



# OPTIMISING THE CONTACT QUALITY BETWEEN CONTACT STRIPS AND OVERHEAD LINE



Tramway in Oostende, Belgium. March 2008

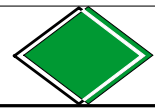
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Editing by ZTR Control Systems



## 1. Introduction

The global economic crisis has forced public transport companies to be more efficient and careful with their resources. As a result, maintenance management systems should be designed to allow for uninterrupted operation of the transportation service and minimum cost.

Deutzer Technische Kohle GmbH (DTK) performs track, clearance, and third rail measurements. DTK also performs measurement & analysis of the distance between platform edge and vehicle entrance, travel comfort, overhead wire, and pantograph. DTK's customized solution for each application results in services that minimize equipment wear with the least possible interruption and cost. This Case Study will use examples of DTK's solution in Oostende, Belgium to describe the data measurement and analysis done to significantly improve the operation of the overhead wire system.

One of the most important steps in improving the operation of the overhead wire system is to measure the contact quality between catenary and contact strips. Insufficient electrical contact can lead to electric arcs. But even if no electric arc is created, the current density increases at the remaining contact points when contact quality is poor. The resulting heat is so intense that catenary material is melted. The molten copper remains as sedimentation in the pores of the carbon, on the vehicle roof and on the contact strip.

There are many causes for insufficient contact between contact strips and catenary. The overhead wire rise or decline may be so large that the contact strips can no longer follow the course of the overhead wire. The pantograph can also be unsuitable for the network or its inertia can be too high. Other causes may include structural defects in the carbon body or the transfer

too much electrical power through the contact point.

Expert analysis of the measurement data allows for specific recommendations to improve the en-tire current collection system. Implementation of DTK's recommendations will reduce overall maintenance costs and increase infrastructure uptime.

## 2. Current Collecting System in Oostende

The "De Lijn – Oostende" overhead wire system is nearly 100 km (62 miles) long. The route often follows the North Sea coast, crosses the sand dunes and connects the cities of De Panne, Oostende, Knokke and Zeebrugge. The track has long sections on very soft track bed. When a vehicle is passing over, the pumping of the tracks affects the contact quality between the carbons and the contact wire. The saltwater climate also makes the current collection extremely difficult, since aluminium clamps get worn and unusable very quickly. As a result, De Lijn uses special contact strips called "coastal strips".

The North Sea wind whips up sand that settles down on the carbon's contact surface. The friction and the electrical resistance between the contact strips and the contact wire grows. This in turn increases the contact wire and carbon wear.

To add to the challenge, the harbor entrances are equipped with

lift bridges which include track and power supply. There are often strong shocks against the contact strips at the connecting points between these lift bridges and the remaining network.

## 3. Description of Electric Contact

Fortunately, the causes of disturbances in current collection systems can be identified and analyzed for corrective action.

Contact surfaces are subject to wear due to force impulses, friction and power transmission. A very large proportion of the wear is caused by poor electrical and mechanical contact during power transmission. This generates electrical arcs between the wire and the contact strips. At the top of the electrical arc, material melts on the surface of the copper wire. At the other end, carbon material gets burned. But even without an electric arc, there can be high material loss. In the case of a borderline contact interruption, the current density increases in the last remaining contact points. There is so much energy being passed through these points that it gets transformed into heat and the overhead copper wire starts melting. This melting contact condition is shown in Figure 1.

Due to the high current density and heat, the molten copper gets abruptly sprayed and deposited in the pores of the carbon and on the contact strip.

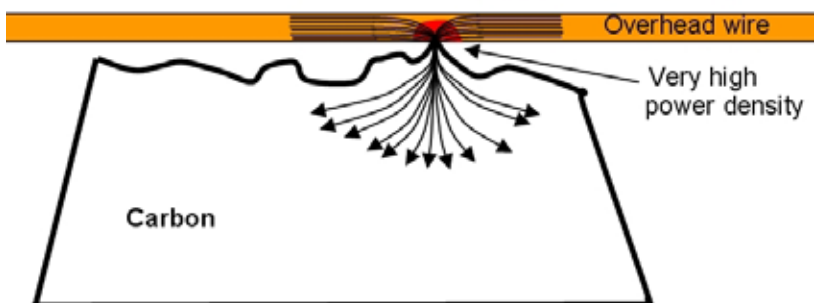
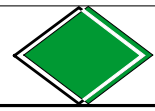


Figure 1: High current density at the last remaining contact point.



A damaged contact strip is shown in Figure 2.

Copper deposits can be seen on the contact surface and on the side of the carbon piece. In addition, the carbon body is damaged by grooves caused by insufficient wire stagger or an overload of the carbon section.

The goal of DTK's catenary and pantograph analysis is to identify the causes of insufficient contact quality and make recommendations about how to improve the interaction between overhead wire and contact strips. DTK also records the track position along with the other variables, such as overhead wire position, transferred power, overhead wire voltage and shocks. This is because track position and these other variables can have a significant influence on the interaction of contact strips and catenary.

## 4. Performing The Measurements

DTK always customizes its measuring system to the customer's application. Measurements of overhead wire and pantograph are typically performed as a core part of the service. During an overhead wire measurement session, the height, stagger, shocks, current, current direction, and the voltage of the overhead wire are monitored and logged. In addition to these parameters, DTK's system records the GPS coordinates and the vehicle movements with each measurement point.

The pantograph analysis clearly identifies the characteristics, behavior during changes in height at different speeds, suitable working range, natural frequency, and the reaction to shocks. If required or desired, the track position is also recorded and this data is analyzed together with the overhead wire measurement.

Once the data is analyzed, system factors that deteriorate operating and maintenance efficiencies are identified.

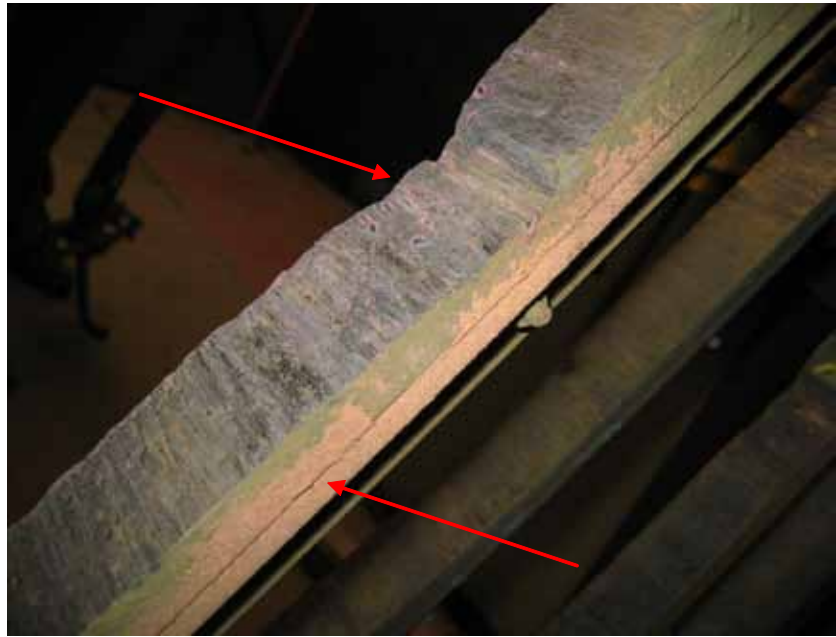


Figure 2: Contact strip with grooves and copper deposit

The client then gets specific recommendations about the actions needed to solve the problems.

### 4.1. Overhead Wire Measurement & Analysis

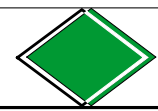
The measurement surveys are performed in normal traffic with DTK's system installed on a normal tramway. DTK records the geographic coordinates of each measuring point which allows for any discrepancy to be assigned to a precise location. The coordinates are imported into the analysing software by selecting the "Tools", "Coordinates" and "Read Coordinates" icons. Then a second window will open and show the corresponding measured routes either on top of the first window (if using one monitor) or on two monitors in separate windows. If a cursor is set in one of the images, then the software will place another cursor in the second display at exactly the same distance.

The coordinates of the cursor positions for the distance, the time and the overhead wire height are all indicated on the right side of the chart. Below these values, the software displays the rise and fall

of the contact wire for this route section. Below that, you'll see the recommended speed in order for the pantograph to adequately follow the change in height of the overhead wire.

The coordinates allow you to find and select exactly the same route sections for comparison of data that was measured at different times. To view the coordinates of the start and end points of a route section, just set two cursors and let the software do the comparison.

It is also possible to find the routes from different measurement surveys in DTK Explorer and select the respective data for overhead wire, track, gauge etc.



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Figure 3 shows the routes surveyed at De Lijn Oostende. If a cursor is set at any route point, a separate window will come up and show the coordinates for this point, the file name, and the distance from departure.

DTK's Explorer makes it possible to quickly compare the same route sections selected from different measurement surveys. DTK's Explorer also allows you to display the track position and the arc radius when analyzing stagger exceedances. Note that this is an example of how the analysis software can be used and that there are many other features not presented here.

Figure 4 shows an overhead wire measurement chart and the corresponding route. From top to bottom, the chart displays the overhead wire height and the stagger, the pantograph shocks, and the tram's speed. Other data can be added or filtered out to assist in the analysis.

You can see the cursors located at the 17,534 m and 17,894 m positions (the beginning of the route being 0) and in the separate graph for the route, there are two colored points which mark the corresponding GPS co-ordinates.

DTK's software allows you to stretch or compress charts or display selected curves and hide all other values. For example, if only the overhead wire height is displayed (See Figure 5), then the chart shows that:

- The overhead wire height is outside the limits of the allowance area (marked in green);
- The height's standard deviation is very high (24.17 cm or 9.52 in); and
- The rate of rise and decline of the overhead wire is very steep.

Such characteristics often result in insufficient electrical contact between the overhead wire and the contact strips.

Figure 5 shows the height profile of the overhead wire on top and its corresponding distribution below. The average overhead wire height is 563.80 cm. With a value of 24.17, the standard deviation is very high.

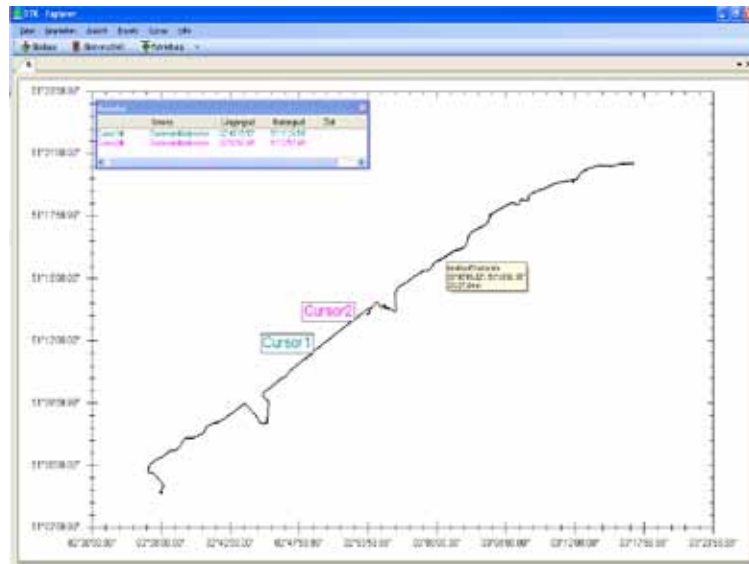


Figure 3: DTK Explorer

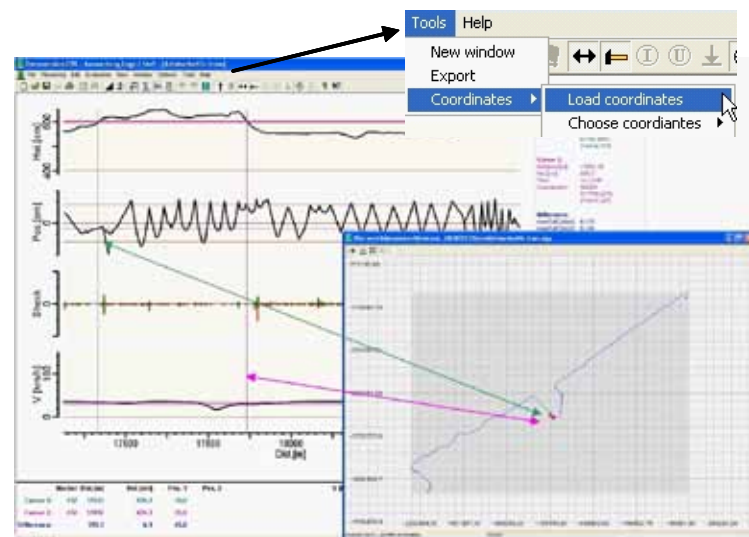


Figure 4: Measurement chart and course angle

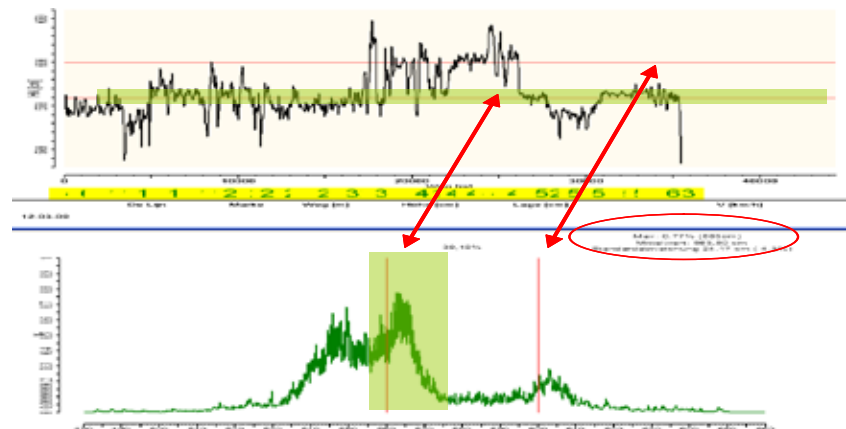
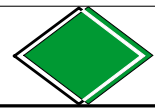


Figure 5: Height of overhead line and corresponding distribution curve



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The height is over 6.5 meters for 1.700 meters of the route. Most of the time the overhead wire's height is 5.64 m.

The markers (red lines) were set at a height of 5.6 m and 6 m. After having activated the "Evaluation height" icon in the DTK software and set 600 cm as the upper height limit, a click on the "Test" button will show that this height is exceeded on 45 route sections (See Figure 6).

With a click on the "Okay" button, the software displays a list of the corresponding sections in a spreadsheet (See Figure 7) including their coordinates from the beginning to the end of the identified setpoint. The spreadsheet is sorted by the out of spec height from maximum to minimum. The highest value in this example is 650.5 cm. A quick click will start a corresponding video sequence, which in this case showed very strong pantograph vibrations and a fluttery run of the contact strips.

DTK's pantograph analysis can reveal if the contact force between the contact strips and overhead wire is insufficient under these conditions.

Insufficient contact between overhead wire and contact strips can also be caused by an excessive rate of overhead wire rise or decline. The contact strips cannot respond fast enough to follow the change in height. The analysis function "Rise/fall of overhead wire" (See Figure 8) creates a spreadsheet listing the sections with a "Rise/fall more than 24 cm per second" (See Figure 9). This spreadsheet shows only the largest sections with a rise or fall over 24 cm, out of 58 route sections. The coordinates are also listed in the spreadsheet in order to easily find any section.

The spreadsheet's top row lists a 3 m long section (red rendered row) with a maximum rising speed of 41.7 cm per second, much higher than 24 cm per second, which is the maximum speed this pantograph can move and still keep contact with the overhead wire.

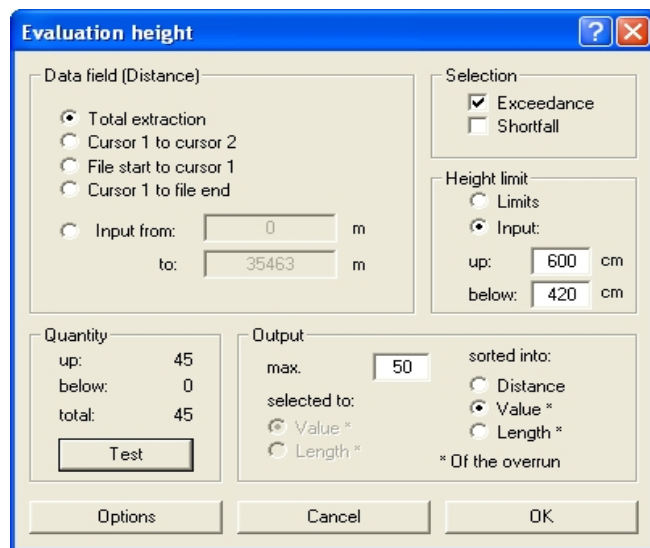


Figure 6: Selection window for overhead wire height analysis

start [m]	Length [m]	Hei [cm]	Time	Distance to	Marker	Koordinaten (WGS84)
17534	360,7	650,5	16:13:24	657	32	51°86.81'N 2°44'34.74'E
24149	581,1	647,9	16:20:11	434	45	51°10'13.91'N 2°46'47.12'E
24923	224,1	638,5	16:29:25	165	46	51°10'31.13'N 2°47'13.89'E
20391	293,8	623,9	16:19:50	195	38	51°8'59.12'N 2°45'25.9'E
25474	606,7	621,3	16:30:31	226	47	51°10'41.34'N 2°47'36.61'E
20693	101,5	619,0	16:20:10	460	38	51°9'7.9'N 2°45'15.4'E
18761	90,3	619,0	16:16:15	125	35	51°8'10.95'N 2°45'15.04'E
18426	27,6	618,6	16:15:02	27	33	51°8'1.70'N 2°45'14.48'E
23408	208,5	616,4	16:26:04	720	42	51°10'2.47'N 2°46'14.29'E
23826	237,3	611,9	16:27:33	49	44	51°10'9.9'N 2°46'32.67'E
21538	56,7	611,3	16:23:04	505	41	51°9'27.85'N 2°44'57.29'E
22966	279,4	611,3	16:25:20	323	42	51°9'53.49'N 2°45'57.3'E
22565	350,5	608,8	16:24:18	1599	41	51°9'46.10'N 2°45'40.47'E

Figure 7: Excerpt from spreadsheet – height position above 6 m.

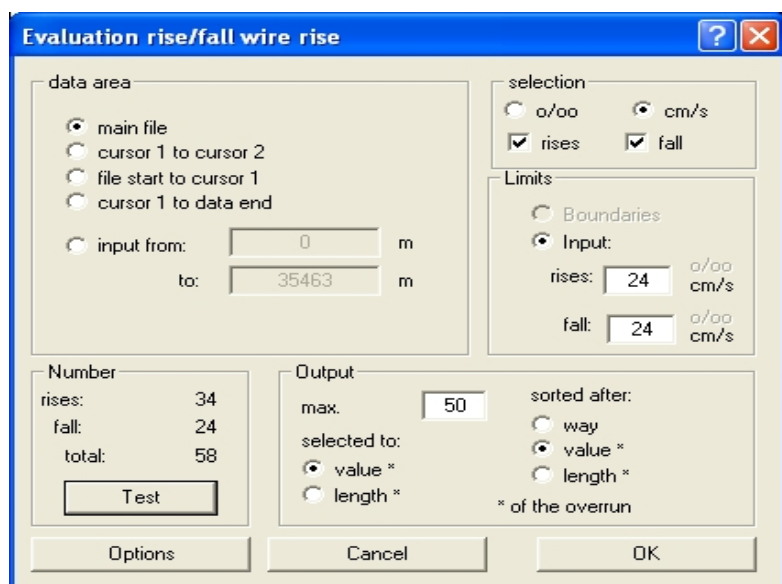
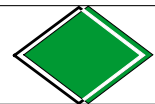


Figure 8: Selection window "rise and decline"



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With a double click on the spreadsheet's first row, the software will display the corresponding route section in a chart. Figure 10 shows the graph for this section. Considering the vehicle speed of 45 kph, the pantograph has to change heights at an average speed of 32.009 cm per second. At the position of the second cursor the overhead wire is 7.7 cm higher. The distance between both cursors is passed through in 240 ms. The diagram also shows a clamp at +35 cm. The coordinates for both cursors are displayed on the right hand side of the chart. A click on the film icon will start the corresponding video sequence.

The pantograph test results show that such a steep rise of the overhead wire disturbs the contact between contact strips and overhead wire, which creates the problems described earlier in Section 3 of this article.

## 4.2. Pantograph Tests

In the De Lijn application, the contact strips are continuously exposed to the sea climate. The holders are strongly affected by the salt water climate and the amperage, which results in frequent failures. For this reason, a new pantograph had to be developed for Oostende's public transport company. This pantograph had to withstand the coastal climate conditions and is hence called a "coastal pantograph".

The pantograph head carbon holders are made of stainless steel. They last longer but are much heavier than aluminum holders. The carbon body is furnished with a slot in which a copper wire is soldered. The entire current runs through the copper wire from the contact strip to the pantograph. The holders do not participate in the current transmission.

### 4.2.1. Contact force during changes in height

Figure 11 shows the pantograph analyzed with DTK's equipment.

start [m]	Length [m]	rise/fall(max.) [cm/s]	Time	Distance to	Marker	Koordinaten (WGS84)
8850,0	3,0	41,7	15:53:50	260	18	51°16'58"N 2°38'40,36"E
12482,1	0,5	38,0	16:00:45	335	23	51°16'58"N 2°41'17,58"E
17547,3	0,2	-34,4	16:13:08	511	32	51°16'54"N 2°44'35,6"E
16688,8	0,2	31,3	16:09:25	184	30	51°16'27,96"N 2°44'8,63"E
19016,9	0,2	-31,2	16:16:45	337	35	51°16'17,26"N 2°45'19,71"E
12929,6	0,5	-30,3	16:01:15	763	23	51°16'15,35"N 2°41'36,77"E
10787,1	0,2	29,4	15:56:44	775	20	51°17'47,92"N 2°39'59,60"E
19005,2	0,2	-29,0	16:16:43	325	35	51°16'16,99"N 2°45'19,31"E
8853,5	0,2	29,0	15:53:50	281	18	51°16'16,54"N 2°38'40,47"E
8845,3	0,5	28,8	15:53:49	273	18	51°16'16,56"N 2°38'40,10"E

Figure 9: Excerpt from spreadsheet – rise or decline higher than 24 cm per second

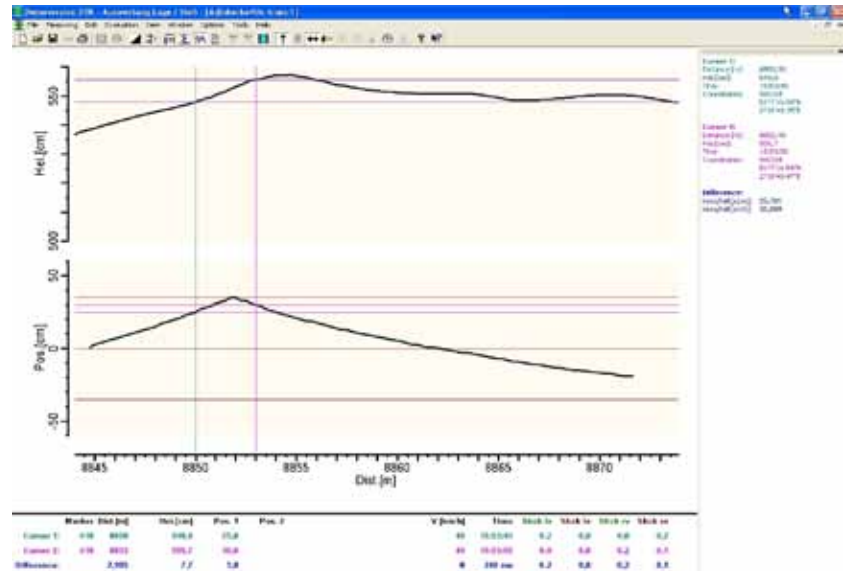


Figure 10: Chart for the first row of the spreadsheet (Figure 9)



Figure 11: Pantograph with DTK's contact force measuring equipment

To develop a contact force profile of the pantograph, its contact force is measured at different simulated conditions. The DTK test fixture controls a servo motor to simulate OHL rate of height changes. One end of a cord is fixed on the linear bearing and the other end is connected to a force sensor that is fixed on the contact strips (or on a piece of overhead wire lying on top of the contact strips). The linear bearing allows the pantograph to move downward.

During this motion, the central spring force presses the pantograph against the overhead wire. The overhead wire is pushed upwards with a certain speed.

During this motion, the force sensor measures the pressure between contact trips and overhead wire. The software changes the rise and fall of the pantograph in double steps of 2 to 30 cm per second. The pantograph's whole working range is divided into steps of 10 cm. After the 10th cm, the motion stops for 5 seconds.

Figure 12 shows the contact force measured during a rise or decline at a speed of 24 cm per second. From top to bottom it shows the curve for the pantograph height (at a simulated overhead wire rise), the corresponding curve for the contact force, the curve for the simulated overhead wire fall, and the corresponding contact curve.

The pantograph's working height is 210 cm. This chart shows that at a rise or fall speed of 24 cm per second the tested pantograph can not follow the changes in height of the overhead wire.

The contact force between contact strips and overhead wire drops to a value of 0 Newton for a longer time. Under such conditions, if the vehicle needs current in order to accelerate, the problems described

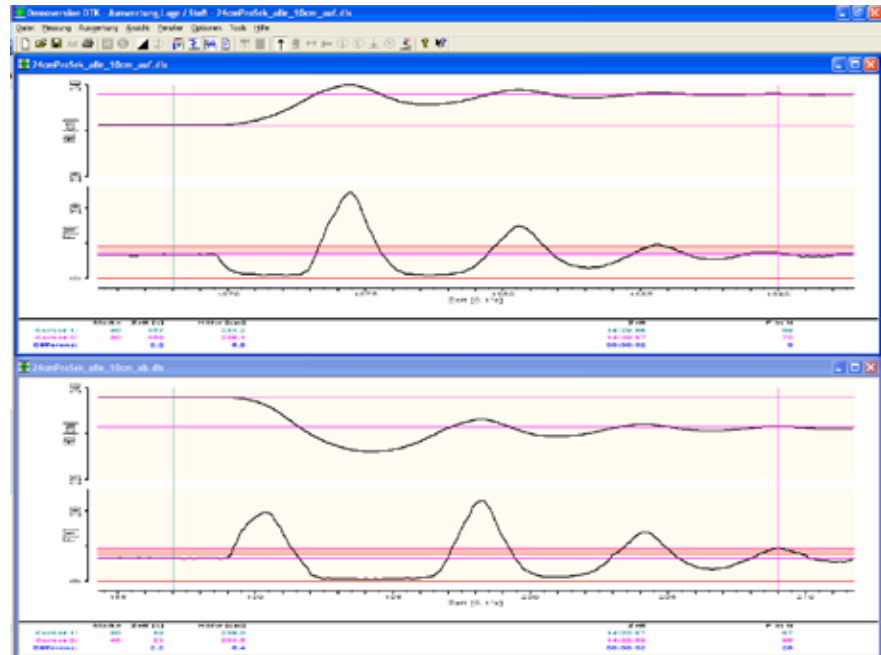


Figure 12: Pantograph monitoring at a speed of 24 cm per second

earlier in Section 2 will occur, e.g. as electric arcs.

Thanks to the results of the pantograph analysis, DTK's system can define the maximum vertical speed the pantograph will need in order to maintain a sufficient contact between the contact strips and the overhead wire. The operator now has three options at its disposal to eliminate this condition: Change the rate of rise/fall of the OHL. Reduce the normal speed of the trains's operation in these sections. And/or modify the dynamic response of the pantograph.

Below we will show that in this particular case the customer should first try to reduce the weight of the pantograph's head. Moreover, we recommend a reduction in the changes of contact wire gradients as far as possible and adjustment of the contact wire height so that it complies with the nominal value.

#### 4.2.2. Pantograph response curve

Because of the special climate conditions, Oostende's public transport operator has decided to use contact strips

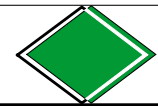
with an integrated copper cable, which is brazed in their bottom side. The contact strips are held by clamps made of stainless steel. These clamps are insulated against the carbon strips, so that no electric arc can affect them if there is insufficient electrical contact. As a result, the contact strips are relatively stable, given the poor contact conditions.

The end pieces of the pantograph's head are made of metal pipe. The head's construction as a metal frame makes it quite heavy since the mass that the pantograph has to carry is above 17 kg. This special pantograph head is called the "Seaside tramway collector head".

Figure 13 shows the special carbon strips with the brazed copper cable.



Figure 13: Contact strips



The pantograph's response curve also shows the heavy mass of the pantograph's head. The response curve is obtained by moving the pantograph upward and downward over its complete operating range at a very slow rate of change (0.3 cm per second). Figure 11 shows a pantograph with DTK's system installed. During the up and down motion, DTK measures the contact force continuously and displays the recorded values in an xy chart called a response curve.

The response curve of Oostende's pantograph is shown in Figure 14. The nominal range the contact force should comply with is marked in yellow. The chart shows that the contact force stays within the nominal values during downward motion between a working height of 2.30 m and approx. 1.00 m. Below this level in downward motion and over its complete working range upwards, the contact force does not comply with the nominal range. The highest discrepancy is 38 N below the pantograph's nominal value. At this point the remaining force of the contact strips is only 42.2 N. The average contact force in up and down motion differs by approx. 21.5 N. In the case of lighter pantograph heads, both curves would be much closer to one another.

This pantograph is not able to follow even rather small contact wire gradients. The head mass it has to move, and consequently its inertia, are too high. The result is contact interruptions as shown in Figure 14.

So you can see that the response curve provides a rough evaluation of the pantograph's quality. Below we'll look at multiple changes in height, carried out at different speeds, which allow for a more detailed assessment. In this application, it wasn't necessary to perform further pantograph tests at different accelerations or decelerations.

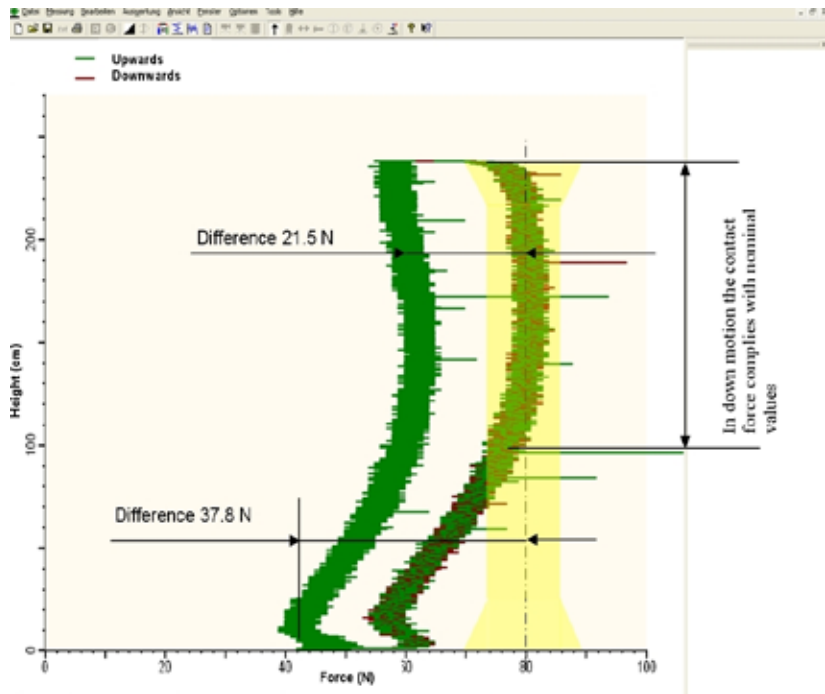


Figure 14: Pantograph response curve

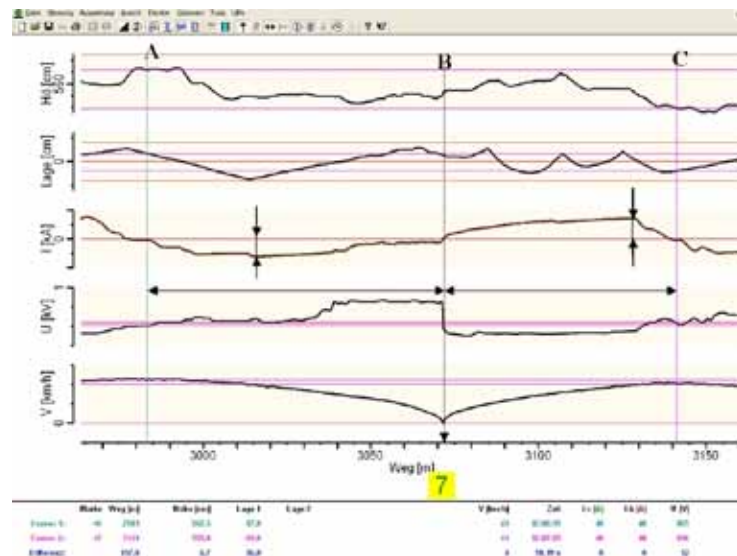
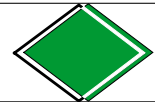


Figure 15: Measurement chart

### 4.3. Contact Quality Assessment

Figure 15 shows (from top to bottom) the contact wire height, stagger, current transmitted through each contact strip, voltage, and the vehicle speed.

The x axis represents the distance. DTK measured the individual amperage for each strip, regardless of whether the current was consumed by the vehicle or returned to the overhead wire in case of deceleration. The current that corresponds to the front contact strip displays in brown, while



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the green curve corresponds to the rear contact strip. The software can also summarize both curves as one total current value. In this chart, three locations have been set with letters: "A" at position 2983 m, "B" at 3072 m and "C" at 3141 m. Along the route between A and B, the vehicle has decelerated until at a full standstill. The return current, which is shown where the curves are below zero, causes an increase in voltage.

The vehicle takes off and accelerates between the positions B and C. While doing so it consumes current that is shown in the curves above the zero line. The current consumption results in a decrease in voltage. In addition to this, the voltage can be affected by other vehicles driving along the same power section, either consuming current or returning part of it to the overhead wire. But the voltage won't oscillate even in this case.

Figure 16 shows (from top to bottom) the contact wire height, shocks between contact strips and overhead wire, and the voltage on this route section. Any other available chart has been hidden for clarity. Along the route between the two cursors, the chart shows a strong variation in voltage. At the positions "1" and "2", the voltage collapses for a short while. The synchronized videos show a power section change that is caused by a bridge at the harbor entrance. In this specific instance the entire bridge, including track and power supply, can be lifted and put aside if required.

On the bridge, the system consists of a rigid power rail situated above the train. You can observe more shocks on this route section. These shocks disturb the contact quality between contact strips and power rail. On another bridge situated at a harbor entrance, an overhead wire was installed instead of a power rail. This section is displayed in Figure 17. The pictures displayed under the chart were generated out of the corresponding synchronised video. Since an overhead wire is used on this bridge, the current collecting system remains elastic. That is why there are fewer shocks between

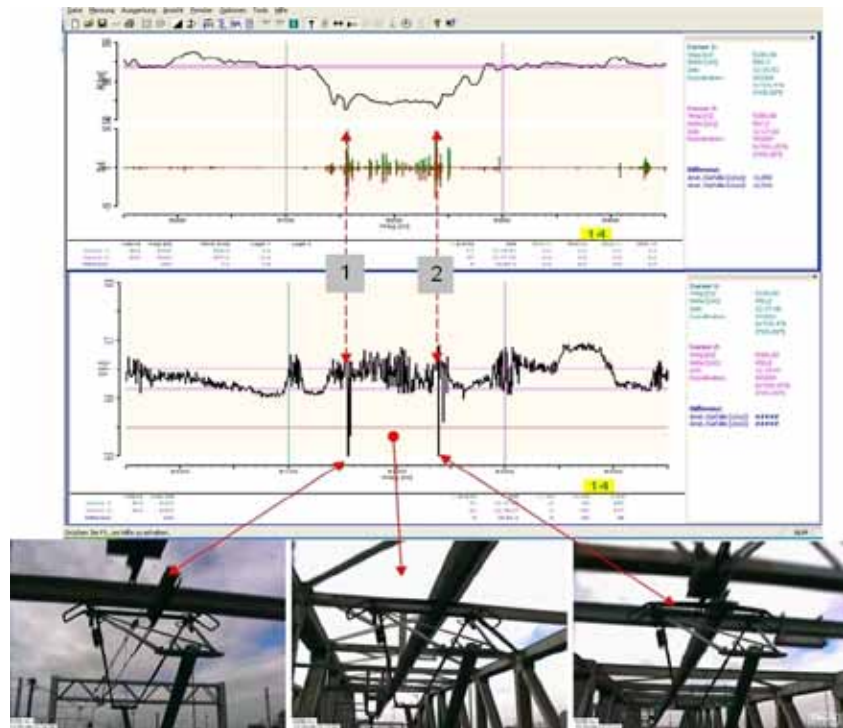


Figure 16: Insufficient contact between contact strips and power rail

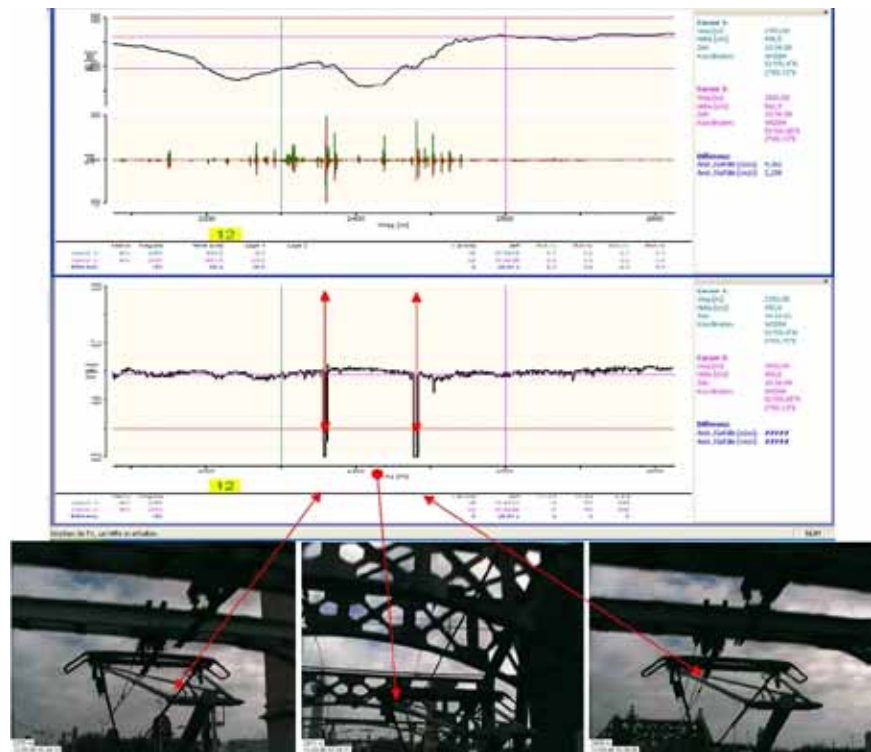
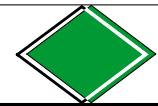


Figure 17: Good contact between overhead line and contact strips on a bridge



contact strips and overhead wire than on the similar section using a power rail. The electrical contact between the contact strips and overhead wire is better on this route section. Thus, the overhead wire voltage varies considerably less.

To further illustrate this, sections with relatively good, not so good, and bad contact between overhead wire and contact strips were selected on different

routes. Figures 18 to 20 show the consumed and returned current, measured voltage, and the speed for different current collection systems. All other values are hidden.

The curve for voltage in Figure 18 shows no short time oscillations. The variations are influenced only by the vehicles taking or returning current among the same power section. In Figure 19 and especially in

Figure 20, the measured values oscillate very strongly.

These oscillations are predominantly caused by the discontinuous contact between overhead wire and contact strips. The corresponding video sequence shows the pantograph's run.

Oscillations similar to those displayed in Figure 20 occurred several times during the survey at De Lijn's.

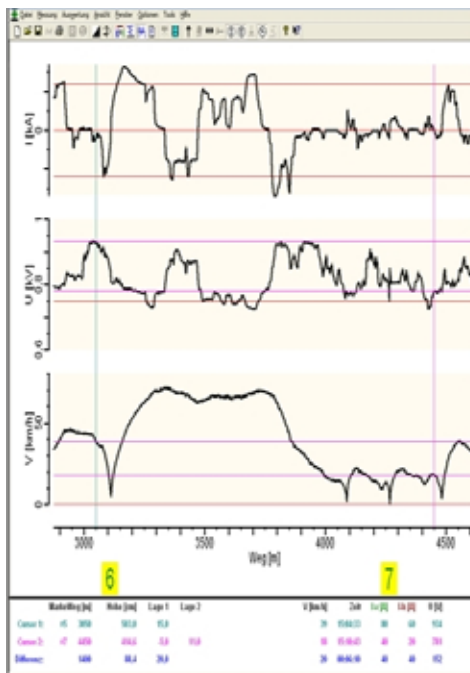


Figure 18: Sufficient contact

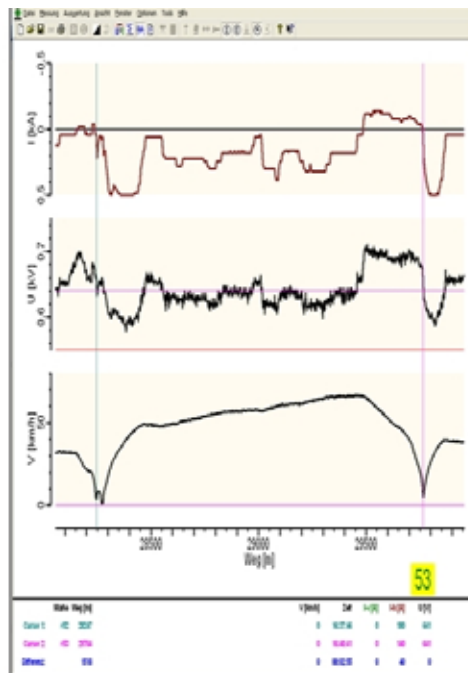


Figure 19: Insufficient contact

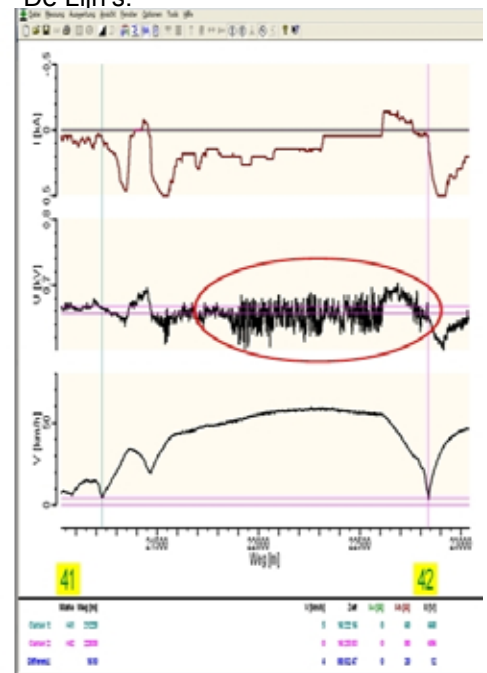


Figure 20: really bad contact

Figure 21 shows a route section of 46 m where the overhead wire climbs from 6.19 m to 6.48 m. This is a rise of 6.28 percent. Considering the vehicle speed, the pantograph's maximum rate of change must be kept below 5.94 cm per second.

Above an overhead wire height of 6 m, the contact force between contact strips and overhead wire is no longer sufficient. The transfer

resistance between overhead wire and contact strips oscillates wildly. The voltage values show these oscillations. On another route section the overhead wire's height drops from 516.5 cm to 500.9 cm in a distance of 2.488 m.

This is a decline of 62.66 percent. The pantograph has to follow this change in height at a rate of 30.148 cm per second. The pantograph curves (previously shown in Figure 12)

show that the pantograph already loses contact with the overhead wire at a rate of 24 cm per second.

The bottom chart in Figure 22 (on the following page) shows the result of the overhead wire decline: the voltage collapses and the contact strips lose contact with the overhead wire.

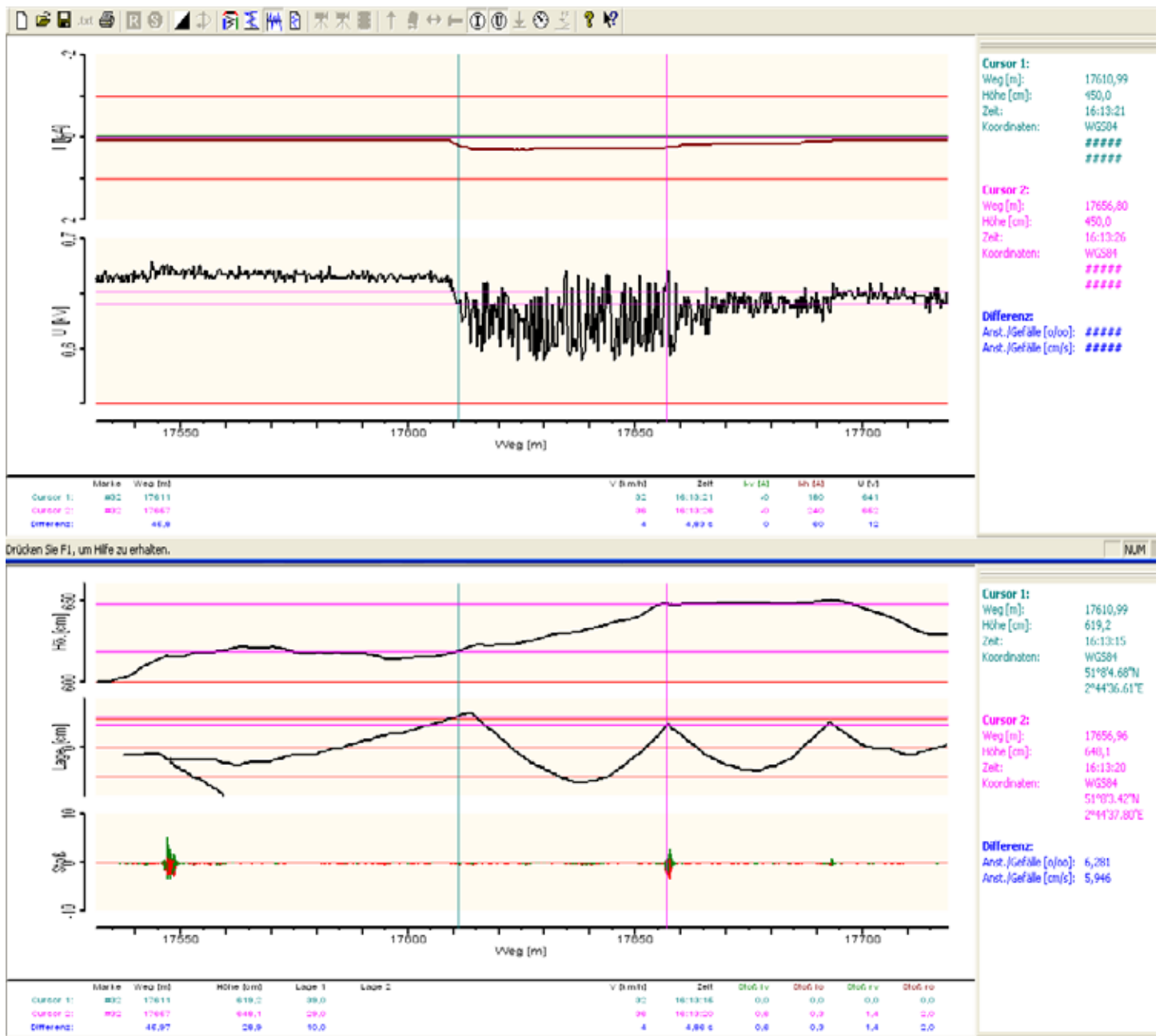
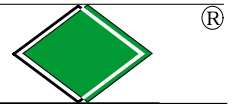


Figure 21: Overhead wire rise above the pantograph working range



## Case Study 3

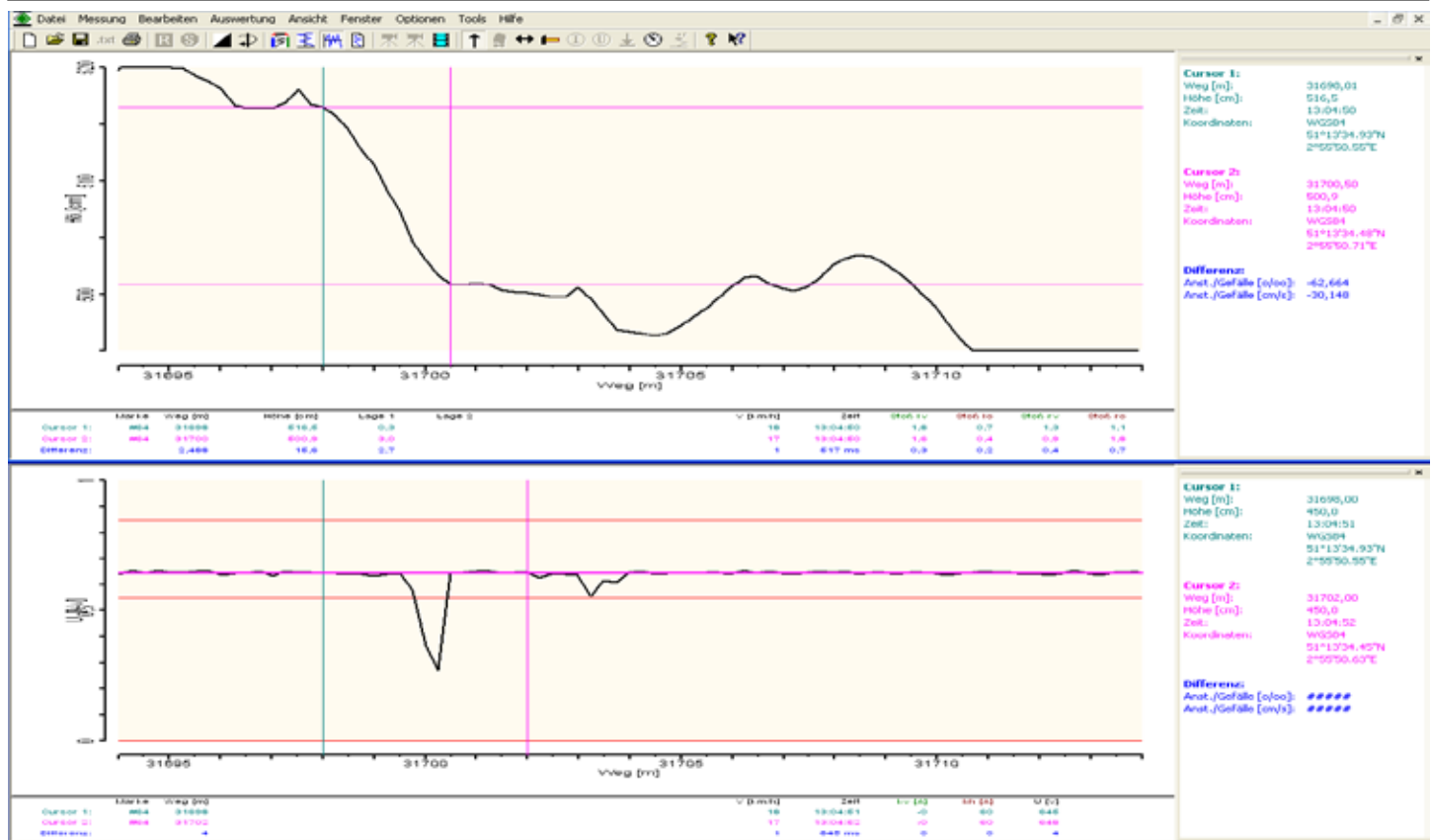


Figure 22: Interruption in contact

## 5. Summary

The public transport company in Oostende, Belgium must operate in difficult conditions caused by the seaside climate and special contact strips were developed in order to help reduce failures.

In spite of this, the current collection system had a lot of problems that resulted in low contact strip lifetime and excessive overhead wire wear. DTK was hired to identify the root causes for these problems. DTK performed a route survey that measured the overhead wire position (i.e. the height and stagger) location of the shocks between overhead wire and contact strips, current consumed and returned to the network, voltage, and the vehicle speed. The vehicle movements and coordinates were recorded simultaneously.

At the same time a pantograph and contact strip test were performed at the depot.

The pantograph tests revealed poor contact quality between the overhead wire and contact strips, even at low rise and decline rates for the overhead wire. It has been shown that these interferences are caused by the pantograph's weight, by the overhead wire height, and by the route sections with too fast a rise or decline of the overhead wire. Under these conditions, the pantograph is not able to keep sufficient electrical contact between the contact strips and overhead wire.

DTK made recommendations to enable better interaction of the pantograph and overhead wire. These included regulating the overhead wire height, the rate of overhead wire height changes, and reducing the

weight of the contact strip. The measurement survey and analysis was all completed while the tramway remained in normal revenue service. The end result was reduced overall maintenance costs and increased infrastructure uptime for De Lijn-Oostende.