Evaluation of the efficiency of dry electrostatic cooling by the transfer current

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Abstract. Practical examples and physical mechanisms of dry electrostatic cooling efficiency when processing materials by cutting are considered. The assumption is made that efficiency of dry electrostatic cooling process depending on the mode of equipment operation directly depends on the value of electric charge carried by air flow - transfer current. A stand has been developed to measure the current flowing from an grounded plate under the action of dry electrostatic cooling airflow. Using the stand, experiments were made with the «Varkash» dry electrostatic cooling unit. As a result of the experiments, a relationship was found between the transfer current from air pressure and the length of the air flow. Experiments were made on turning structural steel with high-speed steel tools, varying the air pressure of the dry electrostatic cooling unit and the distance from the nozzle to the cutting zone. Based on the results of the experiments, it was verified that the transfer current corresponds to the efficiency of dry electrostatic cooling during cutting.

1. Introduction

An important component of the environmental impact of modern metalworking is the use of cutting fluids. In addressing the problem of reducing the use of coolants when cutting metals, we are actively researching methods of treatment without the use of cooling, with minimal use of liquids and the use of non-liquid coolants [1].

Dry electrostatic cooling (DEC) is based on the delivery of corona treated air [2] to the cutting zone under pressure.

Practical research by DEC has shown the efficiency of this technology when machining parts in the aerospace industry (stainless steels and nickel-based heat-resistant alloys) [3], hardened steels [4] and titanium alloys [5].

In addition to practical research, there are a number of works aimed at researching the tribological aspects of DEC efficiency [6, 7].

Theoretical research [8, 9] DEC for cutting determines three main efficiency factors: cooling, lubricating effect and strength reduction (Rebinder effect). The cooling effect of DEC is to increase the heat exchange processes in the presence of crown discharge and electric fields. The lubricating effect of SEA is ensured by more intense oxidation of juvenile surfaces that form when chips are cut. As a result, adhesion between chip and cutter materials is reduced and tool wear is slowed down. Strength reduction with SEA is based on a reduction in the energy required to create a crack, which is the focus of further destruction of the material being machined. This is due to a reduction in surface
energy during electrical polarization, which in turn is due to the presence of a permanently supported unipolar electric charge in the cutting zone.

The foregoing allows us to conclude that DEC technology has considerable potential. Research on this technology is mainly of a practical nature, aimed at studying the efficiency of DEC when machining different materials using different methods. At the same time, there are works aimed at experimental and theoretical evaluation of the physical mechanisms that determine the efficiency of DEC. The optimization of machining processes with DEC has been relatively poorly researched at present. The reason for this may be the need for a large number of time and material consuming experiments on tool wear during machining. This determines the need for a way to evaluate the efficiency of the DEC without experimenting on metal cutting equipment.

The intensity of the processes that determine the efficiency of DEC - cooling, lubrication and strength reduction - depends on the number of charged particles that enter the cutting zone in a unit of time. In order to evaluate the efficiency of the DEC, it is therefore sufficient to measure the amount of electrical charge introduced by the air flow into the cutting zone - the transfer current.

The aim of the research is to check whether it is possible to evaluate the efficiency of the dry electrostatic cooling in relation to the transfer current.

In the course of the work, the following tasks have been solved:

- A stand has been developed to measure the transfer current.
- Using the stand, the dependence of the transfer current on the DEC operation mode has been determined.
- Based on the results of experiments on metalworking equipment with the assessment of the value of tool wear, the dependence of the DEC efficiency on the DEC operation mode was established.

2. Materials, tools and methods

The transfer current $I$ was measured with a microammeter. For this purpose, a metal plate was installed at a certain distance from the DEC nozzle perpendicular to the air flow. The microammeter is connected between the plate and the ground.

During the experiments on the stand, the distance $L$ from the nozzle to the plate and the air supply pressure $P$ were varied. The electrical voltage of the SEA unit was maintained at a maximum corresponding to the steady corona discharge mode (the maximum at a further increase in which the corona discharge passes into a spark plug).

Experiments on metalworking equipment were done on a 16K20F3 turning lathe when 40H steel was machined with R6M5 high-speed steel tools. Pipe face turning was done at a cutting speed of 1 m/s with a feed of 0.1 mm/rev and a cutting depth of 1 mm. After each 50 passes, the maximum height of the wear area $h$ on the flank of the tool was measured. Processing continued until the condition $h > 0.1$ mm was reached. The number of passes $N$ corresponding to wear $h = 0.1$ mm was calculated by linear interpolation between the last two measurements.

In the constant operating modes of the DEC, each experiment is repeated three times. The average of $N$ three repetitions was used as the result. The basic series was done when machining without cooling, the others when cooling the DEC.

The efficiency index $E_i$ is calculated as the ratio of the number $N_i$ of passes when DEC is cooled in the $i$-th setting to the number $N_0$ of passes when machining without cooling.

In order to correlate the results of the transfer current measurement with the relative efficiency in machining, non-dimensional values of the respective values given on a scale from 0 to 1 are used.

The non-dimensional transfer current $I^{*}_i$ is calculated as a ratio of the difference between the transfer current $I_i$ and the minimum transfer current $I_{min}$ to the spread $I_{max} - I_{min}$ of the transfer current values obtained during the experiment: $I^{*}_i = (I_i - I_{min})/(I_{max} - I_{min})$.
The non-dimensional efficiency index $E^*$ is calculated as a ratio of the difference between the efficiency index $E_i$ and the minimum efficiency index $E_{\text{min}}$ to the spread $E_{\text{max}} - E_{\text{min}}$ of the efficiency index values obtained during the experiment: $E^*_i = (E_i - E_{\text{min}})/(E_{\text{max}} - E_{\text{min}})$.

3. Results and discussion

During the experiments, air pressure $P$ and air flow length $L$ were used as variables. In the stand experiments, the length of the air jet is the distance from the SEA nozzle to the current receiving plate. In experiments on metalworking equipment, the length of the air jet is the distance from the SEA nozzle to the cutting zone. Each parameter was varied on three levels with equal pitch. The pressure variation limits were from 0.05 to 0.25 MPa. Variation limits for distances from 10 to 90 mm. The results of the transfer current measurement are shown in table 1.

| Air pressure $P$, MPa | Air flow length $L$, mm | Transfer current $I$, mcA | $I^*$ |
|-----------------------|-------------------------|---------------------------|------|
| 0.25                  | 10                      | 31                        | 1.00 |
| 0.15                  | 10                      | 13                        | 0.38 |
| 0.05                  | 10                      | 9                         | 0.24 |
| 0.25                  | 50                      | 25                        | 0.79 |
| 0.15                  | 50                      | 5                         | 0.21 |
| 0.05                  | 50                      | 3                         | 0.03 |
| 0.25                  | 90                      | 21                        | 0.66 |
| 0.15                  | 90                      | 4                         | 0.14 |
| 0.05                  | 90                      | 2                         | 0.00 |

The results of experiments on metal cutting equipment are presented in table 2. When machining without DEC, the number of tool passes is $N_0 = 141$.

| $P$, MPa | $L$, mm | $N$ | $E$ | $E^*$ |
|----------|---------|-----|-----|------|
| 0.25     | 10      | 264 | 1.87| 1.00 |
| 0.15     | 10      | 190 | 1.35| 0.43 |
| 0.05     | 10      | 155 | 1.10| 0.16 |
| 0.25     | 50      | 249 | 1.77| 0.88 |
| 0.15     | 50      | 171 | 1.21| 0.28 |
| 0.05     | 50      | 138 | 0.98| 0.02 |
| 0.25     | 90      | 227 | 1.61| 0.71 |
| 0.15     | 90      | 143 | 1.01| 0.06 |
| 0.05     | 90      | 135 | 0.96| 0.00 |

The Pearson correlation coefficient of 0.989 correlates the non-dimensional transfer current $I^*$ and the non-dimensional efficiency $E^*$, indicating a good correlation between the transfer current measurement and the DEC efficiency in turning.

The graph of the dependence of the non-dimensional transfer current and non-dimensional efficiency on distance and air pressure shown in figure 1 illustrates the fact that, as distance increases, efficiency decreases due to recombination of the charge in the air flow.

There are two reasons for the increase in efficiency as pressure increases:

- as pressure increases, the air flow velocity increases and the recombination of the charge decreases during the movement from the nozzle cut to the cutting zone;
- an increase in the air velocity in the corona discharge zone increases the corona voltage without passing the corona discharge into the spark plug and increases the initial amount of charge carried by the air flow.

![Figure 1](image)

**Figure 1.** Diagram of the dependence of the non-dimensional transfer current $I^*$ and the non-dimensional efficiency $E^*$ on distance $L$ and air pressure $P$.

### 4. Conclusions

From the results of the work carried out, it follows that the proposed method of measuring the efficiency of the DEC in the transfer current allows for a quick assessment of changes in efficiency in the operation mode or design of the DEC unit.

Comparison of the results of the carrying current measurement on the stand with those of the metal cutting equipment showed a high level of correlation between the carrying current and the impact of SEA on metal cutting tool wearing.

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