The supertemperature of the warmest isotherm in the brush can be calculated by means of Eq. (13.06) and a figure similar to (19.01). It is found to be about 70° which is more than $\vartheta$. This result confirms the statement that the thermal gradient at the contact is directed into the collector.

**Example II**: Contact during a voltage flash. A flash is always caused by a conducting area which is decreased below adaptation size because of reduction of the load. Assumptions: Flash time of $2 \cdot 10^{-5}$ sec. The conducting area decreases by loss of contact spots so that one remaining a-spot has to carry the whole current (8 A). In addition the area of this one spot decreases, say to a clean circular area of radius $1/3a_c = 1.33 \cdot 10^{-5}$ m. As is readily checked, this means a constriction voltage of $U = 6.8$ V. This voltage is called a flash; see § 45.

The electrically produced power is now 58 watt (instead of 0.8 watt in Example I), of which at least 14 watt flow to the collector. The friction heat is diminished to approximately 2 watt. Therefore assuming

$$q = \frac{16}{(2 \cdot 10^{-5})^2} = 1.27 \cdot 10^{10} \text{ watt/m}^2$$

we have

$$\vartheta = \frac{2 \cdot 10^{-5} \cdot 1.27 \cdot 10^{10}}{380} = 670$$

$$z = \frac{380}{3.4 \cdot 10^6 (2 \cdot 10^{-5})^2} 2 \cdot 10^{-5} = 5.6$$

$$\vartheta = \vartheta \cdot 0.88 = 590°$$

$\vartheta$ is the maximum supertemperature near the center of the spot. The average supertemperature during the flash time is smaller, namely about 500° as judged from Fig. (21.11). With a bulk temperature of 70 °C, the contact temperature can reach 843 °K. This suffices to harmfully soften the copper if the duration of the flash exceeds a certain minimum. This minimum is $7.5 \cdot 10^{-5}$ sec according to Eq. (17) of R. Holm [38]. This is more than the assumed flash time of $2 \cdot 10^{-5}$ sec. However, flashes may occur several times in the same spot and the softening effects partly add. Five consecutive flashes of the assumed strength in the same spot can render the respective spot soft and prone to increased wear.

§ 44. Friction and wear with a carbon-brush collector contact

Any wear rate treated in this chapter is of the microtype; cf. classification Table (41.05). In spite of the small rate, the wear can be intolerable due to great distances of travel. Fairly subtle discriminations

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1 See R. Holm [38].
are important in practice. The present theory can not help much in this situation. Therefore, the exposition will be mainly confined to summarizing the empirical results obtained under fairly well defined conditions. Threading (grooving) and copper picking of brushes as well as blistering of the collector film will not be treated. Concerning these phenomenas we refer to R. Holm [37] p. 271, Shobert [7], and J. E. Thompson [2] where further references are noted.

A. Mechanical wear with sliprings, no current. We suppose smooth sliding, i.e., a mechanical system that does not cause such disturbing factors as for instance vibrations. They could increase the wear tenfold. We also suppose a graphite material without special grinding components added. Then, friction and wear with a graphite brush and a copper ring covered with its normal collector film are much the same as with the same graphite brush and a ring of the same material. It does not matter that a copper oxide film is adjacent to the copper. The upper layers of the collector film always consist of graphite platelets with their basal planes, placed essentially horizontally along the sliding track of the ring, either graphite or copper. A similar film also prevails on the brush face.

When the brushes on a copper slipring have run in, the sliding surfaces are very smooth. This occurs when the three interdependent variables, friction coefficient, contact temperature and contact voltage, have become almost constant (cf. Fig. [39.03] and text) and when the platelet film with its characteristic coverage has been formed on both members. The wear may then be represented by $Z \approx 10^{-3}$. In practice, on commutators, $Z \approx 10^{-2}$ is common.

B. Influence of the current on the wear (absence of arcs). The current does not directly influence the brush wear except for an occasional small electrolysis; but it may be the cause of a high temperature that produces oxidation and eventually softening of the ring material. This leads to increased wear. If brushes slide smoothly on a ring of graphite or a non oxidizing metal (as gold) the wear remains largely independent of the current and dependent on the load alone. However, when the ring consists of oxidizing material such as copper, oxidation plays a great role. It is well known that the cathodic brush wears about 2 to 4 times more than the anodic brush (individual tracks); cf. E. Holm [15] Table 1. The wear of the anodic brush shows little dependence on the current. It can even happen that the wear is less with current than without.

The difference in wear can be explained, according to § 42C, by

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1 See in E. Holm [12] the replica pictures (10) and (12).