Measuring System to Monitor Strain of Bridge, Overpass Components and Bridge Clearance

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***Abstract* —**On the basis of the application of optic methods and systems to measure bridge structure strains and the principle of laser beam sweep in horizontal and vertical planes, this paper describes the devices, which are designed by the authors of the article, to monitor bridge structure strains and bridge clearance that can be used in the ASSM.

***Keywords* —**strain monitoring of bridge structure, bridge clearance, optical scanning system, laser, collimator, photodetector, step motor.

I. Introduction

Bridge structures are usually complex dynamic systems. Across the world, bridge span lengths are increasing and flexible structures are being widely used, making these structures even more sensitive to dynamic loads.

In order to monitor and forecast the condition of the bridge structure, in order to give early warning of trends in the geometric parameters of the structure, it is necessary to carry out periodic surveys of the structure of the bridge or the track.

II. Analysis of publications

The main task of monitoring the deformation of bridge structures is to determine the tendency of the geometric parameters of the structures to change by means of periodic monitoring of the deformations of the structural units of the structure and to prevent the occurrence of unacceptable deformations in the components constructions [1,2,3].

Traditionally, periodic monitoring of the condition of the structure is carried out using various geodetic means [4]:

•optical high-precision lowers (definition of vertical displacement)

• Electronic TPS tachyometers (definition of horizontal and vertical displacement)

• GPS satellite receivers (horizontal and vertical displacement)

• Rangefinder (Horizontal Displacement Determination) Sensors for Inclination, Accelerometers, Tensometers, Alkalemers and Other Data Collection Tools.

However, the Automated Deformation Monitoring Systems (ASSM) of a bridge structure need to employ other methods, instrumentation and deformation measurement systems that allow for 24 hours a day and 365 days a year to carry out monitoring with the specified discretionary value [2].

Modern Assms are in demand and are widely introduced and used both at home and abroad.

The use of ASSM of a bridge structure makes it possible to rapidly monitor the condition of the bridge structure, the displacement and the bends caused by the effects of external natural and climatic influences and the heavy vehicle load, and in cases of high dynamic load of overpasses by aircraft (Picture 1) [5] and by rail (Picture 2) [6.7].

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Picture. 1. Dynamic load of overpasses by aircraft

Picture. 2. Dynamic load of rail tracks

It should be noted that the displacement and bends of the bridge structure also affect the sub-mural dimension. According to DBN B.2.3.-22:2009 (Appendix B) of Ukraine, the height H of the gauge of the overpass above the surface of the pavement on the roads of the I - III categories and in cities are taken equal to 5 m, and on roads of the IV and V categories - 4.5 m.

But there are sections of roads for which height limits are imposed. The sign «Height limit» [8] is displayed on these sections in order to limit the movement of overall transport. If the height of the vehicle (both with and without load) exceeds the marked border, passage on this section of the road is categorically prohibited (Picture. 3).

Picture. 3. Overall traffic restrictions

If the damage to the side-by-side vehicle (Picture. 4) results in possible injury to the driver, damage to the heavy-duty bridge structure (overpass) (Picture 2) could lead to a fatal disaster with many casualties.

Picture 4. Failure of the driver to comply with the sign «Height limitation»

Therefore, it is necessary to install at a certain distance from the bridge the information structure of the beam or frame system with a corresponding position equal to the underside of the bridge with the corresponding signs (Picture. 5). Even if, in this case, if the driver does not comply with the sign «Height limitation» the overall vehicle and the information structure will be damaged, however this will make it possible to avoid damage to the bridge structure.

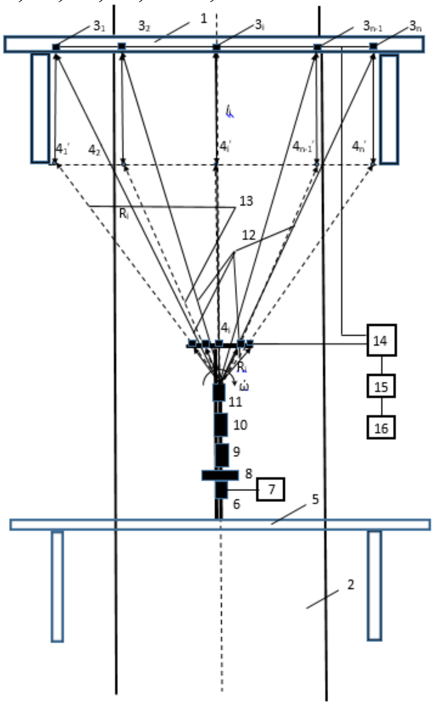
Picture 5. Information construction of the beam and frame system

Devices based on deploying optical systems have been proposed for the deformation monitor of the bridge structure and for the determination of the under-pillar dimension in [9]. However, as noted in the article, when the laser beam deployment unit and the stepper engine are located on the side of the road on one side of the bridge structure, the position of the photoreceivers on the bridge bulkhead will be very uneven. That is, on the bypass beam of the bridge structure on the side of which the laser beam is deployed, if the distance between the photodetectors is centimetres, on the opposite side of the bypass beam up to several meters. This, in turn, will lead to a significant error in calculating the deformation of the bypass beam and the underside of the portion where the distance between the photodetectors is measured by metres. Therefore, the proposed step motor, the laser beam deployment unit and the photodetector are located in the middle of the road under the bridge structure on the information structure of the beam or frame system (Picture. 5) at a certain distance from the bridge structure. Thus, the information structures of the beam or frame system, in this case, have a dual function: the installation of signs informing drivers of the height of the under-pillar, thereby protecting the bridge structure against damage by road traffic, and the location of the equipment for measuring the deformation of the bridge structure and the underside clearance.

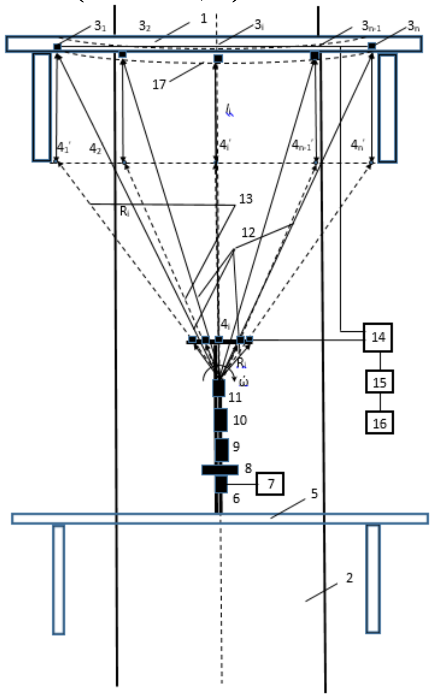
Consider in more detail the proposed design solution and the operation of the device for measuring the deformation of the bridge structure and the under-bridge dimension.

Photodetectors 3_1, 3_2,…, 3_i,…, 3_n, which are distributed and fastened throughout the length of the span beam of the bridge structure and photoreceivers 4_1, 4_2,…, 4_i,…, 4_n, which is mounted on a support on the structure of the beam or frame system 5 above the middle of the roadway at a certain distance from the bridge, each of which is in the same vertical plane with corresponding 3_1, 3_2,…, 3_i,…, 3_n photodetectors fastened to the span beam of the bridge structure (Picture 6).

Step engine 6, which is programmed by block 7 of step engine control, installed on the structure of the beam or frame system 5 above the middle of the roadway at a certain distance from the bridge and, accordingly, at a certain distance from the photodetectors 4_1, 4_2,…, 4_i,…, 4_n, wherein a platform 8 is fixed to the shaft of the stepper engine, on which a light source 9 in the form of an IR-range laser, a collimator 10 and a unit 11 of a laser beam diffuser are mounted in series. To select the points of installation of the photodetectors 3_1, 3_2,…, 3_i,…, 3_n along the entire length of the spanning beam of the bridge structure and measurement of the submersible dimension l_i (bottom of photoreceivers 3_1, 3_2,…, 3_i,…, 3_n on the passing beam 1 of the bridge and points 4_1', 4_2',…,4_i',…, 4_{n-1}', 4_n' on the road 2 (Picture 6) are used, for example, a tachyometer. Points of installation of photodetectors 3_1, 3_2,…, 3_i,…, 3_n and 4_1, 4_2,…, 4_i,…, 4_n, selected according to the angle of rotation (step) of the shaft of the stepper engine (e.g., $\gamma = 0.9^\circ$ or 1.8°), which is installed at the position of the tachyometer on the beam or frame structure above the middle of the roadway. Cameras 4_1, 4_2,…, 4_i,…, 4_n, is mounted on the support structure of the beam or frame system above the middle of the roadway in such a way that points 4_1', 4_2',…,4_i',…, 4_{n-1}', 4_n' were their sequel 13 on Road 2 (Picture 6, 7).



Picture 6. General appearance of the device without deformation of the bridge bulkhead

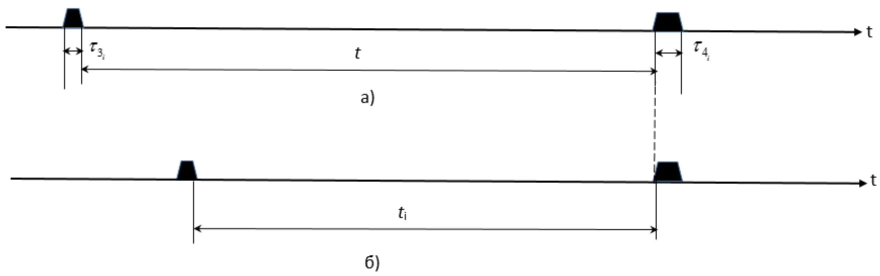


Picture 7. General view of the device with overflow beam deformation

The device uses a laser 9 (laser diode) with continuous radiation of an infrared ray (IR) range of a certain wavelength. In series with laser 9, an optical collimator 10 is arranged, consisting of a lens, in the focal plane of which the output of a laser beam 12 is located. The optical collimator 10 ensures the parallel of the laser beam 12 and therefore, due to the practically zero divergence, all the laser beam energy will be concentrated on the sensitive surface of each photodetector made of a certain material, A laser beam that passes through without major obstacles. Each photodetector 3_1, 3_2,…, 3_i,…, 3_n and 4_1, 4_2,…, 4_i,…, 4_n, contains a photodiode preceded by a sensitive surface or an optical filter which passes a beam of only a certain wavelength of a laser. All elements of the photodetector are placed in a sealed housing. For example, the unit for scanning 11 is in the form of an engine on which the shaft has a mirror at an angle of 45° to a laser beam, or a scanning optical wedge, by means of which the laser beam is unfolded in a vertical plane.

The laser 9, the optical collimator 10 and the unit for deploying the 11 laser beam are placed on platform 8, which is mounted on the shaft of the stepper engine 6, which, according to the program of block 7 of the control of the stepper engine, rotates the shaft of the stepper engine and, correspondingly, the platform is one step (the angle is equal to γ). After some time, from block 7 of step engine control, a command enters the step engine, resulting in its shaft being rotated to a different angle γ, etc. until the pitch engine angle from the zero point reaches the value ά = n * γ, installed by a tacheometer and programmed in block 7 of step engine control. The step engine shaft is then returned to the reference (zero) point and the process is repeated.

Thus, the optical signal 12, unfolding from the unit of the deployment 11, successively runs on the sensitive surface $3_1, 3_2,\ldots, 3_i,\ldots, 3_n$ and $4_1, 4_2,\ldots, 4_i,\ldots, 4_n$, photoreceivers of certain length h (Picture 6, 7). Electrical signal from photodiodes of each of the photodetectors $3_1, 3_2,\ldots, 3_i,\ldots, 3_n$ and $4_1, 4_2,\ldots, 4_i,\ldots, 4_n$, the amplifier of the electrical signal of the corresponding photodetector which, after amplification, enters the switching unit 14 (Picture 6 7). The duration of the electrical pulse from the output of the photoreceiver will be determined by the rate of passage of the laser beam on the sensitive surface of the photoreceiver, which in turn, will be determined by the angular speed ώ of the engine of the deployment node and the distance R of the deployment node to the corresponding photoreceiver (Picture 6, 7). Therefore the duration of impulses with $3_1, 3_2,\ldots, 3_i,\ldots, 3_n$ and $4_1, 4_2,\ldots, 4_i,\ldots, 4_n$, the photodetectors will be different and will increase as the photodetector approaches the deployment node (Picture 8)



Picture 8. Time diagrams of operation of the device without deformation of the bridge span (a) and after deformation (b).

$$\tau_{3_i} = \frac{h}{\omega R_i}, \quad (1)$$

where ώ = 2*π*f is the rotational speed of the engine;

R_i is the distance between the laser beam scanning unit and the photodetector 3i, where i = 1, 2, ..., n.

Then for photoreceiver 4_i the pulse duration will be, respectively,

$$\tau_{4_i} = \frac{h}{\omega R_j}, \quad (2)$$

where i = 1, 2, ... , n; j = 1, 2, ... , n.

The duration t of the laser beam passing from photoreceiver 3_i to photoreceiver 4_i will correspond to the length li of the submersible dimension in the absence of deformation of the bridge span beam. It should be noted that the time *t* is taken from the rear of the pulse of photoreceiver 3i to the front of the pulse of photoreceiver 4i (Picture 8, a).

If the structure of the bridge is deformed at 17 (dotted lines in picture 7), the sub-bridge gauge will change, respectively, to l_i' (Picture 7), corresponding to the time t_i of passage of the laser beam from photodetector 3_i to photoreceiver 2 4i (Picture 8, b)The pulse length shall be the same as for a structure without deformation (Picture 8, a).

After receiving pulses from photodetectors 3_1, 3_2, …, 3_i,…, 3_n and 4_1, 4_2, …, 4_i, …, 4_n via unit 14 of switching to unit 15 of calculation, the latter performs calculations first t and ti, and then sub-measure by expression

$$\frac{t}{t_i} = \frac{l_i}{l_i^{'}}, \tag{3}$$

where i = 1, 2, ... , n.

$$l_i^{'} = \frac{l_i \cdot t_i}{t}. \tag{4}$$

From where, the deformation value of the bridge span will be

$$\Delta l = l_i - l_i^{'}, \tag{5}$$

After the transformation and calculation, the information about the size of the submersible dimension and the amount of deformation of the span beam of the bridge is transmitted from the 15 calculation unit to the recorder 16 (Picture 6, 7).

The developed device has been tested in laboratory conditions, has demonstrated a high performance and a sufficient accuracy (up to 1 mm) of measuring the under-pillar dimension and deformation of the structure of the bridge structures.

The device can be used in an automated system for monitoring deformations and bridge dimensions (ASDM), which makes it possible to rapidly monitor the state, displacement and deflection thereof resulting from the effects of external natural and climatic influences, as well as a continuous traffic flow on road bridges, as well as aircraft and trains on the corresponding overpasses.

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