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NEW WHEELS, NEW WHEELSETS, NEW BOGIES

NOVÉ KOLESÁ, NOVÉ DVOJKOLESIA, NOVÉ PODVOZKY

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1 INTRODUCTION

Innovation looks nowadays linked only to digital revolution. Some concepts in the railway industry are so well established that re-thinking fundamental (structural) components of rolling stock seems impossible or useless.

The authors believe on the opposite that modern simulation packages, advances in manufacturing processes and the use of new materials should be applied for a deep re-analysis of existing products in running gears, transmissions, structural elements and so on.

This paper is the result of a long lasting R&D work that led to the development and patenting of new solutions, always keeping an eye on costs, industrial applicability and compatibility with the existing railway system.

Therefore we are glad to introduce three major advances in the technology o safety-critical components: a novel concept of tyred wheels (“*Liberty wheels*”) that dramatically impact on maintenance, an innovative wheelset (“*AIR Wheelset*”) largely improving safety (and reducing costs) and a bogie frame for freight wagons (“*4L bogie*”) that saves up to 3 tonnes vs. a conventional Y25 bogie and allows higher speeds.

All these innovations were carefully assessed by virtual homologation and are ready for deployment. In one case (the *Liberty Wheels*) the development phase happily ended with tests on a real vehicle.

2 INNOVATION IN WHEELS: THE *LIBERTY WHEEL*

Monobloc wheels superseded tyred wheels for maintenance cost reasons and braking limitations when applied to freight vehicles. We analysed separately structural issues (tyre loosing, stress considerations during tyre fitting and service, [9,10]) and maintenance issues (complex machining operations, need of adjustment for each single wheel, [11]).

The weakest points were found in a non-optimal design of wheel centre (it should be considered that the design of new tyred wheels was discontinued several decades ago),

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and in the tyre / wheel centre mounting procedure that was traditionally performed by adjusting the tyre bore diameter on the wheel centre diameter after its machining. Worn tyre removal was performed by turning away the retaining ring, cutting the tyre (sawing of with oxyacetylene torch) and by using mechanical extractors that damaged the wheel centre mating surface.

Recalling one of the basic principles of mechanics, i.e. interchangeability of components thanks to proper tolerancing, the authors developed a “dovetail coupling” that removed the need for the retaining ring traditionally present in tyred wheels. The new design proved to be safe from a structural point of view, easy to machine and positively affecting the maintenance cycle.

With this new technology, in fact, all is needed is a device to remove the tyre by heat without damaging the wheel centre (e.g. with an induction heater or propane burners) and a similar device to heat the new tyre up before installation.

The entire process makes sense only if fully machined tyres can be installed on machined wheel centres without needing any machine tool (e.g. the “wheelset lathe”). Specific tests were conducted on real wheelsets and we can state that both radial and lateral run-outs of the assembled wheelset with new tyres largely remain within the tolerances prescribed by the International Standards. Extensive workshop activities were performed leading to line tests on a DMU vehicle [15]. The results were fully positive and all the expected targets were achieved.

Summarizing, with this new approach tyre changing can be performed in any workshop, even the most remote, as it does not involve machine tools or any other specific “complex” operation. The wheelset maintenance cycle simplifies dramatically and consists only in tyre removal by heat, cleaning of the surface, installation of a new (fully machined) hot tyre and tyre cool down. The idea proved to be simple, easy to machine and even easier to be applied.

The comparison of the different types of wheels in shown in ***Fig. 1***, while details of workshop operations, FEM calculations and line tests are shown in ***Fig. 2*** and ***Fig. 3***.

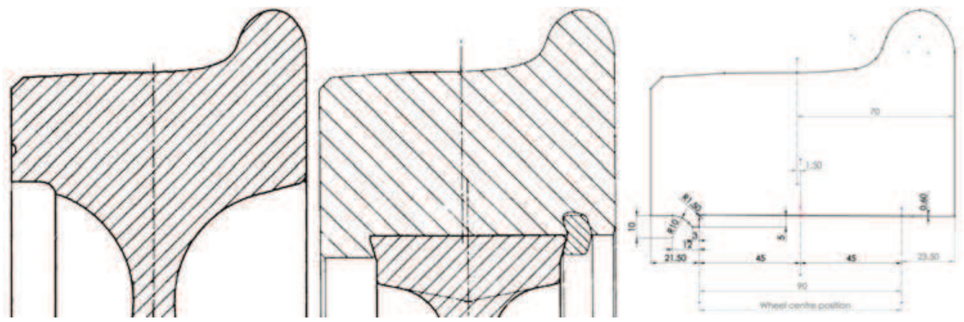


Fig. 1 *Left: monobloc wheel. Centre: conventional tyred wheel (cylindrical mating with retaining ring). Right: tapered tyre without retaining ring.*

Obr. 1 *Vľavo: monoblokové koleso, v strede: konvenčné obručové koleso (valcový spoj s poistným prstencom), vpravo: kužeľová obruč bez poistného prstenca*

For reasons linked to a better distribution of the contact forces between the tyre and the wheel centre, a stiffer radial wheel web was developed. In order to avoid increasing too much its mass, the wheel centre was re-designed and casted with a different material (Austempered Ductile Iron – ADI) with a two-rank of spokes architecture [13]. The main advantages of this design are lightness, the possibility of designing wheels of nearly any shape due to the high castability of spheroidal graphite iron and the extremely good medue to the high castability of spheroidal graphite iron and the extremely good mechanical properties of this material after the austempering heat treatment.

Fig. 2 *Left: Tyre removal by means of a portable induction heating device. Right: tyre fitting without retaining ring*

Obr. 2 *Vľavo: snímanie obruče pomocou prenosného indukčného ohrievacieho zariadenia, vpravo: nasadzovanie obruče bez poistného prstenca*

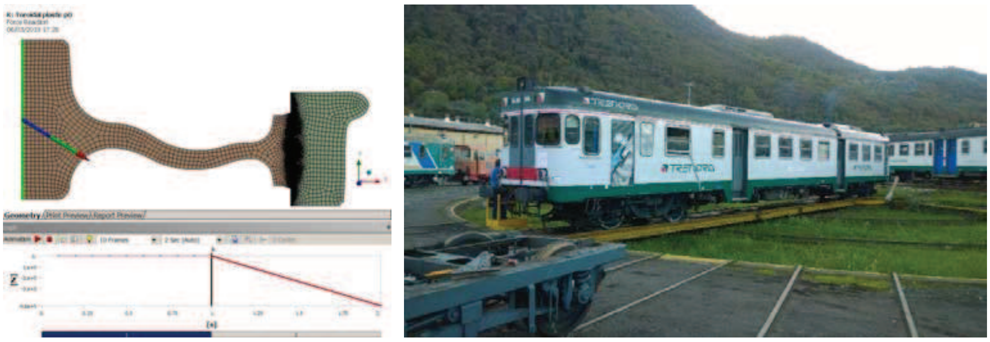


Fig. 3 *Left: Finite Element proved that the solution without retaining ring is as safe as the one with the retaining ring. Right: during the line tests (Nov. 2018).*

Obr. 3 *Vľavo: MKP preukázala, že riešenie bez poistného prstenca je bezpečné tak isto, ako s poistným prstencom, vpravo: počas jazdných skúšok (nov. 2018)*

Design was adapted to the vehicle available for testing, 12 samples were produced and a bogie was equipped with 4 casted wheel centres and the aforementioned solution for tread taper. Design details can be found in [14]. ***Fig. 4, Fig. 5*** and ***Fig. 6*** illustrate the phases of the testing of the *Liberty Wheel* (May 2019).

One of the most interesting features of this project is the fact that the supply chain is totally different from conventional forged and rolled wheels. Foundries able to provide perfect quality spheroidal cast iron parts are many more than the existing wheelset manufacturers. The other central advantage of this technology is that wheel centres and axles last forever (no need to change them unless in case of accidents), dramatically reducing costs. Once the wheelsets are in service, only fully machined tyres have to be purchased and (very simply) replaced. For all of these reasons the project was named *Liberty Wheel*.

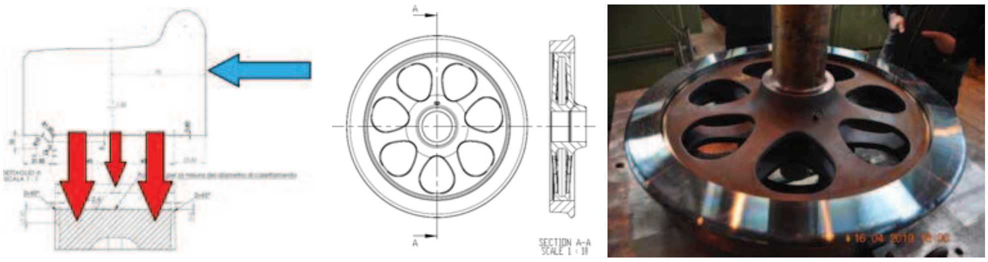


***Fig. 4** Left: Justification for the need of a two-rank of spokes wheel centre. Mid: design of the wheel centre. Right: assembly of the first Liberty Wheel with ADI cast iron wheel centre.*

***Obr. 4** Vľavo: zdôvodnenie potreby dvojradového hviezdicového stredu kolesa, v strede: konštrukcia stredu kolesa, vpravo: montáž prvého Liberty Wheel s odlievaným kotúčom*

***Fig. 5** Left: the first Liberty Wheel produced. Right: set of wheelsets ready for line tests (one conventional bogie and one with Liberty Wheels for comparison).*

***Obr. 5** Vľavo: prvé vyrobené Liberty Wheel, vpravo: dvojkolesia pripravené na jazdné skúšky (jeden konvenčný podvozok a jeden s Liberty Wheels pre porovnanie)*

We are at the moment engaged in the development of a *Liberty Wheel* for a double-deck passenger car, while a preliminary agreement was established with a braking equipment manufacture to develop a version of the *Liberty Wheel* with a “spoke-mounted” brake disc. Of course we can develop a specific *Liberty Wheel* for in principle any vehicle. The *Liberty Wheel* design is patent pending.

***Fig. 6** Liberty Wheels in the workshop (left) and during line tests (right).*

***Obr. 6** Liberty Wheels v dielni (vľavo) a počas jazdných skúšok (vpravo)*

3 INNOVATION IN WHEELSETS: THE *AIR WHEELSET*

The concept of fatigue was introduced by August Wöhler on the basis of the failure of a wheel of a locomotive. Axles are prone to fatigue failure as well and, being a safety component, they demand large maintenance resources for both equipment and skilled technicians. Independently Rotating Wheels (IRW) technology, applied to trams, eliminated the axles but fails in restoring the wheelset to the centred position even while running in straight track, and this explains why IRW technology is not used on heavier vehicles (metro, conventional rail, heavy haul) that do not require low-floor architecture as wheel flanges wear prematurely.

We developed a brand new concept for a wheelset whose wheels are supported by individual bearings (similarly to IRW) but are connected by a central shaft acting as a "torsion bar" restoring the connection between the wheels. For this reason the innovative wheelset was named "Apparently Independently Rotating" (*AIR*) Wheelset (***Fig. 7***).

SUB-ASSEMBLY	Symbol	Name	Code of practice	Description and function
BRIDGE	B1 (light purple)	Axlebridge	EN 13749:2011	Fixed (non rotating) axlebridge Supports vertcal-lateral-longitudinal loads
	B2 (red)	Transmission shaft	EN13104:2012 (loads)	Torsional joint between the wheels
	B3 (dark blue)	Stub axle	EN 13749:2011 VDI 2230:2003	Fixed wheel support bolted to axlebridge
WHEEL	W1 (green)	Wheel	EN 13979:2011 EN 13262:2011 (with modifications)	Derived from existing (homologated) wheels Lower stresses (no press-fit on the axle)
	W2 (grey)	Brake disks	EN 13979:2011	Web mounted brake discs (identical to existing ones)
	W3 (grey)	Bearings	EN 12082:2011 (with modifications)	Bearings (new arrangement mounted inside wheel hub)
	W4 (yellow)	Abutment rings on outer bearings race	VDI 2230:2003	Outer bearings race abutments
WHEELSET	A1 (grey)	Abutment rings on inner bearings races + internal flange	VDI 2230:2003	Inner race abutments + axial locking
	A2 (light blue)	External flange + torque limiter housing	VDI 2230:2003	Wheel locking + connection to torque limiter
	A3 (dark purple)	Torque limiter	N/A	Torque limiter (let the wheel to rotate freely)

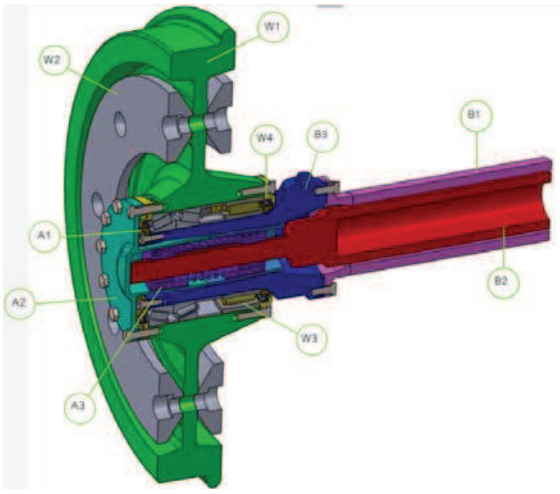


Fig. 7 *Components of the AIR Wheelset*

Obr. 7 *Komponenty AIR dvojkolesia*

The concept, introduced in [1], removes the axle and therefore the related failures (a fixed axlebridge is present instead) and issues proper warnings with large advance as deteriorating bearings conditions are easy to detect by temperature (while an axle works perfectly one second before fracturing for fatigue). It should be also considered that inboard bogies are spreading today and that *AIR Wheelset* components (web-mounted brake discs, large bore bearings) are readily available on the market. Bearings temperature monitoring has become a standard for passenger vehicles and also freight wagon are nowadays "smarter" than before including sensors and "intelligence" thanks to the "digital revolution".

Another great advantage of the solution is that wheels concentrate all serviceable components (the wheel itself, brake discs, bearings) in one element, dramatically simplifying maintenance, that can be performed everywhere with simple tools. Last, but not least, the optional use of suitable torque limiters improves steerability and reduces wear, corrugation and noise due to negotiation of sharp curves, while keeping the conventional wheelset behaviour in straight track and mild/large curves ran at higher speeds.

The amount R&D of work we performed on the *AIR Wheelset* is too large to be described here. The reader is referred to papers [2] about running dynamics, [3] about contact mechanics and curving, [4 about the validation of the torque limiter, [5] about the estimation of bearings life, [6] about the evaluation of savings in maintenance, [7] about the integration of the AIR Wheelset with inboard bearings bogies and [16] about the Common Safety Analysis of the new design.

Wheelset manufacturers for clear reasons opposed the introduction of the *AIR Wheelset* as the axle disappears. This is in fact at the same time an enormous advantage for the final user and a great loss of business for wheelset manufacturers.

We developed the design of the AIR Wheelset solution for freight wagons, passenger cars and also for driven axles. We are therefore readily available to develop the design for any specific situation. The *AIR Wheelset* solution is patented.

4 INNOVATION IN FREIGHT BOGIES: THE *4L BOGIE*

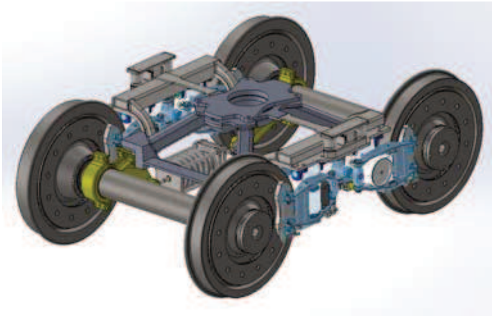
Almost all freight wagons are equipped with bogies of the Y25 series or derivate. Low manufacturing costs, high standardization and high reliability are key feature of this bogie that is more than 50 years old.

Nevertheless, Y25 bogies have known speed limitations linked to poor running dynamics over 120 km/h when unloaded and to braking power (tread braking only) over 100 km/h when loaded. Newer series of Y25 and “competitor” bogies include rubber elements, hydraulic dampers, two-stage suspensions, disc braking and other “improvements”. Although running dynamics benefits from these changes, costs are so high that none of these “new” bogies seriously eroded market segments to the good, old, classical Y25. Some minor modifications, like symmetric Lenoir Links or cross-bracing improved some features of the bogie, but its limitations largely remain.

We developed a brand new concept of an inboard bearings bogie to replace the Y25 fighting on the same ground, i.e. keeping the same interface and using only one stage of suspension and welded steel elements. As cost is paramount in the freight industry, we decided to keep as much as possible the new bogie sticking to extremely simple components and solutions.

As the vertical load is around least ten times the maximum lateral load, the most straightforward way to bring the vertical load acting on the centre bowl to the wheel-rail contact point is the use of a very lightweight truss structure with four “legs” (from which the name “*4L bogie*”) that are only subjected to compression (not to bending). The other key feature is the use of swinging arms that convert the vertical movements of the wheelsets in a longitudinal movement reacted by a common progressive coil spring (the whole bogie has only 2 springs compared to 16 springs of Y25).

Fig. 8 shows the *4L bogie* in the configuration with web-mounted brake discs and the AIR Wheelset. The version with conventional wheelsets (with thermostable wheels) and tread braking with compact brake units has a mass of approximately 3600 kg, a value not reachable by the Y25 under any circumstance. Main elements are made by welded standard profiles, while a load-dependent friction damping is provided in the hinges of the swinging arms by suitable wear elements.



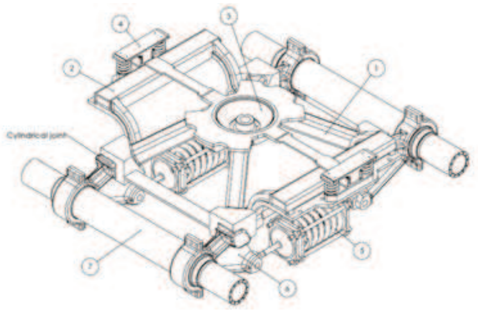


***Fig. 8** Left: 4L bogie with disc braking on wheel web. Right: main components of the 4L bogie. 1: pyramidal frame; 2: supporting arm for side bearer and brake callipers for wheel web mounted discs (or compact tread braking units); 3: centre bowl; 4: side bearers; 5: horizontal coil springs with single-stage progressive stiffness; 6: swinging arm; 7: Inboard bearings axlebridge for AIR wheelset (a design for conventional wheelsets already exists).*

***Obr. 8** Vľavo: 4L podvozok s kotúčovými brzdami pôsobiacimi na kotúčev koiesách. Vpravo: hlavné prvky podvozku 4L: 1 - ihlanovitý rám, 2 – nosné ramená pre klznice a brzdové klieštiny pre disky namontované na kotúče kolies (alebo brzdové jednotky klátikovej brzdy), 3 – spodná časť guľového otočného čapu, 4 – klznice, 5 – horizontálne vinuté pružiny s lomenou charakteristikou, 6 – kyvné rameno, 7 – nosník pre vnútorné ložiská AIR dvojkolesia (konštrukcia pre konvenčné dvojkolesia už existuje)*

Running dynamics of empty, partially loaded and fully loaded vehicles with 4L and Y25 bogies is described in papers [12] and [17], from which the superiority of 4L immediately arises. Stability is achieved at over 140 km/h in empty conditions, while maximum stable speed at full load increases up to 165 km/h (but braking may be insufficient). Structural strength and flexibility, opposite but equally important design targets for a bogie that has a rigid frame, were conducted according to EN 14363 on running dynamics and EN 13749 on loads acting on the bogie.

We can provide all the support necessary to manufacture, test and homologate the bogie with existing vehicles having full simulation capabilities of structural validation as well as running dynamics assessment.

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Summary

Innovation looks nowadays devoted only to digital revolution. Nevertheless, the authors developed some brand new concepts about running gears and structural elements thanks to improvements in calculation resources, modern manufacturing techniques and the use of new material..

The paper introduces a novel concept of tyred wheels (“Liberty wheels”) that dramatically affects maintenance, an innovative wheelset (“AIR Wheelset”) that improves safety (and reduce costs) and a bogie frame for freight wagons (“4L bogie”) that saves up to 3 tonnes on a conventional freight wagon at the same time increasing the speed.

All these innovations were assessed by virtual homologation and are ready for deployment. The designs and the products are patented or patents are pending.

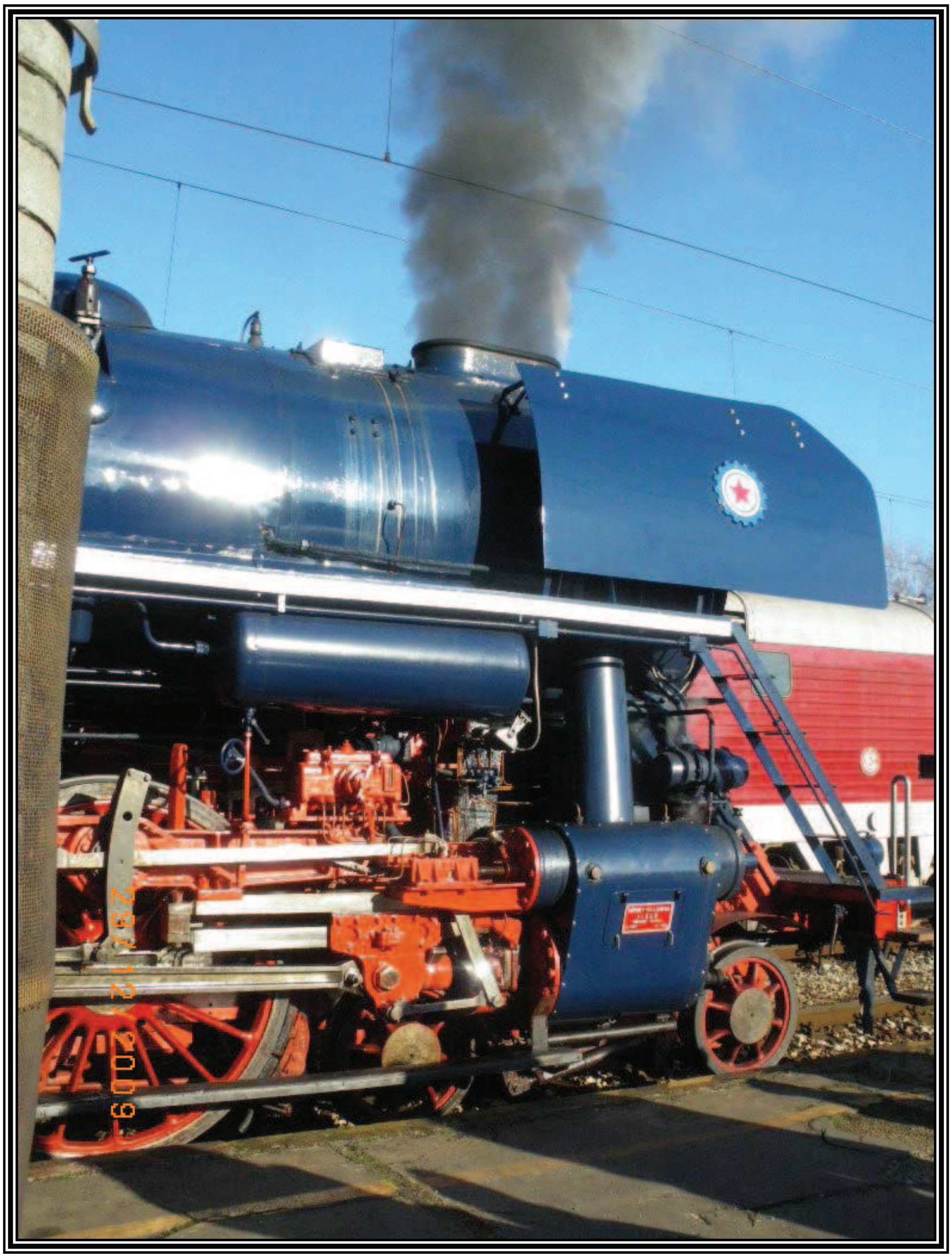
Resumé

Zdá sa, že inovácie sú v súčasnosti zamerané iba na oblasť digitálnej revolúcie. Autori vyvinuli niektoré nové koncepcie v oblasti pojazdu a konštrukčných prvkov vďaka pokroku v oblasti výpočtových metód, moderných výrobných technológií a používaní nových materiálov.

V príspevku sú uvedené nové koncepty obručových kolies (“Liberty wheels”), ktoré dramaticky ovplyvňujú údržbu, inovatívnych dvojkolesí (“AIR Wheelset”), ktoré zlepšujú bez-

pečnosť (a znižujú cenu) a rám podvozku pre nákladné vagóny (4L bogie"), ktorý vedie k zmenšeniu hmotnosti konvenčného nákladného vagóna o 3 t a súčasne zväčšuje rýchlosť.

Všetky tieto inovácie posúdené virtuálnou homolgizáciou a sú pripravené na použitie. Konštrukcie a produkty sú patentované alebo v patentovom riadení.



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