International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in; editorijoer@gmail.com

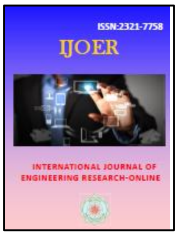
Vol.7., Issue.3, 2019
May-June

RESEARCH ARTICLE

ISSN: 2321-7758

UPDATE DEVICE FOR TESTING THERMOELECTRIC MODULES

Dr. ABDURAHIM A. SAKEB[1], ABDULLATIF MEHEMED GOHMAN[2]
[1]Azzaytuna University, Faculty of Engineering, Dept. of Mechanical Engineering, Libya
[2]Azzaytuna University, Faculty of Engineering, Dept. of Mechanical Engineering, Libya
Doi: https://doi.org/10.33329/ijoer.73.51



ABSTRACT

The purpose of this work is to propose changes to an existing experimental system to calculate thermoelectric module parameters. The research analyses the current state of operation and defines the requirements for system modification. A new solution was subsequently designed in accordance with these requirements. The quality of the design is evaluated in ANSYS. Drawing documents required for its development was drawn for the layout of the updated equipment.

Index words: Thermoelectric module, measurement, measuring apparatus

1.0 Introduction

The ever-increasing dependence of man on electrical energy has resulted in efforts to expand its production possibilities even in places and conditions where the use of conventional sources is not possible. One possibility of electricity production is the use of thermoelectric phenomena. These phenomena convert heat directly into electrical energy without the need for rotating parts. The efficiency of thermoelectric conversion is low, but when properly designed, it is sufficient to power low-income applications. In the past, these applications included, for example, powering space probes, radio beacons on the north coast of Russia, or tube radio. For design of thermoelectric generators it is necessary to know exact parameters of used devices, thermoelectric modules (TEM). For measuring the parameters of thermoelectric modules, a device was designed to measure low temperature modules. Therefore, a request for modification of this device was created, which is processed in this work.

To design the apparatus it is necessary to know the basic physical principles with which it works mostly on Thermoelectric effects (Seebeck effect, Thermoelectric pair, Semiconductors, Peltier effect, Thomson effect, Kelvin relations etc.,). As with any device used as a power source, TEM also needs to be measured to optimize the downstream circuit. The difficulty of the issue is given by influencing the measurement by thermoelectric phenomena. The performance is strongly dependent on the coefficient of thermoelectric efficiency ZT, which itself depends on three other parameters.

1.2 Currently used and developed materials include:

1.2.1 Thermoelectric materials

Thus, to achieve high ZT values, a material with high electrical conductivity and Seebeck coefficient and low thermal conductivity would be needed. Metals have high thermal conductivity and low Seebeck coefficient. Insulators, on the other hand, do not carry electric current at all. Between these materials are semiconductors. As seen in figure A, the maximum of $\alpha 2\sigma$ is located in the semiconductor range[1].

International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in; editorijoer@gmail.com
Vol.7., Issue.3, 2019
May-June

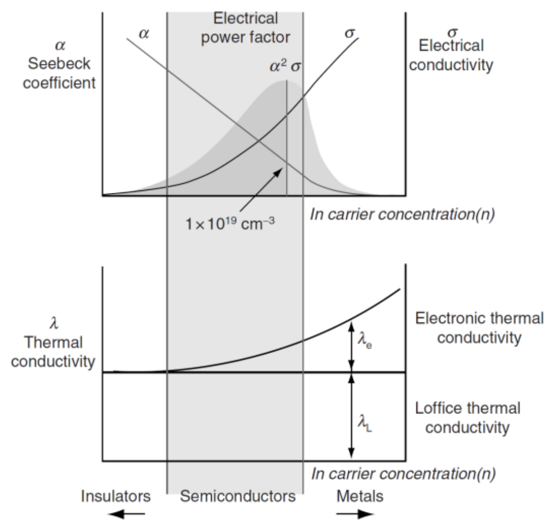


Figure A: Dependence of material properties on the concentration of charge carriers

Semiconductor materials are preferred for thermoelectric properties for TEM construction. The desired properties of the resulting posts are achieved in addition to the selection of a suitable material, also by its suitable manufacturing process. A commonly used process is to melt the powder with the desired proportions of the individual components. The alloy is then poured into a silicon vial in which it is enclosed to prevent contamination and oxidation. This vial is further heat treated to achieve the desired crystalline structure. For high temperature materials, arc remelting using different atmospheres or vacuum can be used. After remelting, the material is again enclosed in a silicon vial and is further heat treated. For the manufacture of nanomaterial columns, a hydrothermal synthesis method can be used which crystallizes solutions at high temperatures and pressures. Also preferred is the formation of a single crystal column by controlled crystal growth. Further improvements in the properties of the materials can be achieved by processes such as doping with other materials to increase the concentration of charge carriers. Alloying and thus disrupting the original crystal lattice to increase electrical conductivity. Layering various materials and creating nanocomposites, nanostructures. As can be seen in Tab. In Bi_2Te_3, the effect of the properties on various treatments is considerable[2].

Bi_2Te_3 - This is the most widely used material in commercial thermoelectric modules. It is used for low temperature applications up to 230 ° C. It has good electrical conductivity, Seebeck coefficient and low thermal conductivity. It can be doped as p i n semiconductor. Many different variations of the structures used and other impurities are produced. Plasma sintered and meltblown P-type reaches ZT = 1.5 at 117 ° C[3].

PbTe - They are characterized by low thermal conductivity and high Seebeck coefficient at room temperature. A suitable operating temperature range for PbTe is from about 300 to 530 ° C. Like Bi2Te3, both n and p semiconductors can be formed by different doping. Unsubsidized PbTe reaches ZT = 0.71 at 700 ° C, plasma sintered PbTe ZT = 1.8 at ° C and doped PbTe: Tl (2%) ZT = 1.48 at 467 ° C.[4]

SiGe - SiGe alloys have good mechanical properties. Thanks to their high melting point (>930 ° C), they are suitable for use in high temperature applications. They have high thermal conductivity at room temperature. At higher temperatures, the increasing Seebeck coefficient and relatively good electrical conductivity cause the resulting ZT to be 0.94 at 930 ° C. Thus, there is an attempt to reduce thermal conductivity, for example by Nano structuring, where the thermal conductivity has been reduced from 4.2 W / mK to 2.5 W / mK, thereby increasing the heat recovery to 1.3 at 900 ° C.[5]

Skutterudites - are crystalline materials that have free space in their crystal lattice to accommodate another atom. Inserting a large heavy atom will interfere with the oscillation of other atoms and thus reduce thermal conductivity. Frequently used material is $CoSb_3$, which itself achieves ZT = 0.1 at 327°C. After insertion of the Yb atom, the material $Yb_{0.19}Co_4Sb_{12}$ ZT = 1.08 at the same temperature.[6]

$AgSbTe_2$, $AgSbSe_2$ and LAST - $AgSbTe_2$, $AgSbSe_2$ are materials crystallizing in a disrupted NaCl lattice, where Ag and Sb take the place of a metal sub-grid. They are characterized by very low thermal conductivity, which is caused by the broken grid. $AgSbTe_2$ is a very good thermoelectric material type p. The problem with its use is instability at temperatures below 360 ° C, which decomposes to α-Ag_2Te and Sb_2Te_3. Alloying with other cubic lattice materials such as GeTe, PbTe and SnTe stabilizes it to form a material called

1.3 Review of Literature

Various devices were constructed for measurement by the methods described above. The design of the device varies considerably. In order to obtain accurate results, in addition to the correctly selected method, it is also necessary to apply it appropriately, that is, to design the apparatus properly, and to use appropriate instruments to minimize the influence of the environment. Only devices enabling measurement of whole modules are described in detail.

Hsu et al.[7] developed an apparatus for measuring the Seebeck coefficient of TEM using the steady state method. Because it uses this method without modification, the formulas described above can be used. The measuring apparatus is assembled as follows (from top to bottom) heater - copper plate - TEM - copper plate - cooler. Water cooled in an external cooler was used as the cooling medium. The pressure was exerted by the weight that was applied to the whole assembly. The weight of the weights was 12 and 18 kg (pressure per module up to 0.634 kg / cm^2) during two series of measurements. Unspecified thermocouples were used for temperature measurement. Heat losses were not considered. The measurement was carried out at atmospheric pressure in air. No thermal insulation was specified in the paper. It has been shown that the variation of the contact force acting on the module has a measurable effect on the measurement results, (Fig. 1). The design of the device does not provide unidirectional heat conduction; the cold side temperature instability was also proven and the measurements had to be repeated several times.

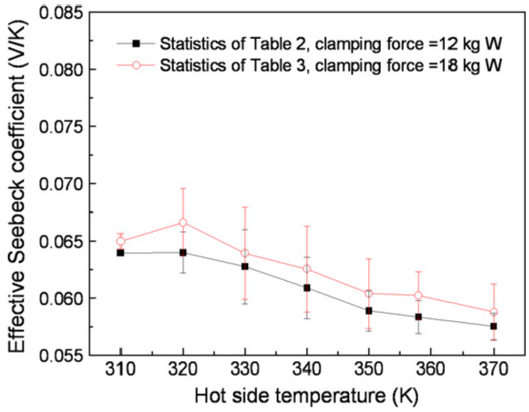


Figure 1: Seebeck coefficient as a function of temperature for different contact forces[7]

Man et al [8]. described measurements on a commercially available apparatus "TEGeta" (Fig 2) from the manufacturer PANCO GmbH. This apparatus uses steady state methods. The construction consists of (from top to bottom) pressure plate - insulation - heater - block of reference material - graphite insert - TEM - gel insert - block of reference material - cooler - pressure plate - spring - washer. The thrust is exerted by the nuts which transfer the force to the thrust plate via a spring. The pressure on the module measured 1.3 MPa, which is the value recommended by the manufacturer. The heater temperature reached up to 800°C, which was sufficient to reach a temperature of 626 ° C on the heated side of the module. Theoretically, it should be possible to reach 1000 ° C on the heater. Both heat flux measuring blocks were equipped with four thermocouples which were inserted in holes of 1 mm diameter. Thermocouple type not specified. The position of the thermocouples in the direction of heat flow was 2.5 mm from the edge, then 3 x 5 mm, the block overlap from the last thermocouple was again 2.5 mm. Since the temperature on the area in contact with the module was not measured, this temperature was extrapolated. In order to reduce losses, the apparatus was lined with vermiculite insulation. The measurement was carried out with an initial heater temperature of 400 ° C and a final 800°C, between these temperatures every 100°C was measured. Each cycle lasted ~ 500 s, the whole measurement thus 2000s.

Sempels et al[9]. built a device measuring on the principle of steady state method. The device was assembled as follows (top down) pressure plate - reference block - TEM - reference block - cooler. The pressure was exerted by tightening the nuts on the threaded rods between the cooler and the pressure plate. The pressure was not measured. The heating was realized by five heating cartridges of 150 W steel output. Copper block with the same geometry. A total of 4 probes were used on each block and were of the PT100 type.The temperature difference achieved on the module was ~ 30.5 ° C during the measurement. The measurement was controlled using Matlab. No corrections for temperature losses were considered.

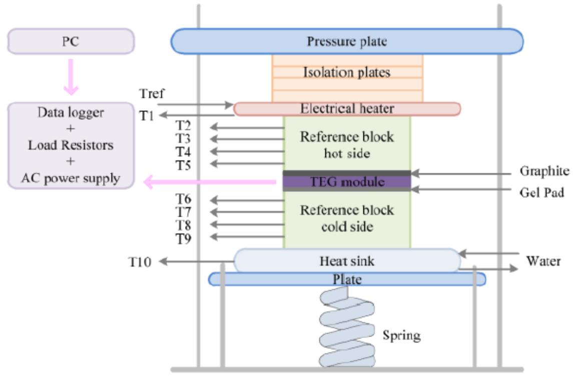


Figure 2: Simplified scheme of the TEGeta measuring system[9]

Mitrani [10] is based on the Harman method (under category of Transient state method), so the formulas are the same as above. This differs from the Harman apparatus by adding a reference aluminum block for measuring heat flux and a second TEM used to maintain a constant temperature on one side of the block. The construction is made as follows (in the direction from top to bottom) fan - cooler - control TEM - reference block - measured TEM - thermally conductive block. The entire assembly is held by steel threaded rods, the thrust being exerted by the nuts on these rods. The entire apparatus is wrapped with thermal insulation to minimize heat loss and ensure one-dimensional heat conduction. The apparatus cannot be used for bipolar measurements. The achieved ΔT was ~ 20 ° C. The measuring cycle lasted ~ 4200 s.

Cylian[11] deals with the same method as Ahiska[12]. The measuring apparatus is described in general and the measuring microprocessor circuit is described in detail. The principle of measurement and measured values are the same as in the case of Ahisk. The thermal part is composed as follows (from top to bottom) insulation - heat sink - TEM - heater - copper plate - TEM - copper plate - heat sink - insulation. As can be seen, the apparatus comprises two TEMs. These TEMs are identical. One is measured and the other serves to control the amount of heat passing through the measured TEM. Cooling is realized by water circuit. Type K thermocouples are used for temperature measurement, but type T is also possible. The entire device is insulated with a 5 cm thick insulation layer.

2.0 Experimental

The apparatus uses the steady state method. When designing all the design parameters described above have been taken into account in the existing plant. In spite of these efforts, after the measurement set has been carried out, it has been found appropriate to modify the structure. The aim of this chapter is to describe the construction of a new experimental measuring apparatus for measuring parameters of thermoelectric modules.

2.1 Construction of the existing measuring apparatus

The apparatus can be divided into three main parts, similar to the apparatus described above. The first part is the thermal part of the device itself, which has the task of heating and cooling the measured sample. This part consists of a thrust mechanism, insulation, a heated plate, and a reference block, a module mounting space, a heat sink and a cage. The whole assembly is placed on the milled base. Guide bars are installed for easier operation. The cage consists of duralumin plates which are held by threaded rods. The pressure is exerted by a stepper motor. The force is transmitted by three springs to ensure uniform pressure. Insulation plates are used to reduce the thermal load on the cage. Part of the equipment between the heater and cooler is insulated. For heating use a plate heater. The heat flux is measured on both sides of the module by copper blocks. Holes are drilled in the block to allow temperature probes to be inserted. In order to minimize the transient thermal resistance, a

International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in; editorijoer@gmail.com

Vol.7., Issue.3, 2019
May-June

graphite foil is placed on both sides of the measured TEM. Cooling is realized by a water loop, which is connected via a heat exchanger to another circuit, which is cooled by compressor cooling. Strain gauges are placed under the cooler to measure the pressure. At present, measurement under vacuum or inert atmosphere is not possible. The second part is a power electronic part. This includes a voltage source for the heating elements, their regulation and the supply to the circulation pump of the cooling circuit. Its control is realized by PID controller programmed in LabVIEW environment. The temperature of the cooled side is controlled by the pump output, as is the LabVIEW PID controller on the heated side. The third part is the measuring apparatus itself. Type K thermocouples are used for temperature measurement. A total of 8 thermocouples are placed on the reference blocks. Voltage and current measurements are made by a pair of Agilent instruments.

2.2 Requirements for measuring apparatus

Since the establishment of the apparatus described above, the requirements placed on it have changed. The apparatus was built with the requirement to measure commercially available TEMs under their normal operating conditions. This means a temperature of the heated side to 300 ° C, cooled in the range of 30 ° C to 100 ° C at a pressure of <1.5 MPa. Also, measurements in an inert atmosphere or vacuum were not required because under these conditions the module will not work in real operation. These requirements have been extended as follows: it is currently required that the apparatus be able to measure modules and materials newly developed with the highest precision. The aim is to verify the maximum possible parameters of these measured samples and also to find the limits at which they can still work. As described in Chapter 0, the materials tested today are capable of operating at temperatures above 800 ° C. In the past measurements on the current apparatus were found several other design deficiencies. The first is the deflection of the acetonitrile base of the cooling block. Due to the relatively high forces acting on this block, deformations occurred during the measurement. This could cause the coolant to leak if the pressure increases further.

The amended requirements could therefore be summarized as follows:

a) Maximum temperature of the heated side> 500 ° C,

b) Maximum cooled side temperature 150 ° C

c) Possibility to control the measuring atmosphere

d) Improve the accuracy of the results

e) Sufficient mechanical strength

2.3 A suggested solution

The following chapter describes the design of the modified equipment according to the requirements described above. Due to the extent of necessary modifications and the very low reusability of the individual parts of the equipment, the apparatus itself was re-designed. The design is still based on a steady state approach. The entire measurement assembly is shown in figure 3.

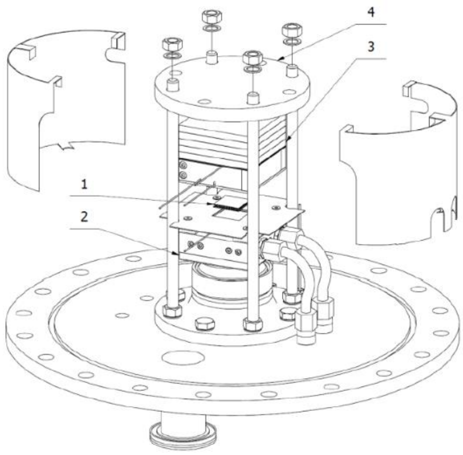


Figure 3: Measuring part of the proposed device (1) module to be measured, (2) cooler, (3) heater, (4) cage

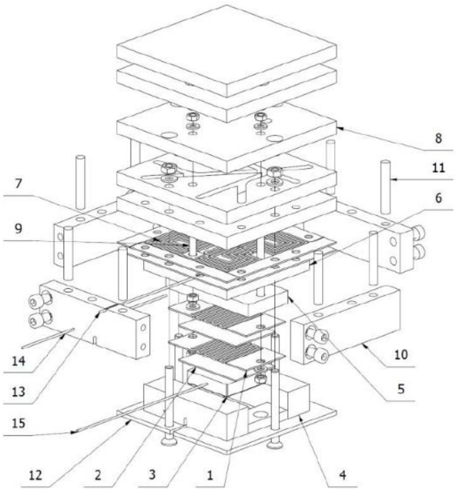


Figure 4. Heating unit assembly

2.4 Design of the thermal part of the equipment

An important modification is the change of the heated part of the device due to higher required temperatures. Heat flow measurement on the reference material reduces the achievable temperature on the warm side of the measured module. The large area of these reference areas provides space for heat exchange with the environment. This increases the error. The approach to construction was chosen similar to that of Mahjan[13] and Rauscher[14]. For this method, it is necessary to ensure that all heat supplied by the main heater passes through the measured module. This is achieved by a protective heater maintaining the same temperature as the measuring heater. By enclosing the main heater together with the heat transfer block in contact with the measured TEM, it creates conditions for one-dimensional heat conduction. The existing thick film resistors used to heat the module are not rated for temperatures higher than 400 ° C and are therefore not suitable for use on a conditioning device. The heating elements must be able to provide sufficient heat output, and must also be able to operate at high temperatures. This requirement overrides the heating cartridges that are often used in the articles described above. Thus, a plate made of resistive material will be used in which the grooves are milled to achieve the desired length and cross-section. If necessary, these sheets can be stacked upon insertion of the insulating layer to increase the heat output of the part. The heating elements will be connected using threaded rods.

The treated heated part is designed as follows (Figure 4): the basis is the main heating plates (1), these plates are interspersed with ceramic electrical insulation (2). It is desirable that this insulation have good thermal conductivity. That is why the plates made of AIN - aluminum nitride were chosen. Heat is transferred to the temperature compensation block (3). This block should have the best possible thermal conductivity. It was therefore made of copper. Geometry was chosen with regard to the use of original extenders. The whole assembly is insulated by a layer of thermal insulation (4,5,6), in the vertical direction a protective heater (7) is placed on the insulation, which is produced by the same process as the heating plates. It is further insulated by five layers of pressure-resistant insulation (8), in which the grooves for the connecting wires and threaded rods (9) are milled. Horizontal flow is prevented by a cage mounted from copper plates (10) heated by heating cartridges (11). This cage is provided with a stainless steel bottom (12) which holds the assembly together. Stainless steel was chosen for low thermal conductivity. If the thermal conductivity is too good, the heat flux through the copper insert could be affected. The temperature is measured by means of Pt100 resistance sensors in the copper insert (15), in the middle of the protective heater near it. (13). And at the end of the cage of the protective heater (14).

2.5 Cooling design

Adjustments to the cooled side are not as radical in terms of access to measurement as on the heated side. The use of the ertacetal base has been shown to be unsuitable because of its deformation. This increases the risk of coolant leakage through the gasket between this base and the copper adapter. The base was therefore designed with different geometry and other material. It was considered to use the existing extension, but only for specific measurements when it will be necessary. In the basic configuration, this adapter has been replaced by a thermoelectric module in conjunction with a copper plate on which the temperature is measured. This change results in faster and easier control of

International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in; editorijoer@gmail.com
Vol.7., Issue.3, 2019
May-June

the temperature of the cooled side as well as significantly lower temperatures of the cooled side of the module. The cooling Peltier module is designed with dimensions of 62x62 mm. Between the heated and cooled parts of the device, it is proposed to place a radiation shield to reduce the heat flux between these surfaces.

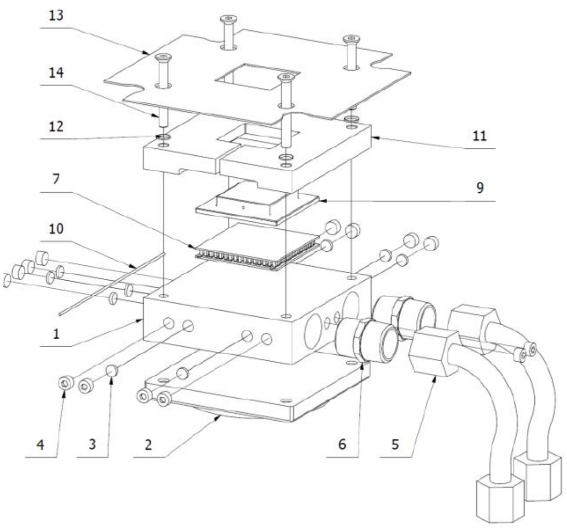


Figure 5: Assembly of the cooling part of the device

Considering these modifications, the cooled side is designed as follows: a copper water-cooled block (1) is placed on a stainless steel support (2), ensuring uniform pressure transfer. Holes are drilled in the cooled block into which the seals (3) are pressed to form a defined liquid flow path. At the ends, these holes are closed with screw plugs (4). Hose connections for fluid inlet and outlet (5) are provided with G3 / 4 double-sided threaded fittings (7). The heat flux is led to the cooled block via said Peltier element (8), which is connected to the measured module by a copper insert (9). The temperature on this insert is measured using a Pt100 sensor (10). The entire assembly of the Peltier cell and the copper liner is insulated with a foam ceramic (11) over which a radiation shield (13) is placed over the washers (12). The whole assembly is held integral with countersunk head screws M6 flush with the top edge of the radiation shield.

2.6 Design of thermal shielding and insulation

Because the device is designed for high temperatures - 600 ° C, it is very suitable to insulate the device well. This will reduce the power that will have to be supplied by the protective heater. For measurement at atmospheric conditions it is proposed to surround the heated and cooled parts with a layer of insulation. The insulation must be resistant to high temperatures and must be easy to disassemble even in multiple applications. Therefore, a solid insulation in the form of ceramic foam was chosen. In vacuum measurement, this insulation is not necessary as convection is suppressed as explained in the coming sections. Thus, in the case of a vacuum measurement, it is proposed to place a radiation shield between the device itself and the vacuum chamber housing.

2.7 Design of clamping system

It is not possible to use an existing thrust motor using the specified requirements. The first is the problem of torque transmission, the second is the impossibility of placing the engine in a vacuum where it would overheat. It was therefore necessary to design the whole system again. In the apparatuses described in the search part, nuts are often used to exert a thrust which compress the entire device against the springs. In this approach, it is necessary to take into account a number of influences that affect the resulting downforce and its distribution. Such as whether the springs become hot during measurement or the effect of uneven tightening of the sides. For this reason, a pressure system using a hydraulic piston was chosen. This method allows easy regulation of the applied force and minimal influence on the conditions prevailing inside the vacuum chamber.

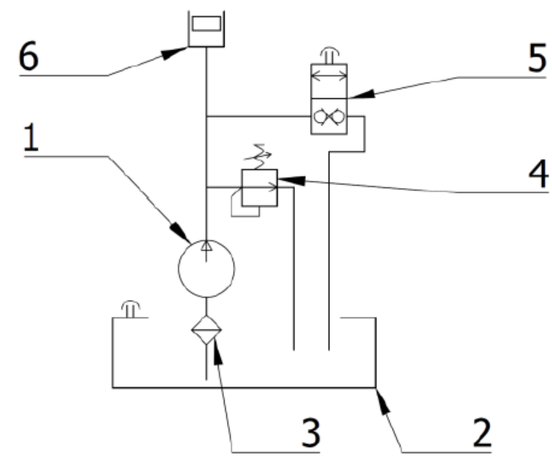


Figure 7: Hydraulic circuit diagram

The piston is designed to be single acting for ease of implementation. The piston is located at the bottom of the vacuum chamber. A grommet passes through this bottom and is further connected to the oil system. An oil system schematic can be seen in FIG. 33. The hydraulic pump (1) pumps oil from the tank (2) through the filter (3) into the pressure part of the machine. The pressure is controlled by the pressure relief valve (4). The manual valve (5) is considered for manipulation with the piston (6).

2.8 Vacuum chamber design

In the design of the vacuum chamber, consideration was given to unrestricted access to the device inside with the chamber open. Thus, the structure was gradually coming out of a vertically placed tube permanently blinded on one side. For access to the chamber, this lid can be completely removed, so as not to reduce the working space on the device.

2.9 Instrumentation

In addition to the equipment necessary for the operation of the parts described above, namely the vacuum pump and the oil pump, measuring and other equipment must be modified by changing the parts of the equipment. Due to the complete overhaul of the heated part, two additional power supplies are required to supply the heating protective heater. It is also necessary to control those using PID controllers. Resistance temperature sensors are also used instead of thermocouples for temperature measurement. The minimum number of measured temperatures dropped to four. For cooling it is possible to use an existing cooling loop equipped with compressor cooling.

2.10 Determination of vacuum technology

The apparatus is designed for measurement under unregulated conditions, argon atmosphere and low pressure. Measurement in an argon atmosphere is considered to protect individual parts from oxidation at high temperatures. The requirement for vacuum measurement was to eliminate the effects of convection and heat conduction in order to achieve the highest possible temperatures. Given the difference in purchase prices of oil and turbomolecular pumps, this part of the thesis is devoted to the assessment of the possibility of using these two pumps. This will be achieved by comparing the total thermal conductivity between the device under consideration and the chamber walls. A value of <1% compared to atmospheric measurements will be considered as a sufficient reduction in the overall thermal conductivity of the environment. For the calculation, the flow in an enclosed space of rectangular shape with a height H = 0.3 m and a wall distance L = 0.1 m will be considered. The total thermal conductivity at atmospheric pressure will be calculated first.[15]

3.0 Results

3.1 Verification of functionality of proposed modifications

The aim of this chapter is to assess the functionality of the proposed solutions described above. For this purpose, the measurement conditions necessary for temperature simulations will be determined first. The ratio of the heat flux delivered by the measuring resistor to the heat flux that passes through the hot side measured by the TEM will be taken as an indicator to assess the functionality of the design.

3.1 Thermal simulations

The simulation program ANSYS was chosen for verification by simulations. The original models created in the design of the device have been partially simplified to maintain their functional parameters, for example, by removing the hexagon socket at the screw heads. To simulate the atmosphere inside the chamber, a model of air was created to follow the interior of the vacuum chamber and the external shape of the device. The measured TEM was replaced by a module with a thermal conductivity corresponding to the modules. The Peltier cell was neglected during the measurement and replaced by a copper plate. The temperature of the heating resistance was determined to be 600°C; this temperature was chosen due to the higher load on the device and thus higher sensitivity to possible errors. Although symmetry is often used with simulation methods, this device was not possible due to the combination of axial and area symmetry in different parts. Individual materials were considered with the following properties.

International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in; editorijoer@gmail.com
Vol.7., Issue.3, 2019
May-June

The simulations were performed at atmospheric pressure, low vacuum 0.5 Pa and high vacuum, where the thermal conductivity of the environment was neglected. The results of these simulations are compared with simulations performed on the model of the existing equipment. Since the existing equipment was not built at such high temperatures, the conditions were adjusted to a heater temperature of 250 ° C and a cooling of 50 ° C.

Table 1: Properties of materials used in simulations

Material	Emissivity [-]	Thermal conductivity [W / mK]
Copper[16]	0.07	388
Ceramic foam[17]	0.6	0.15
Stainless steel [18]	0.8	16.7
Kanthal A[19]	0.7	13
AlN[20]	0.73	72
Al_2O_3[21]	0.9	18
Air (101325 Pa)	-	0.04
Air (0.5 Pa)	-	0.02
Aluminum[22]	0.19	237
TEM[23]	-	1.5

**Super Scripts indicates references*

3.2 Simulation under atmospheric conditions

The input parameters of the simulations were entered as described in the previous section. The aim is to assess the suitability, quality and usability of the structure for measurement under atmospheric conditions. Because heat transfer conditions vary considerably with pressure, minor adjustments to the equipment are also required to achieve the desired results. The changes concern radiation shields. The radiation shield described in the design of the device has been changed to a smaller one, following the shape of the protective heater. This change was necessary to allow easy installation of insulation around the entire equipment. This change made the use of an external radiation shield unnecessary. Therefore, it was not considered in the simulations. The heat transfer coefficient was chosen from the calculation above and increased to ensure less favorable conditions. The value was thus set at 2.5 $Wm^{-2}K^{-1}$. The value of the heat transfer coefficient on the outside of the vacuum vessel was determined to be 5 $Wm^{-2}K^{-1}$

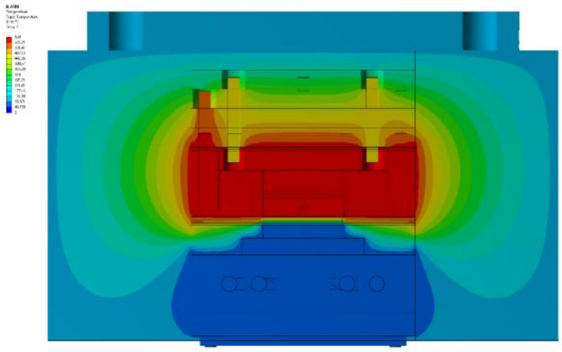


Figure 8: Temperature field distribution during simulation of measurements under atmospheric conditions

On figure. 8 shows the temperature distribution in cross-section through the device. The temperature remains constant throughout the volume of the protective heater, so the basic requirement has been met. The asymmetry is given by the plane of cut, which passes through the area in which the location of the thermal probe is designed, to move the housing out of the internal space of the heater, a screw holding the protective heater connected to the insulation has been moved. It is also apparent that, under these measurement conditions, the cooled side is considerably affected despite the use of a radiation shield. This is not suitable when trying to achieve the highest temperature differences.

The cross-section of the apparatus showing the specific heat flux confirms the above statement. Thus, the thermal power generated by the measuring heater is conducted through the thermoelectric module and not into the environment. Significant heat flux can also be observed on the radiation shield. The concern that connecting the power to the measuring heater with threaded rods would result in heat dissipation from it was not confirmed. Although some heat flow flows through them, it is the heat supplied by the overhead heater.

The distribution of the specific heat flux across the TEM area was chosen as the last qualitative indicator. As shown in fig. 9 the layout is very consistent with small fluctuations at the module edges. We can say that the loaded module will work constantly over its entire surface.

International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in; editorijoer@gmail.com
Vol.7., Issue.3, 2019
May-June

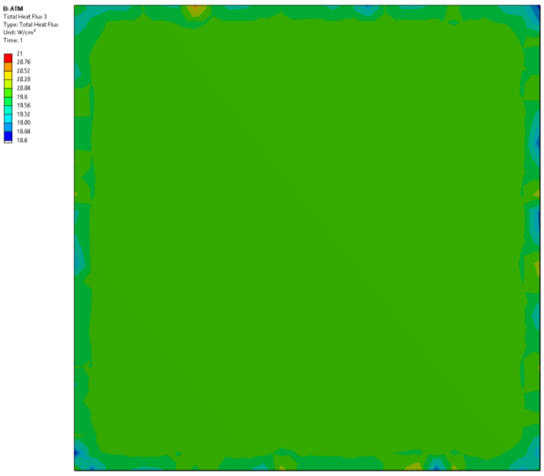


Figure 9: Distribution of specific heat flux across the area of the measured module when simulating measurements under atmospheric conditions

3.3 Simulation under reduced pressure

Since the cost of the oil pump is much lower than the turbomolecular pump, the conditions considered unsuitable in the previous section will also be considered. The design of the equipment was chosen as for high vacuum measurements. In the temperature field FIG. 10 shows the function of a heat shield that divides the device at the level of the module being measured. Due to the presence of a thermally conductive atmosphere and the absence of thermal insulation to prevent heat transfer by radiation, there is greater influence on the cooled side than in simulation under atmospheric conditions. The external radiation shield is heated to ≈180 ° C. Even under these conditions, the constant temperature condition inside the protective heater is maintained.

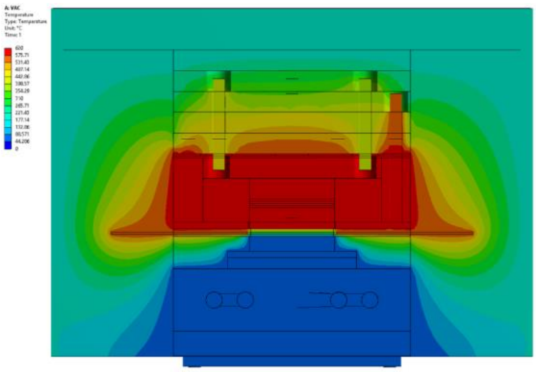


Figure 10: Temperature field distribution when simulating measurements under reduced pressure

3.4 High vacuum simulation

Since it is costly to achieve these conditions, it is appropriate to verify that the preconditions that make this requirement are met. Under these conditions, conduction and heat flow are neglected. It is expected that the highest temperature difference on the module will be achieved and that the measurement of heat fluxes will be least affected where this is not required.

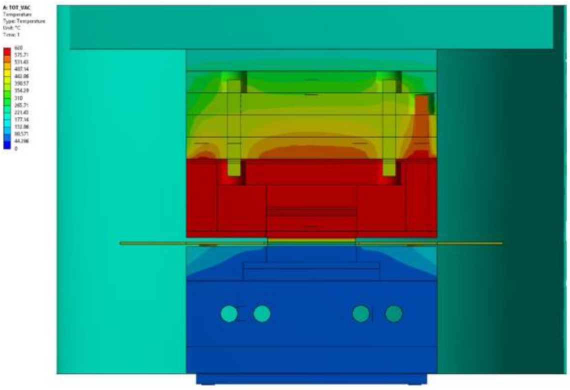


Figure 11: Temperature field distribution in high vacuum measurement simulation

In the temperature distribution FIG. 11, it is clear that the insulation and radiation shield on the cooled side of the device are less affected by the heated side. For a heat shield, this temperature difference is about 100 ° C. On the surface of insulation up to 200 ° C. The screws holding the radiation shield are considerably less stressed. The only adverse effect that can be observed is an increase in the temperature of the pressure flange.

3.5 Simulation of existing equipment

To compare and evaluate whether the design of the proposed device is beneficial, the measurement under atmospheric conditions on the original device was simulated. As mentioned above, the temperature of the heated side was selected at 250 ° C and cooled at 50 ° C. The TEM measured was considered to have the same characteristics as in the previous cases. The boundary conditions were the same as in the previous section.

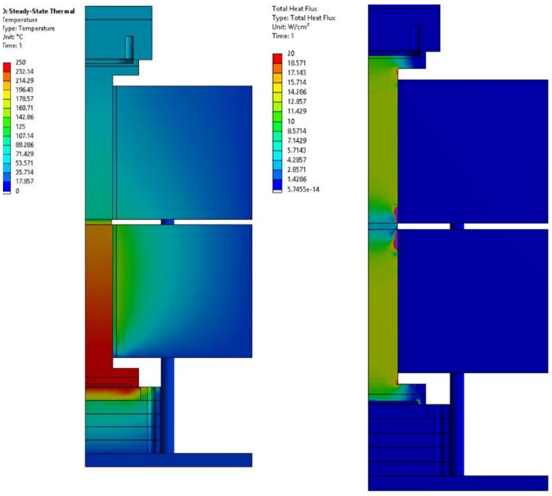


Figure 12: Distribution of temperature field and specific heat flow during simulation of existing equipment

The temperature field corresponds to the assumptions. Due to the considerably longer length of the extender, the thermal difference at both ends is 30 ° C. Due to the method of heat flux measurement, it is not possible to change this state. The temperature difference on the extender was only 8 ° C for the heated side, resp. 10 ° C for the cooled side. Significant differences in specific heat flux near the module can also be observed. The distribution of the heat flux across the module area shows that there is a significant decrease towards the corners of the module. This can result in uneven power distribution between the individual columns of the module. The resulting values calculated under these conditions will be considerably inaccurate. As the temperature rises further, this inaccuracy can also be expected to increase.

4.0 Conclusion

The current measuring apparatus has some drawbacks. The main problem encountered in use is the deflection of the components in the area of the cooling block. Because since the time of its establishment, the demands on the apparatus have been increased. This caused that the maximum working temperature of the plate heaters used was not sufficient. This problem is exacerbated by the chosen approach to heat flow measurement, when the temperatures at the edges of the module are about 30 ° C lower, resp. higher for the cooled side, based on TEM Marlow Industries TG-12-6 catalogue values.

The extent of adjustments necessary to meet newly defined requirements was evaluated. These modifications mean a change to the entire device. The modifications are therefore considered as a design of the new equipment. The design used a different approach to heat flow measurement, which does not use a block of reference material for its determination, but the power supplied by the voltage source. The condition for the use of this method is to ensure adiabatic conditions of the surroundings of the measuring heater. The advantage of this approach is a significant reduction in the temperature difference between the heater and the sample being measured. This will make it possible, together with other adjustments, to achieve the desired temperature increase. The whole system was designed for use in the vacuum chamber, which is part of the design, as well as the hydraulic pressure system. The vacuum chamber is designed with regard to the possibility of creating an inert atmosphere. It has been calculated that an oil pump is not sufficient to derive conditions where conduction and heat flow can be neglected and a turbo molecular pump will have to be used.

In order to verify the functionality of the modifications, a simplified version of the device model was created, in which various measurement conditions in the ANSYS program were simulated. These conditions were measurements at atmospheric pressure, 0.5 Pa pressure and deep vacuum. The results of these simulations correspond to the assumptions and confirm the functionality of the solution. In all simulations, adiabatic conditions in the vicinity of the measuring heater were ensured, and thus the condition necessary for the functionality of the proposed approach was observed.

Simulations at atmospheric pressure showed the disadvantages of the presence of a thermally conductive atmosphere. This caused that the thermal insulation on the cooled side was considerably heated. This increases the cooling demand because this heat has to be dissipated through the cooling loop. In this case, the radiation shield reaches temperatures about 50 K lower than the lower surface of the protective heater. Despite such unfavourable conditions, a good heat flux distribution was achieved on the heated side of the module, where the difference between the maximum and minimum specific heat flux was 2 Wcm^{-2}. The temperature on the heated side of the module was 592° C and on the cooled 60 ° C.

The state at a pressure reduced to 0.5 Pa indicates that it is inappropriate to use a slight vacuum and radiation shield instead of thermal insulation. Under these conditions, although a significant amount of added technology is required over atmospheric pressure measurements, they do not have a positive impact on the temperature field in the plant. The specific heat flux at the heated part of the measured module was more uneven than in the simulations at atmospheric pressure, namely 4.7 W / cm^2. This inaccuracy can already be assessed as significant if it were spread over the entire area. Since values with a greater deviation from the average temperature are present only on a small part of the module, it can be said that their effect will not be too great. Another criterion was the calculation of the inaccuracy of the indirect measurement, where the error was calculated based on the instruments used, using the catalogue parameters to determine the measurement conditions. The greatest error difference was achieved in the calculation of heat flows and the quantities calculated from them. Here it was calculated that when the heat flux on the reference material is measured, the temperature differences achieved are too small due to the inaccuracy of the temperature measuring probes used. The objectives set out in this work can therefore be considered fulfilled. The proposed device will be able to achieve higher temperature differences, it will be able to be placed in a vacuum and the measurement error will be reduced.

References

1 ROWE, David. Thermoelectrics handbook: macro to nano. 1st edition. Boca Raton: CRC/Taylor, 2006. ISBN 978-0849322648

2 GAYNER, Chhatrasal a Kamal KAR. Recent advances in thermoelectric materials. Progress in Materials Science. 2016, 83, 330-382. DOI: 10.1016/j.pmatsci.2016.07.002

3 XIE, Wenjie, Jian HE, Hye KANG et al. Identifying the Specific Nanostructures Responsible for the High Thermoelectric Performance of(Bi,Sb)2Te3 Nanocomposites. Nano Letters. 2010, 10(9), 3283-3289. DOI: 10.1021/nl100804a

4 HEREMANS, J., V. JOVOVIC, E. TOBERER, A. SARAMAT, K. KUROSAKI, A. CHAROENPHAKDEE, S. YAMANAKA a G. SNYDER. Enhancement of Thermoelectric Efficiency in PbTe by Distortion of the Electronic Density of States. *Science*. 2008, **321**(5888), 554-557. DOI: 10.1126/science.1159725

5 ROWE, David. CRC handbook of thermoelectrics. 1st edition. Boca Raton, FL: CRC Press, 1995. ISBN 978-0849301469.

6 NOLAS, G., M. KAESER, R. LITTLETON a T. TRITT. High figure of merit in partially filled ytterbium skutterudite materials. *Applied Physics Letters*. 2000, **77**(12), 1855-. DOI: 10.1063/1.1311597.

7 HSU, Cheng-Ting, Gia-Yeh HUANG, Hsu-Shen CHU, Ben YU a Da-Jeng YAO. An effective Seebeck coefficient obtained by experimental results of a thermoelectric generator module. Applied Energy. 2011, 88(12), 5173-5179.

8 MAN, Elena, Erik SCHALTZ, Lasse ROSENDAHL, Alireza REZANIAKOLAEI a Dieter PLATZEK. A High Temperature Experimental Characterization Procedure for Oxide-Based Thermoelectric Generator Modules under Transient Conditions. *Energies*. 2015, **8**(11), 12839-12847

9 SANDOZ-ROSADO, Emil a Robert STEVENS. Experimental Characterization of Thermoelectric Modules and Comparison with Theoretical Models for Power Generation. *Journal of Electronic Materials*. 2009, **38**(7), 1239-1244.

10 MITRANI, D., J.A. TOME, J. SALAZAR, A. TURO, M.J. GARCIA a J.A. CHAVEZ. Dynamic measurement system of thermoelectric module parameters. In: Proceedings ICT'03. 22nd International Conference on Thermoelectrics (IEEE Cat. No.03TH8726). IEEE, 2003, s. 524-527

11 CIYLAN, Bünyamin a Sezayi YıLMAZ. Design of a thermoelectric module test system using a novel test method. International Journal of Thermal Sciences. 2007, 46(7), 717-725. DOI:10.1016/j.ijthermalsci.2006.10.008

12 AHISKA, R., S. DISLITAS a G. OMER. A new method and computer-controlled system for measuring the time constant of real thermoelectric modules. Energy Conversion and Management. 2012, 53(1), 314-321.

13 MAHAJAN, S. A Test Setup for Characterizing High-Temperature Thermoelectric Modules. Kate Gleason College of Engineering, 2013. Thesis

14 RAUSCHER, L., H.T. KAIBE, H. ISHIMABUSHI, S. SANO, E.W. MULLER aD. PLATZEK. New approach for highly accurate efficiency determination of thermoelectric generator modules. Proceedings ICT'03. 22nd International Conference on Thermoelectrics (IEEE Cat. No.03TH8726). IEEE, 2003, , 508-511. DOI:10.1109/ICT.2003.1287560. ISBN 0-7803-8301-X.

15 INCROPERA, Frank. Fundamentals of heat and mass transfer. 6th ed. Hoboken, NJ: John Wiley, 2007. ISBN 978-0471457282.

16 Emissivity Coefficients of some common Materials. Engineering ToolBox [online]. 2003 [cit. 2018-05-25]. https://www.engineeringtoolbox.com/emissivitycoefficients-d_447.html

17 Emissivity Materials. Http://www.infrared-thermography.com [online]. 2000 [cit.2018-05-25]. Available from: http://www.infrared-thermography.com/material-1.htm

18 Stainless Steel - 17-7PH - online catalogue source - supplier of research materials in small quantities - Goodfellow. Supplier of materials for research and development – Good fellow [online]. b.r. [cit. 2018-05-25]. http://www.goodfellow.com/E/Stainless-Steel-17-7PH.html

19 Mechanical and physical properties. KNTL a.s. Kanthal brand in the Czech Republic and Slovakia KNTL [online]. b.r. [feeling. 2018-05-25]. Available from: http: //www.kntl.cz/getFile/case: show / id: 17737

20 Temperature Sensors and Heater Plate Materials Suitable for Use in High-Temperature Guarded Hot Plate. National Physical Laboratory [online]. [cit. 2018-05-25]

21 Aluminum Oxide, Al_2O_3 Material Properties. Accurate, Engineered Advanced Technical Ceramic Components, Ceramic Materials [online]. 2013.

22 Aluminum - Radiation Heat Emissivity. Engineering ToolBox [online]. 2003 [cit.2018-05-25].

23 POWELL, R., C. HO a P. LILEY. *Thermal Conductivity of Selected Materials*. UNITED STATES DEPARTMENT OF COMMERCE, 1966.