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Actual types of sensors used for weighing in motion

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Abstract. In last decade, the overloaded trucks increase in countries with weak infrastructure, for examples in Indonesia the percentage of overloaded trucks is more than 60% [1]. To prevent this violation of the country regulations was developed weigh-in-motion (WIM) network stations. For France and not only, the network of WIM stations improved traffic safety, fair competition between transportation companies and infrastructure lifetime [2]. The WIM station is able to determine: the type of the vehicle, the gross weight of the vehicle, the load on each axle, vehicle's speed and so on. The most common sensors used for obtain data information are strain gauges force sensors and piezoelectric sensors. In this paper will be analyzed the main advantages and disadvantages of each type of sensors used for WIM stations.

1. Introduction

The road traffic increase year by year and seems to be more difficult to ensure good traffic conditions by the authorities. A report from European Automobile Manufacturers Association show the number of vehicles on the road grew from 243 to 257 million and there are 6.3 million trucks on the EU's roads. Poland has the largest truck fleet in the EU, with more than 1 million trucks, followed closely by Germany and Italy. In Romania the total cars fleet increase with 5.7% every year. The same report shows that Romania has the oldest fleets, with vehicles older than 16 years [3].

Monitoring of current road traffic could not be possible without the help of the sensors. There is a wide range of sensors that can be used for this purpose: sensors for determine the speed of vehicles, sensors for determine the vehicle dimensions (length, width and height), weight, proximity sensors, and video camera etc.

The sensors used for weighing in motion can be classified in two types: intrusive and non-intrusive sensors, depends if there are mounted in the road (intrusive) or off the road (non-intrusive) which can be mounted on pillars, bridges, footbridges, in metal boxes or wardrobes mounted near the road.

With the help of a suitable interface and dedicated programs the output signal from the sensors is acquired and processed by computers. After decoding the output signal the dates are transmitted to authorities by radio or cable. The overload trucks are identified and automatic recorded without perturbing the traffic circulation. Usually for determine more parameters of the vehicles there are used several types of sensors for the same location, so part of the road or bridge can act like a smart technology (for example: the speed of the vehicles can be restricted until stopping, deviation or re-start the traffic circulation on that part of the road/bridge can be achieved). In Hong-Kong for prevent the bridge collapse, all the vehicles which use the entrance to the bridge are weighing in motion.

For safety reasons the total load of the vehicle is important for protect the bridge and the infrastructure. The load of the vehicles that cross the bridge depends of the initial load bearing capacity of the structure, but also of bridge degradation degree. In first of august 2007, 13 people die in collapse of Minnesota Bridge, US, during the evening rush hour (140,000 vehicles cross the bridge daily) [4]. More recent, in 2018, another bridge collapse in south Kolkata, India during the evening rush hour, one man dies and 28 was injuries [5] and so on.

2. Actual types of sensors used for weigh-in-motion and vehicle's monitoring

The weighing can be making *static* (with fix or mobile platforms by stopping the vehicles) or *dynamic* (with low speed 5-15 km/h or high speed 80-130 km/h). The static weighing is more precise than dynamic weighing, but has some disadvantages like: the vehicle must be complete stopped and this can conduct to traffic jams, takes long time to weigh the vehicle because the scales are in fixed locations. In Figure 1 is presented the working scheme of a fix weighing platform, where the truck is positioned on a plate 1 which is set on a dynamometric strain gauges and the weight of the truck is read it on the display 3.

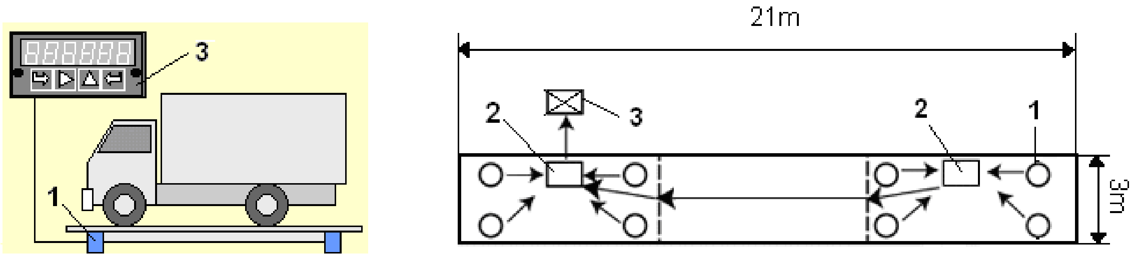

Figure 1. Scheme of a fix weighing platform (a. lateral view; b. top view): 1 - load cell; 2 - junction box; 3 - display.

The weighing in motion can be done by weighing with low speed or high speed. The advantages of weighing at low speed are: decrease time allocated to weighing, higher accuracy than weighing at high speed and precise identification of the vehicles. The sensors used for weighing at low speed (<15 km/h) are intrusive, they are fixed in the road. The active surface of the sensors is enough bigger to register all the contact between tyre and sensor. For determine the entire weight of the vehicle the sensors weigh each wheel or axle. The sensors used for weighing at high speed (>80 km/h) also call it weigh-in-motion (WIM) sensors are embedded in the road (intrusive sensors) and they can determine the weigh and other parameters (speed, temperature, humidity, vehicle's dimensions, type of vehicle, registration plate and so on).

A WIM system mounted in USA (a country with few violations of regulations)give the following results: 12.41% of trucks are overloaded with a average of 6 kN/axle; 4.89% of trucks exceeded the maximum allowed load on the bridge; because of this types of sensors avoiding the overloaded trucks could extend the life of roads with approximative 2 years.

The WIM sensors works in difficult conditions (dynamic loads, vibrations, big temperature differences, salt water, ice, dust and so on).There are several types of weighing sensors such as: piezoelectric sensors, those who use strain gauges, optical fibbers, capacitive sensors and hydraulic sensors. In present there avaible on the market there are single load cell, bending plate and piezo quartz.

Single load cell consist on a box fixed in the road with a rigid plate on the top, which is at the same level with the road. The tyres in contact with the plate transmit the force to a single load cell mounted in the middle of the plate. Inside the box a bars systems transmit the force to the cell load (other solutions use, inside the box, a hydraulic system to transmit the force - the plate leans on the hydraulic cylinders and the under pressure fluid is conduct at the load cell). The WIM sensors are mounted together with other sensors such as: two inductive loops for determine the speed and sensors for detecting the presence of the axle (to determine the number of axles and the space between them) (Figure 2). The presence of the axle can detected, for example, with the help of piezoelectric cable or

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optical fibbers. The single load cells were developed in ’68 in USA and they present some advantages like: are robust and reliable; high precision and easy maintenance. The main disadvantages are: the cross-section dimensions are large, difficult installation; high initial costs and so on.

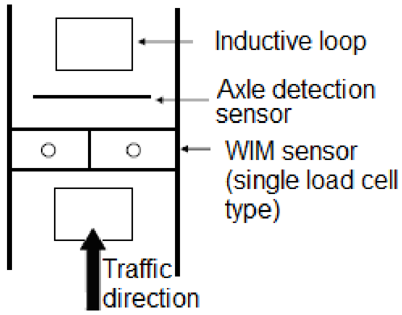

Figure 2. Scheme of a WIM system with single load cell.

To install the sensors, the traffic circulation must be stopped for 3 days and it must wait 28 days for the concrete arrive on maturity; also, for better resistance, it is recommended to replace asphalt with concrete on a 60-90 m section, thus the cost for installing this kind of sensors is high.

The accuracy of this kind of WIM sensors is ±6%, average lifetime is 12 years, the total cost for install the sensors is estimated at 48,700 $ and the annual maintenance consts are estimated at 8,300 $.

Bending plate sensors consist on a box embedded in asphalt with a flexible plate on the top and some strain gauges attached on the inferior surface of the flexible plate. The tyre cross the plate and the force applied to the plate is reading with the help of the Wheatstone bridge.

The flexible plate is consider the elastic element of the sensor and need to be made of high strength steels. The sensors may range from 1,825-2,000 mm in length, 600 mm in width and 60-150 mm in thickness, depends of the needs. The advantages of this kind of sensor are: the bending plate sensor has a smaller in thickness compared to the single load cell, have lower costs and the maintenance is simplified. The main disadvantages are: lower accuracy and endurance in comparison with single load cell, maintenance at every 5 years is required and when the vehicle crossing the sensor they are noisy.

The accuracy of this kind of WIM sensors is ±10%, average lifetime is 6 years, the total cost for install the sensors is estimated at 21,500 $ and the annual maintenance consts are estimated at 6,400 $.

Piezoelectric sensors use piezoelectric materials (quartz, for example) which generated an output signal proportional to the force applied. These types of sensors are developed since ’96 and now they are they are widely used in WIM stations. On the market this sensor may range from 750-1,000 mm in length, 50-190 mm in width, 44-145 mm in thickness depends of the needs and the weight of the sensor at minimum dimensions is 4.9 kg. The sensor consist of extruded aluminium profile with a special shape, inside which are mounted the blades of piezoelectric material (quartz).

Due to the small cross-section a line sensor may be mounted in less than one day; the traffic disturbance is significantly less than other sensors. The tyre footprint is not entire on the active surface of the sensor, because the sensor have a small width, so tyre is applied on the sensor and the road in the same time. The weighing calibration is making by integrate the output signal of the sensor when the tyre crosses the sensor. The main advantages are: the sensor has a small weight and a small transversal cross section, the sensor price and the installation costs are lowest on the market, the influence of the change of temperature is very low (the sensor temperature range from -40˚C till +80˚C), the sensor can work at lower speeds (5 km/h) or higher speeds (200 km/h) (Figure 3). The disadvantages are: it is less accurate in comparison with other commercially available sensors; it has smaller lifetime period and relatively difficult maintenance and so on.

There are two types of wide WIM sensors: single load cell and bending plate. The entire tyre footprint is on these sensors. Another category is the strip WIM sensors: piezoelectric sensors and so on. Only a part of tyre footprint takes place on the active surface's sensor. In order to estimate the weight of the vehicles with strip sensors needs to integrate the output signal. At wide sensors this operation is not necessary.

The accuracy of piezo quartz sensors is ±15%, average lifetime is 4 years, the total cost for install the sensors is estimated at 9,000 $ and the annual maintenance consts are estimated at 4,750 $.

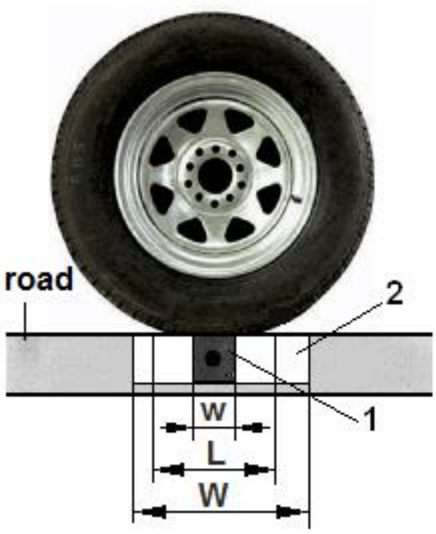

Figure 3. Wide sensor (1) and strip sensor (2): W and w = sensor widths; L = the length of the tyre footprint.

Fibreoptic sensors for weighing the vehicles are based on change of optical signal output by straining the fibres when the wheel will cross the sensor. Narrow grooves filled with resilient rubber there are make it in the road for mounting the fibre optic cables. This type of sensor can: sorting the vehicles by types; indicate the exceed axle weight limit; send the info to a centralized system of data [6]. The main advantages of fibre optic sensors are: high sensitivity; small cross section; low weight; low transmission losses; insensitivity to electromagnetic fields. The disadvantages are: sensitive at temperature variations; sensitive at vehicles speed and the vehicles identification is not really precise.

The optic fibre is mounted on two steel plates, thus the wheel applies force on the plates and the strain the optic fibre, this solution is better than installed on bridge beam, also the high sensitivity of could be a disadvantage if the cables are mounted into the bridge [7].

The tyre inflation pressure has influence on the sensor's output signal. If the inflation pressure is lower, the tyre footprint has a bigger area and the signal will be bigger; if the pressure is higher, the output signal will be lower, but will have the same amplitude. So the tyre pressure will have some influences on sensor's output signal. The relationship between magnitude of the applied load and the output signal of the optic fibre is good and the location of the applied force can be determinate with good accuracy [8]. Usually the fibre optic is made by fibre glass, but on the market exists also polymer optical fibres (with larger strain rates) and varies types of fibre optic sensors: micro-bend, wavelengths, distributed, fibre optic Bragg grating, hybrid sensors and so on [9].

The necessity to embedded fibre optic sensors inside a composite material in last 40 years has increase in domains like airspace, defence and automotives. There are a lot of types of fibre optic sensors which are measure the strain or temperature in composite materials, such us: fibre Bragg grating sensors, fibre optic micro bend sensors, distributed sensors, optical fibre polarimetric sensors and so on [10].

Pneumatic road tubes consist on rubber tubes that are mounted across lanes of a road and commonly they are used in combination with weigh-in-motion sensors to determine vehicles parameters such as: speed, number of axles, traffic directions. The basic principle of how they work is change in pressure of the pneumatic tube. When the vehicle's speed increase and the distance between vehicles decrease the pneumatic road tube can't differentiate the number of vehicles travelling [11].

The main advantages of this kind of sensors are: quick installation, waterproof, easy maintenance, non-intrusive sensors and they are enough sensitive to detect the pressure applied by bicycles or motorcycles. The estimative price on the market for this type of sensor is between 250$ to 420$ [12].

Bridge Weigh-in-Motion (B-WIM) consists on sensors mounted on existing bridges for measure the weights of the passing trucks. B-WIM provides additional data information about bridge condition such as: strain measurements, influence lines, load distribution factors and dynamic amplification of loading [13]. The most common B-WIMs use sensors like strain gauges and strain transducers.

The bridge weigh-in-motion solutions were used on simply supported girder bridges, but in time this concept was extended to all types of the bridges. Depends of the level of accuracy the bridge are selected to install this types of sensors, based on the distance between two furthest points that affect the measurement. The main advantages of this solution are: the instrumentation and maintenance are simpler and less intrusive than WIM systems mounted in pavement, no need of sensors on the road surfaces (no traffic disturbing to install the sensors) and because the weighing will be on the bridge, the drivers of the overloaded trucks can't avoid them [14].

New B-WIM sensors were designed for weighing the trucks with the help of wireless connection. The system consists on individual wireless sensing nodes and ultrasonic non-destructive evaluation devices [15]. A new concept of contactless bridge weigh-in-motion was tested in UK by using two cameras instead of intrusive sensors. First camera magnifies the image to measure the bridge deflection and second one was used for determine the axles distance of the truck. The synchronization between cameras was making using light-emitting diodes [16].

Hydraulic sensors are simple, but they have a very limited use as WIM sensors because liquids has a bigger thermal coefficient than steel and the WIM sensors need to work in a big temperature range (-40°C and +80°C). The main advantages are: simple construction, low thickness, robustness and so on.

Y.S. Moon et al. present a new hydraulic tube structure for weighing in motion with double-tube structure which improve the pressure changes according to the temperature and reduce the nonlinearity [17].

Video Image Detection is used in weigh-in-motion systems for detect and identify the register plates of vehicles (Automatic Number Plate Recognition). The information from this system helps authorities to identify the vehicle owner and to charge violations of regulations. The main advantages of this kind of system are: accurate counting and identification of vehicles etc. [11].

On-board weighing systems consist of follow components: the sensors (load cells, air pressure transducers, strain gauges, accelerometers or displacement sensors), the interconnecting internal harness (e.g. cables) and the box which including data processing units and communication interfaces. The on-board weighing systems are installed on the vehicles and are able to determine the weight data any time from a moving vehicle. On-board weighing systems can be on two types: static or dynamic measurements. For static solutions estimate cost is under 1,000 €/truck and they are universal - installing on all types of trucks - the costs can be decrease with 50% if are fitted in-line during production for all models. For dynamic solutions estimate costs are bigger than static solutions, the estimate cost start from 5,000€/truck till 13,000€/truck. The main advantages of this solutions are: can be synchronize with WIM data information, the weight of vehicles can be monitoring any time, this system can be synchronize with GPS system for monitoring the weight of vehicles on the all route transportation, no need to stop vehicles for weighing, no pavement destructions for installing the sensors [19].

Piezoelectric cables are embedded on the pavement for vehicle's detection, classify the vehicles and determine the number of the axles. In figure 2.9 is presented piezo cable components: polyethylene outer jacket, copper braid, piezo-film tape, standard centre core.

The electrical output is proportional with the load applied on the cable. The domain of sensing is substantial (>200 dB), the cables have withstood pressures of 100 MPa. The work temperature range is -40˚C to +125˚C. The piezo cable sensors are used for aircraft identification, safety and security applications [20].

3. Conclusions

This paper presents actual types of sensors used for weigh-in-motion (WIM) and vehicle's monitoring and some advantages and disadvantages by using each type of sensor. Weigh-in-motion systems can measure the axle truck weight and if is synchronize with existing tolling system, the municipality can develop a tolling assisted by WIM system. The overloaded trucks phenomena can decrease by using WIM systems and violation of the regulation can be charge by weight. According to Camea Technology, one overload truck makes the same damage as 28,000 passenger cars [18].

The installation place of the WIM shall be in an area where the vehicles have a constant speed, this is needed because the system is sensitive to the dynamic forces of the vehicle, and thus, if the vehicle is accelerating or decelerating, the readings will be affected.

The most common technologies available on the market are: strain-gauge sensors, piezo-polymer strips and bars, piezo-ceramic bars, piezo-quartz bars. The WIM sensors market growing up, North America is the largest share of WIM market, because the government increase the initiative of weighing in motion initiative. In China, Japan and South Korea increase the market of intelligent transportation systems.

More and more countries are investing in weigh-in-motion technology in order to protect the road pavement and environment, increase the traffic safety and avoid the traffic jams and so on.

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