Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria

Instrumentation for real time monitoring of the overhead contact line acceleration

Tudor Popa[a*], Laurentiu-Dorin Buretea[a], Lucian-Emanuel Anghel[a]

[a]*ADS Electronic Research, str. Giovani Boccacio nr.45, sect. 4, 041401 Bucuresti, Romania*

Abstract

In any railway power supply system, the contact line is considered one of the most important component influencing the life cycle of the system. The analyses, which estimates the wearing of the contact line but also of the pantograph contact strips, are based on the value of the contact force, which defines the interaction between pantograph, as external component, and overhead contact line. The instrumentation solutions, developed in time of the same project, provide two systems focused for acquisitioning the acceleration and displacement information of the overhead contact line.

The first developed system uses sensor devices hanging by the contact line, having as objective to collect acceleration information at the contact point of the moving pantograph; the system is described in this paper.
The second developed system uses one high speed video camera, placed aside the rail track, which register the movements of the contact line. Being a very different technology this system will make subject of other article.

The both systems have main focus to determine, indirectly, the value of the contact force, but also to optimise a list of controllable factors.

Keywords: overhead contact line, sensor devices, acceleration, displacement information, high speed video camera, contact force, controllable factors

[*] Corresponding author. Tel: +4-074-505-7991
E-mail address: tudor.popa@ads-electronics.ro; popa.tudor@yahoo.com

1. Introduction

1.1. Measuring vibrations as point of interest

Vibrations and displacements in the contact line section may cause two major concerns. One concern is the lower spectrum of the frequencies which will cause decreasing of the contact line resilience. Low frequency vibrations have a major influence because they are easy propagated, with low attenuation, into the longitudinal section of the lines. The second is represented by the phenomenon of large amplitude vibrations in the overhead contact line (OCL), which can lead to fatigue cracks in the section of wires, mostly where they are fastened.

The main and comprehensive objective of the systems designed is to collect acceleration data at the contact point between contact line and the pantograph; acceleration double antiderivative provides displacement information.
The both systems developed intended to provide solutions for analyses and creating models for optimisation of the controllable factors for existing railway overhead lines. The controllable factors taken in consideration for modelling, due to their great importance in study of dynamic behaviour of the contact line are: line tension, contact line materials, contact force. Also, the benefits for new power supply designs but also for existing ones are represented by the long-time collecting and using data in modelling applications, for getting optimised combination of the controllable factors. There are expected that the systems developed and the models created to finally provide solutions for maintaining performance at lowest life cycle cost for the railway power supply systems, as generally and contact line as particularly.

The main focus is to determine, indirectly, the value of the contact force. To determine the contact forces, the sensor devices and video camera should focus in a contact line section where elasticity coefficients are known. Between contact force, displacement and elasticity of contact line there is a direct relationship; knowing elasticity and displacement of the contact line, under the action of the pantograph, the contact force can be determined.

According to the standards addressing railway power supply systems, the contact force should be within a restricted range, to ensure normal wearing and safety operations; any deviation from this range must be corrected as soon as possible. The immediate benefit is to check for all locomotives, passing that contact line segment, if the pantograph uplift force is within the standard range. When the information of limits exceeded are available in real time, the uplift of the pantograph could be recalibrated avoiding damages. [Kiessling et al. (2012)]
Resuming the importance, the system will help to increasing the life cycle of the railway overhead power supply system, decreasing the needed maintenance and improving solutions for new designs.
The information which included in this presentation paper are related to developed systems in the project NeTIRail-INFRA, part of the EU Research and Innovation programme H2020.

As state of the current situation, for the existing systems with the same field of applicability, at European level, we can exemplify the measurement system used by DB (Deutsche Bahn). In that solution, the acceleration sensors are mounted on the pantograph structure and the contact force is determined from the locomotive side, from the movements of the pantograph. The system is installed on specialized trains, equipped with sensors and complex measuring equipment, used for large range of parameters determination on railway networks. [Kiessling et al. (2012)]

To determine the significance of the system for the potential users, had conduct an extensive technical analysis before the design stage. On the basis of numerous contacts with infrastructure managers and with the owners of rolling stock, it was established that obtaining these data type will have a special importance for the reduction of the operating costs of the electrified railway sections; at the same time could be expected improvements of the new infrastructure designs and also for the equipment inside the electric locomotives, that come in direct contact with the power supply systems and which have the role of capturing the electricity needed for functioning.

The theory and research of these subjects are vast, therefore, the presentation is focused on the technical important aspects for developed solutions.

2. Developed systems description

2.1. System of sensors for measuring acceleration of the overhead contact line

Under this title, the system developed is represented by three types of hardware and firmware devices:

- **WSDO** (**W**ireless **S**ensor **D**evice for **O**verhead Line)
- **WCDO (W**ireless **C**oncentrator **D**evice for **O**verhead Line**)**
- **WLRCD (W**ireless **L**ong **R**ange **C**ommunication **D**evice**)**

There are also one Software Application running on the PC Desktop, for receiving and saving data. All these are short presented in the following paragraphs.
Even from the initial phase of the system analysis, several and distinct packages of functions, required for the system implementation, have been identified. Therefore, the three types of devices have been developed to work together, but each realizing a particular system functionality class.

2.1.1. Levels of the system management

The system has the following levels of data management and processing:

- **WSDO** fulfils the initial role of acquiring vibration data from the overhead contact line level, of which it is fixed. After data vibration are collected, **WSDO** device will send as fast as possible to the concentrator for freeing the local memory for next acquisition.
- **WCDO** has the role of collecting data from a defined acquisitioning area, populated with **WSDO** devices. The role of the data concentrator is essential because vibration data will be acquired by several **WSDOs** at the same time as the train passes through the area of interest.
- **WLRCD** takes data from the **WCDO** and will sent over long distance, to a Control Centre, for final storage and further analysing. For this stage of development was chosen the Wi-Fi communication type for long range sending data. When is not possible to establish Wi-Fi communication, the Data Logger function become active and vibrations data are stored locally only.

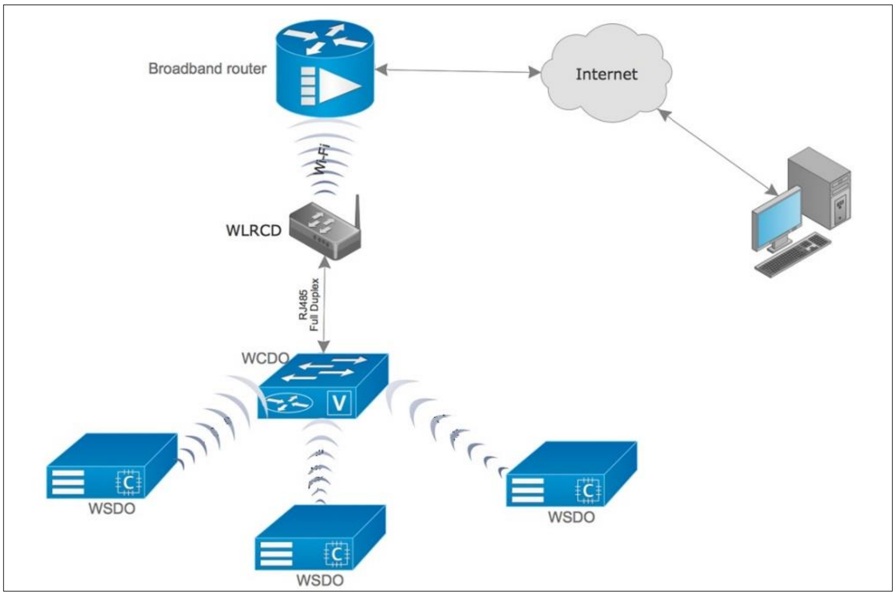

Fig.1 - Block design of the system

2.1.2. Innovation aspects

The main technical project objective was accomplished using new technologies from embedding systems area; these allow the acquisition of vibration-type data from the contact line level to a greater extent volume than other older systems solutions. Collecting a large amount of data, over a long period of time, will allow effective analysis of the dynamic effects of the interaction between the pantograph and the contact line. The information obtained and after that using the models for analysing, will help for enabling maintenance to be tailored to actual loads experienced, including dynamic effects and dynamic loading that affect the contact line system for the section of interest. This is a step change from current practice of planning maintenance at regular time interval and will bring a great reduction in maintenance costs

The second objective and benefit is the possibility to calculate the contact force between pantograph and contact line. Knowing this value is very important for infrastructure manager but also for the locomotive owners. The contact force should be in a standard range and exceeding this will result in accelerating wearing of the contact line but also of the locomotive pantograph.

The requirements in the project description, related to acquiring a large amount of data over a long time period has been solved by designing the system's autonomy solution. Li-Po batteries are used to power the devices, ensuring increased reliability and operating capacity. The battery is sized to make the device, corresponding it, to work for few days, without a charging source. Further, the battery charging solution was designed and developed using a photovoltaic cells area. Solar cells surface must ensure battery charge even in low light conditions. For this purpose, a specialized power harvesting circuit with boost voltage converter is used.
During the experiments planed as part of the development, it is expected that the photovoltaic cell surface to be changed through reducing, in order to obtain an optimized solution. This will depend by the power consumption in real field conditions, for having total autonomy in different and adverse conditions. This is also cost-effective optimization because the solar cells component represents the highest cost of the devices.

One of the most important technical features, which makes the difference by other existing systems, is the communication and collection of acceleration data as wireless mode. In this way a reduction in installation costs is achieved but, more important, a great increasing in operating reliability because there are no cable links, which can be interrupted by harsh functioning conditions.

Another system performance issue is the solution of using a specialized application microcontroller that integrates the wireless communication module. The process controller has the tasks to perform the firmware program and manage all the interfaces with other circuits placed on main layout board. But the most important element is the optimal achievement, with the maximum speed and priority, of the firmware communication functions. This is possible now because for managing and transmitting data between the two working cores (the central unit computing unit and RF – Radio Frequency core) will be done through the registers and using internal memory of the microcontroller. [TI-Texas Instruments]

2.1.3. Challenges for developing of the system

From the beginning of the design stage, the system developed had to consider adversary conditions. In this regard, could be enumerated few categories of the constraints for the devices:

- Electrical restrictions: the system should face with high level of perturbations as electrostatic discharges and intensity of the electromagnetic field;
- Mechanical restrictions: high difficulty of installing and maintenance of **WSDO** devices;
- As the environmental conditions, the devices developed should support restrictions provided by the real field implementation and long-time functioning. In this regard, the devices have to function in outdoor conditions and isolated locations; the system has to work 24 hours / 7 days, in real conditions, with total autonomy.
- For precision results of the modelling, the elasticity coefficients of the contact line section, should be known; in this way, the system will help the theoretical models for estimating the contact force of the pantograph.

One system installation includes at most 7 **WSDO** devices, one **WCDO** device and one **WLRCD** device. Wireless communication between **WSDO's** and **WCDO** will be on the same frequency, with time division.
The system has to confront with categories of restrictions; in time of the development phase but especially in time of experimenting and data collecting, these restrictions will be mitigated with technical adaptations or even with upgraded versions.

2.1.4. WSDO - Wireless Sensor Device for Overhead lines

The most important and challenging restriction is represented by the group of environmental conditions that the devices, parts of the system, should support in the functioning life. These requirements are represented by the outdoor placement, in open air and isolated field locations, with weather and climate negative influences and also harsh mechanical conditions.

The **WSDO** device will be the most affected by the working environment. It will have to function with direct mechanical contact with the overhead contact line and withstand all negative influences (e.g. water and snow covering, extreme temperature conditions); to these limitations are added the mechanical ones, the device should be able to withstand the strong vibrations and large amplitude displacement of the contact line.
For sealing device against harsh environment condition, the electronic components, battery and the pack of photovoltaic cells are compounded in a rigid block of transparent resin, sealing class at least IP67.

Another restriction is the life of the device's functionality. The system should be useful tool for improving models of behaviour for wearing of the contact line and also for contact force estimation, for these goals long time measurement should be achieved.
Considering placement of the devices in isolated field area, with no power supply and very difficult possibilities of device replacing, the total autonomy using batteries and photovoltaic cells have been considered for development. The version developed in this iteration includes an over capacity battery power supply and a larger than needed surface of photovoltaic cells (based on estimates of power consumption). As the tests will be carried out, through optimizing the power consumption, these features are to be reduced, thus reducing the size of the devices. This is possible because the surface of photovoltaic cells and battery sizes dictate the degree for compaction of the modules.

One of the most performant functions of this system is the capability of sending acquisitioned data, in real time from contact wire, over a short distance to the **WCDO** type device, using IEEE 802.15.4 RF standard protocol stack (ISM 868 MHz Band for Europe).
The device has possibility to store data locally, for a few minutes, for the situation when the train blocks the visibility of the RF signal, but the device should send as fast is possible the vibration samples to the concentrator device.
For **WSDO** device, the fastening option is the mounting on grooves of the contact wire, using a metal clamp - for example as in figure below (Fig. 2):

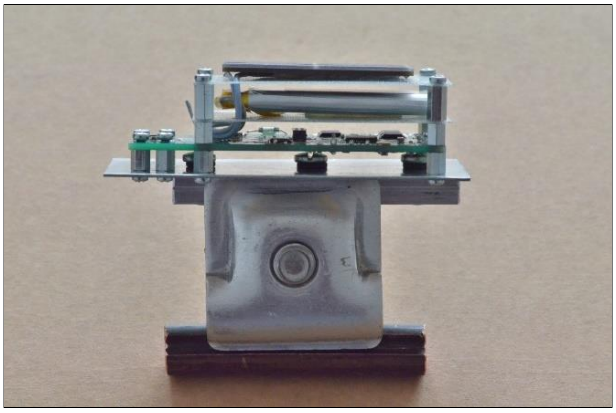

Fig. 2 – Hardware structure layers and fastening solution on the contact line, for WSDO device

For acceleration data acquisitioning is used one integrated circuit; it has an integrated three-axis acquisition module. The sampling of the acquisition module will be done at the same time on all three axes. In this way a "complete image" will be obtained from the measured values. The firmware of the device will filter and will keep for transmitting only useful data, when there are values outside the "no train" range; in this way, the device hardware core could stay in very low power mode almost entire time. [ST-Microelectronics]

A secondary function is achieved by one temperature sensor inside the **WSDO**, with centigrade scale. The significant importance of this sensor resides in the possibility of acquisitioning the temperature of the contact line and sending alarms for extreme lower and higher values. These will rise up improved management of the locomotive number running in one electrified section and for performance optimisation of the resistive de-icing systems.

2.1.5. WCDO - Wireless Concentrator Device for Overhead lines

The **WCDO** device has to comply following requirements, as mainly:

- Collects data from **WSDO's;**
- Sends sensors data to the **WLRCD** device, with data logger function and long range communication capability;
- Provide the function as gateway device for external settings and commands, necessary **WSDO**;
- There are total autonomy using battery and photovoltaic cells;
- Housing box with sealing class at least IP65.

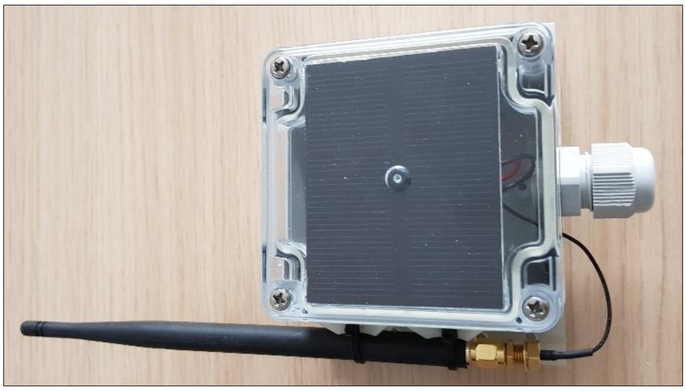

Fig. 3 – View of the assembled **WCDO** device

Even the concentrator device has memory for short term storage of the received vibration values, the intended solution is to send very fast the volumes of data to the **WLRCD** device.
As a functional condition, the **WCDO** device should be located into an area with visibility of the **WSDO's**; most desirable solution is mounting on the poles, near the track lines.

2.1.6. WLRCD - Wireless Long Range Communication Device

The **WLRCD** device has to comply as resumed the following requirements:

- Receive data from WCDO, through a cable link, using fast RS485 full duplex standard;
- Perform Data Logger function using SD Card;
- Default version for Long Range Communication is Wi-Fi Ethernet solution. A secondary solution could be GSM support communication;
- Total autonomy using battery and photovoltaic cells;
- Housing box with sealing class at least IP65.

Because the range of Wi-Fi communication is few hundred meters, the system should be placed near the train stations, where, in almost situations there are Wi-Fi and Internet support.
Communication link between **WCDO** and **WLRCD** is achieved by wire connection support, using RS485 full duplex protocol which provides optimum balance between fast baud rate and good protection against electrostatic and electromagnetic negative influences.

To complement the possible situations in which it has to work, **WLRCD** has two modes of operation: data logger for the acquisitioning vibration values. When data logger mode, it is assumed that the long range communication solution is not active or not available. In this case, the **WLRCD** was provided with a non-volatile SD Memory Card with GB memory range; accelerometer data can be saved for a long time, even weeks, until it is transferred on external memory support for analysis and modelling. The second way to execute the firmware program is based on the existence of a high-speed wireless communication connection, and the data received from the **WCDO** will be only temporarily stored on the SD Card memory, until they are transmitted to the Control Centre.
The **WLRCD** device type is recommended to be mounted in near vicinity of the **WCDO** device, from which will be linked with cable using RS485 full duplex standard communication. The best solution will be the same pole placement as **WCDO** device.

2.1.7. Efficient power supply and power recharging solutions

All devices involved in the system functionality will be powered from their own battery, located inside the mechanical assembly. The type of battery used and charging capacity are selected based on the estimated consumption for each category of equipment.
From the three specified categories, the **WLRCD** device type will have the highest power consumption due to specific consumers: the Wi-Fi communication module and the SD Card for storage; the SD card will support the data logger function.

A lithium polymer battery, or more correctly lithium-ion polymer battery (abbreviated variously as Li-Po, LIP, Li-poly and others), is a rechargeable battery of lithium-ion technology using a high conductivity solid (gel) polymer electrolyte (SPE) instead of the more common liquid electrolyte. Our solution for battery power supply is Li-Po technology for all devices from the developed system.
The reasons for this option are performant characteristics of Li-Po technology, offered by the manufacturers. From these, could be enumerated:

- High Energy Density – Li-Po batteries offer more times the energy capacity for the same weight, compared with other solutions (Ni-Cd and Ni-MH batteries).
- Flat Voltage Curve – Lithium Polymer cells are fully charged at 4.2 volts and are considered fully discharged at 3.0 volts. This allows for a relatively flat voltage discharge curve, providing solid performance throughout the discharge cycle.
- No Memory Effect – The cells could be partially charged and discharged without damaging their performance as long as they are maintained within normal operating voltage parameters.
- Low Self Discharge – Lithium Polymer cells provide a very low rate of self-discharge when not in use: around 5% per month, compared with over 30% per month (Ni-HM batteries) and 20% per month (Ni-Cd batteries). This means that users can use batteries many days later, after charging, with still nearly a high capacity.

2.1.8. Solar cells for efficient power supply and power recharging

Solar cells and solar panels provide electricity only in DC voltage type. The solar cell handles direct charging and provide electricity for portable batteries which could be mostly any type, ranging from traditional alkaline recharging battery to battery most advanced as Li-Ion or Li-Po; our solution is Li-Po batteries.
The solar cells used are monocrystalline, being high-efficiency and having mechanical surface mount package; they are lasting and can be used in harsh environments. The main characteristics for monocrystalline technology is a very high power conversion efficiency (22%), which means that 22% of the light energy is converted into electrical energy [IXYS]. This is very important in applications requiring solar power generation in a limited space. Also very important improvement of using monocrystalline cells, they have a wide spectral sensitivity: 300 to 1100 nm and for these characteristics can be used in indoor and outdoor applications; the irradiance is generally much higher outdoors.
With a cell efficiency of typically 22%, it gives the ability to extend run time even in “low light” conditions, increase battery life and run time in a small footprint, which can be easily accommodated in the our design of portable products, requesting minimum hardware space.

2.1.9. High speed video data gathering from the contact of the pantograph and overhead line.

High speed video data system is developed as alternative for above presented instrumentation. Mainly reason was to have solution for situations where not possibilities to hang the acceleration sensor by the contact line. Also, the high speed video system is useful for that situations were are not necessary long time measurements.

Detailed description of this system and results will be part of other further paper but, as general characteristic, high speed video camera system is focused for registering images from the contact point, between pantograph and overhead line. The objective is to characterise dynamic behaviour, as the displacement of the overhead contact line, under the contact force.
The recording of the images will be achieved with a high sampling rate (eq. 500 - 1000 FPS) and will include the time of balancing of the contact line under the action of the contact force, exerted by the locomotive pantograph.
The video will be played back at a normal viewing frequency (20 - 30 FPS), which will highlight all the details of the dynamic behaviour of the contact line.

The high speed video system consists mainly of one high speed video camera and accessories for functioning. Also in this system should be included the video post process modelling application, which has to have at least a minimum list of properties and functionalities for achieving the technical objectives.

2.1.10. Potential of transferring technologies into the commercial area

The systems presented were designed and developed within the framework of the NeTIRail-INFRA Project, with European funding, part of the EU Research and Innovation programme H2020.
There has been no plan for commercialization of the implemented technologies. The signals received from the group of potential users, since the start of the technical analysis and definition of the technical requirements, have highlighted a great potential of utility if the performances achieved will be at the level of the technical requirements.

In support for increasing the potential of the technology transfer in practice, especially for the sensors system that measures the contact line acceleration, NeTIRrail-INFRA required since from the design phase an important objective: the solution should be in the low cost category. In this regard, the expected cost objective for electronics components and materials is under 50 €/device, estimated at the price when at least 100 pcs produced.

3. Conclusions

The system for measuring the acceleration of the overhead lines, proposed and developed for the NeTIRail-INFRA project, has the objective of technological innovation to continue the acquiring function for displacement values with functions of remote wireless short range but also long-distance transmission of collected data and also, achieving the functionality of the power supply autonomy of the system.
The system has been designed to bring some of the latest electronics and automatics technologies to the railway applications. These are the proposed elements of innovation in this area and are resumed by the following functionalities:

- Acquisition of vibration data from the contact line, taking into account existing very high power supply voltage values (e.g., 25kVdc);
- All info, including sensor acquisitioned data, are changed with in the fields devices in wireless mode; this will greatly increase the degree of reliability in operation because there are no data cables that can be interrupted during use;
- Further, data will be "brought" out of the field, via the Internet, at the Control Centre level, for storage and analysing.
- The concept of total autonomy of running has been introduced in the system's functionality, field devices can transmit a large amount of data over a long period without external power supply.
- Taking into account the sum of these technical specifications, the acceleration sensors system can be included in the category of IoT systems, applicable in the railway domain.

At the time of writing this document, the development of the contact line vibration acquisition system reached TRL 4, the system pass the functioning tests in the laboratory environment. NeTIRail-Infra project has planned sessions of successive experiments and iterations; until the end of the first quarter of the year 2018, they will bring the system to at least TRL 6 level.

4. References

Kiessling, F.; Puschmann, R.; Schmieder, A.; Schneider, E; 2012. Contact Lines for Electric Railways: Planning, Design, Implementation, and Maintenance; 2nd Edition

TI-Texas_Instruments; http://www.ti.com/product/CC1310

ST-Microelectronics. http://www.st.com/en/mems-and-sensors/iis2dh.html.

IXYS; http://ixapps.ixys.com/datasheet/kxob22-01x8f_nov16.pdf