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MAINTAINABILITY OF WHEELSETS:

A NOVEL SOLUTION TO SAVE TIME AND MONEY

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Abstract

A new type of wheelset with wheels supported by roller bearings and connected through a transmission shaft has been proposed recently. This design resembles the typical independently rotating wheels architecture, widely used in low-floor trams, but with the peculiarity that the wheels look "apparently" independent (from which the acronym *AIR wheelset*, i.e. *Apparently IRW*). The presence of torsional constraint and the use of a torque limiter guarantee both optimal running dynamics at high speed and high track friendliness on winding lines. Trenitalia maintenance practice of conventional wheelsets is described and compared to the possible cycle for the AIR wheelset, showing that distinct advantages may be obtained under several aspects.

1. Introduction and description of the *AIR Wheelset*

Independently rotating wheels (IRWs) mounted on inside frame bogies or "axlebridges" are often used in trams and in all vehicles that require a low floor arrangement. This layout favours the maintenance as it allows to dismount the wheels without the need to lower the wheelset or to lift the carbody up as required with conventional wheelsets.

The absence of the torsional constraint between the wheels in IRWs leads nevertheless to premature wear of wheel flanges, as the bogie tends to run skewed and with one or more wheel flanges in continuous contact with rail gauge corner. The gravitational stiffness proves to be insufficient to restore the central position of the wheelsets. This evidence, already clear in the '70s of the last century, explains why no IRW-equipped vehicles are used in conventional railways.

In order to overcome this drawback, the fully passive "apparently" independently rotating wheels wheelset (*AIR Wheelset* for short) was developed and patented [1].

The *AIR Wheelset* consists of two wheels supported on stub axles by means of different bearings arrangement depending on the axleload, the maximum speed and the dynamic behaviour of the vehicle.

Two versions of the *AIR Wheelset* are available, a motor one and a trailing one. In both the arrangements the wheels are connected by a rotating shaft passing through the hollow supports.

In the case of the trailing *AIR Wheelset*, the connection can be made with or without torque limiters that allow finite rotations between the wheels in case the torque limit set is exceeded (Figure 1, Figure 2). Further information can be found in [2] that describes the mechanical design and the basic development concepts of the *AIR wheelset*.

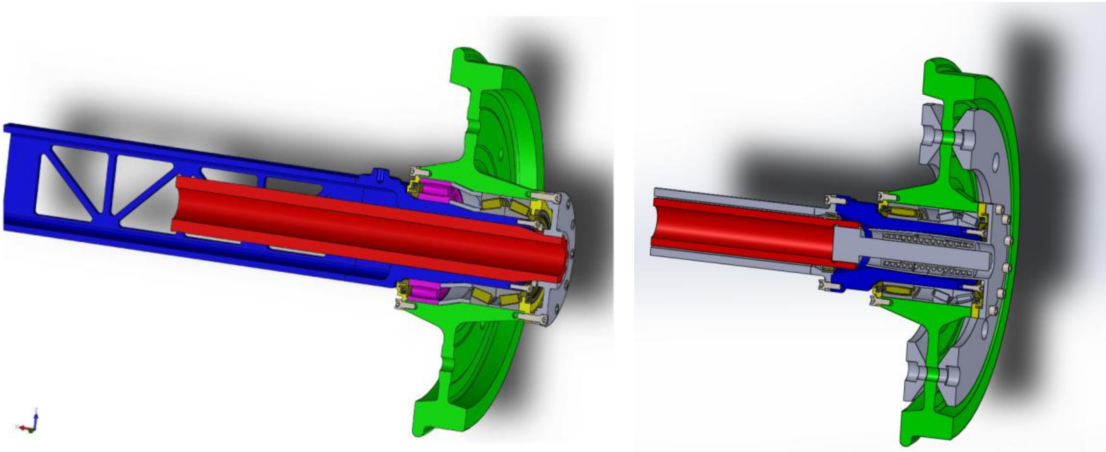

Figure 1. Three-dimensional view of a trailed *AIR Wheelset*. Left: a heavy axleload / high speed (30 t/axle, 250 km/h) version with rigid joint. Right: a lighter axleload / conventional speed (20 t/axle, 200 km/h) version with one of the available versions of torque limiter (see also [6]).

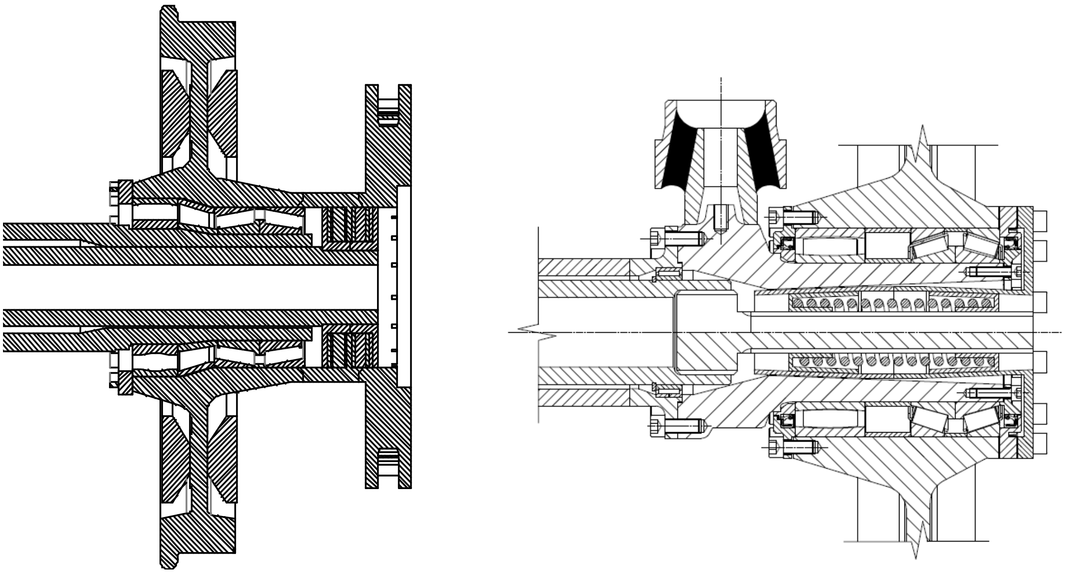

Figure 2. Cross section of two different versions of a trailer *AIR Wheelset.* Left: the heavy solution with an external torque limiter and an optional external brake disc. Right: the light solution with a more compact arrangement (bridge diameter = 160 mm, wheel bore diameter = 240 mm) and an internal torque limiter.

It was known that the introduction of a torsionally softer shaft connecting the wheels may have adverse consequences on running dynamics of a vehicle. The behaviour of a “standard vehicle” (the ERRI wagon) retrofitted with the *AIR wheelset* is described in [3]. The impact on critical speed, track shifting forces and derailment ratio L/V (or Y/Q in the European practice) for both ideal and defective track and for the classical axle, the torsionally flexible axle and the “torque limited” *AIR wheelset* solution are shown. It was concluded that the effect of the axle torsional flexibility does not affect in practice the dynamic behaviour of the vehicle provided that suitable anti-yaw dampers are used. The introduction of the torque limiter was shown to be beneficial in terms of increase of critical speeds and decrease of track shifting forces.

Contact mechanics advantages of the *AIR Wheelset* are discussed in [4] that describes the improvements that can be obtained by the use of the version with torque limiters. If the arrangement with rigid connections between the wheels and the axles is in fact absolutely identical to a conventional wheelset in terms of wheel and rail tear & wear, the greatest advantage can be obtained by using torque limiters with the proper maximum torque setting. Longitudinal forces can be dramatically limited in both mild curves reducing RCF phenomena and tight curves reducing corrugation formation and growth.

Further possibly interesting readings are [5], that introduces the concept of the *AIR Wheelset* after a review of history, research and development in the wheelset sector, [6], that explains in detail the design and the validation of the torque limiter that equips the *AIR Wheelset* and [7], that describes several solutions for the possible arrangement of the bearings within the wheels of the *AIR Wheelset* concept.

2. Advantages offered by the *AIR Wheelset*

This paragraph summarizes the advantages offered by the adoption of the *AIR Wheelset* and depicts also the limitations that are apparent at the moment. It should be underlined, in fact, that although several contacts are well advanced with several wheelset manufacturers and with systems integrators, no *AIR Wheelsets* have been tested in a real environment.

In the following, it should be considered that the same item may have impact on different aspects (e.g. safety, maintenance and cost) and will be repeated accordingly.

The **typical applications** of the *AIR Wheelset* require specific solutions. It is worth to underline that the *AIR Wheelset* requires the use of “inside frame bogies”, a solution that can be very easily derived from the existing “inboard bearings” solution that are gaining more and more favour thanks to their high track friendliness. For the moment, the following applications were developed:

- regional and commuter trains, for both driving and trailed wheelsets, typically on EMU and DMU trainsets, with speed up to 160 km/h and axleload up to 18 t/axle;
- long distance passenger trains up to 200 km/h with an axleload up to 20 tonnes;
- heavy haul freight cars, up to 30 t/axle and 120 km/h;
- high speed trains (v>200 km/h) are not dissimilar to the long distance solutions but should be carefully checked because of the possible limitations of the arrangement with bearings with rotating outer ring;
- similarly, solutions with up to 4 discs “per axle” can be developed but it is believed that for conventional applications this option will not be considered.

The advantages of the *AIR Wheelset* in terms of **running dynamics** are as follows:

- running in straight track or in large radius curve with the solution incorporating the torque limiter as well as if the version without torque limiter is used, no differences with a conventional wheelset in terms of dynamic behaviour are expected, meaning that contact forces, ride characteristics and wear are absolutely comparable with the conventional design;
- the “centring effect”, necessary for the proper guidance and totally absent in IRW arrangements, is fully kept in the *AIR Wheelset* until the set torque limit is reached. Even after, the residual longitudinal forces are higher than those needed to restore the centred position in tangent track. Wheelset offset is therefore completely avoided;
- instability problems, caused by the progressive increase of the equivalent conicity γ_e, are reduced as the most important cause of wear of the running table (i.e. longitudinal force in mild and sharp curves) is greatly reduced, leading to longer reprofiling intervals;
- opposite to conventional IRW arrangements, the *AIR Wheelset* still possess the steering ability intrinsic in conventional wheelsets, but it is limited by the torque limiter to an “equivalent

coefficient of friction" of around μ=0.35. This avoids the highest longitudinal peak forces that are responsible of rail damages in dry season or in metros where it is not uncommon to observe $\mu\cong$0.6;

The advantages of the *AIR Wheelset* in terms of **safety** are as follows:

- for the possibly most common solution (i.e. passenger trains at conventional speeds), wheel design is absolutely similar to ordinary wheels, keeping the same level of safety of existing vehicles;

- as the size of the sub axles of the bridge is driven by adjacent parts (connecting shaft, bearings), they are subjected to very low maximum static stresses (typically < 100 MPa), with resulting very low utilization factors;

- for the same reasons, non-alloyed or lightly-alloyed steels can be used with very favourable crack propagation properties;

- the ratio of alternate stresses / static stresses on stub axles is low, largely reducing the consequences of fatigue;

- non-destructive testing (NDT) become therefore less critical as 1) stresses and crack propagation are lower and 2) inspection of stub axles is straightforward once wheels are removed. In practice NDT checks on should be performed according to the maintenance plan of the bogie frame;

- skipping or mistaking a NDT should have less tragic consequences than in case such even happens on an axle;

- while axle cracks often become evident only after an accident due to a broken axle, any failure in the bearings can be observed by monitoring their temperature. This possibility is specifically mentioned in the standard EN 15437-2:2012 on on-board bearings monitoring. Any failure can therefore be promptly detected without accidents and with minimum impact on service, as a vehicle with a "hot box" can reduce its speed freeing the line in a reasonably short time;

- the new components introduced in the design of the *AIR Wheelset*, i.e. the front flange, the torque limiter, the connecting shaft and the other minor parts added, benefit from the "fail safe" philosophy. In case any of them is broken, the *AIR Wheelset* behaves as a "classical" IRW arrangement, the latter having no critical speed (hunting is anyway avoided) and possibly slightly higher forces in sharp curves. Any failure in the "transmission path" between the wheels can be promptly detected by measuring the relative wheels speed with the usual speed sensors used for wheel slip protection. Safety is therefore always guaranteed also in case of failure.

The advantages of the *AIR Wheelset* in terms of **maintainability** are as follows:

- it should first noted that *all serviceable components are grouped in one element* that include the wheel, the bearings and the brake discs;

- routine checks on axleboxes, wheel profile and brake discs wear can be done as usual without any change. Wheel reprofiling with underfloor lathes can be done as usual. From this point the adoption of the *AIR Wheelset* is neutral;

- on-condition maintenance is totally different from the one on conventional wheelsets. In case of sudden events that require a wheelset replacement, a difference practice will be used as only the wheels have to be replaced. Simple tools for wheel removal / mounting can be used in semi-prepared environment, i.e. in almost all remote and non-structured depots or sheds or even on a yard. All is needed is to lift one side of the bogie to gain access to a wheel that has to be changed. Overhead cranes, lifting or underfloor jacks, bogie/wheelset equipment drops and the like are not needed anymore;

- the possibility of removing the wheels to turn on-condition the brake discs in a conventional lathe is a new feature that is a distinctive advantage of the *AIR Wheelset* solution;
- wheel replacement requires virtually no intervention on stub axle. This condition is totally opposite to conventional wheelsets that, in case a wheel has to be replaced, force to the overhaul of the entire wheelset (axle and possibly bearings included);
- minor adjustments can be done by using simple machine tools (a vertical lathe) without all the equipment needed to overhaul a conventional wheelset. As a consequence, much easier service from external supplier can be found, as tools needed for overhaul can be easily found in any conventional mechanical workshop.

The advantages of the *AIR Wheelset* in terms of **logistics** are as follows:

- while the size and the mass of conventional wheelsets historically forced to fully equip many workshops over a given territory (in practice there was a full wheelset overhaul shop in every large or mid-size city), managing only wheels changes the repair practice and the logistics and the spare parts supply chain;
- local depots may rectify with limited equipment (possibly only a vertical lathe) most of the defects encountered during normal operations;
- new wheels, new bearings and new brake discs can be supplied as spare parts to local workshops, that may assemble new complete wheels in a reduced time and with reduced costs;
- fully worn wheels, bearings that needs to be overhauled or brake discs that have reached the end of their useful life can be shipped all together with reduced weight and costs. Consider that a 32 t semi-trailer can only theoretically carry 21 wheelsets (1.5 t each) because of the irregular wheelset shape, while it could carry without problems 64 wheels (500 kg each);
- major overhaul (wheel replacement, bearings check / cleaning / re-greasing, discs reprofiling / replacement) could be therefore centralized is a few workshops in a country;

Some considerations about **life cycle cost** start from the consideration that *AIR Wheelsets* are intrinsically more expensive than conventional ones for several reasons (number of bearings double, presence of more components, relatively high precision machining and assembly, etc.). Nevertheless the initially higher purchasing cost can be recovered quite easily generating at the end a consistent reduction in the life cycle cost, for the following reasons:

- stub axles become robust parts that belong to the bogie and that require in practice no maintenance. Their cost is therefore spread on the entire life cycle cost of the bogie. Possibly, this part could be designed, produced and assembled by the bogie manufacturer instead of the wheelset manufacturer. This is completely different from the conventional design, where the wheelset is supplied as a whole with higher costs;
- maintenance cycles completely change, leading to reductions of the overhaul time and as a consequence of the overhaul direct costs in the order of 25%. One of the most important factors in cost reduction is the reduction of non-destructive testing (NDT) on the stub axles, that can be inspected less frequently;
- bearings size, dictated by adjacent part, is such that in many applications they should last over 10 million km. This would be in line with the current practice in the automotive sector in which the bearings of a wheel last for the entire life of the vehicle. The attention is therefore shifted to

bearings greasing / cleaning / maintenance procedures. The initially higher cost of the bearings can therefore be easily recovered considering that they last "for life";

- the use of the torque limiter greatly reduces wheel and rail tear and wear, limiting longitudinal forces that are one of the fundamental parameters to calculate direct costs according to [8] (point 5.2.h "longitudinal stiffness of vehicles and horizontal forces impacting on the track") and that are explicitly mentioned in [9] for the "evaluation and background of the rail surface damage quantity";

- track access charges ("TACs") may correspondingly be reduced (see [10]) , paying the possibly higher cost of the solution for itself in a very short time. Consider that currently the Variable User Charge in the UK [11] allocates 85 % of the charge to track costs, and that 30% of these track costs are related for 30% to horizontal rail forces. Even under the very cautious hypothesis of a reduction of 60% of the "longitudinal surface damage", this leads to a reduction of around 15% of the infrastructure access charge.

3. Maintenance of conventional wheelsets and *AIR wheelsets*

This paper is the outcome of the cooperation between the inventor of the *AIR Wheelset* (Prof. Andrea Bracciali) and the most important train operating company in Italy (Trenitalia SpA). The interest for this subject comes from the obvious consideration that a new product / project may be considered as interesting if it's able to pass the "most critical" test, namely the cost of the life cycle (LCC).

Roughly speaking, the cost of a wheelset can be split in three main chapters:

- the purchasing cost, that is negative;
- the maintenance cost, negative as well;
- the scraping cost, which is positive as steel can be easily recycled.

The relative importance of the three phases is not generally known. It depends on the complexity of the wheelset (motor wheelset are most expensive, freight wheelsets are the less expensive) and on the expected and practical life of the wheelset (number of wheel / bearings changes, reprofiling, maintenance performed on axles / discs, etc.). It can also be said that the positive income from steel scrap has a rather limited importance on total LCC.

Estimation of manufacturing costs of the *AIR wheelset* are still in progress and will not be further addressed here. This paper, in fact, concentrates on modifications of the maintenance procedures and practices in case the *AIR Wheelsets* are used in place of conventional wheelsets.

As a prerequisite, it must be observed that the *AIR Wheelset* is designed for inside frame bogie frames, a design which recently gained much favour in continental Europe (e.g. the trailing bogies of the ICx for Deutsche Bahn), after having been developed and now widely used in Great Britain (Aventra by Bombardier, Desiro City Thameslink by Siemens and IEP from Hitachi) mainly for low track access charge reasons. The combination of inside frame and *AIR Wheelsets* makes it possible to dramatically change the maintenance operations on "wheelsets", as described in the following.

The outline of this work started from some basic considerations, arising from the characteristics of new design of the *AIR wheelset*:

- as the rotating bending axle "disappears", most of the conventional workshop repair activities disappear as well. Compared to traditional wheelsets, the only part subjected to maintenance is the wheel, on which brake disc and bearings are fitted;
- personnel, equipment, and procedures involved in NDT of axles can be eliminated as well. The stub axles become in fact part of the bogie and are subjected to its (much longer) maintenance cycle;

- the entire logistics of the wheelset changes. Wheel removal and replacement will be possible with standard and low-cost equipment in all depots requiring only to lift up the wheels just to free the flanges from the rail head (no lifting jacks and bogie drops are required);
- a centralized workshop can serve many operators. Possibly only one main centre in a country is needed, as logistics of wheels is much easier than that of wheelsets;
- vehicle dynamics considerations may lead to oversized bearings. They can possibly last "for life", similarly to street vehicles where bearings are almost never changed.

Wheelset maintenance in Trenitalia

Trenitalia SpA, a railway enterprise belonging to the holding Ferrovie dello Stato Italiane SpA, operates the largest fleet of vehicles in Italy, ranging from locomotives to passenger cars, from high-speed trains to EMUs, DMUs and freight wagons.

As Trenitalia originated from the split of the former FS historical national railway, maintenance of the fleet is complicated by the extension of the network covered by Trenitalia services (around 16.000 km) and by the multitude of vehicles of different concept and age.

The fleet that Trenitalia operates consists of the following vehicles (indicative figures subject to change):

- 2400 locomotives;
- 180 high-speed trainsets;
- 640 EMUs and DMUs;
- 6900 passenger cars;
- 22000 freight wagons.

About vehicle maintenance, Trenitalia is organized in around 40 "first level" workshops and 8 "second level" workshops evenly distributed on the nation's territory (Figure 3).

Second-level workshops are located as follows:

- wheelset for locomotives are repaired directly in major overhauls maintenance site (Foligno, Verona);
- freight wagon wheelsets, considered as "simple" as they include only the axle, two wheels and the axleboxes, are mainly repaired in Foggia, Voghera and Santa Maria La Bruna;
- passenger cars wheelsets, considered as "more complex" as they include brake discs installed on the axle or on the wheel web, and wheelsets with transmission components (gearboxes) for Pendolino and ETR high speed trains, are mainly repaired in Firenze Osmannoro, Santa Maria La Bruna and Vicenza.

First level workshops perform in-service check of wheel tread and flange, inspection on braking systems components and wear, external check of axlebox bearings and reprofiling wheels with underfloor lathes for minor/normal/acceptable wear and damage rectification.

In case excessive wheel wear (hollow tread, worn flange), wheel flats, damages of the axleboxes and worn brake discs are found and these defects cannot be rectified on site (e.g. by means of reprofiling with an underfloor lathe), the wheelset is removed from the vehicle and sent to the appropriate second-level workshop. Wheelset dismounting consists in disconnecting the (primary) suspension connection between the axlebox and the bogie frame, lifting the vehicle up with jacks and shipping the wheelset to the second-level maintenance centre.

Second level workshops clearly perform a much more complex sequence of overhaul operations aimed at restoring the full functionality of wheelsets. They are sent back to service an "as new" assembly.

The operations performed in second level workshops are not described here for two reasons: first, because they are well known in the railway maintenance sector (see the relevant EN standard [9]) and, second, because the operations involved in the calculation of the advantage given by the AIR Wheelset are described in par. 5 in the following.

Figure 3. First- and second-level workshops operated by Trenitalia SpA in Italy.

An average number of wheelsets overhauled by second-level workshops is as follows:

Table 1: Wheelsets maintained in second-level Trenitalia workshops in 2015

Second-level workshop	Passenger cars	Locomotives	Freight wagons	Total
Santa Maria La Bruna	2600		2369	**4969**
Voghera	1427		2787	**4214**
Foggia	1234	529	5506	**7269**
Vicenza	2045	334	884	**3263**
Bologna	159	120		**279**
Firenze Osmannoro	3170			**3170**
Verona	391	65		**456**
Foligno		834		**834**
Total	**11026 (45%)**	**1882 (8%)**	**11546 (47%)**	**24454 (100%)**

4. Wheels life statistics and wheel change numbers

The frequency of events requiring a wheel change and the consequent wheelset dismounting depends on numerous factors:

- service conditions are the main cause for the "normal" deterioration of wheels. Service in winding lines, high axleload, bad steering of vehicles conceived for high speed, etc. define the practical duration of the wheel profile;

- reprofiling maintenance policies, taking into account also the availability of resources (rolling stock, personnel, machine tools, etc.), have a distinct impact on the wheels changing interval (e.g.: more frequent and light reprofiling, for some applications may be better than "heavy" reprofiling);

- malfunctioning of any device related to running gear (poorly tuned flange lubricators, malfunctioning of anti-skid devices) may generate abnormal wear.

It is therefore not possible to define general rules to estimate the duration of a wheel in service, although statistics collected along one or more typical services may help to define practical targets, often included in tenders for new vehicles.

For the scope of this work only average estimations can be made. The authors are conscious that the values of average distance run before wheel changing listed below are only relative and strongly depend on the specificity of service conditionsthe network (e.g. high-speed vehicles suffer from hollow tread while vehicles in mountain area suffer from wheel flange).

Nevertheless, as long as the aim of this paper is to provide some practical results, it appears necessary to perform some calculations, i.e. some numerical estimations based on figures that may be criticized but that are central to the conclusions that will be listed below. It should be said that although the experience of main train operating companies (i.e. those belonging to "old" classical administrations, such as FS, DB, SNCF, RENFE, etc.) may be similar, it is hoped that the method presented here will help the reader to re-analyze the results according to the practice of the railway enterprise that he belongs to.

Having said that, reasonable estimations of wheel life in service are as follows:

- intercity service passenger car: 3 reprofiling, typical life: 800.000 km, average distance run per year: 200.000 km, wheel change every 4 years;

- high-speed passenger car: 4 reprofiling, typical life: 1.000.000 km average distance run per year: 333.000 km, wheel change every 3 years;

- high power locomotive (for freight and heavy passenger services): 3 reprofiling, typical life: 800.000 km average distance run per year: 200.000 km, wheel change every 4 years;

- EMUs and DMUs: 3 reprofiling, typical life: 800.000 km average distance run per year: 200.000 km, wheel change every 4 years;

- freight wagon: 3 reprofiling, typical life: 600.000 km average distance run per year: 100.000 km, wheel change every 6 years.

5. Wheelset maintenance

5.1 Introduction

The comparison of maintenance practice can be done considering a number of different factors, including the level of automation of certain operations, the availability of specific or generic tools, local job legislation, labour costs and so on.

The parameter used here to compare the advantages offered by the AIR wheelset is the labour time. Clearly, times can be reduced by heavily investing in automation, but this could be quite difficult in maintenance workshops that have to deal with many different typologies of vehicles. The working times shown in the following, indicated in man-hours, may be considered therefore representative in the authors' opinion.

The approach used in this paper is based on the experience of Trenitalia in the overhaul and repair of conventional tread braked wheelsets (from now on "freight wheelsets") and on wheelsets braked with two brake discs mounted on the axle (from now on "passenger wheelsets").

The use of a freight wheelset as the basis of the following analysis descends from the consideration that the AIR wheelset in its simplest form, i.e. the one without torque limiter, resembles it. Moreover, a freight wheelset is not normally equipped with bearing cartridges, making it more similar to the current design of the AIR Wheelset, where *tapered bearing units* are not used at the moment. When such units will be developed, the maintenance times of bearings will be further reduced.

Freight wheelset are normally checked at predetermined time intervals (6 years in Italy); according to the conditions of the wheelset at the arrival at the second level workshop, the maintenance operations are specialized and different cycles may be applied. This introduces a further variable in the calculation, i.e. the mix of wheelsets in different conditions (ranging from needs for only reprofiling and axlebox revision to fully heavy wheelsets maintenance, with changing wheels, turning of the axle and complete new painting). In the paper, the weighing factors used for time estimation of overhaul and repair were considered according to the "mix" of different maintenance cycles and activities cited above.

The impact of brake discs installed on passenger wheelsets on maintenance interval is estimated, considering that brake discs are changed every fourth wheel reprofiling. As the number of brake disc arrangements is quite large on different rolling stock materials (monobloc disc, in 2 sectors with tangential bolts, in 5 sectors with axial bolts and so on), the imputed time for these maintenance activities can be considered less accurate, but nevertheless it gives an insight on the advantages potentially offered by the AIR Wheelset.

5.2 Impact of the AIR Wheelset on first level workshops

The use of the AIR wheelset may dramatically reduce the level of complexity of wheelset exchange in first level workshops, for either a freight or a passenger wheelset.

The use of the AIR wheelset seems very attractive because wheels exchange may require a very short time, since lifting only one bogie frame side at a time is sufficient to remove the wheel. Conventional, large lifting jacks are therefore not required anymore (and not even to lift the entire vehicle up, as done in some cases for freight rolling stock material). After wheel replacement, the process can be repeated on the other side also in semi-prepared environments. After wheel replacement the vehicle is immediately operating without any further check.

A preliminary analysis comparing the maintenance practices revealed that very likely the time needed to change the wheelsets on a freight wagon and the time needed to change the wheels in case the AIR Wheelset is used are comparable. This leads to the conclusion that the adoption of the AIR wheelset is basically *neutral with respect to first level maintenance times*.

This may lead to the wrong conclusion that there is no advantage in using the AIR Wheelset. All the other advantages linked to the use of the AIR Wheelset are in fact not described simply by the exchange of wheels/wheelsets in first level workshops. It should be in fact considered that the handling of spare wheels within the workshop is much easier than that of wheelsets, that warehouse spaces may be limited, that the maintenance can be done with simpler and lighter equipment and that the road haulage of spare wheels is much less expensive. A crucial advantage is that when the wheel is removed all the parts subjected to maintenance (bearings, brake discs) are removed at a time.

Moreover, the AIR wheelset doesn't need UT checks on the axle (often included in maintenance schemes of "standard" wheelsets, at first level too).

All these factors are not quantified here by numbers, but they represent certainly significant advantages of the AIR Wheelset solution.

5.3 Impact of the AIR Wheelset on second level workshops

The largest impact of the use of AIR wheelsets on maintenance time is on second level workshops. As long as they do not receive axles anymore, the number and entity of operations change noticeably.

Table 2 compares the second-level operations performed on a standard freight wagon wheelset based on Trenitalia experience compared to the estimation of the same or the similar phases on the AIR Wheelset.

Table 3 computes the impact of the architecture of a disc braked passenger wheelset on the standard freight wheelset. Although not mentioned before, it is worth to highlight that the AIR wheelset can accommodate two more discs connected to the outside face of the wheel hub (see [2]).

6. Conclusions and further developments

The paper focused on maintenance practice on current freight (block braked) and passenger (disc braked) wheelsets and on the influence that the introduction of the AIR Wheelset may have on maintenance times.

The AIR Wheelset considerably simplifies the whole maintenance cycle, from needed equipment to non-destructive checks, from logistics to warehouse space and spare part organization.

The figures obtained by a thorough analysis of the data available at Trenitalia show that the reduction of overhaul time of wheelsets in "second-level" workshop may decrease sensibly, leaving first-level times almost unaffected, reducing nevertheless their workload.

The authors are conscious that the values obtained from this first analysis are only a first approximation and that the calculations shown here will require a deeper investigation and further insights. From these work it can be concluded that maintenance times of Trenitalia passenger vehicle wheelsets, the preferred field of application of the AIR Wheelset, could be reduced by approximately 25% by using this innovative solution.

Table 2. Maintenance man-hours needed for a standard freight wheelset and an AIR Wheelset (highlighted in yellow). Notes: (1) maintenance cycle on freight wheelset weighed on the mix of wheelsets processed with different cycles in Trenitalia. (2) For the AIR Wheelset, these phases belong to bogie frame maintenance cycle, but their impact is deemed negligible.

Id	Description for standard freight wagon wheelset	Standard wheelset (1)	AIR wheelset
1	Wheelset unloading from lorry	0.13	0.07
2	Wheelset loading for washing/cleaning	0.13	0.09
5	Wheelset unloading from washing/cleaning	0.13	0.09
6	Wheelset pre-examination	0.25	0.25
7	Dismounting of axleboxes and bearings	1.90	2.47
8	Axleboxes cleaning and exhaust grease recover	0.20	0.20
9	Cleaning of axleboxes spare parts	0.22	0.22
10	UT check of axle	0.40	0.00
11	Axle straightness and eccentricity check (2)	0.25	0.00
12	Axle cleaning with pneumatic grinder	0.32	0.00
13	Axle (with wheels) rectification	0.28	0.00
14	External reprofiling and marking	0.20	0.00
15	MT check of axle (with wheels)	0.27	0.00
16	Check of journals (2)	0.08	0.00
17	Check of bearings	0.20	0.20
18	Washing and out-of-place check of bearings	1.00	1.20
19	Turning of bearings internal spacers	0.48	0.48
20	Welding of axleboxes plates and accessories	0.66	0.00
21	Axleboxes mounting according to repair plan	2.40	2.88
22	Wheelset painting	0.60	0.30
23	Tag management	0.32	0.32
25	Wheels pressing-off	0.28	0.00
26	Bare axle grinding	0.50	0.00
27	Wheels turning & dimensional check acc. to repair plan	0.54	1.20
28	MT check of axle	0.11	0.00
29	Wheels shrink fitting	0.23	0.00
30	Mechanical resistance test (*décalage*)	0.11	0.00
31	Wheelset cutting for withdrawing	0.00	0.00
32	Extra for heating oven handling	0.18	0.00
33	Handling to storage warehouse	0.06	0.03
34	Wheelset loading on lorry	0.06	0.03
	Averaged overhaul and repair time of freight wheelset	12.23	10.02
		AIR Wheelset time saving	**18%**

Table 3. Influence of the architecture of a two-brake discs arrangement of a passenger wheelset on the maintenance man-hours of a freight wheelset and comparison of a standard passenger wheelset and an AIR Wheelset (highlighted in yellow). Only phases of interest are considered. Notes: (3) This estimation comes from an average of brake discs typology and reprofiling evidences as obtained from Trenitalia revenue services. Non-numbered phases belong to AIR Wheelset only.

Id	Influence on passenger wheelset	Standard wheelset (3)	AIR wheelset
6	Integration to the standard pre-examination cycle of disc-braked wheelsets	0.25	0.25
	web-mounted brake disc disassembly	0.00	0.06
	web-mounted brake disc reassembly	0.00	0.06
13	Brake discs active face machining, thickness check, check of cracks, recording of data	0.38	0.38
14	Wheels pressing off	0.13	0.00
15	Disassembly of external brake discs	0.13	0.00
20	Measurement of disc seat / turning of brake disc bore / check of interference	0.38	0.00
23	Press-fit of brake discs hub	0.25	0.00
26	Shrink fit of wheels	0.25	0.00
28	Mechanical resistance test (*décalage*)	0.06	0.00
29	Axial out-of-plane check of brake discs	0.25	0.25
	Incidence of brake discs	2.06	1.00
	Averaged overhaul and repair time of passenger wheelset	14.29	11.02
		AIR Wheelset time saving	**23%**

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