

APPLICATION REPORT



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New measuring track curve in Wegberg-Wildenrath test and validation centre

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All measurement requirements of the track curve stated in DIN EN 14363 can be satisfied and more extensive measurements taken in the PCW.

A series of type tests is specified for the acceptance of running characteristics of railway vehicles. These are described in the DIN EN 14363 [1] standard. Evidence of operability using stationary testing is always required before running behaviour on the track can be tested.

- Wheel load scales: for measuring the static vertical wheel forces on a level track and a twisted track (twist test rig)
- Rotary / tilt table: for measuring the rotational resistance of bogies
- Tilting equipment: for recording the sway characteristics
- Measurement track curve: for measuring the lateral and vertical wheel forces in the track curve

Despite the PCW not having S-shaped curve test equipment, all important tests can be carried out. Testing for safety against derailment under longitudinal forces in S-shaped curves is only needed for certain freight wagon designs [2].

A level measuring track curve with three measurement points in each of its two measuring fields was commissioned at the PCW in 2001. The experiences gained with these test facilities with regard to the level of calibration work required and the limited amount of measurement data which can be recorded during each pass across the scales indicated significant room for improvement. Detailed

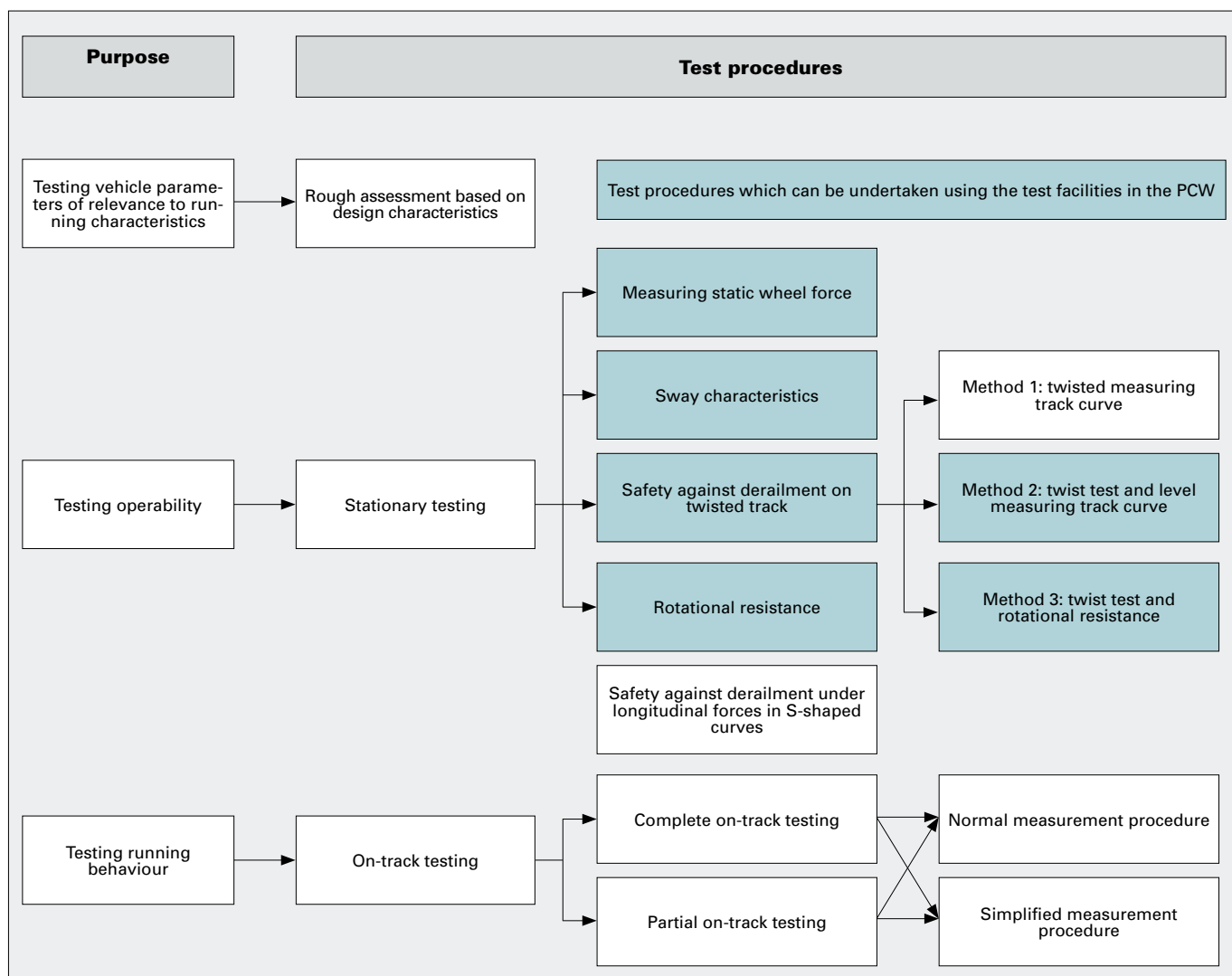


Fig. 1: Test procedures according to DIN EN 14363 and those procedures covered by test facilities in the PCW

investigations were then carried out with the Institute of Rail Vehicles and Materials Handling at RWTH Aachen. We were able to define the precise requirements of the new measuring technology and track structure as a result of these investigations.

Preliminary investigations

The preliminary investigations conducted at the Institute of Rail Vehicles and Materials Handling at RWTH Aachen under the supervision of Univ. Prof. Dr. Ing. T. Dellmann were initially intended to record signal characteristics from the existing application of strain gauges on the rail under load and under defined laboratory conditions (track mounting). Proposals for optimising the arrangement were also to be produced. The investigations concentrated on the following points:

- influencing measurements through the point at which force is introduced to the rail head
- influences of overlapping vertical, horizontal and longitudinal forces
- the influence on measurements by rail inclination (e.g. 1:40) and
- influence of track and rail position and stability, including elasticity

A test rig was built at the institute to produce the lab conditions. This involved equipping a piece of track with the same measuring technology as would be used on the existing measuring track curve and positioning this under a fixture for introducing load. The influence of track elasticity was therefore investigated by varying the position of the track unit (Fig.2).

The key finding of the preliminary investigations was that no significant improvements would be gained from modifying the measuring track curve by optimising the original strain gauge arrangement even if an elaborate mathematical correction method is added. The main reason for this is that the rail is not a suitable measurement unit. The investigation showed that with a justifiable amount of technical measurement and arithmetic effort no conclusion on the forces introduced can be reached with a satisfactory level of accuracy by distorting the rail alone in the event of overlapping vertical and horizontal loads, especially when the point at which load is introduced is not known (wheel/rail contact point). Consideration of other criteria such as remaining development work, prospects of success (risk assessment), estimated expenditure and the total amount of time before commissioning reinforced the decision that optimum implementation of the findings from the preliminary investigations can only take place by building a new measuring track curve.



Fig. 2: Track unit for preliminary investigations

The preliminary investigations did however also include comparisons of different measurement procedures, for example with regard to the level of measurement accuracy and reproducibility achievable, levels of calibration and development work, costs, independence from weather conditions and track position and stability. An appropriate measurement procedure with separate distortion units positioned under the rail was recommended on the basis of this comparison. Finally a measurement principle already available from Schenck Process GmbH for measuring the vertical wheel forces in a straight track was selected. Everyone agreed that with some straightforward adjustments this is able to satisfy the requirements of the new measuring track curve.

Requirements of the new measuring track curve

The measuring track curve must ensure a direct measurement of the forces acting between the wheel and rail. [1] describes two different test procedures for this. Procedure 2 "Testing on the twist test rig and level measuring track curve" was deliberately chosen for the measuring track curve in the PCW for the following reasons:

A rail vehicle's characteristics with regard to safety against derailment are greatly influenced:

- by the redistribution of wheel load by twisting the vehicle, and
- by the track guiding properties in the track curve, where redistribution of wheel load also takes place in the track curve. This redistribution occurs in a level track curve simply as a result of the track guiding (lateral) forces and the leverage forces acting on the wheel set.

APPLICATION REPORT

Only procedure 2 as detailed in [1] allows a distinction to be made between the reasons for the two possible forms of wheel load redistribution named. Once the test is complete, this allows the vehicle manufacturer to be provided with clear information as to the extent to which these two vehicle characteristics contribute to safety against derailment on twisted tracks and whether modifications to the torsional stiffness or track guiding characteristics may result in a need to increase safety against derailment.

In order to undertake these tests, if technically and economically feasible, the measuring track curve must be produced as a level measuring track curve such that overlapping vehicle twisting doesn't apply when travelling through the curve.

Deviations in rail height should be kept as low as possible in order to minimise wheel load redistribution due to vehicle twisting. The requirements of measuring tracks for category B and C vehicles according to DIN 27202 part 10 apply here.

The following values must not therefore be exceeded:

- ± 0.5 mm height deviation between the two rails in the track's lateral direction
- ± 0.5 mm over a reference distance of 30 m for each rail in the track's longitudinal direction

Since travel through the measuring track curve is a quasi-static test (travelling at max. 10 km/h), the length of the test zone according to [3] must be viewed as a reference distance of more than 30 m (max. vehicle length including overhangs) moving with the vehicle.

The main requirements can be derived from the standard requirements /1/:

- Track layout requirements – presence of a track curve with a curve radius of 150 m without transition curve, twisting and cant followed by a straight section; also without twisting and cant
- Rail profile – track gauge and state of maintenance must reflect the standard conditions of a typical track
- Test zones – these must be located at the start of the curve and in the middle of the curve
- Measuring points – at least three must be positioned in each test zone

The findings gained from the first measuring track curve in the PCW and the results of the preliminary investigations result in further requirements:

- Measurement uncertainty for the decisive criterion – the ratio of lateral to vertical wheel forces (Y/Q) should be less than 5%. The individual lateral and vertical wheel forces measurement parameters should therefore display correspondingly less measurement uncertainty
- Measurement accuracy – this should be independent of ambient temperatures
- Position where force is introduced to the rail – regardless of wheel/rail contact points and/or position of points of contact between rails and flange flank, it must be possible for the measurements to be taken with the level of accuracy required
- Y and Q forces – independent of the ratio between the acting Y and Q forces, it must be possible for the measurements to be taken with the level of accuracy required
- Bogie wheel bases – it must be possible for the wheel forces on every single wheel to be measured with the level of accuracy required even for short bogie wheel bases without this being influenced by the neighbouring wheels
- Wheel set loads – the facilities must be sized with sufficient reserves for the highest wheel set loads and

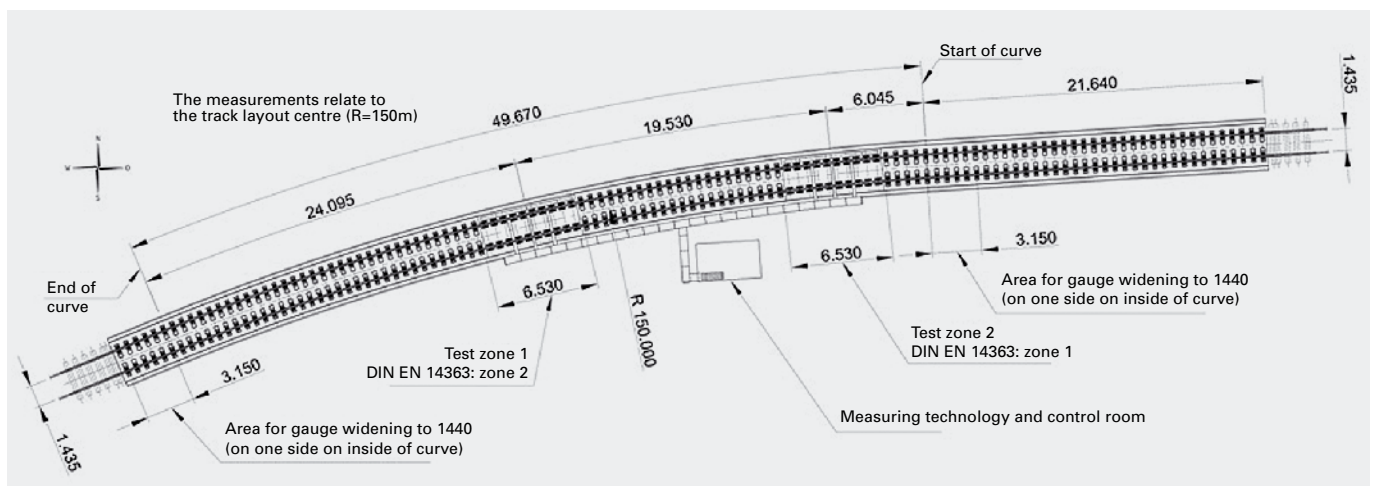


Fig. 3: Dimensions of measuring track curve

very high track guiding forces. On the basis of the max. static wheel set loads permitted in the PCW of 26 t and maximum conceivable wheel load redistribution due to high track guiding forces, the track and measuring sensors should be sized for vertical wheel forces of up to 250 kN and lateral forces of ± 180 kN

- Long-term stability – track and measuring technology must have a high long-term stability

Requirements of more extensive investigations:

- Continuity – it must be possible for the vertical and lateral wheel forces to be measured continually over the entire measurement range lengths (measurement fields)
- Scope for modification – modification to other rail inclinations (e.g. from 1:40 to 1:20 or to 1: ∞) must be possible
- Gauge widening – it must be possible for the influence of gauge widening to be measured in the track curve
- Track elasticity – it must be possible for the influence of track elasticity to be measured

As a rule, but also in particular through recognition of the test and validation centre as a test body accredited by the German Accreditation Council according to DIN EN ISO 17025, there are special requirements of the measuring track curves in relation to scope for calibration and traceability:

- Scope for calibration using calibration equipment – equipped with force measuring devices traceable to measurement standards
- Introduction of force – it must be possible for the vertical and lateral wheel forces to be introduced individually and as overlapping forces during the calibration process
- Confluence of force – when force is introduced via the calibration equipment, impermissible confluence of force must not arise either within the calibration equipment or above the track and
- Appraisal of measurement uncertainty – it must be possible for the measurement uncertainty to be appraised with sufficient accuracy within the entire measurement and calibration chain

Implementation

The measuring track curve was set up according to the requirements of DIN EN 14363 – with a curve radius of 150 m and two test zones. Test zone 2 is near the end of the curve such that when entering the curve the leading bogies have not yet fully rotated and that when exiting the curve the trailing bogies are rotating back. Test zone 1 on the other hand is positioned in the curve such that at least all the vehicle's running gears, which are adjacent to the running gear in this test zone, are also fully in the track curve. All of

the measuring track curve's key dimensions can be taken from Table 1.

A permanent railway was also implemented with the Rail-One Rheda 2000 system and the Vossloh 300 rail fastening system. Very robust laser-welded load cells made from stainless steel with a very high degree of protection and high long-term constancy were also used.

Mention should also be made of the EMC and overvoltage compatibility measures taken on all the measurement equipment to ensure unaltered and reproducible measurement results.

Vehicle parameter	Symbol	Long vehicle	Short vehicle
Typical vehicle		Double-decker coach	Freight wagon
Bogie wheel base in chassis	2a+	2,500 mm	1,800 mm
Distance between bogie pivots	2a*	20,000 mm	5,200 mm

Table 1: Vehicle parameters for defining position and length of measuring field

The position of the two measurement fields was defined such that at least the values specified in [1] can be adhered to. Data from especially long and also especially short vehicles which already exist or are to be tested in the future was investigated for this purpose in order to test as wide a range of vehicles as possible. The vehicle parameters bogie wheel base in chassis 2a+ and distance between bogie pivots 2a* were considered in particular.

As can be seen in Fig. 3, both test zones have a length of 6530 mm. Measurement data for several wheel sets in long bogies can then be measured at the same time over a sufficient measuring section.

Each measurement range provides a number of measurements for each wheel, both for lateral and vertical force. To this end the test zones are split into sub-sections which may only ever contain one single vehicle wheel. The rails themselves are not interrupted and therefore ensure smooth vehicle passage. The lateral and vertical forces acting in the sub-sections are measured quasi-continuously at a frequency of 1000 Hz. They are processed and output in the form of data records for further processing at a sampling rate of 200 Hz.

The distance between the start of the curve and the first measuring point is stipulated as > 3000 mm in [1]. The first

APPLICATION REPORT

measurements are recorded as of a distance of 2780 mm from the start of the curve. When evaluating according to the standard specification, the measurements of the first (or last) 220 mm are not taken into account.

The distance between the start of the curve and the position of the third measuring point in zone 1 (in the PCW corresponds to test zone 2) must according to [1] be less than the smallest distance between bogie pivots expected. Information relating to very small distances between bogie pivots can be found in [4], Annex D1 where a distance between bogie pivots of 5200 mm is stated. As a result at least 3 valid measurement data records should be recorded by this distance from the start of the curve so that the requirements of the standard can be satisfied for vehicles with this short distance between bogie pivots too. This criterion can also be reliably satisfied by the quasi-continuous recording of measurements. If evaluation of the measurement results is to be strictly limited to the measurements at individual measuring points according to the standard, this can of course be done by selecting corresponding data records from the quasi-continuous recording of measurements.

The minimum distance between test zone 1 and the start of the curve using the data from table 1 is 22 500 mm. For the benefit of greater test zone lengths, again here we defined a slightly earlier start at 22 310 mm.

The distance between the end of test zone 1 and the end of the curve is not specified in the standard. A value of 20 830 mm is reached for the measuring track curve in the PCW because of the 49 670 mm curve length. With this value, the longer vehicles are still fully within the track curve or at a

position where the track guiding forces correspond to those of passing through a curve.

The measuring track curve is not designed as a ballast track but as a “permanent railway” (Fig.4). An exact rail height can thereby also be ensured in the long term. When free of load, the measuring track quality is achieved over the entire curve length. An exact track position is also ensured in the long term in the lateral direction, as is compliance with the curve radius. The manufacturers, some of whom check at short intervals, can rely on stable rigidity figures.

In order to roughly imitate the elasticity of a ballast track, the rails are supported on the rail fastening elements using flexible interim plates. A vertical rigidity of the rail support of 22.5 kN/ mm is reached using the interim plates fitted at the moment. This value can however be changed by varying the interim plates. The measuring track curve is produced using UIC 60 rails. Its track gauge is 1440 mm and it has gauge widening of 5 mm. This value can also be altered by interchanging angular guide plates. Varying the base plates of the rail fastenings can also change the rail inclination. The standard rail inclination is 1:40.

Multi-component load cells are positioned under each rail support point for the recording of forces within the test zones (Fig.5).

Ten of these load cells are positioned in each test zone on the two rail webs. This means that a total of 40 multi-component load cells are used. They measure the lateral and vertical forces which are transferred from the wheel via the rails to the base of the railway.

Several shearing force sensors have also been pressed into holes in the rail web. These can be clearly seen in



Fig. 4: View of measuring track curve

East to west arrangement of test zones	
Start of curve	0.000m
Start of measuring sections in zone	22.780m
Centre of test zone	26.045m
End of measuring sections in zone	29.310m
Start of measuring sections in zone	122.310m
Centre of test zone	125.575m
End of measuring sections in zone	128.840m
End of curve	49.670m

Table 2: Main characteristics of test zones

Fig. 5 and are mainly used to detect the position of the wheels and therefore to assign the measurement signals of the 40 load cells to the vehicle's individual wheels. The measurement signals from the shearing force sensors are transferred to DC measurement amplifiers via a special measurement cable. These are located in a switch cabinet in the measuring technology and control room. Fig. 6 gives an idea of the scope of measuring technology installed.

The amplified measurement signals are supplied via A/D converter to the measurement data recording computer and evaluated using special software.

The quasi-continuous measurement of wheel forces on many wheels (even with very small bogie wheel bases) places very high requirements on the measuring technology and evaluation of measurement data. Added to this is the need for the rails to also be fitted in the measurement fields without interrupts and without deviations from the standard elasticity characteristics. When implementing the project, the supplier of the measuring track curve, Schenck Process GmbH, worked with the PCW to significantly extend the existing measurement principle to measure the vertical wheel forces in the straight track. One of the purposes of this was for the lateral forces acting horizontally to also be measured. This allows all the requirements of the new measuring track curve to be satisfied.

Since considerably more measurement data records are produced than are required in the standard (three data records) each time each test zone is passed, the measurement results can be substantiated with a high level of statistical certainty. Compared with the random measurements taken at the three measurement points per measurement field and rail used previously, when checking for safety against derailment, this is a crucial benefit.

Critical measurements can be analysed in more detail when evaluating the measurement data. This includes:

- the absolute maximum and minimum values,
- the effective length (track length) of particularly high and therefore critical values for the ratio between lateral and vertical wheel forces and
- average values over a specified track length

If all the wheels of one bogie are in one test zone, useful plausibility checks can be undertaken using the complete set of information for all wheel forces, such as total lateral forces and total vertical forces.

This provides another verification instrument alongside calibration for quickly checking the validity of measurement data.

The force patterns even also allow comparison with multi-unit simulations, which are currently the latest tools in designing a new vehicle in terms of travel properties. The measurements can be used to verify and also improve these.

Calibration and adjustment

Several measuring sensors under the rails of the measuring track curve and in the rail webs always act together and the wheel forces have to be calculated taking into account the overlap functions. Individual calibration of these measurement sensors on a lab test rig therefore offers no information about the forces acting between the wheel and rail in the measuring track curve.

When building the new measuring track curve, a calibration device was therefore also developed and obtained to allow the forces acting in the measuring track curve to be specifically applied. This must firstly ensure that the requirements relating to the independent introduction of force without distorting confluences of force are ensured with the level of measurement accuracy required and secondly it must make calibration as efficient as possible.



Fig. 5: View of test zone 1 and detail of shearing force sensors



Fig. 6: The inside of the switch cabinet in the measuring technology and control room with more than 160 DC measurement amplifiers and the computer containing A/D converters

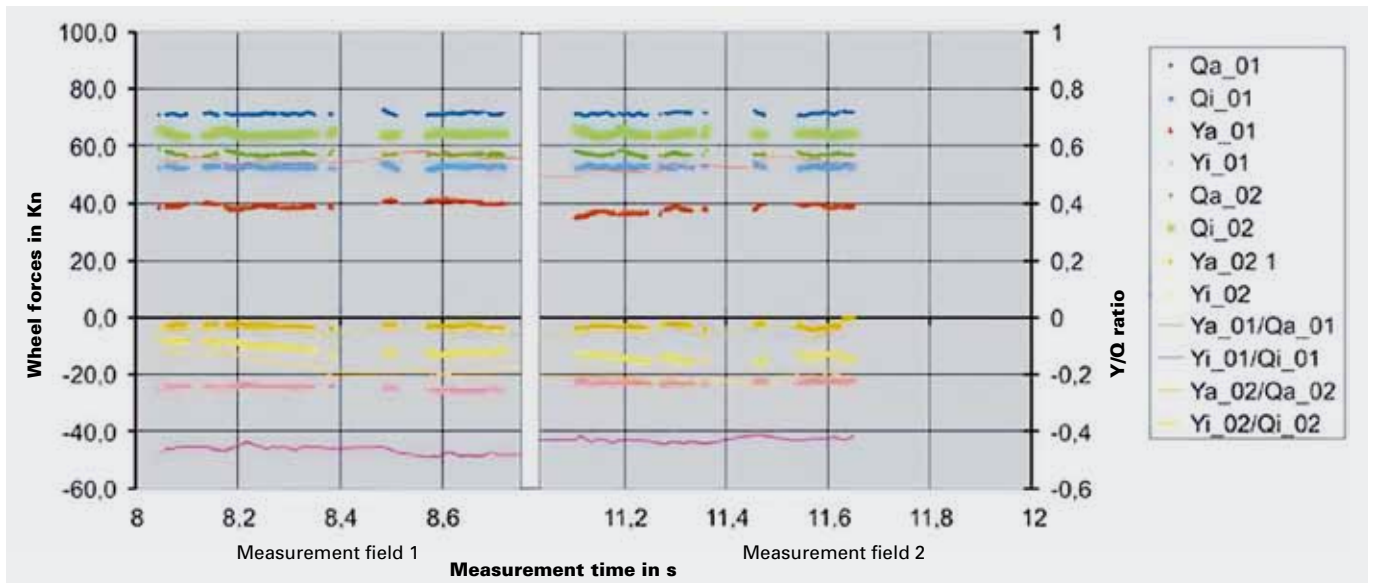


Fig. 7: Measurement data for one passage
Selection of measurement data for the times when 2 of the wheel sets of one bogie are in one of the two measurement fields at the same time

This calibration device is fitted in the centre (lengthwise) under a Smp flat car (Fig. 8). The flat car has a bogie centre distance of 9400 mm and a bogie wheel base of 2000 mm each.

The inner wheels are therefore 3700 mm away from the calibration device. At this distance forces which originate from the freight wagon's wheels are insignificant at the position to be calibrated. The flat car is first loaded with around 50 t to allow the vertical test forces to be applied to both rails.

The calibration device allows vertical test forces to be applied to both rails, up to a magnitude of 250 kN on each side. Horizontally-acting test forces of up to 180 kN to the outside of the track or 100 kN to the inside of the track are applied at the same time. The overlapping introduction of load is needed because all known multi-component measuring sensors have different levels of influence in the different load directions and when passing through the curve this overlap always occurs in an initially unknown ratio. When developing the measuring sensors, care was taken to ensure that this reciprocal influence is kept as low as possible. This was demonstrated accordingly in the supplier's test lab.

Since the track is not a rigid system and therefore distorts under load, the overlapping introduction of load must not result in twisting and associated disruptive forces. This would distort the calibration in an impermissible way. Great

emphasis was therefore placed on retaining the degrees of freedom needed for this when designing the calibration device. This was done by transferring the vertical forces via horizontal linear guides.

These linear guides also only have a very low known displacement resistance within their order of magnitude, even at high forces. In the event of extra horizontal force, the rails may therefore bend outwards or inwards without the friction applied by the vertical forces preventing this deformation between the point at which load is introduced and the rail and would result in distortion by the level of friction force. The linear guides can also be used to move the calibration device laterally under the flat car such that calibration is possible both in the full curve and in the start of the curve.

The point at which load is introduced for the test forces in the rail is designed such that this is done via a calotte at a precisely defined point in the rail's longitudinal direction. In the rail's lateral direction, load may be introduced at eight different positions on the rail head in the lateral direction and also on the rail head flanks. During calibration, the various wheel set positions which the wheel set can adopt from the existing gauge clearance can then be simulated. The level of independence from the point at which load is introduced can be determined at any time thanks to the option of introducing force at various points. Calibration first determines how accurately the forces measured by the measuring track curve match the reference forces measured in the calibration device. To

do this the measurement data for the calibration device is recorded in a file along with the measuring track curve measurements. The reference force sensors fitted in the calibration device can be disassembled with ease. In turn these can be easily calibrated traceable to force standards in the test lab.

The software for the measuring track curve can evaluate these differences by using the records for all or selected calibration measurements. If differences are found, the appropriate adjustment factors are calculated using the software.

These adjustment factors produce the best possible correlation between the forces measured by the measuring track curve and the calibration device. The calibration improves

the more calibration positions have been approached in a longitudinal direction.

New dimension for measurements

The new measuring track curve in the Wegberg-Wildenrath test and calibration centre is the first device of its kind to be able to determine the forces acting between the wheel and rail and to do so quasi-continuously and independently of measurement elements on the vehicle over two measurement sections of around 6.5 m in length. Designing the track as a "permanent railway" guarantees values which correspond to the standards normally required in terms of track elasticity values. Compared with the ballast track, a high long-term stability should however be expected. This railway structure also enables the elasticity values to be easily measured and therefore checked.



Fig. 8: Loaded Smp flat car with calibration device

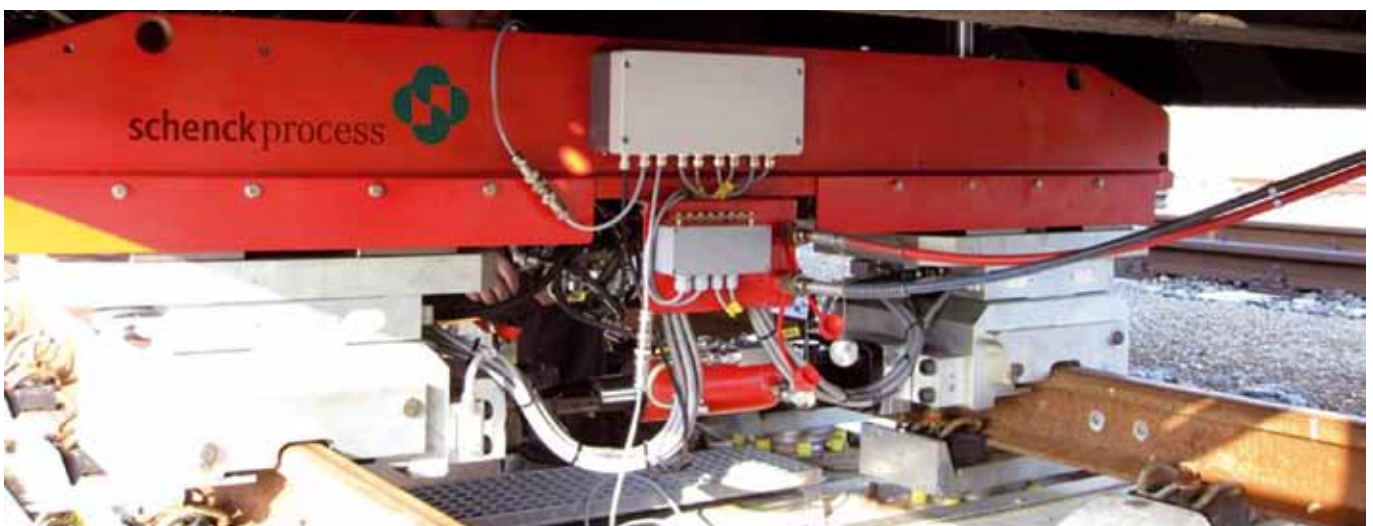


Fig. 9: Calibration device

APPLICATION REPORT

The new calibration device can be used to calibrate all parameters to be measured such that they are traceable to force standards, individually and in the event of overlapping introduction of vertical and horizontal force. The point at which load is introduced in the rail varies over the entire range of possible points of contact between the wheel and rail.

Measurement accuracy has now been demonstrated over wide ranges of potential load introduction points. Measurements which do not yet satisfy our requirements are excluded from the evaluation. Even the standard requirements relating to the number of valid measurements are clearly exceeded because when passing at 2 m/s and a sampling rate of 200 Hz there are around 300 valid sets of measurement data per wheel and test zone. It is expected that the measurement accuracy will again be increased by additional calibration measurements and ongoing optimisation of the evaluation software. Measurements have since been undertaken on the customer's behalf on two multiple

unit trains, one of which obtained its approval months ago and the other of which is currently in the approval phase.

In addition to the requirements of the standard, additional measurements can be recorded. The curve-passing behaviour of the vehicles to be tested and their characteristics in relation to safety against twist derailment can thereby be recorded.

Where the standard only envisages 3 points per measurement field for measuring the forces acting between the wheel and rail, the test equipment in PCW can offer more. The sensor arrangement allows a quasi-continuous measurement to be taken in each of the two fields of the lateral and vertical wheel forces of all the wheels of a train subject to testing.

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