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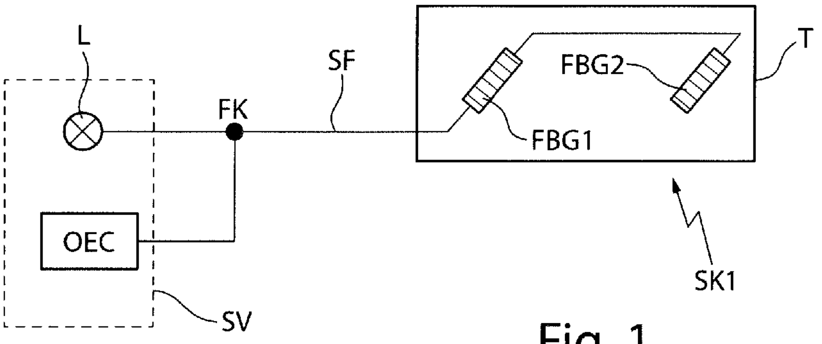

Fig. 1

(57) Abstract: The invention relates to an axle counting method for rail-bound vehicles, having the following method steps: • coupling light into at least one sensor fiber (SF, SF1, SF2), the sensor fiber (SF, SF1, SF2) comprising at least one fiber Bragg grating (FBG1, FBG2) mounted on a rail (T), wherein each fiber Bragg grating (FBG1, FBG2) has a reflection spectrum with a reflection peak (P1, P2) at a Bragg wavelength (λ1, λ2) with a half-value width (FWHM), • generating a differential signal of two shear stress signals by detecting and filtering the time intensity curve of the light power reflected through the two mutually spaced fiber Bragg gratings (FBG1, FBG2, FBG2'), and • generating a wheel signal if the deferential signal exceeds a specified shear stress differential threshold.

(57) Zusammenfassung: Die Erfindung betrifft ein Achszählverfahren für schienengebundene Fahrzeuge mit folgenden Verfahrensschritten : • Einkopplung von Licht in mindestens eine Sensorfaser (SF, SF1, SF2), wobei die Sensorfaser

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(SF, SF1, SF2) mindestens ein an einer Schiene (T) montiertes Faser-Bragg-Gitter (FBG1, FBG2) umfasst, wobei jedes Faser-Bragg-Gitter (FBG1, FBG2) ein Reflexionspektrum mit einem Reflexionspeak (P1, P2) bei einer Bragg-Wellenlängen (λ1, λ2) mit einer Halbwertsbreite (FWHM) aufweist, (FBG1, FBG2) • Erzeugen eines Differenzsignals zweier Schubspannungssignale durch Detektion und Filterung des zeitlichen Intensitätsverlaufs der durch zwei voneinander beabstandeten Faser-Bragg-Gitter (FBG1, FBG2, FBG2') reflektierten Lichtleistung, • Erzeugung eines Radsignals wenn das Differenzsignal einen festgelegten Schubspannungsdifferenz-Grenzwert überschreitet.

Axle-counting method and axle-counting device

Background to the invention

The invention relates to an axle-counting method for railbound vehicles.

An axle-counting method may comprise: coupling light into at least one sensor fibre, the sensor fibre comprising at least one fibre Bragg grating mounted on a rail, each fibre Bragg grating having a reflection spectrum (intensity profile of the light output reflected by the fibre Bragg grating depending on the wavelength) having a reflection peak which is at a Bragg wavelength and has a full width at half maximum, and detecting the light reflected by two fibre Bragg gratings spaced apart from one another.

Such a method is known from the application DE 10 2014 100 654.4 which has not yet been published.

Axle-counting systems are known in which axles travelling past a counting unit are detected by means of induction. The problem with said systems is that electromagnetic fields, for example from air conditioning units mounted on the train, can lead to interference and miscounting.

WO 2005/093971 Al describes a railway monitoring system in which sensor fibres which are attached to the track are used for counting axles. By coupling light into the optical fibres (sensor fibres), light is emitted into the fibre Bragg grating, wavelengths which are within the filter bandwidth around the Bragg wavelength, being reflected. The Bragg wavelength is generally defined as λB=neff-2Λneff-Λ where neff is the effective refractive index and Λ is the grating period of the fibre Bragg grating. As a result of a force acting thereon, the sensor fibre and thus the fibre Bragg grating is stretched and the reflection and transmission wavelength of the fibre Bragg grating changes such that, on the basis of the stretching of the fibre Bragg grating, light of different wavelengths is reflected and can be transmitted to an evaluation and analysis unit. The individual fibre Bragg gratings are mounted at a distance of 2.5 m apart from one another. The individual fibre Bragg gratings have different Bragg wavelengths, wherein the difference of the Bragg wavelengths has to be greater than the change in Bragg wavelength of the corresponding fibre Bragg grating owing to loads.

The not yet published application DE 10 2014 100 654.4 describes a rail measurement system for measuring a mechanical variable, which acts on a rail, by means of fibre optic sensors. The fibre Bragg gratings used in this case are attached to the rails at an angle of from ±30° to ±60°, in particular of ±45°, relative to the neutral fibre. This offers the advantage that shear strains, which lead to a positive or negative stretching and do not extend parallel to the neutral fibre, are detected by the fibre optic sensor unit.

One disadvantage of the known arrangements is that the sensitivity is not sufficient in order to detect every axle reliably, meaning that the safety integrity level required for trains (SIL4) is not ensured since the signals that emerge from the measurement of the shear stress are not suitable for performing a threshold value evaluation.

In view of the foregoing it would be desirable to provide an axle-counting method which on the one hand is not very susceptible to interference, in particular with respect to electromagnetic interference, and on the other hand has sufficient sensitivity in order to meet the required safety integrity level.

Description of the invention

In accordance with the present invention there is provided axle-counting method for railbound vehicles, comprising the following method steps: coupling light into at least one sensor fibre, wherein the sensor fibre comprises at least one fibre Bragg grating mounted on a rail, wherein each fibre Bragg grating has a reflection spectrum having a reflection peak which is at a Bragg wavelength and has a full width at half maximum, detecting the light reflected by two fibre Bragg gratings spaced apart from one another, thereby resulting two shear stress signals of the rail for each of the two fibre Bragg gratings respectively; generating a shear stress difference signal from the two shear stress signals; generating a wheel signal within a signal-processing unit if the shear stress difference signal exceeds a predetermined upper limiting value or falls below a predetermined lower limiting value.

As disclosed herein, a shear stress difference signal, i.e. a signal by means of which the temporal changes of the difference of two shear stresses at two sensor positions that are spaced apart from one another can be deduced, is generated. The shear stress difference signal becomes very large in terms of its absolute value in the range of the change in algebraic sign of the shear stress (i.e. when the discharge of a force into the rail by the wheel occurs precisely between the two fibre Bragg gratings), which allows a simple detection of a wheel. A shear stress signal, i.e. a signal by means of which the shear stress occurring at a certain sensor position can be deduced, can, for example, be received as a result of detection of the light reflected by the fibre Bragg grating mounted at the sensor position, the fibre Bragg grating being arranged obliquely with respect to the neutral fibre, in particular at an angle of ±45° or ±90°. The shear stress difference signal is generated by detecting and establishing the difference in the temporal profile of the change in wavelength of the Bragg wavelengths of the fibre Bragg gratings, the wavelength change being determined by detecting the change in intensity of the reflected light of the fibre Bragg grating. This can be achieved in various ways and is described in detail below with reference to various variants. In the case of all of the variants, the temporal intensity profile of the light output reflected in the sensor fibre(s) is detected, preferably by means of one or more fibre-coupled photodiodes.

Preferred variants

A particularly advantageous variant of the axle-counting method **(OEC concept)** according to an embodiment of the invention is characterised in that sensor fibres each having two fibre Bragg gratings that are arranged in a row and have different Bragg wavelengths are used at two sensor positions that are spaced apart from one another in the rail direction and in that the shear stress difference signal is generated optically within a signal-processing unit by means of an optoelectronic component by the temporal intensity profile of the light output reflected in the sensor fibre being detected by means of the optoelectronic component and filtered at two filter edges of a wavelength filter of the optoelectronic component, the filter edges each being in the range of one of the Bragg wavelengths of the fibre Bragg gratings and having gradients having different algebraic signs, and in that the filtered intensity profile is detected as the difference signal. By processing the difference signal within the signal-processing unit, (digital) wheel signals are generated.

In the case of the OEC concept, optoelectronic components (OE chips) are used for measuring the reflected light output and for signal conversion. Owing to the loads on the sensor positions and the associated shear stresses, the Bragg wavelengths of the fibre Bragg gratings shift. The portions of the reflected light output originating from the various fibre Bragg gratings are subject to filtering at different filter edges. The changes in the Bragg wavelengths are a measure for the shear stresses occurring. The optical difference of the shear stress signals is established in that the portions of the reflected light output of the two fibre Bragg gratings originating from the various fibre Bragg gratings (total spectrum of the light reflected by the two fibre Bragg gratings) along one filter edge in each case of the optoelectronic component shift, the filter edges having gradients with different algebraic signs.

The portions of the reflected light output of the two sensor elements are thus filtered to varying extents. The Bragg wavelengths and the filter edges are preferably adapted to one another such that during an assumed load, the reflection peak of the fibre Bragg grating does not shift into the other filter edge in each case. In this manner, a minimum and a maximum (the algebraic sign depends on the angular orientation (±45°) of the fibre Bragg grating with respect to the neutral fibre depending on how the fibre Bragg gratings are aligned with respect to the neutral fibre) emerge in the profile of the reflected light output, when the difference in the shear stresses at the two sensor positions becomes very large. This can be digitalised by a comparator.

In order for the total output to remain constant in the event of small changes, it is advantageous for the full widths at half maximum (FWHM) of the spectra and their reflectivities (R) of the fibre Bragg gratings to be similar. In a particularly advantageous variant, the full widths at half maximum of the reflection peaks of the two fibre Bragg gratings therefore differ by less than 0.5 nm and the reflectivities of said gratings differ by less than 20%. Apart from this, the deviations from the operating point (preferably the central position) in the filter edge should be small, typically < 1 nm. Otherwise, undershoots and overshoots can occur before and after the minimum output, which consequently restrict the minimally detectable loads. Fibre Bragg gratings having the following values, for example, can be used for detecting train axles on a rail: λ_1= 1541.9 nm, R1 = 45 %, FWHM1 = 550 pm; λ_2 = 1550.1 nm, R = 55 %, FWHM = 650 pm.

Preferably, a reference signal is detected from the temporal intensity profile of the light output reflected in the sensor fibre, without said reference signal being filtered by means of the optoelectronic component, and the difference signal is compared with the reference signal.

In an alternative variant **(RR concept)** of the method according to an embodiment of the invention, sensor fibres having two fibre Bragg gratings that are arranged in a row and have different Bragg wavelengths are used at two sensor positions that are spaced apart from one another in the rail direction, the shear stress difference signal being generated optically by a spectral overlap of the reflection peaks of the two fibre Bragg gratings during the transition from an unloaded state to a loaded state. By processing the difference signal within the signal processing unit, (digital) wheel signals are generated.

The shift of the Bragg wavelengths is a measurement for the shear stress occurring at the sensor position in each case. The degree of overlap of the reflection peak is a measurement for the shear stress difference.

The overlapping of the reflection peak preferably occurs in the loaded state. In this variant, the Bragg wavelengths of the two fibre Bragg gratings are selected such that the reflection peaks of the two fibre Bragg gratings of one rail-contacting half overlap in the loaded state. The more the reflection peaks overlap, the less light is reflected. The loading of the rail is accordingly detected as a minimum intensity. In this variant, a shear stress difference signal is therefore generated as a result of the overlapping of the reflection peaks when the rails are loaded. For this purpose, the spacing between the Bragg wavelengths of the fibre Bragg gratings is selected such that in the event of a load having an expected mass, a perceptible overlap, preferably a full overlap, of the reflection peaks occurs. It is, however, also possible to select the spacing and the full widths at half maximum such that the reflection peaks overlap in the unloaded state and shift away from one another during loading. In this case, a maximum intensity would be measured during loading.

This RR concept is characterised by a low complexity of signal processing on the adapter board.

In a third variant **(OE2 concept)** of the axle-counting method according to an embodiment of the invention, two sensor fibres each having one fibre Bragg grating are used, the fibre Bragg gratings of different sensor fibres being arranged at sensor positions that are spaced apart from one another in the rail direction. For each sensor fibre, a filtered signal of the temporal intensity profile of the light output reflected by the fibre Bragg grating is generated within a signal-processing unit by filtration at each filter edge of a wavelength filter of an optoelectronic component, the shear stress difference signal of the two fibre Bragg gratings being generated electronically by means of a microcontroller. The light reflected by the fibre Bragg grating without said light being filtered or rather the electronic signal obtained by processing the signal from said light acts as the reference signal (light output signal that has not been optically filtered).

In this variant, therefore, the shear stress difference signal is not determined within a rail-contacting half but rather in the microcontroller from the signals processed by the optoelectronic components of the two rail-contacting halves. A difference of electrical signals is therefore carried out.

It is particularly advantageous for a reference signal to be detected from the temporal intensity profile of the light output reflected in the sensor fibre, without said reference signal being filtered by means of the optoelectronic component and for the shear stress signal to be determined from the ratio of filtered signal to reference signal. Independence from the irradiated light output is thus achieved.

In order to detect a fault, it is possible to check whether the reference signal exceeds a third limiting value (third limiting value = upper limiting value) or falls below a third limiting value (third limiting value = lower limiting value). The latter variant is preferable, i.e. that a fault is detected if the reference signal falls below a predetermined third limiting value. The axlecounting method is therefore preferably performed according to a "standby light principle" (similar to the standby current principle). This means that in standby operation, a signal reflected by the fibre Bragg gratings is detected continuously. If the light source fails or if a cable (for example, between the rail contact and the signal processing board) is cut, then the reference signal falls below the predetermined limiting value, as a result of which a simple fault detection of the optical components can be achieved. In this way, the detection of possible defects (failure of the light source, cutting of a cable, contamination at socket positions) in the optical part of the signal processing system, the glass fibre supply line and at the sensor itself is made possible without an additional diagnostic device (self-testing functionality of the fibre Bragg grating). A test can, for example, be carried out in that the light source is switched off for a short time. Another possibility is to modulate the intensity of the light of the light source. If the detected light has the same modulation, the test is rated as successful. It is not necessary in this case to switch off the light source.

The invention also relates to axle-counting devices for performing the various variants of the method according to the invention.

A first axle-counting device according to an embodiment of the invention **(OEC axle counter)** comprises a light source, at least one counting unit, each counting unit comprising two rail-contacting halves for mounting to a rail. Each rail-contacting half comprises a sensor fibre comprising a first fibre Bragg grating having a first Bragg wavelength and a second fibre Bragg grating having a second Bragg wavelength, the fibre Bragg gratings being designed to be mounted on the rail obliquely with respect to the neutral fibre. In addition, the rail-contacting half comprises an optoelectronic component for performing an optical subtraction of the light output reflected by the two fibre Bragg gratings of a sensor fibre, the optoelectronic component comprising a wavelength-dependent filter having two filter edges, the filter edges each being in the range of one of the Bragg wavelengths of the fibre Bragg grating and having gradients having different algebraic signs.

Preferably, the gradients of the filter edges are of the same absolute value. In this case, it is sufficient if the gradients are of the same absolute value in the range within which the Bragg wavelengths shift.

In order to save material, the fibre Bragg gratings of the two rail-contacting halves of one counting unit can be arranged within a common sensor fibre. The signals can be assigned to the individual rail-contacting halves by means of a frequency-separating filter. In a particularly material-saving development of this embodiment, the rail-contacting halves of a counting unit have a common fibre Bragg grating.

A second axle-counting device according to an embodiment of the invention **(RR axle counter)** comprises a light source and at least one counting unit, each counting unit comprising two rail-contacting halves for mounting to a rail, each rail-contacting half comprising a sensor fibre comprising two fibre Bragg gratings arranged in a row at two sensor positions that are spaced apart from one another, the fibre Bragg gratings being designed to be mounted on the rail obliquely with respect to the neutral fibre and the Bragg wavelengths of the two fibre Bragg gratings and the distance between the two sensor positions being selected such that the reflection spectra of the two fibre Bragg gratings overlap when the rail is subjected to a predetermined load between the two sensor positions. In addition, a signal-processing unit for detecting and subsequently processing the light reflected by the fibre Bragg grating is provided.

Preferably, the Bragg wavelengths of the two fibre Bragg gratings and the distance between the two sensor positions (i.e. the distance between identical parts of the two fibre Bragg gratings) are selected such that the two reflection spectra of the fibre Bragg gratings fully overlap during a predetermined loading of the sensor positions.

In order to achieve a good saturation effect, one of the fibre Bragg gratings should have a reflection peak having a large full width at half maximum whereas the full width at half maximum of the reflection peak of the other fibre Bragg grating should be small. The full widths at half maximum of the reflection peaks of the two fibre Bragg gratings therefore preferably differ by 1 to 2 orders of magnitude. As a result of this, a full overrun of the reflection peaks in the event of heavy trains is prevented which would otherwise result in two peaks per axle in the intensity profile of the reflected light output.

It is particularly advantageous if the Bragg wavelengths of the two fibre Bragg gratings do not differ by more than 5 nm, and the full width at half maximum of one fibre Bragg grating is at least 0.05 nm and the full width at half maximum of the other FBG is at most 5 nm. Preferably, the reflection peaks of the two FBGs overlap slightly in the unloaded state, the Bragg wavelength of the first fibre Bragg grating (the fibre Bragg grating facing the signal processing unit) being larger than the Bragg wavelength of the second fibre Bragg grating (the fibre Bragg grating facing away from the signal processing unit).

A third axle-counting device according to an embodiment of the invention **(OE2 axle counter)** comprises a light source and at least one counting unit each comprising two rail-contacting halves for mounting on a rail. Each rail-contacting half comprises a sensor fibre comprising a fibre Bragg grating having a Bragg wavelength, the fibre Bragg grating being designed to be mounted on the rail obliquely with respect to the neutral fibre. Furthermore, each rail-contacting half comprises a signal-processing unit for generating shear stress signals, the evaluation unit comprising an optoelectronic component having a filter edge (optical filter). The axle-counting device has a microcontroller for generating a difference signal of the shear stress signals emitted by the signal-processing units.

The microcontroller is a programmable component, which determines the difference of the shear stress signals from the signals processed by the optoelectronic components of the two rail-contacting halves.

For all of the axle counters according to embodiments of the invention, a broadband light source, for example, a super-luminescent diode, is preferably used as the light source.

In the case of all of the axle-counting devices that are proposed, it is most advantageous for the fibre Bragg gratings (i.e. the extension of the fibre Bragg gratings in the direction of light propagation) to be attached to the rail in parallel with one another at an angle of from ±30° to ±60°, in particular of ±45°, with respect to the neutral fibre. With the aid of the oblique arrangement of the fibre Bragg gratings, shear stresses in the rail are measured by detecting the light reflected by the fibre Bragg gratings when a wheel rolls along the rail. The method is therefore independent of the size of the wheel and of the wheel rim.

Preferably, the fibre Bragg gratings intersect the neutral fibre of the rail.

In the case of an advantageous embodiment of the axle-counting device according to the invention, the fibre Bragg gratings are equipped with a converter structure for compensating for temperature expansion of the rail. The absolute value of the wavelength change resulting from temperature changes of the rail is limited by means of the converter structure. At the same time, the converter structure has the task of enhancing the relatively low strain level of the shear stress in order to be able to detect low axle loads as well.

It is particularly advantageous for the fibre Bragg gratings to be fastened to the rail under pretension. In this way, it can be ascertained in a simple manner if a fibre Bragg grating has come loose from the rail since the Bragg wavelength of the fibre Bragg grating changes when the pretension is no longer present. The fastening of the fibre Bragg grating under pretension makes it possible to detect if a fibre Bragg grating has come loose from the rail since when the fibre Bragg grating comes loose, the pretension is no longer present and the Bragg wavelength of the fibre Bragg grating changes accordingly. Consequently, a permanent wheel signal is emitted. The pretension can be achieved mechanically before attaching the fibre Bragg grating to the rail or thermally by means of a bracket while the bracket is fastened to the rail under pretension.

It is particularly advantageous for a trimming device to be provided for adjusting the pretension under which the FBGs are mounted onto the rail.

Preferably, the signal-processing unit comprises a fibre-optic beam splitter. The beam splitter serves the purpose of picking up a reference signal by means of a second photodiode in addition to the edge-filtered signal.

Further advantages of the invention and its embodiments will emerge from the description and from the drawings. According to the invention, the features that are referred to above and those that are described in further detail hereinafter, can each also be used individually or collectively in any combination. The embodiments shown and described are not to be understood to be a complete list but rather are of a nature for describing the invention by way of example.

Detailed description of the invention and drawings

Fig. 1	shows the schematic structure of a rail-contacting half of an axle-counting device according to the EOC concept.
Fig. 2	is a block wiring diagram of the processing of an optical signal received by the rail-contacting half from Fig. 1 (EOC concept).
Fig. 3	shows the profile of the reflection peak relative to the filter edges (EOC concept).
Fig. 4	shows the temporal profile of the photocurrent of the difference signal detected by the photodiodes according to the OEC concept and the portion of the detected photocurrent assigned to the individual fibre Bragg gratings.
Fig. 5	shows the schematic structure of a rail-contacting half of an axle-counting device according to the RR concept.
Fig. 6	is a block wiring diagram of the processing of an optical signal received by one of the rail-contacting halves from Fig. 5 (RR concept).
Fig. 7a, b	shows the arrangement of the reflection peak in an unloaded and in a loaded state.
Fig. 8	shows the temporal profile of the difference signal according to the RR concept.
Fig. 9	shows the schematic structure of two rail-contacting halves of an axle-counting device according to the E02 concept.

Fig. 10	is a block wiring diagram of the processing of signals received by the two rail-contacting halves according to Fig. 9 (OE2 concept).
Fig. 11	shows the arrangement of a reflection peak relative to the filter edge in an unloaded state of the rail.
Fig. 12a	shows the temporal profile of the shear stress signals of the two rail-contacting halves according to the OE2 concept.
Fig. 12b	shows the temporal profile of the difference signal according to the OE2 concept.
Fig. 13a	shows fibre Bragg gratings of two rail-contacting halves fastened to a rail according to the OEC and RR concepts with separate sensor fibres.
Fig. 13b	shows fibre Bragg gratings of two rail-contacting halves fastened to a rail according to the OEC and RR concepts with a common sensor fibre.
Fig 13c	shows fibre Bragg gratings of two rail-contacting halves fastened to a rail according to the OE2 concept.
Fig. 14	is a cross section of a rail with a fibre Bragg grating fastened to the rail according to Fig. 13a-c.
Fig. 15	shows the general structure of an axle-counting device according to an embodiment of the invention.

Fig. 1 shows the structure of a rail-contacting half SKI of an axle-counting device according to the invention according to the EOC concept. The rail-contacting half SKi comprises a sensor fibre SF having two fibre Bragg gratings FBG1, FBG2, which are spaced apart from one another and are preferably pre-assembled on a bracket T such that they can be mounted on a rail S simply in the desired orientation (see Fig. 13a, b). The fibre Bragg gratings FBG1, FBG2 have different Bragg wavelengths λ_1, λ_2 and accordingly reflect light of the relevant Bragg wavelength λ_1, λ_2. Light is coupled into the sensor fibre SF by means of a light source L. The light reflected by the fibre Bragg gratings FBGI, FBG2 is transmitted to an optoelectronic component OEC by means of a fibre coupler FK, within which optoelectronic component the reflected light is processed. In the present case, the optoelectronic component OEC and the light source L are part of a signal processing unit SV.

Fig. 2 shows how the reflected light is subsequently processed within the signal processing unit SV. The reflected light is transmitted from the sensor fibre SF into the optoelectronic component OEC, in which the light is split by means of a beam splitter ST. In a first channel, the reflected light is filtered by means of a wavelength filter F and detected as an electrical difference signal S_D by means of a first photodiode PD1. In a second channel, the reflected light is transmitted directly onto a second photodiode PD2 and detected there as a reference signal S_R, the reference signal S_R being proportional to the total reflected light output. According to the invention, the wavelength filter F has two filter edges K1, K2, the two filter edges K1, K2 having gradients that have different algebraic signs. Owing to the different algebraic signs, shifts of the Bragg wavelengths $\lambda 1$, $\lambda 2$ of the two fibre Bragg gratings FBG1, FBG2, for example to larger wavelengths, are evaluated differently, i.e. due to an increase in the detected light output in the case of the first fibre Bragg grating FBG1, and due to a reduction in the detected light output in the case of the other fibre Bragg grating FBG2.

Transimpedance amplifiers V1, V2 convert the difference signal S_D and reference signal S_R into stress signals. Said stress signals can now be subsequently processed (for example, by low pass filtering). In order to determine the actual measured variable, the ratio between the difference signal S_D and the reference signal S_R is provided. Path neutrality is thus achieved and measurements which are independent of damping effects are made possible. The signal generated thus is proportional to the axle load, which can be analysed separately. The analogue signal can be converted into a digital wheel signal (wheel pulse RI1) with the aid of a comparator.

Fig. 3 shows a possible profile of the filter edges K1, K2 relative to the reflection peak P1, P2 of the fibre Bragg grating FBG1, FG2. The two filter edges K1, K2 have the same absolute value of gradient, but are inclined in different directions in the diagram shown (different algebraic signs). The reflection peaks P1, P2 of the fibre Bragg gratings FBG1, FBG2 are selected so as to be symmetrical to the filter edges K1, K2. The filter edges K1, K2 extend through the reflection peaks P1, P2 such that shifts of the reflection peaks to larger and to smaller wavelengths lead to a change in light intensity, a shift of the first reflection peak P1 to larger wavelengths causing an increase in intensity, whereas a shift of the second reflection peak P2 to larger wavelengths brings about a reduction in intensity.

Fig. 4 is a diagram of the profile of the difference signal S_D (solid curve) and of the portions of the light reflected by the fibre Bragg grating FBG1, FBG2 in each case from the difference signal (FBG1: dashed curve, FBG2: dotted curve). In the example shown, the first fibre Bragg grating is compressed owing to an approaching load and the Bragg wavelength λ1 of the first fibre Bragg grating FBG1 is shifted to larger wavelengths, i.e. along the rising filter edge K1. An increase in the intensity of the light output is brought about as a result of this. If the load moves over the first fibre Bragg grating FBG1 towards the second fibre Bragg grating FBG2, the first fibre Bragg grating FBG1 is stretched, the Bragg wavelength λ1 of the first fibre Bragg grating FBG1 is therefore shifted to smaller wavelengths (along the falling filter edge K1) while the second fibre Bragg grating FBG2 is compressed, the Bragg wavelength λ2 of the second fibre Bragg grating FBG2 is therefore shifted to larger wavelengths (along the falling filter edge K2). This results in the difference signal S_D in the profile shown in Fig. 4. A wheel pulse RI1 is detected if the difference signal S_D falls below a predetermined limiting value G.

Fig. 5 shows the structure of a rail-contacting half SK1 of an axle-counting device according to the RR concept. The rail-contacting half SK1 comprises a sensor fibre SF having two fibre Bragg gratings FBG1, FBG2, which are spaced apart from one another and are preferably preassembled on a bracket T such that they can be mounted simply on a rail S in the desired orientation (see Fig. 13a, b). The fibre Bragg gratings FBG1, FBG2 have different Bragg wavelengths λ1, λ2 and accordingly reflect light of the relevant Bragg wavelength λ1, λ2. Light is coupled into the sensor fibre SF via a light source L. The light reflected by the fibre Bragg gratings FBG1, FBG2 is transmitted into a signal processing unit SV, in which the reflected light is processed. The light source L in the present case is part of the signal processing unit SV.

Fig. 6 shows how the reflected light is subsequently processed within the signal processing unit SV. The reflected light is detected as an electrical difference signal S_D by means of a photodiode PD. Shifts of the Bragg wavelengths λ1, λ2 of the two fibre Bragg gratings FBG1, FBG2. A transimpedance amplifier V converts the difference signal S_D into a stress signal. Said stress signal can now be subsequently processed (for example, by low pass filtering). The analogue signal can then be converted into a digital wheel signal (wheel pulse RI1) with the aid of a comparator.

Fig. 7a, b show a particularly advantageous example of the reflection peaks P1, P2 of the two fibre Bragg gratings FBG1, FBG2 in an unloaded state (Fig. 7a) and in a loaded state (Fig. 7b). The reflection peaks P1, P2 have different full widths at half maximum FWHM. In the unloaded state, the reflection peaks P1, P2 overlap slightly in the example shown such that shifts of the reflection peaks to larger and also to smaller wavelengths lead to a change in light intensity, a shift of the reflection peaks P1, P2 away from one another causing an increase in intensity whereas a shift of the reflection peaks P1, P2 towards one another brings about a decrease in intensity since an overlapping of the reflection peaks P1, P2 reduces the bandwidth of the reflected light. A difference signal S_D is generated by the overlapping of the reflection peaks P1, P2 since part of the light to be reflected by the second fibre Bragg grating FBG2 is already reflected by the first fibre Bragg grating FBG1 and therefore does not reach the second fibre Bragg grating FBG2 and consequently cannot be reflected by the second fibre Bragg grating FBG2.

Fig. 8 is a diagram of the profile of the difference signal S_D. In the example shown, the first fibre Bragg grating is compressed owing to an approaching load and the first reflection peak P1 of the first fibre Bragg grating FBG1 is shifted to larger wavelengths, i.e. towards the second reflection peak P2. As a result of this, the overlapping of the reflection peaks P1, P2 increases, which leads to a reduction in intensity of the light output. If the load moves over the first fibre Bragg grating FBG1 towards the second fibre Bragg grating FBG2, the first fibre Bragg grating FBG1 is stretched, the Bragg wavelength λ1 of the first fibre Bragg grating FBG1 and therefore the first reflection peak P1 is shifted to smaller wavelengths, while the second fibre Bragg grating FBG2 is compressed, the second reflection peak P2 of the second fibre Bragg grating FBG2 is therefore shifted to larger wavelengths. The reflection peaks P1, P2 therefore move away from one another. As a result of this, the overlap of the reflection peaks P1, P2 reduces, which leads to a rapid increase in the intensity of the light output. This results in the profile of the difference signal S_D shown in Fig. 8. A wheel pulse RI1 is detected if the difference signal S_D exceeds a predetermined limiting value G.

Fig. 9 shows the structure of two rail-contacting halves SK1, SK2 of an axle-counting device according to the invention according to the EO2 concept. The rail-contacting halves SK1, SK2 each comprise one sensor fibre SF having one fibre Bragg grating FBG1, FBG2. The fibre Bragg gratings FBG1, FBG2 of the two rail-contacting halves SK1, SK2 have Bragg wavelengths λ1, λ2 and accordingly reflect light of the relevant Bragg wavelength λ1, λ2. In this variant, the Bragg wavelengths λ1, λ2 can be the same. Light is coupled into the sensor fibres SF via a light source L in each case. In principle, however, just one single light source can be provided which supplies light into the two sensor fibres SF. The light reflected by the fibre Bragg gratings FBG1, FBG2 is transmitted by means of a fibre coupler FK to an optoelectronic component OEC within each rail-contacting half SK1, SK2, in which optoelectronic component the reflected light is processed. The optoelectronic components OEC and the light source L are parts of the signal-processing unit SV in the present case. The optoelectronic components OEC convert the detected signals into electrical currents, process said currents and subsequently conduct them to a microcontroller MC in which a difference signal is generated. Within the microcontroller MC, a digital signal is generated from the difference signal by means of establishing the threshold value, which digital signal is emitted as a wheel pulse.

Fig. 10 shows how the reflected light is subsequently processed in the signal-processing units SV. The light reflected in the two sensor fibres SF is transmitted from the sensor fibres SF into the optoelectronic components OEC, in which the light is split by means of a beam splitter ST. The reflected light is filtered within a first channel in each case by means of wavelength filters F having a filter edge K and detected as shear stress signals S_1, S_2 by means of first photodiodes PD1. The reflected light is transmitted directly onto second photodiodes PD2 within a second channel in each case and detected there as reference signals S_{R1}, S_{R2}, the reference signals S_{R1}, S_{R2} being proportional to the total light output reflected in the relevant sensor fibre SF1, SF2. Transimpedance amplifiers V1, V2 convert the shear stress signals S_1, S_2 and the reference signals S_{R1}, S_{R2} into stress signals. Said stress signals can now be subsequently processed (for example, by low pass filtering). In order to determine the actual signals to be subsequently processed, the ratio between the difference signal S_D and the reference signal S_R is provided. These ratio signals are then transmitted to the microcontroller MC, which generates a difference signal by subtracting the electrical signals.

Fig. 11 shows a possible profile of the first filter edge K relative to the first reflection peak P1 of the first fibre Bragg grating FBG1. The filter edge K extends through the reflection peak P1 such that shifts of the reflection peak to larger and also to smaller wavelengths lead to a change in light intensity, a shift of the first reflection peak P1 to larger wavelengths causing a reduction in intensity, whereas a shift of the first reflection peak P1 to smaller wavelengths causes an increase in intensity. The profile of the second filter edge K relative to the second reflection peak P2 of the second fibre Bragg grating FBG2 is preferably the same.

Fig. 12a shows the temporal profile of the shear stress signals of the two rail-contacting halves according to the OE2 concept.

If the difference of the two shear stress profiles is formed, this is at a maximum when the load transfer into the rails by the wheel takes place precisely between the two sensors, as shown in Fig. 12b.

Fig. 13a, 13b show fibre Bragg gratings FBG1, FBG2, which are fastened to a rail S, of two rail-contacting halves SK1, SK2 according to the OEC and RR concepts. A first fibre Bragg grating FBG1 and a second fibre Bragg grating FBG2 are each arranged together on a bracket T at two sensor positions SS1, SS3 which are spaced apart from one another in the rail direction, which bracket is mounted on the rail S under pretension. In Fig. 13a, a separate sensor fibre SF is provided for each rail-contacting half SK1, SK2 into which sensor fibre the first fibre Bragg grating FBG1 and the second fibre Bragg grating FBG2 are written, the two fibre Bragg gratings FBG1, FBG2 being spaced apart from one another. Fig. 13b shows another embodiment, in which the fibre Bragg gratings FBG1, FBG2 of the two rail-contacting halves SK1, SK2 are part of one single sensor fibre SF. The signals are transmitted by means of a frequency-separating filter FW to the signal processing units SV of the corresponding rail-contacting halves SK1, SK2. The four fibre Bragg gratings FBG1, FBG2 must, however, have different Bragg wavelengths for this purpose.

Fig. 13c shows fibre Bragg gratings of two rail-contacting halves fastened to a rail according to the OE2 concept. Each fibre Bragg grating FBG1, FBG2 is written into its own sensor fibre SF1, SF2 and preassembled on a bracket T in each case.

In Fig. 13a and Fig. 13c, the fibre Bragg gratings FBG1, FBG2 are fastened to the rail at a 45° angle relative to the neutral fibre NF. Fig. 13b on the other hand shows an embodiment in which the fibre Bragg gratings FG1, FBG2 are fastened to the rail at an angle of -45° relative to the neutral fibre NF. The two attachment options are possible with all three concepts described here. The different orientations of the fibre Bragg gratings FBG1, FBG2 in Fig. 13a, c on the one hand and Fig. 13b on the other hand have the effect that the shear stress signals and also the difference signal having different algebraic signs are emitted. Preferably, an orientation is selected such that the wheel signal is emitted as a minimum. Preferably, the two fibre Bragg gratings are arranged at a spacing of about 150 mm from one another. If the two sensor elements are located close enough to one another (preferably closer than 150 mm), they also both experience the same temperatures such that a varying temperature behaviour of the fibre Bragg gratings does not occur. Torsions of the rail as a result of lateral input of force into the rail head can also be compensated in this manner.

Fig. 14 is a cross section of a rail S, having a fibre Bragg grating attached to the rail S by means of a bracket T according to Fig. 13a-c.

Fig. 15 shows the general structure of an axle-counting device according to the invention. The axle-counting device shown comprises two counting units ZP each having two railcontacting halves SKI, SK2, each rail-contacting half SKi, SK2 generating a wheel pulse R11, R12 which is transmitted to a counting device within each counting unit. The direction of travel can be determined within each counting unit using the wheel pulse R11, R12. The detected information (wheel pulses R11, R12, direction of travel) are transmitted to an evaluation unit ACE.

The reference in this specification to any prior publication (or information derived from it), or to any matter which is known, is not, and should not be taken as an acknowledgment or admission or any form of suggestion that that prior publication (or information derived from it) or known matter forms part of the common general knowledge in the field of endeavour to which this specification relates.

Throughout this specification and the claims which follow, unless the context requires otherwise, the word "comprise", and variations such as "comprises" and "comprising", will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integers or steps.

List of reference signs

ACE	evaluation unit
F	wavelength filter
FBG1, FBG2	fibre Bragg gratings
FK	fibre coupler
FW	frequency separating filter
FWHM	full width at half maximum
G	limiting value
K, K1, K2	filter edges
L	light source
MC	microcontroller
NF	neutral fibre
OEC	optoelectronic component
P1, P2	reflection peaks
PD, PD1, PD2	photodiodes
RI1, RI2	wheel pulse
SK1, SK2	rail-contacting halves
S	rail
SF	sensor fibre
SS1, SS2	sensor positions
ST	beam splitter
SV	signal processing unit
S_D	difference signal
S_R, S_{R1}, S_{R2}	reference signal
S_1, S_2	shear stress signals
T	bracket
V, V1, V2	transimpedance amplifier
ZP	counting unit
$\lambda 1$, $\lambda 2$	Bragg wavelengths

The claims defining the invention are as follows:

1. Axle-counting method for railbound vehicles, comprising the following method steps:
   - coupling light into at least one sensor fibre, wherein the sensor fibre comprises at least one fibre Bragg grating mounted on a rail, wherein each fibre Bragg grating has a reflection spectrum having a reflection peak which is at a Bragg wavelength and has a full width at half maximum,
   - detecting the light reflected by two fibre Bragg gratings spaced apart from one another, thereby resulting two shear stress signals of the rail for each of the two fibre Bragg gratings respectively;
   - generating a shear stress difference signal from the two shear stress signals;
   - generating a wheel signal within a signal-processing unit if the shear stress difference signal exceeds a predetermined upper limiting value or falls below a predetermined lower limiting value.

2. Axle-counting method according to claim 1, characterised in that
sensor fibres each having two fibre Bragg gratings that are arranged in a row and have different Bragg wavelengths are used at two sensor positions that are spaced apart from one another in the rail direction, and
in that the shear stress difference signal is generated optically within a signal-processing unit by means of an optoelectronic component by the temporal intensity profile of the light output reflected in the sensor fibre being filtered at two filter edges of a wavelength filter of the optoelectronic component by means of the optoelectronic component, the filter edges each being in the range of one of the Bragg wavelengths of the fibre Bragg grating and having gradients having different algebraic signs, and
in that the filtered intensity profile is detected as the difference signal, and in that wheel signals are generated by processing the difference signal within a signal-processing unit.

3. Axle-counting method according to claim 2, characterised in that the full widths at half maximum of the reflection peaks of the two fibre Bragg gratings differ by less than 0.5 nm, and the reflectivities of said gratings differ by less than 20 %.

4. Axle-counting method according to claim 2, characterised in that a reference signal is detected from the temporal intensity profile of the light output reflected in the sensor fibre,

without said reference signal being filtered by means of the optoelectronic component, and in that the difference signal is compared with the reference signal.

5. Axle-counting method according to claim 1, characterised in that
sensor fibres having two fibre Bragg gratings that are arranged in a row and have different Bragg wavelengths are used at two sensor positions that are spaced apart from one another in the rail direction, and
in that the shear stress difference signal is generated optically by a spectral overlap of the reflection peaks of the two fibre Bragg gratings during the transition from an unloaded state to a loaded state.

6. Axle-counting method according to claim 5, characterised in that the reflection peaks overlap in the loaded state.

7. Axle-counting method according to claim 1, characterised in that
two sensor fibres each having one fibre Bragg grating are used, the fibre Bragg gratings of different sensor fibres being arranged at sensor positions that are spaced apart from one another in the rail direction, and
in that, for each sensor fibre, a filtered signal of the temporal intensity profile of the light output reflected by the fibre Bragg grating in the sensor fibre is generated as a shear stress difference signal within a signal-processing unit by filtration at each filter edge of a wavelength filter of an optoelectronic component, and
in that the shear stress difference signal of the two fibre Bragg gratings is generated electronically by means of a microcontroller.

8. Axle-counting method according to claim 7, characterised in that a reference signal is detected from the temporal intensity profile of the light output reflected in the sensor fibre, without said reference signal being filtered by means of the optoelectronic component, and in that the shear stress signal is determined from the ratio of filtered signal to reference signal.

9. Axle-counting method according to any one of the preceding claims, characterised in that a fault is identified if the reference signal falls below a predetermined third limiting value.

10. Axle-counting device for performing the method according to claim 2, comprising:
a light source,

at least one counting unit, wherein each counting unit comprises two rail-contacting halves for mounting to a rail, wherein each rail-contacting half comprises:

-a sensor fibre comprising a first fibre Bragg grating having a first Bragg wavelength and a second fibre Bragg grating having a second Bragg wavelength, wherein the fibre Bragg gratings are designed to be mounted on the rail obliquely with respect to the neutral fibre,

-a signal-processing unit having an optoelectronic component for performing an optical subtraction of the light output reflected by the two fibre Bragg gratings of a sensor fibre, wherein the optoelectronic component comprises a wavelength-dependent filter having two filter edges, wherein the filter edges are each in the range of one of the Bragg wavelengths of the fibre Bragg grating and have gradients having different algebraic signs.

11. Axle-counting device according to claim 10, characterised in that the gradients of the filter edges are of the same absolute value.

12. Axle-counting device according to either claim 10 or claim 11, characterised in that the fibre Bragg gratings of the two rail-contacting halves of a counting unit are arranged within a common sensor fibre.

13. Axle-counting device for performing the method according to claim 4, comprising:
a light source,
at least one counting unit, wherein each counting unit comprises two rail-contacting halves for mounting to a rail, wherein each rail-contacting half comprises:

- a sensor fibre, comprising two fibre Bragg gratings arranged in a row, at two sensor positions that are spaced apart from one another,

wherein the fibre Bragg gratings are designed to be mounted on the rail obliquely with respect to the neutral fibre, and wherein the Bragg wavelengths of the two fibre Bragg gratings and the distance between the two sensor positions are selected such that the reflection peaks of the two fibre Bragg gratings overlap when the rail is subjected to a predetermined load between the two sensor positions,

- a signal-processing unit for detecting and subsequently processing the light reflected by the fibre Bragg grating.

14. Axle-counting device according to claim 13, characterised in that the full widths at half maximum of the reflection peaks of the two fibre Bragg gratings differ by 1 to 2 orders of magnitude.

15. Axle-counting device according to either claim 13 or claim 14, characterised in that the Bragg wavelengths of the two fibre Bragg gratings do not differ by more than 5 nm, and in that the full width at half maximum of one fibre Bragg grating is at least 0.05 nm and the full width at half maximum of the other fibre Bragg grating is at most 5 nm.

16. Axle-counting device for performing the method according to claim 7, comprising:
a light source,
wherein each counting unit comprises two rail-contacting halves for mounting on a rail, wherein each rail-contacting half comprises:

- a sensor fibre comprising a fibre Bragg grating having a Bragg wavelength, wherein the fibre Bragg grating is designed to be mounted on the rail obliquely with respect to the neutral fibre,
- a signal-processing unit for generating shear stress signals, wherein the signal-processing unit comprises an optoelectronic component having a filter edge, and

  comprising a microcontroller for generating a difference signal of the shear stress signals emitted by the signal-processing units.

17. Axle-counting device according to any one of claims 10 to 16, characterised in that the fibre Bragg gratings are attached to the rail in parallel with one another at an angle of from ±30° to ±60°, in particular ±45°, with respect to the neutral fibre.

18. Axle-counting device according to any one of claims 10 to 17, characterised in that the fibre Bragg gratings intersect the neutral fibre of the rail.

19. Axle-counting device according to any one of claims 10 to 18, characterised in that the fibre Bragg gratings are equipped with a converter structure for compensating for temperature expansion of the rail.

20. Axle-counting device according to any one of claims 10 to 19, characterised in that the fibre Bragg gratings are fastened to the rail under pretension.

21. Axle-counting device according to claim 20, characterised in that a trimming device is provided for adjusting the pretension under which the fibre Bragg gratings are mounted onto the rail.

22. Axle-counting device according to any one of claims 10 to 21, characterised in that the signal-processing unit comprises a fibre-optic beam splitter.

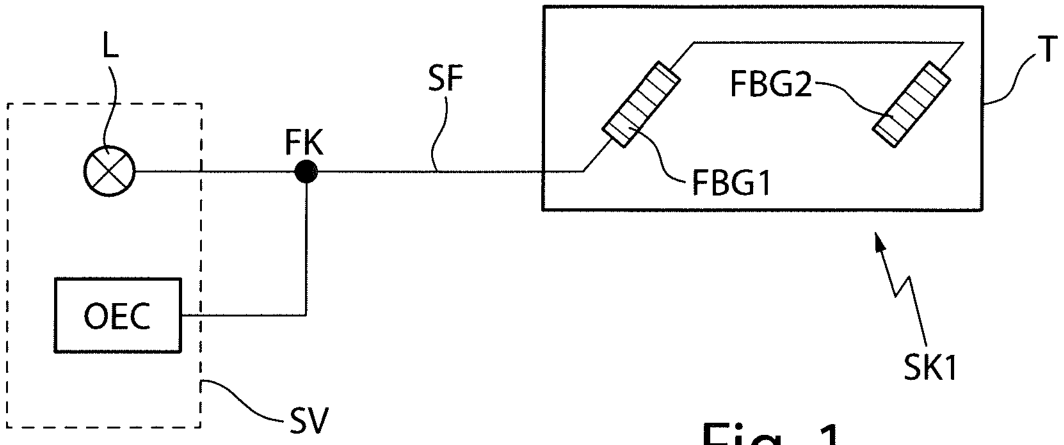


Fig. 1

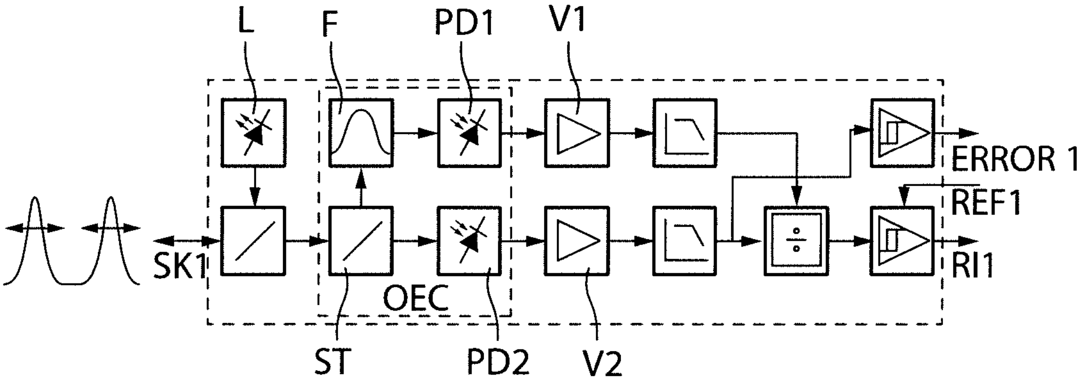


Fig. 2

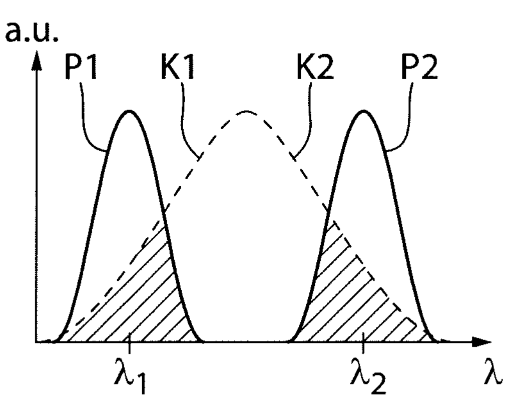


Fig. 3

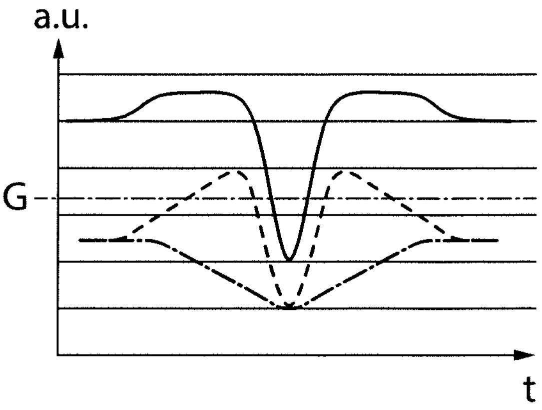


Fig. 4

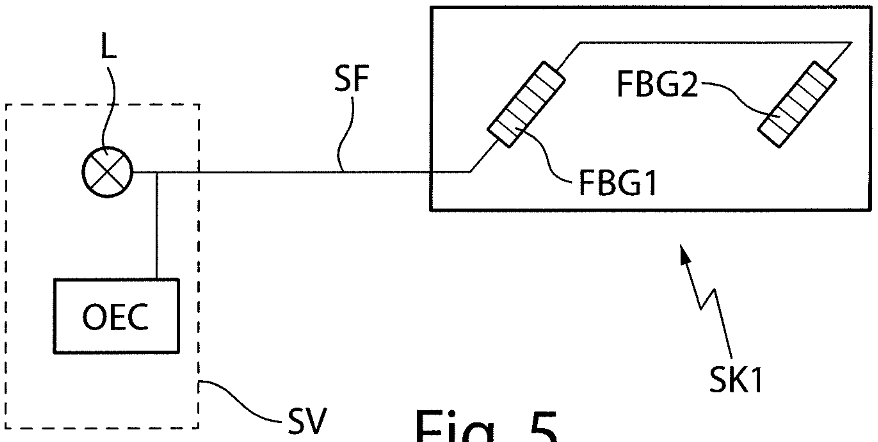


Fig. 5

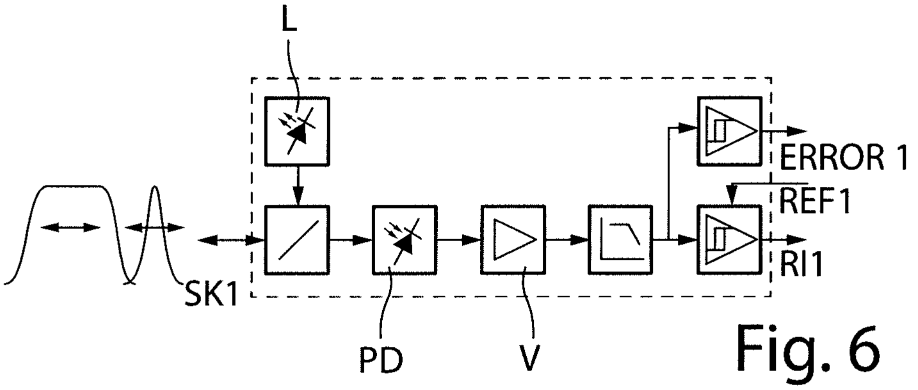


Fig. 6

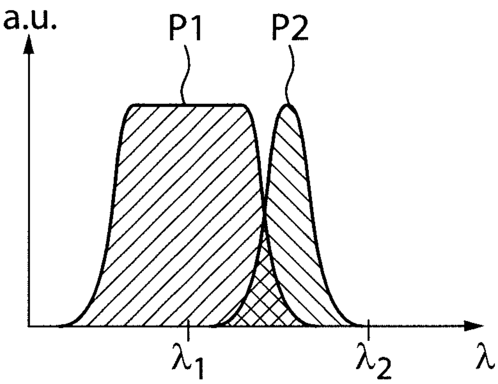


Fig. 7a

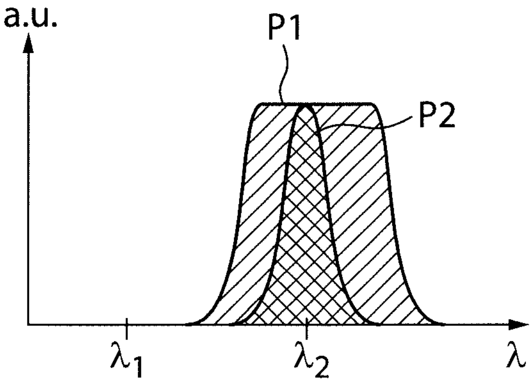


Fig. 7b

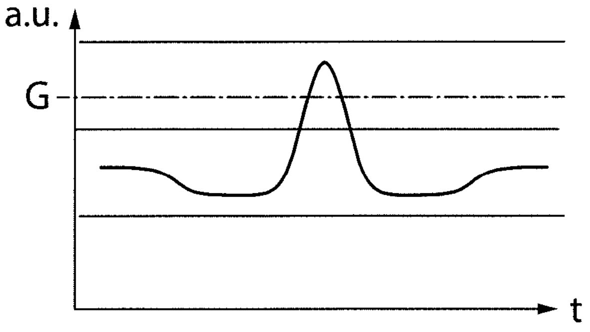
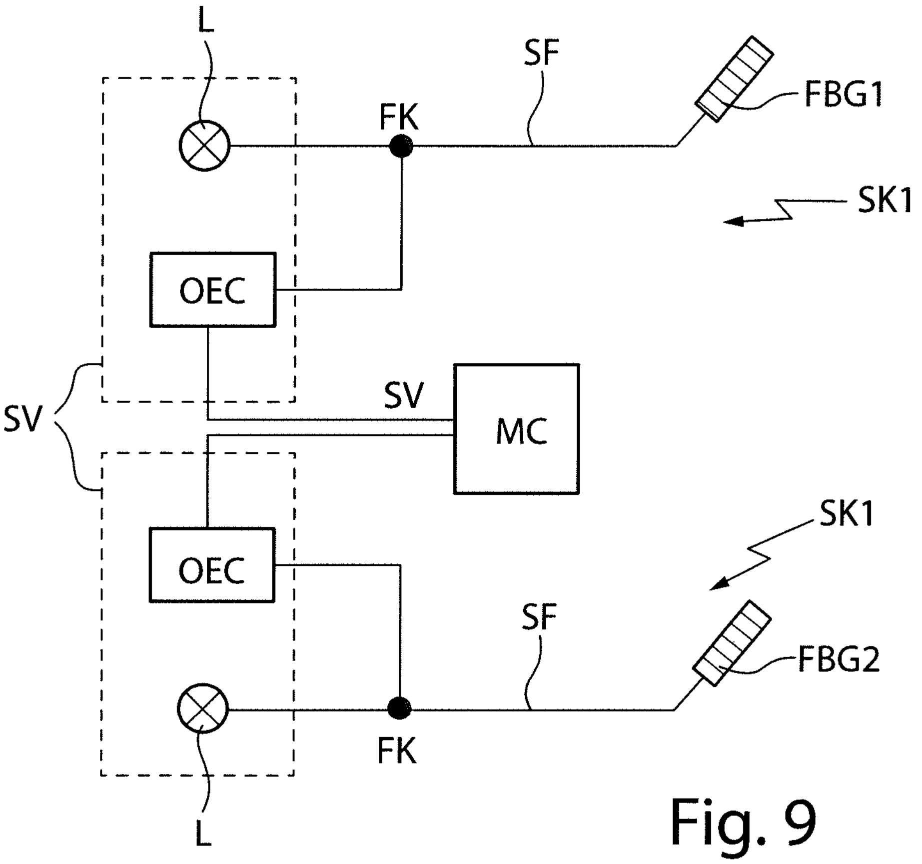


Fig. 8


L
SF
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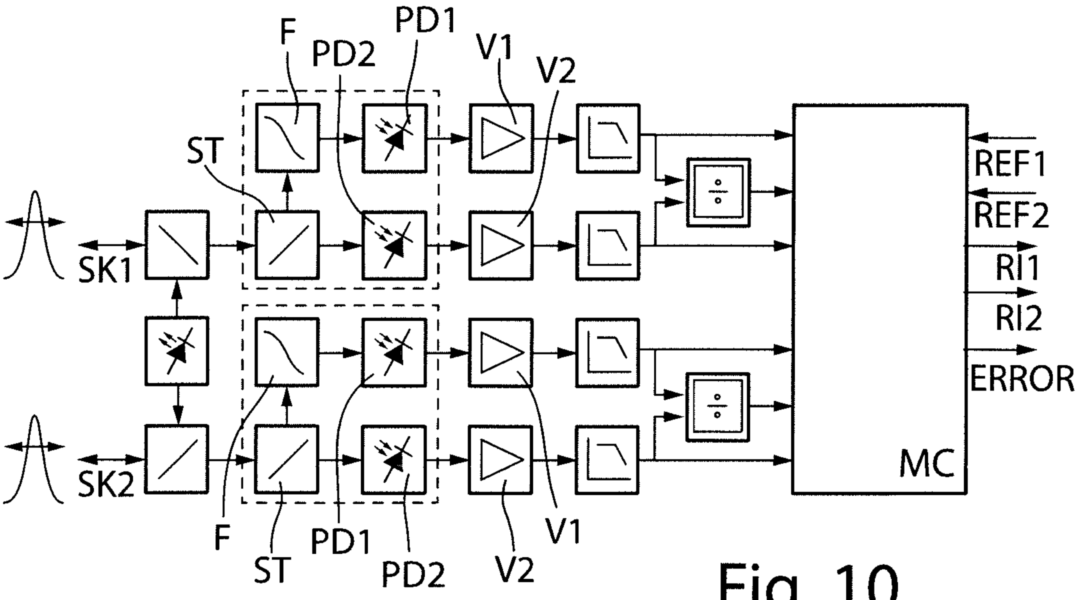
FK
SK1
OEC
SV
SV
MC
OEC
SK1
SF
FBG2
FK
L

Fig. 9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PD2
PD1
V1
V2
ST
REF1
REF2
RI1
RI2
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SK1
SK2
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F
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PD1
PD2
V2
V1

Fig. 10

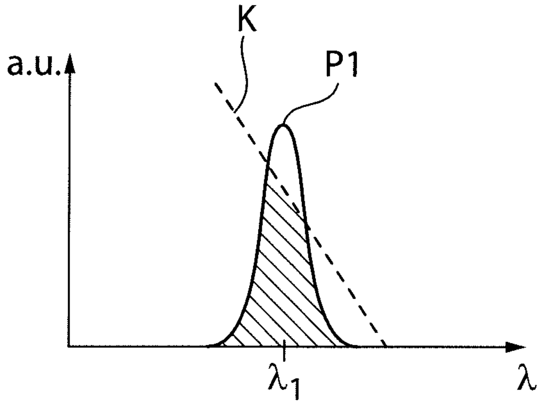

Fig. 11

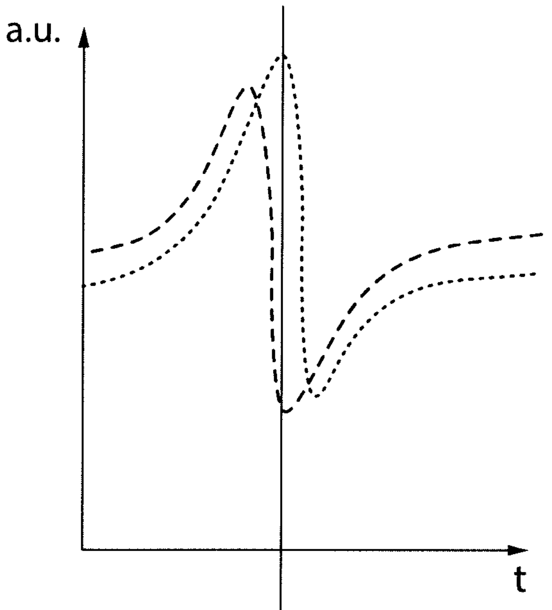

Fig. 12a

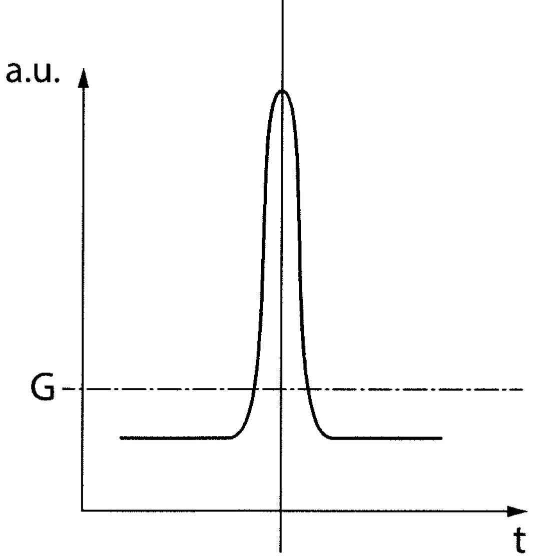

Fig. 12b

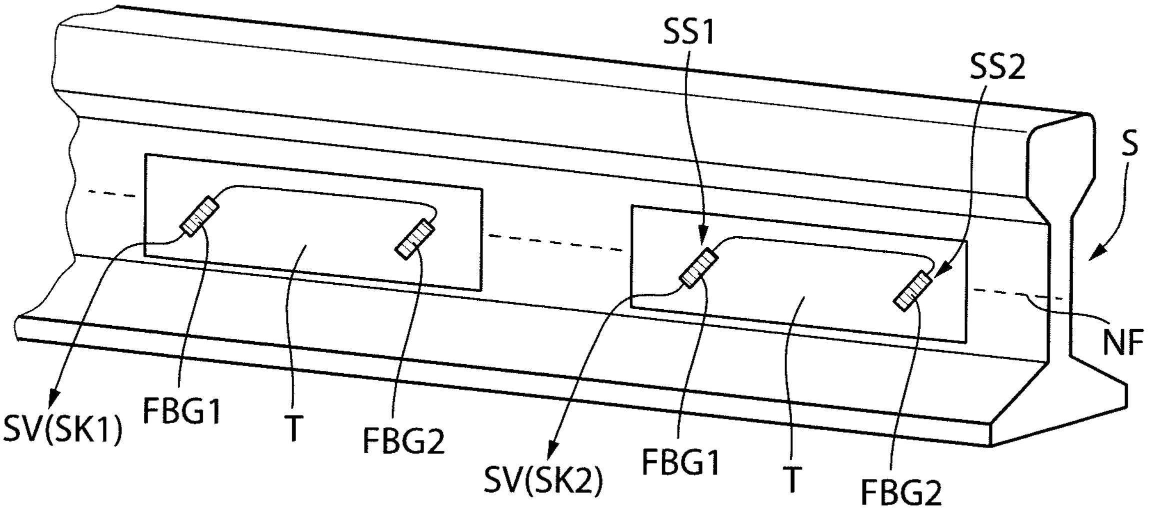

Fig. 13a

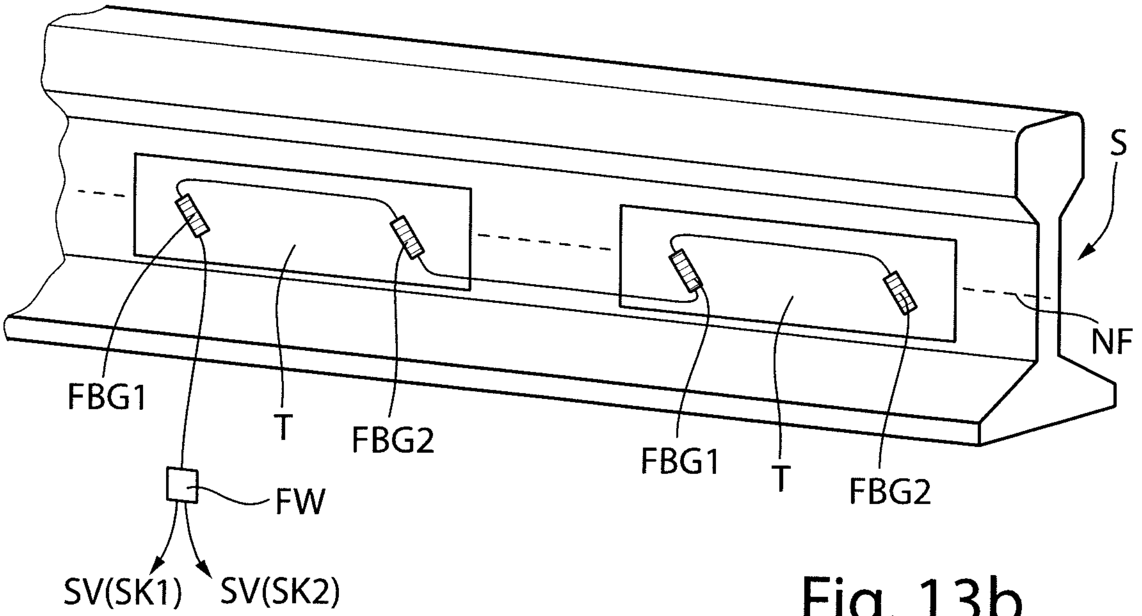

Fig. 13b

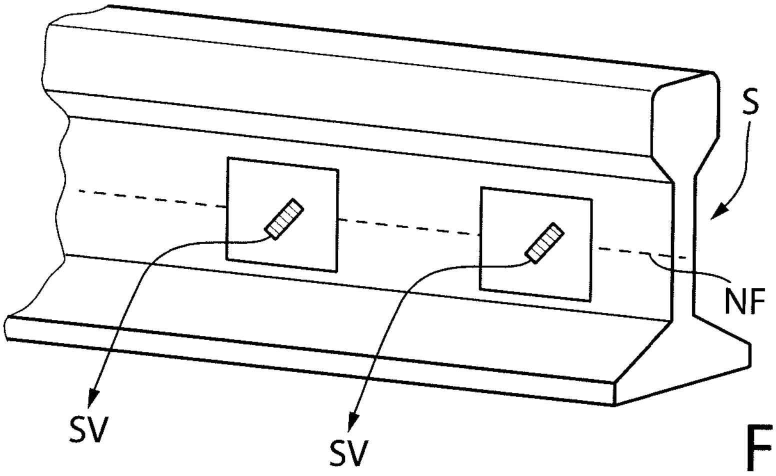

Fig. 13c

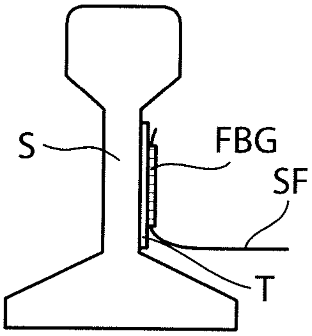

Fig. 14

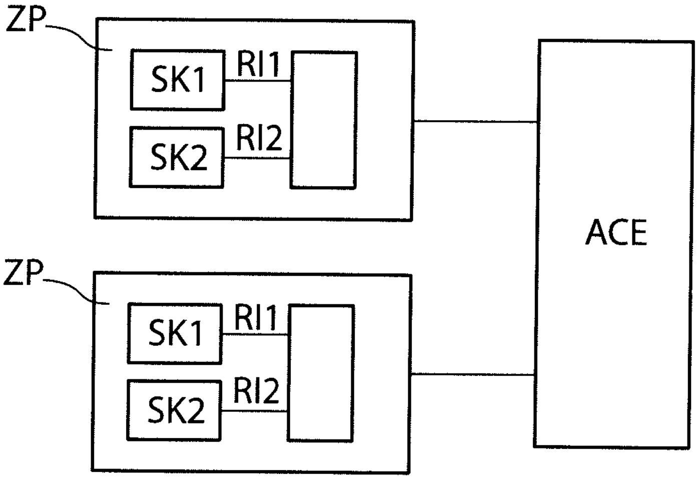

Fig. 15