Innovation in wheelsets

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Abstract: Wheelsets are a safety-critical component of the railway industry. It is therefore not surprising that regulations and standards in this sector are particularly stringent in order to ensure an always acceptable level of safety. The European Legislation on railways is based on the Technical Specifications for Interoperability (TSIs) that are supported by the EN standards; these prescribe tight specifications limiting the freedom of the designer. Nevertheless, there are anyway two ways to introduce modifications in a railway system: either using the EU Regulation 402/2013 ("common safety method") showing that the modification has no impact on safety or using the "Innovative solutions" described e.g. in Art. 10 of 2014 LOC & PAS TSI 1302/2014/EU. An overview of the innovations in the wheelset sector is given with the relevant discussion on standardization and on market implications, discussing wheelset architecture and its integration in the vehicle.

Keywords: wheelset; innovation; standardization; market analysis; safety

1 Introduction

As defined in Ellis' British Railway Engineering Encyclopaedia, a wheelset is made of *two rail wheels mounted on their joining axle*. This architecture still applies today also for independently rotating wheels (IRW) where the "physical" rotating axle is replaced by a so-called *axlebridge*. Apparently there is small room for innovation in the wheelset sector, which contrasts with the large number of papers published on the subject and even more with the existence of conferences such as the *International Wheelset Conference* (IWC). This paper looks at innovation from a larger point of view, analyzing the history of wheelsets, looking at the present and depicting scenarios for the future taking into account the specific situation in Europe where laws and regulations impose strict limits to R&D in this sector.

2 Different perspectives on wheelsets

2.1 Designing a wheelset

Today the designer of a wheelset has to fulfil a number of requirements dictated by standards. This is, by far, the most critical point about innovation in wheelset sector, such as someone defines wheelsets as "a commodity" in the sense that wheelsets may be purchased from any supplier complying with the regulations and not on the basis of technical considerations or advantages.

The practical design starts from the definition of the loads acting on the wheelsets and on the chosen architecture, that falls in a very limited number of typologies for trailed wheelset (outboard bearings, inboard bearings, IRW). For driving wheelsets the actual design depends on a number of factors (type and position of the motor, details of the transmission, presence of a quill) although in its basic elements the wheelset remains unaffected.

Design is the phase where innovation has to be introduced to have a fallout effect on all other phases. The larger part of this paper is devoted to the analysis of this phase.

2.2 Manufacturing a wheelset

Modern wheelsets are produced with the most up-to-date technologies and resources. As an example, casted wheels / forged wheels production ratio continuously changed since the beginning of the railway era as well as the production of wheelset from ingots or continuous casting.

Although of the highest interest to win the market battle, innovation is typically not involved in *architectural* development of wheelsets. Technology is in fact rather general, and casting, forging, milling, machining and so on are general *tools* that are used to manufacture any mechanical component.

2.3 Checking a new wheelset

As long as safety is involved, the most accurate checks at the end of manufacturing it are of paramount importance.

The most interesting field is for sure that of Non-Destructive Testing (NDT), which by itself is a fundamental sector in the whole manufacturing industry. It is not surprising that wheelset manufacturers invested considerable resources to set up automated NDT lines in order to reduce as much as possible the inevitable uncertainty associated to NDT checks performed by humans. Innovation in this sector is therefore largely related to automation, as long as no new methods were developed specifically for railways but only the well known general NDT methods (UT, MT, RT, VT, etc.) are adapted and applied to wheelset components check.

2.4 Operating a wheelset

Generally speaking, with the word *operations* or *exploitation* the total life of the wheelset is intended.

The responsibility of the operation of a wheelset is in charge of the railway enterprise. The wheelset manufacturer' responsibility is in fact limited to the fulfilment (compliance) of the requirements listed in the tender and / or in the relevant standards. Historically, once the manufacturer delivered the vehicle, checks and maintenance have been performed by national railway administrations. This scenario changed since vehicle manufacturers offered not only the rolling stock but also the maintenance for a rather large time period after delivery (contracts including with 30 years of maintenance are nowadays rather common).

Typical routine (first level) maintenance operations on wheelsets are about inspections to check the conditions of the various components (wheels profile, axleboxes heating, brake components wear, etc), while overhaul (second level) maintenance involves a large set of operations (wheel changing, axle rectification, bearings check, etc.) with the aim of sending the wheelset back to service in an "as new" condition.

NDT is fundamental also in these phases to decide whether to keep or to scrap a certain component. NDT technologies and timing / inspection intervals together with advanced damaging models are an important research sector for wheelsets.

3 Analysis of the papers given at the IWC

The author has recently given an opening lecture [1] at the Third International Conference on Railway Technology (Cagliari, Italy, 5-8.4.2016). Although the reader is referred to that paper for a complete analysis on R&D in this sector, it is nevertheless interesting to report here about the analysis performed on the proceedings of the past editions of IWC. The reasons why the IWC proceedings were chosen (and not others) is trivial in this context and does not need to be explained here.

To restrict the field of the analysis, but considering in any case that the railway sector is rather conservative and that developments need normally over ten years to become widely spread and adopted, the proceedings of the last five editions were reviewed:

- 13th IWC, Rome, Italy, 17-21 September 2001;
- 14th IWC, Orlando, FL, USA, 17-21 October 2004;
- 15th IWC, Prague, Czech Republic, 23-27 September 2007;
- 16th IWC, Cape Town, South Africa, 14-19 March 2010;
- 17th IWC, Kiev, Ukraine, 22-27 September 2013.

Considering the 3 years interval between conferences, it may be said that this analysis covers the last 15 years of industrial development in the wheelset field.

Papers were categorized according to their title. Where the attribution was not straightforward, e.g. with papers such as "Assessment of Crack Initiation and Propagation from Press Fits of Railway Axles" that could possibly fit into two or more categories, the full papers were analyzed and a final decision was taken. As with any decision process, if repeated by other people it could lead to slightly different results. It is nevertheless believed that the results would substantially be the same.

The results of this analysis are shown in Table 1. The following conclusions can be drawn:

- the number of presented papers is decreasing. This may reflect a tendency of the world economy after the 2008 crisis (66 papers in 2007 and only 48 in 2010, with a minimum of 37 in 2013);
- fatigue / fracture and NDT are the only two topics which are consistently the preferred subjects for R&D with a total number over 10%. Materials, life & cost and Production / Manufacturing are over 7%, identifying how economic indicators are important in industry papers;
- at the last conference the papers on fatigue / fracture are 30% of the total;
- some categories tend to fade away. It should not be forgotten that other scientific (International Workshop on Railway Noise – IWRN, Contact Mechanics and Wear of Rail/Wheel Systems – CM, International Association of Vehicle System Dynamics – IAVSD) and railway (World Congress on Railway Research – WCRR, International Conference on Railway Technology – ICRT, EuroBrake, etc.) conferences may look more attractive to some authors who may decide to publish the results of their activities elsewhere;
- categorized papers were (arbitrarily) grouped in those with more and those with less than 4% of total papers presented. Group 1 (≥ 4%) counts 76% of the total number of papers, Group 2 (< 4%) counts 20% of the total number of papers;
- a limited number of papers (10, around 3% of the total) that doesn't fit in any category (such as papers on rails or on track conditions analysis) is considered only for completeness;
- the last line of the table separately indicates how many papers are focused on axles. It can be observed that the axle is by far the most important component of the wheelset, attracting 17% of the total number of papers given to the 5 considered conferences, and even 32% of the last edition. This may also be the consequence of the well known serious accidents due to axle failures.

Table 1. Analysis of the papers given at 13th-17th IWC, sorted in decreasing order of percentage for all editions. Papers on all subjects about axles are also reported at the end of the table.

Code	Conference number	IWC 13	IWC 14	IWC 15	IWC 16	IWC 17		All editions		Group 1	Group 2
	Total # of papers	72	67	66	48	37	%	290	%		
Code	Description										
FAT	Fatigue and fracture	6	10	11	5	11	30%	43	15%		
NDT	NDT	6	10	10	8	1	3%	35	12%		
M	Materials	5	6	5	3	5	14%	24	8%		
LC	Life & Cost	8	2	2	5	5	14%	22	8%		
P/M	Production / Manufacturing	7	2	7	2	1	3%	19	7%		
D	Design	2	6	3	4	1	3%	16	6%	221	76%
N	Noise	2	3	4	4	1	3%	14	5%		
RCF	RCF	2	5	3	3	0	0%	13	4%		
L	Loads	3	3	4	1	2	5%	13	4%		
FIT	Press-fit	0	2	4	3	2	5%	11	4%		
BEA	Bearings	3	4	2	2	0	0%	11	4%		
R	Residual stresses	2	1	4	0	2	5%	9	3%		
B	Braking	3	2	1	2	0	0%	8	3%		
DYN	Dynamics	7	1	0	0	0	0%	8	3%		
W	Wear	1	4	0	1	0	0%	6	2%		
TFAT	Thermal Fatigue	1	0	0	2	2	5%	5	2%		
WF	Wheel flats	2	1	2	0	0	0%	5	2%	59	20%
MON	Monitoring	3	1	0	0	1	3%	5	2%		
C	Corrosion	0	1	2	0	1	3%	4	1%		
PROF	Wheel profile	2	1	0	1	0	0%	4	1%		
S	Return from service	0	0	0	1	1	3%	2	1%		
ADH	Adhesion	1	0	1	0	0	0%	2	1%		
DISC	Brake discs	0	1	0	0	0	0%	1	0%		
O	Other	6	1	1	1	1	3%	10	3%	10	3%
(A)	Papers about axles	3	7	16	10	12	32%	48	17%		

4 European Standardization on wheelsets

4.1 Introduction

The aim of this paragraph is to briefly depict the certification process of wheelsets in Europe. It is not intended as a reference to thoroughly analyze the process, as this is the job of Notified Bodies (No.Bo.).

4.2 European Legislation

For the purposes of this paper, it will be sufficient to consider the latest version of the 2014 LOC & PAS TSI 1302/2014/EU [2] on the rolling stock subsystem. This Technical Specification supports the Directive 2008/57/EC on the interoperability of the rail system within the European community.

Within this TSI, wheels are defined at point 5.3.4 as *interoperability constituents* as they interface with other subsystems and "*upon which the interoperability of the rail system depends directly or indirectly*". The wheel can obtain a specific certificate as an IC (Interoperability Constituent) when geometrical characteristics, mechanical characteristics and thermo mechanical characteristics (where applicable) are assessed for an "area of use".

Wheelsets in their entirety are described at point 4.2.3.5.2 and "*are defined to include main parts ensuring the mechanical interface with the track (wheels and connecting elements: e.g. transverse axle, independent wheel axle) and accessories parts (axle bearings, axle boxes, gearboxes and brake discs)*". They are subjected to loads described at point 4.2.2.10.

As long as their behaviour has a direct impact on safety, the wheelset and its various components are described separately:

- mechanical behaviour of wheelset: 6.2.3.7
- mechanical behaviour of axles: 6.2.3.7
- mechanical behaviour of axle boxes: 6.2.3.7
- mechanical behaviour of wheels: 6.1.3.1

Annex H indicates which characteristics has to be assessed for wheelsets in terms of "Design Review" and "Type Test" for the design and development case and if "Routine Tests" must be performed during the production phase.

4.3 European standards

European standards are drafted and released by the European Committee for Standardization (CEN). Within the CEN there are numerous Technical Committees (TC), each structured in Sub-Committees (SC) if needed and then is Working Groups (WG).

Wheelsets are standardized by CEN/TC 256/SC 02/WG 11, i.e. Technical Committee 256 ("Railway Applications"), Sub-Committee 02 ("Rolling Stock Products"), WG 11 ("Wheelsets"). The current convenor is Mr. Pineau from SNCF and the Technical Secretariat is held by the Franch NSB (AFNOR). Standards already published are listed in Table 2 while standards in development or under approval are listed in Table 3.

Table 2. Standards published by CEN/TC256/SC02/WG11

Reference	*Date*	*Title*
EN 13979-1:2003 +A2:2011	2011-03-16	Monobloc wheels - Technical approval procedure - Part 1: Forged and rolled wheels
EN 13260:2009 +A1:2010	2010-10-20	Wheelsets - Product requirements
EN 13261:2009 +A1:2010	2010-10-20	Axles - Product requirements
EN 13715:2006 +A1:2010	2010-10-20	Wheels - Tread profile
EN 13262:2004 +A2:2011	2011-03-16	Wheels - Product requirements
EN 13103:2009 +A2:2012	2012-07-25	Non-powered axles - Design method
EN 13104:2009 +A2:2012	2012-10-31	Powered axles - Design method
EN 15313:2016	2016-04-13	In-service wheelset operation requirements - In-service and off-vehicle wheelset maintenance
CEN/TS 13979-2:2011	2011-09-14	Monobloc wheels - Technical approval procedure - Part 2: Cast wheels
CEN/TS 15718:2011	2011-09-14	Product requirements for cast wheels

Table 3. Work programme of CEN/TC256/SC02/WG11

Reference	*Date*	*Title*
prEN 13103-1 (WI=00256637)	Under Approval	Railway applications - Wheelsets and bogies - Part 1: Design guide for axles with external journals
prEN 13261 rev (WI=00256810)	Under Drafting	Railway applications - Wheelsets and bogies - Axles - Product requirements
prEN 13979-1 rev (WI=00256809)	Under Drafting	Railway applications - Wheelsets and bogies - Monobloc wheels - Technical approval procedure - Part 1: Forged and rolled wheels
prEN 16910 (WI=00256643)	Under Approval	Railway applications - Rolling stock - Requirements for non-destructive testing on running gear in railway maintenance

There are some interesting things to note:

- cast wheels never reached the "full norm" status as the CEN/TS 13979-2:2011 is emitted as a Technical Standard;
- the original EN 13103 is renamed as EN 13103-1 to deal with external journal wheelsets only (see below)
- only 7 years after the Viareggio accident an European standard on NDT on running gear in railway maintenance is going to be emitted (previously there were no common standards on this subject).

4. 4 The "Innovative solutions" opportunity

The word "innovation" was not even present in TSI HS RST 2002 (rolling stock subsystem of the trans-European high-speed rail system - 2002/735/EC).

The concept was introduced in the TSI HS RST 2008 ('rolling stock' sub-system of the trans-European high-speed rail system - 2008/232/CE) that in the introduction says:

"(14) The TSI is based on best available expert knowledge at the time of preparation of the relevant draft. To continue to encourage innovation and to take into account the experience acquired, the attached TSI should be subject to periodic revision.

(15) This TSI allows for innovative solutions. Where these are proposed the manufacturer or the contracting entity shall state the deviation from the relevant section of the TSI. The European Rail Agency will finalise the appropriate functional and interface specifications of the solution and develop the assessment methods."

At point 4.1 there is written: "*The functional and technical specifications of the subsystem and its interfaces, described in sections 4.2 and 4.3, shall not impose the use of specific technologies or technical solutions, except where this is strictly necessary for the interoperability of the trans-European High Speed rail network. Innovative solutions, which do not fulfill the requirements, specified in this TSI and/or which are not assessable as stated in this TSI require new specifications and/or new assessment methods. In order to allow technological innovation, these specifications and assessment methods shall be developed by the process described in clauses 6.1.4 and 6.2.3.*"

At point 6.1.4 there is written: "*If an innovative solution is proposed for an interoperability constituent, as defined in section 5.2, the manufacturer or his authorised representative established within the Community shall state the deviations from the relevant clause of this TSI and submit them to the European Railway Agency (ERA). The ERA shall produce and finalise the appropriate functional and interface specifications for the constituents and develop the assessment methods.*

The appropriate functional and interface specifications and the assessment methods so produced shall be incorporated in the TSI by the revision process.

After entry into force of a decision of the Commission, taken in accordance with Article 21(2) of Directive96/48/EC, as modified by Directive 2004/50/EC, the innovative solution is permitted to be used before being incorporated into a TSI."

After the so-called "recast" process, the Conventional Rail (CR) TSIs and the High Speed (HS) TSIs originated the TSI [2]. The theme of innovation is still present. At point 4 of the introduction it says "*In order to follow technological evolution and encourage modernisation, innovative solutions should be promoted and their implementation should, under certain conditions, be allowed. Where an innovative solution is proposed, the manufacturer or his authorised representative should state how they deviate from or how they complement to the relevant section of the TSI, and the innovative solution should be assessed by the Commission. If this assessment is positive, the Agency should define the appropriate functional and interface specifications of the innovative solution and develop the relevant assessment methods.*"

The full article 10 of [2] is dedicated to the innovative solutions process. The scope was broadened as now "*Innovative solutions may be related to the rolling stock subsystem, its parts and its interoperability constituents*". References to this article are found many times within the TSI; about wheels seen as an IC, par. 6.1.3.1.8 states that "*In case of innovative design for which the manufacturer has no sufficient return of experience, the wheel should be subject to an assessment of suitability for use (module CV; see also clause 6.1.6).*"

4. 5 An application of "Innovative solutions"

To the author's knowledge, in only one case the innovative solutions approach was applied.

The applicants (Siemens and Bombardier) asked the European Commission to get an opinion from the European Railway Agency [3] about the use of inboard bearings wheelsets for the ICx trains (now ICE4) for Deutsche Bahn. Siemens is the manufacturer of the trains while Bombardier supplies the trailer bogies.

The novelty of the solution lies in the fact that the EN standard for wheelsets valid at that time (EN 13103:2009) defines the stress calculation method "*for axles with outside axle journals*".

In the application reference was made to TSI CR Loc&Pas as the [2] was still under development at that time. As "*it is permitted to use other standards where the EN standards do not cover the proposed technical solution*", the applicants referred to the BS 8535 standard [4].

After having analyzed the application, the Agency advised the Commission to accept the proposal for the innovative solution. The role of the appointed Notified Body was nevertheless not played down, as the EC conformity assessment was requested in any case.

It is known in the railway technology field that inboard bearings wheelsets were calculated, manufactured and used in revenue service since the very beginning of the railway era. Nearly all steam locomotives, for example, were equipped with such kind of wheelsets.

It can be concluded that the word "innovation", to the European authorities, means "something that is not (yet) described in the regulatory frame, i.e. in the EN standards supporting the TSIs", regardless of the fact that that specific solution has been regularly used for more than a century.

In the author's opinion this contrasts with the definition of innovation (see e.g. [5]), i.e. either "*a new idea, device, or method*" or "*the act or process of introducing new ideas, devices, or methods*". In the case of inboard bearings wheelsets there is nothing really new.

5. Regulations 402/2013 on common safety methods for risk assessment

The regulation [6] repealed the former EC 352/2009 regulation. It is interesting in this context because the evaluation of the impact of a generic modification on safety is obviously applicable to wheelsets.

If the proposed modification is considered "*not significant*" (see Art. 2(2)(b)) on the basis of a set of well defined criteria (see Art. 4(2)(a) to (f)), "*keeping adequate documentation to justify the decision shall be sufficient*". The assessment has to be performed by the proposer under his responsibility without further evaluations, acting as the owner of a Safety Certificate with an approved Safety Management System.

In this field there are several devices / solutions that apply to wheelset. For example, nearly all the devices used on wheel web or rim to reduce vibrations and therefore noise (such as damping layer treatments or tuned absorbers) may theoretically introduce a higher risk (e.g. of flying parts detaching from the rail). Similarly, axle treatments (thick paint layers) applied to prevent damages from flying ballast may detach. The risk analysis process conducted on these "minor" modifications must lead in practice always to the conclusion that the final risk level is equal or lower than the original one, otherwise that modification would become practically unusable.

The author believes that the correct application of [6] may be a serious challenge in case of *really* innovative solutions. In case no EN standard exists and the risk assessment leads to a higher level of risk, the process could require to draft a new EN standard and then the European Commission and the ERA should take a decision and eventually incorporate the innovative solution in the next TSI revision. This process may take decades.

6. Some examples of "innovative wheelsets"

6.1 Performance vs. detailed standards

It should first of all distinguished between the fundamentally different types of technical EN standards. Some of them are totally binding while others leave more freedom to the designer.

The first example we consider is the case of bogie frame calculation. The relevant EN standard [7] describes how the loads on the bogie frame must be calculated on the basis of the axleload and of the mass of the carbody. The bogie frame designed according to these requirements must be subjected to full-scale fatigue tests that ultimately validate the solution. It is interesting to observe that *no details on the material are given*, leaving to the designer the highest flexibility. Theoretically a bogie frame could be made of welded steel profiles and sheets or a steel casting (the most common options) or even of aluminium, composite materials, etc.

Similarly, bearings are accepted for service upon the positive completion of the procedures for design (EN 12080), greases (EN 12081) and full-scale performance testing (EN 12082). Also in this case the designer has a rather large flexibility descending from the fact that the last word about a potentially innovative bearing is given by the performance testing. New designs are not prevented by the use of this set of standards and this explains the continuous improvement in bearings observed in the last decades.

Braking systems are a complex subject and the discussion on their development goes beyond the limits of this paper. Tread braking implementation reduced considerably for passenger rolling stock, being today applied only to some EMU typically with sinter or composite brake blocks, and is used therefore mainly on freight wagons. Brake discs became standard, first mounted on axles and more recently directly on wheel web. To the wheelset designer, the brake system manufacturer supplies the thermal and mechanical loads needed for wheel calculation. In any case, also braking systems are specified in terms of performance and not on *exact* specification of the single component / subsystem (brake unit, disc, etc.), so development in possible with the limits described above.

Axles and wheels do not have the same freedom. The set of relevant EN standards (see Table 2) specifies both steel chemical composition and thermal treatments. As a result, the vast majority (nearly all) of wheels in Europe are produced in ER7 and ER8 steel grades. Paper [8], although published 10 years ago, still gives a reliable of picture of the ongoing situation. Similarly, axles are nowadays nearly produced only in A1N/A1T/A4T steel grades.

The entry into force of TSIs in 2002 has changed the role of EN standards. As known, the application of a standard is voluntary and forms part of the agreement between the supplier and the customers. The fact the EN standards are explicitly mentioned in the TSIs (that are laws for all European citizens) raised their level to that of a law.

This means that nobody can operate an interoperable train that does not satisfy EN standards. As an example of the consequences of this situation, in the aforementioned paper [1] the author described the case of Italian hollow axles made of 30NiCrMoV12 that were introduced more than 20 years ago and that have accumulated hundreds of millions kilometre without any accident or trouble of any kind under the high speed fleet of Trenitalia SpA. Regardless of the fact that this component is lightweight, highly efficient and thoroughly inspectable by NDT, that steel was never introduced in the relevant standard on axles, and this prevents its use on existing and future interoperable trains.

This opens a set considerations that lie outside the scope of this paper on the standardization process that is based on the voluntary participation of representatives from EU industry and railway undertakings. Lobbying is obvious and may lead to this kind of technically incomprehensible situations.

6.2 Selection of wheelset innovative solutions

A huge number of patents on railway wheels and axles can be found. Although interesting from a scientific point of view, they are of poor interest to the technical community which is interested to practical results.

Three cases were selected, one coming from industry, one from the technical centre of a major railway administration and the last one from a project funded by the European Union. A further four case is introduced to depict how running dynamics of a vehicle can be improved by the use of innovative wheelsets.

The first example is the so-called *Springy Wheel* developed internally by the Swiss company Sulzer. The aim of the innovative solution was to introduce a radial flexibility of the tyre w.r.t. the axle such that the primary suspension was not necessary anymore. This solution, widely used in light rail and in the past also in heavy rail with rubber components, has the peculiarity that the wheel tire is connected to the hub with a set of "S-shaped" steel springs bolted at their ends. The design was bought near the end of the '90s by Lucchini Sidermeccanica (now LucchiniRS) and was tested on the roller rig available at the company site. The concept was particularly interesting for several reasons: it would have reduced the unsprung masses with the longest operating life (no aging from rubber components) and possibly with lower emitted noise. Despite all these potentials, the project was abandoned, mainly in the aftermath of the Eschede accident in 1998. Some views of the solution are shown in Figure 1.

The second example is the application of Austempered Ductile Iron (ADI) for wheel manufacturing. The use of such alloy and treatment to produce wheels was known already in the early '90s (see the paper from K. Jokipi cited in the references of [9]) but was further investigated by Deutsche Bahn technical centre in Germany in the early 2000's. There were several potentially interesting features in the use of these material, whose wear and damage properties are rather different from the carbon steels normally used for monobloc wheels and tires. Nevertheless, "*after the positive test rig results, trials were planned… however… the wheel manufactured for this purpose showed unpermitted indications in the wheel* *tread and web so that the use of these wheels in service was abandoned*" [8].

Figure 1.The "springy wheel" developed by Sulzer in the '90s pictured in the Lucchini Sidermeccanica plant.

The third example comes from the European funded project HIPERWHEEL. A composite wheel was developed by using a conventional steel tire mounted on an aluminium wheel centre. Numerous tests on specimen and on full-scale wheelsets were performed and interesting results were found [10]. The main reasons for using a different material for wheel centre was the reduction in wheelset mass of around 25%, that with the current attention to unsprung masses for charging the access to the infrastructure would be extremely interesting. Despite the importance and the strength of the consortium that developed this solution (it included e.g. LBF, FS, Chalmers University, etc), to the author's knowledge no prototypes were tested in service.

6.3 Solutions to improve running dynamics and maintenance

The wheelset, although important, is integrated in a subassembly that is even more critical, i.e. the bogie. Running dynamics is in fact a compromise between stability at high speed and curving behaviour at low speed that largely depends on the designer's choices on suspension elements.

Wheelset architectures with torque limiters were mainly used in low-floor vehicles such as trams (see e.g. [11]) that run in very sharp curves (down to 15 m radius), while on mainline vehicles both active [12] and, more recently, fully passive [13] solutions were proposed (Figure 3 and Figure 4). The solution shown in Figure 4 claims to be particularly effective in terms of maintenance costs reduction.

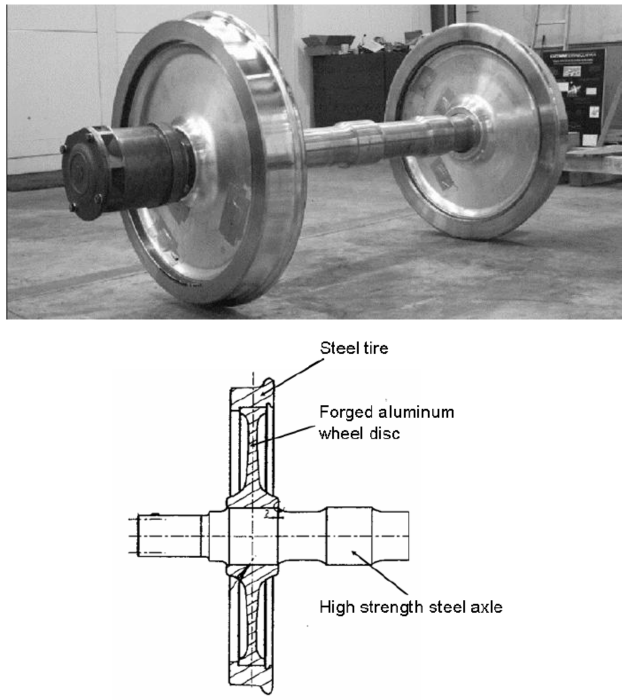

Figure 2. Composite wheel developed within the HIPERWHEEL European project

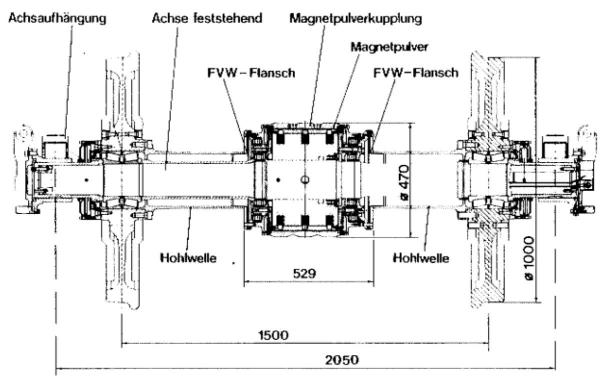

Figure 3. Wheelset with active magnetic powder coupling connecting the wheels [12]

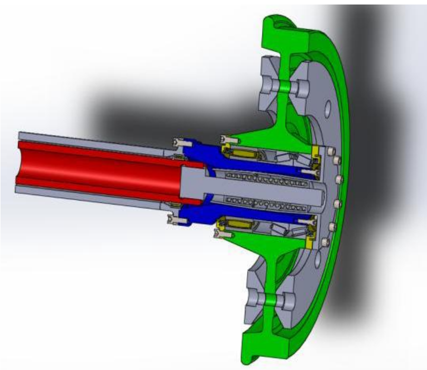

Figure 4. Wheelset with wheels coupled through passive torque limiters [13][12]

None of this solutions was applied in practice, although some reached the prototype level. The only measure adopted in practice to improve curving at low speed without sensibly affecting stability is the use of hydraulic bonded rubber bushes (also known as HALL bushes, see [14] and [15]). In this case the wheelset design remains totally unchanged.

7. Conclusions

Wheelset architecture did not change over two centuries. The inspiring principles are still valid and ensure compatibility and steady incremental improvement without sudden changes. In the aircraft industry, piston engines disappeared in favour of jet engines. Nothing similar happened about wheelsets: a modern wheelset is just an improved version of those used at the dawn of the railway era.

As a consequence, innovation in its strict meaning is something that is not applicable to wheelsets. More properly, it should be talked about *development* of the basic concept. A modern wheelset silenced by damping treatments, protected by flying ballast, with hollow axle to allow NDT bore axle testing, equipped with the most advanced sensors is just a natural development of the initial design that is still alive and valid. A bright example of this statement is reported in the recent supplement on *wheelset design & development* [16] that describes the improvements in the current wheelset design made by the members of European Railway Wheels Association (ERWA), the UNIFE wheelset committee.

Innovation should therefore be intended for wheelsets as whatever is going to be developed and that is not already considered in the existing standards. This point of view may look limited but ensures safety. Wheelset manufacturers then naturally tend to introduce development that does not affect safety but that improve performances. This proved through the decades the only winning strategy to keep consistent portions of the market. The role of certification bodies is nowadays central to all safety-related components in the railway industry and this is certainly the case also for wheelsets.

Acknowledgment

The author would like to thank Dr. Steven Cervello from Lucchini RS for the information about the "springy wheel" and the photographs supplied.

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