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Testing of Railway Pantograph

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Abstract

The Department of Rail Transport of the Silesian University of Technology conducted certification research of carbon composite materials provided by different manufacturers to be applied as pantograph strips. Additional tests were conducted apart from standard testing, as required by norms and regulations. These included amongst others laboratory test of the friction coefficient between the various materials used for pantograph strips and copper material used for overhead wires of the overhead line system. Apart from that bench testing was conducted in order to test the heating up of the overhead wire at different values of static contact pressure exerted by collector shoes. As part of own research measurements and observation with respect to the behaviour of the new pantograph strips and collector shoes were conducted in operating conditions. The research included amongst others the measurements of wear and forces between the pantograph strips and the overhead wire when in motion.

1. Introduction

Until January 2011 Poland was the only EU country in which electric locomotives and EMUs could operate with pantographs equipped with copper pantograph strips. According to the TSI regulations (Technical Specifications for Interoperability) on 1st February 2011 [1] PKP PLK S.A. introduced an obligation to use pantograph strips made of a carbon material.

The Department of Rail Transport of the Silesian Technical University conducted certification testing of carbon composite materials provided by different manufacturers to be used as pantograph strips [2, 3].

As part of own research additional tests connected with pantographs were conducted. These included amongst others laboratory test of the friction coefficient between the various materials used for pantograph strips and copper material used for overhead wires of the overhead catenary system. Apart from that bench testing was conducted in order to

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test the heating up of the overhead wire at different values of static contact pressure exerted by collector shoes.

The requirement to apply carbon pantograph strips in AKP type pantographs (i.e. the most commonly used in operational railway vehicles) was connected with the application of a special adapter - collector shoe. A few new constructions of collector shoes were developed which enabled the application of two carbon pantograph strips instead of a copper collector shoe. Therefore additional measurements and observations concerning the behaviour of the new pantograph strips and collector shoes were conducted in operating conditions. The research included amongst others the measurements of wear and forces between the pantograph strips and the overhead wire when in motion. In these examinations a purpose-designed measuring device was used, which enables the measuring and recording of the forces occurring between the collector shoe and the overhead wire when a locomotive is in motion.

2. Laboratory and Bench Tests

Apart from the tests and measurements related to the introduction of the new pantograph strips and collector shoes required by the norms and regulations e.g. Let-4, additional tests were conducted associated with the interaction of pantograph strips with the overhead catenary.

As part of laboratory tests the friction coefficient was measured for the various materials used for the fabrication of pantograph strips when interacting with the material used for the manufacturing of overhead wires. The testing was performed on a T-11 type tribology tester (pic. 1).

Fig. 1. The T-11 tribological test stand

Samples were made of 5 carbon materials with UTK certification for operation: MY7A2 (a), RH 83H6 (b), SK07Cu (c), P-8511 (d), P-5696 (e) and of copper Cu 485 ETP (f) (pic. 2).

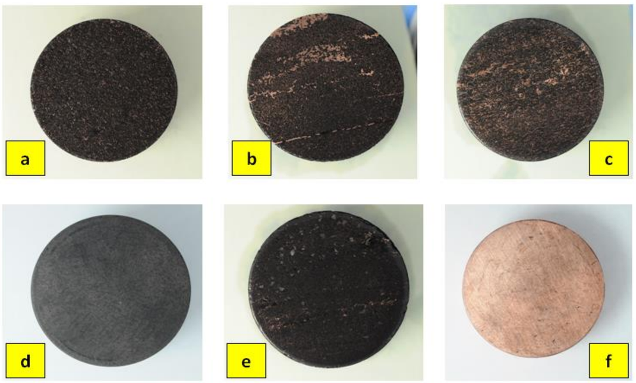


Fig. 2. Test samples made of various materials

Carbon materials used for pantograph strips are carbon composites of different chemical composition. The norms regulate only the content of copper which is not to exceed 40%, both the composition and the percentage of the remaining components has not been determined. Therefore, as can be seen on pic. 2 the structure of the individual materials differs significantly.

Several tests of the friction coefficient were performed on the T-11 test stand during the interaction of samples described on fig. 2 and the counter-sample made of copper used for overhead wires (pic. 3.). In case of the friction pair of materials made of Cu 485 ETP - Cu ETP copper material it was necessary to use graphite grease, as in case of dry friction an adhesion wear took place. The graphite grease applied was the same as the one used in the operation of railway vehicles.

Fig. 3. View on samples during friction testing

As a result of the testing performed the following values of friction coefficient were received for individual tribological pairs:

- P8511 - Cu ETP - mi value = 0.116
- SK07Cu - Cu ETP - mi value = 0.116;
- P5696 - Cu ETP - mi value = 0.118;
- Cu 485 ETP - Cu ETP - mi value = 0.139;
- RH83H6 - Cu ETP - mi value = 0.144
- My7A2 - Cu ETP - mi value = 0.147;

The values of the friction coefficient for carbon materials are comparable to copper ones. Analysing the composition of carbon materials and the friction testing performed, it is possible to observe that the friction coefficient decreases along with the growing carbon content. The smaller the value of friction coefficient the smaller the friction resistance.

At the same time, in the course of bench testing (pic. 4), apart from the standard measurements required by the norms, additional measurements were performed associated with the interaction of the new pantograph strips with the overhead catenary.

According to regulations [4], if carbon pantograph strips are being used, the force of static contact pressure exerted on the overhead wire is to be regulated it ranges between 80 and 120 N (for copper pantograph strips the maximum permitted contact pressure ranged from 70 to 90 N).

Therefore all thermal measurements are to be conducted for the contact pressure of 110 N [5]. In case of current collectors equipped with carbon pantograph strips, the thermal testing related to the heating of overhead wire is a very important component of certification testing. The research has shown, that the temperatures attained on the joint of the pantograph strip with the overhead wire are much higher for these materials than in the case of using copper. That is why it is so important to determine if temperatures will not exceed the acceptable temperature levels, particularly in case of difficult operating conditions e.g. when a locomotive is stationary and collects greater values of current for a longer period of time (for example when a train is preheated in winter period).

Fig. 4. Test stand for testing of current collectors

However, as mentioned above, such testing is conducted on a perfectly adjusted pantograph. In the course of our bench testing we measured how too great or too weak a contact pressure of a pantograph influences the temperature of an overhead wire. That is why the bench testing temperature measurements were performed for contact pressure values for both 70 [N] (acceptable for copper pantographs strips) and 130 [N].

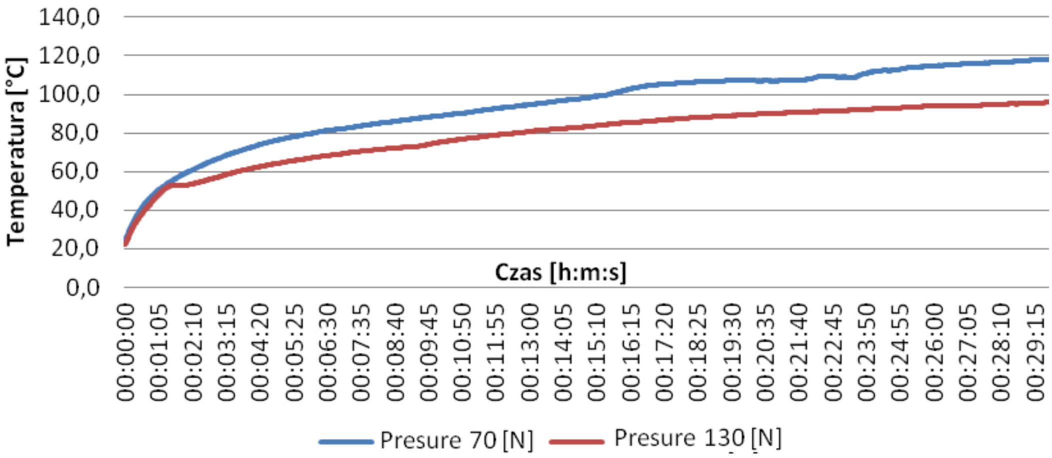


Fig. 5. Overhead wire temperature values for differing contact pressure forces

As can be seen on the diagram above (fig. 5), as long as nothing wrong happens at higher static contact pressure (temperature increase within limits), in case of insufficient contact pressure the temperature of the overhead wire exceeds acceptable values (above 100°C).

3. Wear Measurement

Operational testing of pantograph strips was conducted on locomotive ET41-142 (pic. 6) in the Silesian Division of PKP CARGO S.A. in Tarnowskie Góry and took place from 10 December 2010 to 13 December 2011. In this period the extent of wear of copper and carbon strips was tested by measuring of their thickness in the course of periodic inspections (P1, P2, P3 and NB), every 30 days.

a)  b)

Fig. 6. Locomotive ET41-142: a) in front of the locomotive depot, b) on a traverser

In the period of 12 months the locomotive ET41-142 covered 55 077 km with operational current collectors. The results of measurements of linear wear of pantograph strips for an ET41 locomotive are presented in fig. 2. On 09.06.2011 the copper pantograph strips were replaced as they were worn out (threshold reached). The threshold for copper pantograph strips in the spring-autumn period is 2.5 mm and 3 mm in winter. The carbon pantograph strips were being used further due to the fact that they didn't achieve their thresholds, which amounts to 5 mm in spring-autumn and 8 mm in winter.

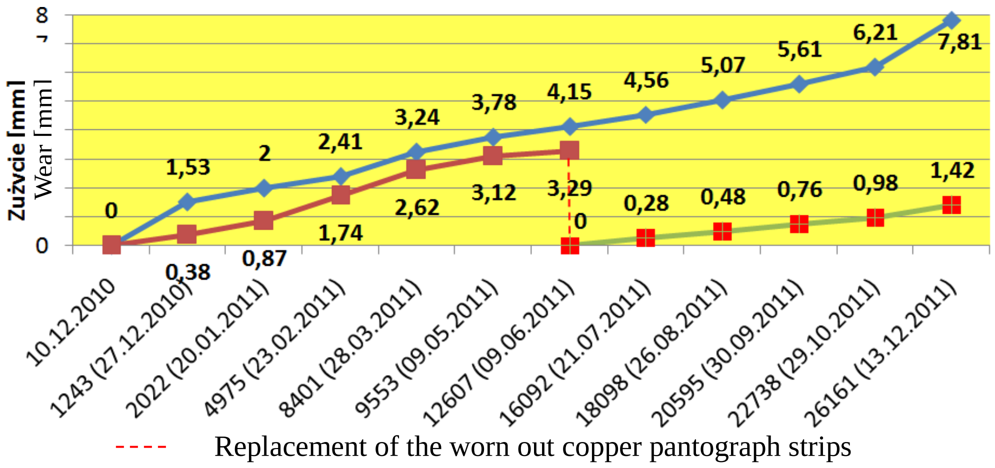


Fig. 7. Linear wear of carbon (blue line) and copper (red line) pantograph strips and the distance covered

In the course of operational testing of pantograph strips a significant dependence of wear on time of the year has been detected. In case of an ET41 class locomotive the wear of pantograph strips increased several-fold in the winter period (December and January 2010, December 2011) when carbon pantograph strips were being used (fig. 8).

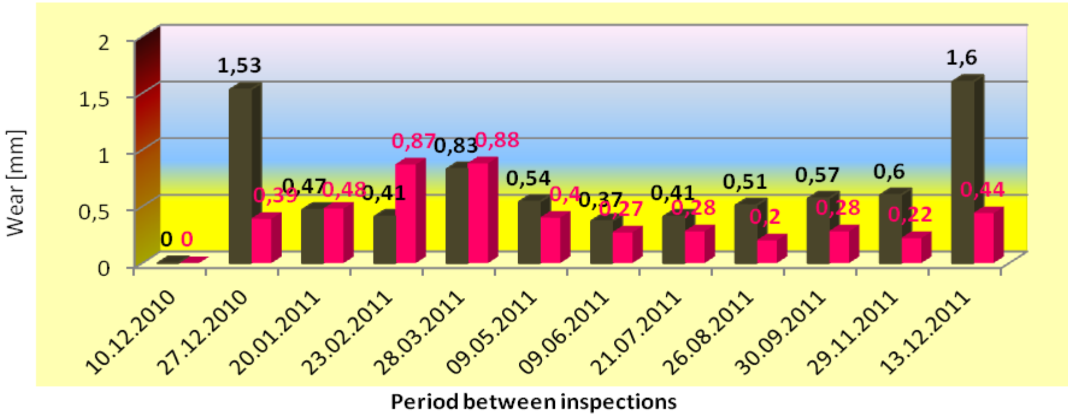
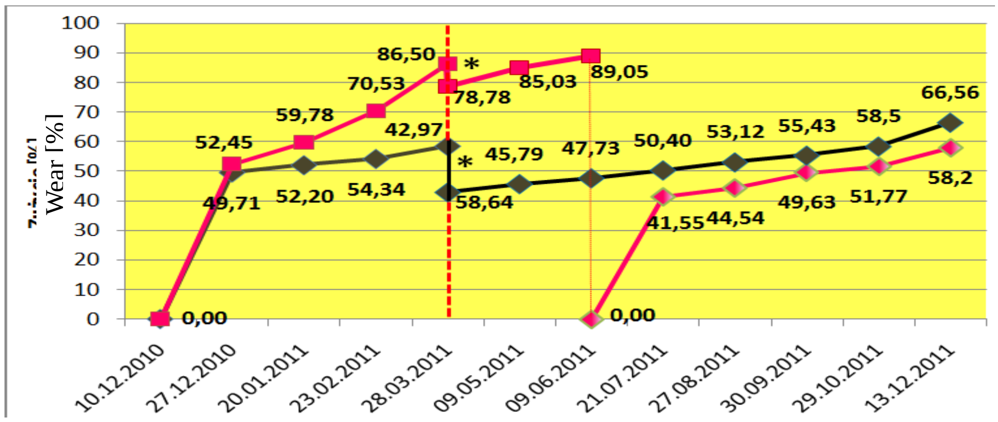


Fig. 8. Average wear of carbon (blue line) and copper (red line) pantograph strips of ET41 - 142 locomotive in the period between inspections

The analysis of figure 8 shows, that in winter period (in adverse weather conditions) carbon pantograph strips wear out 3-times as much as in the remaining period. In general in the spring - autumn period the wear of both carbon and copper strips was much less intense than in December 2010, January and December 2011.

Figure 4 presents the outcomes of the observation of percentage wear for the entire testing period. The percentage wear of carbon and copper pantograph strips was presented in the form of a graph as the measured thickness of the strip to its initial thickness ratio including the wear threshold, which is the following for:

- carbon strips 5 mm (spring-autumn period) and 8 mm (winter),
- copper strips 2.5 mm (spring-autumn period) and 3 mm (winter).



Change of the minimum thickness of pantograph strips (winter - summer)

Replacement of worn out pantograph strips

* Discrete % wear is connected with the change of the threshold wear values (winter summer).

Fig. 9. Percent wear of carbon (blue line) and copper (red line) pantograph strips measured during periodic inspections

The wear shown in percentage is important, as it signals to the operating entity when a pantograph strip reaches its minimum permitted thickness, which indicates that it should be replaced. Bearing this in mind the outcomes of the pantograph strip wear analysis provided in fig. 9 show that cooper pantograph strips wear out quicker than the carbon ones. This is caused by the fact, that the initial thickness of carbon pantograph strips was three times the thickness of the cooper ones and therefore they can be used for longer periods of time (they reach their minimum permitted thickness later than cooper strips).

As has been indicated above, the research has shown that winter period is particularly demanding for carbon pantograph strips which wear out quicker. Moreover in winter period additional adverse phenomena occur due to hoar-frost or ice on overhead wires both when carbon and cooper pantograph strips are used. Short breaks in the pantograph strip/ overhead wire contact result in resistance losses within a few milliseconds which are connected with sparking and releasing of large amounts of heat at the connecting point, which leads to defects of pantograph strips. An electric arc occurs during the loss of connection of the pantograph strips with the overhead wire which in turn results in the partial melting of both the overhead wire and the pantograph strips. Serious mechanical damage of the overhead wire and pantograph strips may occur in particularly adverse conditions, for example when an overhead wire is covered with ice.

4. Testing of the Interaction of the Collector Shoe and the New Type of Pantograph Strips with the Overhead Catenary

One of the additional tests conducted during the period of operation was the determining of the quality of interaction of the new type collector shoe with carbon strips and the overhead catenary. For that purpose a FAN type collector shoe equipped with pantograph strips made of MY131 [7] carbon material was mounted on the ET22-1137 locomotive (pic. 10). A purpose-built measuring device was devised and installed on the new type collector shoe with carbon pantograph stripes in order to analyse the connectivity of the collector shoe with the overhead catenary when the locomotive is in motion. When installed on the collector shoe, the device enables real-time measurement and recording of the forces occurring between the pantograph strips and the overhead wire of the overhead catenary system (pic. 11).

Fig. 10. The ET22 locomotive before testing with the collector shoe installed

Fig. 11. Testing collector shoe installed on the pantograph

Additionally during the measurement of forces by means of the testing collector shoe precise recording of the location of the locomotive was performed by means of a GPS sensor. Moreover HD video cameras were recording the work of both the pantograph and collector shoe when the locomotive was in motion.

The locomotive with such measuring devices installed was used for test rides on chosen routes. An exemplary diagram of forces between the pantograph strips and the overhead wire received as a result of the recordings performed on a chosen testing route is shown on fig. 12.

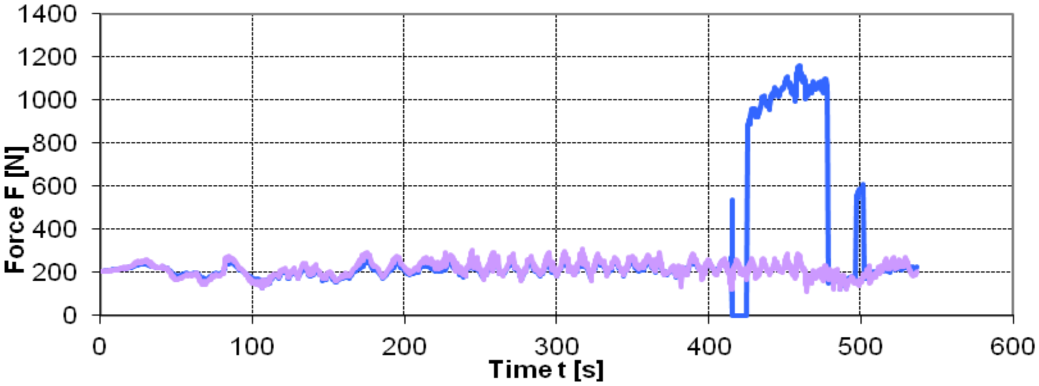


Fig. 12. Exemplary diagram of forces occurring between the collector shoe and the overhead wire

As can be seen from this graph, at some point on the test route the permitted values of forces were significantly exceeded. As a result of incorrect interaction with a section insulator these forces reached almost 1150 N, while a maximum permitted value is 350 N for rigid elements of overhead catenary system according to TSI Energy [6].

Therefore, in first it is necessary to develop a system to test forces in the pantograph strip – overhead line and then the introduction of routine testing necessary traction in this regard. Systematic approach to this type of measurement and the consequent traction control will result in a much smaller number of failures of overhead line and pantograph which significantly contribute to the reduction in transport costs.

5. Conclusions

The testing and measurements of current collectors with carbon and copper pantograph strips have led to the following conclusions:

1. The values of the friction coefficient of carbon materials are comparable with copper ones. In case of copper it is important to apply graphite grease, because in case of the lack of such lubricant a sudden increase of the friction coefficient takes place followed by adhesion wear of the samples.
2. It is essential to maintain the value of pressure exerted by the pantograph strips on the overhead wire in the required range, as its decrease may result in a significant increase of temperature of the overhead wire in adverse operating conditions.
3. In the course of operational testing greater linear wear of carbon pantograph strips as compared to copper strips has been detected. However due to the different initial thickness of the pantograph strips (copper 7 mm, carbon 20 mm), the carbon pantograph strips (in spite of their greater linear wear) can be used 1,7 times longer than copper ones until they need to be replaced.
4. The results of the operational testing performed indicate that weather conditions have considerable influence (particularly ice and hoar-frost on overhead wires) on the wear of

both carbon and copper pantograph strips. In the winter period linear wear of carbon strips is a few times more intense than in the summer period.

5. In case of using collector shoes with carbon strips it is particularly important to maintain both the pantographs and the overhead catenary in correct technical condition in order to prevent damage to both pantographs and the overhead catenary system.

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