A concept of technology for freight wagons modernization

M Płaczek1, A Wróbel1 and A Buchacz1

1 Silesian University of Technology, Faculty of Mechanical Engineering, Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Konarskiego 18A, 44-100 Gliwice, Poland

E-mail: marek.placzek@polsl.pl

Abstract. Rail transport is a very important part of the modern economy, one of the components determining its dynamic development. It is therefore important to conduct research and taking action aimed at the development and refinement of this branch of industry. Such actions directly translate into an increase in its effectiveness, safety, reduction of burden on the environment and society. Nowadays numerous studies are conducted, aimed at introducing new technologies and solutions, both in terms of railway infrastructure and logistics management systems, as well as in traction vehicles themselves. Introduction of modern technology helps eliminate or reduce nuisance problems associated with the implementation of any kind of transport or the operation of the used technical means. Presented paper concerns an issue of freight wagon modernization using composite materials. It presents a part of a research project that aim is to develop a technology of freight wagons modernization during their periodic repair. The main problem during exploitation of concerned types of freight wagons designed for coal transport is corrosion of the wagon’s body shell. The goal of the project is to elongate the period between periodic repairs (by better corrosion protection) and improve conditions of exploitation of modernized freight wagons (for example easier unloading during winter conditions – no freezes of the charge to the freight wagon body shell). One of elements of the project is also to develop a system for diagnosing the technical condition of the modernized shell of wagon body during operation. For this purpose the use of non-destructive testing methods of technical state of constructions will be used, including methods that use the analysis of dynamic response of the object. Application of the composite panels to the freight wagon’s body shell was proposed as the solution that can solve mentioned problems during exploitation of freight wagons. The composite panels composed of fiberglass and epoxy resin were proposed. They will be mounted on the body shell using blind rivet nuts. What is more the body shell of the modernized freight wagon will be painted using an anti-corrosion agent. The research project is realized by a consortium composed by research units and industry and supported by the Polish National Centre for Research and Development.

1. Introduction
Railway transport is very important for the development of the modern economy this is why many research works concerning with problems occurring in this way of transport and its development are being carried out all the time [1-3]. The goal of those works are usually to develop the infrastructure that is used for transport of goods and people, make it more cost-effective, safe and less burdensome for the environment [4-6]. Very important are problems of freight wagons dynamics during exploitation in variety driving conditions [7-11]. In all of those works the problem of modelling of real
object has a strong influence on obtained results and has to be solved using precise methods [8, 12-18]. This is why computer-aided methods, include Finite Element Method, are used very often [19-24]. On the other hand, experimental analysis and tests are also very important in order to verify results of calculations and simulations [25]. Nowadays, computer aided methods, new materials and technology are widely used in development of all technical devices [26-33].

Presented paper concerns the possibilities of freight wagons modernizations using composite materials [24-37]. Work presents a concept of technology for modernization of freight wagons using composite panels and a report of the process of modelling and computer aided analysis of freight wagon type 1415 A3 designed for coal and aggregate transport. It is a part of the research project that is carried out by the consortium that consists of research unite – Institute of Engineering Processes Automation and Integrated Manufacturing Systems of the Silesian University of Technology and enterprises – DB Schenker Rail Poland SA and Germaz. The aim of this research project is to modernize the analysed freight wagon during its renovation using new materials. Effects that are to be achieved by the modernization are:
- better corrosion protection of the wagon elements,
- easier unloading of the wagon in winter conditions (no freezing of the cargo to the floor and sides),
- reduction of the weight of the wagon while its payload increases,
- easier management of the freight wagons during exploitation.

In this work the process of modelling of the analysed freight wagon using Siemens NX software is presented. The 3D model was created on the basis of very incomplete documentation and measurements of the real object. Precision of the created model was verified by checking its mass after defining material properties of wagon components and juxtaposing it with the mass of the real wagon. The created 3D model is very detailed and obtained discrepancy is about 5% of the real freight wagon mass. After its verification the model was used in strength analysis using the Finite Element Method in NX software. Obtained results – stress and displacements of elements were calculated.

2. The analysed types of freight wagons – problems during exploitation

The presented work is continuation of the previous research project concerned with modernization of the freight wagons using new, non-classical materials. The proposed solution for modernization of the freight wagons shells was to use the composite materials connected to the old elements made of steel. In this research project the scope of works is wider. Not only tasks concerned with use of new materials in the freight wagons body in order to obtain better corrosion protection and easier unloading are considered. The possibility of reduction of the weight of the wagon while its payload increases is also considered as well as introduction of systems for easier management of the freight wagons during exploitation (monitoring, management of the freight wagons life cycle).

In the present research project four types of freight wagons were considered:
• type 1415 A3 of open freight wagon series EAOS, produced by BREC Belgium,
• hopper freight wagon type 418V,
• hopper freight wagon type FALS Slovak production,
• hopper freight wagon type FALS Bulgarian production.

In figure 1 created CAD models of all considered freight wagons are presented. The freight wagon type 1415 A3 was designed for coal and aggregate transport and was designed for tipping unloading. Examinations of real objects were performed and photographic documentation of damages of freight wagons prepared for repair was created. Also employees of repair facility were interviewed about typical defects and operation problems. Recurring damage and their causes were indicated. In case of all considered types of freight wagons the main problems occurring during their exploitation are: corrosion of the freight wagons shells of body and floors and freezing of the cargo to the sides and floor of the wagons. In case of the type 1415 A3 there is also a problem with damages of the vehicle body shells that occurs as the result of inappropriate methods of unloading (using scoop, excavator, etc.). For the wagon type 1415 A3 it can be also noticed that it has a very durable wagon supporting
frame and frame of the body – there is almost no damages in repaired wagons. It means that there is a possibility to reduce the weight by the use of smaller cross-sections profiles.

![Figure 1. CAD models of considered freight wagons.](image1)

In the presented research project an application of composite panels to the freight wagon’s body shell was proposed as the solution that can solve mentioned problems that occur during exploitation of freight wagons [34-37]. The applied composite panels will be composed of fiberglass and epoxy resin and will be mounted on the body shell using rivet nuts. The body shell of the modernized freight wagon will be painted using an anti-corrosion agent. The composite panels mounted on the modernized freight wagon’s doors and walls are presented in figure 2. The composite material that is to be applied is glass-epoxy composites based on epoxy resin belong to the group of chemically hardenable materials. They are produced as the result of fiberglass saturation and compressed into a layer. This type of composite was chosen because it is distinguished by the following features: good mechanical properties and insulation, high parameters of bending and compressive strength with low weight, the possible wide range of applications and also low water absorption.

![Figure 2. The modernized freight wagon 1415A3 and composite panels mounted on the modernized freight wagon’s door and wall.](image2)

On the other hand the system for structural health monitoring should be developed as a system that includes elements from different science areas, such as mechanics, electronics and informatics. Such connection brings new possibilities and new effects, so these systems can be called a mechatronic system [38-41]. Piezoelectric transducers were proposed to be used in the developed system. Taking
into account their possibilities, piezoelectric transducers can be used in various modern devices as sensors or actuators [42-49]. A process of freight wagons qualification to repair can be supported by the system designed for inferred from the dynamic response of the wagon about the changes in its technical condition. At this moment all freight wagons are verified about their technical condition at a certain time interval and during this qualification process a standard qualifying protocol is used. The protocol that is used by the DB Schenker Rail Poland SA Company during qualification process includes such data as:
- the analysed freight wagon’s type;
- the drawings including views of all side walls and the floor of the wagon;
- the identification number of the wagon;
- the date and type of the previous and actual repair;
- the list of wagon’s elements with the possibility to mark whether the item is suitable for repair, replacement, or it is in good technical condition;
- the responsible people signatures and the place for other notes.

During carried out research project a statistic analysis of data from qualifying protocols were analysed in order to verify if some wagon’s elements are the most exposed to damage during exploitation of freight wagons. Qualifying protocols from years 2012 up to 2014 were analysed and the number of analysed protocols in case of BDŻE, CFRE, CSDE, 401W, 408W and 412W types of freight wagons was 221. The percentage of repairs of individual wagons elements was specified on the basis of protocols analysis. Obtained results for mentioned types of wagons are presented on chart in figure 4. In order to analyse the data from protocols, all elements of the freight wagon’s body shell were named and marked on the scheme of the freight wagon. Designations of elements of the BDŻE, CFRE, CSDE, 401W, 408W and 412W wagons types are presented in figure 3.

![Figure 3. Designation of BDŻE, CFRE, CSDE, 401W, 408W and 412W wagon’s elements.](image)

The most important, taking into account the aim of the research work – the modernization of the freight wagons using composite panels mounted to their body shell, is the information about the damage of its elements. Percentage of repairs of individual elements of the shell of the body in case of BDŻE, CFRE, CSDE, 401W, 408W and 412W types of freight wagons is presented in figure 4.
Figure 4. Percentage of individual elements repairs of the body shell of freight wagons types BDŻE, CFRE, CSDE, 401W, 408W and 412W.

Analysis of qualifying protocols shows that there is no part of the freight wagon’s body shell that is more exposed to damage during exploitation of the wagons than the other elements. It is necessary to carry out a more accurate operational documentation in order to obtain more precise information about the process of damage of individual elements of the freight wagons body shell during their exploitation. This documentation should be created starting from the production of wagons and it should take into account operating conditions of carriage, such as the type of transported cargo, as well as all carried out repairs. The mechatronic system for structural health monitoring of freight wagons that is to be developed will also provide data about individual wagon’s operation conditions and it should be storage in wagon’s documentation. The system should inform about destruction of the wagon’s body shell during operation of the wagon. By using the system it will be possible to detect major defects of wagon’s body shell without transporting it to the service station. It is necessary to verify the possibility of inference from the dynamic response of the wagon about the changes in its technical condition during its standard operation in order to develop such system [34].

3. The CAD model of the considered freight wagon type 14151 A3

The presented in figure 1 CAD models of all considered in the research project types of freight wagons were created using the NX 8.5 software. In case of type 1415 A3 all documentation supplied by consortium member – DB Schenker Rail Poland SA, consists of:

- operation and maintenance manual,
- technical conditions of repair and receipt after repair of 4-axle freight wagon series Eaos type 1415 A3 production BREC Belgium,
- calculations of air brake,
- program of performance tests,
- report on the performance tests,
- 11 construction drawings including assembly drawing, drawings of support, wagon body, floor, cargo doors with overall dimensions, without giving details of the used profiles, sheet thickness, etc.

The incomplete documentation of the considered freight wagon supplied by consortium member forced the visual inspection of real objects and measurements. Selected elements of created CAD model of the considered freight wagon are presented in figures 5 to 7.
Figure 5. CAD models of the considered freight wagon’s elements – the support frame and floor.

Figure 6. CAD model of the considered freight wagon’s elements – the wagon’s body.

Figure 7. CAD models of the considered freight wagon’s elements – the wagon’s doors.
By juxtaposing the weight of the real object and the CAD model after the material parameters were applied, the created CAD model of the 1415 A3 type of freight wagon was verified. The weight of the considered freight wagon is 20600 kg, while the weight of the CAD model is 19500 kg. The difference in weight is 5.34 %. It is caused by omission of the braking system (air pipes, brake pads, etc.). It can be assumed that the created CAD model of the considered freight wagon is very precise and can be successfully used in next analysis.

4. The Strength analysis
As the next step of the presented work the strength analysis of the body of the considered freight wagon type 1415 A3 was carried out. It was realized using Siemens NX 8.5 software and Finite Element Method. In accordance with norm EN 12663-2:2010: Railway applications - Structural requirements of railway vehicle bodies - Part 2: Freight wagons [Required by Directive 2008/57/EC] the load of the model was assumed [50]. The structural design and assessment of freight wagon bodies depend on the loads they are subject to and the characteristics of the materials they are manufactured from in agreement with this norm. It is intended to provide a uniform basis for the structural design and assessment of the vehicle body within the scope of this European Standard. Based on proven experience supported by the evaluation of experimental data and published information the loading requirements for the vehicle body structural design and assessment are. The aim of this European Standard is to allow the supplier freedom to optimize his design whilst maintaining requisite levels of safety considered for the assessment [50].

The way of verification described by the norm is that the following tests are to be carried out:

- a) Forcing outwards in the horizontal direction at a level of 1.5 m above the floor:
  1) force of 100 kN applied at four centre posts of each side wall;
  2) force of 40 kN applied at the corner posts of wagons equipped with drop ends.

The significant permanent deformation at the point where the force is applied shall not exceed 1 mm. In addition, the elastic deformation observed during the test shall not result in any encroachment of the loading gauge. In figure 8 the way of the freight wagon forcing is presented [50].

![Figure 8. The way of the freight wagon forcing [50].](image)

The CAD model of the considered freight wagon was forced by a system of forces presented in figure 9. Those forces are transferred to the wagon’s body by additional rigid beams.
Results obtained using the Finite Element Method in NX 8.5 software are presented in figures 10 and 11 as the freight car displacements and stress respectively.

Maximum value of the displacement was equal 4,084 mm and it occurred on the upper side beam. Average stress obtained in strength analysis is 50-65 MPa while the yield strength is 235 MPa. The maximum value is 72 MPa.

The support frame analysis was carried out twice. In the first case only the uniformly distributed load of 58 tons (the maximum weight of cargo) was being taken into consideration, while in the second case also compressive force of 2 MN in the axis of bumpers was applied. In the first case the maximum value of displacement was 4,32 mm, and maximum stress 170 MPa, while its average values were about 40 to 60 MPa. In the second case the maximum displacement was 4,49 mm in the vertical axis and 0,74 mm in the axis of the bumpers. Maximum value of stress was 180 MPa and is average value was also about 60 MPa. Selected results are presented in figures 12 to 14.
Figure 12. Displacement of the considered freight wagon’s support frame.

Figure 13. Stress of the considered freight wagon’s support frame.

Figure 14. Displacement of the considered freight wagon’s support frame in the axis of the bumpers.

Also strength analysis of the cargo door was carried out. Obtained results are presented in figures 15 and 16. The maximum value of displacement is 4.49 mm and maximum stress is 160 MPa.

Figure 15. Displacement of the considered freight wagon’s door.

Figure 16. Stress of the considered freight wagon’s door.

Presented results of the strength analysis will be verified during the future works, while tests on the real objects and prepared laboratory stands will be carried out.
5. Conclusions
Railway transport is very important for the development of the modern economy. This is why nowadays there are a lot of research works concerned with this mean of transport that main aim is its modernization and development. It should be noted that there are a lot of problems with old infrastructure in railway transport that cases a lot of loss and not necessary costs. The goal of those works are usually to develop the infrastructure that is used for transport of goods and people, make it more cost-effective, safe and less burdensome for the environment.

Presented paper concerns the possibilities of freight wagons modernization during their periodic repairs. The possibility of composite materials application in the construction of the freight wagon body is considered as well as reduction of the weight of the wagon while its payload increases. In order to do it a series of analysis of the real object and its model in its present form had to be carried out, especially the strength analysis. The incomplete documentation of the considered freight wagon supplied by consortium member forced the visual inspection of real object and measurements. However, after the verification of the created CAD model it can be assumed that it is very precise and can be successfully used in such kind of analysis. The carried out analysis proved that there is a possibility to use smaller cross-sections profiles and thickness of the wagon body sheets could be reduced in the modernized wagons. What is more, the additional composite panels mounted to the wagon’s body shell will also bring an additional stiffness to the structure. It means that it will not be necessary to replace the corroded panels during repairs of the wagons while composite panels will be applied. The presented concept of technology for freight wagons modernization should solve mentioned problems that occur during exploitation of freight wagons. The proposed technology of mounting composite panels to the wagon’s body shell during its renovation is easy to apply and will extend the period of time between necessary repairs of freight wagons what will reduce costs of their exploitation.

Acknowledgments. The work was carried out under the project number PBS2/A6/17/2013 agreement implemented under the Applied Research Program, funded by the National Centre for Research and Development.

References
[1] Berghuvud A and Stensson A 2001 Consequences of Nonlinear Characteristics of a Secondary Suspension in a Three-Piece Freight Car Bogie, Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility 36 (1) 37-55
[2] Jönsson P A, Andersson E and Stichel S 2006 Influence of link suspension characteristics variation on two-axle freight wagon dynamics, Vehicle System Dynamics 44 415-423
[3] Johnson M, Welch R and Yeung K 1977 Analysis of Thermal Stresses and Residual Stress Changes in Railroad Wheels Caused by Severe Drag Braking, J. Manuf. Sci. Eng. 99 (1) 18-23
[4] Andersson E, Häggström J, Sima M and Stichel S 2004 Assessment of train-overturning risk due to strong cross-winds, Proceedings of the Institution of Mechanical Engineers Part F: Journal of Rail and Rapid Transit 218 (3) 213-223
[5] Hecht M 2009 Wear and energy-saving freight bogie designs with rubber primary springs: principles and experiences, Proceedings of the Institution of Mechanical Engineers Part F: Journal of Rail and Rapid Transit 223 (2) 105-110
[6] Song Z, Fang S, Zhang Y and Xie J 2013 Cracking analysis of bolster cover plate in C70 freight wagons, Engineering Failure Analysis 30 43-60
[7] Berghuvud A. 2002 Freight car curving performance in braked conditions, Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit 25-29
[8] Bruni S, et al. 2011 Modelling of suspension components in a rail vehicle dynamics context, Vehicle System Dynamics 49 (7) 1021-1072
[9] Connolly D. P, et al. 2014 Assessment of railway vibrations using an efficient scoping model,
[10] Dukkipati R V and Dong R 1999 The Dynamic Effects of Conventional Freight Car Running over a Dipped-joint, Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility 31 (2) 95-111

[11] Zakharov S and Goryacheva I 2005 Rolling contact fatigue defects in freight car wheels, International Journal on the Science and Technology of Friction, Lubrication and Wear 258 (7-8) 1142-1147

[12] Jönsson P A, Stichel S and Persson I 2008 New simulation model for freight wagons with UIC link suspension, Vehicle System Dynamics 46 695-704

[13] Rusiński E, Koziołek S and Jamroziak K 2009 Quality assurance method for designing and manufacturing process of armoured vehicles, Eksploatacja i Niezawodność – Maintenance and Reliability 3 70-77

[14] Zhai W M 2004 Modelling and experiment of railway ballast vibrations, Journal of Sound and Vibration 270 (4-5) 673–683

[15] Jamroziak K, Bocian M and Kulisiewicz M 2013 Energy consumption in mechanical systems using a certain nonlinear degenerate model, Journal of Theoretical and Applied Mechanics 51 (4) 827-835

[16] Jamroziak K and Kosobudzki M 2012 Determining the torsional natural frequency of underframe of off-road vehicle with use of the procedure of operational modal analysis, Journal of Vibration Engineering, 14 (2), 472-476

[17] Wrobel A 2012 Kelvin Voigt’s model of single piezoelectric plate, Journal of Vibration Engineering, 14 (2), 534-537

[18] Monica Z 2015 Virtual modelling of components of a production system as the tool of lean engineering IOP Conf. Series: Materials Science and Engineering 95 012109

[19] Iacob-Mare C and Manescu T S 2013 Study of the freight wagon body through the method of finite elements, Metalurgia 65 (7) 13

[20] Kovalev R, et al. 2009 Freight car models and their computer-aided dynamic analysis, Multibody System Dynamics 22 (4) 399-423

[21] Lee S H 2005 A CAD–CAE integration approach using feature-based multi-resolution and multi-abstraction modelling techniques, Computer-Aided Design 37 (9) 941-955

[22] Herbus K and Ociepka P 2015 Analysis of the Hexapod Work Space using integration of a CAD/CAE system and the LabVIEW software, IOP Conf. Series: Materials Science and Engineering 95 012096

[23] Bojović N J 2002 A general system theory approach to rail freight car fleet sizing, European Journal of Operational Research 136 (1) 136-172

[24] Connolly D. P, et al. 2014 Assessment of railway vibrations using an efficient scoping model, Soil Dynamics and Earthquake Engineering 58 37-47.

[25] Jönsson P A, Andersson E and Stichel S 2006 Experimental and theoretical analysis of freight wagon link suspension, Proceedings of the Institution of Mechanical Engineers Part F: Journal of Rail and Rapid Transit 220 (4) 361-372

[26] Papraska I, Kempa W. M, Grabowik C and Kalinowski K 2014 Predictive and reactive scheduling for a critical machine of a production system, Advanced Materials Research 1036, 909-914

[27] Gwiazda A, Herbus K, Kost G and Ociepka P 2015 Motion analysis of mechatronic equipment considering the example of the Stewart platform, Solid State Phenomena 220/221, 479-484

[28] Jamroziak, K, Kosobudzki M and Ptak J 2013 Assessment of the comfort of passenger transport in special purpose vehicles, Ekspl. i Nieuwodnosc - Maintenance and Reliability 15 (1), 25-30

[29] Rusinski E, Dragan S, Moczkó P and Pietrusiak D 2012 Implementation of experimental method of determining modal characteristics of surface mining machinery in the modernization of the excavating unit, Archives of Civil and Mechanical Engineering 12.
[30] Klarecki, K, Rabsztyn D and Hetmanczyk M 2015 Analysis of pulsation of the sliding-vane pump for selected settings of hydrostatic system, *Maintenance and Reliability* 17 (3) 338-344.

[31] Grabowik C, Cwikla G and Jnık W 2014 The New Approach to Design Features Identification, *Applied Mechanics and Materials* 657 750-754.

[32] Kalinowski K, Grabowik C and Kempa W 2014 The Graph Representation of Multivariant and Complex Processes for Production Scheduling, *Advanced Materials Research* 837 422-427.

[33] Klarecki K, Rabsztyn D and Hetmanczyk M 2015 Influence of setting the selected parameters of hydraulic systems on pressure pulsation of gear pumps, *Diagnostyka* 16 49-54.

[34] Placzek M, Buchacz A and Wrobel A 2015 Use of piezoelectric foils as tools for structural health monitoring of freight cars during exploitation, *Eksplatacja i Niezawodnosc – Maintenance and Reliability* 17 (3) 443-449.

[35] Placzek M, Wrobel A and Baier A 2015 Computer-aided strength analysis of the modernized freight wagon, *IOP Conference Series-Materials Science and Engineering* 95 Art. No 012042.

[36] Wrobel A, Placzek M, Buchacz A and Majzer M 2015 Study of mechanical properties and computer simulation of composite materials reinforced by metal, *International Journal of Materials & Product Technology* 50 (3-4) 259-275.

[37] Zolkiewski S 2011 Testing composite materials connected in bolt joints, *Journal of Vibroengineering* 13 (4), 817-822.

[38] Buchacz A and Galezowski D 2012 Synthesis as a designing of mechatronic vibrating mixed systems, *Journal of Vibroengineering*, 14 (2), 553.-559.

[39] Banaś W, et al. 2015 Determination of the robot location in a workcell of a flexible production line IOP Conf. Series: Materials Science and Engineering 95 012105.

[40] Białas K, Buchacz A and Galezowski D 2015 Comparison of active and semi-active damping in synthesis of various mechatronic discrete systems, *Int. J. of Materials and Product Technology* 50 (3-4) 340-355.

[41] Buchacz A and Galezowski S 2015 Designing of discrete mechatronic vibration systems with negative value parameters, *Mechanical Systems and Signal Processing* (in press) DOI: dx.doi.org/10.1016/j.ymssp.2015.02.003.

[42] Tuma J, et al. 2011 Active Vibration Control of Hydrodynamic Journal Bearings, Springer Proceedings in Physics 139 619-624.

[43] Tuma J 2009 Gearbox Noise and Vibration Prediction and Control, *Int. J. of Acoustic and Vibration* 14 (2) 99-108.

[44] Buchacz A, Placzek M and Wrobel A 2014 Modelling of passive vibration damping using piezoelectric transducers – the mathematical model, *Eksplatacja i Niezawodnosc – Maintenance and Reliability* 16 (2) 301-306.

[45] Placzek M 2013 Dynamic Characteristics of a Piezoelectric Transducer with Structural Damping, *Solid State Phenomena* 198 633-638.

[46] Placzek M 2015 Modelling and investigation of a piezo composite actuator application, *International Journal of Materials & Product Technology* 50 (3-4) 244-258.

[47] Buchacz A, Banas W and Placzek M 2015 Influence of the excitation parameters of the mechanical subsystem on effectiveness of energy harvesting system, *IOP Conference Series-Materials Science and Engineering* 95 Article number 012052.

[48] Tuma J, Suranek P and Mahdal M 2014 Simulation of the parametric excitation of the cantilever beam vibrations, 15th International Carpatian Control Conference 588-591.

[49] Suranek P, Mahdal M and Tuma J 2014 Modelling and Simulation of an Active Damped Structure, 15th International Carpatian Control Conference 588-591.

[50] EN 12663-2:2010: Railway applications - Structural requirements of railway vehicle bodies – Part 2: Freight wagons.