Machines for Catenary Construction and Maintenance

Just as in track engineering, continuous-type procedures are being used more and more for work on catenaries. It has now become possible to replace whole catenary sections with the track concerned only needing to be closed to normal traffic for a period of less than five hours. Moreover, trains are able to run at their full speed again immediately after the work has been completed. These new continuous techniques are bringing a two-fold benefit: they are reducing the amount of disruption to operations caused by catenary work, and the quality of the finished work is appreciably enhanced. This results in a longer service life for the whole catenary installation and a concomitant reduction in life-cycle costs. The activities of catenary inspection and maintenance also call for methods that facilitate fast, top-quality diagnoses and repairs, whereby the safety afforded to catenary workers must also be as high as possible. The consistent use of modern hydraulic and electronic systems is the key to performing such tasks economically. It has been clearly shown that machines that actually run on the rails themselves are far superior in terms of both their stability and the speed at which they can work.

1 Introduction

The development of mechanized approaches to permanent-way engineering started to have a clear impact on the work involved back in the 1950s and to bring the railways significant savings.
History shows that the "production line" type of track-renewal techniques that were developed by Plasser & Theurer had become the standard methods by 1968, and it was not long before other companies imitated them. For a long time, however, the application of comparable methods to catenary renewal was considered impossible.

It was in 1990 that Plasser & Theurer achieved a breakthrough in catenary-replacement methods too — with Banverket (Sweden). Before then, the usual practice had been to install the new messenger and contact wires purely provisionally to begin with. They were then allowed some considerable time to settle down, before the tension on them was increased to its final value, and they were fixed in their definitive position. This time was necessary for the catenary's elastic system to arrive at a longitudinal equilibrium. Compared with all of this, the new system envisaged applying the full definitive cable tension to the new catenary from the moment it was put in place.

The advantage of this technology is that the new overhead wires can by used at the top speed permitted for the particular section of track immediately after work has been completed on them.

2 Catenary construction

Since the first continuous catenary-replacement system was introduced in Sweden, there have been numerous noteworthy developments to enhance the speed of advance and the quality of the finished job of work:

2.1 Preconditions for techniques to replace catenaries at their definitive cable tensions

Cable-tension control
A key feature of Passer & Theurer's technology for the positioning of new catenaries or the replacement of existing ones is that the new cables and wires have their definitive tension applied to them right from the very beginning. No matter how the machine may move, the predefined tension is maintained through the interplay of hydraulic and mechanical forces and electronic adjustment and control elements. Depending on the actual type of catenary system to be replaced, the cable tension can be set at will within a range of approximately 3-20 kN (and even as high as 30 kN for special applications). Separate values can also be set for each individual wire or cable.

The cables are unwound from standard drums that slot into special cradles on the machine itself. The cable is reeled out through two friction winches and on to the telescopic guide arm with its pulleys for correctly positioning the cable.

Figure 1 shows all the elements that make up the very sensitive system for controlling the cable tension. The required cable

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tensions are entered using the control panel in the machine's cab (1) and fed into the central electronic system. The actual value is measured directly on the cable offtake just after the deflection pulleys (2). This value is also fed into the central electronic system, where it is compared with the setpoint value. A control card is used to compute the value required to compensate for the computed difference, and this is fed into the valve control or hydraulic motor that operates the friction winch.

The actual cable-tension value is shown on a large display panel on the outside of the machine and also on the control instruments inside it. Catenary engineers can thus keep a watchful eye on it as necessary.

Another sensor measures the thickness of the wound cable remaining on the feeder drum. Its signal is fed through a control card, which sends the required impulses to the valve control on the drum's hydraulic motor. This arrangement ensures that the cable is always prestressed at a constant value as it leaves the drum. Without such a device, there would be a risk of the cables sagging while unrolling. The sensor also reacts if the amount of cable left wound on the nearly-empty drum falls below a preset minimum value. It brings the work to an immediate stop until the drum is changed.

Safety devices
In order to maintain both functionality and safety even in the event of unforeseeable occurrences, the central electronic system monitors certain limit values and imposes precautionary measures if any of them is violated. To give one example: if the hydraulic pressure falls below its preset value (which might be caused, for instance, by a broken cable), the brakes will be automatically applied on the friction winch and the vehicle's running gear. A further example is cable tension: if this exceeds the preset value, first of all a warning signal is issued to give the operator the chance to react manually; if the tension still continues to increase, however, all the brakes will be applied, bringing the work to a stop.

Cable guidance inside the machine
For any catenary – or just the contact wire in the case in point – it is essential to

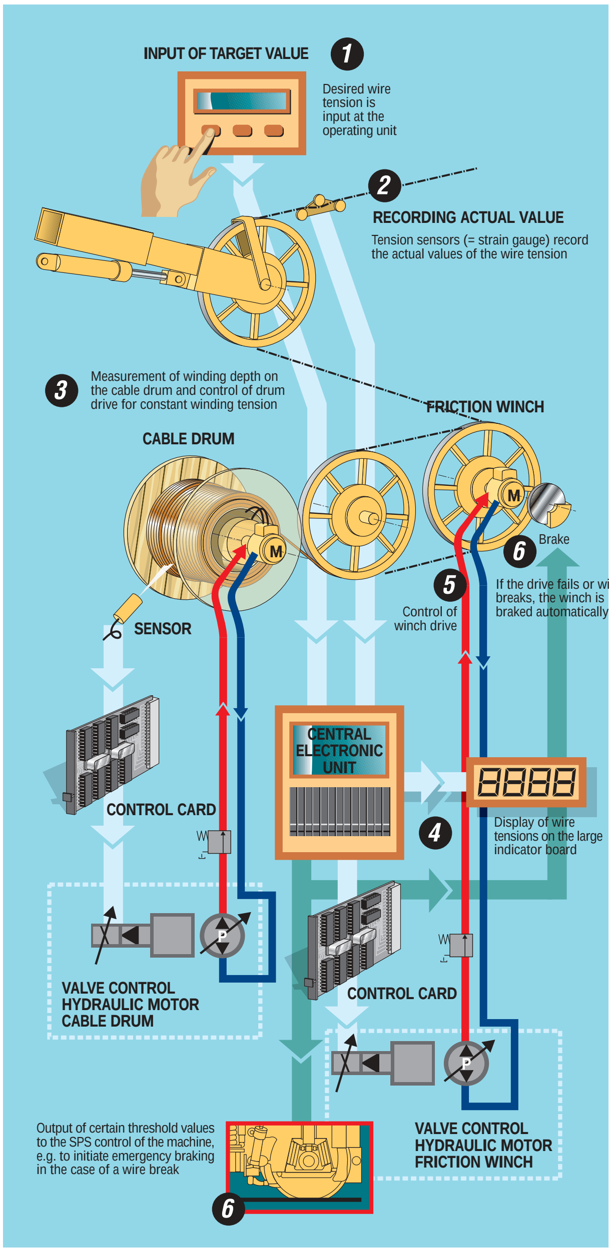


Fig. 1: Block diagram of the cable-tension control

remain within defined limit values to prevent excess tensions that could cause buckling. It must also be considered that double-flanged pulleys only permit a limited amount of angular deviation from the optimum feed direction before the cable springs out of its guides. Precision cable guidance is thus decisive for smooth working routines and top-quality results. The individual machines have thus been designed with a high degree of relative movement between their cable-guidance components, to make sure that the cable can be run out without buckling.

Several different directional steering devices take charge of the necessary advance and adjustment of the various active devices along the cable's path of travel. These are located at strategic points right next to where the cable runs onto or off the drums and deflection pulleys. Potentiometers send an electric voltage to the control if the line of cable guidance departs from its optimum. The appropriate actuator is then moved in the required direction until the voltage falls to zero again.

The cable drums are housed in cradles and can move from side to side – an essential precondition for unwinding without causing buckling stresses.

Making adjustments as the vehicle starts
Even when the vehicle starts, stops or reverses it is still guaranteed that the messenger and contact wires will be positioned with their correct, definitive tension.

In order to make sure that no sudden jolts or excessive peak stresses occur when the machine starts to move, any movement from a standing start is kept under electronic control. The operator may, for instance, set the vehicle in motion using a remote control. The hydraulic pressure in the transmission will, of course, always build up. However, all the brakes remain applied until the pressure reaches the level that is necessary to overcome the sum of the forces resulting from both starting inertia and the tensile forces acting through the cables. It is only then that the brakes applied to the running gear and/or the friction winches are automatically released and the machine starts to move without jolting.

2.2 The ÖBB's catenary renewal system

On the most heavily trafficked routes in Austria, the ÖBB uses a 16.7 Hz system with an extra cable to reinforce the power supply looped between the tops of the masts and an earth-return line on the outside of the masts. The ÖBB uses a complete set of machines both for converting existing catenaries and for installing overhead wires on newly-built high-capacity lines. The first step involves

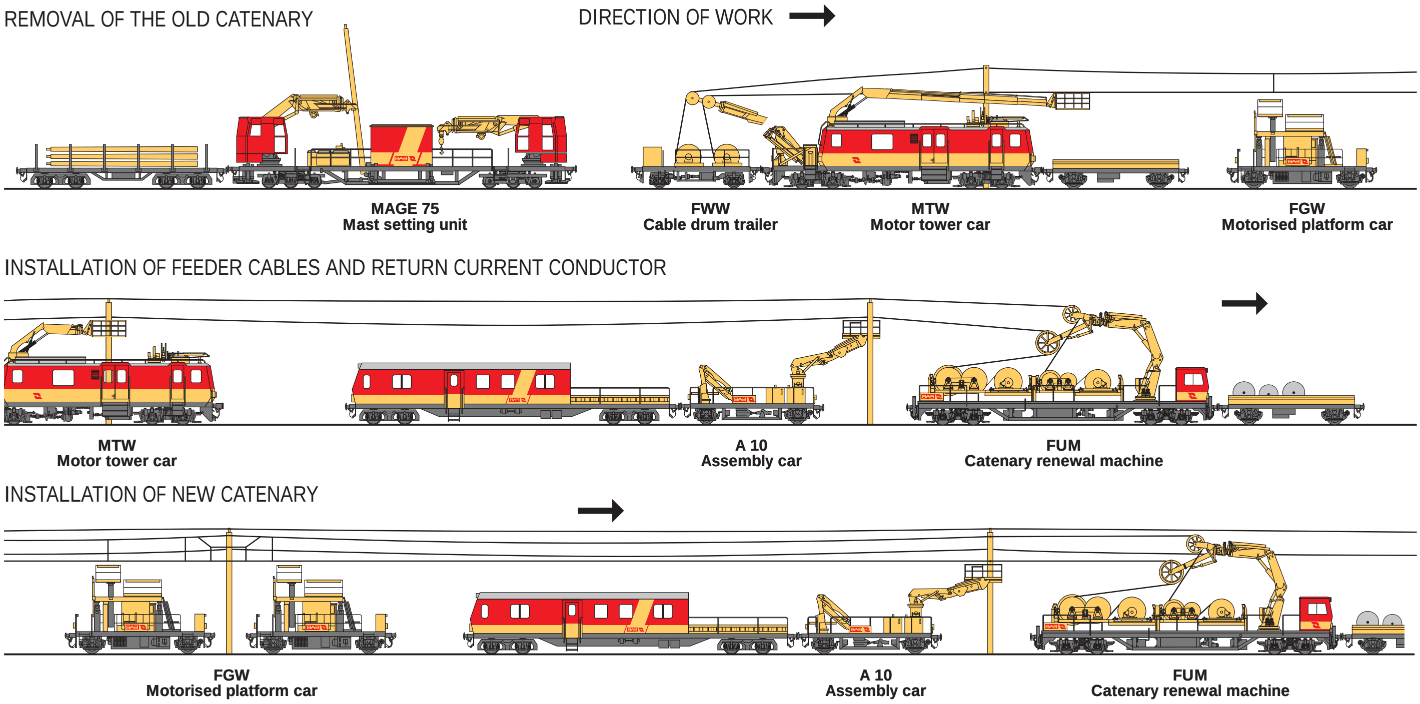


Fig. 2: The convoy of machines used for catenary replacement by the ÖBB

removing the old catenary system including the mast brackets, whilst the reinforcement-supply and return cables are detached from the masts but kept under controlled tension. During the second stage, the new mast brackets are installed and the messenger and contact wires are suspended from them – also with their definitive tension. If necessary, the convoy of machines can also include a special crane for setting masts. The most important items of machinery and the work sequence are illustrated in Fig. 2. They are:

- ▷ A four-wheel hydraulic motorized platform car with a three-part hydraulic lifting platform. Two of these three platforms can be manoeuvred vertically and horizontally independently of one another. One is used for removing old droppers and the other two for installing new ones. The workers can reach any point on the catenary from the work platforms. This particular machine is also equipped with a mechanical device for measuring the height of the contact wire and an electronic telemetric unit for the correct positioning of droppers;
- ▷ A standard motor tower car with an hydraulic column including deflection pulleys and winding devices for both the contact wire and the messenger wire. The machine's elevated platform can be used, for instance, to dismantle brackets or to disconnect the old contact and messenger wires from their brackets;
- ▷ The central unit is the catenary-replacement vehicle, FUM 100.046, which positions the new messenger and contact wires in a single operation;
- ▷ An assembly car, A 10, with an elevating work platform for installing brackets and fastening the catenary. The telescopic platform is able to withstand lateral forces of up to 400 daN. This makes it easy to manoeuvre the tensile-stressed cables at the beginning and end of work;
- ▷ A mast-erecting crane for removing old catenary masts and erecting new ones (only sometimes used).

Each of these is an autonomous machine; however they have all been carefully matched to each other in terms of working method and power. One big advantage is that the order of the machines can be modified to suit changed site conditions. Both the vehicle's drive and its installed equipment can be operated by means of remote controls.

2.3 Replacing three cables simultaneously

The Polish Railway, PKP, has a DC form of electrification which requires two contact

Fig. 3: Catenary-installation machine for handling three cables simultaneously

Fig. 4: Catenary-replacement machine with a directional telescopic column

wires. Plasser & Theurer managed to bid successfully in an international call for tenders and has received an order for the supply of a catenary-renewal train for upgrading high-capacity routes. The droppers are removed and installed from vehicles with longitudinally adjustable working platforms, like in Sweden. This means that the droppers can be renewed at the correct point in the work cycle, despite the fact that the whole renewal train remains constantly on the move. As in Austria, the brackets are assembled with a dedicated machine that has a telescopic work platform.

A machine known as the "FUM 100.051" has been developed for catenary replacement. It is the first-ever machine able to handle three cables simultaneously (Fig. 3, s. page 26). The system was successfully deployed throughout the whole of 1999 and performed excellently.

2.4 Swivelling telescopic column

In parallel with the developments just presented, a somewhat different solution was devised for Italy. The lower voltage of DC 3 kV used in that country and the higher current intensity that goes with it makes it necessary to construct catenaries with no fewer than four cables (two messenger wires and two contact wires) on the FS's most heavily trafficked routes. Other less busy routes need only a three or two-cable catenary. The machine that has been built is thus one that can be extremely versatile in handling the various different installations encountered. It can install any two cables at a time at their definitive tension and without the need for any subsequent adjustment. It is possible to choose between:

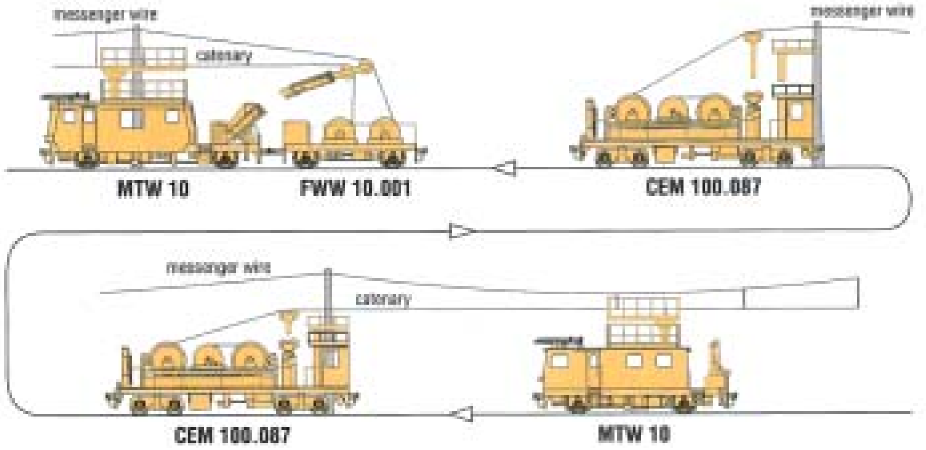


Fig. 5: Contact-wire replacement during short track-closure periods

- two messenger wires,
- two contact wires,
- one messenger wire and one contact wire.

The machine in question is known as the "FUM 100.080". It positions the messenger wire and the contact wire by means of a rotating telescopic column. This column, the guide rolls, the friction winches and the feeder drums are all housed in the tilting frame and make all movements in harmony with each other. The cable is thus run off in a straight line right through to the fastening points at the masts, without becoming twisted. This eight-wheel machine has two such complete cable runoff units, and in between them is a hoist for loading the cable drums.

A variation on this model, that is known as the "FUM 100.087" (Fig. 5), has been designed to do its work when there are only short intervals between trains. It has only one rotating telescopic column, which is also installed in the same tilting frame as the friction winches and cable drums. The use of two of these machines simultaneously, one for the messenger wire and one for the contact wire, reduces the time that has to be spent at each bracket, since only one cable at a time needs to be clamped in place (compared with two cables when using the bigger machine). This enhances the rate of advance. Another advantage of this particular solution is that it can be easily adapted for changing working conditions. Depending on the needs of the moment, it is possible to work with just one machine by itself or with several machines. Its other equipment includes an elevating platform and a hydraulic crane.

3 Catenary maintenance

Tower cars are used for routine maintenance, the correction of faults and safety inspections. The demands for this sort of work to be completed quickly,

Fig. 6: The MTW 100.083/1 for both constructing and maintaining catenaries

cheaply and dependably have led to the development of 100% hydraulic machines with electronic controls.

3.1 Expectations of modern tower cars

Safety constraints

- ▷ It must be possible to reach all parts of a catenary installation from a safe working position;
- ▷ Work on catenaries must remain safe even during train movements on adjacent tracks;
- ▷ Hydraulic cranes and platforms must react in a failsafe manner if the hydraulic-supply system fails;
- ▷ The machines must have guaranteed stability even with their platforms and/or cranes fully extended;
- ▷ Cranes must be built in such a way as to minimize the risk of their touching contract wires;
- ▷ It must be possible to earth the catenary through the machine itself.

Demands related to the execution of work

- ▷ Given the shortage of human resources, the machines must ensure excellent productivity;
- ▷ There must be mechanical devices available for lifting all parts to where they are required;
- ▷ It must be possible to move the machines without jolting while their platforms and/or cranes are fully extended
- ▷ Platforms must have an energy supply point (electrical or pneumatic) on them for any tools that are going to be needed;
- ▷ Adequate lighting must be provided for work at night;
- ▷ It must be possible to clamp the cables in position vertically and horizontally whilst they are being repaired;
- ▷ It is essential to operate all machine functions through a set of remote controls from one single place in order to avoid uncoordinated movements that could be dangerous;
- ▷ Inspection equipment for checking and commissioning work must be provided.

3.2 Motor tower cars with elevating work platforms

In all its designs, Plasser & Theurer attaches particular importance to being able to meet this demand. The class “MTW 100.013” and “MTW 100.083” used by the ÖBB have demonstrated their productivity and cost efficiency in practical use. The “MTW 100.083/1” (Fig. 6) represents the latest development stage. Its salient features and items of equipment are described in the following sections:

Structure
At either end of the eight-wheel machine is a comfortable driver's cab. Each of these contains all the controls and instruments that are necessary both for carrying out work and for transfers in accordance with railway regulations. The machine is operated with a programmed control system which prevents virtually all false moves. The cabs also contain workshop and recreational areas. The hydraulically operated work platform can be laid flat in the middle of the machine. No worker ever needs to climb on the vehicle's roof, either at the start of work or during it.

All items of traction equipment are mounted underfloor. A 376-kW diesel engine makes it possible to travel at up to 120 km/h during transfers. A second, smaller engine, rated at 74 kW can be used as an alternative means of traction during work, which means that the bigger engine can be saved from operating at too low a power over long periods of time. An auxiliary hydrostatic transmission makes it possible to position the machine precisely and without jolting at a crawling speed in the range of 0-5 km/h.

The running gear has been designed for speeds of up to 140 km/h.

Elevating work platform
Plasser & Theurer equips its machines with elevating work platforms, which no longer have to treat the catenary as an impassable obstacle. With them, it is even possible to access the rear side of masts, for instance, to install earth-return lines.

The work platform is arranged on a newly developed articulated, retractable cantilever construction. It is equipped with tool holders, anti-dazzle lighting, power points for electrical devices and a compressed-air connector. Its tilting mechanism has been designed to give it not only a carrying capacity of 400 daN but also the strength to withstand tensile and/or compressive forces up to 350 daN, which occur, for instance, on different types of reinforcement and feeder lines.

In its unsupported state, this work platform can be used for catenary work up to a height of 15.5 m above the top of the rails or down to 4 m below the top of the rails and out as far as 4.5 m to either side of the track’s central axis. An electro-hydraulic level-control system ensures that the platform remains in a horizontal position. When the platform is being used for work next to a track that is still open to traffic, a built-in safety device automatically limits its movement to stop it from being manoeuvred into the danger zone around the neighbouring track. Should it ever be necessary to traverse this zone in exceptional circumstances, it is possible to do so, but that calls for a deliberate override of the safety function, which triggers a continuous warning light.

Hydraulic loading crane
The hydraulic loading crane is able to handle virtually all the conventional lifting situations necessary for work involving catenaries. It can reach points up to 22 m above the rails and up to 16.7 m to either side of the track centre line. The hydraulic installation operates with two different pressures and its low-pressure mode is particularly useful for manoeuvring with high precision at ultra-slow speeds. The crane has a built-in protection against overloads, which ensures its stability.

If necessary, the hydraulic crane can have a work cage attached to it. This has a load-carrying capacity of 280 kg. That is enough for two workers along with tools and light material, and they can work safely at heights of up to 22 m.

Clamps for contact and messenger wires
With the hydraulically-operated clamping units it is possible to hold all the angular and vertical forces that occur during catenary installation and maintenance work. Machines have two clamps that can be moved from side to side. They can thus be placed in a working position on either the right or the left of the catenary. A classical application for such clamps is the replacement of insulators on brackets.

Earthing pantograph
The earthing pantograph rests on insulators on the front end of the cab. The earth connection is established through a roof-mounted line that is switched by a compressed-air actuator commanded by the vehicle's programmed control system. To operate the earthing switch calls for a deliberate action (which is recorded). A special key is required for the purpose.

4 Catenary inspection

The equipment that is necessary for inspecting and measuring catenaries can be installed either on general-purpose motor tower cars or on dedicated track-recording cars.

4.1 Inspection equipment for motor tower cars

It is possible to carry out continuous observation of the catenary throughout the whole of the inspection run thanks to a video system that is comprised of a camera, a recording unit and a device for blending in other data.

Dynamic measuring and earthing pantograph
The purpose of the isolated measuring pantograph is to record what happens to the height of the contact wire when it is subject to dynamic loads. Measurements are made at speeds of up to 60 km/h under catenaries that carry their normal electricity. The contact pressure is set pneumatically to any desired value between 5 and 15 daN. Currently, it is possible to retrieve the measured results at any time simply by playing back the video recording. The catenary's stagger can be seen clearly. Before the test run starts, limit values for the permissible stagger are set with adjustable pneumatic switches. If these values are then exceeded, the system saves an overflow signal as part of the video recording and it is then easy to return to the location again afterwards.

Static measuring pantograph
This pantograph serves two purposes. One is to measure the static position of the contact wire with a contact pressure of 5 N at crawling speed. The other is to help align a wire at a predefined height above the top of the rails. In both cases, the vehicle's suspension springs are blocked with hydraulic jacks, giving the pantograph a rigidly defined position relative to that of the track. Just as for dynamic measurements, these static results can be recorded on video too.

Observation turret
A roof turret with glazing in all four directions affords a good all-round view for performing visual inspections.

4.2 Contact-free catenary measurements

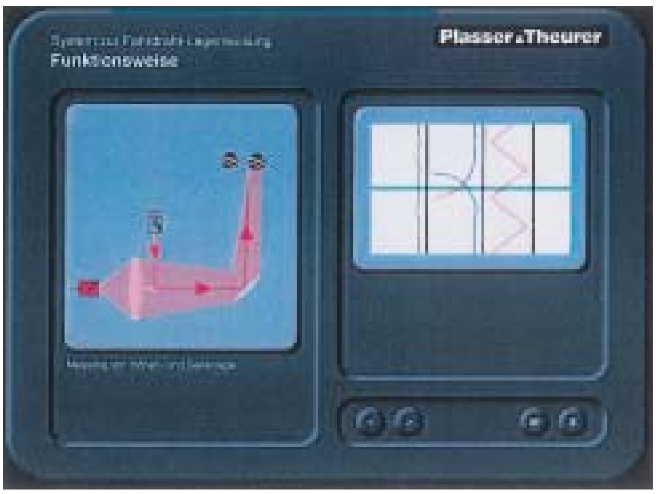
Modern catenary maintenance concepts that meet up to technical and economic demands call, more than ever before, for comprehensive checks and observations to be carried out at regular intervals. That is the only way of ensuring the necessary operational reliability. Beyond that, however, knowing how changes occur in the catenary network is an important precondition for making optimum economic use of maintenance machines. Work can be made much more effective if maintenance is performed as a function of the actual state of the catenaries.

Today, modern measuring and recording vehicles are used to provide incisive decision-support tools for the deployment of machines. They not only produce graphic logs of the state of the catenary but also supply immediate analytical results.

Producing geometric catenary data calls for many different individual parameters to be measured: the height of the contact wire above the top of the rails, the position of masts, the rate of advance of the recording vehicle, the position of "milestones", etc. along the track as well as the location of engineering features, such as bridges.

In cooperation with the Fraunhofer Institute for Physical Metrology, Plasser & Theurer has developed measuring systems that provide optimum cover for this range of

Fig. 7: Operating principle for the contact-free measurement of catenaries



applications. Such systems can either be installed in new special-purpose vehicles or integrated in existing ones. They are suitable for recordings at speeds of up to 300 km/h.

Measuring the position of the contact wire
Recent developments in fields such as laser technology and fast computers have made it possible to introduce contact-free measuring techniques including evaluations in real time. For measuring distances, a laser beam with a sinusoid modulation is targeted on an object. The light reflected back off the object is focused through a lens and measured by a detector. The phase difference between the transmitted laser beam and the return beam can be used to compute the distance. If the angle of the deflecting mirror is measured simultaneously, then it is also possible to compute both the height and the lateral position of the contact wire (Fig. 7).

One means of distinguishing between the contact wire and any other object is to include the intensity of the reflected laser light in the evaluation. The system's software is capable of filtering out any irrelevant elements.

Recognition of masts
The laser-supported mast-recognition system works indirectly by detecting mast brackets. It does this with the help of laser devices arranged on either side of the vehicle. In order to determine the masts' longitudinal position (kilometric position), these positions are recorded during a measurement run and are linked to the system of distance coordinates.

Recording and analysis
All the parameters, such as speed, lateral position, height and location of masts, are displayed in real time on a monitor as they are recorded. They are also saved and can be printed out on a logger too, if so desired.

Along with its contact-wire and mast-recognition system, Plasser & Theurer also provides software with a very broad range of options for evaluating the measured data. The appropriate display and interpretation modules can be used immediately during the recording run itself to permit an instant check to be carried out on the data. Alternatively, the data may be analyzed "off-board". For this purpose, it simply has to be transferred via a suitable medium to any computer equipped with the appropriate software.

5 European experience outside of Germany

This final section summarizes experience in three other countries.

Banverket, Sweden
When the newly-developed MTW 100.017 was delivered to Banverket in Sweden in 1990, there were very precisely formulated demands as to what was required of the new machine. One of these was that it was expected to be able to replace a whole catenary section (1200 – 1600 m) in a single track-closure period of six hours. Another was that it would have to be possible to resume rail traffic at its normal top speed immediately the track was reopened. Yet a third demand was for the elimination of the need for the sort of subsequent readjustments to the catenaries that had been common practice up until then. Using conventional methods and machines, no fewer than five track-closure periods had formerly been needed to complete work on a single section of catenary.

As it turned out in practice, all the above requirements were met. Productivity was improved by a factor of 5:1, and personnel requirements were halved.

Another element ensuring cost effectiveness is the system's high level of reliability and working safety (and it should not be forgotten that outdoor railway-engineering work in Sweden is sometimes carried out at temperatures as low as –27 °C).

Swiss Federal Railways
As part of the "Ariane" programme, Swiss Federal Railways (SBB/CFF) introduced a catenary replacement vehicle that led to the following productivity gains resulting from savings in the workforce:

- ▷ roughly 40% for replacement of just the contact wire;
- ▷ roughly 55% for replacement of the whole catenary.

Austrian Federal Railway
The additional functions implemented in the system developed for the Austrian Federal Railway (ÖBB) include installation of a tensile-stressed earth-return cable and a power-supply line looped between the tops of the masts as well as the occasional erection of concrete masts. Once again, all the original specifications were met in full.

The ÖBB summarizes the economic success of this system as follows:

- ▷ labour costs reduced to one sixth;
- ▷ return on investment (ROI) for the catenary replacement system in 4.5 years;
- ▷ track-closure periods shortened from 8 hours to 2 1/3.
- ▷ the hoped-for cut in labour costs of 40% was significantly exceeded in practice, and even 60% was achieved.

In other words, the ÖBB has thus computed a return on investment (ROI) for its maintenance vehicles of less than six years and has been able to reduce the number of employees in this sector by 35 %.

The use of the new construction and maintenance machines has enabled track-closure periods to be cut to one third, and the number of hours required to complete one unit of work have been reduced to roughly one sixth.

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