Research of the possibilities of SmartEnergyCoating applying for thermal insulation of engines in harsh climate

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Abstract. The investigated SmartEnergyCoating is able to generate electricity independently, provide a stable temperature regime for some types of technological coatings, elements of machines and control systems. The article presents the results of investigation to determine the time of the efficiency of the composition elements for the possibilities of generating electricity by the temperature difference between the technological coating and an environment.

1. Introduction

The developed material SmartEnergyCoating is an innovative form of energy production at the surface of machine elements and control systems along with effective insulating properties. This coating has proven effective in the laboratory [1-3]. It can be used to convert low-grade heat from various sources into high-quality energy, which can be used to transfer signals and other purposes, as well as to use and store energy in several forms. The authors propose to modify the material with a layer containing the phase transition material and thermoelectric elements to improve its thermotechnical properties.

In some technical processes, there is an excess of waste heat. This energy is lost in an environment or gives heat or cooling to the surrounding elements, which can convert for future use. The developed material does not require high labour requirement and consists of a simple structure. The material can use in extreme temperatures and harsh climate, especially in harsh climatic conditions, where temperature fluctuations during the day can reach more than 20-25 degrees. Also the material can be used in emergency conditions when other sources of energy cannot work, when structures, pipelines or installations is used in non-stationary temperature conditions or processes with excessive heating and loss to the environment.

Earlier, the advantages of the developed material were noted [4,5,8]. It is a best way to get energy in a small space. The absence of moving parts makes the system very reliable. There is no need to change the refrigerant (for example, freon, because it is away), no sensitivity to vibrations, what is important for transport. Thermoelectric devices do not contain toxic refrigerants. This is an environmental friendliness [6,7,9]. There is the possibility of smooth and precise temperature regulation [10-17]. The material can have an arbitrary orientation in space and a gravitational field and can apply to any surface.

The elements for thermal insulation are securely fixed in their layer, can be defined in compliance with working conditions and provide a thermal mode. The material has a slight inertia and transforms from cooling to heating mode easily.

In previous studies, dependences of the geometry, shape, and composition of the material that could affect the temperature profiles and behaviour were determined. Also it has been proven that thermoelectric effects are associated with temperature lines and a temperature gradient. The distribution
gradient and coating behavior can model for specific operating conditions. The possibility of theoretical control of thermoelectric effects with thermal properties of materials was been proven also. Next research is aimed at the identifying of the dependences of the heat-insulating materials included in the composition on the thermal characteristics and properties of the material layers. For the study, we took the case of using Smart Energy Coating for generating excess heat from a motor or warm surface.

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2. Theoretical description of the process
In the developed coating the thermal insulation materials and thermal mass play a certain part. The model contains the heat source, what accumulates heat mass with a specified heat capacity and environment with variable dynamic parameters.

For the generality of the processes description for the model, the heat transfer is composed of heat conduction and convection. The radiation component is been excluded, considering that in the process the radiation losses are minimal.

The study was conducted the Simulink model using. For simplicity, it accepted the model consist of a heat source with a total thermal power $P$. The temperature inside the coating is $T_i$, the ambient temperature is $T_{amb}$. We are interested in how the temperature $T_i$ changes when the power $P$ changes. Since the ambient temperature is negative, the heat flux distributes from a heated source to a cold one. (Fig. 1).

![Figure 1](image-url)

**Figure 1.** Model of the coating energy flows along the input-output during engine operation in the energy storage mode.

Before modelling, it should to consider some properties. Firstly, if the heat source is turned on, then the temperature will rise and stabilize. In this case, a thermal equilibrium has been reached between the
external heat and accumulated by the heat mass. Then it will be dissipate into the environment. If the 
heat source is turned off then temperature and energy decreases. Finally, the temperature of the coating 
brings closer the ambient temperature, but it has time to accumulate a determine energy already. In this 
case the essential parameters of the model are: 

Ambient temperature - the lower it is, the more heat leaves by the coating and the more heater power 
need to insulation. The bed thermal insulation - the more heat has been releasing into the environment. 

Heat capacity and mass inside the coating. The larger this parameter, the more energy is required and 
the heating time to a predetermined temperature is longer. Also the coating saves the heat during long 
time when the source of heating is turned off. 

In heat engineering, there are models that simulate heating and cooling processes with varying order 
of accuracy. Further, we will consider the simplest of them. For this, it is necessary to introduce the 
concept of the heat amount. It is the energy necessary to change the thermodynamic parameters of a 
body (for example, temperature). 

The amount of heat \( Q_i \) that comes from a heat source or heater with a power \( P \) during time \( \tau \) is the 
time integral:

\[
Q_i(\tau) = \int_0^\tau P(t) \, dt \tag{1}
\]

To determine a waste heat to the environment, it is necessary to use the concept of heat flux \( Q_{amb}(t) \) - 
the amount of heat passing through the surface per time unit. The unit heat flux is proportionally to the 
temperature difference:

\[
Q_{amb} = -k (T_i - T_{amb}) \tag{2}
\]

Over a particular period of time:

\[
Q_{amb}(\tau) = -k \int_0^\tau (T_i(\tau) - T_{amb}) \, d\tau \tag{3}
\]

The general heat balance equation is:

\[
Q = Q_i + Q_{amb} \tag{4}
\]

By differentiating both parts by time, we can write down a differential equation of relating the 
dynamics of the temperature \( T_i(\tau) \) to the heater power:

\[
cm \frac{dT_i}{dt} = k(T_{amb} - T_i(\tau)) + P(\tau) \tag{5}
\]

Designate the coefficient \( cm = a \) and dividing the variables for integration, we can write:

\[
Q(\tau) = a \int_0^\tau (k(T_{amb} - T_i(\tau)) + P(\tau)) \, d\tau \tag{6}
\]

The last expression is a model of the heat transfer process, when heat is received from the engine and 
the cold from the environment. To control the properties of the coating, we cannot directly affect the 
ambient temperature parameter \( T_{amb} \), so we can monitor the parameter \( P \). 

Let's to see how this system was simulated using Simulink. 

3. Modelling 
The part of the model diagram in which the connections between the blocks are present and their settings 
are shown in Figure 2.
The temperature inside the coating drops from a given temperature to a certain temperature. In this case, the specific heat of the coating for calculations is \( C = 3.2 \text{ kJ / kg} \cdot \text{°C} \), the mass of the material is 1 kg, the heat transfer coefficient is \( k = 0.34 \text{ W / m}^2 \cdot \text{°C} \), taking into account the heat of the phase transition.

**Figure 2.** Preliminary model diagram.

The upper graph shows the expected temperature of the coating, the lower graph shows the daily temperature difference. The initial temperature of the coating has been equal +5 degrees, because the motor has not cooled down yet.

From the results of the graphs, it can see that we can wait for the Smart Energy Coating to cool for some time without reducing the power generation. But it is necessary to provide for the engine starting. After the heater starts the temperature parameters reach the required values in short time. Those, we found that the design parameters of the coating composition to eliminate the need of the heater activation during 4 hours after temperature reduction. This time uses to the thermodynamic equilibrium between heat supplied by the heater and outward. With these composition parameters SmartEnergyCoating, we simulated the time of thermal energy receipt and its probable transition into electrical energy. The model allows making the dependence of the composition cooling time without heating at certain temperature parameters and determining conclusions about the parameters of coating composition.

By thermal conductivity change and different heat capacity of SmartEnergyCoating we can maintain a certain temperature level of the coating depending on the temperature (material properties), to improve the properties.

**4. Implementation**

After simulation results, a prototype SmartEnergyCoating with certain properties was created. SmartEnergyCoating features were improved. The phase transition structure has been composing in such
a way, that its melting point was equal to the work temperature (ambient). The phase material was resolved on which provided for a synthetic paraffin substance and adaptable physical properties.

The generated electricity can use for pipelines with automation elements, heat-insulating composite materials and electricity generating. The paper presents the effect of thermal insulation and independent energy production by the coating. Most of the mass of the phase-transition material is located on the outer surface. This allows ensuring the damping of temperature deformations and independent power supply to remote elements.

One of the goals of this study was to modelling the coating installation under the hoods of cars in freezing conditions to prevent prolonged warming up during “cold start” of the car. Installation of the coating allowed reducing the time between engine starts, since heat accumulation takes place. In addition, a small amount of current can use to add power to the starting torque. Flexible conductive compounds constantly supported the work of the phase transition material and allowed to work with a sufficient level of quality. In this case, linear elongation of the base material did not occur, and the coating worked as a heat-insulating layer with electricity generation.

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