21st International Conference ENGINEERING MECHANICS 2015
Svratka, Czech Republic, May 11 –14, 2015
Paper #194, pp. 174–175

Prediction of Optimal Load and Performance of Thermal Batteries

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Keywords: Thermal battery, internal resistance, optimal load, optimal performance.

Abstract: Direct conversion of heat into electrical energy is one of appropriate alternatives to generating electric current in conventional ways. Although thermal batteries are now usually used beyond the reach of energy distribution networks, however, prospectively, their wider use could be considered. In particular, more than 50 % of the energy used in homes, in car engines it is up to 70 %, is being lost as waste heat (for example – heated car exhausts, waste heat from refrigerators, computers, or solar panels can be used to power electrical circuits in those appliances).

Historically, in manufacturing the first thermal batteries, only metals (tellurium, antimony, germanium, silver) were used, later then different alloys and semiconductors. Lead telluride is considered to be the most effective thermoelectric material, but it is not allowed because of its toxicity. Material researchers from the University of Osaka achieved promising results with the use of nickel and iron, but with the addition of thallium, i.e. also a toxic element. Researchers from General Motors very intensively examine skutterudites allowing heat absorption and passage of electric current, and conveniently with regard to relatively high temperature differences [1]. Further development of thermoelectrically efficient materials in the future should be oriented in particular to an environmental thrift and a relatively high efficiency, i.e. to material and structural resistance to high temperature differences (in the hundreds of degrees Celsius), which would allow to utilize significant waste heat from high-temperature processes (e.g. in steel production, etc.).

To demonstrate a sample measurement of proposed performance characteristics, classical thermal batteries of ternary alloys have been chosen. Ternary alloys are characterised (compared to metals or semiconductors) by relatively convenient values of material coefficients. Using them, for example, for the temperature difference from 400 to 1 000 K, theoretically up to 30 % of material efficiency can be achieved. Practically, however, the temperature differences tend to be lower in the use of waste heat (as a result of heat dissipation into the surrounding environment and to the equipment itself). Even high temperature differences, however, do not guarantee a high level of efficiency of thermal batteries of ternary alloys, because under relatively high temperature differences, the thermal batteries are considerably amortisable.

Measuring internal resistance of thermal battery

Impairment of efficiency in thermal battery amortisation is primarily caused by growing internal resistance R_i. The temperature developments of the internal resistance of thermal batteries of ternary alloys was measured; the measurement results were then compared with the indirect measurements of internal resistance (computationally), namely repeatedly under comparable operating conditions and the corresponding temperature differences ΔT (U_S Seebeck thermoelectric and electromotoric voltage, I thermal current, R resistance of load).

$$R_i(\Delta T) = \frac{U_S(\Delta T) - I \cdot R}{I} \tag{1}$$

The thermal battery of ternary alloys can be evaluated as a source of hard voltage; the terminal voltage under load is detected as the smaller, the greater thermal current is taken. So, if the thermal battery has very small internal resistance compared to external load resistance, the terminal voltage under load varies very little. The problem arises when the thermal battery is thermally amortised.

Amortised thermal batteries behave in an electrical circuit as non-linear elements, i.e. they exhibit non-linear current-voltage characteristics.

Performance measurement and optimum load determination

Thermal batteries of ternary alloys heated by an external heat source were a source of Seebeck electro-motoric voltage. Performances of 3 classic thermal batteries were measured, namely under various loads at different equi-temperature levels. For this purpose, measurements of the 1 temperature of walls, 2 current, 3 terminal voltages under various loads (resistance standards) were made. Under comparable conditions, the measurements showed a qualitatively comparable character of the dependence of performance on load resistance and a comparable character of the dependence of performance on the temperature difference between the thermal battery walls. The optimum load R_{opt} was found by the method of least squares as maximum performance squares were sought using a local extreme of functions as follows

$$P_{max} = U_{max} \cdot I_{max}. \qquad (2)$$

These maximum performance squares were inscribed in the appropriate performance triangles for the given temperature difference ΔT between the thermal battery walls. The straight line of the optimum load was a connecting line of all maximum performance levels P_{max} of all equi-temperature levels of the carried out measurements (Fig.1).

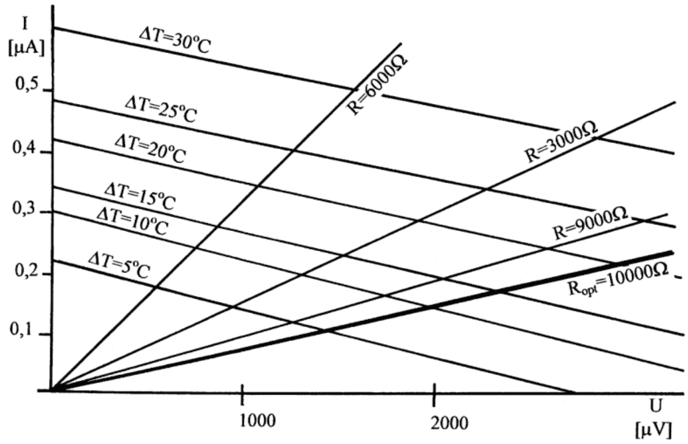

Fig. 1: Character of the dependence of performance of the thermal battery of ternary alloys (thermal current and thermal voltage under load *R*) for a temperature difference between the thermal battery walls ΔT and prediction of the optimum load R_{opt} for maximum performance.

Conclusions

In conclusion, it can be said that for each thermal battery with regard to its specific material, geometric and structural properties, a maximum permissible operating internal resistance to be specified and the internal thermal battery resistance to be continuously monitored. In addition, such optimum operating load of each thermal battery was determined in order to submit the maximum possible performance linearly dependent on the temperature difference between its walls.

References

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