

Electric surface heating —

Part 2: Guide to the design of electric surface heating systems

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Foreword

This Part of this British Standard has been prepared under the direction of the Power Electrical Engineering Standards Committee.

It is intended that this standard will comprise the following Parts.

- *Part 1: Specification for electric surface heating devices;*
- *Part 2: Guide to the design of electric surface heating systems;*
- *Part 3: Code of practice for the installation, testing and maintenance of electric surface heating systems.*

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 26, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

0 Introduction

Stabilized electric surface heating systems are designed on the basis that stabilization is achieved at a specified temperature under empty pipe or zero process flow conditions. This leads to stabilization after a specific time when empty, or after a longer specific time with zero process liquid flow, in both cases at the same stabilized temperature. Where a stabilized design cannot be achieved, ESH temperature controllers are incorporated.

1 Scope

This Part of BS 6351 provides a step-by-step guide to the design of a safe ESH system. The guide takes into account energy requirements, temperature considerations and the selection of ESH devices, thermal insulation and control equipment.

The standard requires that the designs take account of the maximum temperature of the process fluid that may flow or be present.

NOTE The titles of the publications referred to in this Part of BS 6351 are listed on the inside back cover.

2 Definitions

For the purposes of this Part of BS 6351, the definitions given in BS 6351-1 apply.

3 Minimum safety requirements for ESH devices and control equipment

3.1 General. A system of service categories is described which is derived from the consideration of the risks to which an ESH device will be exposed in the environment where it is to be used.

Requirements are given for the ESH device and its associated control equipment for use in each service category.

These requirements are considered the minimum permissible; additional constraints may be imposed by special environmental conditions or local regulations and legislation.

Clause 22 of BS 5345-1:1976 gives requirements for earthing in hazardous areas.

3.2 Service category. The first digit of the service category indicates the degree of exposure of the ESH device to water and the second digit of the service category indicates the risk of mechanical damage to the ESH device, as shown in Table 1.

Table 1 — Service categories

Service categories	Probability of presence of water	Risk of mechanical damage
00	None	None
01	None	Low
02	None	High
10	Low	None
11	Low	Low
12	Low	High
20	High	None
21	High	Low
22	High	High

Where there is any doubt as to the degree of risk the higher service category should be assumed, taking into account the risk of damage during installation, operation and maintenance.

The grades of ESH devices described in clause 4 of BS 6351-1:1983 correspond with these service categories. For example, an ESH device graded 11 is the minimum requirement for use in a service category of 11.

3.3 Equipment

3.3.1 Non-hazardous areas. The minimum requirements for use in non-hazardous areas are given in Table 2.

Over-current protection should be provided for each heating zone. This may be either a fuse or a miniature circuit-breaker.

It is essential that equipment enclosures have protection appropriate to the areas in which they are installed.

If there is a possibility of damage due to overheating, the system should be designed to stabilize at a safe temperature, or an over-temperature controller should be fitted to each heating zone.

3.3.2 Type of protection “N”. Minimum requirements for ESH systems with type of protection “N” for use in hazardous areas are given in Table 3.

Over-current protection should be provided for each heating zone. This may be either a fuse or a miniature circuit-breaker.

It is essential that the residual current operated circuit-breaker has a trip current not greater than 100 mA and operates within 100 ms, but values of 30 mA and 30 ms are to be preferred unless there is evidence that this will result in a marked increase in nuisance tripping.

Table 2 — Minimum requirements for ESH systems (see 3.3.1)

Service category		Minimum grade of ESH device	Over- current protection	Residual current protection with trip indication	Means of isolating system from supply	Over-temperature limitation
Exposure to water	Exposure to mechanical damage					
0	0	00	X		X	see 3.3.1
0	1	01	X		X	see 3.3.1
0	2	02	X	X	X	see 3.3.1
1	0	10	X		X	see 3.3.1
1	1	11	X		X	see 3.3.1
1	2	12	X	X	X	see 3.3.1
2	0	20	X		X	see 3.3.1
2	1	21	X	X	X	see 3.3.1
2	2	22	X	X	X	see 3.3.1

X indicates requirement.

Table 3 — Minimum requirements for ESH systems with type of protection “N” (see 3.3.2)

Service category		Minimum grade of ESH device	Over- current protection	Residual current protection with trip indication	Means of isolating system from supply	Over-temperature limitation
Exposure to water	Exposure to mechanical damage					
0	0	11	X	X	X	X
0	1	11	X	X	X	X
0	2	12	X	X	X	X
1	0	21	X	X	X	X
1	1	21	X	X	X	X
1	2	22	X	X	X	X
2	0	21	X	X	X	X
2	1	21	X	X	X	X
2	2	22	X	X	X	X

X indicates requirement.

It is essential that equipment enclosures have protection appropriate to the areas in which they are installed.

An ESH system has to be designed so that under all conditions that may reasonably be foreseen the surface temperature of the ESH device is limited to the T-classification temperature or lower. This is achieved either by a stabilized design or by fitting two ESH temperature controllers to each heating zone. In the latter case, one has to be an over-temperature controller set to ensure that the maximum temperature of the surface to be heated is not exceeded but the other may be utilized at a lower setting for process or other requirements. The sensors of the controllers have to be located where it may reasonably be foreseen that the maximum temperature will occur and due consideration should be given to the direction of flow, the lowering of liquid level and the material in the vessel or pipe.

Where the maximum withstand temperature of the ESH device is below the T-classification of the area, it is essential that the stabilized design or over-temperature controller specified limits the ESH device to its maximum withstand temperature.

NOTE Should the criteria for a stabilized design have been met apart from exceptional specified operations or conditions, the following may be provided as an alternative to having two ESH temperature controllers.

a) A safe system of work is formally adopted such that the ESH system is de-energized whilst the specified operations are taking place,

and

b) either:

1) an inter-lock system is fitted to prevent specified operations taking place whilst the ESH system is energized;

or

2) one over-temperature controller is fitted which de-energizes the ESH system before the maximum temperature of the surface to be heated is reached.

3.3.3 Type of protection “e”. Minimum requirements for ESH systems with type of protection “e” for use in hazardous areas are given in Table 4.

Over-current protection should be provided for each heating zone. This may be either a fuse or a miniature circuit-breaker.

It is essential that the residual current operated circuit-breaker has a trip current not greater than 100 mA and operates within 100 ms but values of 30 mA and 30 ms are to be preferred unless there is evidence that this will result in a marked increase in nuisance tripping.

It is essential that equipment enclosures have protection appropriate to the areas in which they are installed.

An ESH system has to be designed so that under all conditions that may reasonably be foreseen the surface temperature of the ESH device is limited to the T-classification temperature or lower. This is achieved either by a stabilized design or by fitting two ESH temperature controllers to each heating zone. In the latter case, one has to be an over-temperature controller set to ensure that the maximum temperature of the surface to be heated is not exceeded but the other may be utilized at a lower setting for process or other requirements. The sensors of the controllers have to be located where it may reasonably be foreseen that the maximum temperature will occur and due consideration should be given to the direction of flow, the lowering of liquid level and the material in the vessel or pipe.

The over-temperature controller should either be a lockout type or be fitted with an over-temperature alarm and has to fail to safety. If an over-temperature alarm is used, provision of adequate monitoring of that alarm, such as 24 h surveillance, is necessary.

Where the maximum withstand temperature of the ESH device is below the T-classification of the area, it is essential that the stabilized design or over-temperature controller specified limits the ESH device to its maximum withstand temperature.

NOTE Should the criteria for a stabilized design have been met apart from exceptional specified operations or conditions the following may be provided as an alternative to having two ESH temperature controllers.

a) A safe system of work is formally adopted such that the ESH system is de-energized whilst the specified operations are taking place,

and

b) either

1) an inter-lock system is fitted to prevent specified operations taking place whilst the ESH system is energized;

or

2) one over-temperature controller is fitted which de-energizes the ESH system before the maximum temperature of the surface to be heated is reached.

3.3.4 Other types of protection. For ESH systems having other types of protection (see clause 11 of BS 6351-1:1983), the control equipment may be subject to special consideration.

Table 4 — Minimum requirements for ESH systems with type of protection “e” (see 3.3.3)

Service category		Minimum grade of ESH device	Over- current protection	Residual current protection with trip indication	Means of isolating system from supply	Over-temperature limitation
Exposure to water	Exposure to mechanical damage					
0	0	22	X	X	X	X
0	1	22	X	X	X	X
0	2	22	X	X	X	X
1	0	22	X	X	X	X
1	1	22	X	X	X	X
1	2	22	X	X	X	X
2	0	22	X	X	X	X
2	1	22	X	X	X	X
2	2	22	X	X	X	X

X indicates requirement.

4 Thermal insulation

4.1 General. The thermal insulation system, comprising the thermal insulation itself, its weatherproofing and any outer mechanical cladding or finishing, is an integral part of any electric surface heating system.

Details of the thermal insulation system will often be specified to the ESH system designer; on other occasions he will be required to choose the system himself.

Systems should be designed to comply with BS 5970 and BS 5422 unless otherwise specified. Specified thermal insulation for temperatures above 230 °C should be non-combustible as defined by the test in BS 476-4, whilst for temperatures below 230 °C, grade P of BS 476-5 will apply unless there are special circumstances.

4.2 Choice of a thermal insulation system. A number of often conflicting factors should be taken into account when deciding upon a thermal insulation system, including:

- a) hot surface temperature;
- b) thermal conductivity and its variation with temperature;
- c) chemical compatibility with pipe, ESH device and process materials, including the possibility of exothermic reaction with any material which may leak from the pipe;
- d) economics;
- e) service category (see 3.2);
- f) mechanical properties including strength and water absorption;
- g) emissivity of thermal insulation and cladding.

Non-combustible materials should be used wherever possible (see BS 476-4).

It is essential to use data from the thermal insulation manufacturer, particularly in critical cases such as stabilized designs or in hazardous areas, where the use of accurate data is essential for safety.

4.3 Cladding and finishing. Many protective finishes in common use are flammable, such as bituminous compounds and polymers, and even fire retardant compounds may only afford temporary protection. Suitably resistant finishes such as sheet metal or other non-absorbent coatings should be specified, particularly where danger of contamination by oil or other flammable chemicals exists.

It may be noted that galvanized steel is preferred on grounds of resistance to fire hazard but site conditions, particularly outdoors, may militate against its selection.

In conditions where the operating temperature of a plant is below that of the outer surface of the insulation system, water vapour will migrate towards the cooler surface and will condense inside the thermal insulation at the dew point line and possibly become ice at the 0 °C line. To prevent degradation of the system an effective vapour barrier should be applied over the thermal insulation.

5 Wiring systems

5.1 General. The wiring system is that part of the installation between the feeder cable and the ESH device. It includes the distribution board and the wiring between the system components such as temperature controllers and low voltage transformers.

5.2 Design. The regulations, codes and standards applicable to conventional electrical distribution systems and wiring systems apply equally to the design and installation of those for electric surface heating. The whole of any installation is required to be in conformity with the current edition of the Institution of Electrical Engineers' Regulations for the Electrical Equipment of Buildings.

Clause 25 of BS 5345-1:1976 gives an outline of the requirements for wiring systems in hazardous areas.

Electric surface heating systems may, however, exhibit characteristics which influence the design of wiring systems, such as the following.

- a) Protective devices require to be rated to allow for any inrush current to the ESH device when cold. The wiring system may be required to be rated for this condition rather than for the normal circuit current.
- b) Special wiring methods may be required to allow for vibrations and movements due to expansion or contraction of the heated equipment.
- c) Electric surface heating is frequently installed in areas having unusual environmental conditions or requirements.
- d) ESH systems frequently have discrete heating zones which require an electrical supply remote from the main distribution source and early consideration should be given to feeder cable sizing.
- e) Approval of ESH systems for use in hazardous areas may require the protective devices in the wiring system to have specified characteristics.

6 System design guide

6.1 General. The general principles adopted in this guide are based on current heat transfer theory combined with the experience of major manufacturers, installers and users and the guidance of approval authorities and other interested bodies.

6.2 Heating duties. Required heating duties may be divided into:

a) *Temperature maintenance.* Temperature maintenance requires the provision of power to a surface equal to the rate of heat loss due to the temperature difference between the surface and the surroundings. It is difficult to design a system which provides exactly this balance under all conditions. Therefore it is necessary to design for the worst condition and to provide some form of heat regulation. This may be achieved by stabilization techniques described in this clause or by using ESH temperature controllers. In the latter case it is usual to design the heating system such that the temperature controller is on for no more than 90 % of the time under the most onerous conditions expected. This means that at least 10 % more power is available should conditions on site prove to be worse than anticipated due to variations in thermal insulation materials, etc. However, this extra power has to be taken into account if the system is to be used in a hazardous area or operated close to the material specification limits. Details of the design calculations for heat loss are given in this clause.

b) *Process heating.* The purpose of process heating is to provide an energy input to raise the temperature of a material or system, change the state of a material or to promote or control a chemical reaction. The design of an ESH system will involve the calculation of the powers required for some or all of these, together with compensation for heat losses as in 6.2 a).

Temperature limitation may be achieved by use of ESH temperature controllers or by the stabilization techniques described in this clause.

6.3 Information required. The information required by the ESH system designer will generally be specified in the enquiry documents from which the designer is working but discussions may be required with the plant designer and the user/occupier. Where assumptions have to be made it is essential that they are clearly stated and err on the side of safety.

The information required is as follows:

- a) the duty required, whether temperature maintenance or process heating, with required temperatures and rates of heating;
- b) full dimensional data of all items of plant including vessels, pipes and pipe fittings, pumps, strainers, supporting structures, etc.;
- c) full details of the materials from which the items in b) above are constructed;
- d) the layout and relative positions of all items in b) above;
- e) full details of the process materials, including spoiling and other critical temperatures such as ignition temperatures;
- f) the mass of process material to be heated, together with flow rates and the highest and lowest possible material levels within vessels, pipes, etc.;
- g) the highest and lowest possible input temperatures of process materials;
- h) full details of the thermal insulation system, where this is specified by other than the ESH system designer, including material types and thicknesses and thermal conductivities;
- i) the range of environmental conditions including meteorological data, corrosive or other hostile agencies, etc.; (reference may be made to Appendix E for meteorological data in the absence of other guidance.)
- j) service category (see 3.2);
- k) power supply details including voltage, frequency and power available, with tolerances;
- l) any special considerations, for example maintenance or access requirements or the need for steam cleaning;
- m) where applicable, hazardous area classification, the gas hazard present with ignition temperatures and the temperature classification of the equipment required.

6.4 Heating zones. The electric surface heating system should be so designed as to provide the minimum number of heating zones consistent with the operational requirements of the plant. The method by which the system is divided into heating zones should be decided by reference to the plant layout and process conditions. Heating zones should be determined so that:

- a) all ESH devices within a heating zone may be temperature controlled by a single means and may be isolated as a group;
- b) attention is given to the location and loading of available power sources;

- c) due regard is given to the practical requirements of installation and maintenance;
- d) identification of each separate heating zone is possible;
- e) heating is not generally applied above the maximum fluid level; (If the properties of the material, e.g. thermal conductivity, viscosity, etc., permit, it is desirable to heat only the area of a vessel or pipe which is wetted at the lowest operational fluid level. If it is necessary to heat a greater area to cater for conditions when the fluid level is above the minimum, it may be important to provide means of switching off sections of the heating systems as the fluid level falls.)
- f) if only a small portion of a vessel is heated, it is important to ensure that critical temperatures for the fluid and vessel material are not exceeded.

The layout should be so designed as to ensure that cable runs between circuit junction boxes and ESH temperature controllers and/or supply points are kept as short as possible and that the locations of temperature sensors are such that they are not unduly influenced by adjacent heating zones.

6.5 Design loading. To calculate the design loading it is necessary first to establish the minimum power required for each aspect of the heating duty and then make adjustments for other design considerations.

The minimum total power required is the sum of any powers required for the following.

- a) *Temperature maintenance.* The power required for temperature maintenance is calculated in accordance with Appendix A.
- b) *Raising the temperature of the workpiece in the required time.* The power required to raise the temperature of a pipeline, vessel or fitting is the product of the mass to be heated, its specific heat and the temperature rise, divided by the required time to raise the temperature.
- c) *Raising the temperature of the contents in the required time.* The power required to raise the temperature of the contents is calculated in the same manner as in b), using the mass and specific heat of the contents.
- d) *Changing state in the required time.* The power required to change state is the product of the mass and its latent heat, divided by the required time to change state.
- e) *Any endothermic reaction.* The power required for an endothermic process should be determined from the client's specification.

NOTE Often the power requirement calculated for b) to e) will be adequate for temperature maintenance.

The total power required, calculated as in a) to e), has to be adjusted to take into account power reductions resulting from declared tolerances on voltage and heating conductor resistance.

The adjusted power is calculated from the following equation:

$$P_A = \frac{P_o (R_{\max}/R)}{(V_{\min}/V)^2}$$

where:

- P_o is the minimum total power as calculated above;
- P_A is the minimum total power adjusted for minimum voltage and maximum resistance;
- $R_{\max}$ is the upper limit of resistance;
- R is the nominal resistance;
- $V_{\min}$ is the lower limit of voltage;
- V is the nominal voltage.

It is recommended that this value is further increased to allow for at least 10 % reserve power (see 6.2.1). The final value is defined as the design loading.

For each heating zone the design loading is the sum of the design loadings for all pipework and fittings within that heating zone. This value should now be compared with the available power at the proposed supply point and recorded for subsequent documentation.

NOTE For self-limiting ESH devices the manufacturer's published data should be used to determine the minimum rate of heat output at the operating temperature.

6.6 Selection of ESH device. For a particular application there are some basic design requirements which may limit the choice of the ESH device. These are as follows:

- a) the grade of the ESH device has to be equal to or better than the minimum specified for the service category in the appropriate Table 2, Table 3 or Table 4;
- b) the maximum withstand temperature of the ESH device has to be greater than the maximum possible workpiece temperature (which may be greater than the normal operating temperature);
- c) the ESH device has to be suitable for operation in the environmental conditions specified, for example a corrosive atmosphere or a low ambient temperature;
- d) the ESH device has to be suitable for use in the hazardous area, if applicable.

NOTE Any change to certified apparatus may invalidate the certificate.