The Fifth International Conference on Railway Technology
RAILWAYS 2022
22–25 August 2022
Montpellier, France

Proceedings of the Fifth International Conference on
Railway Technology:
Research, Development and Maintenance
Edited by J. Pombo
Civil-Comp Conferences, Volume 1, Paper 27.9
Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.1.27.9

Passing Train as Source of Energy for Autonomous LoRa Monitoring System

Z. Hadas, O. Rubes, F. Ksica, Z. Majer, M. Moncman and J. Chalupa

**Brno University of Technology
Czech Republic**

Abstract

This paper deals with a concept of an autonomous railway monitoring system with energy harvesting source of electric energy. There are several ambient sources of energy on trackside which could be converted into useful electricity for autonomous sensors and electronics. A waste energy of passing train is occurred in form of a rail and sleeper mechanical vibrations. The kinetic energy of mechanical vibration could be transformed into useful electricity in time of passing trains. The presented kinetic energy harvesting device could provide autonomous source of energy for sensing and communication modules. The lab test of energy harvesting device and the autonomous operation of sensing system with communication is presented. The presented system was successfully tested with LoRa module, which could operate for a distance of a few kilometres, and it could transfer information about track condition or dynamic load, e.g. axle counting or vibration monitoring.

Keywords: Trackside, Vibration, Sensing, Energy Harvesting, Communication.

1 Introduction

This paper deals with a concept of an autonomous trackside monitoring system with energy harvesting source of energy. There are several ambient sources of energy on trackside which could be converted into useful electricity for autonomous sensors and electronics. A wind and solar sources are commonly used in many industrial applications and these sources could be placed beside track and provide autonomous source of energy, e.g. [1], [2]. Furthermore, a waste energy of passing train is occurred in form of a rail and sleeper mechanical vibrations or displacement. A small sag of rail or sleeper could be amplified and converted by linear electromechanical generators [3]. The kinetic energy of vibrations could be converted by several physical principles of electromechanical conversion. The most promising principles are piezoelectric and electromagnetic conversion for trackside application. Several devices for trackside energy harvesting were published with varied range of output power and target application: e.g. displacement energy harvester from Stony Brook [4], Virginia Tech trackside system [5], a ramp-lever mechanism [6], a drum design of the piezoelectric generator under sleeper [7], a stack-type piezoelectric transducer at the bottom of a steel rail to harvest the mechanical energy [8], a track-borne electromagnetic energy harvester and sensor node [9], piezoelectric vibration cantilever harvester [10], a concept of electromagnetic vibration energy harvesting device inside sleeper [11], etc.

Our proposed concept of autonomous trackside monitoring system employed both piezoelectric and electromagnetic principle of vibration energy harvesting. The electromagnetic kinetic energy harvester is fixed on a vibrated sleeper and it provide useful electricity in time of passing train [11]. This system could be fully integrated inside innovative sleeper. Also, a piezoelectric effect is used and the piezoceramic patch is fixed on a rail and this system generates electrical voltage [12], which is proportional with strain in time of passing train. However, energy from this piezoelectric system is very low but it provides useful signal about rail dynamics under moving trains.

The sleeper energy harvesting system could generate useful electricity for a signal processing of rail piezoelectric signal and wireless communication, which autonomously transfer data from trackside area. The concept of this autonomous system and lab test are presented in this paper.

2 Methods

The passing train dynamic provides mechanical oscillation of the sleeper which is depicted in Figure 1. Sleeper oscillation is in form of sleeper sag pulses [11]. Due to dynamic of sag pulses the kinetic energy could be harvested using an electromagnetic resonator [13]. Outputs of a vibration energy harvesting system depends on a quality of track bed and moving loads, which subsequently determine sag of sleeper. The harvested power mainly depends on parameters of the electromagnetic resonator and used electronics.

The physical principle of kinetic energy harvester was verified and the test of this device is shown in Figure 2. The very sensitive vibration electromagnetic energy harvester for helicopter application was used for this initial test [14]. An operation of kinetic energy harvester on a rail was tested on local track in Czech Republic. The voltage response on optimal load is also shown in Figure 2. This energy harvesting system on the rail generated around 9 mW in peak during passing of a local train. On the base of this experiment a new development of kinetic energy harvester for train application was started under S2R ETALON project.

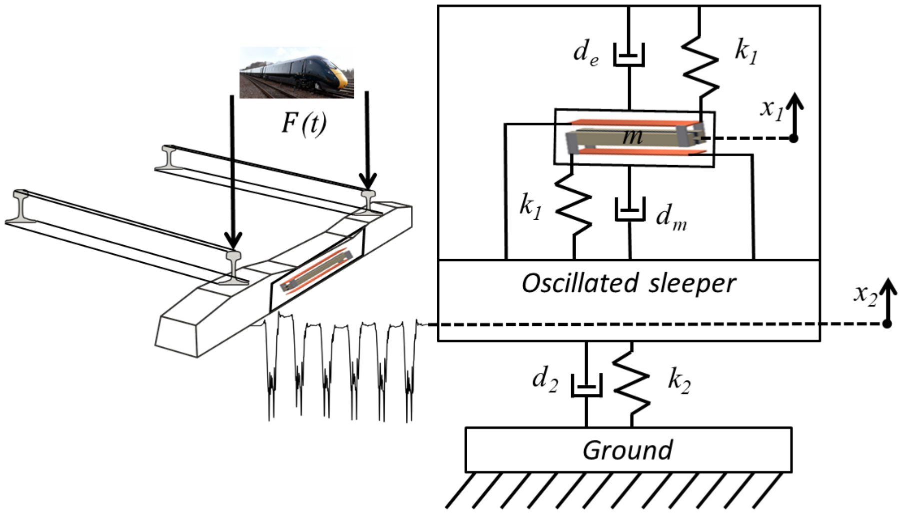

Figure 1: Concept of kinetic energy harvester on sleeper.

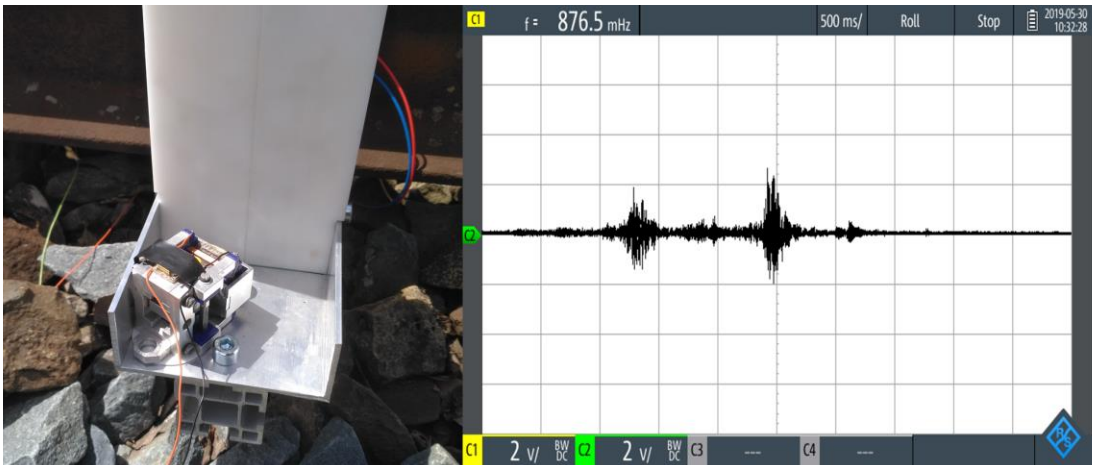

Figure 2: Rail installation of kinetic energy harvester on rail and voltage response on local train.

The piezoelectric effect was also tested under previous experiment and the piezoceramic composites [15] were fixed on the rail and a voltage responses were measured. The rail installation of piezoelectric elements and voltage response are shown in Figure 3. This measurement was done with the same track and train as previous kinetic energy harvesting system. The output power is very low however voltage signal could be useful for monitoring and diagnostic systems.

This experiment on local track shows that the kinetic energy harvesting system could be used as autonomous source of energy for ultra-low power electronics and communication. The response of piezoceramic composite on the rail could provide an active voltage signal for sensing node. Power management electronics with energy storage capacitor will be used for direct powering of microprocessor, A/D transducer and communication module. The signal processing could be used for simple analysis of signal and determination of maximal load, average vibration or counting of axles.

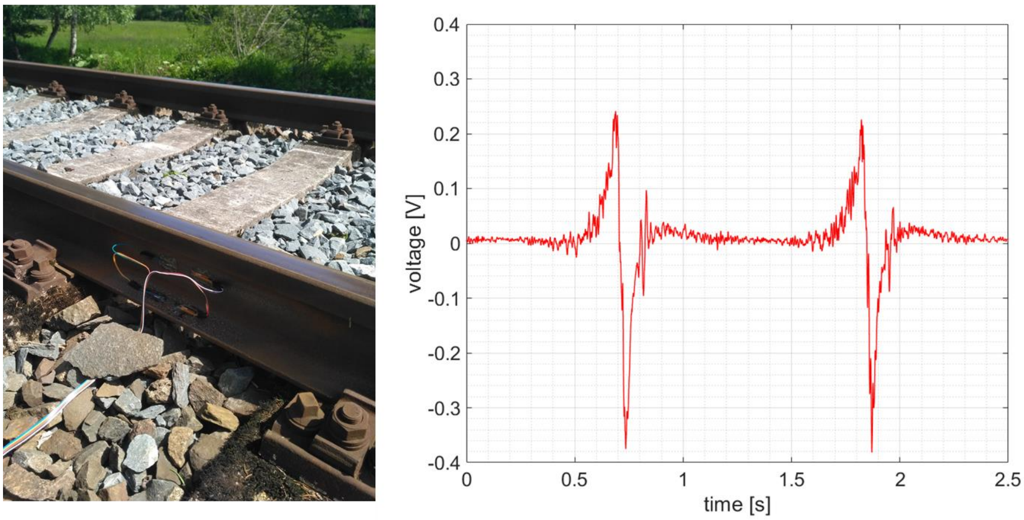

Figure 3: Rail installation of piezoelectric composites on rail and voltage response on local train.

3 Results

The trackside kinetic energy harvester was developed under H2020 S2R ETALON project for an autonomous operation of wayside objects. However, energy density in vibration of sleepers are not enough for all day operation of common wayside objects. The developed device is shown in Figure 4 and it could provide maximal power around 300 mW for resonance operation. It could be enough for wireless operation of sensor node with active piezoelectric measurement of rail strain in Figure 3. The experimental results and outputs of this device during passing train in simulated lab condition are presented.

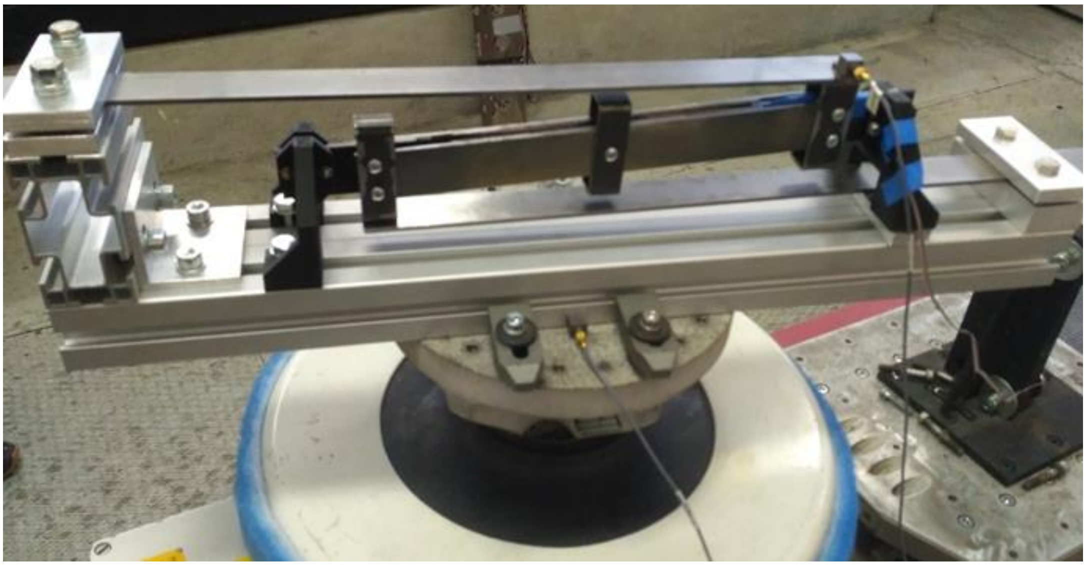

Figure 4: Shaker test of developed kinetic trackside energy harvester; dimensions 600 x 150 x 90 mm, frequency 12 Hz, weight 1.45 kg without base.

Our lab used for tests several records of sleeper vibrations during passing of different trains on different tracks. These acceleration data were used for a transient shaker test in time domain. The shaker could reproduce the sleeper vibration during time of passing train. This controlled environment test is used for analysis of energy harvester as the autonomous source of energy for different sensing purposes and communication protocols.

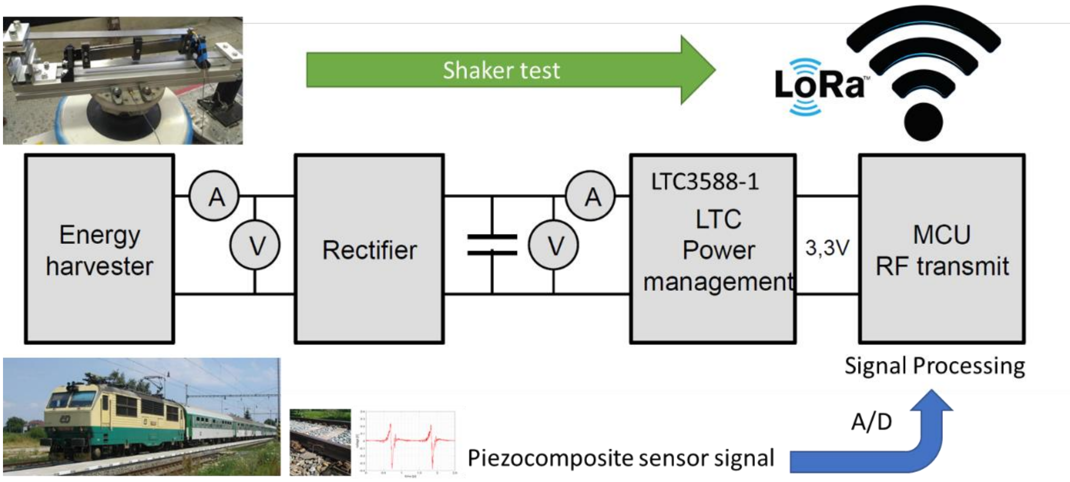

Figure 5: Controlled environment shaker test of energy harvester with electronics, sensing and communications.

The energy harvesting shaker tests in controlled environment is illustrated in Figure 5. The test setup consists of the shaker (real vibration of sleeper), electromagnetic energy harvester, power management electronics with rectifier, microprocessor with A/D input and signal processing function, and finally communication LoRa module. The electric voltage signal, which could measure a rail deformation, is generated by piezoelectric composite from Smart Material company.

The generated voltage on energy harvesting device is shown in Fig. 6. The energy harvester voltage response corresponds with passing of individual bogies. The acceleration data of a passenger train in speed 80 km per hour (locomotive and seven cars) was used for this test. The acceleration corresponds with average sleeper sag around 1.5 mm.

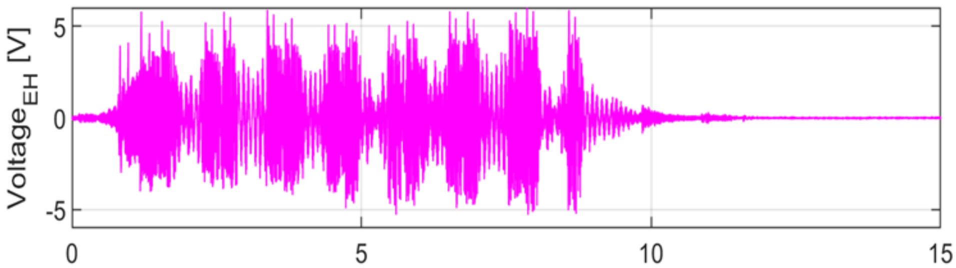

Figure 6: Response of kinetic energy harvester on shaker.

The operation of LTC power management electronics and operation of LoRa communication module are shown in Figure 7.

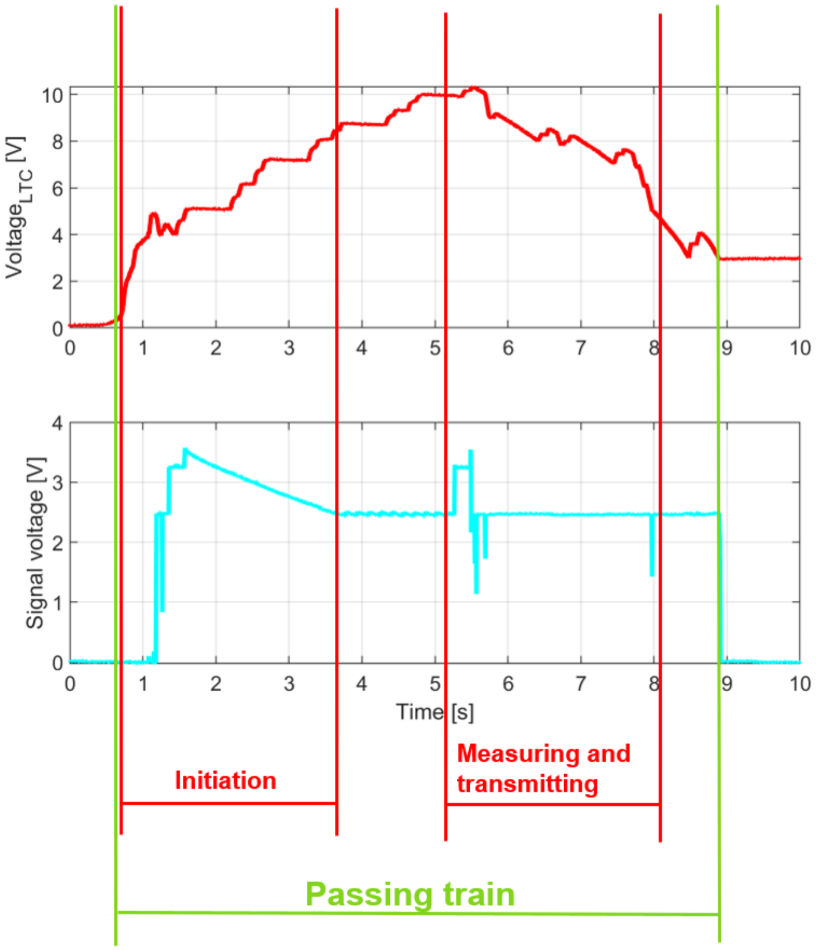

Figure 7: Power management operation and state of communication electronics – shaker test.

4 Conclusions and Contributions

The proposed concept of kinetic energy harvester with sensor for trackside monitoring could provide useful device for monitoring, maintenance and diagnostic applications. The kinetic harvester was developed with respect to requirement of maintenance free device which could be fully integrated inside a new generation of sleepers. Alternatively, it could be fixed on or beside of current sleepers. The output power depends mainly on the sleeper sag; the sag higher than 1 mm provides enough power for communication electronics in time of passing train.

The harvested energy during the shaker test of passing train was used for waking up and operation of microprocessor, signal processing of input signal and transmitting information via LoRa module. The operation of wireless sensor and communication operation is clearly presented in Figure 7 and this train provide enough energy for sensing and communication. Microprocessor unit could be used for signal processing of information like train speed, axle counting, index of track quality or response for different track parameters for monitoring applications. The LoRa module could transmit data to cloud application for long time monitoring tasks.

A potential of the proposed concept of energy harvesters, piezoelectric patches and communication could be very useful for diagnostics and monitoring applications. This system could operate just in time of passing train and a rest of time it is hibernated. In time of passing train, it could provide required data and information about train and trackside condition. All transmitted data could be collected on cloud system and diagnostics and analytics of long-time big data could be processed by artificial intelligence. The trends in long-time data analysis could provide information for maintenance and it could indicate a track wear. The maintenance free operation and mounting on common sleepers are also advantage of this system.

Acknowledgements

The presented kinetic energy harvesting system was developed under H2020 S2R ETALON project. The development of autonomous sensing system and communication electronics is supported by the project FW01010281 “Modular axle counter 4.0” under Technology Agency of the Czech Republic.

References

[1] N. Popovic, G. Feltrin, K.-E. Jalsan, M. Wojtera, Event-driven strain cycle monitoring of railway bridges using a wireless sensor network with sentinel nodes, Struct. Control Heal. Monit. 24 (2017) e1934.

[2] H. Hayashiya, H. Itagaki, Y. Morita, Y. Mitoma, T. Furukawa, T. Kuraoka, Y. Fukasawa, T. Oikawa, Potentials, peculiarities and prospects of solar power generation on the railway premises, in: 2012 Int. Conf. Renew. Energy Res. Appl., IEEE, 2012: pp. 1–6.

[3] X. Zhang, Z. Zhang, H. Pan, W. Salman, Y. Yuan, Y. Liu, A portable high-efficiency electromagnetic energy harvesting system using supercapacitors for renewable energy applications in railroads, Energy Convers. Manag. 118 (2016) 287–294.

[4] J.J. Wang, G.P. Penamalli, L. Zuo, Electromagnetic energy harvesting from train induced railway track vibrations, Proc. 2012 8th IEEE/ASME Int. Conf. Mechatron. Embed. Syst. Appl. MESA 2012. 11787 (2012) 29–34.

[5] T. Lin, Y. Pan, S. Chen, L. Zuo, Modeling and field testing of an electromagnetic energy harvester for rail tracks with anchorless mounting, Appl. Energy. 213 (2018) 219–226.

[6] A. Pourghodrat, Energy Harvesting Systems Design for Railroad Safety, University of Nebraska-Lincoln, 2011.

[7] Y. Tianchen, Y. Jian, S. Ruigang, L. Xiaowei, Vibration energy harvesting system for railroad safety based on running vehicles, Smart Mater. Struct. 23 (2014) 125046.

[8] J. Wang, Z. Shi, H. Xiang, G. Song, Modeling on energy harvesting from a railway system using piezoelectric transducers, Smart Mater. Struct. 24 (2015) 105017.

[9] M. Gao, P. Wang, Y. Wang, L. Yao, Self-Powered ZigBee Wireless Sensor Nodes for Railway Condition Monitoring, IEEE Trans. Intell. Transp. Syst. (2017) 1–10.

[10] M.Y. Gao, P. Wang, Y. Cao, R. Chen, C. Liu, A rail-borne piezoelectric transducer for energy harvesting of railway vibration, J. Vibroengineering. 18 (2016) 4647–4663.
[11] Z. Hadas, J. Smilek, O. Rubes, Energy harvesting from passing train as source of energy for autonomous trackside objects, MATEC Web Conf. 211 (2018) 05003.
[12] Z. Hadas, F. Ksica, O. Rubes, Piezoceramic patches for energy harvesting and sensing purposes, Eur. Phys. J. Spec. Top. 228 (2019) 1589–1604.
[13] G. Gatti, M.J. Brennan, M.G. Tehrani, D.J. Thompson, Harvesting energy from the vibration of a passing train using a single-degree-of-freedom oscillator, Mech. Syst. Signal Process. 66–67 (2016) 785–792.
[14] Z. Hadas, C. Ondrusek, V. Singule, Power sensitivity of vibration energy harvester, Microsyst. Technol. 16 (2010) 691–702.
[15] O. Rubes, P. Tofel, R. Macku, P. Skarvada, F. Ksica, Z. Hadas, Piezoelectric Micro-fiber Composite Structure for Sensing and Energy Harvesting Applications, in: Proc. 2018 18th Int. Conf. Mechatronics - Mechatronika, ME 2018, 2019.