T.A. Ismailov, O.V. Yevdulov, M.A. Khazamova, D.A. Gidurimova

Federal State Budget Educational Institution of Higher Professional Education
“Dagestan State Technical University”, 70, Imam Shamil Ave.,
Makhachkala, 367015, Russia

EXPERIMENTAL INVESTIGATIONS OF THERMOELECTRIC DEVICE FOR THE THERAPY OF WHITLOW

The paper is concerned with the results of experimental investigations of prototype thermoelectric device for the therapy of whitlow. The device construction, the test bench, as well as the results of full-scale experiment in the form of plots of time history of temperature at device control points under different operating modes are presented.

Key words: thermoelectric device, whitlow, test bench, full-scale test, thermopile, temperature.

Introduction

In recent years there have been a growing number of suppurative inflammatory hand diseases, namely all kinds of whitlows and phlegmons. Suppurative diseases of fingers and hand rank first in frequency among all suppurative processes. From all newly-admitted patients who apply to surgeon those with whitlows and hand phlegmons make up from 15 % to 31 % [1]. The results of traditional surgical treatment of suppurative open fractures of finger bones and hand cannot be recognized satisfactory because of frequent repeated surgeries (17.1 %), amputations of fingers (7.1 %) and adverse functional and aesthetic outcomes. Repeated surgeries result in patients’ invalidity. Hand injuries account for about 1/3 of all traumas of locomotor system, reaching in some industrial fields up to 70 %.

Treatment of suppurative diseases is a complicated therapeutic process aimed at regulating local and general disease manifestations, as well as at suppressing and liquidating pathogenic agents, correcting homeostasis, stimulating immune and reparative processes.

Based on the analysis of the references, the following methods for treatment of suppurative diseases of hand fingers have been revealed.

For the therapy of early forms of whitlow and hand phlegmon, procedures based on using various hot baths with curative solutions are employed [2]. For instance, 5 % propolis water at a temperature of 311 K [3], as well as potassium permanganate solution at a temperature of 310 – 312 K can be used [4]. However, it is known that hot baths, irrespective of the composition of aqueous medium, contribute to oedema of inflammatory tissues of fingers and hand, increase congested effects in the focus of inflammation, affect microcirculation, contribute to forced accumulation of metabolic products in the area of inflammation and in general have a negative impact on the results of therapy.

Similar to the above treatment option is naphthalan therapy, ozokeritotherapy and paraffin therapy, when heated peloid-like substances, namely naphthalan oil, ozokerite and paraffin, are applied to affected areas [1]. In so doing, said treatment options also have the disadvantages considered above.

For conservative therapy of whitlow use is also made of novocaine blocks, infiltration of the focus of damage with 1 % dioxydine solution, *X*-ray therapy, i.e. radioactive cobalt application, ultrasound, laser beams [2, 5]. However, because of ethiopathogenetic invalidity of curative effect of the above mentioned means, their low therapeutic efficiency, awkwardness and technical complexity of application they have not gained widespread application in treatment practice.

Conservative treatment of the initial forms of whitlow is realized with the use of local prolonged hypothermia [6]. The local prolonged hypothermia in serous-infiltrative phase of whitlow and hand phlegmon possesses powerful ethiopathogenetic curative effect and allows clinical differentiation of serous infiltration phase from suppurative inflammatory changes in tissues. The most common treatment methods in this case are considered to be cold applications, cryogel, ice massage, cold bath (water temperature about 273 K), cold pack, the use of cryoaerosols, etc. [7].

Here it should be noted that technical implementation of these methods is insufficient. The disadvantages of existing modern hypothermia means include the absence of precise temperature control and duration of exposure, impossibility of cold and heat alternation, "non comfort" appreciation of procedures by patients. In this connection it is reasonable to develop new systems and devices for performance of such procedures having high operational performance. According to their mass-dimensional, reliability and energy parameters, thermoelectric power converters that have not been studied yet in terms of using in this technical field are suitable for creation of such systems.

The purpose of this work is to conduct full-scale test of prototype thermoelectric device for the therapy of whitlow developed by the team of laboratory of semiconductor thermoelectric instruments and devices of Federal State Budget Educational Institution of Higher Professional Education "Dagestan State Technical University" [8], as well as to study and analyze the results obtained.

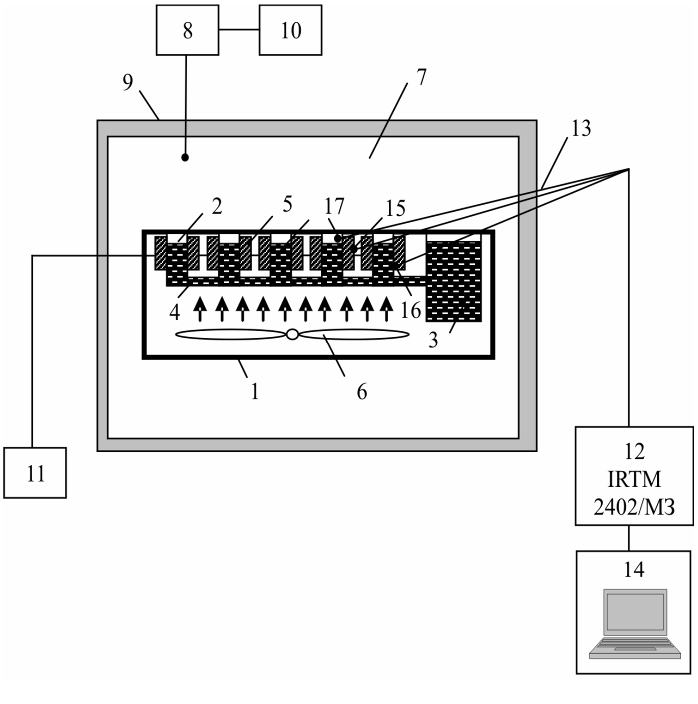

Fig. 1. Schematic circuit of test bench.

The object of experimental research was prototype thermoelectric device (Fig. 1) consisting of a case 1, with openings provided in its upper part, to which metal glasses 2 for human fingers are soldered. The glasses are arranged so as to enable one to sink fingers into them. Case 1 also has a vessel 3 for the curative solution imitator. Vessel 3 via tubes 4 is connected to all glasses 2 similar to communicating vessels. The working junctions of thermopile 5 are connected to the external surface of glasses 2 with provision of thermal contact. The reference junctions of thermopile 5 are blown by air flow forced by unit 6. As a thermopile during full-scale test of device prototype, standard thermoelectric modules of TB-63-1.0-2.0 thermopile type were used (manufactured by Kryotherm engineering-production firm [9]). The device is shown in Fig. 2. Aqueous solution of potassium permanganate was used as curative solution imitator.

For performance of experimental investigations the prototype thermoelectric device was placed into a thermally insulated climatic chamber 7, the temperature and relative humidity in which is regulated by control unit 8 connected to temperature and humidity sensor 9 whose readings are recorded by digital information display 10. The thermopile was powered by electric supply 11. The measurements were performed with the use of ammeter and voltmeter embedded into electric supply, as well as IRTM 2402/M3 multi-channel meter 12 connected to a personal computer.

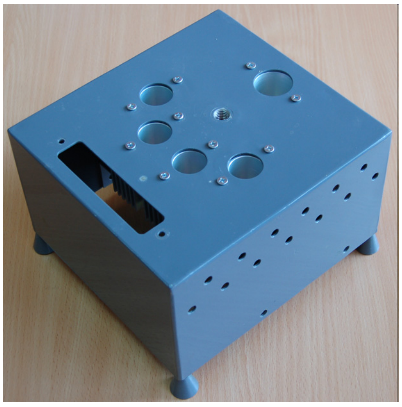

Fig. 2. Prototype thermoelectric device for the therapy of whitlow.

In the course of the experiment there were determined voltage and current on thermopile, ambient temperature, temperatures at control points of the prototype thermoelectric device. Temperature measurement was performed using copper-constantan thermocouples 13 whose reference junctions were arranged in a Dewar vessel, and the signal was picked up by IRTM 2402/M3 meter 12 and output to personal computer 14. Thermocouples 13 were arranged at control points, namely on thermopile reference junctions 15 and working junctions 16, in the curative solution imitator 17.

Prior to the performance of the experiment the reliability of thermal and electric contacts was checked. The experiments were performed in series, 5 experiments each, under identical conditions. The ambient temperature was assigned equal to 296 K, the relative humidity – 55 %.

Figs. 3 and 4 show the plots of time history of temperature at control points of thermoelectric device with thermopile operated in cooling and heating mode for its current supply value equal to $I = 1.8$ A. Considered is time history of the temperature of the thermopile working and reference junctions, as well as the curative solution imitator. According to the represented data, temperature variation, both in the case of cooling and heating of the curative solution imitator is of a monotonous character, decreasing in the former case and increasing in the latter, tending to certain steady-state value. With the stipulated thermopile supply current and the respective operating conditions of thermoelectric device, the temperature at control points takes on given steady-state value in about 7 – 7.5 min, which corresponds to the obtained theoretical results. In so doing, the difference in temperatures between the thermopile working junctions and the curative solution imitator on reaching the steady-state mode by the system is about $2.5 \div 3$ K. This fact enables one to speak about minor thermal losses in the elaborated device and its sufficiently high energy characteristics.

Figs. 5 and 6 show the curves describing time history of the curative solution imitator temperature with the thermopile operated in cooling and heating mode for different supply current values. For heating mode the value of current strength was 2.2 A, 1.8 A, 1.4 A, and for cooling mode – 1.8 A, 1.3 A, 1.1 A, respectively. According to given dependences, increase in the value of thermopile supply current results in reduction of the curative solution imitator temperature with thermoelectric device operated in cooling mode and a rise in its temperature with thermoelectric device operated in heating mode, which corresponds to increase in cooling capacity and calorific power of thermopiles. Thus, increase in thermopile supply current from 1.4 A to 2.2 A on cooling the curative solution imitator, reduces its temperature from 281 K to 276 K, and, on heating, increase in thermopile supply current from 1.1 A to 1.8 A increases the temperature of biological object from 313 K to 317 K.

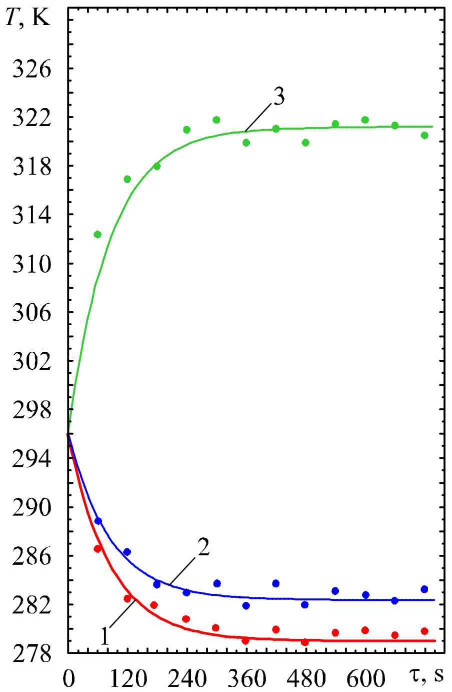

Fig. 3. Time history of temperature at control points of thermoelectric device with the thermopile operated in cooling mode for I = 1.8 A. 1 – working (cold) junction of the thermopile, 2 – curative solution imitator, 3 – reference (hot) junction of the thermopile.

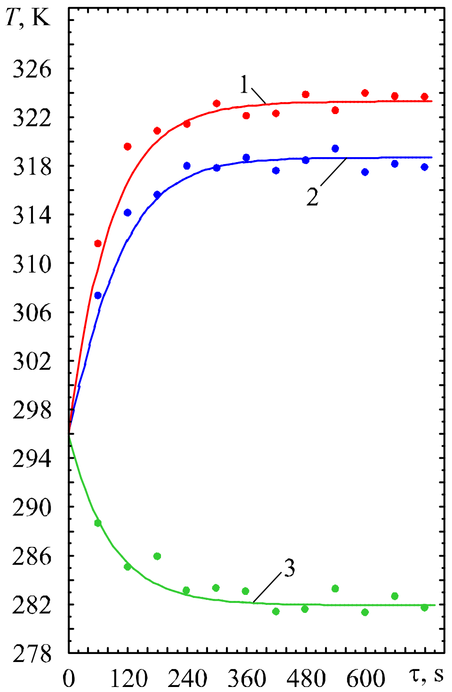

Fig. 4. Time history of temperature at control points of thermoelectric device with the thermopile operated in heating mode for I = 1.8 A. 1 – working (hot) junction of the thermopile, 2 – curative solution imitator, 3 – reference (cold) junction of the thermopile.

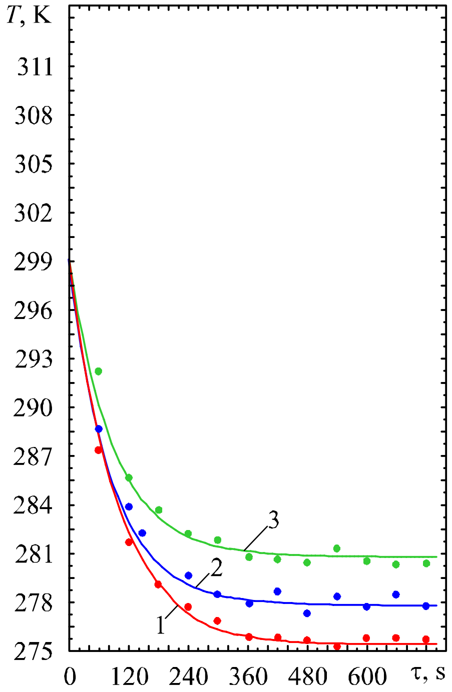

Fig. 5. Time history of the curative solution imitator temperature with the thermopile operated in cooling mode for different values of supply current 1 – I = 2.2 A; 2 – I = 1.8 A; 3 – I = 1.4 A.

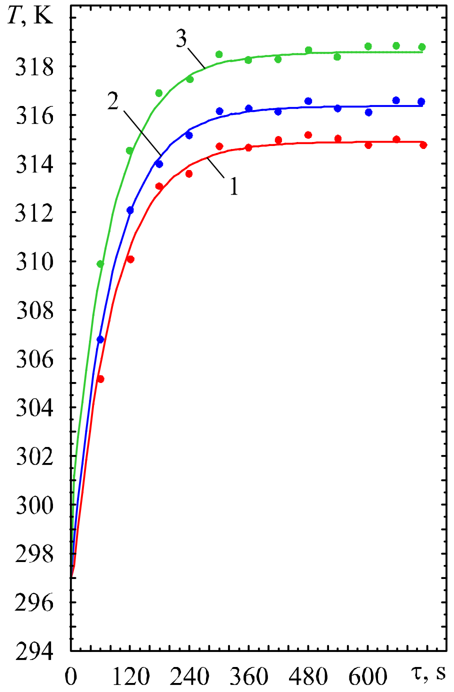

Fig. 6. Time history of the curative solution imitator temperature with the thermopile operated in heating mode for different values of supply current 1 – I = 1.1 A; 2 – I = 1.3 A; 3 – I = 1.8 A.

Thus, according to the experiment, for the implementation of required medical procedures determined primarily by the temperature of the curative solution imitator, the use of a standard thermoelectric module of TB-63-1.0-2.0 thermopile type is quite justified.

To analyze the possibilities of dynamic operating mode of thermoelectric device, the plots of time history of the curative solution imitator temperature with a change of device operation from cooling to heating mode and vice versa, are given in Figs. 7 and 8. In the first case the results are given for thermopile supply currents 1.2 A, 1.5 A and 1.8 A, in the second case – for supply currents 1.4 A, 1.6 A and 1.8 A. The experimental findings also correspond to calculation data. In both cases the duration of transition from cooling to heating mode and vice versa is of the order of 8 minutes, which corresponds to theoretical calculations with adequate accuracy.

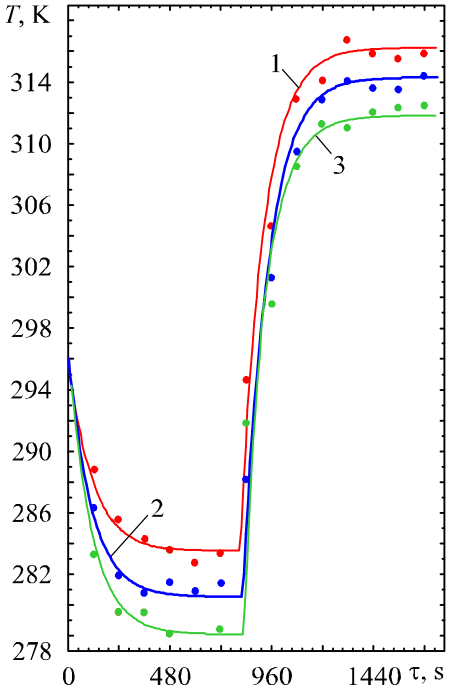

Fig. 7. Time history of the curative solution imitator temperature at contrast thermal procedure with thermoelectric device passing from cooling to heating mode for different values of thermopile supply current 1 – I = 1.8 A; 2 – I = 1.5 A; 3 – I = 1.2 A.

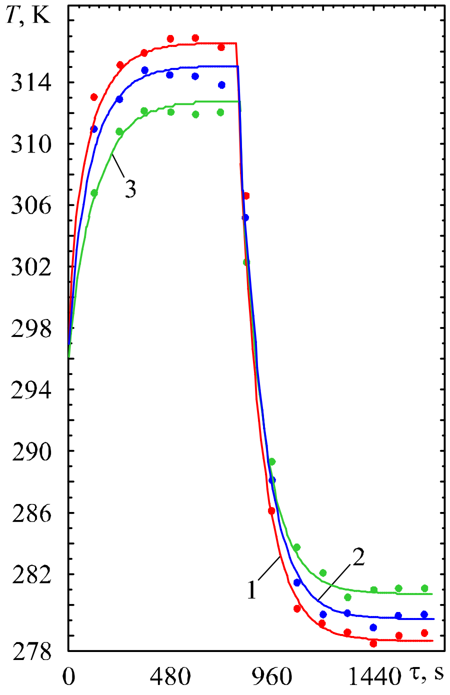

Fig. 8. Time history of the curative solution imitator temperature at contrast thermal procedure with thermoelectric device passing from heating to cooling mode for different values of thermopile supply current 1 – I = 1.8 A; 2 – I = 1.6 A; 3 – I = 1.4 A.

Fig. 9 represents the data related to time history of the biological object and the curative solution imitator temperature with thermopile operated in cooling and heating mode for $I = 1.8$ A. According to represented data, the temperatures of the curative solution imitator and the biological object as such do not correspond to each other. It is primarily due to finite values of heat capacity and thermal conductivity of the biological object, as well as to its internal heat release. For the investigated conditions the difference in temperature values of the biological object and the curative solution imitator is about 3.5 K.

Reliable operation of the elaborated thermoelectric device depends in many respects on the efficient heat pickup from the thermopile reference junctions. To estimate the possibilities of heat pickup from the thermopile hot junctions in the system, Fig. 10 represents the data on the time history of device base temperature under cooling effect for different values of thermopile supply currents.

From the represented plots it follows that the temperature value of thermopile hot junctions is quite acceptable for the type of standard modules employed. This fact determines rather efficient heat pickup from the thermopile hot junctions under conditions being considered and gives grounds to suppose a reliable operation of the elaborated device when conducting the required medical procedures.

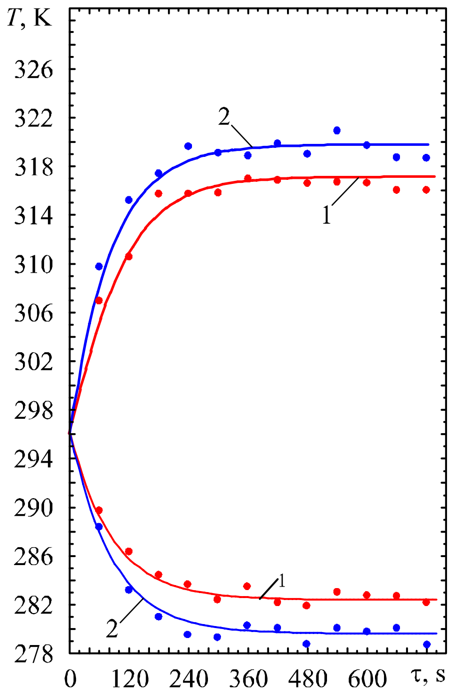

Fig. 9. Time history of biologic object (1) and the curative solution imitator (2) temperature with the thermopile operated in cooling and heating mode for $I = 1.8$ A.

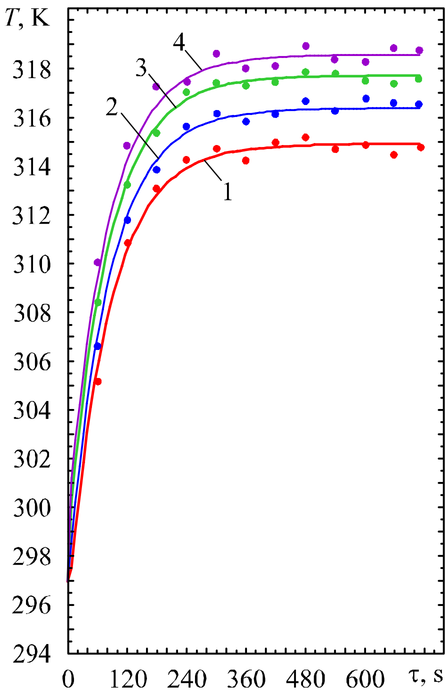

Fig. 10. Time history of the thermopile hot junction temperature when operated in cooling mode for different values of supply current 1 – $I = 1$ A; 2 – $I = 1.2$ A; 3 – $I = 1.4$ A; 4 – $I = 1.6$ A.

According to the results of the experiments, comparison of the design and experimental data has been conducted. Apart from the experimental points, Figs. 3 to 10 represent the results of theoretical research.

The represented research results determine the acceptable coincidence of the theoretical and experimental data. Their maximum divergence does not exceed 5 – 6 %. The greatest deviation of calculated data from the experiment is mainly observed on the time interval related to reaching the mode by the system which is determined by the environmental influence and non-perfect thermal insulation of "device-object" system, as well as certain spread in thermopile and measuring instrument parameters. In so doing, in case of cooling the experimental results have somewhat larger values than the calculated ones, and in case of heating – the lowest values over the entire measurement range. This fact is mainly due to imperfection of thermal insulation, which does not meet the requirements accepted in the design models, hence, heat penetration to the device.

Thus, based on the research performed, the following conclusions can be made:

1. Hypothermia method based on the thermoelectric device developed by the authors can be used for conducting medical procedures in the therapy of whitlow.
2. The thermoelectric device is a fast-response one, namely the time of reaching the steady-state working mode in the investigated range is 7.5 minutes.
3. The difference in temperature between the working junctions of thermopile and the curative solution does not exceed 3 K enabling to speak about minor thermal losses in the device.
4. When conducting the required medical procedures, for thermoelectric device it is sufficient to use a

standard thermoelectric module of TB-63-1.0-2.0 type with maximum supply current 2.3 A.

5. With device operated in the dynamic mode, the process of transition from cooling to heating mode and vice versa is of the order of 8 minutes.
6. According to the data obtained, the temperature of the curative solution and the biological object as such do not correspond to each other: in the investigated range the difference in their temperature is 3.5 K.
7. To assure normal operation of thermopile in thermoelectric device, it is sufficient to use forced air cooling.
8. When comparing the calculated and experimental data, their maximum divergence did not exceed 5 to 6 %.

References

1. A.D. Badikov, Application Beta-Therapy in a Combined Treatment of Whitlow on an Outpatient Basis, *PhD Thesis* (Saint-Petersburg, 2005), 146 p.
2. A.V. Meleshevich, *Whitlow and Phlegmon of Hand*, Manual for Surgical Curriculum for Students of all Specialties, in 3 Parts, Part 3 (Grodno, 2002), 264 p.
3. L.A. Komarova, L.A. Blagovidova, *Manual for Physical Methods of Treatment* (Leningrad: Meditsina, 1983), 264 p.
4. Rehabilitation of Patients with some Diseases and Injuries of Hand, *Proceedings of Gorky Research Institute of Traumatology and Orthopedics*, Ed. By V.V. Azolov (Gorky, 1987), 187 p.
5. Masai Taksahani, Clinical Experience of Combined Use of Hyperthermia and Radiation Therapy, *Medical Radiology* **12**, 25 (1988).
6. V.V. Kenz, A.I. Sukhenko, and T.M. Duca, Local Cold Effects in Physiotherapy, *Voprosy Kurortologii (Balneotherapy Issues)* 2, 83 – 87 (1983).
7. D.N. Kadanov, Yu.T. Bozhenkova, and V.I. Ivanov, Treatment of Suppurative Diseases of Soft Tissues by Cryogenic and Cryosurgical Methods in Ambulatory-Care Clinic, *Surgery* **5**, 141 – 143, 1985.
8. T.A. Ismailov, O.V. Yevdulov, M.A. Khazamova, and D.A. Gidurimova, Results of Mathematical Simulation of Thermoelectric Device for Treatment of Hand Fingers, *Thermal Processes in Engineering* **9**, 426 – 432 (2011).
9. http://www.kryotherm.ru.

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