}, X_{2TB}, X_{2TC} = secondary phase-reactances of transformer for the tap on which the test was performed;

X_{2Tm} = mean secondary phase-reactance of transformer for the tap on which the test was performed;

R_A, R_B, R_C = phase resistances of the heavy-current line;

X_A, X_B, X_C = phase-reactances of the heavy-current line; and

Z_A, Z_B, Z_C = phase impedances of the heavy current line.

NOTE 1 — The data concerning the arc furnace transformer may include the reactor if it is used. Special care should be taken if the reactor saturates during the test.

NOTE 2 — Account should be taken of different values of transformer reactance on each tap in calculation of characteristics for taps other than those used in the short-circuit test.

The adopted phase-resistance (reactance) of the heavy current line of the arc furnace installation is the arithmetic mean of resistances (reactances) determined during two or more tests.

4.7 Determination of Assymmetry Factor on Primary Side — The assymmetry factor shall be calculated on the basis of value of phase impedances Z_{1A}, Z_{1B} and Z_{1C} from formula (1).

NOTE — With mutual agreement between the manufacturer and the user, detailed information may be developed by using formulae (1A) and (1B).

The arithmetic mean value of the assymmetry factor from two or more measurements shall be adopted as the test results.

Formula (1) gives a practical result for furnaces with an out-of-balance where $K_{as} < 10$ percent. The test will show the assymmetry of the design.

NOTE — The conditions for determining the assymmetry factor including the case of out-of-balance, $K_{as} > 10$ percent are under consideration.

4.8 Determination of Main Operating Characteristics During the Melt-down Period

4.8.1 *General* — Measurement of the operating characteristics are as follows:

a) Specific electrical energy consumption,

b) Specific melt-down rate,

c) Power factor during melt-down period (*see* Note 3 under **2.22**), and

d) Net melt-down time.

4.8.2 *Test Conditions* — The tests shall be carried out during five successive test melts with normal melting conditions. The bulk density of scrap shall be the subject of agreement between the manufacturer and the user. For each test melt, the following values shall be determined:

4.8.2.1 Specific electrical energy consumption during the melt-down period shall be derived as the ratio of the active electrical energy consumption to the weight of liquid metal:

$$e_p = \frac{E_{pt} - E_{po}}{G} \text{ kWh/t}$$

where

E_{pt} = reading of the active energy meter at the end of the melt-down period, kWh;

E_{po} = reading of the active energy meter at the begining of the melt-down period, kWh; and

G = mass of liquid metal, t.

NOTE — The end of melt-down period shall be reckoned when no melted piece of scrap exists within the molten bath. However, no consideration shall be given to the charge handing on the banks.

4.8.2.2 Specific melt-down rate during the melt-down period shall be derived as follows:

$$P = \frac{G}{t_m} \text{ t/h}$$

where

t_m = duration of melting down period, h.

NOTE — The measurement of electric energy consumption for melting the scrap is to be stopped when no unmelted piece of scrap exist within the bath.

4.8.2.3 Power factor mean value of the melt-down period shall be derived from the following expression:

$$\cos \Psi \approx \frac{E_{Pt} - E_{Po}}{\sqrt{(E_{Pt} - E_{Po})^2 + (E_{Qt} - E_{Qo})^2}}$$

where

E_{Qt} = reading of the reactive energy meter after the melt-down period, kVarh; and

E_{Qo} = reading of the reactive energy meter at the beginning of the melt-down period, kVarh.

The measurement of active and reactive electrical energies shall be made by means of a suitable and verified three-phases meter installed on the transformer primary.

4.8.2.4 Net melt-down time (T_m) shall be measured by means of a timer according to the definition (*see* **2.21**).

4.8.3 *Test Results* — From the five values of each of the operating characteristics during the melt-down period, obtained from measurements taken from the five test melts, the following arithmetic mean values shall be calculated.

e_{p_m} , P_m, $\cos\psi_m$, T_{m_m}

4.9 Measurement of Specific Electrode Wear — The measurement of the specific electrode wear may be carried out by the furnace user to determine the specific electrode consumption. However, this will not be mandatory on the furnace manufacturer to demonstrate this, as this is a process dependent function.

The electrode wear G_{el} is determined by the mass (kg) of electrode consumed during the five test melts (total heats, tap to tap) deducting the weight of the unuseable electrode sections which may have broken during the tests.

The specific electrode wear g_{el} is determined as the quotient G_{el} of electrode wear (breakages excluded) expressed in kilograms and the total mass of liquid metal G expressed in tonnes.

$$g_{el} = \frac{G_{el}}{G} \text{ kg/t}$$

NOTE — If the specific electrode wear g_{el} is to be referred to the quantity of the charged scrap, this shall be agreed between the manufacturer and the user.

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