Conception of the system for traffic measurements based on piezoelectric foils

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Abstract. A concept of mechatronic system for traffic measurements based on the piezoelectric transducers used as sensors is presented. The aim of the work project is to theoretically and experimentally analyse the dynamic response of road infrastructure forced by vehicles motion. The subject of the project is therefore on the borderline of civil engineering and mechanical and covers a wide range of issues in both these areas. To measure the dynamic response of the tested pieces of road infrastructure application of piezoelectric, in particular piezoelectric transducers in the form of piezoelectric films (MFC - Macro Fiber Composite) is proposed. The purpose is to verify the possibility to use composite piezoelectric transducers as sensors used in traffic surveillance systems - innovative methods of controlling the road infrastructure and traffic. Presented paper reports works that were done in order to receive the basic information about analysed systems and their behaviour under excitation by passing vehicles. It is very important to verify if such kind of systems can be controlled by the analysis of the dynamic response of road infrastructure measured using piezoelectric transducers. Obtained results show that it could be possible.

1. Introduction
While developing new devices and machines engineers have the opportunity to apply new materials as well as new methodology to design more effective and cheaper devices and systems [1-3]. In a great part it is a result of the possibility of smart materials application. Such materials can change one or more of their properties during operations and this change can be controlled [4-14]. Powerful tools in this process are also computer aided methods of designing, manufacturing and product life cycle management [15-18]. In this paper a conception of mechatronic system is considered, so the system in which elements from different science areas, such as mechanics, electronics and informatics are included. Mechatronics brings new possibilities and one can say that it brings new level in technical devices [19-27]. At the same time such devices have also a positive influence onto realization of the principles of sustainable development by the method of its production, as well as the whole product life cycle. The sustainable development means 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. The mechatronic system designed for better traffic control and road infrastructure managing is the project that is in agreement with those ideas.
Research into new applications of smart materials that enable the fulfilment of the newly proposed technical measures their requirements regarding increasing durability, reliability, precision operation or lower energy intensity are also increasingly conducted [28-34]. Designers’ strivings to miniaturization of the designed systems should also be noted. In many cases this requirement is possible only through the use of smart materials, including piezoelectric materials. Due to the piezoelectric phenomena nature, these materials can be successfully applied both as actuators and sensors. In both cases, using a piezoelectric material, it is possible to simply convert mechanical energy into electrical energy and vice versa. The advantage of piezoelectric transducers is also wideband signal transfer and high energy conversion efficiency. Not without significance is the high speed and precision of action, as well as the possibility to design and produce piezoelectric elements of any shape, suitable for the application. In addition, they may be both, bonded on the surface of other components, as well as be an integral part as in the case of laminated parts.

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 [35-37]. MFC transducer is consists of rectangular piezo ceramic rods sandwiched between layers of adhesive, electrodes and polyimide film. Main benefits of the MFC given by the manufacturer are: increased strain actuator efficiency, damage tolerance, environmentally sealed packages, available as elongators and contractors. The development of transducers allows new applications of piezoelectric materials inter alia, solutions such us the recovery of electric energy from mechanical vibrations (energy harvesting systems) and improves operation of existing devices [31]. However, designing of such modern devices is a challenge for designers, forcing the development of new methods for their design and modelling.

Paper presents assumptions of the mechatronic system for traffic measurements based on the piezoelectric transducers used as sensors. The aim of the work project is to theoretically and experimentally analyse the dynamic response of road infrastructure such as protective barriers, acoustic screens, lighting components, etc. forced by a circular motion. The subject of the project is therefore on the borderline of civil engineering and mechanical and covers a wide range of issues in both these areas. Modern surveillance of the traffic such us innovative methods of controlling the road infrastructure, such as lighting, traffic lights or self control of traffic in the assumed area are very important. Such solutions are being increasingly used and research on their development is widely conducted. In times of significant expenditure on environmental protection and the implementation of the Sustainable Development Policy in almost every area of life, the use of this type of intelligent traffic control systems, or the lighting of road infrastructure can have a direct impact on reducing the cost of maintaining the road network, reduce the "carbon footprint" and to reduce light intensity in areas with significant light pollution. The aim of the presented work is therefore to investigate the possibility of using vibration measurement of selected elements of road infrastructure and application of received measurement signals to control this type of systems. As an example described above solution used to actively control the illumination of the road infrastructure by analyzing the electrical potential caused by moving vehicles can be proposed.

2. An overview of the conceptions of traffic surveillance systems with piezoelectric transducers

Nowadays, there is the large interest of the scientific community in proposed topics. Large number of scientific articles and other documents can be found during literature review. For example in international patent number EP 2253762 B1 titled “Road barrier structure with an integrated system for energy generation and detection and classification of collisions” authors present assumptions of the road barrier structure with an integrated system for energy generation and detection and classification of collisions [38]. The idea of the system is described that a road-barrier structure is provided with a plurality of piezoelectric modules (3 in Fig. 1) integrated in a wall (2 in Fig. 1) thereof and distributed along the latter. The wall is shaped and set in such a way as to be subject to vibrations as a result of the passage of motor vehicles along the road on which the road barrier is installed. The piezoelectric
modules are arranged and oriented for exploiting said vibrations in an optimal way in order to produce electrical energy. Furthermore, the piezoelectric modules are arranged in such a way as to be able also to perform, together with the function of generators, also the function of deformation sensors, designed to detect collisions against the road barrier. The modules are connected to an electronic control unit (4 in Fig. 1) programmed for processing the signals at output from the piezoelectric modules and classifying the detected collisions against the road barrier on the basis of a predetermined scale of seriousness. The control unit is supplied with the energy generated by the piezoelectric modules. The electronic control unit moreover includes wireless transmission means for transmitting the information regarding the data detected. This system is presented in Fig. 1.

![Diagram of road barrier structure with integrated system for energy generation, detection and classification of collisions.](image)

**Figure 1.** The road barrier structure with an integrated system for energy generation, detection and classification of collisions [38].

Also in European Patent Application number EP1167629 A2 a highway crash barrier monitoring system is proposed [39]. In presented system a highway crash barrier includes a collision sensor that detects when a vehicle collides with the crash barrier. In work [40] authors presents a system for detection of truck collisions with highway bridges. They mentioned that the detection of collision impact and evaluation of the impact level is a critical issue in the maintenance of a concrete bridge. Systems based on piezoelectric transducers applications are also used in railway transport. Dynamic loads generated during the passage of railway trains are deleterious to the infrastructure, such as bridges or buildings located near tracks, as well as people staying in them. There is however the possibility of their use in systems for condition monitoring of infrastructure components. In paper [41] the system for monitoring loads or state truss railway bridges are presented in which piezoelectric transducers are used as sensors. The system is based on an analysis of the signals generated by the transducers mounted on railroad tracks before entering the bridge and on the truss bridge elements. The wireless transmission of measured signals is possible. The amplified and filtered measuring signal can be interpreted in order to identify the load, so weighing the passing train and monitoring the technical condition of the truss bridge. The theoretical assumptions of the authors are supported by the presentation of the results of measurements on a waveform signals recorded by piezoelectric sensors when the train is passing and the reference signal level to the mass of the wagon, determined by a static weight. The values obtained allow clear identification of the type of wagon after previous calibration of the measurement system.

The presented work corresponds with research works that were done by other researchers. The aim was to verify if non-classical piezoelectric composite can be used as sensors in innovative systems designed for traffic monitoring.
3. CAD models of road infrastructure elements and their analysis

CAD models of protective barriers were created to carry out a series of analyzes to predict areas susceptible to deformation. Assemblies of elements were simplified by the absence of screws, nuts and washers. They were created in NX 8.5 software. In each of the assemblies a fundamental element is a type B barrier fence. This version is currently the most common on the Polish roads. A road barrier type SP-04 with the fence type B with the pillars spacing of 1000 mm is presented in Fig. 2. It is a barrier used mainly on public roads and where it is necessary to install reinforced barriers. It consists of:

- The type B guide,
- The arm of the type B guide,
- The spacer made of section C120,
- The pillar made of section IPE 140 with a length of 1900mm,

![Figure 2. The Assembly of the protective barrier type SP-04/1.](image)

The modal analysis was carried out in order to identify elements and places on protective barriers with the maximum values of displacements and to identify measuring points where piezoelectric foils should be glued during measurements on real objects. Those points are presented in Fig. 3 for the road barrier type SP-06. In this type of barrier the additional profile belt is used.

![Figure 3. Measuring points on the road barrier type SP-06.](image)
Measurements of the dynamic response of protective barriers were carried out on the highway. The sensors were glued on the elements of the protective barrier that separates the lanes in opposite directions and is located on green belt.

4. Results and conclusions
Measurements were carried out using Macro Fiber Composite piezoelectric transducers type M-8514-P1 produced by Smart Material corporation. Simultaneously to measurements passing vehicles were recorded by a video camera. Recorded video was then compared with the voltage waveforms generated by the MFC piezoelectric transducers in order to analyze and interpret the results. Examples of the signals generated by the piezoelectric films are shown in Fig. 4. In this figure the waveforms generated by different piezoelectric transducers are indicated, respectively:
• the red waveform denotes voltage generated by the MFC transducer glued on the profile belt (number 4 in Fig. 3);
• the black waveform denotes voltage generated by the MFC transducer glued on the upper edge of the guide (number 1 in Fig. 3);
• the blue waveform denotes voltage generated by the MFC transducer glued on the flat surface of the guide below stamping (number 2 in Fig. 3);
• the purple waveform denotes voltage generated by the MFC transducer glued on the front part of the pillar (number 3 in Fig. 3).

Using the vertical lines the moment of passing of different types of vehicles is indicated, respectively:
• a vehicle of weight up to 3.5 tons moving along the right lane of the road - the yellow line;
• a vehicle of weight up to 3.5 tons moving along the left lane of the road - the green line;
• a vehicle of weight over 3.5 tons moving along the right lane of the road - the red line;
• a vehicle of weight over 3.5 tons moving along the left lane of the road - the blue line.

The analysis of signals generated by all Macro Fiber Composite piezoelectric transducers it was found that the profile belt is too susceptible element for measurements. Numerous spikes of the generated signal voltage were observed reflecting not passing of any vehicle but resulted from wind. Most precisely the vehicle passing is reflected by the waveform generated by the piezoelectric film mounted on the pillar. Passing of a vehicle of weight over 3.5 tons moving along right and left lanes of the road as well as passing of a vehicle of weight up to 3.5 tons moving along the left lane of the road can be easily detected. Signals generated by all transducers were also affected by vehicles travelling in the opposite direction on the road lanes separated by a green belt. This element should be reduced by filtering signals and proper configuration on the sensors. The impact of the vehicles passing on the opposite road lane as well as the possibility to detect light vehicles driving on the right lane can be solved by a proper distribution of the system’s sensors. The mentioned problems should be solved by distribution of sensors on all protective barriers (external barriers and barriers on the green belt). Waveforms generated by all sensors in the system can be than filtered and juxtaposed in order to correctly infer the type, location and direction of movement of vehicles. It will be the aim of the author’s future work.

The work proved that the MFC piezoelectric transducers can be successfully used as sensors in modern in traffic surveillance systems. Additional features that will be developed include the ability to monitor traffic on a given part of road, measuring the traffic, the speed of vehicles and the acquisition of data that are extremely important because of the traffic management. An important advantage of such kind of system is the assembly of its components to existing elements without violating of the road surface and the retention of the traffic. In future work more effective methods of signals processing will be used in order to develop the system.

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