Plasser & Theurer's "FDMA" system for measuring overhead wires

The overhead wires for high-speed and/or high-capacity railway lines must be positioned precisely within tight tolerances both vertically and laterally. In addition to that, it is essential to make sure that the catenary maintains more or less constant vertical elasticity. If these two characteristics are achieved at the same time, they will ensure that pantographs run smoothly, that the amount of wear and tear will be minimised, and that the service life of the overhead wires will be extended. Plasser & Theurer's new system for measuring overhead wires (known as "FDMA") is presented in this article.

The competitive environment has pushed the railways to keep on increasing their operational speeds. France has now reached 320 km/h, Spain 350 km/h, and China even intends to run at 380 km/h in normal daily operations in future. Seen in this context and also in combination with economic considerations, it is crucial to adapt and optimise the procedures for constructing and maintaining electrical overhead wires. Very significant performance improvements and savings can be attained by using modern machines for working with overhead wires (self-propelled catenary installation machines and self-propelled tower cars), when hanging new catenaries as well as when upgrading and maintaining existing ones.

1 Quality requirements for catenaries

Overhead wires do not have any inbuilt redundancy. That makes their availability particularly important. New quality criteria for the interaction between overhead wires and pantographs are intended to ensure that the current pickup stays constant and that the wear on the contact wire remains low. This requires very tight tolerances as regards the geometric position of contact wires both vertically and laterally. The height of the contact wire ought to be as close to constant as possible, in other words there ought to be no height differences between neighbouring droppers or support points. Any irregularity in height leads to higher contact forces, the result of which is severe wear on the contact wire. It is imperative to abide by the tolerances laid down in the TSIs (Technical Specifications for Interoperability), the ENs (European standards) and the guidelines of each individual railway. Particular attention must be paid to ensuring that the contact wire is positioned accurately. Its quality must thus be established and documented with technical measuring equipment after its initial installation and in relation to any subsequent maintenance activities.

When trains run faster, there are bound to be higher tensile forces acting on both the contact wire and the messenger wire. That, of course, also makes it necessary to use new materials with higher mechanical-strength values. The high contact and messenger-wire forces guarantee a low and even vertical elasticity in the catenary and a velocity of wave propagation in the contact wire that is 30% higher than the highest operational train speed. This satisfies one of the most important quality criteria for the dynamic interaction between the contact wire and the pantograph – in other words a pattern of contact forces that remains as close to constant as possible.

2 Standards and guidelines for construction and maintenance

Standards and guidelines form the basis of the technical specification for the "energy" subsystem of the interoperable European railway system. The requirements as regards geometric and dynamic properties are described in detail in the following European standards: EN 50367, EN 50317, EN 50318, EN 5 0149 and EN 50119. According to TSI Energy, the manufacturer is required to disclose operational limit values, for example, as regards the permissible tolerances for the lateral position. The vertical jolts over the length of the contact wire must also be kept within limits. According to EN 50119, the maximum permitted change in the gradient of overhead wires for velocities of up to 200 km/h, for example, is 1‰, and, for velocities of up to 250 km/h, it is as little as 0.5‰.

The infrastructure manager is required to maintain the characteristics defined for overhead wires throughout the whole of their service life and to document this through measurements. What is of particular interest in this context is the height and lateral position of the contact wire both at rest (i.e. in a static state) and in its uplift position (i.e. its dynamic behaviour with pantographs running along it).

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TSI HS Energy states that the position at rest is to be measured at low speeds and with a contact force in the range of 5–10 N. Otherwise, the contact force is usually set at 150 N in order to obtain a good approximation of the pantograph sag in normal operating conditions and the contact forces that then occur between the contact wire and the pantograph. This also serves to be able to check what happens to the uplift level of the contact wire caused by the pantograph's lift at critical points such as at steady arms, crossovers and overlaps. In tunnels and at locations with unusual properties, measurements are made with contact forces of up to 250 N. At the same time, the lateral position of the contact wire is measured by means of inductive proximity sensors attached to the measuring pantograph (Fig. 1).

Thanks to the special mechanical and pneumatic properties of the overhead-wire measuring system and a computer program developed especially for it, it is possible to make extremely precise measurements. Other computer programs can then be used to evaluate these measurements to produce special static and dynamic characteristic values, such as the vertical elasticity ("resilience") of the whole catenary assembly.

The measuring system described below satisfies all the necessary precision requirements and is thus ideally suited for checking and accepting the relevant limit values in accordance with the TSIs and the European standards. The measuring device is suitable for installation on a self-propelled tower car, which makes it possible to use this vehicle as a multifunctional one, i.e. as both a work machine and an acceptance vehicle. With this configuration, work can be inspected immediately after its completion.

3 The "FDMA" system for measuring overhead wires

The "FDMA" system for measuring and recording the position of the contact wire relative to the running surface of the rail and the central axis of the track was developed by Plasser & Theurer assisted by European Trans Energy GmbH (EUROPTEN). The device establishes the lateral position and height of the contact wire, saves this data and presents it in the form of a plot of measured values against distance.

The pantograph has a specially developed measuring contact bar mounted on top of it (actually a proprietary tubular-steel measuring contact bar with two force sensors (load cells) and inductive proximity switches (Fig. 1)). When measurements are to be made, this special-purpose bar is flipped into place by means of a hinge mechanism. In all other circumstances, the vehicle runs with its standard contact bar. The lateral position of the contact wire is measured with special inductive proximity sensors mounted along the measuring strip (at intervals of 2.5 cm). The height of the contact wire is determined by a high-resolution rotational-angle sensor, which measures the angle by which the contact wire has been uplift and derives the wire height from that. The measuring pantograph is attached to the top of the driving cab and can be electrically insulated from it as an option. With this latter configuration, it is possible to measure live overhead wires (carrying voltages of up to 25 kV) without needing to restrict the power supplies needed for normal railway operations. Alternatively, the pantograph can be grounded by an earthing disconnector and thus take over the safety functions. The measuring unit is positioned dead-centre above the bogie or axle (in the case of vehicles with single-axle running gear) to ensure a precise measurement of the lateral position of the contact wire relative to the central axis of the track.

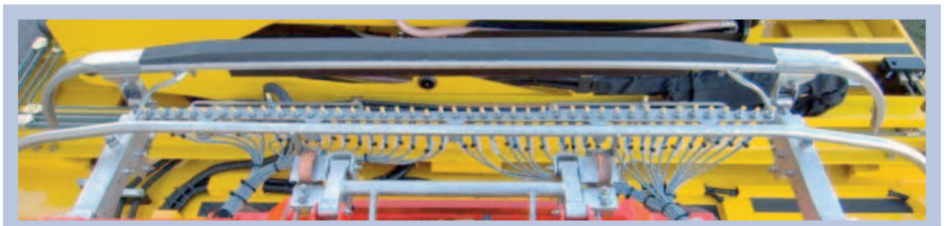


Fig. 1: Pantograph with fully assembled inductive proximity sensors for detecting the lateral position of the contact wire *(source of all figures: the authors)*

In order to compensate for any influences affecting the height of the contact wire, such as differing loads, spring settings or rocking movements by the carrying vehicle, the primary and secondary springs of the running gear's axles or bogies are blocked relative to the body of the vehicle while measurements are taking place.

The precise distance advanced by the measuring device is recorded via a pulse encoder mounted directly on the axle stub. The transducer can be calibrated very easily using the vehicle display on the machine's driving console, which compensates for worn-down wheels and thus improves the accuracy of the measurement of distance. Calibration is based on a standardised section of track with a length of typically 50 metres, which the vehicle moves along making a measurement.

Figure 2 contains a schematic diagram of the overhead-wire measuring system in its assembled state. The pantograph's contact pressure can be set with infinite variability within a range of 7 to 150 N (and even up to 250 N if required), which allows both the static position at rest and the static uplift of the overhead wire to be measured. A precise pressure control ensures that the measuring unit's contact pressure against the contact wire remains constant throughout the whole measuring run. To achieve that, the pantograph is kept pressed upwards through a pneumatic cylinder regulated by a proportional valve. The force exerted on the measuring contact bar can be measured via two force sensors (load cells) and immediately and continuously adjusted to the chosen target pressure though the enclosed circuit (with a PID controller). The mean deviation between the height measurement at rest and the contact-free measurement is around 4 mm (simple standard deviation). The measured data is recorded and saved equidistantly every 10 cm.

The control unit, including the measurement of the contact force, and the elements for determining height and lateral position, is placed directly on the pantograph (Fig. 3). Given that the whole measuring installation is also able to function with the overhead wire in a live state, it is fed from the vehicle through a special high-voltage transmitter. The continuous voltage supply thus guarantees that measuring runs will not need to be interrupted for the purpose of replacing or recharging batteries.

While the measurement is taking place, the operator does not need to move from the cab and can simply watch the plot of measurements in real time and check them for irregularities. Optical waveguides are used to transmit the data from the control unit to the machine controller. The image of the overhead wire is transmitted for observation purposes from a dedicated measuring station inside the cab to a flat-screen monitor. Two video cameras mounted on the vehicle roof (one for each direction) make it possible to recognise relevant events (such as masts, section insulators, droppers or engineering structures), so that the operator can then flag them specifically and thus mark their precise length on the log of measurements. Roof-mounted headlights assist with optical checking when measuring runs are made in the dark.

The vehicle normally advances at 8 km/h while measurements are being made. Its speed can be infinitely adjusted within a range of 0–8 km/h. It is thus possible to adapt its speed optimally to a poor state of track or to eliminate the effects of winds.

Ethernet is used to connect the vehicle's control with the measuring function of the process control system. The software runs on an off-the-shelf portable computer and is configured in such a way that, when it is booted, it automatically starts up the process control system. The simple sequence of menus means that even inexperienced

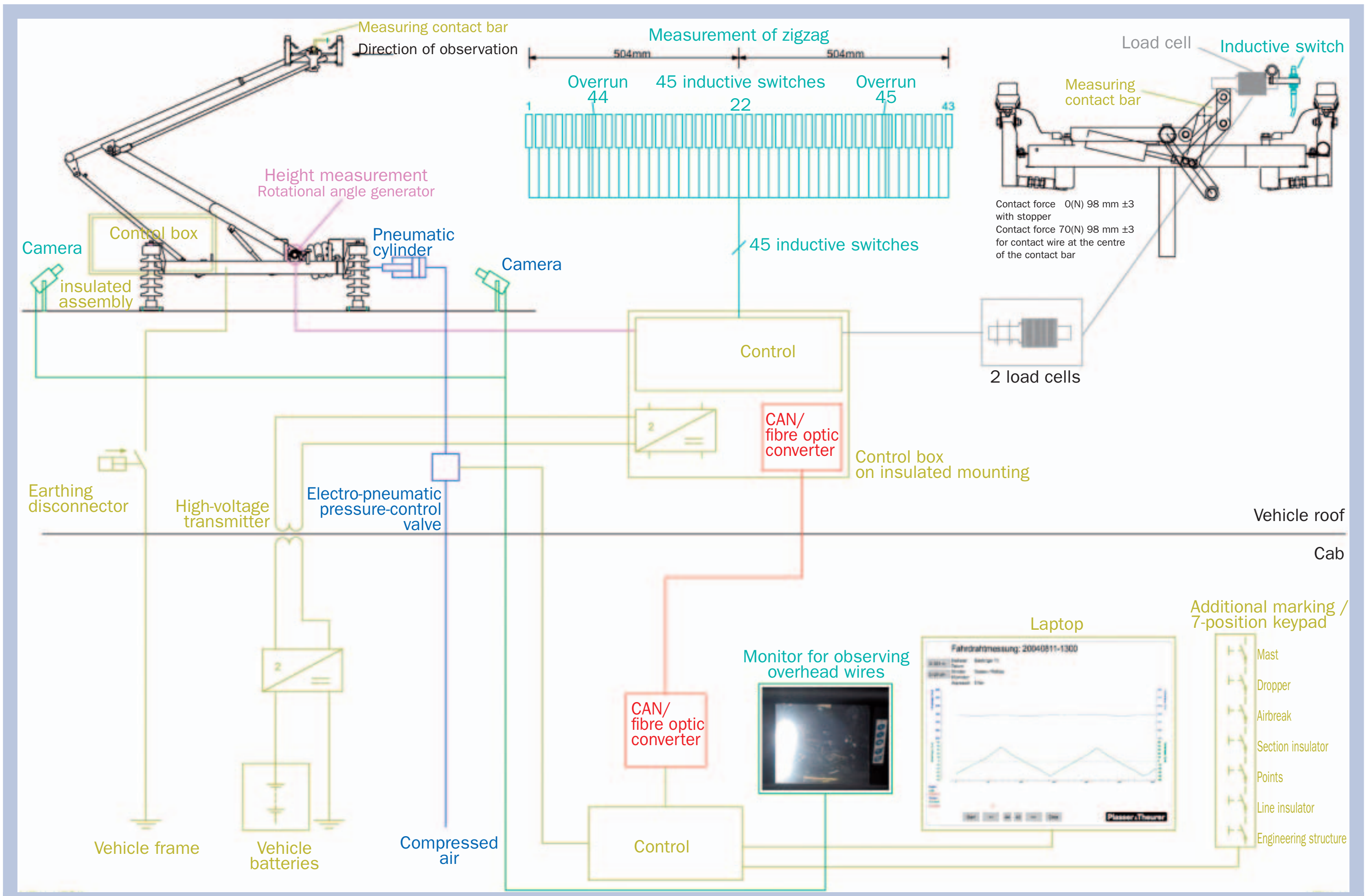


Fig. 2: Schematic diagram of the measurement of an overhead wire

operators are soon able to grasp the system's fundamental operations. Figure 4 shows the main menu on the left-hand side and the monitor image for entering the characteristic values for a measurement on the right-hand side.

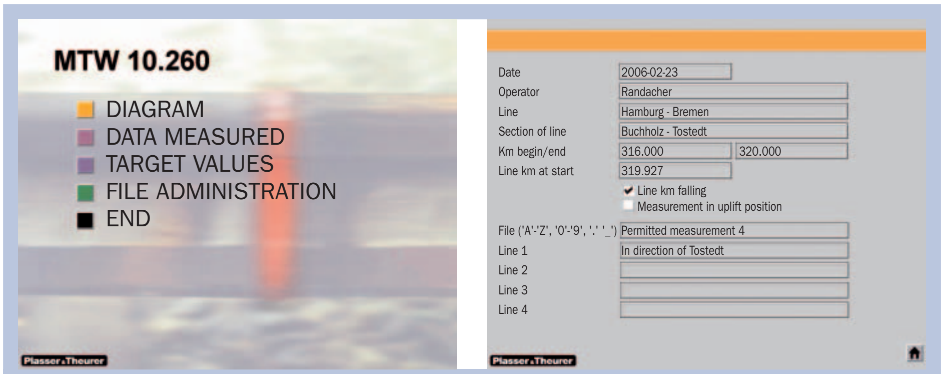
Fig. 3: Roof superstructure including the measurement electronics

The log displays the height and lateral values together. Figure 5, for instance, shows the lateral position (magenta) and the height (green) for a static measurement at 10 N, while the amount of contact-wire uplift at 150 N is plotted in grey. In the screen view, the height and lateral values can be switched on and off independently of one another, if desired. Flagged events, such as masts, section insulators, droppers or engineering structures are fed into the measuring system by the operator, who activates the appropriate pushbutton for the event on the control console. Such events appear on the graphic display with a highlighted background. Another feature integrated in the software is the generation of a spreadsheet evaluation which, for the purpose of this example, is structured in accordance with the details contained in DB Netz's technical communication "EM (Eb) AM 003/2005".

In order to be able to react to the individual requirements of various infrastructure managers, the characteristic values of the overhead-wire types currently in use have been pre-loaded in the system. It is also possible to enter and save user-defined catenaries and their special properties (such as stiffness and geometric threshold values) permanently in the software.

Data can be followed directly online on a portable computer while the measurements are being recorded. Once the measurement has been completed, the data, which is saved in a format known as SVG (scalable vector graphics), can be printed out true-to-scale or exported to a USB memory stick. After that the measured data and the tabular reports generated from it can be viewed on any personal computer that has Internet Explorer installed on it (version 6 or later).

The software supports the simultaneous display of the measured data at rest and with the contact wire in its uplift position. In



Date 2006-02-23
Operator Randacher
Line Hamburg - Bremen
Section of line Buchholz - Tostedt
Km begin/end 316.000 320.000
Line km at start 319.927
☑ Line km falling
☐ Measurement in uplift position
File ('A'-'Z', '0'-'9', '.' '_') Permitted measurement 4
Line 1 In direction of Tostedt
Line 2
Line 3
Line 4

Fig. 4: Examples of monitor images for guiding operators

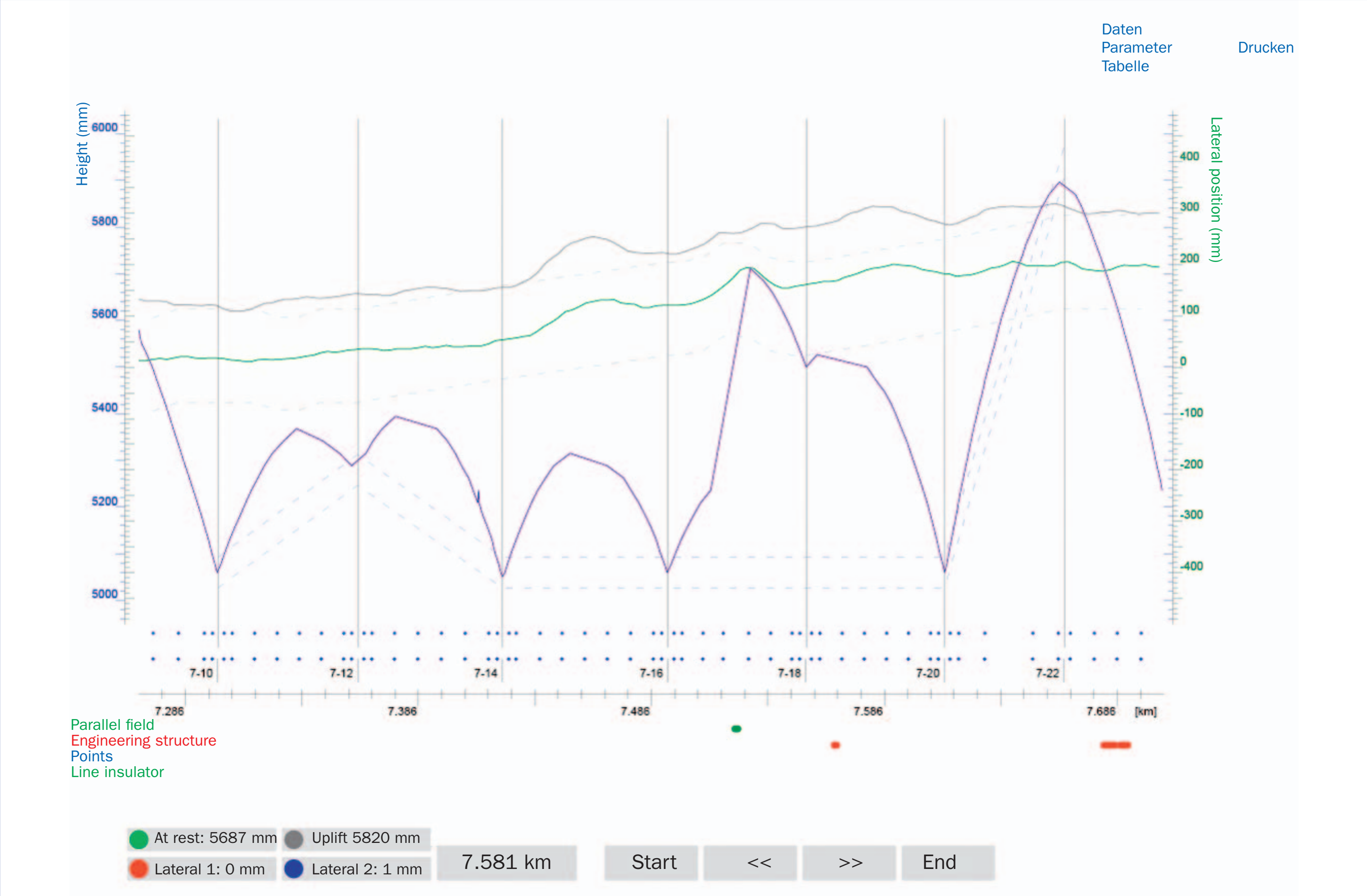


Fig. 5: Diagram of the height and lateral positions measured for an overhead wire

this way, it is possible to obtain a diagram of how the overhead wire behaves over time in various conditions. One further advantage of SVG files is that the diagrams generated from them are interactive. What that means is that, even in an offline display, a simple mouse click can select various items of diagram data for inclusion, for instance, the at-rest and/or uplift vertical position, the lateral position and the distance of the chosen point along the line section.

The hardware part of the system for measuring overhead wires can be attached to most of Plasser & Theurer's two axled self-propelled tower cars of classes MTW 10 and MGW 10 as well as the class MTW-100 or MTC-100 machines, which run on bogies.

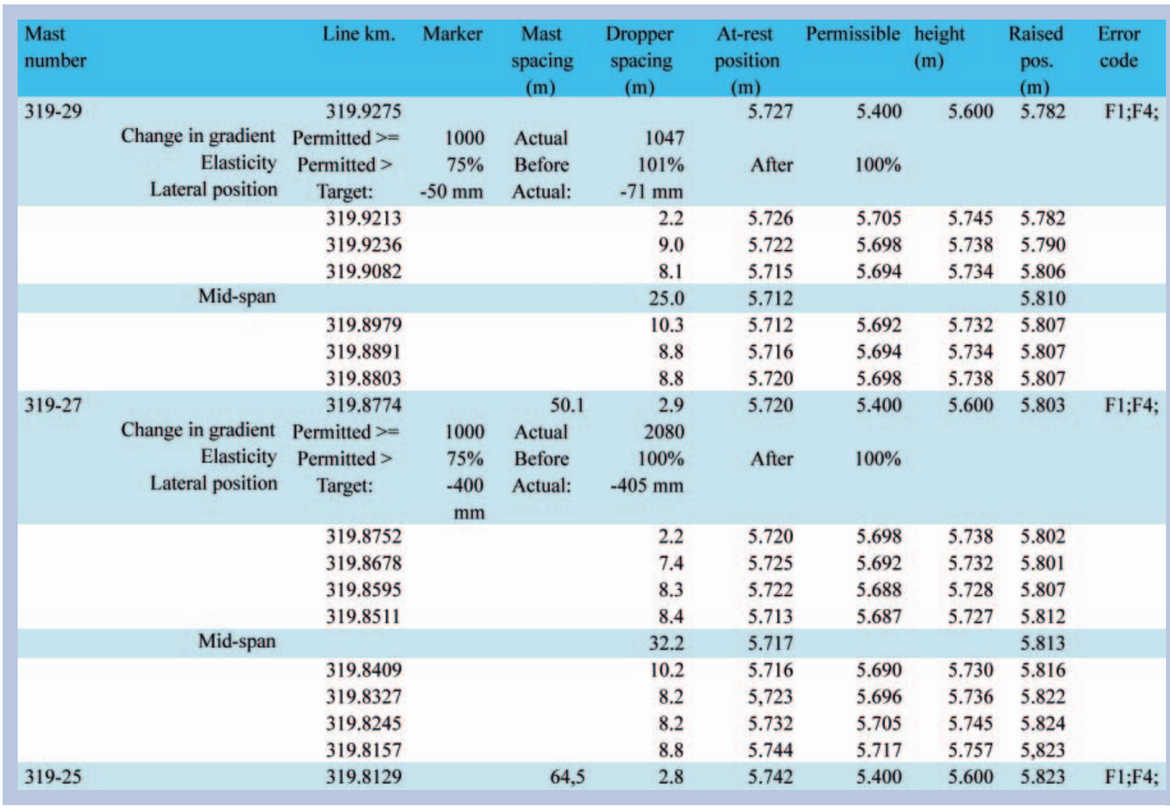
Units for measuring contact wires mounted in the way described in this report on vehicles supplied by Plasser are currently in service in Germany (Fig 6), Austria, Switzerland and Sweden, and there is also a special version for the metro in Sao Paulo, Brazil. Retrofitting measuring systems to existing vehicles is also possible. DB Netz has granted the necessary technical release for them to be used (in its technical communication "TM 2008-259I.NVT 4 (E)" as well as the technical communication from Deutsche Bahn AG, no. "TM 2008-260I.NVT 4 (E)" of 20 November 2008). It is thus possible for other Plasser & Theurer systems with the same basic structure to obtain their approval through the simplified authorisation procedure (check of structural and test conformity).

4 Practical experience

In the period up until summer 2009, approximately 300 kilometres of overhead wires were measured on tracks forming part of Deutsch Bahn's network. As a rule-of-thumb, a realistic productivity figure is roughly 40 km in one shift, with one parameter being measured – either the at-rest position or the static uplift position.

Track possessions necessary for measurement work to be carried out need to be planned and announced long in advance. That makes it all the more important to use them as efficiently as possible. If advanced planning is done skilfully, it will be possible to keep a measuring run going over long sections of track without needing to interrupt it. Thanks to various technical details, such as the insulation of the measuring hardware and the voltage supply to the computers from the onboard network, the deployment conditions for the measuring system are very favourable. It is no longer necessary to switch off the power supply to the overhead wire and to earth it for the sake of measurement runs. Measurements

Fig. 6: Acceptance measurement of an overhead wire during a real-case deployment on Deutsch Bahn's network



Mast number		Line km.	Marker	Mast spacing (m)	Dropper spacing (m)	At-rest position (m)	Permissible	height (m)	Raised pos. (m)	Error code
319-29		319.9275				5.727	5.400	5.600	5.782	F1;F4;
	Change in gradient	Permitted >=	1000	Actual	1047					
	Elasticity	Permitted >	75%	Before	101%	After	100%			
	Lateral position	Target:	-50 mm	Actual:	-71 mm					
		319.9213			2.2	5.726	5.705	5.745	5.782	
		319.9236			9.0	5.722	5.698	5.738	5.790	
		319.9082			8.1	5.715	5.694	5.734	5.806	
	Mid-span				25.0	5.712			5.810	
		319.8979			10.3	5.712	5.692	5.732	5.807	
		319.8891			8.8	5.716	5.694	5.734	5.807	
		319.8803			8.8	5.720	5.698	5.738	5.807	
319-27		319.8774		50.1	2.9	5.720	5.400	5.600	5.803	F1;F4;
	Change in gradient	Permitted >=	1000	Actual	2080					
	Elasticity	Permitted >	75%	Before	100%	After	100%			
	Lateral position	Target:	-400 mm	Actual:	-405 mm					
		319.8752			2.2	5.720	5.698	5.738	5.802	
		319.8678			7.4	5.725	5.692	5.732	5.801	
		319.8595			8.3	5.722	5.688	5.728	5.807	
		319.8511			8.4	5.713	5.687	5.727	5.812	
	Mid-span				32.2	5.717			5.813	
		319.8409			10.2	5.716	5.690	5.730	5.816	
		319.8327			8.2	5,723	5.696	5.736	5.822	
		319.8245			8.2	5.732	5.705	5.745	5.824	
		319.8157			8.8	5.744	5.717	5.757	5,823	
319-25		319.8129		64,5	2.8	5.742	5.400	5.600	5.823	F1;F4;

Fig. 7: Spreadsheet of the measured results, showing values in excess of the tolerance and the corresponding error codes

can be performed without causing major disruptions to ongoing train operations. It is this last point that has emerged in practice as the biggest advantage of all.

If the target geometry of the track to be measured is fed into the system before the measurement is made, the exceptions report can then be generated automatically (Fig. 7). This report is then available immediately a measurement has been completed, which helps derive maximum use from the potential of the measuring system. Approvals of catenary installations can also be completed within a tighter timeframe. It takes a crew of only two to operate the measuring system: the driver and a trained operator. The simplicity of operation makes employee training easier.

Plasser & Theurer's machines for overhead wires and the components for the systems for measuring them are fully integrated in the company's proprietary remote diagnostics system for the technical equipment and controls of vehicles. If problems do arise, Plasser & Theurer's technical customer service is able to provide speedy support. That has tremendously shortened the duration of downtimes. Thanks to the modular structure of the measuring system, it is a simple matter to replace defective components.

Class-MTW 10 self-propelled tower cars are used for the installation and dismantling of catenary installations. Using them for carrying the new measuring system too only became possible thanks to the latter's compact dimensions. The additional parts are arranged in places in which they are well protected, while sensitive components, such as the cameras, have pluggable connections and are thus easy to remove. The additional function for the self-propelled tower car that can be achieved by adding the measuring unit to it brings about a very considerable increase in efficiency in installing catenaries. The fact that is it no longer necessary to buy in the service of measuring overhead wires in order to secure their acceptance greatly simplifies the whole process. It has led to a significant transfer of know-how to the company executing the work, from which customers are also benefiting.

5 Concluding summary

For the purposes of acceptance testing of overhead wires and performing quality inspections of them, one of the requirements is for documentation of the static and dynamic characteristic values in accordance with the European standards. With the "FDMA" system for measuring contact wires mounted on railway vehicles, it is possible to measure and document with precision the height and lateral position in both the at-rest state and under the effect of adjustable contact forces. In addition to that, various quality criteria can also be computed and values in excess of the limits detected while the measurement is still going on. These quality criteria include vertical elasticity, the slope of the contact wire and changes in its slope. Given that the measuring pantograph is attached to the roof of the driving cab through insulators, it is possible to make the measurement runs under live overhead wires at voltages of up to 25 kV.