FUTURE CHALLENGES TO AXLE COUNTING SYSTEMS

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SUMMARY

Future-proof and highly available axle counting systems will be based on inductive wheel sensor systems with analogue output signals. Decades of experience for Frauscher Sensortechnik GmbH and over sixty thousand installations worldwide show that in the long term only this technology will be able to meet the challenges arising from the application environment. Increasing functional demands can be satisfied by different evaluation boards featuring specific software evaluation algorithms. However, tapping the full potential will only be possible, if the core elements – wheel sensor and evaluation board – are optimally tuned to each other.

These systems combined with optimised rail claw mounting and plug-in sensor cables meet all future requirements in regard to cost-effectiveness, flexibility and optimal maintainability.

The possibility to transfer complex information that goes beyond wheel detection, by means of serial interfaces of evaluation boards to higher-level applications, opens up a wide range of functional possibilities not yet used today, especially in highly integrated complex electronic interlocking systems.

With the increasing, worldwide spread of axle counting technology as track vacancy detection, the requirements as well as the opportunities of such systems are also increasing. Modularity, flexible modern interfaces and comprehensive but optimal configurability of additional functionalities in axle counting systems provide the best conditions to meet the necessary requirements both as a stand-alone solution and as highly-integrated components in modern interlocking systems.

Modern communication interfaces between the interlocking and axle counting systems allow more economical, decentralised solutions with a maximum availability of information and data to be designed at any particular location.

The safety and availability of modern axle counting systems are crucially determined by extremely available wheel detection systems tolerant to interference. Further optimisation of the interface between the vehicle and the wheel sensor, as well as increasing standardisation in this area will further accelerate the replacement of track-circuit technology by axle counting systems.

In addition to classic track vacancy detection, the opportunity of generating further additional information from wheel detection and passing this to higher-level systems enables a whole series of new, integrated applications based on this.

1 INTRODUCTION

Axle counting systems with inductive wheel sensors have established themselves with many railway operators worldwide as reliable and cost-effective track vacancy detection systems. Progress in the “state of the art” achieved through the development of the operating principles, manufacturing processes, materials and practical experience (already decade-long) are the basis for the steadily growing number of applications and solutions. However, development of ever more advanced and diverse vehicles, along with increases in electro-magnetic emissions and speed, remain a major challenge for safe and reliable wheel detection.

In many countries of the world modern axle counting systems have long since taken over from track vacancy detection based on the track-circuit principle and are increasingly understood as an integral component of higher-level technical interlocking and signalling equipment. Nowadays, they are able to provide a great deal of information to the complete system beyond track vacancy detection.

Here, the challenge is to meet the widest range of requirements of the track operators and system integrators with reference to environmental conditions, interfaces, reset procedures, direction information, diagnostic information, etc. at the lowest possible life-cycle costs.

This article provides some background information an overview of modern wheel sensor systems – the basis for future-proof axle counting systems – and will deal with the state of the art in axle counting.

2 Wheel detection

2.1 Wheel detection

Even in the early days of the railway in the 19th century, wheel detection had been an urgent desire for railway engineers concerned about signalling safety. Their use as a switching device for train-controlled level crossing systems, track vacancy detection systems, automatic switching of signals to stop aspect or automatic route release, and also as on/off switching devices for a wide range of track equipment (e.g. measurement systems, gates, washing plants, weighbridges) significantly increased their importance over time - and with it the requirements regarding availability and safety.

The devices developed to this effect are still known as track switches or rail contacts due to their intermittent principle of operation.

In the past no special components for evaluation of signals were necessary because the switch contacts integrated in the track switching system were usually directly looped into the relay circuits. That is not the case where modern wheel sensors are concerned. Here analogue signals form the output signal, which requires interpretation by an evaluation component (such as an evaluation board) (Figure 1).

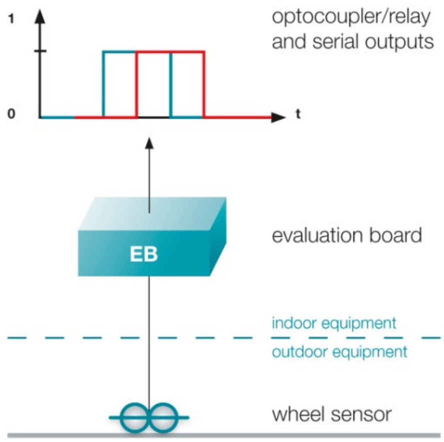

Figure 1: Components for wheel detection

2.2 The operating principles of track switching equipment [1]

2.2.1 Mechanically operated rail contacts

In general, they consist of a contact device mounted on the inside of the foot of rail, which is actuated by the wheel flange via a lever. Due to their susceptibility to errors they were replaced in Europe at the end of the 19th century by hydraulic rail contacts. They can still be found in non-signalling applications, such as warning systems for work gangs.

2.2.2 Hydraulically operated rail contacts

The not very widespread class of hydraulic rail contacts was usually actuated by the deflection of the rail caused by the axle load. Cylinders - at first filled with mercury, and then with hydraulic oil - operated a contact set. As early as 1920, these hydraulic track switches were replaced in Germany by pneumatically operated switching elements.

2.2.3 Pneumatically operated rail contacts

Due to their long-term use several types have emerged, which differ quite widely in terms of operation and construction. In essence, the force exercised on a piston led to pressure differences in airtight chambers, which for example, via a membrane actuated a contact device. To achieve a reasonably acceptable availability this type of track switch required specific axle loads or minimum speeds, which, naturally, limited their application. So, from the fifties on they were progressively replaced by magnetic contacts.

2.2.4 Magnetically operated rail contacts

The first contactless switching devices were employed in the middle of the last century. The rail contacts known as axle counting magnets or pulse generators feature a permanent magnet system, to which magnet-operated electrical contacts are exposed. The effect of the iron of the wheel flange triggers a contact actuation due to the change of the magnetic field. Magnet-operated rail contacts of different types and operating principles can still be found at many railways in the world. In Central Europe, they are increasingly replaced by inductive devices as they are sensitive to external magnetic fields.

2.2.5 Inductive operating principles

In parallel with the development of magnetically operated track switches, contactless switches based on the transformer principle were launched in the market. A primary coil generates an AC magnetic field in an iron core with at least one air-gap in direction of the head of rail. A wheel flange passing over the air-gap changes the magnetic flux and consequently the induction in a secondary coil, preferably designed as a differential coil. This operating principle was later improved by using ferrite magnets and increasing operating frequencies.

During the same period, devices were designed that operate according to the magneto-dynamic principle. The operating principle of the rail contacts designated as magnetic pulse generator is based on a permanent magnet system with a soft iron core. The flux changes caused by the passing wheel flanges induce measurable voltages in the coils placed in the area of the magnetic flux. This operating principle requires a certain speed, which, however, by means of continuous improvement of the circuits, was reduced to practically zero.

Rail contacts with a transmitter coil on one side of the rail and a receiver coil on the other are widely used. The wheel or tyre affects the inductive coupling between transmitter and receiver. The devices are mostly designed as double sensors and are often used as counting heads for axle counters.

In the seventies, the emergence of integrated circuits strongly influenced the operating principle of rail contacts. Simultaneously with an enormous advance in development in the field of industrial electronics, the operating principle of the inductive proximity switch took its first steps. At first, so-called head of rail switches were mounted into a vertical bore in the head of the rail in order to allow detection of the wheel treads. Subsequently, a model prevailed which was mounted laterally to the inside face of a rail and whose upward placed coils detected the presence of the wheel flange.

Track switches based on this fundamental principle are today being used as wheel sensors of different types and varying modes of operation and will be the basis for safe wheel detection with maximum availability in the future.

2.2.6 Other operating principles

The limits of use of inductive track switches imposed by the laws of physics as well as the extremely complex technological hurdles to design a reliable and safe sensor based on theses operating principles, always lead to the development of wheel sensors that are based on other principles of physics. Examples include microwave technology, piezoelectrics, fibre optics or sound technology. However, none of these approaches has so far led to a licensable system ready for serial production.

2.3 State of the art

The state of the art of wheel sensor system is geared towards the requirements users want developers to meet. Almost all of the systems described above can still be found, even today, in many rail networks. This paper endeavours to outline which technologies will play a crucial role in the future.

2.3.1 Challenges

- **Mechanical loads (vibration and shock)**

Shocks are mainly caused by flats on the running surface of the wheels, while vibrations are generally caused by short pitch corrugation of the rail surface. EN 50125-3 defines the values for mechanical shock and vibrations. In practice, significantly higher loads may apply. Less important, but defined by rail operators in some specifications, are minimum loads the sensors are required to withstand without so much as moving.

- **Climatic constraints (ambient temperature, humidity, snow)**

The extreme temperature range from -40 to + 85°C (reaching up to minus 60°C in Nordic countries) is covered by most electronic components, but is a major challenge for the development of frequency-stable and quality coils. The fact that coils are still made of copper conductors which need to be embedded into a sealing compound in order to be protected against humidity entails the following problems: Increased temperature implies higher copper resistance and reduces coil quality, which is also influenced by the dielectric loss factor of the sealing compound between the coil windings. The relationship between dielectric loss factor and temperature is not linear and normally increases distinctly after 60°C. The magnetic fields generated in practice by inductive sensors and ranging from a few kHz up to several Mhz do not, as a rule, cause interference in case of humidity, snow and frost. However, high operating frequencies also generate electrical fields, which respond to the capacitive influence of water. It is therefore necessary to compensate this equipment against the propagation of electrical fields influenced by water or ice.

The requirement for compliance with the highest protection class IP 68 according to EN 60529 becomes a technological challenge for modern electronic wheel sensors, particularly with regard to use and / or life cycles at the track, because the sensors must ensure reliable operation even under extreme climate conditions.

- **Rail temperature, track currents**

The head of rail is very much exposed to the sensor coils. At a rail temperature of -40 up to +100°C (additional heating of the rail due to linear eddy current brake) both permeability and conductivity of the iron change considerably. This leads to a drift in the sensor coil and causes, as temperature rises, an increase of eddy current losses and, simultaneously, a decrease in hysteresis losses due to declining permeability of the material. Neither process is linear in regard to the given operating frequency.

Furthermore, the rail material is affected by permeability changes due to track currents. Track return currents generate a magnetic field, which also magnetizes the surface of the rail material. As a result permeability of the head of rail material is reduced and, consequently, the hysteresis losses registered by the sensor coil decrease. AC traction is also different from DC traction. Short-circuits up to 40 kA in the overhead contact line or transients due to discharge into atmosphere can cause magnetic saturation of the rail material and thereby suppress hysteresis losses altogether.

- **Magnetic field generated by track return currents**

Track return currents generate a magnetic field that is disposed concentrically around the rail, whereby the sensor coil is fully exposed to the field. If the sensor coil has a ferrite core, the magnetic field may cause its saturation. Short-circuits in the overhead contact line and currents from discharges into the atmosphere entail similar effects.

- **Traction current commutation**

The sparks which can often be seen at quite a distance around the pantographs of the vehicles or contact problems between rail and wheels cause changes in the level of the return current within a broad range of frequencies. The resulting magnetic fields induce voltages into the sensor coil, which have to be compensated.

- **Electro-magnetic rail brakes, eddy current brakes**

These braking elements have several effects on wheel sensors. On one hand, the metal and coil volume of the brake, which reaches laterally over the head of rail into the effective range of the sensor, causes a partial damping of the sensor system, which must not trigger the sensor as if it were a wheel flange. On the other hand, both types of brakes, especially the eddy current brake, generate an enormous magnetic field, which in turn has two different effects. The magnetic field permeating the steel of the head of rail will cause its magnetic saturation. Effects are similar to those described before (see rail temperature, track currents) and the leakage magnetic field also reaches the sensor, which has to cope with it without disturbance. Effects are similar to those described in the subsection “magnetic field generated by track return currents”.

- **Interfering magnetic fields generated by vehicles (inverters, coils, transformers)**

Low-loss performance inverters require high switching frequencies and steep switching flanks. Therefore, interfering magnetic fields with large band width and frequencies ranging up to several MHz are to be expected under the vehicles. Where an interfering magnetic field collides directly with the operating frequency of the sensor, effects are especially drastic.

- **Vehicle geometries (effective ranges)**

All wheel sensors have defined and more or less clearly identifiable effective ranges. Sensitivity with regard to approaching iron masses differs accordingly.

Especially in the case of trams, subways and suburban trains (light rail vehicles) optimized bogie geometries in combination with electro-magnetic rail brakes often cause problems for safe and readily available wheel detection. In the case of modern vehicles with underfloor mounted equipment in particular, the wheel flange signal can hardly be distinguished anymore from other interfering iron masses, such as the electro-magnetic rail brake. This is further compounded by smaller wheel diameters in combination with small distances between axles.

The wheel-axle-rail-sleeper geometry can also be looked at as a conductor loop, which is exposed to part of the magnetic field generated by the sensor. If the resonant frequency range of the loop is similar to the operating frequency of the sensor, the sensor system may be affected. At Frauscher, this type of interference is designated as “parasitic absorption”.

- **Installation and Mounting**

The requirements regarding installation and mounting are the results of historically evolved regulations of the rail operators, which factor applications and structural conditions regarding rail profile, superstructures and track embedding (for example, in roads).

Meanwhile, wheel sensors are being used in large quantities. Their cost-effectiveness is, therefore, also geared towards fast mounting and dismounting. Here, web of rail mounting with drilling has mostly been replaced by clamping. Moreover, short mounting periods with inherently shorter permanence of work gangs at the rail are a clear safety gain.

For example, when used as a switching device for warning systems for work gangs, in addition to mounting and commissioning times (adjustment of sensor system), the weight of sensors and rail claws also plays a decisive role.

Furthermore, the mounting technique is expected to be highly flexible. Mounting in the space between sleepers or on a sleeper, in the immediate vicinity of guide rails, in grooved rails beneath tram track or fixed track systems are, for instance, current requirements for such systems.

2.3.2 Highly available wheel sensors

Among the operating principles described in section 1.2, inductive wheel sensor technology has become widely accepted. Specific properties are required to allow trouble-free masking out of known interference, while correctly sensing the wheels.

Generally and for the purpose of failure detection, a wheel sensor comprises two sensor systems that operate independently. The redundancy affords other functionalities of the wheel sensor system, resulting from the temporal context and the intensity of the interference.

Although, in all cases using this operating principle at least one coil through which AC current is passing acts as a core element, on closer examination it is necessary to further differentiate between the following methods:

- **Eddy current method and hysteresis method**

The AC magnetic field radiating from the sensor coil causes eddy current and hysteresis losses in ferromagnetic materials that are exposed to it (here: wheel flange). These losses reflect on the sensor coil and reduce the quality of its oscillating circuit.

- **Field deflection method**

The magnetic field generated by a coil supplied with alternating current is deflected by existing ferromagnetic materials in such a way that induction in a close by receiver coil changes. This deflection can increase or decrease.

- **Inductivity method**

The inductivity of a sensor coil changes due to the influence of ferromagnetic materials in its vicinity. The influence of the material depends on the operating frequency.

2.3.3 Track switches – Wheel sensor

A track switch can only send two types of information, i.e. “occupied” or “free”. Further information, such as its position with regard to the track; occupation status; evaluation of external interferences or deficient wheel flange formation is not within its scope.

Several decades of experience in the development of inductive sensors has shown that it is practically impossible to meet the challenges stated under 2.3.1 without an analogue output signal that measures the distance. This becomes especially apparent when wheel sensors are used in an environment affected by such undesirable interferences, such as extremely busy track sections with multiple traction units (AC and DC), applications under extreme environmental conditions such as industrial facilities located in extreme climate zones or in trams with underfloor mounted equipment.

The picture shows the signal curve of a typical Frauscher wheel sensor with two independent sensor systems (sys 1 and sys 2) while being traversed by a wheel (Figure 2):

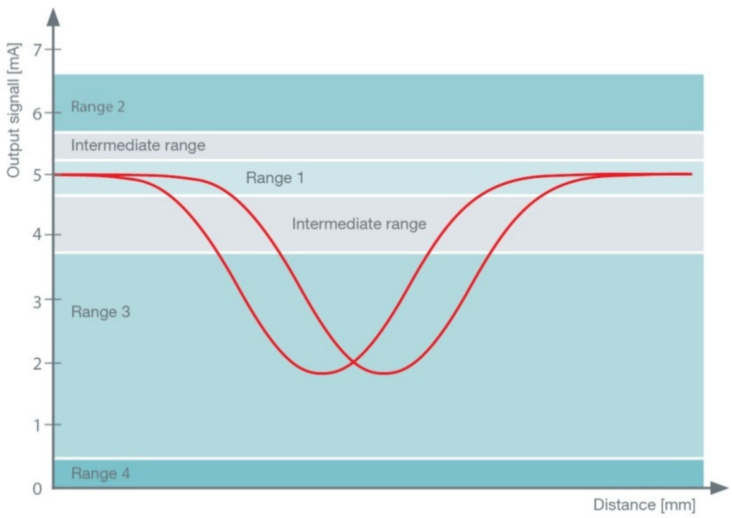

Figure 2: Evaluation example of an analogue signal

The possible overall signal range can be divided into the following ranges:

- Range 1: Sensor correctly mounted on rail, no interference from wheel
- Range 2: Sensor dropped off from rail (signal rises, because the head of rail is outside the effective range).

- Range 3: Sensor damped by wheel
- Range 4: Wire break or defective component

Contrary to a switch limited to "ON" and "OFF" or "High" and "Low" status detection, an analogue sensor provided with a matching intelligent evaluation board affords a measure of further information.

2.3.4 Evaluation features

The signal values are provided at the wheel sensor in the form of injected current values, which can be evaluated remotely (over a cable link) by an intelligent board (the evaluation board) using different algorithms. To that effect, and in addition to the actual useful signals of the wheel sensors, status data regarding safe operation of the sensor can also be transmitted - such as drop-off detection; proper installation; deficient damping; drift values and faults in the sensor system. This allows the system to dispense with sensitive and expensive trackside electronics, which not only increases the economic efficiency of the installations but also provides sustained reduction of commissioning and maintenance costs.

The supply of the analogue signal values affords a number of further evaluations besides the status outputs mentioned above.

In addition to wheel detection proper, modern wheel sensors combined with intelligent evaluation boards are able to also determine wheel diameter, traversing speed, traversing direction, wheel centre above the sensor or the presence of external influences (e.g. of an electro-magnetic rail brake).

Furthermore, the analogue sensor signal allows triggering of the output of the rectangular signal used for counting purposes at freely pre-selectable signal levels, thereby affording detection of wheel running surfaces without wheel flanges or wheel flanges exercising less contact on the head of rail.

It is also possible to derive relatively simple basic information for centralised diagnosis of the sensor system by the remote installation.

There are already a large number of evaluation boards available for all these data exploration options, as well as several hardware platforms, with different versions of software and evaluation algorithms.

Thanks to the possibility of customized evaluation options under known conditions, or others to be defined, maximum functionality and availability can be achieved for each specific application. This is why innovative suppliers place particular emphasis on customer transparent test installations in the preliminary stages, particularly with regard to their interference capability on critical wheel sensor applications.

Furthermore, these evaluation boards can also be differentiated based on their interface to the higher-level application. There are versions including relay interfaces, optocouplers or serial Interfaces.

2.3.5 Modern installation options for wheel sensors

Mounting and installation procedures for wheel sensors at the rail have major bearing on the practicality, life cycle costs and possible applications of wheel sensor systems.

The state-of-the-art is high-quality, highly available and safe rail claw technologies that can be used for all known railway designs and different rail profiles (grooved rails). The installation of wheel sensors using rail claws that can be mounted easily and quickly without need of special tools also affords the use of this latest technique of wheel detection as temporary or flexible solutions, e.g. for warning systems for work gangs.

The fact that the cable to the sensor (sensor cable) for the inductive wheel sensors described herein is not part of the mode of action of the sensor, further allows flexible customized sensor cable assemblies even after installation.

In future, plug-in cables for sensors will become a global standard. Wheel sensors RSR 123 and RSR 181 by Frauscher already provide these options with all the advantages for the installation of new signalling systems or for mounting and dismounting during track maintenance work (Figure 3).

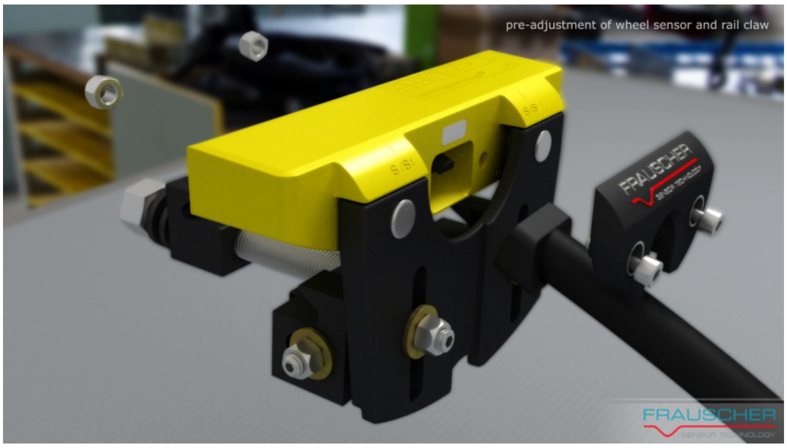

Figure 3: Fast and easy mounting of a sensor using rail claws and plug-in cables

2.4 Wheel detection and its applications

If track switching equipment as part of track vacancy detection systems meets the specification requirements of railway operators for axle counting systems, in theory they could also be used for other safe systems. A classification of such systems as CENELEC SIL 4 systems has increasingly become a global basic requirement, e.g. for axle counting systems.

Inductive wheel sensors with analogue output signals and a matching evaluation board have potential to support a wide range of possible applications, both as SIL 4 systems as well as for systems with graded safety degrees according to CENELEC D, i.e. SIL 0 - SIL 3.

2.4.1 Track vacancy detection

Axle counting for track vacancy detection has been and still is the most challenging field for track switching equipment. Only inductive wheel sensors made safe axle counting highly available and such systems are increasingly and gradually replacing track vacancy detection with track circuits all over the world.

Over the years, many forms of track vacancy detection have been developed on the basis of axle counters.

2.4.2 Level crossings

Track switches to activate and / or deactivate level-crossings have been around since the early days of track switching equipment. Modern wheel sensor systems meanwhile allow safe on/off switching points for level crossing using just single sensors. The globally available range of configurations and combinations with axle counting circuits is almost endless.

Further development of wheel sensor systems (e.g., the ability to provide speed information safely and cost-effectively) will make these applications even safer, more flexible and more cost-effective.

2.4.3 Switching applications (triggering)

Modern wheel detection, accurately switching highly available systems, with high resolution on and off, in near real time is nowadays an integral part of many different systems. Examples are trailing messages, hot axle box detectors, flat detection equipment, weighbridges, washing plants, gates, tunnel lights and passenger information systems.

2.4.4 Measurement applications

As wheel detection with analogue output, in addition to wheel detection proper, using several intelligent algorithms, also provides information about traversing speed, traversing direction, wheel diameter, wheel centre above sensor or the existence, for example, of an electro-magnetic rail brake, a large number of other applications based on wheel detection are feasible, being designed and already implemented.

For example, implementation of speed control sections for speed restrictions - based on speed measurement by inductive wheel sensors. Speed-sensitive passenger information systems also use this option. Wheel centre detection has been implemented in several hot axle box detector systems (HOA). Wheel diameter detection, for example, can be used to optimise the operation of rail brakes.

Within the scope of intelligent axle counting systems with serial interface to integrated electronic signal boxes, this information (especially speed) can be processed for a wide range of additional functions in the signal box in parallel with track vacancy detection and be used in additional features to the benefit of the customer.

3 Axle Counting

3.1 Track vacancy detection - The basis of safe management

Track vacancy detection permanently monitors the clear or occupied status of sections, as well as points and block sections. Automatic track vacancy detection replaces visual checks by people and thus increases the safety of the respective signalling equipment.

Nowadays, track vacancy detection is the basis of automated and safe operational management.

The influential systems in automatic track vacancy detection are track-circuit and axle counting technologies. The first systems based on track circuits were developed and patented in around 1870. This technology found its way into many rail networks worldwide by the mid- to late-20th century and is still in use today in some areas.

Due to the weaknesses and limits of the principle of track circuits, and the meteoric development of digital technology, track circuits are being increasingly replaced by axle counting systems [2, 3]. Swiss rail operators were the first to introduce axle counting in around 1950. Today, the majority of rail operators rely on this safe and highly-available technology.

3.2 Track-circuit technology versus axle counting technology

The use of track circuits is still widespread today. This primarily affects countries in which these systems are also used for transmitting signal information to the vehicle (e.g. Russia, France and China). But this technology is increasingly becoming less significant in modern railways due to its technical limitations with reference to the scope of information and the introduction of modern train-control systems such as ETCS, CTCS and CBTC.

One advantage of track-circuit technology is that the system requires no reset devices or procedures. An additional main argument for this principle is the ability to identify rail breaks under certain circumstances. There are numerous investigations and studies that conclude that track circuits in no way guarantee reliable identification of rail breaks. Figures of 20 % to a maximum of 60 % are given [4].

In addition, practice shows that the majority of possible rail faults (see UIC Catalogue 712) have already been detected and investigated before a rail break occurs. Modern systems to monitor the state of the rail, regular rail work (grinding, milling) and also the rail-manufacturing procedures that have improved significantly in the last 25 years have allowed track circuits to be pushed to the background as rail-break recognition systems.

The disadvantages of track-circuit technology can be clearly seen when compared directly with axle counting systems. On the one hand, under specific environmental conditions, it is difficult to maintain rail insulation at the quality level necessary, due to low-level ballast resistance (protection, moisture, flooding). On the other hand, the unreliable electrical contact by light vehicles on rails with low train frequencies may lead to faults (availability, safety).

In the meantime, axle counting technology with its crucial benefits compared to the principle of track circuits has proved itself in practice to be a highly-available and safe system for track vacancy detection in the widest range of applications. Essentially, this technology is based on high-end wheel detection technologies. The quality of the wheel sensors used decisively determines the safety and reliability of each axle count.

Another significant factor is that axle counters can be overlaid on another detection system (whether track circuits or another axle counter system) for upgrade migration purposes – whereas usually only one track circuit can be installed on a section of rail at a time.

Figure 4 compares the most important properties of modern axle counting technology with the principle of track circuits. See also Railway Signalling & Interlocking, Eurailpress [5]; track vacancy detection of DB AG – Tasks and functions, EIK 2008 [6].

	Track circuit	**Axle counting technology**
Track superstructure requirements	Electrically insulating	None
Measures with reference to track return current	Special measures required (meshing)	None
Sensitivity to external influences (e.g. overvoltages, track currents, etc.)	High	With high-quality wheel detection, can be compensated to the greatest possible extent
Sensitivity to climatic influences (e.g. heat, cold, dirt, etc.)	High, particularly with reference to ballast resistance (leaves, wetness, etc.)	With high-quality wheel detection, can be compensated to the greatest possible extent
Section length	Less than 2000 m	No restriction
Recognition of rail breaks	Possible under certain circumstances	Not possible
Reset	Not required	Required - various variants available
Functional scope	Track vacancy detection	Track vacancy detection, direction information Number of axles, number of wagons, speed, etc.
Monitoring of complex point structures, etc.	Can be carried out under certain circumstances	Can be carried out without restriction
Can be modified	Only with great outlay (superstructure adaptations; rail joints)	Simple (by mounting wheel sensor using rail claw)
Installation	Installation of rail joints Drilling of connection cable	Rapid assembly through the use of rail claws
Availability	AF- TC high LF - TC average	Very high
Required travel cycles	24 hours	Up to 2 years
Maintenance outlay	High	Low
Installation costs	High	Low
Investment costs (components)	Comparable	Comparable

Figure 4: Comparison of the most important characteristics of track-circuit and axle counting technology

3.3 Worldwide applications of axle counting systems

It is now impossible to imagine the main and regional railways in many countries of the world without axle counting systems. A significant increase has also been seen in metros, tramways and industrial railways. The benefits of the system and the additional functionalities of axle counting technology compared to the traditional principle of track circuits are increasingly winning out at an international level.

3.4 Sections and stations

The main application of axle counting is consistent track vacancy detection in association with interlocking systems on sections and station. In addition to monitoring station sections that are short due to operational reasons (from a few metres up to several hundred metres), sections between two stations (up to several kilometres) are also monitored here. Fixed track vacancy detection is also a mandatory component of the complete system on the introduction or upgrading to ETCS Level 1 and 2.

3.4.1 Back-up systems

Modern train control and train protection systems (e.g. CBTC, ATP, etc.) allow a high train density and an optimised running of trains. These highly-complex systems generally use proven fixed and automatic track vacancy detection as a back-up or fall-back plan.

3.4.2 Point changeover protection

Axle counting is often used as highly-reliable changeover protection for points. The clear or occupied notification is then evaluated as a release or locking of the point mechanism. A further application is the implementation of EOWs (locally operated electric points systems). Unlike track-circuit technology, axle counting technology can also be used unrestrictedly and easily for depicting multiple branching gridirons.

3.4.3 Level crossings

There are numerous opportunities for monitoring level crossings using signal technology - including with the use of axle counting. In this variant, a wheel detection component [1,7] is used as activation and an axle counting section located in the centre of the level crossing (train has completely passed the level crossing) is used as a releasing element.

3.4.4 Shunting and industry

With its robust properties, its economy and, in particular, its higher range of functionalities (axle/wagon counting, wheel diameter, speed, etc.), axle counting technology has spread particularly quickly in the field of industrial plants, depots, and shunting and marshalling yards.

3.4.5 Metros and tramways

An area of application of axle counting that is not yet widespread but is growing rapidly is the field of metros and tramways. In addition to high levels of safety, aspects such as low repair and maintenance costs, as well as compatibility with all rail vehicles, are at the forefront. Here particularly high requirements are set for wheel detection; see [1].

3.5 Architecture

Track vacancy detection and axle counting are integrative components of technical signalling systems (e.g. interlocking, level crossings, EOWs, etc.). Also decisive for the future-proofing of axle counting systems will be its integration in modern signalling systems. Implementation in both centralised and decentralised architecture must be fully mastered.

3.5.1 Centralised architecture

Centralised architecture is understood as the entire arrangement of axle counting components at one site (e.g. interlocking area). The entire axle counting logic is bundled and positioned here. This design has so far been the rule, and is carried out using both a secure computer for several track sections (software configuration) and a secure computer per section (hardware configuration). Communication with the interlocking as well as the configuration, diagnostics, etc. takes place centrally. The depiction of section blocks can be implemented using copper lines or optical-fibre lines (closed networks to EN 50159-1) (Figure 5).

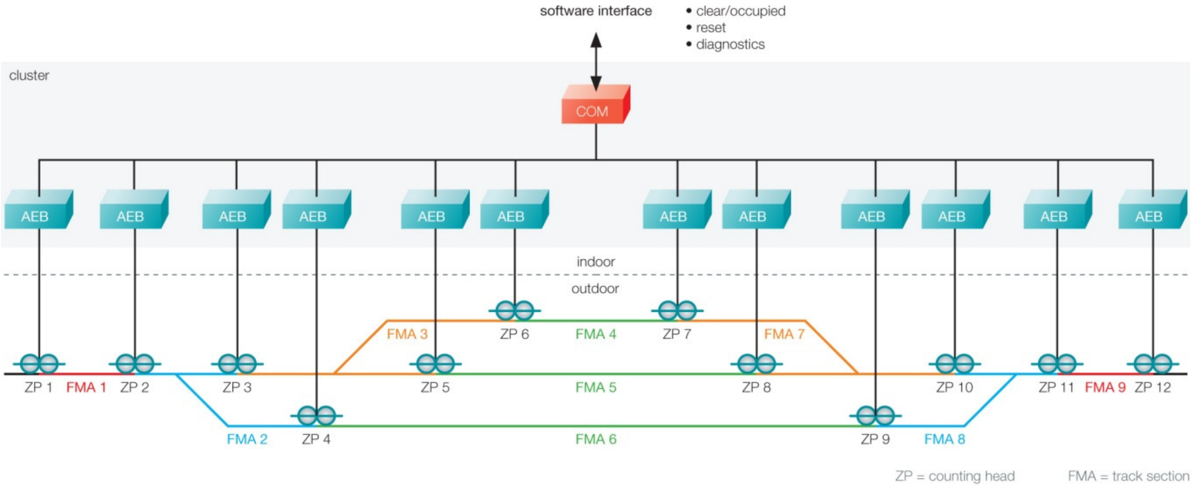

Figure 5: Centralised architecture

3.5.2 Decentralised architecture

Due to modern transmission technologies, decentralised arrangements are gaining in significance and are becoming more economical with reference to the cable infrastructure, amongst other things. Unlike centralised architecture, the axle counting logic here is decentralised, distributed across several, freely-selectable locations. Here individual interlocking clusters along the section (field controller; area controller; object controller) are arranged, for example, in cabinets. These clusters communicate with each other through existing or new network infrastructures (open networks to EN 50159-2, Class 5). They are operated and maintained decentrally through higher-level locations (Figure 6).

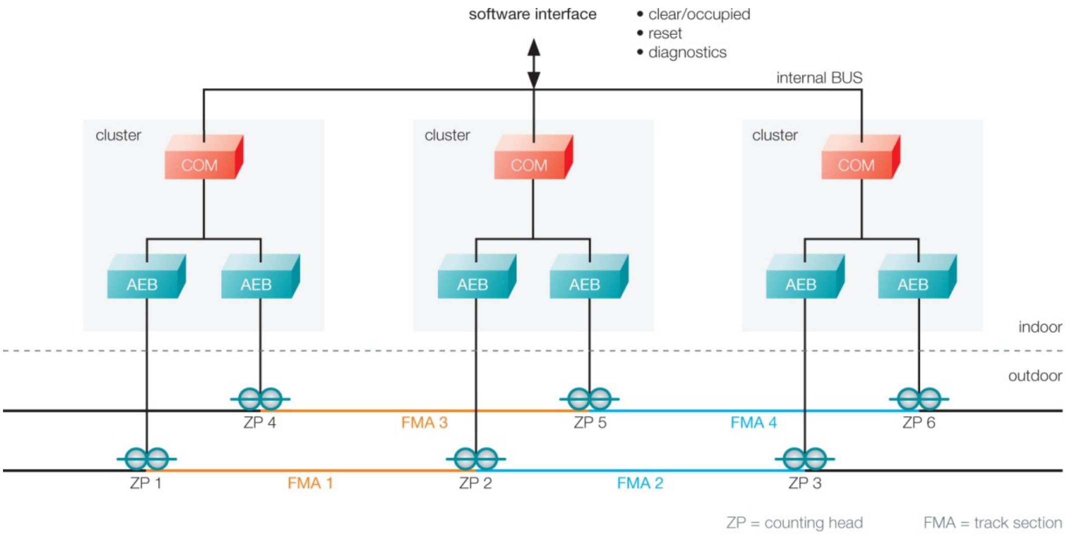

Figure 6: Decentralised architecture

3.6 Interfaces

Further significant features of the ability to integrate axle counting technology are the physical interface to higher-level system and its information content.

3.6.1 Relay interface

The voltage-free, fail-safe relay, interface has proven itself over the course of development. At the forefront was the integration into electromechanical, relay and electronic interlocking. The information content generally includes "clear" / "occupied" as an output variable and "reset" as an input variable of the axle counting system.

3.6.2 Software interface

Decentralised architectures require modern serial and safe software interfaces. A link to existing, safe, communications within an interlocking system must be possible. Compared to a relay interface, this technology allows the exchange of innumerable additional items of information. The serial connection and flexible configuration of the axle counting system open up almost endless opportunities.

The centralised and decentralised arrangements, as well as the interfaces, particularly shape the optical appearance and the mechanical integration of the axle counting components. If standard modules have so far been used to a large extent in 19" board rack format, then it is anticipated that the axle counting components will also be installed in modern plug-in housings or customer-specific container systems.

3.7 Functionalities of modern axle counting systems

At first glance, a current axle counting system provides information on whether a defined section is "clear" or "occupied". Modern axle counting systems, however, are able to provide significantly more information than this. Significant functionalities and those that may be required in the future are described briefly here:

3.7.1 Reset variants

During the commissioning phase, and also due to operational reasons (faults, maintenance, etc.), it is necessary to reset the axle counting system to a fault-free state.

Conditional (restricted) and unconditional (unrestricted) reset variants must be able to be achieved. The status of the track section, for example, is drawn on as a criterion for this ("last axle counted in", "last axle counted out", "partial traverse", "negative axis", etc.).

At times, the reset should be able to be carried out by the station master (CTC) alone or in collaboration with maintenance staff at the site of the equipment, dependent on the type of fault and the status of the system. Furthermore, reset variants with an urgent clearance drive (clearing of the section) may be requested - depending on the requirements of the operator.

3.7.2 Partial traversing management

Fail-safe wheel sensors [1, 7] consist of two sensor systems. One is for the clear detection of the direction of the vehicle, and the other on reaching the safety level (CENELEC SIL 4). If the wheel sensor is now not completely traversed for operational reasons (only one sensor system is traversed), the track section generally switches to the "occupied" status. In the case of a subsequent complete traverse, the partial traversing is then automatically reset. If no traverse is made, the section remains in the "occupied" state and must be returned to its original setting by the interlocking system.

From an operative point of view, including the safety of the complete system, the operator can request that the axle counting system has to suppress several partial traversing procedures (no "occupied" output). The number of permitted partial traversing procedures can also be configured.

3.7.3 Diagnostic information

Preventive maintenance, the optimisation of fault rectification, unrestricted online access to data from the axle counting system, the minimisation of maintenance work and the reduction of life-cycle costs are important aspects that are possible using modern diagnostic systems. With integration into a higher-level system, diagnostics play an increasingly important and system-critical role. A good overview of diagnostic tasks and requirements will be given in detail in Article [8].

3.7.4 Direction output

The output of the traversing direction can be required in the case of safety systems on level crossings and in the shunting and industry areas. If this information is safely provided in accordance with CENELEC SIL 4, it can also be used for closing and opening level crossings and for the control and release of points in shunting areas. For reasons of integration, the direction output generally takes place using galvanically isolated optocouplers or voltage-free relays.

3.7.5 Speed, wheel diameter

The wheel detection [1, 7] on which the axle counting is also based allows the complete system to output the traversing speed and wheel diameter if the wheel sensors are of a correspondingly high quality. A combination or integration of axle counting in SCFs (speed-check facilities), speed-dependent level crossings and (in the case of humps) point position dependent on wheel diameter are possible.

3.7.6 Counting head control

Naturally, the safe function of the axle counting system takes priority. Almost as important is the maximum availability of the complete system. Availability can be further increased using the "counting head control" functionality, by which counting heads are moved to a type of stand-by mode under certain circumstances (e.g. if adjacent track sections are "clear". In this idle state, a freely-configurable number of non-permitted dampings by tools, trolleys, pedestrians, vandals, etc. can be suppressed. With this procedure, no "occupied" status will be generated. This means that a reset is not required. Approaching vehicles switch off the stand-by mode and are therefore safely detected and output.

3.7.7 Configuration, control and operation

Railway operators and maintenance staff are being confronted with different and ever more complex equipment. 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.

3.7.8 Configurable time response

The integration in various systems (ESTW, relay interlocking, SPS controls, etc.) and the use of radio in transfer sections require individual adaptation of the input and output variables of the axle counting system.

3.8 Development trends and challenges

Based on the functionalities shown and discussed above, there are several challenges in the development of axle counting systems.

Frauscher Sensortechnik GmbH has already brought out the main innovative features and is continuing to work on the implementation of these developmental trends, which are seen as follows:

3.8.1 Architecture and interfaces

The integration of axle counting systems will doubtless make advances in the existing architectures and interface plans of respective interlocking manufacturers. An expansion or push towards decentralised architecture and fail-safe software interfaces (Ethernet-based) is also conceivable. A standardisation of these interfaces on a European level would be desirable.

3.8.2 Compact and compressed construction

A prevalent trend is the often restricted space availability in interlocking environments and in enclosed cabinets arranged on each section. It is necessary to combine various functionalities (counting head evaluation, axle counting function, diagnostics, direction output, communication, etc.) and thus reduce them to fewer components.

3.8.3 Remote maintenance

The increased centralisation of maintenance staff analogously requires unrestricted remote access. Efficient diagnostic functionalities and mobile access (via web browsers, smart phones, etc.) will be the answer to this.

3.8.4 Simple configuration concepts

The merging of axle counting systems and interlocking is also accompanied by a necessary adaptation in the sense of configuration and operation. Close collaboration and joint agreement by all parties involved in these areas is essential in order to be able to deliver a consistent and comprehensible concept to the rail operator.

3.8.5 Power consumption

As the decentralisation of components in the interlocking structure progresses, so does the requirement to minimise power input to the axle counting system (e.g. operation using solar cells, buffer batteries, etc.). Optimisation of these features will also shape further developments.

3.8.6 Trolleys, maintenance vehicles and special vehicles

The increasing spread of axle counting technology requires the reliable detection of various vehicle types. For example, in some countries the counting of trolleys must be suppressed, but maintenance vehicles and special vehicles must be accurately recorded. Depending on the rail operator, the requirements here may vary enormously. Special evaluation algorithms and functionalities of the axle counting system may be the solution.

3.8.7 Reset variants

In addition to the wide range of reset variants described above, there are increasing requirements for automated resets using "supervisory track sections". Here a higher-level track section (supervisory section) is defined for several freely-configurable track sections. As long as it is itself "clear", this higher-level section automatically resets lower-level faulty sections. Under certain conditions, this functionality may lead to a further increase in availability.

3.8.8 Additional information

"Clear" or "occupied" will no longer be sufficient as an input for the interlocking systems. Axle counting systems of the future must be able to deliver additional information such as wheel diameter, direction information, speed outputs, defined and freely-configurable output impulses or diagnostic information.

4 Conclusion and Outlook

Future-proof and highly available axle counting systems will be based on inductive wheel sensor systems with analogue output signal. Decades of experience of Frauscher Sensortechnik GmbH and over sixty thousand installations worldwide show that in the long term only this technology will be able to meet the challenges arising from the interferences listed in section 2.3.1. The increasing functional demands are satisfied by different evaluation boards featuring specific software evaluation algorithms. However, tapping the full potential will only be possible, if the core elements – wheel sensor and evaluation board – are optimally tuned to each other.

These systems combined with optimised rail claw mounting and plug-in sensor cables meet all future requirements in regard to cost-effectiveness, flexibility and optimal maintainability.

The possibility to transfer complex information that goes beyond wheel detection, by means of serial interfaces of evaluation boards to higher-level applications, opens up a wide range of functional possibilities not yet used today, especially in highly integrated complex electronic interlocking systems.

With the increasing, worldwide spread of axle counting technology as track vacancy detection, the requirements as well as the opportunities of such systems are also increasing. Modularity, flexible modern interfaces and comprehensive but optimal configurability of additional functionalities in axle counting systems provide the best conditions to meet the necessary requirements, both as a stand-alone solution and as highly-integrated components in modern interlocking systems.

Modern communication interfaces between the interlocking and axle counting systems allow more economical, decentralised solutions with a maximum availability of information and data to be designed at any particular location.

The safety and availability of modern axle counting systems are crucially determined by extremely available wheel detection systems tolerant of interference. Further optimisation of the interface between the vehicle and the wheel sensor, as well as increasing standardisation in this area will further accelerate the replacement of track-circuit technology by axle counting systems.

In addition to classic track vacancy detection, the opportunity of generating further additional information from wheel detection and passing this to higher-level systems will surely enable a whole series of new, integrated applications based on this.

5 Bibliography

[1] Rosenberger, M.; Future Challenges to Wheel Detection and Axle Counting, SIGNAL+DRAHT, 2011, Volume 9.

[2] Fenner, W.; Naumann. P., Trinckauf. J.: Bahnsicherungstechnik: Steuern, Sichern und Überwachen von Fahrwegen und Fahrgeschwindigkeiten im Schienenverkehr, ISBN 3-89578-177-0, 2004.

[3] Association of German Transport Companies, Axle Counting Equipment within Public Transport, Communication no. 3307, December 2005.

[4] Gifford, J. ARTC & FIRSE, Trevor Moore ARTC & FIRSE and Joseph Borg SELECTRIX: Axle counters for heavy rail traffic applications (23 March 2007, Case study in Australia).

[5] Theeg, G., Vlasenko S.: Railway Signalling & Interlocking, Eurailpress, ISBN 978-3-7771- 0394-5.

[6] Kinze, L.: Gleisfreimeldesysteme der DB AG – Aufgaben und Funktionen, Eisenbahn Ingenieur Kalender, 2008.

[7] Frauscher, J.: From track switch to inductive wheel sensor using a variety of technologies, SIGNAL+DRAHT, 2006, Volumes 1+2.

[8] Grundnig, G.; Raschhofer, S.: Increased availability thanks to the FDS Diagnostic System. SIGNAL+DRAHT, 2010, Volumes 1+2.

[9] Uhlig, T., Lehner, G.; Haipl, G.; T., MNR: Mobiles Messsystem zur Analyse von Fahrzeug-Magnetfeldern im Praxiseinsatz, SIGNAL+DRAHT, 2011, Volume 6.

6 Figures: