IOP Conf. Series: Materials Science and Engineering **145** (2016) 072012 doi:10.1088/1757-899X/145/7/072012

An analysis of the possibility of Macro Fiber Composite transducers application in modernized freight wagon

M Płaczek, A Wróbel, A Buchacz
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. Paper presents an analysis of the possibility of application of piezoelectric foils – Macro Fiber Composite (MFC) in modernized freight wagons. It was verified if they can be successfully applied as sensors in developed system for structural health monitoring and in energy harvesting system. It is a part of a research project that aim is to develop a technology of freight wagons modernization. The goal of the project is to elongate the period between periodic repairs (by better corrosion protection) and improve conditions of exploitation of modernized wagons (easier unloading during winter conditions – no freezes of the charge to the freight wagon body shell). The additional aim is to develop system for structural health monitoring of the modernized body of the freight wagon as well as the system supporting management of a fleet of wagons using GPS system with power supply based on the energy recovered by MFC's from the wagon's vibrations during its exploitation. Results of laboratory tests as well as results of measurements on the real freight wagon during observed driving of the wagon are presented. At the same time measurements of the electric voltage generated by the MFC transducers excited by low frequencies harmonic excitation were verified.

1. Introduction

Nowadays, engineers have the opportunity to apply new materials and new methodology to design devices and systems that, for example are more effective, have better properties and lower costs of production. This is why a lot of effort is spent on development of any types of devices that are used by a human because new materials and new technologies are opening brand new possibilities for designers and engineers [1-4]. The new opportunities are also results of the possibility of smart materials application, so the materials that can change one or more of their properties during operations and this change can be controlled [5,6]. Smart materials are piezoelectric transducers which are widely used in many kinds of technical devices and number of their applications is still increasing. The main reason for this process is that using a piezoelectric phenomenon it is easy to transform mechanical energy into electrical energy in simply piezoelectric effect applications or electrical energy into mechanical energy when reverse piezoelectric effect is used. In the second case piezoelectric transducers are used as actuators for example in order to obtain precise elements positioning or to generate vibrations [7-11].

Applications growth of piezoelectric transducers is parallel to the process of piezoelectric materials development. New, more efficient transducers are searched all the time. Very important step in this process was done in 1996 by NASA when a Macro Fiber Composite (MFC) was invented. MFC transducer is consists of rectangular piezo ceramic rods sandwiched between layers of adhesive, electrodes and polyimide film. Main benefits of the MFC are: increased strain actuator efficiency, damage tolerance, environmentally sealed packages, available as elongators and contractors [6,9,11]. The development of transducers allows new applications of piezoelectric materials and improves operation of existing devices. Also in this paper some benefits obtained by using new piezoelectric actuators application is presented. In previous works for example efficiency of both PZT and MFC actuators used as actuators of the mechanical system was presented. An analysis of the considered mechatronic system was done using a discrete-continuous mathematical model and an approximate method presented in previous publications [7-10].

On the other hand, computer aided methods of designing, manufacturing and product life cycle management are also powerful tools that helps to design and produce modern technical devices [12-15]. Modern systems include elements from different science areas, such as mechanics, electronics and informatics. Such connection brings new possibilities and new effects, so those systems can be called mechatronic systems [16-18]. In spite of all of those benefits of modern engineering it is also important to take into account that designed technical system should also has a positive influence onto realization of the principles of sustainable development by both, the method of its production, as well as the whole product life cycle. The principles of sustainable development is understood as to ensure the development of the present generation, among others in terms of economic growth and meet its needs, while maintaining opportunities for further development and meet the needs of future generations. It is an idea that is committed to social justice through economic and environmental efficiency projects undertaken. In this light, the development of currently used technical devices that aim is to obtain their longer exploitation that will lower demand for raw materials and improve their use is the idea of the research project which results are presented in this paper as well as is the main idea of other researchers work [11,14].

New technologies and materials are also implemented in objects from rail transport infrastructure which is a very important component which determine development of modern economy. Rail transport and its elements appear as technical devices which a lot of possibilities for development using new materials and technologies. This is why a lot of research works are carried out by researches and engineers all over the word. They concern both, railway infrastructure and logistics management systems and aim to increase effectiveness and safety of the rail transport, as well as reduction of burden on the environment and society [19-21]. The same targets are to be achieved for any kind of transport using new materials and technologies [3]. Presented work is also a part of the research project that aim is to modernize elements of the rail infrastructure – freight wagons which are used for coal and aggregates transport. The project is conducted by a consortium that consists of scientific unit (see affiliation of the paper authors) and industry companies DB Schenker Rail Poland SA and Germaz. The aim that was assumed by the consortium is to create a technology for freight wagons modernization during their periodic repairs in order to obtain longer period of exploitation and to eliminate problems connected with wagons body shell corrosion and freezing transported cargo to the shell of the body in the winter conditions. What is more by applying new materials there can be a possibility to reduce weight of the wagons and increase a permissible load. Some tasks are also undertaken in order to develop system for freight wagons status monitoring using implemented mechatronic system designed for structural health monitoring as well as generating data for logistic management [22-24]. This paper presents some aspects of this mechatronic system development – the analysis of possibility to apply the Macro Fiber Composite piezoelectric transducers as sensors for measuring of the freight wagon's elements vibration during their exploitation [6,11]. The idea is to measure dynamic response of the monitored freight wagon onto standard excitation that occurs during its exploitation. The measured signals can be then analysed by the system in order to infer about technical condition of the object and also report other information, such as information that the monitored wagon is empty or loaded. The generated data should be sent to a supervisory system together with data from GPS system, collected and analyzed. As the main elements of freight wagons modernization an application of the composite panels to the wagon's body shell was proposed. It is a solution that can solve mentioned problems during exploitation of freight wagons [6,11,14,22-24]. The composite panels composed of fiberglass and epoxy resin were proposed. They will be mounted on the body shell using rivet nuts. What is more the body shell of the modernized freight wagon will be painted using an anti-corrosion agent.

2. Measurements of the dynamical response of the freight wagon using MFC transducers

In the presented paper results of dynamical response measurements of the freight wagon are presented. Presented work was an introduction to the development of the system for continuous status and technical condition monitoring of the wagon during its standard operation. The system should analyze measured signals and generate alarms in case if some defect is detected. The aim of the presented work was to examine the usefulness of the MFC piezoelectric transducers to be used in the system as sensors for vibration measurements of selected wagon’s elements. The repeatability of the measurements in different weather conditions was verifies as well.

While a literature review one can find a lot of articles concerned with measurements of the dynamical response analysis also concerned with freight wagons. Also tasks connected with influence of vibration generated by rail transport onto infrastructure located near tracks and people are very important and undertaken by many researchers [19-21]. Usually generated vibrations are treated as harmful effects but on the other hand they can generate some useful information. Those research are nowadays very important, taking into account increasing speed of rail transport.

In presented work the object of research is the four axial freight wagon of ordinary type Eaos 1415-A3 production BREC Belgium. The considered freight wagon and composite panels mounted on its doors are presented in Fig. 1. It was being taken into consideration because it is one of the most popular types of wagons designed to unload with the use of tipplers.

a) *b*)

Figure 1. The considered type of freight wagon (*a*) and its doors with mounted composite panels.

During the carried out tests M-8514-P1 model of MFC transducer was used. Four sensors were glued on the surface of the frame and body shell of the tested wagon and connected to the portable measurement system for data acquisition. Measurements were carried out while the observed train was driving (locomotive and two wagons) with the maximum travelling speed about 10 km/h. The train was driving a section of about 400 meters, stopped and then it was returning. The test was repeated five times to verify the repeatability of the results. Measurements were made in repair facility of DB Schenker Rail Poland in Rybnik. Measurement points were selected as:

- Channel 1 - the centre of the top envelope of the box, interior of the freight wagon;
- Channel 2 - the support frame - the bottom surface of the main, outer beam of the frame;

IOP Conf. Series: Materials Science and Engineering **145** (2016) 072012 doi:10.1088/1757-899X/145/7/072012

- Channel 3 - the support frame - the inner surface of the main, outer beam of the frame;
- Channel 3 - the support frame - side surface of the crossbeam.

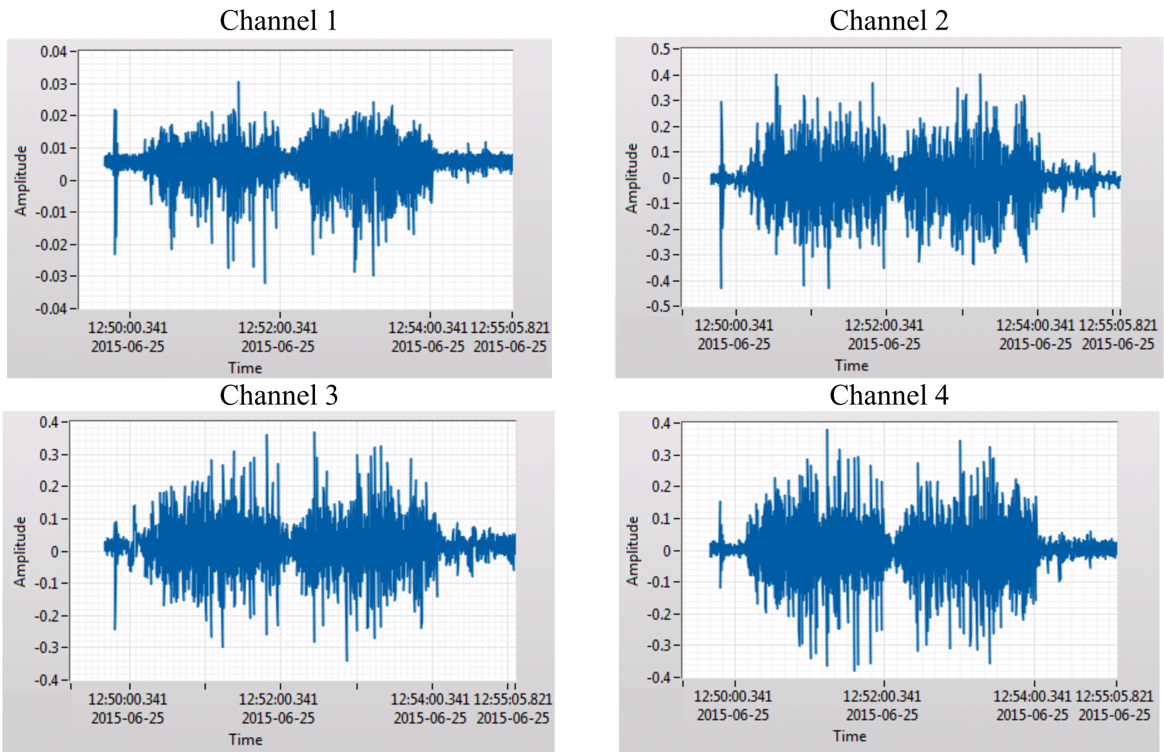

Figure 2. The measured profile of excitations occurring during operation (empty wagon and max. speed 10 km/h).

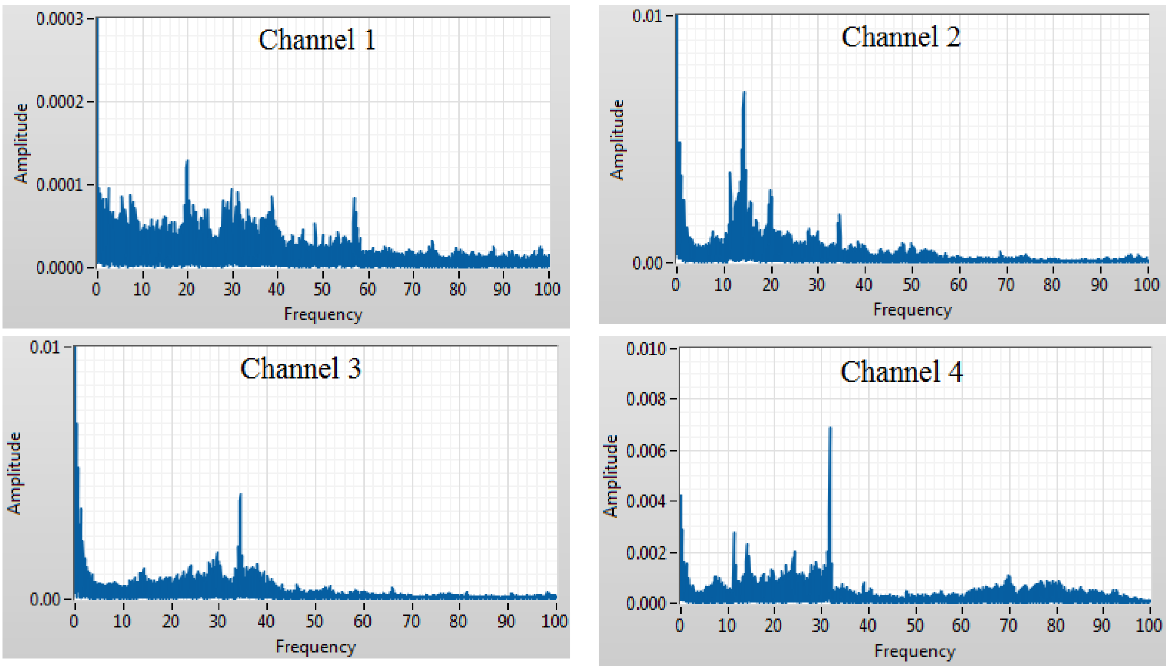

Figure 3. An example of results of measured signal FFT analysis.

The main aim of the measurements was to acquire a profile of excitations that are elements of the freight wagon exposed to during standard exploitation of the wagon. This profile can be used in future tests using laboratory stands in order to verify their dynamical response onto the excitation occurring during standard operation. In Fig. 2 examples of results of measurements obtained for the described channels are presented. The measured profile of excitations occurring during standard operation for empty wagon and maximal speed 10 km/h for all measuring points is presented.

It can be observed that values of the electric voltage generated by the piezoelectric MFC sensors has not a high value but measured signal can be used in order to reproduce the extortion profile course during laboratory tests.

The measured signal was then analysed used Fast Fourier Transform to verify the resonance zones of the vibrating elements. An example of results of measured signal FFT analysis is presented in Figure 3.

The carried out measurements proved that results are repetitive and can be used in future works.

3. Conclusions

In the next stage of this work measurements on the real object during its standard operation will be carried out again after its modernization. Composite panels will be mounted on the whole body shell of the freight wagon using rivet nuts. The measured signals will be then analysed in order to detect differences in the dynamical response of the modernized wagon juxtaposed with the standard one. It is a first step to develop a system for diagnosing the technical condition of the modernized shell of wagon body during operation. Verification of the MFC transducers usefulness for sensors application in different weather conditions was necessary and it was proved. The MFC transducers can be easy applied to the surface of existing object. What is more they do not need any power supply but only the device for data acquisition with its power supply. It was proved that they can successfully operate in normal conditions of the freight wagon exploitation provided that they are protected against mechanical damage. What is more the measured profile of freight wagon's elements vibrations can be used in laboratory tests on models of freight wagons prepared in scale. In such conditions it is much more easily to modify technical condition of the model and verify influence of this modification onto its dynamical response for excitations with the same parameters as those that occur during standard exploitation of freight wagons. Therefore, carried out tests were very important taking into account future research.

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

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

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

[4] Rusinski E, Dragan S, Moczko P, 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**, 471-476

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

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

[7] Buchacz A, Placzek M, Wrobel A 2014 Modelling of passive vibration damping using piezoelectric transducers – the mathematical model, *Eksploatacja i Niezawodnosc – Maintenance and Reliability* **16 (2)** 301-306
[8] Placzek M 2013 Dynamic Characteristics of a Piezoelectric Transducer with Structural Damping, *Solid State Phenomena* **198** 633-638
[9] Placzek M 2015 Modelling and investigation of a piezo composite actuator application, *International Journal of Materials & Product Technology* **50 (3-4)** 244-258
[10] Wrobel A 2012 Kelvin Voigt's model of single piezoelectric plate, *Journal of Vibroengineering*, **14 (2)**, 534-537
[11] Buchacz A, Banas W, 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
[12] Banas W, Sekala A, Foit K, et al. 2015 The modular design of robotic workcells in a flexible production line IOP Conf. Series: Materials Science and Engineering **95** 012099
[13] Jamroziak K, 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 Vibroengineering*, **14 (2)**, 472-476
[14] Placzek M, Wrobel A, Baier A 2015 Computer-aided strength analysis of the modernized freight wagon, *IOP Conference Series-Materials Science and Engineering* **95** Art. No 012042
[15] Monica Z 2015 Optimization of the production process using virtual model of a workspace IOP Conf. Series: Materials Science and Engineering **95** 012102
[16] Buchacz A, Galeziowski D 2012 Synthesis as a designing of mechatronic vibrating mixed systems, *Journal of Vibroengineering*, **14 (2)**, 553 -559
[17] Gwiazda A, Herbus K, Kost G, Ociepka P 2015 Motion analysis of mechatronic equipment considering the example of the Stewart platform, *Solid State Phenomena* **220/221**, 479-484
[18] Klarecki, K, Rabsztyn D, Hetmanczyk M 2015 Analysis of pulsation of the sliding-vane pump for selected settings of hydrostatic system, *Maintenance and Reliability* **17 (3)** 338-344
[19] Grebowski K, Zielinska M 2015 Modelling of dynamic interactions of Pendolino train type on structures of historic railway bridges in Poland, *Przeglad Budowlany* **1** 27-32 (In Polish)
[20] Oleszak P, Ciesla J, Szaniec W 2013 Study of the effects of side impacts on railway viaduct lying on the arc, *Budownictwo i Architektura* **12 (2)** 47-54 (In Polish)
[21] Stypula K 2009 Selected problems of surface building protection against vibrations generated by underground communication, *Gornictwo i Geoinzynieria* **3(1)** 351- 362 (In Polish)
[22] Wrobel A, Placzek M, Buchacz A, Majzner 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
[23] Baier A, Zolkiewski S 2013 Initial research of epoxy and polyester warp laminates testing on abrasive wear used in car sheathing, *Eksploatacja i Niezawodnosc – Maintenance and reliability* **15 (1)** 37–43
[24] Zolkiewski S 2011 Testing composite materials connected in bolt joints, *Journal of Vibroengineering* **13 (4)**, 817-822