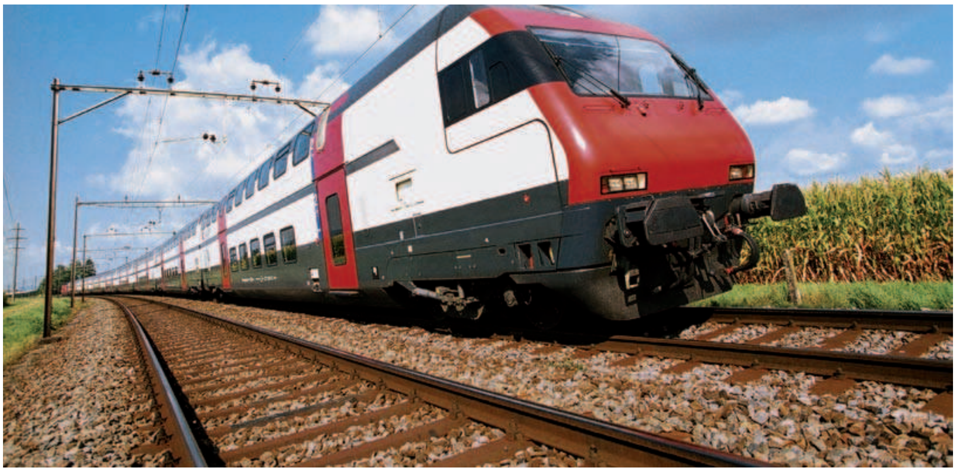
TRACK DEFECTS THE NEVER-ENDING STORY FOR VEHICLES

TODAY, EUROPEAN NORMS AND COMMON PRACTICES DEFINE, MEASURE AND MAINTAIN TRACK DEFECTS TO 'ACCEPTABLE' STANDARD LEVELS. THIS HELPS OBTAIN THE BEST PERFORMANCES OUT OF VEHICLES IN TERMS OF RUNNING STABILITY, RIDE COMFORT, NOISE AND VIBRATIONS TRANSMITTED TO STRUCTURAL COMPONENTS AND PASSENGERS. NEVERTHELESS SOME CRITICAL ISSUES ARE STILL NEGLECTED AND RISK UNWELCOME CONSEQUENCES WHEN SWITCHING ROUTES OR SERVICES.

Nothing is perfect and railway track is certainly no exception. For intrinsic reasons or as a result of the service, any track is subjected to, the original geometry after lay down changes in time depending on the amount of traffic. This is usually expressed in terms of Million Gross Tonnes (MGT). From a vehicle manufacturer's perspective, deviations from the nominal track geometry may impact the behaviour of rolling stock depending on several properties:

- the wavelength of the defect
- its amplitude, and
- direction (vertical/lateral)



This article explores the traditional architecture of a railway passenger car with a car body supported by bogies, although similar considerations are valid for freight wagons with two wheelsets. This architecture has several features designed to better respond to different track irregularities.

LONG WAVELENGTH DEFECTS

Long vertical defects, with a wavelength longer than three metres, are described according to the definition of 'longitudinal level' by standard EN 13848[1]. They are normally caused by ballast settlement or, typically, transitions from the plain line to different subgrade stiffness parts of a line, e.g. a bridge.

The passenger vehicle has two levels of suspension – primary and secondary – with the latter designed to offer good ride quality to passengers. The golden rule when designing secondary suspension is to reach a first, natural frequency of the carbody considered as a rigid body (the so-called 'vertical bouncing mode') close to 1.5Hz. This is the frequency of walking and is therefore extremely well tolerated by passengers.

Vehicle dynamics on longitudinal long wavelength defects are mostly dominated by movements of the carbody in the vertical plane. As a general rule, secondary suspensions, either with coil, air or rubber springs, should be damped in order to limit the amplitude at the resonance. Similarly, abnormal stresses or discomfort in the vertical plane are normally avoided by using extremely smooth vertical transitions (with a radius in the order of 20 to 30km).

Long lateral defects, with wavelength longer than three metres are also described according to the definition of 'alignment' by standard EN 13848[1]. Curves are much tighter than vertical transitions and designers must pay maximum attention here. In general, the lateral deviation from nominal track geometry can be described in statistical terms (e.g. see[2]) or with reference to the classes defined in the standards for the acceptance of running characteristics of railway vehicles[3].

As a result of the comfort issue described above, secondary suspensions are rather soft and result in possible problems in terms of '*souplesse*' (i.e. the rotation around the longitudinal axis of the vehicle when running at speeds higher or lower than the speed for which the centrifugal acceleration is fully compensated by track cant) and lateral displacements of the carbody. These two effects are contrasted by the use of 'anti-roll bars', i.e. an elastic system that only exhibits torsional stiffness, leaving vertical stiffness unchanged, and by the so-called 'active secondary suspension', i.e. typically a pneumatic system with cylinders centering the carbody. The first solution ensures passenger comfort by avoiding rotations increasing the acceleration felt by the passenger; the second solution avoids dynamic gauge problems while at the same time reducing the intervention of lateral bump stops that limit the lateral excursion of the carbody.

Lateral dynamics are certainly more complex and harder to tackle for vehicle designers, also because they involve a complex motion that alters the wheel-rail contact position, and hence the dynamics of the whole vehicle (carbody + bogies).

SHORT WAVELENGTH DEFECTS

These defects can be considered 'local' since they are typically shorter than the wheelbase of the bogie. Vertical deviations from the nominal longitudinal level may be caused by *rail joints* (insulated or not), *rail welds* or run on the *crossing panel* of a switch, or run on *local railhead defects* (wheel burns, squats, ballast prints). Lateral local defects are quite rare and can be provoked by a misalignment of rails after welding in a curve, or to local situations at transitions between plain line and bridges or level crossings. Generally speaking, local defects have a typical wavelength shorter than one metre.

Track gauge and *track twist*, the latter based on the definition of cross level, are described in the long

> **SHORT WAVELENGTH DEFECTS ARE MANAGED AT A BOGIE LEVEL – THE ASSEMBLY OF TWO WHEELSETS, FOUR GEAR BOXES, A BOGIE FRAME AND THE PRIMARY SUSPENSION CONNECTING THE AXLE BOXES TO THE BOGIE FRAME. THIS AREA IS BY FAR THE MOST CRITICAL TO SAFETY, SINCE FAILURE IN ANY OF THE ABOVE COMPONENTS MAY HAVE DRAMATIC CONSEQUENCES**

wavelength domain as nominal track geometry parameters. Local deviations from the prescribed values can introduce or trigger abnormal behaviour by the vehicle. Local track gauge deviations, for example, can trigger dynamic instability (hunting phenomena) while local twist irregularities can lead to a reduced safety coefficient against derailment, especially in tight curves. A noticeable exception to the apparently local nature of short wavelength defects is the phenomenon of *corrugation*. This is the vertical deviation of the railhead profile exhibiting a regular and long-lasting, quasi-sinusoidal shape for long distances, in the order of hundreds of metres. It typically affects the low rail of almost all metros and tram lines, although conventional railways encounter major problems with it for curve radius normally below 400 to 500 metres. Once started, corrugation, with a period of typically around 6 to 10cm, grows and leads to high stress levels for both vehicle and track components.

Short wavelength defects are managed at a bogie level – the assembly of two wheelsets, four gear boxes, a bogie frame and the primary suspension connecting the axle boxes to the bogie frame. This area is by far the most critical to safety, since failure in any of the above components may have dramatic consequences.
While designed to be as rigid as possible laterally, the wheelset/primary suspension assembly is designed to filter out high frequency components of the wheel-rail contact force in a vertical direction. The vertical displacement of the axle boxes is transformed into a force by the primary springs and thus transferred to the bogie frame. As for any single-degree-of-freedom system, resonances must be damped by either friction dampers (e.g. used in leaf springs or the Lenoir link on Y25 bogies) or viscous dampers (for all modern vehicles).
Vertical accelerations recorded at axle box level are of the highest levels in mechanical engineering. The extremely high contact stiffness of the Hertzian wheel-rail contact, in the order of 1GN/m, is responsible for peaks that can reach (in exceptional cases) a value of $500 m/s^2$[4]. This value, measured by accelerometer chains capable of reaching $1000 m/s^2$[1], is more than a hundred times greater than the acceleration levels recorded on the carbody (accelerometers are normally located on the coach floor). This explains why wheels, axles and axle boxes are heavy, and why maintenance and non-destructive testing is critical to guaranteeing the safety of rail.

WHY DO PROBLEMS STILL EXIST?

Underestimating short wavelength defects is rather common for several reasons. First of all patrolling of railway lines has disappeared for cost reasons and infrastructure diagnostics are now carried out by special measuring cars. These cars are rather expensive, require specially trained staff and are normally used very intensively, checking the status of several hundred kilometres of track per day. It is clear that local conditions that do not directly affect vehicle stability or safety are of relatively low importance. A bad weld, for example, is harmful to rail integrity, but until it is not broken the measuring train considers it one of the many localised defects found on such long runs. Similarly, extensive corrugation phenomena are almost not perceived at all on the vehicle except for noise, which has never been considered a safety issue. Nowadays locomotives have such good riding characteristics and driver cabs are so well designed that a driver will scarcely even notice the presence of localised defects.

Nevertheless not all vehicles have the 'simple' architecture described above. Locomotives, for example, have electric motors and gear boxes that can be affected by short wavelength defects.

In order to avoid an excessive load (the so-called 'unsprung masses') on the wheelset due to the motor/gearbox pair, the hollow shaft arrangement ('quill drive') was introduced many decades ago to directly connect the motor/gearbox unit to the bogie frame. Yet it is a complex and expensive arrangement that can be avoided in locomotives designed to run at low speeds (around 120 to 140km/h), using the older and simpler 'nose suspension' approach. Here the motor/gearbox unit is connected to the axle (with roller bearings) and at the other end is prevented from rotation by a support.

Although this simplified design functions perfectly on good track where the dynamic load at low speeds is low, it may experience

serious trouble on tracks with extensive corrugation. In this situation, in fact, even if axle box accelerations have levels compatible with the aforementioned values, they can excite resonance of the motor/gearbox unit on its suspension, leading to failures in bearings, gears and windings of the electric motor.
Another category of vehicles prone to failures are low-floor vehicles for urban or commuter trains. In these cases the primary suspension can even be missing – local defects are absorbed by using 'elastic wheels' as a surrogate primary suspension. The design of elastic wheels is further complicated because they must be laterally and torsionally stiff (to transmit the traction and braking torque, as well as guaranteeing the wheelset gauge) but still soft enough vertically to behave as primary suspension. Consequently complicated arrangements, used in the past, are only used today when it is absolutely necessary to omit conventional primary suspension.

DESIGN DATA AVAILABLE TO ROLLING STOCK MANUFACTURERS

Long wavelength defects are described extensively in a number of technical documents and European standards. Designers can also take into account the levels of irregularity of a line and verify the ability of the train they are working on to cope with real service conditions. These defects are regularly checked by infrastructure owners, can be simulated in running dynamics packages and are, moreover, clearly felt by drivers and train crews, who can immediately report any feelings of deviated conditions, e.g. arising from early buckling in hot weather. Lines can be categorised with respect to defect amplitudes[5]. This allows designers to estimate the life of a car by adding the damage introduced by each load case using the concept of damage tolerance or residual life.
Quite different is the situation for short wavelength defects[6]. These are distributed along networks, possibly concentrating around stations/yards where turnouts are present and maintenance is harder to carry out. In this case designers have no alternative but to consider the worst case scenario and overestimate the loads, then oversize the mechanical elements directly affected by the impacts at the wheel-rail contact.

STAKES AT PLAY

No European standard exists for the maximum forces/accelerations applied to a wheelset. No limits are defined for maximum corrugation allowed in service. With these boundary conditions (or, even better, in the absence of well-defined boundary conditions) life is tough for a manufacturer when structural problems occur during the service life of a vehicle. The customer, represented by an operator with a typically low engineering background, quite simply expects the train it has purchased to give value for money and run efficiently.

On the other hand, the infrastructure owner is in practice not obliged to maintain the track local defects within any specified value. Views commonly expressed are, "many other trains run on these tracks and none of them had any trouble", "in the tender it was specified that the train had to be compatible with this infrastructure" and "you had the chance to visit the lines as many times as you wanted before starting to design the vehicle".

As the number of rolling stock manufacturers is quite low, generally because of the need to keep development and production costs to a minimum, vehicles tend to be scattered across Europe. It does happen, nevertheless, that a vehicle that runs perfectly in one country or on one line suddenly suffers problems when operated elsewhere. Trouble-shooting can be difficult and also lead to 'strange' decisions like withdrawing a fleet, changing all bogies/gear boxes/wheelsets or taking legal action.

Certainly operating conditions (or 'mission profiles') need to be more clearly defined, together, wherever possible, with a statistical description of the network where the train is to operate. Measuring systems and analysis of short wavelength defects have yet to be defined – and it looks unlikely in the near future. So designers are obliged to rely on experience and negotiate any aspects with their customers to help them avoid errors.

Personally I have faced these troubled situations several times in my professional life. In some cases it was really discouraging to realise that despite the availability of off-the-shelf, sophisticated equipment and analysis techniques, this was countered by complete ignorance of the basic phenomena of wheel-rail contact and vehicle dynamic behaviour. As both a university professor and consultant I can only hope that teaching and educating technicians about wheel-rail contact problems will help reduce them. It is only through a common and agreed path that many problems affecting our vehicles today can be avoided in the future■

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