Operation of brushes with increased service life on traction machines of electric vehicles

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Abstract. The paper describes how to use a split brush with increased service life. Serial brushes were compared with those proposed by design, reliability and cost characteristics. The authors propose a method of how to improve the design of serial brushes and demonstrate a dynamic performance curve.

Introduction
The operation of electrical traction vehicles of rolling stock includes the periodic replacement of brushes subject to mechanical and electroerosive wear.

Operational investigations show that the service life of a serial brush can significantly vary due to different operational factors. The observations demonstrate that the service life of the brush is found to be much lower compared with the calculated values. This happened because the manufacturer failed to comply with the appropriate workmanship: low-quality materials; deviations from the design (collector geometry excursion due to insulation shrinkage); poor setting of machine black band; poor quality balancing of machine rotating parts, etc. All these factors make the brushes wear faster and reduce their service life.

Long-term observations show that these negative phenomena are pretty much difficult to control, i.e. this approach is ineffective. This requires many efforts to launch more stringent regulations for manufacturing the electrical machines; radical renewal of hardware at maker facilities, etc. It is necessary to search for beneficial solutions aimed at increasing the service life, manufacturability, cost reduction and increase of the operational reliability of the brushes [1, 2, 3].

Description of brushes with increased service life

The recommended brush is fundamentally different in design features and in terms of operation from the existing ones. This brush is composite in design [4], while the existing brushes are solid ones. The chemical composition and proportions of the components of composite brushes and their sizes do not differ from the serial ones. The design values of the electrical machine and the brush holder also remain unchanged. This means that the new type of brushes do not pose any technological risk while in service [5, 6].

The main idea of the project is to increase the service life of electrical machine brushes (additionally from 30\% to 44\%), depending on their design.
The brushes experience a continuous wear every time the motor running. Worn brushes cannot be restored and must be replaced along with valuable components:

1) flexible non-insulated braided wire. Material: refined copper.
2) tinned cable lugs. Material: copper.
3) unworn section of brush (the brush wears out 2/3 of its height). Material: graphite, carbon black, copper.
4) materials for connecting the conductive wire with the carbon-graphite section of the brush (caulker, electrically conductive adhesive);

The estimated cost of the not completely used upper section of the brush is 40% of its total cost. The proposed engineering solution makes it possible to use the upper (not completely used) section of the brush many times by means of a removable liner, which, in turn, can significantly reduce operating costs. The entire process of replacing the replacement liner greatly facilitates the work of the maintenance personnel, and reduces the time of maintenance up to 70% as the personnel does not need to loose and secure the lug bolt of the conductive shunt of the brush.

Fig. 1 shows a serial brush and its main components.

Fig. 1 A serial brush.
1 - tinned lug; 2 - flexible non-insulated braided copper wire;
3 - materials for connecting the conductive wire with the carbon-graphite section of the brush (caulker, electrically conductive adhesive); 4 - carbon-graphite section.

Functionally, the composite brush does not differ from the serial one. The main difference lies in its design. It consists of two sections: the main section that supplies power from the brush holder, and a replacement graphite liner. As the electrical machine is in service, the replacement graphite liner wears out almost completely and during the routine inspection/repair is replaced with a new one [7, 8].

The main section of a new brush includes valuable components described above. As the wear part of the brush when used properly is a replacement graphite liner, its upper section is wear-free not requiring the replacement. Obviously, it is beneficial in terms of saving funds on valuable components, which are waste during the operation of a serial brush. Therefore, the use of a composite brush excludes the possibility of under-utilization of the design service life of the brush.

The wide application of the proposed brush design is determined by the typical brush holder. This unit is designed to provide accurate positioning of the brushes on the collector and reliable contacting. The brush holder shall be so designed that the brush is nearly to be engaged to ensure stable pressing on the brush, regardless of the degree of its wear in height and reliably insulated from the housing. The
Brushes are held in the brush holder by special sleeves. The technical condition of the brush holder should meet the specifications for their operation.

Fig. 2 depicts a fragment of a serial brush holder. The sleeve of the brush holder 1 receives the upper section of the composite brush 2 and the lower replacement graphite liner 3 sliding along the collector 4 of the electrical machine. The brush is pressed to the collector by a spring 5. This force creates a reliable contact in the contact surface 6 between the main section of the composite brush and the replacement graphite liner. A puller 8 is used to inspect the condition of the brushes and replace the extremely worn bottom replacement section. The tip of the puller 8 goes into the hole 7 of the lower replacement section 3. Then the puller 8 takes the lower replacement section 3 out of the brush holder sleeve 1.

The recommended brush with an increased service life has been successfully tested in actual operating conditions in test trolley buses and trams at Metroelectrotrans, the Municipal Unitary Enterprise of Kazan, as well as in the facilities of Nizhnekamskneftekhim, JSC in Nizhnekamsk and Electrotransport, LLC in Naberezhnye Chelny. These tests confirmed the increased service life and reliability of its operation, both on rolling stock and on synchronous machines. Weekly inspections of motors equipped with composite brushes showed the absence of any tell tales of undesirable processes in motors (sparking, local burnout of collector plates, destruction of brushes, flashing, winding overvoltage, current pulsations leading to dynamic beating of the armature of the traction motor, etc).

![Fig. 2 A schematic of brush holder sleeve with a composite brush:](image)

1 - brush holder sleeve; 2 - upper section of composite brush; 3 - lower replacement liner; 4 - collector; 5 - brush holder spring; 6 - contact surface between sections of composite brush; 7 - hole for replacement graphite liner puller; 8 - puller.

The replacement liners of brushes with increased service life shall be replaced as soon as they are worn out. To improve the switching conditions of new liners, they are recommended to pre-grind to fit the radius of the collector. A grinding matrix serves for this purpose (Fig. 3). Ease of handling and small size shorten the time of the installation of replacement liners that, in turn, minimizes the downtime of the electrical machine.
The dynamic performance of the split-type brushes are shown in Fig. 4 [9, 10].

Using split-type brushes makes it possible to:
1. Reduce the impact force of the collector;
2. Spread impact pulses $F_2$ and $F_3$ in time;
3. As a result, the brush less detaches from the collector surface;
4. All this improves the switching and reduces the contact resistance (collector – brush);
5. Reducing the impact of mechanical and electrical (switching) factors reduce the wear of the components in rubbing contact, i.e. collector and brushes.

The existing approach of how to operate the brushes is inefficient resulting in:
to the low service life of brushes and in some cases it can drop to 44%;
- copper waste;
- significant labor costs in their service.

In this regard, a new approach of operating the brushes of electrical machines is recommended to remove these drawbacks. However, the design of the brush holders of electrical machines and the brand name of brushes remain the same. The new approach of operation of brushes has been confirmed through lab and in-service tests [11]. The way they work on traction engines of urban electric transport (trams and trolley buses), electric and diesel locomotives yield encouraging results.

**Summary**

Thus, the in-service tests carried out on diesel locomotives, electric locomotives (Kazan branch of the Gorkovskaya Railway), trams, trolley buses (Metroelectrotrans, Kazan) demonstrate the following essential results:

- the service life of brushes used by the new approach as compared with the existing ones is increased by 30% or higher depending on the height of the brush;
- the cost of a new brush is reduced by 28.8%;
- labor costs are reduced to 70%;
- the payback period is zero.

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