Application of thermal effect as a means to combat ground-and-machine part adhesion

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Abstract. The main cause of the efficiency decrease in productivity of earthmoving machines is the adhesion and friction increase during the development of wet bonded soils under freezing point. This problem exists both in Russia and abroad. When developing frozen clay and wet soils operational winter, the bucket filling and the excavator speed is much lower in winter than in summer. Wet soil, contacting with cooled walls of the bucket, quickly freezes to them, reducing the useful capacity of the bucket and makes unloading difficult. The analysis of self-regulating heating elements has been reviewed. Three TM-40, TM-60 and SRL 30-2 heating elements are considered as possible options to use directly on the excavator bucket to loosen adhesive bonds by heating the working surface of the plant. The results of experimental research are presented, one-factor equations of plate heating temperature regression for each of the heating elements are presented, temperature-time characteristics of three heating elements are constructed, comparative analysis of three TM-40, TM-60 and SRL 30-2 heating elements is made.

1. Introduction
The existing methods for friction and adhesion reducing can be divided into four groups. The first one includes the creation of an intermediate layer in the contact boundary which can serve as a protective screen for molecular phase interaction and must have an adhesive interaction. The second group includes methods resulting in adhesion bonds decrease under external effect. The third approach is based on the structural and mechanical methods. The fourth group is a combination of two or more methods to reduce adhesion[1-10].

In this article the method of external effect is considered, the heating elements in the form of self-regulating heating cables TM-40, TM-60 and SRL 30-2.

2. Formulation of the problem and the method of solution
Let's consider the application of heating elements for loosening of adhesive bonds of a frozen ground in a contact zone of a working metal surface.
Heat cables are the specific type of cables transforming electrical energy into to provoke process for heating and act as a receiver of electrical energy rather than a transmission line. Heating cables differ significantly from ordinary cables and wires, the duty of which is to transmit electrical energy with the smallest losses and with a small voltage drop not more than the length of the line (usually no more than 5%) [5,8].

The heating cable is used in the form of heating sections, i.e. sections of a certain length, when the
applied voltage drops completely. Therefore, the heating section should be considered as an standard receiver of electric energy (as a type of electric heating element).

The negative effect of dissipation of the transmitted energy volume in the form of heat, which is negative for standard cables, but as useful one in heating cables. And the transformation of electrical energy into heat is made in the most optimal and economical way. The transformation is complete, silent, without adding some more substances (fuel, oxidant).

Figure 1 shows the scheme of operation principle of self-regulating heating elements of cables.

The function of the self-regulating heating cable is based on the basic property of the electric current conductor: while heating its resistance increases, and the higher the resistance is, the lower the current strength is and, that means, the power is consumed. The section of the cable that is located in a cooler point has lower resistance, through the heating matrix in this point has a high current flow, and it results in higher heating capacity of the cable and more intensive heating of the pipe. If the temperature is higher, the resistance of the matrix in this point becomes greater and the current flowing through the matrix decreases. Thus, when the self-regulating cable in a pipe with frozen water is switched on, it is switched on at total power and makes the pipe heat up, and the power gradually increases.

The heating cable, itself, does not switch off when the desired temperature of the heated pipe is reached, it continues to function on, but the power decreases. For example, the cable is used in the water pipe section at the entry into the house in winter, to maintain the pipe temperature at +5 degrees preventing its freezing. The self-regulating cable wouldn’t switch the heating process at +5 degrees or higher and wouldn’t switch itself when the temperature drops below +5 degrees, it will continue working, but might vary operationa intensity.

Table 1 shows the comparative specification of the heating elements of the three brands: heating element capacity, outdoor heating temperature, supply voltage and cable length, and shows the application area of the heating elements for each of the three brands.
Table 1. Heating elements characteristics.

| Specifications                  | TM-40 | TM-60 | SRL 30-2 |
|--------------------------------|-------|-------|----------|
| Capacity, W/m                  | 40    | 60    | 30       |
| Air heating temperature, °C    | 95    | 115   | 85       |
| Input voltage, V               | 220   | 220   | 220-240  |
| Cable length, m                | 6     | 6     | 6        |
| Field of application           |       |       |          |
| TM-40                          | Concrete heating, in the refrigeration industry |
| TM-60                          | Concrete heating, in the refrigeration industry |
| SRL 30-2                       | Gutter and roof heating, plumbing heating, tubing and tube heating, reservoir and tank heating |

The analysis of heating cables of TM-40, TM-60 and SRL 30-2 was carried out to reveal the most effective heating element of the maximum heating temperature at the operating time of 10 min. To simulate a working surface the special shift stand was used. The experiment was carried out in a room at the temperature of 20 degrees.

Heating of the metal plate with the heating element has been carried out for 10 min, the values of the heating temperature depending on the contact period were measured in the values of 2, 4, 6, 8 and 10 minutes.

The results of the experiment are shown in table 2.

Table 2. Results of the experiment.

| The heating cables | Plate heating time, min. |
|--------------------|-------------------------|
|                    | 2  | 4  | 6  | 8  | 10 |
| TM-40              | 15 | 16 | 17 | 19 | 20 |
| TM-60              | 22 | 31 | 39 | 46 | 51 |
| SRL 30-2           | 10 | 12 | 14 | 15 | 17 |

Figure 2 shows the general temperature-and-time characteristics of the heating elements TM-40, TM-60 and SRL 30-2.

The results of the experiment are calculated mathematically.

The obtained results were calculated mathematically with the help of MODEL program for one-factor dependencies. To get the one-factor equations of regression the function \( y = C_0 + C_1 \cdot x + C_2 \cdot x^2 \).
The experimental data processing has been resulted in regression equations for three marks of heating cables TM-40, TM-60 and SRL 30-2. The obtained one-factor equations are shown in table 3.

**Table 3. Single-factor equations of plate heating temperature.**

| Temperature-time specification | Plate heating temperature, °C | \( Y = 14 + 0.435714 \cdot x + 0.017857 \cdot x^2 \) |
|--------------------------------|-------------------------------|-----------------------------------------------------|
| Temperature-and-time specification | Cable TM-40 at +20 deg | |
| Plate heating temperature, °C | \( Y = 8 + 1.064286 \cdot x - 0.017857 \cdot x^2 \) |
| Temperature-and-time specification | SRL 30-2 cable at +20 deg | |
| Plate heating temperature, °C | \( Y = 14.066667 + 4.642424 \cdot x - 0.090909 \cdot x^2 \) |
| Temperature-and-time specification | Cable TM-60 at +20 degrees | |

![General temperature-and-time specifications of heating elements](image)

**Figure 2.** General temperature-and-time specification of heating elements.

By means of Microsoft Excel program, on the basis of the obtained one-factor equations, the results have been received and presented on the table 3 of quasi-factor dependences at the fixed value of time
of plate heating. The obtained dependencies are shown in figure 3.

![Figure 3](image_url)

**Figure 3.** Dependence of the plate temperature and the heating contact time a) heating cable TM-40; b) heating cable TM-60; c) heating cable SRL 30-2.

3. Results and discussion
When moisture dispersed masses come into contact with the heated surface, the number of processes occur that can result in complex temperature dependency of the adhesion. It takes place when the temperature increase leads to the passage of firmly bonded ground moisture into less bound and free water. Reducing the viscosity and surface tension of water and increasing temperature reduce the capillary forces, which in some cases affect the adhesive component of friction force. Long-period contact at high temperatures leads to the intensive moisture vaporization and drying the contact area. Moisture drying, as a rule, is accompanied by the significant shrinkage, which, on the one hand, leads to the destruction of adhesive bonds and is consistent with previous studies [3,5].

4. Conclusion
The results of the experimental studies of the contact zone heating effect on soil-to-metal surface adhesion at negative temperature let us give a number of conclusions and practical recommendations. The review analysis of the application of self-regulating heating elements as a control of soil-to-metal
surface adhesion of earth-moving machines the working bodies has been carried out. Mathematical calculating of one-factor dependencies of the experimental data results obtain regression equations quasi-factor dependencies has been constructed.

The heating cable TM-60, as the most effective one, has been shown, according to the resulting in experiment, at each interval of time heating element TM-60 has shown, itself, more effective than heating cable TM-40, by 1.5-2.6 times higher. As for SRL 30-2 the heating cable TM-60 turns out to be 2.2-3 times more effective.

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