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Passive Safety Mechanisms in Freight Wagons

Maciej GRZYWNA[1], Tymoteusz RASIŃSKI[2]

Summary
Safety is one of the most important aspects of the railway sector. The issue is of particular significance in the transportation of hazardous goods that pose a threat to human health and life and have a damaging effect on the natural environment. Modern structures of freight wagons meet the requirements specified mainly in the International Carriage of Dangerous Goods by Rail (RID), enabling safe transportation of these goods by rail. Equipping them in appropriate passive safety mechanisms makes it possible to limit the negative effects of any potential adverse events. These mechanisms feature sub-assemblies that make it possible to absorb impact energy, eliminate the wheel climbing phenomenon, detect instances of derailment, and reduce the damage caused to wagon filling valves.

Keywords: passive safety, freight wagons, dangerous materials, railway sector

1. Introduction

Carrying dangerous goods by rail involves certain risks caused by fire, chemical, and ecological hazards [17] These threats mean that there is a likelihood of hazards caused by the occurrence of adverse events, especially incidents as well as minor and major accidents, which may take place as a result of damage and manufacturing defects of rail vehicle elements. Other causes include mistakes made in the process of use and operation, adoption of incorrect methods and inappropriate workflow organisation, mistakes and insufficient qualifications of staff, poor technical conditions of infrastructure, filling or discharging performed incorrectly, adverse weather conditions, and acts of terrorism [8]. Occurrence of the said adverse events leads to threats to human health and life, to degradation of the natural environment, and to damage or destruction of material assets.

In the sector of freight carriage by rail, the problem of transporting dangerous goods is found to occur mainly in the area of the structure and the equipment of tank wagons and tanks. In order to mitigate the effects of adverse events, including damage to the bearing structure of vehicle platforms and the transported goods as a result of, for example, travelling at an excessive speed or derailment, the vehicles feature a range of structural solutions and sub-assemblies classified as passive safety mechanisms. They are capable of:

- absorbing and dispersing excessive dynamic force that remains uncontrollable during a collision, which takes the form of elastic and plastic deformation,
- eliminating or limiting the effects of vertical misalignment of buffers – so-called climbing, often leading to the wagon's headstock (tank end) becoming damaged and punctured,
- limiting the damage caused to wagon tank filling valves,
- detecting wagon break-downs, especially instances of derailment,
- providing thermal protection to the carried load,
- improving rescue activities when rail incidents occur.

2. Rules and regulations addressing the carriage of dangerous goods by rail

The practice of entities involved in the carriage of dangerous goods by rail is made uniform and regulated by international regulations, including:

- Regulation on the International Carriage of Dangerous Goods by Rail (RID) [11], which is Appendix C to the Convention on International Carriage by Rail (COTIF),

[1] Eng.; Tadeusz Kościuszko University of Technology, Faculty of Mechanical Engineering; e-mail: grzywna.maciej@student.pk.edu.pl.
[2] M.Sc. Eng.; Tadeusz Kościuszko University of Technology, Faculty of Mechanical Engineering, Institute of Rail Vehicles; e-mail: tymoteusz.rasinski@mech.pk.edu.pl.

- Rules for transportation of dangerous goods – Annex 2 to the Agreement on the International Goods Transport by Rail (SMGS).

If dangerous goods are transported to countries who are not parties to the Convention on International Carriage by Rail (COTIF), provisions arranged between the parties involved shall apply – provided that the transportation takes place in accordance with the security requirements set in RID [16].

In addition, the carriage of dangerous goods by rail in Poland is regulated by the following domestic laws and regulations:

1. PKP PLK internal instructions: Ir-1, Ir-3, Ir-8, Ir-9, Ir-13, Ir-15 [Instrukcje spółki PKP PLK S.A.: Ir-1, Ir-3, Ir-8, Ir-9, Ir-13, Ir-15];
2. Uniform text act, Journal of Laws of the Republic of Poland of 2015, item 915 as amended [Ustawa z dnia 15 listopada 1954 r. Prawo przewozowe, Tekst jednolity Dz.U. rok 2015, poz. 915 z późniejszymi zmianami];
3. Uniform text act, Journal of Laws of the Republic of Poland of 2017, item 576 as amended [Ustawa z dnia 29 listopada 2000 r., Prawo przewozowe, Tekst jednolity, Dz.U. 2017 r. poz. 576 z późniejszymi zmianami];
4. Uniform text act, Journal of Laws of the Republic of Poland of 2017, item 1040 as amended [Ustawa z dnia 21 grudnia 2000 r. o dozorze technicznym. Tekst jednolity Dz.U. 2017 r. poz. 1040 z późniejszymi zmianami];
5. Uniform text act, Journal of Laws of the Republic of Poland of 2017, item 519 as amended Ustawa z dnia 27 kwietnia 2001. Ochrony środowiska. Tekst jednolity, Dz.U. 2014 r., poz. 1987 z późniejszymi zmianami];
6. Uniform text act, Journal of Laws of the Republic of Poland of 2016, item 1987 as amended Ustawa z dnia 14 grudnia 2012 r. o odpadach. Tekst jednolity Dz.U. 2016, poz. 1987 z późniejszymi zmianami];
7. Uniform text act, Journal of Laws of the Republic of Poland of 2017, item 2117 as amended Ustawa z dnia 23 marca 2003 rok o transporcie kolejowym. Tekst jednolity Dz.U. 2017, poz. 2117 z późniejszymi zmianami];
8. Uniform text act, Journal of Laws of the Republic of Poland of 2016, item 1834 as amended Ustawa z dnia 19 sierpnia 2011 r. o przewozie towarów niebezpiecznych. Tekst jednolity, Dz.U. rok 2016, poz. 1834 z późniejszymi zmianami;
9. Regulation of the Minister of Infrastructure of 18 July 2005 (uniform text in the Journal of Laws of the Republic of Poland, item 360 as amended) [Rozporządzenie Ministra Infrastruktury z dnia 18 lipca 2005 r. w sprawie ogólnych warunków prowadzenia ruchu kolejowego i sygnalizacji. Tekst jednolity Dz.U. 2015, nr 172. poz. 1444 z późniejszymi zmianami];
10. Regulation of the Minister of Transport of 2 November 2006 (Journal of Laws of the Republic of Poland of 2007 no. 9, item 63) [Rozporządzenie Ministra Transportu z dnia 2 listopada 2006 r. w sprawie dokumentów, które powinny znajdować się w pojeździe kolejowym. Dz.U. 2007, nr 9, poz. 63, Dz.U. z 2007 r. Nr 9, poz. 63];
11. Regulation of the Minister of Infrastructure and Construction of 16 March 2016 (Journal of Laws of the Republic of Poland of 2016, item 369) [Rozporządzenie Ministra Infrastruktury i Budownictwa z dnia 16 marca 2016 r. w sprawie poważnych wypadków, wypadków i incydentów w transporcie kolejowym, Dz.U. rok 2016 r. poz. 369].

As for tank wagons intended to carry dangerous goods, it is necessary to take into consideration "T" special provisions. These are applicable when there is an appropriate note on the application of a given special provision for a given dangerous good listed in column 13 of Table A, item 3.2 of RID [11]. The said special provisions are divided into 6 categories:

- TU – Using,
- TC – Construction,
- TE – Items of equipment,
- TA – Type approval,
- TT – Tests,
- TM – Marking.

3. Passive safety mechanisms

In order to meet the requirements for the carriage of dangerous goods as set under the said legal rules and regulations, tank wagons need to be designed featuring appropriate sub-assemblies and structural solutions as listed in Table 1 and marked in Figure 1.

Table 1

Sub-assemblies and structural solutions acting as passive safety mechanisms to be featured in freight wagons with regard to the special provisions of RID

Number	Sub-assembly / structural solution	RID special provision
1	Crash buffer	TE22
2	Pneumatic derailment detector	–
3	Anti-climbing module	TE25
4	Tank end wall protective shield	TE25
5	Thermal overload protection module (sun shield)	TE12
6	Filling valve protection frame	–
7	Wagon lifting points	–
8	Tank end wall thickness of 12 or 18 mm	TE25

[Own study].

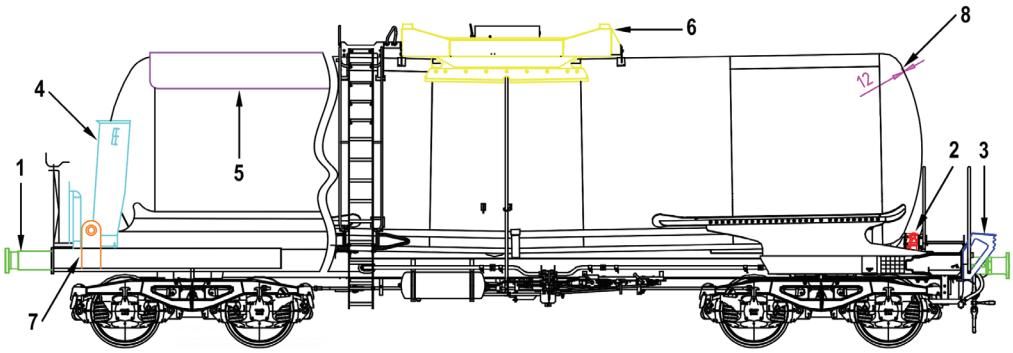

Fig. 1. A model design of a freight wagon equipped with all the essential passive safety mechanisms, in accordance with the requirements set in the RID special provision regarding the category of equipment – TE. The sub-assemblies are described in Table 1 [drawing of authors]

3.1. Crash buffers

The main elements that attenuate the longitudinal forces impacting rail vehicles are buffers. They act as agents between pulled, pushed, released, and otherwise marshalled rail vehicles.

According to special provision TE22 item 6.8.4 b) of RID [11], tank wagons and battery wagons shall be capable of absorbing at least 800 kJ of energy of elastic or plastic deformation affecting each end of the wagon, the subframe, and any additional absorption elements – on a straight track. The tank itself may not take part in the act of absorption on account of the risk of becoming damaged or deformed. Energy absorption by means of plastic deformation shall only occur in conditions other than those encountered during normal conditions of rail transport, i.e. impact speed higher than 12 km/h or individual buffer force greater than 1,500 kN. The requirements set in the provision in question are considered met if crash buffers compliant with PN-EN 15551 [13] and PN-EN 12663-2 [12] standards in the scope of underframe strength are applied. Deformable buffers absorb energy by means of plastic deformation of the buffer casing, as shown in Figure 2.

A standard "crash buffer" needs to absorb and disperse energy of the minimum amount of 400 kJ – in the case of modern freight wagons, or 250 kJ – in the case of older-type freight wagons [3]. A buffer absorbing impact energy is fixed to a wagon's headstock at four points by means of screws tightened with the torque as specified by the wagon's manufacturer. Its spatial dimensions are in accordance with UIC 526-1 [9]. This makes it possible to use buffers of such type interchangeably with standard buffers.

Verification of deformable buffer suitability involves an organoleptic inspection performed by evaluating the section of insertion of the plunger into the casing. The procedure in question can be carried out by referring to an orange triangle painted on the plunger with its vertex facing the casing – Fig. 4. If the triangle is fully outside the casing, the buffer is suitable for use. If a part of the triangle is inside the casing, the buffer might have been plastically deformed to some extent, and as such should be replaced because it is not suitable for further use.

Fig. 2. A buffer absorbing impact energy after plastic deformation of the casing [7]

According to analyses conducted in [3], the price of a crash buffer is two times higher than that of a standard buffer; with four buffers, this gives us a difference of approx. EUR 3,000.

3.2. Pneumatic derailment detector

Freight wagon derailment occurs much more frequently during shunting than during line travel at an increased speed. It often happens because of mistakes made by shunting crew members, e.g. failing to remove brake skids from underneath the wheels before shunting activities start. The material damage occurring as a result of instances of derailment is estimated to amount to millions of euros [14]. During line travel, without any additional aids, the train driver is often unable to notice and detect an occurrence of longitu-

dinal forces caused by derailment of a single wagon or a group of wagons forming a freight train of significant length. When derailment occurs, the train wagons do not always become decoupled and the railway air brake hose (main hose) remains intact. There have been cases of a derailed vehicle travelling for many kilometres, which translates into significant financial losses related to damage caused both to primary and auxiliary railway infrastructure and to trackside equipment. Moreover, damaged rolling stock may pose an additional danger e.g. in the case of leakage from the tank of a vehicle carrying dangerous goods.

To minimise the likelihood of such events and maintain the number of instances of damage related thereto at a low level, derailment detectors are used. They make it possible to automatically initiate the procedure of emergency braking by releasing compressed air from the main hose. This means that the brake cylinders in all train wagons with active service brakes, coupled pneumatically, are filled quickly with air. Derailment detection devices function on the basis of measurements of acceleration in the oscillatory movement of moving mass reacting to vertical acceleration of the train frame. It is important that once a detector is installed, freight wagons still comply with the relevant interoperability requirements, and that the requirements for vehicle service and maintenance do not change.

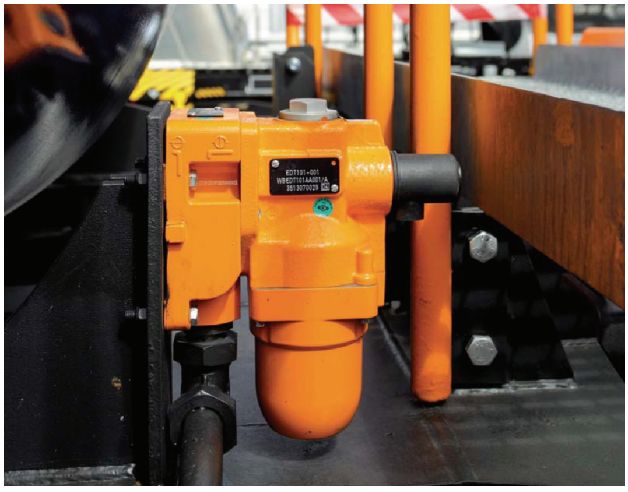

Fig. 3. An example of application of an EDT101 derailment detector in a freight wagon [2]

An example of such a sub-assembly is a derailment detector labelled as EDT101, introduced into the market by Knorr-Bremse. The device can be installed in a wagon without any major modifications necessary to be made to its structure. A possible application of the derailment detector in question is shown in Figure 3. The device is maintenance-free, which means it does not require any additional works to be carried out during the scheduled inspections and repairs. The manufacturer stresses that the installation of the detector should not be used as an excuse for improperly performed maintenance activities. Once a derailment is detected, a red indicator appears on the side of the device, which acts as a notification that the device has just been activated. The indicator remains in the warning state until it is reset to its original position by means of pushing it manually inside the body of the device. In addition, the EDT101 detector features an automatic reset function – i.e. returning to its original position.

Freight carriage by rail is especially sensitive to changes to cost structure, which is why equipping the rolling stock in use with additional devices needs to be reasonably justified. The application of pneumatic devices involves lower investment costs and does not require electrical energy – unlike electronic devices, which is particularly problematic in the case of freight wagons.

When analysing the advantages and disadvantages of the solution in question, it is also necessary to bear in mind the risk that it may malfunction when put into operation. According to studies carried out in Switzerland [14], up to 3% of unnecessary train halts resulting from emergency braking occurred due to the malfunctioning of derailment detectors. This is connected with the occurrence of greater-than-expected vibration levels and overheating of the lubricant in the detectors, which is caused by an excessively high level of ambient temperature. It is obvious that false activation of emergency braking is much unwanted – it leads to delays, mostly of approx. 20 minutes, but it usually does not cause threats to safety. The manufacturer modified the solution accordingly by rescaling the detector's sensitivity from the range of 5÷10 g to 6.5÷11.5 g, which helped bring the rate of false detections to 0. The European Union Agency for Railways (ERA) [4] has published a report according to which even 2–3% of instances of unnecessary braking caused by incorrect detections of derailments does not speak against the feasibility of applying such devices in freight wagons.

Basically, the application of derailment detectors may raise doubts as to the conformity of the functioning of such devices with the requirements of the Technical Specification for Interoperability (TSI) relating to "safety in railway tunnels", concerning the provision on emergency braking in the case of a fire hazard when travelling through a tunnel. According to [2], item 4.4.2., which defines the relevant emergency rule, the train should be brought to a halt before entering a tunnel, or driven out of a tunnel – except during a derailment, which requires an immediate stop. Therefore, any doubts as to the said conformity with the TSI requirements in question are unjustified.

3.3. Anti-climbing module

A common scenario of a rail accident involves one railway vehicle running into another at an excessive speed, which leads to their structures becoming deformed and – quite frequently – their buffers missing each other in the vertical plane, which results in neighbouring vehicles climbing one on top of the other. To prevent this highly harmful phenomenon, leading to, among others, leakage of the tank of a wagon carrying dangerous goods, freight wagons are constructed in a way to feature special solutions preventing the occurrence of climbing. Basically, a set of modules is composed of four low-weight elements (each weighing several dozen kilograms) fixed directly to the vehicle headstock.

According to RID special provision TE25 item 6.8.4a) [11], wagon tanks need to be protected against buffer misalignment and derailment or in order to control the damage caused by such events. The anti-climbing module is designed in a way to completely eliminate the phenomenon of climbing. During a crash, it should guarantee the following:

- that the wagon underframe remains on the same level,
- that the wagon's static and kinematic gauges remain unchanged, including the Berne gauge (space for the coupler),
- that the vehicle is able to pass a curved track of the radius of 75 m,
- that the buffer is able to function normally when exposed to elastic and plastic deformation,
- that it works as intended regardless of the load and wear,
- that it is capable of withstanding a vertical load of 150 kN upwards and downwards,
- that it works regardless of the equipment featured in the neighbouring vehicle,
- that it comes with the width equal to at least the width of the buffer plate (and it should be featured on each buffer),
- that it is compatible with buffers compliant with EN12663-2 [12] and EN 15551 [13] standards,
- that it does not pose a threat of the tank's end wall becoming punctured.

An example of an anti-climbing module preventing buffers from vertical misalignment is AC04 manufactured by EST, shown in Figure 4. There are also other anti-climbing modules available on the market, featuring a slightly different design, offered by Ermewa and VTG Rail Europe.

3.4. Tank end wall protective shield

The requirements to limit the damage occurring as a result of vertical misalignment of wagons carrying dangerous goods are defined in RID special provision TE25, item 6.8.4b), c), d) [11]. The damage caused by this very harmful phenomenon can be minimised by:

- increasing the thickness of tank end walls to at least 12 mm or no less than 18 mm in the case of the carriage of gases UN 1017 CHLORINE, UN 1749 CHLORINE TRIFLUORIDE, UN 2189 DICHLOROSILANE, UN 2901 BROMINE CHLORIDE AND UN 3057 TRIFLUOROACETYL CHLORIDE, or using material of a greater impact energy absorption capacity, TE25 item 6.8.4b) – RID [11],
- using tanks with sandwich cover ends –TE25 item 6.8.4c) of RID [11],
- applying a protective shield at each wagon end – its width should be equal to at least the distance between the outer edges of buffer plates, and its height should cover, measuring from the upper edge of the headstock, at least two thirds of the tank diameter or at least 900 mm; it should also be equipped with an arresting device for climbing buffers; it should offer appropriate wall thickness (at least 6 mm) and be fixed in a way that the possibility of the tank ends being penetrated by the protective shield itself is minimised – TE25, item 6.8.4d) RID [11].

Fig. 4. An EST AC04 anti-climbing module and a deformed EST G2 buffer absorbing impact energy [6]

An example of a headstock protective shield fitted to a wagon tank is presented in Figure 5.

Fig. 5. A tank headstock protective shield and a grip supporting rescue activities [5]

3.5. Thermal overload protection module

In the event of carriage of liquefied gases, the wagon tank needs to feature an appropriate thermal insulation solution in accordance with RID, item 6.8.3.2.14 [11]. Such a solution can be a complete cladding (of adequate thickness) made of insulating materials or a sun shield (Fig. 6) covering at least 1/3 (but not more than half) of the upper part of the tank's surface. The sun shield should not adhere directly to the tank; there should be at least 4 cm of air clearance between them.

The issue of thermal insulation is also addressed by special provision TE12 defined in RID item 6.8.4 (referring to item 6.8.3.2.14), according to which the sun cover and all other exposed parts of the tank shall be painted white or finished in bright metal. The paint coating should be cleaned before each transport journey and renewed in the event of yellowing or deterioration. Tanks shall be fitted with spring-loaded safety valves, emergency pressure-relief devices, and devices to measure the (real) temperature level. If the carried goods and their decomposition products are combustible, the vacuum-relief devices and spring-loaded safety valves of tanks shall feature flame arresters. Due attention shall be paid to the reduction of the relief capacity caused by the featured flame arresters when making relevant calculations.

Fig. 6 . A sun shield covering the top part of a tank [1]

3.6. Module protecting tank filling valves in the event of tipping over

A railway accident may also involve a wagon derailing or tipping over – as a result of rolling down a railroad fill or hitting a bridge pier, a building, or a tree bough. In the case in question, the valves and hatches found on the upper part of the wagon are especially exposed to damage. In order to prevent the said subassemblies from becoming damaged, it is necessary to apply appropriate protection measures. An example of such a solution is a high-durability and low-weight (approx. 500 kg) frame made of structural steel labelled as UE01, designed by WASCOSA – Fig. 7. It protects the upper zone of filling valves (hatches) against colliding with fixed/rigid objects. The manufacturer guarantees the solution's effectiveness if a wagon rolls down a fill of up to 4 m in height.

Fig. 7. A UE01 module protecting tank filling valves in the event of tipping over [1]

3.7. Wagon lifting points

VTG Rail Europe has made some tank wagons feature additional lifting points that make it possible to lift a freight wagon during a rescue operation quickly and relatively easily. A single vehicle features 4 such lifting points, each offering a lifting capacity of 25 tonnes. They are integral parts of the wagon's underframe. The module in question is shown in Figure 5.

4. Conclusions

The freight wagons of today are designed in a way that makes carrying dangerous goods by rail safe. Adequately formulated requirements (mainly those specified in RID) significantly limit the risk of hazards resulting from adverse events. Modern passive safety mechanisms are capable of absorbing impact energy, preventing or mitigating the effects of vertical misalignment of buffers, detecting vehicle derailments, and providing thermal protection to the carried goods. In principle, equipping a rail vehicle

with appropriate structural solutions and protection devices makes the vehicle's empty weight increase by 1.2 t [10] on average, which leads to a limited carrying capacity at the same vehicle length – a crucial matter in the context of freight transportation. Applying passive safety mechanisms in freight wagons involves an increased cost of purchase, which translates into higher costs of transportation of dangerous goods by rail.

A device that may soon become a very common solution, found in the majority of freight wagons – not just in vehicles designed to carry dangerous goods, is a derailment detector. Thanks to this small-sized subassembly, easy to install in the rail vehicles currently in use and operation, it is possible to considerably limit the negative effects of derailments, which lead to significant material damage and railway traffic interruptions.

The passive safety mechanisms featured nowadays in freight wagons do require certain initial expenditure, but they improve the level of safety of carrying dangerous goods by rail to a great extent.

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