Modern measurements techniques in structural monitoring on example of ceiling beams

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Abstract. The problem of the deformation in engineering structures constantly appears in publications, scientific works and technical solutions. Presented therein approaches do not solve the issue of real time control of beam elements, performed in a continuous manner.

The beams are structural elements, which require of knowing their geometrical state during exploitation. The basic measured factor which describe the strain of the element is a deflection that corresponds to the maximum displacement vector.

The study show the potential of supporting applications for geodetic techniques in the inspection of geometric changes in the beam elements. Authors propose solutions used the optoelectronic devices and MEMS.

The approximation of chain curve, which describes the geometry of the element, can be obtained by measuring angles at selected points of the element and the distance between them. For this purpose authors used the accelerometers. Accelerometer remained motionless, detect the direction of the gravity Earth's force field which allows to calculate the angle of inclination from the vertical or horizontal line. In laboratory studies the low-cost devices have shown high accuracy, which allow to use the accelerometers in the measurement systems. The accuracy of the sensing angle is better than 0.3mrad, which means the ability to determine the deformation better than 0.3 mm/m.

The authors propose also the use of measuring set comprising of laser diode and CCD camera. Measuring set enables automatic control in real time. The accuracy of the measurement is better than the pixel, which is determined by the standard deviation of the distance change in the position of the laser beam footprint which is less than 0.3 pixel. This modern supporting methods were compared with the surveying measurement techniques such as precision levelling, tachymetry, terrestrial laser scanning, laser rangefinder and also linear displacement sensors.

Keywords. MEMS technology, optoelectronic, ceiling beams, monitoring

1 Introduction

The forces can act on structures directly and indirectly. They are cause by the factors such as wind, snow, temperature, dead weight, subsidence. The technical condition of a building at the time describe a certain set of characteristics. Features of the load changes with time. The consequence is a change in the geometric state of object. Structural beams can be subject of the displacement and deformation due to the nature of the work they perform in the structure. In order to avoid failure or disaster, deformation measurements should be carried out in accordance with the agreed schedule of geodetic observations (Woźniak 2010). For monitoring of structural elements can be used many geodetic techniques (tachymetry, precision leveling, laser scanning, photogrammetry, etc.) and other (clinometers, inclinometer, extensometers, strain gauges, feeler gauges, pendulum, plummet, etc.) (Setan et al. 2003). These methods allow to perform measurements with high precision and detect the first signs of danger arising from exceeding the thresholds (defined by the constructor). However the results of such measurements are expensive, and the majority of this techniques are periodic and spot metering (Spencer et al. 2004, Wilczyńska 2014).

Geodetic survey on construction projects are contingent on many factors. These include above all the dimensions and geometry of observation. Dimensions of the object and its structural relationship with other elements and phenomena occurring on the optical road (refraction, turbulence, dust, smoke, variable illumination). On the object the phenomena affecting by the metrological characteristics of measuring instruments such as temperature, shock and vibration can occur (Ćmielewski 2007).

The main structural elements of buildings carrying the load are: roof, structural walls, ceiling and foundation. Classification due to the proportion of dimensions is as follows:

- section bars (one dimension substantially greater than the other),
- surface elements (two dimensions significantly larger than the third),
- massive elements (all dimensions are of the same order).

Development of applications used optical instruments in the field of geodesy inevitable, and the combination of optics with electronics provides optimal results. For example, one could mention computer-controlled surveying instruments for measuring deformation and laser systems for determine the higher precision displacement measurement (of static and dynamic) (Bryś et al. 2009, Kledyński 2011).

2 Conception of measuring devices

2.1 Laser diode and a CCD camera

Deflection is an essential subject of measurement. Proposed solution used a laser diode and a CCD camera (Fig. 1). On the object should be mounted a flat mirror. The laser beam is emitted from a constant place. This beam is reflected from a mirror and falls on the CCD matrix. From camera we can read the position of the beam in the CCD coordinate system of x, y. Displacement, change the position of the mirror which causes a movement of the laser beam on the CCD. Scaled reading from camera determine the displacement of the building component. To perform these measurements it is necessary the image recording module in digital form and simple computer application for movement calculation.

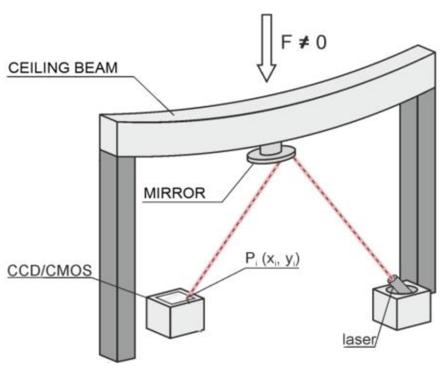

Fig. 1 Functional diagram of low-cost observation system (Wilczynska 2014).

The accuracy of the measurements is calculated at the level under pixel, which is determined by the standard deviation of the distance changes in the position trace of the laser beam and its value is less than 0.3 pixel. This distance corresponds to a change height mirror of 0.1 mm. The resulting standard deviations did not differ statistically significantly as a result of the conducted test F-Snedecor $F < F_{KR}$.

2.2 MEMS sensors observation system

The beams doesn't work always equal, it can occur that beams have some internal weakness points, which can move the point of the maximum displacement from the center of element to one side of it. For that reason it is also important to determine the chain curve, describing the shape of it.

To identify changes in the position of points, we can use MEMS technology (called Micro Electro-Mechanical Systems). Data from the devices such as acceleration vectors from three axis are transmitted in real-time and calculated the Euler angels. Because we know the distance between points we can calculate the displacements. When the limit of this values are exceeded, the warning message is going to be displayed and an alarm is triggered. Then the proper people will launch the appropriate alarm procedure. This device (Fig. 2) in laboratory tests shows high accuracy (Ćmielewski et al. 2011).

Using the known parameters of accelerometer can be obtained accuracy angles of about 1^o. If we want to achieve better results, accelerometers must be calibrated.

Calibration should be carried out in 6 positions, the data should be recorded within 5 - 10 seconds with a frequency of 100 Hz at all 6 position of the accelerometer. Then, using the method of least squares 12 define calibration parameters.

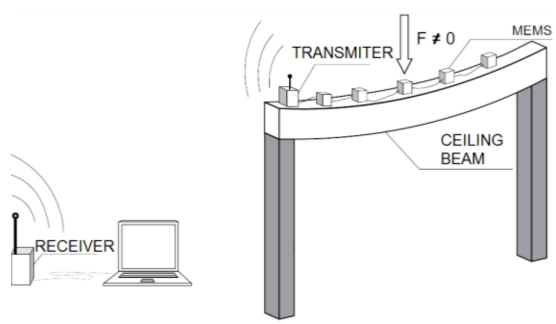

Fig. 2 Scheme of MEMS sensors observation system (Wilczynska 2014).

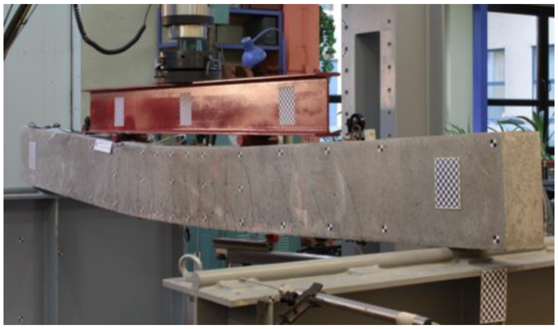

Fig. 3 Laboratory tests on concrete beam.

Table 1. Results of measurments.

	The measurement method					
	Laser	MEMS	Leveling	Scannig	Nivel	PTX
0	0.0	0.00	0.00	0.000	0.00000	0.0000
1	0.5	0.13	0.30	0.107	0.05465	0.0662
2	1.0	0.41	0.73	0.834	0.56957	0.5466
3	2.0	1.21	1.27	2.06	1.23070	1.0475
4	2.5	1.94	2.06	2.002	2.22110	1.7460
5	3.7	2.83	2.94	3.007	3.42909	2.6320
6	9.0	6.87	7.74	7.443	8.01357	7.0285
7	19.0	18.23	17.69	17.665	-	16.1800
8	42.5	40.70	41.63	41.521	-	38.3600
9	66.5	61.40	65.55	65.079	-	60.4150
10	48.0	46.35	47.31	46.897	-	46.9200

3 Test Description and Results

The test of prototypes was conducted on press in Technology Laboratory of Materials and Structures at the Institute of Civil Engineering at the University of Life Sciences in Wroclaw. The beam was equipped for a several control methods. Fig. 3 shown laboratory tests on concrete beam.
Control method were: tachometry, precise levelling, linear displacement sensor, hand laser ranging device "Disto", and prototype methods: MEMS technique and laser beam with CCD camera were tested.

The load has been raised, such that the each measuring phases beam having a constant deflection, allowing comparison of results for different techniques performed at that stage. The first measurement was taken before the load occurred, and was marked as "0". Subsequent measurements correspond to a deflection of 1 mm, 2, 3, 4, 5, 10, 20, 40 and 60 mm. Thus, simulated load continued growth of the component. The deflection was read at mid-span beam using the linear displacement sensor PTX (Wilczyńska 2014).

The continuous measurements were recorded by sensors: MEMS and linear displacement sensor. Measurement data from sensors MEMS and PTX were averaged for comparison with other measurement methods. MEMS sensors have a gentle transition between the various cycles, which is caused by using a Kalman filter. However, in real life we have really rarely to deal with such a sudden increase in the deflection caused by the applied force. In addition, the deflection limits adopted for reinforced concrete beams based on supports with spacing of 3 m is approx. 15 mm.

Methods used in the experiments demonstrate that convergence of the result in the range of 20 mm maximum vertical displacement vector in the middle of the structural element.

4 Summary and conclusions

The proposed apparatus for monitoring of the geometric state of structural components were assumed to be as cheap as possible, but also have sufficient accuracy for the monitoring purposes.
The surveying and physical methods are used primarily because of their accuracy, so the measurements are performed only periodically due to the cost of it.

The aim of this study was to enrich measurement techniques for development more tools to support monitoring of the geometrical status of individual structural elements. For this purposes authors used rapidly growing MEMS technology, piezoelectric sensors and simple measurement solutions like laser diode and a camera CCD / CMOS, which allow for continuous measurement.

The subject of the buildings monitoring in the world still develops, especially in areas threatened by earthquakes. There are also measurement systems that are using of the aforementioned techniques and technologies. However, their implementation is financially expensive. The solutions proposed in the work are cheap and allow to obtain accuracy of less than ± 1 mm while minimizing the cost of sensors and the whole monitoring systems. In case of detection of significant changes in geometry by the proposed solutions, should started the classic observation for an inspection of the object deformation. Therefore, this work has concentrated on the development of the cheap sensors that can be widely used in monitoring, while maintaining accuracy and reliability of measurement purposes. It is worth mentioning that in Poland there is an obligation inspection of large buildings twice a year - in November and March.

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