

Wheel detection and axle counting system solutions for public transport systems

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Due to the growing global population, increasing urbanisation and increasing fuel prices, passenger transport (in German, Öffentlicher Personennahverkehr, ÖPNV) is set to expand significantly in the coming years. The World Association of Public Transport UITP believes that public transport provision will double by 2025. Operators of public transport systems are therefore faced with the challenge of dealing with the increasing passenger numbers both as a result of the expansion and as a result of the modernisation of existing systems. The decisions here focus on the highest safety standards, maximum availability and a low life-cycle cost.

A clear technological revolution from track circuits to wheel detection and axle counting systems can be seen in rail-based public transport systems. New lines and projects are already often equipped with modern axle counting systems, as the benefits of these far outweigh their functionality and operating costs.

The requirements and the framework conditions in rail-based public transport systems do, however, differ sig-

nificantly from those in the standard-gauge railway and long distance rail sectors.

This article deals with the specific features in public transport systems and the ensuing demands on wheel detection and axle counting systems. It indicates that due to the very wide-ranging types of vehicles and structural circumstances, customer-specific solutions are required.

1 Definition and types of public transport systems

In terms of public transport (ÖV), passenger transport (ÖPNV) refers to the part that falls within the framework of basic provision on local roads, rail and by water.

Specific characteristics of rail-based public transport systems are as follows:

- smaller amount of space required in terms of height and width (vehicle width generally around 2.65 m)
- short stopping distances (usually between 600 and 1000 m, also only 400 m in the city centre area)
- the braking behaviour of the vehicle is based on road traffic requirements

- urban railways and light railways usually run on their own lines (however, “mixed operation” is also possible)
- extended networking with the usual means of transport in public transport (e.g. buses, etc.)
- maximum speeds of up to 80 km/h

The individual types of rail-based public transport systems can be differentiated and defined as follows: [1]

1.1 Light railways

Light railways are, in places, operated completely separately from road traffic as underground systems. In areas outside towns, they travel above ground on special rail beds, where level crossings at the same level as road traffic are standard, without light railways being granted the absolute right of way in the programme of road traffic signalling systems (Figure 1).

1.2 Trams

Trams are electrically operated railways that are either run on grooved rails set into roads (street-level rail beds) or on special rail beds. Trams are subject to the local road traffic regulations when using the public transport (Figure 2).

1.3 Suburban railways

Urban and suburban railways are predominantly electrically operated railway systems which are self-contained and serve public transport within a town (elevated railways and underground railways) or a town region (suburban railways) and follow a rigid timetable with frequent trains throughout the day. Suburban railways have the absolute right of way on only some level crossings at the same level as road traffic.

2 History of the rail-based public transport system

Public transport has its historical roots in regular journey connections across riv-



Figure 1: Axle counting systems are gaining in importance in the metro segment

ers and lakes. In the second half of the 19th century, public transport saw a revival when, due to the industrial revolution, towns and industrial regions expanded significantly and the population increased. Those responsible for transport initially responded to this with the construction of the horse-drawn tram network, and from 1890, the rise to prominence of electric trams (street-cars), as well as of electrically operated underground systems began. In very many towns the level of traffic increased so rapidly, however, that by around 1900, trams had to deal with traffic congestion and unreliability. In order to improve the capacity of public transport, rail-based transport systems were therefore given their own routes either above or below ground (elevated railways, underground railways, metro and suburban railways).

As the car became an increasingly popular mass transport method in the mid 1950s, the number of passengers travelling by public transport decreased. It was only within the scope of the environmental debate which began at the start of the 1970s that attempts were made to regain lost ground through the formation of transport associations (joint transport operators) in accordance with the motto "Different transport companies but only one ticket" and with an agreed timetabling structure that was independent of any one company.

Rail-based public transport systems are the most important pillar in public transport today.

3 Legal framework: German Railway Building and Operating Regulations (EBO) vs. the ordinance regarding the construction and operation of trams (BOStrab)

The German Railway Building and Operating Regulations (EBO) is an ordinance that came into force and validity in Germany for the construction and operation of railways. The EBO is usually called upon as a benchmark and for guidance on an international level as well. The objective of the EBO is to construct all rail systems and vehicles in such a way that they fulfil the safety requirements. The method of construction and operating methods of numerous rail facilities are governed here (e.g. platforms, level crossings, signals, sets of points, etc.) along with a number of terms defined for rail systems and operations.

Railways generally came into being in order to form a connection between towns, regions, countries and conti-



Figure 2: Modern tram systems rely on axle counting systems

nents. High-speed trains in passenger transport and heavy-goods trains in freight transport are generally guided on the same tracks. Railways always have a special rail bed and the succession of trains is controlled using signals at a spatial distance. The EBO is used in this internationally networked system of railways.

In towns, the horse-drawn tram network developed into the electric tram system, which ultimately became the metropolitan railway over the following century. Traction vehicle drivers can usually drive based on what they see and are responsible for the route themselves. However, this does not apply in tunnels or on single-track lines.

Suburban railways and underground railways have expanded over time and are therefore usually a local concern. The ordinance regarding the construction and operation of trams (BOStrab) attempted to be a complex of rules for all users here.

The significant differences between EBO and BOStrab are listed below:

Design parameters for track construction

- Regular clearance gauge profile
- Level crossings
- Speeds of travel
- Vehicle guidelines
- Braking capacities

4 Wheel detection and axle counting in urban transport systems

Track circuit technologies are currently the most widespread in urban transport systems. In the meantime, howev-

er, a number of operators have already recognised the benefits of axle counting technology and have implemented this technology successfully. A lasting move towards the axle counting technique is clearly recognisable.

Due to the technology used, the axle counting technique offers significant benefits compared with the track circuit technique [2, 3] in the areas of installation, operation and maintenance work.

Negative effects as a result of insulation shocks, insulation problems, dirt, leaves, salt, etc. are not an issue in axle counting technology. What is more, any track layouts (narrow and complex sections of points, switch harps or level crossings) can be achieved.

A frequent argument for selecting track circuits is the detection of rail breaks. This link can, however, only be made to a certain degree. Due to the meshing of the current feedback cable in rail lines, a rail break cannot be detected by the track circuit (bridging) in these areas. A disclosure of rail breaks can only take place on insulated sections of track [4].

4.1 Signalling in urban transport systems

Signalling in the field of urban transport systems can only be compared to signalling in the area of standard-gauge railways and long-distance lines to a limited extent. The BOStrab generally enables and permits driving based on what is seen, whilst the EBO is based on travelling at spatial distances. Major differences also ensue as a result of the dynamic properties, the delays in braking and the maximum speeds of the vehicle (usually up to 80 km/h).

4.2 Wheel detection applications

Modern track switching methods in the form of wheel sensors in combination with intelligent evaluation boards can make a range of additional information available in addition to actual wheel detection: traversing direction, speed, wheel diameter, etc. to name just a few examples here [2].

The following uses stand out in rail-based public transport.

4.2.1 Securing level crossings

Wheel sensors for switching level crossings on and off have been around since the beginning of track switching methods. With modern wheel detection systems, level crossing safety systems can also be switched on and off securely with individual wheel detection points. On a global level there are now an almost incalculable variety of configurations, including those in combination with axle counting circuits.

4.2.2 Speed restriction

Certain sections of track may only be traversed with certain maximum speeds due to structural circumstances. A possible derailment of the train can also be prevented by a modern wheel detection system. Safety is, of course, the priority over speed here.

4.2.3 Deletion of fault signals

A high number of trains is an important criterion in urban transport. Faulty track sections counteract this. Before the station master can reset a track section, he/she must ensure that this track section is definitely clear. This is usually time-consuming. However, in order to save time in this case, the station master can set a fault signal and allow a train to drive in at sight in the track section. This fault signal must be reset when a train is traversing with a wheel detection system so that the following train can be passed in a controlled manner. If the track section is then free, the required number of trains can be resumed and the fault signal must no longer be set and must be deleted.

4.2.4 Switching applications

In the area of urban transport systems, further applications must be fulfilled, which may require a switching application and triggering using track switching methods. Examples for this include hot box detection systems (HOA), flat spot systems, rail scales, washing systems,

gates, tunnel lighting or passenger information systems. Modern wheel detection systems supply a precise switch on and switch off for this in real-time.

4.3 Axle counting applications

The basic function of wheel detection systems is the secure and reliable recording and counting of axles as a basis for track vacancy detection. Modern, modular and scalable axle counting systems can also be used for a range of different operational requirements [3].

4.3.1 Track vacancy detection for railway traffic

Similar to standard-gauge railways, axle counting is also used in the first instance in urban transport systems for track vacancy detection for railway traffic. Trains can optionally travel at a spatial distance that is restricted by signals. The space between the signals is described as a block and track vacancy detection section.

In contrast to standard-gauge railways, the sections chosen in urban transport systems are usually short. Sections below 200 m are not uncommon, as a high succession of trains can be achieved here. In some cases, the train frequency is below 2 min.

4.3.2 Point changeover protection

Point blocking circuits for monitoring a set of points are widespread. This blocking circuit, consisting of a track circuit, provides information regarding whether a set of points is free or occupied. Switching of a set of points is then approved or prevented accordingly. This function and this changeover protection can be provided in a significantly more reliable manner and made more available with axle counting.

4.3.3 Edge protection equipment

Edge protection equipment should prevent a train from being endangered by other vehicles merging onto the same route (so-called edge collisions). Edge threats are possible due to crossing train and shunting movements. Edge protection equipment is known in different forms, such as protection points, track blocks or block signals. In the application of block signals axle counting sections can be used.

4.3.4 CBTC

Communication Based Train Control (CBTC) is a category of automatic train

control and train security system with which permission to travel and control demands are not indicated using signals, but via data communication between track vehicles and track equipment. As a result, trains can travel closer behind one another than on sections of track that are manually monitored. CBTC systems must be equipped with fall-back plans in case of failure. Track vacancy detection based on axle counting permanently runs redundantly here as a fall-back plan.

5. Urban transport system requirements for wheel detection and axle counting systems

In the context of urban transport systems, there are sometimes significantly different demands placed on the wheel detection and axle counting system technology than compared with standard-gauge railways. In the following we will try to outline the variety and complexity of these demands.

5.1 Vehicles, rolling stock

As mentioned at the start, BOStrab allows considerably more generous room for manoeuvre in terms of design compared with EBO in the structural design of vehicles. This is determined by history and also the manufacturer/operator. Track vacancy detection systems must be completely compatible with these circumstances.

5.1.1 Wheel geometries and wheel flanges

There are high and low wheel flanges, wide and thin running surfaces, large and small wheels. These wheel geometries and wheel flanges have a direct influence on safe wheel detection. Small wheel diameters of up to 300 mm and small wheel flanges of up to 20 mm in height are not uncommon. The spectrum of dimensions in this regard is very varied and must be catered for.

5.1.2 Wheelset geometries and electromagnetic brakes

Wheel sensors have defined and clearly determinable spheres of influence and sensitivity areas. As a result of this, the sensitivity to approaching iron masses is accordingly differentiated. In the case of trams, metros, underground vehicles and urban transport trains, optimised wheelset geometries combined

with electromagnetic brakes often result in problems with secure and available wheel detection. The diagram (Figure 3) shows a small cross-section of possible arrangements of electromagnetic brakes in wheelsets. The ensuing courses of the analogue wheel sensor current are also depicted here. The different influences of the electromagnetic brakes are clearly visible. What is more, different assembly levels and positions make secure and reliable differentiation from axles and electromagnetic brakes more difficult. [5]

5.1.3 Track return currents

Track return currents create around the track concentric magnetic fields, which lie in the area of influence of the wheel detection components. In the case of contact wire short circuits, track return currents of up to 15 kA and higher may occur.

5.1.4 Magnetic fields

IGBT converters and low-loss service inverters require high switching frequencies and steep switching flanks. Therefore, with rail-based vehicles, disruptive magnetic fields are to be expected, which demonstrate a wide spectrum of technical energy frequencies.

5.1.5 Maintenance vehicles

In addition to regular vehicles, different maintenance vehicles such as trolleys for materials and tools, road/rail vehicles or inspection vehicles also run, usually outside operating hours. These usually show very unusual constellations in relation to wheelset and wheel geometries.

5.2 Rail beds and surroundings

The rail bed and its surroundings in urban transport systems differ considerably in a number of factors compared with that of standard-gauge railways.

5.2.1 Traction

In addition to individual alternating current tractions in urban transport systems, direct current tractions are also increasingly used. The frequency range extends from 600 to 1500 V DC here. The direct current tracks can be arranged as overhead cables, however these are usually arranged as so-called "third" rails in or alongside the track bed. Figure 4 shows an elevated railway application in Germany with direct current traction (750 V DC), which is run in a third rail alongside the track.

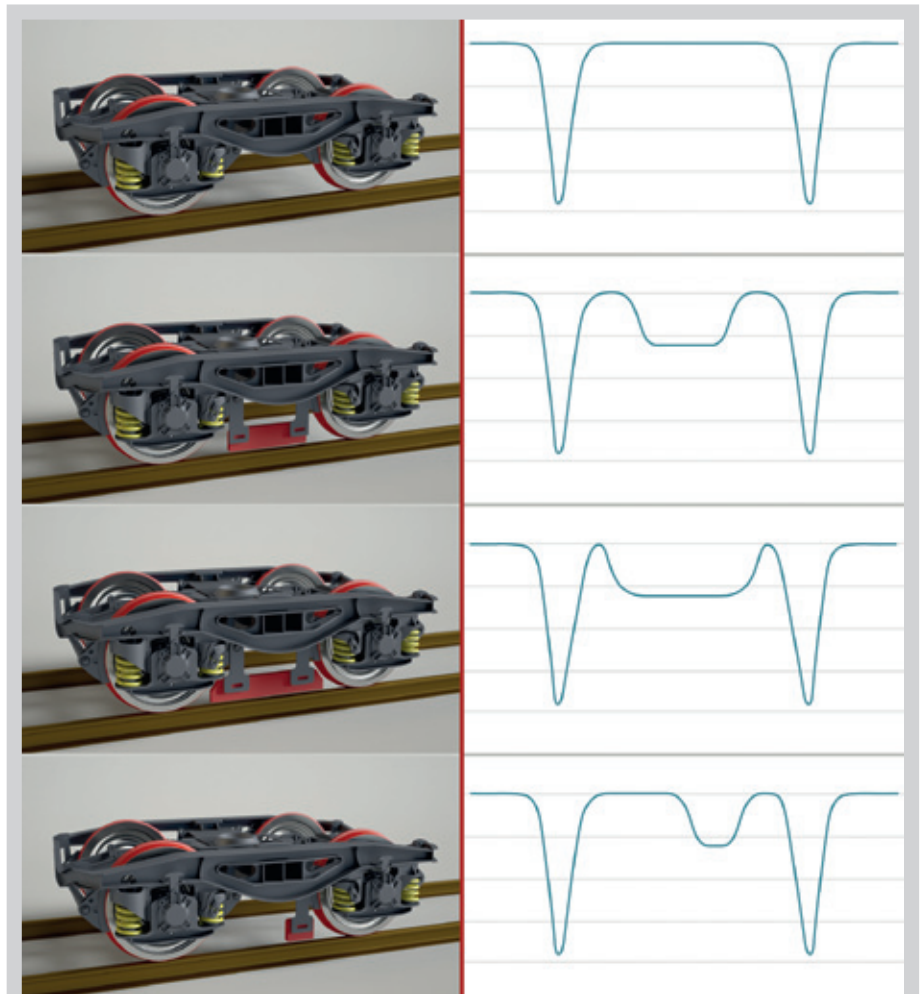


Figure 3: Depiction of analogue sensor signals due to different electromagnetic brakes



Figure 4: Wheel sensors must be resistant to direct current tractions



Figure 5: Robust and compact housing of the wheel detection components

nents on the track, cabling and clamping units.

5.2.4 Traversing and crossing on foot

In the area of urban transport systems in particular, it may be the case that wheel detection points are traversed, crossed on foot or become dirty. Remedies must be found here with technical, operational and structural measures.

6 Modern solutions for urban transport systems

In contrast to standard-gauge railways, urban transport systems almost always require individually adapted wheel detection and axle counting system solutions. Intensive customer contact and joint solutions form the focus here. At Frauscher, the need for reliable and readily available solutions for this area of application was recognised a number of years ago and made into a developmental focal point. In the meantime, a number of specific solutions have been created for use in urban transport systems.

6.1 Specific functionalities

6.1.1 Tailor-made evaluation algorithms

The large variety of types of vehicles and their influences on the sensor technology mounted on the track form a central challenge here, in particular the low-hanging electromagnetic brakes, which can be mounted very close to the wheel (Figure 6).

By carrying out a corresponding evaluation and assessment of the analogue wheel sensor signals, Frauscher is able to adapt the evaluation algorithms and the trigger thresholds on an individual basis. This means that a clear differentiation between the axle and electromagnetic brake is assured and therefore reliable and secure wheel detection is guaranteed. Different hardware and software components are available (SIL3/SIL4).

6.1.2 Counting head control

Metallic objects (e.g. steel-toecapped boots, tins, metallic dirt, lorry or bicycle tyres, etc.) can damp a wheel detection point and therefore cause an undesired “occupied” notification for the track vacancy detection section. This results in a reduction in the availability of the entire system. This effect can be counter-

5.2.2 Track profiles

The wheels and the wheel flanges of trams run on grooved rails (Figure 5). The grooved rails are surrounded by concrete and fixed material here.

5.2.3 Heavy rainfall and flooding

Heavy rainfall and flooding that occur in the area of the grooved rails and the closed design require special protective measures for wheel detection compo-

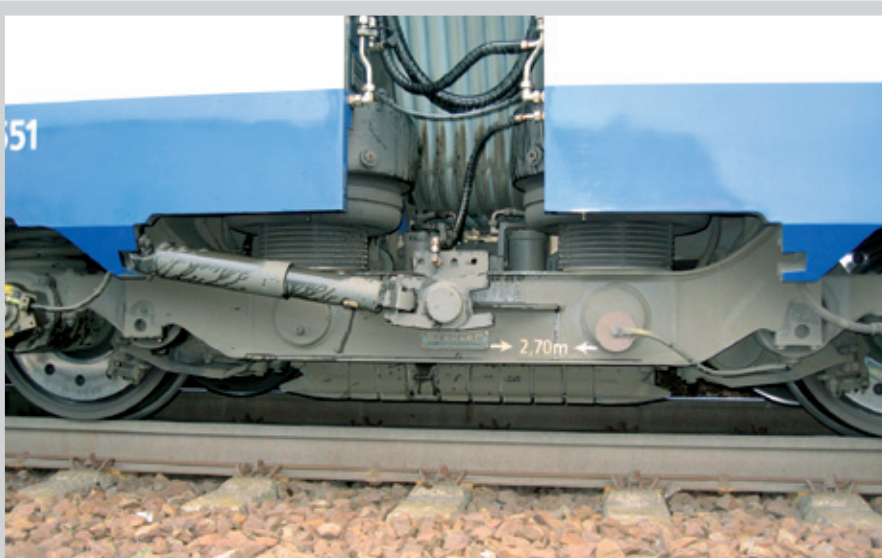


Figure 6: Electromagnetic brakes form a central challenge for wheel detection and axle counting

acted with the “Counting head control” functionality.

If the track vacancy detection sections adjacent to a wheel detection point are clear, the wheel detection point can be set to a type of “Stand-by-Mode”. In this mode, a freely configurable number of unacceptable incidences of damping can be suppressed. An “occupied” notification is not output and the reset control is omitted. Approaching trains switch the Stand-by-Mode off again and are securely detected.

6.1.3. Speed measurement

The ability to determine speed is also increasingly growing in importance in urban transport systems. The Frauscher measuring system VEB provides information on speed, status and diagnostics in a simple and cost-effective manner, via a CAN interface in real time. The evaluation of the traversing speed is carried out with only one wheel detection point and can take place with an accuracy of $\pm 3\%$.

Switching tasks depending on speed can be speed testing equipment, derailment protection, passenger warnings on platforms, speed-dependent level crossings, to name just a few.

6.1.4 Higher-level sections and auto-reset

Track sections lined up after one another can have a further track section laid over them, if desired. If this higher-level track section is reported as being “clear”, then the lower-level track sections must, as a rule, also be clear. If one of the lower-level track sections is, however, occupied, for example due to unwanted damping as a result of equipment, pedestrians, etc., this section can be automatically reset depending on the configuration of the axle counting system. This functionality results in a further increase in the availability of the entire system.

6.1.5 Carrying out the reset procedure

A wide variety of reset procedures may be necessary depending on the operator and the circumstances of the system:

- Conditional reset
- Unconditional reset
- Preparatory reset
- Preparatory reset with acknowledgement

Frauscher axle counting systems offer over ten different reset variants that can be freely selected/configured.

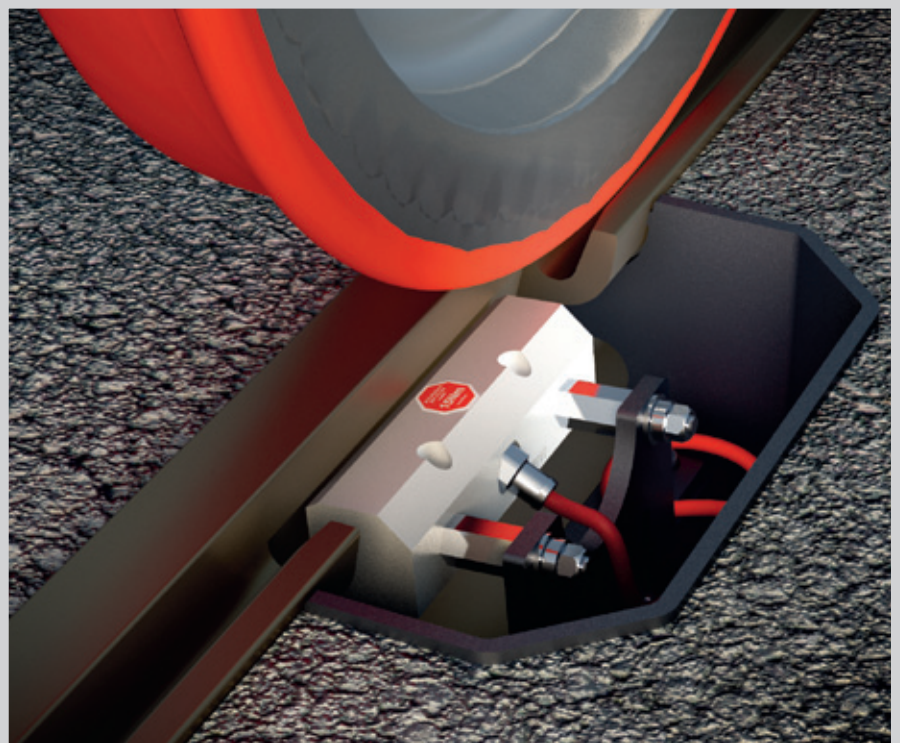


Figure 7: Frauscher rail claws for use in grooved rails

6.1.6 Partial traversing

Under certain circumstances it may be necessary from an operative perspective that axle counting systems suppress several partial traversing procedures. Frauscher wheel detection points consist of two sensor systems, which recog-

nise and evaluate incomplete traversing as partial traversing. As a rule, if complete traversing takes place, partial traversing is reset. If complete traversing does not take place after partial traversing, the track section remains occupied. The section must be reset by the station master (CTC).



Figure 8: Compact arrangement and simple calibration of the wheel sensor due to Frauscher grooved rail claws

■ Axle counting system solutions for public transport systems

Depending on the configuration of the Frauscher axle counting system, one or more partial traversing procedures can be suppressed. The track section remains clear here and is only occupied during complete traversing. The number of partial traversing procedures permitted can be freely configured.

6.2 Mechanical surroundings

6.2.1 Grooved rail claw assembly

The use of grooved rails and a closed superstructure require special mechanical solutions for the assembly of wheel detection points. The wheel flanges guarded by the grooved rails must be reliably and securely recognised. In the region of the wheel detection points, the grooves must be removed over a length of approx. 40 cm.

Figure 7 illustrates the context of grooved rails, wheel flanges, grooved rail claws and wheel sensor assembly. Figure 8 shows a grooved rail claw and wheel sensor RSR180 in an assembled state in a tram application. Grooved rail claws are tailor-made to exactly suit the respective track profile. The claw variants can be clamped, welded or connected using screws, depending on customer requirements. Depending on the assembly variant, the traffic-grade plastic cover can also render traversing possible. The grooved rail claw has already proven itself on a number of occasions in practical use.

6.2.2 Plug-in connection

There is often very little space available close to the track. As no electronics are placed close to the track with the Frauscher architecture, the spatial requirement for the wheel detection point is very small. Clamping units for cable connections (wheel sensor signal cable

for indoor equipment) can be designed as a simple plug-in connection. Where grooved rail claws are used, a water-proof and water-repellent connection box is used as protection for the clamping element.

6.3 Planning, operation and maintenance

6.3.1 Scalable complete system and flexible integration

The wide variation in the requirements from the field of urban transport systems concerning wheel detection and axle counting systems is matched by an equally wide variation in the interlocking and control systems to be used. Scalable systems without unnecessary overheads and different interfaces are required for flexible integration. Frauscher wheel detection and axle counting systems offer a choice of a relay, an optocoupler or even a serial interface.

6.3.2 Installation, maintenance and diagnosis

In contrast to track circuit technology, wheel detection systems enable assembly and installation to be carried out during operation. What is more, railway operators and maintenance staff are being confronted with different and ever more complex systems. In order to be able to handle these systems as well as possible, a simple and compact structure, as well as intuitive operation, are required. This starts back in the planning and design phase and continues through the configuration and commissioning phase to the operation and maintenance phase. Reduction in the maintenance ex-

penditure as a whole, preventative maintenance and rapid and efficient elimination of faults are all factors that are becoming increasingly important for railway operators. Frauscher systems can be equipped with modern diagnosis systems [6] if required.

7 Summary

Practical experience from urban transport projects implemented worldwide has shown that the benefits of modern wheel detection and axle counting systems clearly outweigh the drawbacks in this sector as well. Preconditions for this are, however, project-specific adaptations, which should be discussed and drawn up in advance, together with the operators, interlocking integrators and axle counting manufacturers.

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■ ZUSAMMENFASSUNG

Raddetektions- und Achszählsystemlösungen für den Nahverkehr

Im schienenengebundenen Nahverkehr ist dabei eine klare Technologiewende von Gleisstromkreisen hin zu Raddetektions- und Achszählssystemen feststellbar. Neue Linien und Projekte werden bereits oft mit modernen Achszählssystemen ausgerüstet, da die Vorteile hinsichtlich Funktionalität und Betriebskosten bei Weitem überwiegen. Die Anforderungen sowie die Rahmenbedingungen im schienenengebundenen Nahverkehr unterscheiden sich jedoch maßgeblich von jenen im Voll- bzw. Fernbahnsektor.

Die Praxiserfahrung aus Nahverkehrsprojekten in vielen Ländern weltweit zeigt, dass die Vorteile moderner Raddetektions- und Achszählssysteme auch in diesem Segment deutlich überwiegen. Voraussetzung dafür sind jedoch projektspezifische Adaptierungen, die gemeinsam mit Betreiber, Stellwerksintegrator und Achszählhersteller im Vorfeld zu diskutieren und zu erarbeiten sind. Frauscher ist mit seinem Know-how, den umfassenden Dienstleistungen (Beratung, Labortests, Trials und Schulungen) sowie mit angepassten Hard- und Software-Versionen der Garant für den zuverlässigen und effizienten Betrieb von Straßen- und U-Bahnen.

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