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TEST SYSTEM TO VERIFY THERMAL SHOCK RESISTANCE

SYSTEM TESTOWY DO BADANIA ODPORNOŚCI NA SZOKI TERMICZNE

Abstract

The article presents the method and the prototype system to verify the resistance of technological objects to environmental impacts in the form of increased or decreased temperatures or sudden temperature changes (i.e. thermal shocks), developed in accordance with the following PN-EN 60068 standard requirements as regards environmental testing: PN-EN 60068-2-1:2009 – Test A: Cold [7]; PN-EN 60068-2-2:2009 – Test B: Dry heat [8]; and PN-EN 60068-2-14:2009 – Test N: Change of temperature [9]. The developed solution is also aligned with the testing procedure requirements applicable to military equipment tests [12]. The system is mainly designed for testing prototype technological devices subject to significant changes in the temperature of the environment in which they operate, including thermal shocks; it also enables periodic quality checks of manufactured goods [1, 2]. With the developed system the following may be tested: the operation of individual mechanisms; the shape stability and resistance [10]; the resistance to damage; as well as the operability of electronic systems [3]. The flexible method of programming tests used in the system enables the performance of both normative and non-standard tests, depending on the requirements of the research to be carried out. The article describes the system design process, its architecture, structure, and operation, as well as the prototype verification test results. The validated prototype test system was incorporated into the structure of the laboratory for the identification and verification of technical safety of industrial and special-purpose applications under environmental conditions established at the Łukasiewicz Research Network – Institute for Sustainable Technologies (Łukasiewicz–ITEE).

Keywords: Thermal shocks, tests, environmental impacts, changeable operating temperature

Streszczenie

W artykule przedstawiono metodę i prototypowy system do badania odporności obiektów technicznych na narażenia środowiskowe w postaci znacznie obniżonej lub podwyższonej temperatury otoczenia oraz szybkich zmian temperatury - szoków termicznych. System opracowano na podstawie wymagań następujących norm dotyczących badań środowiskowych: PN-EN 60068-2-1 - "próba A - zimno" [7], PN-EN 60068-2-2 - "próba B - suche gorąco" [8] i PN-EN 60068-2-14 "próba N - zmiany temperatury" [9]. Opracowane rozwiązanie przystosowano również do wymagań procedur testowych stosowanych w badaniach sprzętu wojskowego [12]. System jest przeznaczony przede wszystkim do testowania prototypowych rozwiązań technicznych, które podczas eksploatacji są narażone na znaczne różnice temperatury środowiska pracy, w tym na szybkie zmiany temperatury (szoki termiczne) oraz do okresowej kontroli jakości produkowanych wyrobów [1, 2]. Testowaniu podlegają między innymi: działanie mechanizmów, stabilność kształtu i wytrzymałość [10], odporność na uszkodzenia i sprawność układów elektronicznych [3]. Zastosowany w systemie elastyczny sposób programowania przebiegów testu umożliwia nie tylko realizację badań normatywnych, ale również niestandardowych procedur wynikających ze szczególnych wymagań realizowanych prac badawczych. W pracy opisano proces projektowania systemu, jego strukturę, budowę, zasadę działania oraz wyniki badań weryfikacyjnych prototypu. Zweryfikowany, prototypowy system testowy został włączony w strukturę utworzonego w Łukasiewicz ITEE laboratorium identyfikacji i weryfikacji bezpieczeństwa technicznego aplikacji gospodarczych i specjalnych w warunkach środowiskowych.

Słowa kluczowe: Szoki termiczne, badania testowe, narażenia środowiskowe, zmienna temperatura pracy

1. Introduction

Ensuring safety, durability and reliability of new technological devices requires comprehensive tests to be carried out on a representative product sample in an environment simulating real-life operating conditions in which the device will be subject to various environmental impacts including, most importantly, temperature, air dustiness and humidity, mechanical vibrations, and precipitation. The innovative system to

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monitor the safety of technological objects operating in an environment characterised by significant, and often sudden, temperature changes, developed at the Łukasiewicz–ITEE and described in this article, is an example of a solution proposed in response to a "challenge us" request made in the technical safety area.

As per the PN-EN 60068 standard series, comprehensive environmental tests should be performed on specimens in conditions similar to actual operating conditions, and they should involve tests in which the most significant environmental impacts can be observed. Table 1 contains examples of tests universal for most devices.

Table 1. Examples of tests complying with the PN-EN 60068-1 standard requirements [6] universal for most devices

Test	Comment
A – Cold	Mechanical stress may occur, which may make the specimen more sensitive to impacts assessed in other tests to follow.
B – Dry heat	
N – Sudden temperature change	
E – Shock	Mechanical stress may occur, which may either lead to immediate destruction of the specimen or make the specimen more sensitive to impacts assessed in other tests to follow.
F – Vibration	
M – Low air pressure	These tests reveal the impact of the preceding thermal and mechanical tests.
Db – Damp heat, cyclic (12 h + 12 h cycle)	
Damp heat (steady state)	
K – Salt spray	
L – Dust and sand	These tests may amplify the impacts of the preceding thermal and mechanical tests.
Permeation of solids	
Permeation of water (e.g. rain)	

The system developed by the authors is suitable for the first three tests listed in Table 1. Tests are carried out in thermally isolated chambers with the capacity sufficiently high compared to the size of the specimen and amount of the heat it dissipates. Test severities expressed as the temperature and duration should be provided in the product specification, defined based on dedicated tests, and fall within the values recommended in relevant standards:

- cooling chamber temperature: between –65ºC and +5ºC;
- heating chamber temperature: between +30ºC and +200ºC;
- test duration in a cooling or heating chamber: between 2 and 96 hours;
- individual test duration in Test N (sudden temperature change): between 10 to 180 minutes.

As regards Test N – Sudden temperature change, important test parameters include the number of temperature change cycles and the time of the specimen transfer from one test chamber to another (Fig. 1). If separate requirements do not state otherwise, it is recommended to include five (5) cycles in a test lasting 3 hours. The first cycle starts in point A and ends in point B. Time (t_2) of the specimen transfer between chambers with predefined temperatures T_A and T_B should not extend 3 minutes.

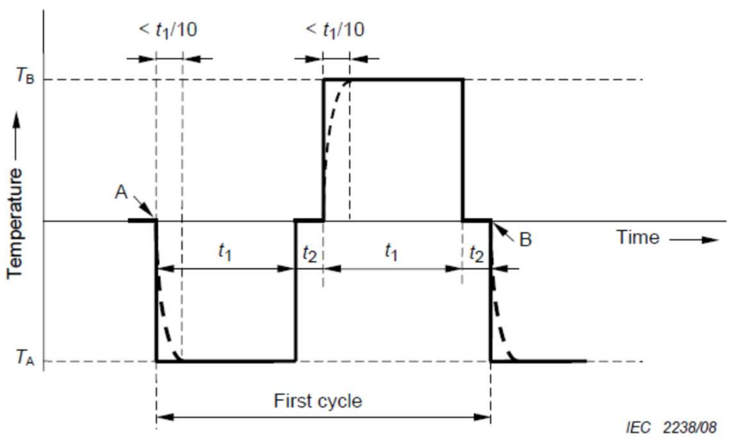

Fig. 1. Temperature change diagram Test N: Temperature changes [9]

2. Technological assumptions

The authors defined the scope of the system application for product groups and its functions including:

- the verification of the impact of temperature changes (also sudden) on performance parameters of prototype mechanical, electric, and mechatronic devices;
- the study of coatings affected by temperature changes; and
- the modelling of the dynamics of variability of environmental parameters impacting technological objects.

Then, based on the assumed system functionality, the authors specified the technical parameters of the two-chamber test system in changeable temperature conditions (Table 2).

Table 2. Basic technical parameters of the test system.

Parameter	Value
Test area dimensions	1000 x 400 x 400 mm
High temperature ranges	between +30°C and +200°C
Low temperature ranges	between –65°C and +5°C
Time to reach maximum temperature	90 min (from ambient temperature to +200°C)
Time to reach minimum temperature	90 min (from ambient temperature to –65°C)
Specimen transfer time	<15 s
Maximum specimen weight	30 kg

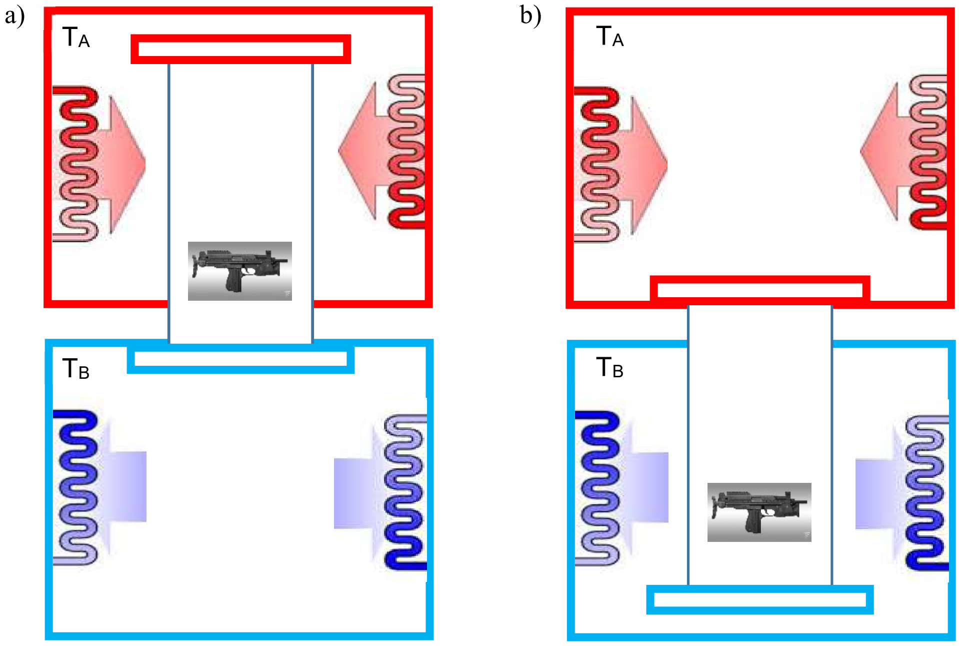

Fig. 2. Concept of the test system and test object transfer: a) hot test phase, b) cold test phase.

It was assumed that the test system will be designed as a system of vertically placed chambers (top – heating chamber and bottom – cooling chamber), as depicted in Figure 2. As regards the heating chamber, the resistive heating elements are the source of the heat, while in the case of the cooling chamber, the source of the cold temperature is the liquid nitrogen directly injected into the chamber.

The chambers are equipped with side doors, and the test object in placed in or removed from each chamber through the top chamber door. The test object is placed in an openwork basket transferred between the chambers with the use of a mechanical lift.

3. 3D model and documentation of the system

The CAD 3D model of the test system was developed based on the adopted technical assumptions (Fig. 3).

The heating and cooling chambers are spaces in which the test object is subject to environmental impacts, i.e. temperatures that are either higher or lower than the ambient temperature. Temperature values in each chamber are obtained and stabilised in accordance with the assumed test parameters. The mechanical lift (Fig. 4) is used to quickly transfer the test object between chambers to cause suitable thermal shock (i.e. a sudden ambient temperature change) in accordance with the test plan. When the lift is in its top position (i.e. when the test object is placed in the heating chamber), its floor constitutes a closing element that separates the chambers; when in the bottom position – the chambers are separated by the ceiling of the lift. Because of the lowest temperature reached in the cooling chamber, the system requires a supply of liquefied gas (nitrogen), the evaporation of which constitutes, in this case, the most efficient method of cooling.

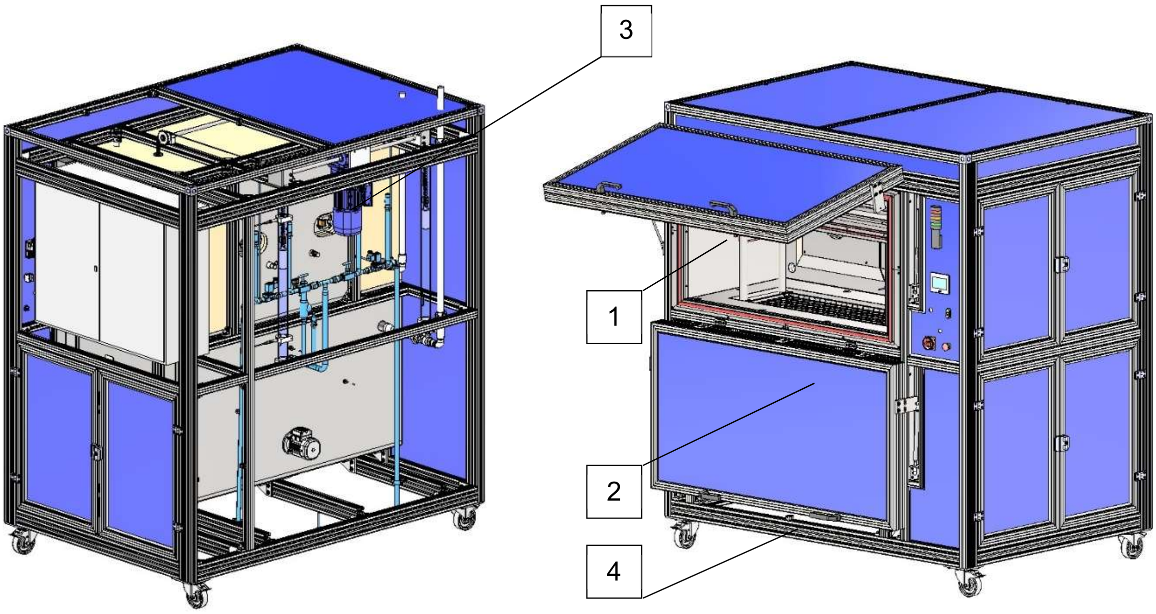

Fig. 3. 3D model of the two-chamber system for tests at variable temperatures 1 – heating chamber; 2 – cooling chamber; 3 – lift's drive system; 4 – load-bearing structure.

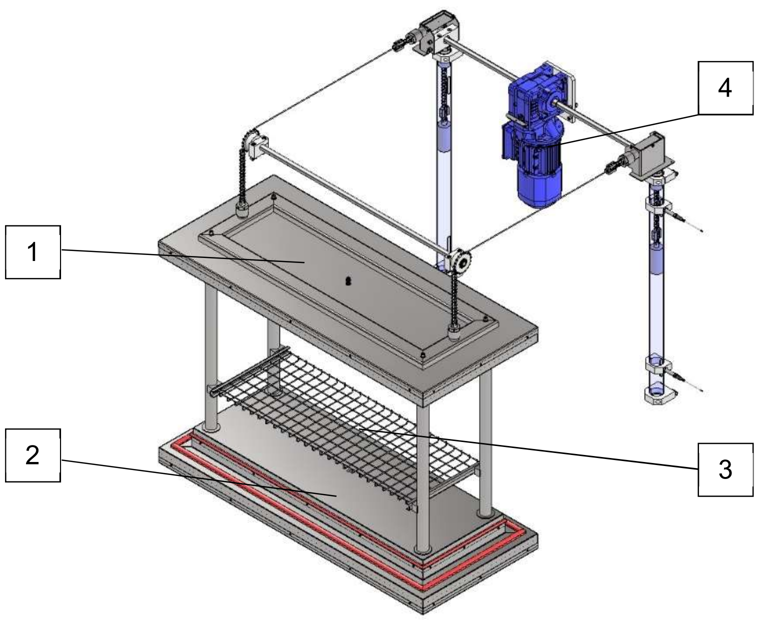

Fig. 4. 3D model of the lift: 1 – ceiling; 2 – floor; 3 – grating for test object positioning; 4 – drive system.

The heating and cooling chambers were designed as thin-walled sheet metal structures filled with thermal insulation whose thickness was adjusted to the assumed temperature gradients. The heating chamber is equipped with electric heating elements, and the cooling chamber – with a liquid nitrogen supply system. In each chamber fans and converters are placed; the first to mix the air, and the latter – to monitor the temperature distribution. The load-bearing structure of the system is made of screwed aluminium struts with casters. In the top part of the system, at the height the heating chamber is located, a control touchscreen panel with dedicated switches is mounted. The system structure is presented in Figure 5.

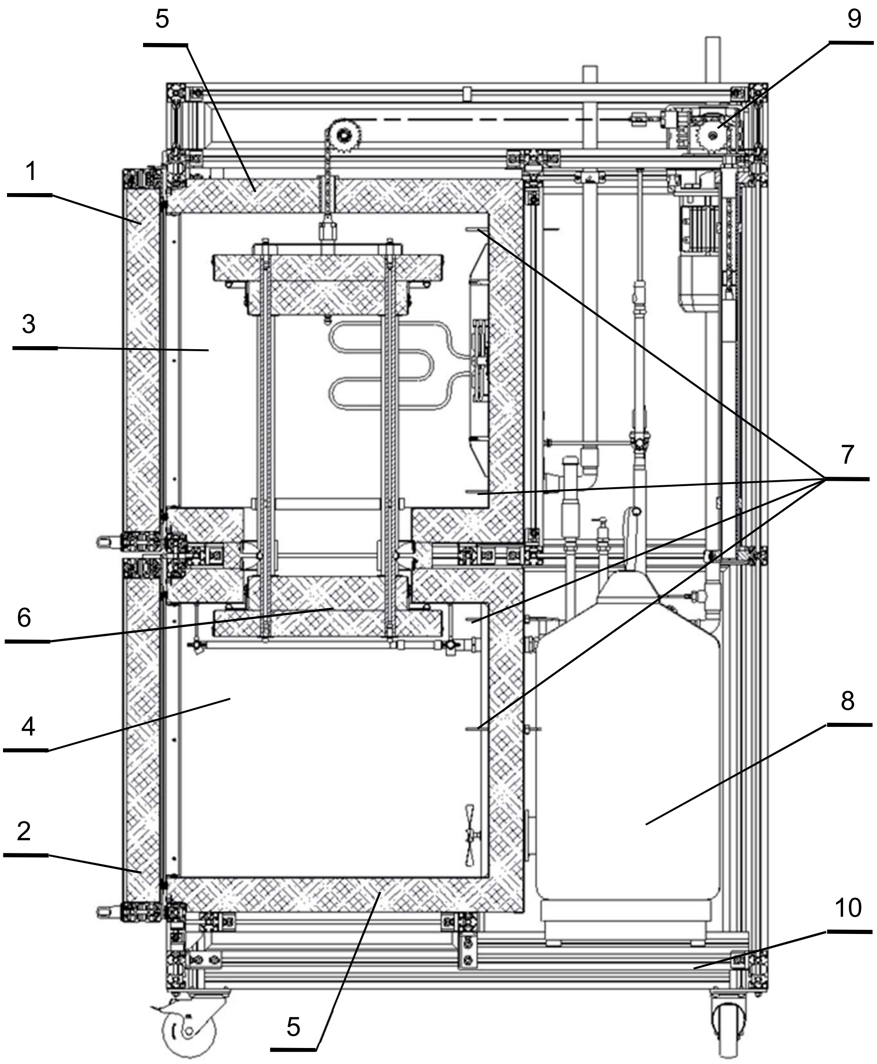

Fig. 5. Test system structure: 1 – heating chamber door; 2 – cooling chamber door; 3 – heating chamber; 4 – cooling chamber; 5 – thermal insulation; 6 – lift; 7 – temperature sensors; 8 – liquid nitrogen tanks; 9 – lift drive system; 10 – load-bearing structure.

4. Measuring and control system

The electronic programmable measuring and control system supervises all automatic functions required to prepare and complete the test. The individual test parameters, i.e. the temperature in the heating and cooling chambers, the exposure time in each chamber, the speed of the test object transfer between chambers, and the number of temperature change cycles, may be programmed by the user and automatically applied in compliance with applicable normative regulations or special test plans.

The authors formulated a concept of a control system for tests carried out in changeable temperature conditions. The system is composed of the following subsystems: a subsystem monitoring the high temperature in the heating chamber, a subsystem monitoring the low temperature in the cooling chamber, a subsystem controlling the test object transfer between chambers, a security subsystem, and a monitoring and visualisation subsystem.

Based on the adopted structure, the authors developed the algorithmic model of the control system, taking into consideration information processing circuits as well as the hardware and software layers. The measuring and control elements were selected in accordance with the 24VDC standard for binary signals, 4-20mA/0-10V standard for analogue signals and Modbus RTU/TCP communication protocol.

The temperature control system mounted in the heating chamber controls the heating elements, fans, and the temperature measurement in two points. Additionally, thermocouples were also used to control the temperature of the heating elements.

The temperature control system mounted in the cooling chamber is composed of two low-pressure tanks (0.3 MPa) containing liquid nitrogen (LN2), a gas supply system, two solenoid valves monitoring the amount of the gas supplied, and a system for gas usage measurement.

The subsystem controlling the test object transfer between chambers is composed of a toothed gear reducer controlled by an inverter, and four limit switches to control the lift's position.

5. Prototype verification

The prototype test system was built based on the adopted assumptions, developed model and technical documentation (Fig. 6). The prototype was equipped with a complete set of instrumentation to verify the correct operation of the individual units and software controlling the automatic implementation of test procedures.

a) b) c)

Fig. 6. Test system prototype: a) front view; b) liquid nitrogen supply system; c) control panel

The prototype verification and validation tests were carried out in real-life operating conditions [11]. Particular attention was paid to the adjustment and stabilisation of temperature in the cooling chamber. The custom cooling method (used for the very first time in a solution developed at the Łukasiewicz–ITEE) took a long time to implement and calibrate. With the use of the developed systems the authors were able to stabilise the temperature in cooling and heating chambers (Fig. 7) and carry out sample test procedures involving sudden ambient temperature changes. Figure 8 presents temperature changes in a 60-minute test.

As a result of the verification tests, the structure of the cooling chamber was modified by introducing a fan, which mixes the air inside the chamber and helps to evenly distribute the temperature; eliminating dead spaces that make even temperature distribution difficult; and mounting additional temperature transducers monitoring temperature distribution inside the chamber. Additionally, the liquid nitrogen supply system was also modified to enable the automatic switch from one supply source to another in the event the liquid nitrogen tank currently in use has been completely emptied. The said supply source switch is triggered by the decreased gas pressure in the tank. This enables the reversible replacement of the LN2 tanks and facilitates the performance of long-term tests at low temperatures.

a) b)

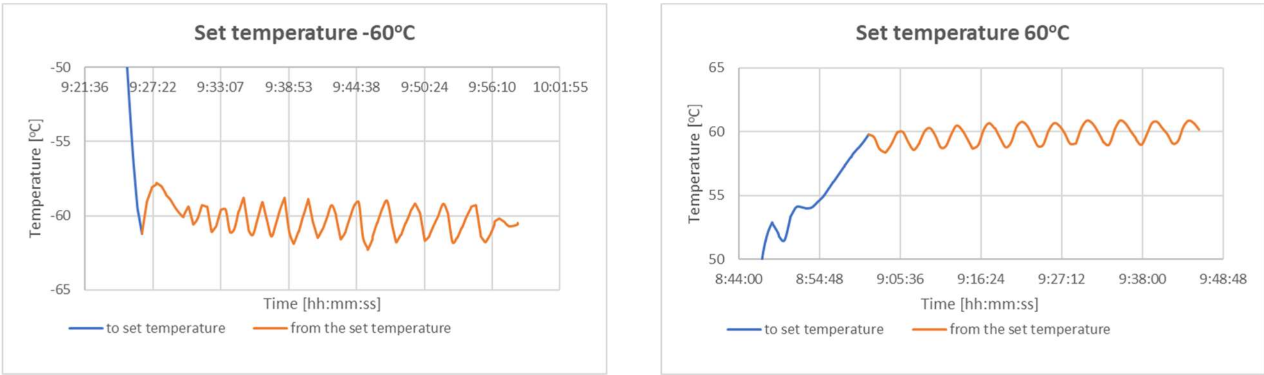

Fig. 7. Sample temperature changes during stabilisation of parameters of the: a) cooling chamber and b) heating chamber.

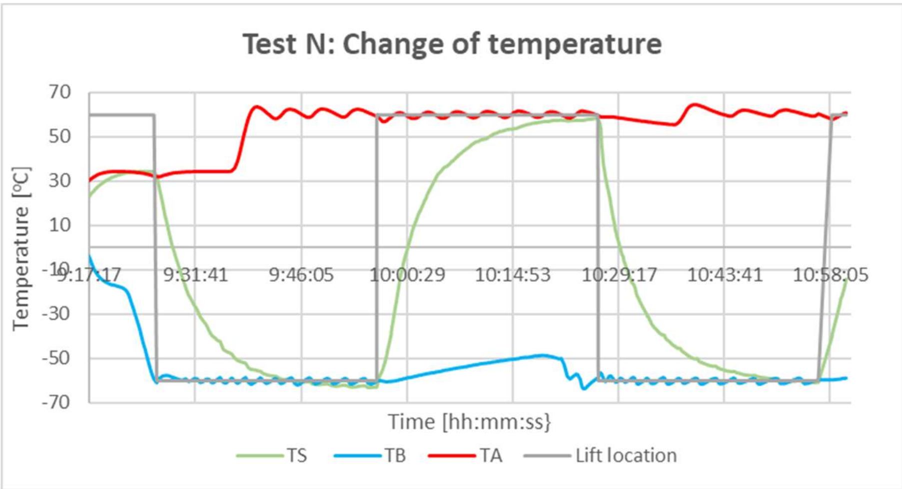

Fig. 8. Sample temperature changes recorded for a test with the following parameters:
T_A = –60ºC, T_B = +60ºC, cycle: 30 min.

The results of the tests carried out after the above-mentioned structural modifications confirmed the compliance of the test system parameters with normative requirements and assumed functionality of the solution.

6. Conclusions

With the developed test system to verify thermal shock resistance, technological objects, and, in particular, electronic systems, mechanisms, and material connections, can be tested in an environment subject to sudden ambient temperature changes. The tests can be carried out in accordance with normative procedures and in an environment with individually defined parameters simulating real-life operating conditions. The test results allow the assessment whether the tested product is fit for its intended purpose and can be used in the environment characterised by sudden and drastic temperature fluctuations.

The developed and validated prototype test system was incorporated into the structure of the laboratory for the identification and verification of technical safety [5] established at the Łukasiewicz–ITEE, and, together with other test devices [4], it enables comprehensive assessment of industrial and special-purpose applications under environmental conditions.

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