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Space engineering - Thermal design handbook - Part 11: Electrical Heating

Raumfahrttechnik - Handbuch für thermisches Design - Teil 11: Elektrisches Heizen

Ingénierie spatiale - Manuel de conception thermique - Partie 11: Chauffage électrique

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Space engineering - Thermal design handbook - Part 11: Electrical Heating

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Raumfahrttechnik - Handbuch für thermisches Design - Teil 11: Elektrisches Heizen

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European Foreword

This document (CEN/CLC/TR 17603-31-11:2021) has been prepared by Technical Committee CEN/CLC/JTC 5 “Space”, the secretariat of which is held by DIN.

It is highlighted that this technical report does not contain any requirement but only collection of data or descriptions and guidelines about how to organize and perform the work in support of EN 16603-31.

This Technical report (TR 17603-31-11:2021) originates from ECSS-E-HB-31-01 Part 11A .

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

This document has been developed to cover specifically space systems and has therefore precedence over any TR covering the same scope but with a wider domain of applicability (e.g.: aerospace).

1

Scope

In this Part 11, the use of electrical heaters and electrical coolers in spacecraft systems are described.

Electrical thermal control is an efficient and reliable method for attaining and maintaining temperatures. Solid state systems provide for flexibility in control of thermal regulation, they are resistant to shock and vibration and can operate in extreme physical conditions such as high and zero gravity levels. They are also easy to integrate into spacecraft subsystems.

The Thermal design handbook is published in 16 Parts

TR 17603-31-01	Thermal design handbook – Part 1: View factors
TR 17603-31-02	Thermal design handbook – Part 2: Holes, Grooves and Cavities
TR 17603-31-03	Thermal design handbook – Part 3: Spacecraft Surface Temperature
TR 17603-31-04	Thermal design handbook – Part 4: Conductive Heat Transfer
TR 17603-31-05	Thermal design handbook – Part 5: Structural Materials: Metallic and Composite
TR 17603-31-06	Thermal design handbook – Part 6: Thermal Control Surfaces
TR 17603-31-07	Thermal design handbook – Part 7: Insulations
TR 17603-31-08	Thermal design handbook – Part 8: Heat Pipes
TR 17603-31-09	Thermal design handbook – Part 9: Radiators
TR 17603-31-10	Thermal design handbook – Part 10: Phase – Change Capacitors
TR 17603-31-11	Thermal design handbook – Part 11: Electrical Heating
TR 17603-31-12	Thermal design handbook – Part 12: Louvers
TR 17603-31-13	Thermal design handbook – Part 13: Fluid Loops
TR 17603-31-14	Thermal design handbook – Part 14: Cryogenic Cooling
TR 17603-31-15	Thermal design handbook – Part 15: Existing Satellites
TR 17603-31-16	Thermal design handbook – Part 16: Thermal Protection System

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References

EN Reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS System - Glossary of terms
EN 16603-31-15	ECSS-E-HB-31-01 Part 15	Thermal design handbook – Part 15: Existing Satellites

All other references made to publications in this Part are listed, alphabetically, in the **Bibliography**.

3

Terms, definitions and symbols

3.1 Terms and definitions

For the purpose of this Standard, the terms and definitions given in ECSS-S-ST-00-01 apply.

3.2 Symbols

A	cross sectional area, [m^2]
I	electric current, [A]
L	length of conductive path, [m]
Q	heat transfer rate, [W]
Q_F	fourier effect heat flow, [W]
Q_J	joule heat flow, [W]
Q_P	peltier effect heat flow, [W]
Q_{cd}	conduction loss, [W]
Q_o	operating heat, [W]
Q_p	process heat transfer rate, [W]
Q_r	radiation loss, [W]
Q_{sl}	steady state loss, [W]
Q_w	warm-up power, [W]
R	electrical resistance, [Ω]
T_a	ambient temperature, [K]
T_f	final temperature, [K]
T_i	initial temperature, [K]

T_s	heat sink temperature, [K]
V	voltage, [V]
W	power, [W]
a	neat seebeck coefficient for two dissimilar materials, [W.K^{-1}.A^{-1}]
c_p	specific heat, [J.kg^{-1}.K^{-1}]
h	latent heat of fusion or vaporization, [J.kg^{-1}]
k	thermal conductivity, [W.m^{-1}.K^{-1}]
m	mass of material in each process load, [kg]
q_T	thomson effect heat flow per unit of conductor length, [W.m^{-1}]
t	cycle time for each load, [s]
tw	desired warm-up time, [s]
ΔT	difference of temperature between two junctions formed by dissimilar materials, [K]
ΔV_S	seebeck effect open circuit potential difference, [V]
ε	emissivity of heat sink material
σ	Stefan-Boltzmann constant = 5,6697 x 10^{-8} W.m^{-2}.K^{-4}
τ	Thomson coefficient, [W.K^{-1}.A^{-1}]

Subscripts

c	cool
h	hot
max	maximum

4
Electrical heating

4.1 General

Reliable long-term performance of most spacecraft components takes place at a specified temperature range. The attainment of some temperature range requires, in many instances, the generation of heat within the spacecraft. This involves simply turning up an electrical, chemical or nuclear heater.

When a local uniform heat source or a profiled heating area is needed, electrical heaters can provide it efficiently due to their versatility. Some applications are reported later in this clause.

Electrical heaters are based on Ohm's and Joule's laws.

Ohm's law states that the steady electric current, I, flowing through an electrical conductor is proportional to the constant voltage, V, and to the reciprocal of the electrical resistance of the conductor, R:

$I = V/R$

According to Joule's law, the heat released per unit time, Q, by an electrical current, I, is equal to the square of the electrical current, multiplied by the electrical resistance, R:

$Q = I^2R$

Three parts can be distinguished in an electrical heater:

4.1.1 Conductive element

Made up by a metal alloy with specific properties depending on the use:

- High-strength alloys to carry mechanical stress.
- Non-magnetic materials.
- High temperature-coefficient alloys for self-regulated heaters.

4.1.2 Electrical terminations

Depending on the objectives and operating conditions of the heater, the most widely used options are:

Welded leadwire

Crimped leadwire

High-temperature wire

UL-approved wire

Solder pads

Pins and connectors

Plated through-holes

Integral flex-circuits

Flat foil leads

4.1.3 Electrical insulation

4.1.3.1 Kapton/FEP insulation

For temperature requirements less than 473 K, heaters constructed of Kapton film and FEP Teflon have been qualified (NASA S-311-79) and flight tested for space. The Kapton film used generally is 0,05 x 10^{-3} m thick, with a thermal conductivity of 163 W.m^{-1}. It is used either onboard spacecraft or for simulation purposes in ground experiments. It has good flexibility and light weight; it is chemical and radiation resistant (to 10^6 rads) and present low outgassing. See Taylor (1984) [11].

Two types of Kapton laminated heater elements are manufactured:

- Coiled wire is used for resistances up to 620 x $10^4\Omega/m^2$. It withstands severe flexing with repeated installations and removals, because flexing does not bend the wire as it does to a printed circuit.
- Printed circuit Kapton/FEP heater is an etched nickel alloy foil with a clear amber pollyimide insulation. It can be quite complex, with cutouts, void areas, and unusual shapes. Varied watt densities within the same element can be obtained by controlling the pattern.

It is the right choice for flat surfaces because heat is more efficiently transferred and, also, the foil heater can be reproduced with great precision by photographic techniques. This kind of heaters has been widely used in space applications.

Higher watt densities and greater reliability can be obtained with an aluminium foil backing: it spreads heat and eliminates hot spots due to voids in mounting adhesives.

4.1.3.2 Other insulations

Electrical heaters working in hard conditions, like temperatures over 473 K, are sheathed in metal. Alumina insulation is used to encase a spiral-wound or a straight wire resistance element within the sheath. Moisture is removed and the enclosure is helium leak tested. Electrical connections are made through a glass-to-metal seal header.

There are other kinds of foil heaters, with different insulations, but their usefulness in space applications is limited. Nevertheless, they are mentioned here:

- Nomex heaters are used as a low cost alternative to Kapton. It is radiation resistant to 106 rads, but it is not suitable for vacuum.
- Silicone rubber is a fiberglass reinforced elastomer, it may be vulcanized to heat sinks and it is resistant to many chemicals but it is not suitable for vacuum or radiation. It is used for commercial and industrial applications because of its low cost and high temperature rating compared to Kapton.
- Mica heaters are rigid, so they should be factory formed and are clamped to heat sinks with rigid backing plates, or else their layers will separate during warm-up. They can be

used in vacuum after burn in. They can withstand temperatures up to 866 K, and high watt densities, up to 1705 x 10^3 W.m^{-1}.

- Kapton/WA is a clear amber polyimide film with acrylic adhesive. It is chemical and radiation resistant, with low outgassing, low cost and high resistance densities. The only problem is its narrow temperature range that limits applications over 423 K.
- Polyimide glass (Fiberglass reinforced polyimide) heaters have reduced flexibility but they have a temperature range up to 513 K and a potential for high watt densities.
- Optical grade polyester heaters have an 82 % light transmission and could be mounted in windows, lenses or between LCD and backlight, in cockpit displays and handheld terminals, in order to prevent condensation and permit cold weather operation.
- Polyester is a low cost solution for economic fabrication of large heaters.
- Scrim is an open weave fiberglass cloth for lamination inside composite structures.

Temperature range for some insulations, compared to Kapton/FEP, are represented in Figure 4-1.

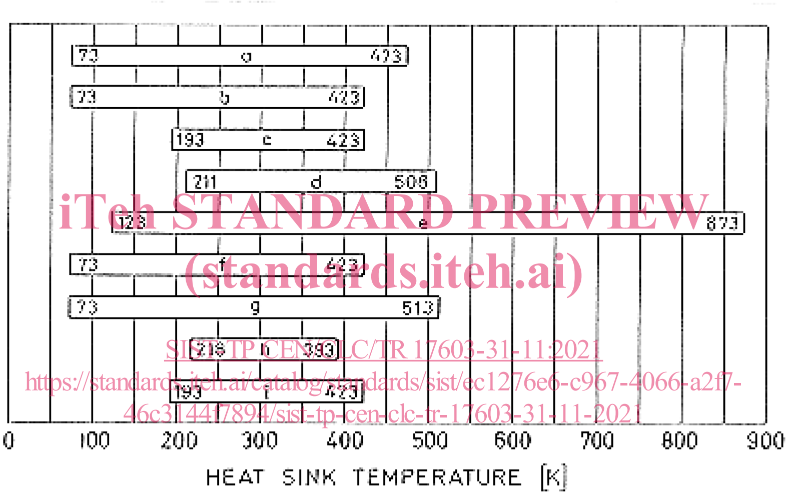

Figure 4-1: Temperature range of thermofoil heaters depending on insulation. From MINCO (1989a) [6]. a) Kapton/FEP, b) Kapton/FEP Al backing, c) Nomex, d) Silicone Rubber, e) Mica, f) Kapton/WA, g) Polyimide Glass, h) Polyester, i) Scrim.

4.1.4 Outgassing

Outgassing in a vacuum environment, in terms of weight loss versus time is an important property in space applications, see Figure 4-2. Essentially the outgassing products are water, carbon monoxide and carbon dioxide. Loss weight in Kapton/FEP is very low, about 1 %, and it occurs during the first few hours of test.