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Optical dynamic weighting of trains

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Abstract

The dynamic weighting of railways carriages is of great importance for both the railways infrastructure managers and rail transport operations. It is particularly the high cost, low carriage speed and the necessity of using the specially designed tracks, usually in the form of a bridge, that restrict the use of the standard weighting systems to only the specific locations of tracks mainly located at the large train stations. In this study we propose a novel dynamic weighting of railways carriages utilizing bend loss of the fiber. Optical fiber which is bound to the railroad track, is deformed by the weight of the passing train. Then, different rail deformation and, consequently, changes in the light intensity passing through the optical fiber can be associated with the weight of the carriages. This system opens a doorway for a novel dynamic weighting of railways carriers at relatively low cost.

Keywords: Dynamic weighting, Fiber optics, Static Weighting, Bend loss of fiber.

1 Introduction

The evaluation of loads caused by the carriages on the tracks which is a fundamental issue for the infrastructure managers and rail operators, can be performed by either the static or dynamic weighting systems [1,2]. The static train weighting systems determine the weight of the individual wheels of train in the stationary conditions. Despite the high accuracy of this system, the low speed of the trainset weighting, that is, a full stop of train is usually necessary for this kind of measurement, make it suitable to specific railways infrastructure areas such as depots [3]. In contrast dynamic or also known as in-motion weighting enables assessment of train weight based on the deflection of rails generated by passing train [1,2]. Unfortunately, these dynamic systems are often applicable to only a limited train speed, requires a specially designed area of railways infrastructure, that is, humping yard and also their accuracy is usually lower that the one of static systems. Majority of these dynamic systems utilizes gauge, piezo or strain sensors [4]. In present study we propose a novel optical method utilizing bend-loss of the fiber, where the train weight is determined based on the changes in the intensity of the laser light imposed by deformation of track loaded by the passing train.

2 Methods

The optomechanical weighting system considered in present study is shown in Fig. 1. It consists of the light source in the form of laser light, optical fiber and photodetector. The large portion of the optical fiber is mounted on track (see Fig. 1a). The wheel of the passing train causes the track deformation and, correspondingly, it bends the fiber. When fiber is bended, the intensity of the laser light decreases and it is proportional train weight, chosen laser wavelength and power [5]. Mathematically, it is described by the following equation

$$2\alpha = \frac{\sqrt{\pi\kappa^4}\exp\left[-(2\gamma^3 R_{\mathrm{e}})/(3\beta_z^2)\right]}{2\sqrt{R_{\mathrm{e}}\gamma^3}V^2 K_{m-1}(\gamma a)K_{m+1}(\gamma a)}, \tag{1}$$

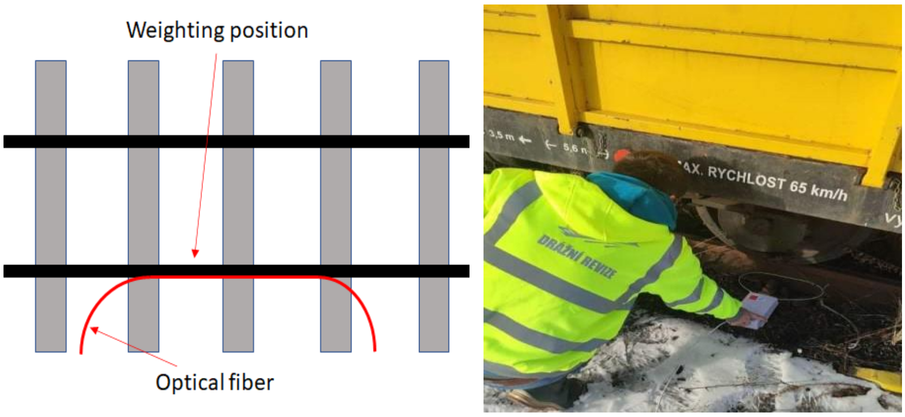
where κ and γ are damping parameters of fiber cladding and core, β is the propagation constant, V is refractive constant depending on the core and cladding properties and laser light wavelength, K is the modified Bessel function and R_{e} is diameter of bending of the fiber which depends on the rail deformation. The dynamic deformation of the fiber is then described by the following wave equation

$$\frac{\partial^2 u(x,t)}{\partial t^2} - 2\delta\frac{\partial u(x,t)}{\partial t} = C^2\frac{\partial^2 u(x,t)}{\partial x^2}, \tag{2}$$

where δ is damping parameter and c is the speed of the wave propagation. For train passing the sensing point the force / deformation caused by wheel can be approximated by the Dirac delta function as $u_{\mathrm{x}}(1, t) = \mathrm{I}\delta(t)$. Solving Eq. 2 with due account for the impulse force one can obtain the following expression

$$u(x, t) = 32I\sum_{n=0}^{m}\frac{(-1)^n\sqrt{\left[\beta_n(3\psi_n^2-\beta_n^2)\right]^2+\left[\psi_n(3\beta_n^2-\psi_n^2)\right]^2}\,sin(q_n X)e^{-\beta_n t}}{\left[(2n+1)^4\pi^4\right]\sqrt{(16-\varepsilon\beta_n)^2+(\varepsilon\psi_n)^2}}cos(\psi_n t+\xi_1-\xi_2) \tag{3}$$

where $\psi_{\mathrm{n}} = (\omega_{\mathrm{n}}^2 - \beta_{\mathrm{n}}^2)^{1/2}$, $\beta_{\mathrm{n}} = \delta q_{\mathrm{n}}^2$, $\omega_{\mathrm{n}} = 4q_{\mathrm{n}}$, $q_{\mathrm{n}} = (2\mathrm{n} + 1)\pi/2$, $\mathrm{n} = 0, \pm 1, \pm 2,..$ and phase shifts ξ_1 and ξ_2 are expressed as: $\xi_1 = \mathrm{Arctan}\left(\frac{\psi_n(3\beta_n^2-\psi_n^2)}{\beta_n(3\psi_n^2-\beta_n^2)}\right)$ or $\mathrm{Arctan}\left(\frac{\psi_n(3\beta_n^2-\psi_n^2)}{\beta_n(3\psi_n^2-\beta_n^2)}\right) + \pi$, while $\xi_2 = \mathrm{Arctan}\left(\frac{\varepsilon\psi_n}{16-\varepsilon\beta_n}\right)$ or $\xi 2 = \mathrm{Arctan}\left(\frac{\varepsilon\psi_n}{16-\varepsilon\beta_n}\right) + \pi$.



(a) (b)

Figure 1: Opto-mechanical weighting system (a) sketch of the location on track and (b) practical testing.

3 Results

Computational results clearly show that the changes in light intensity are the wavelength dependent (see Fig. 2). The higher sensitivity to external load, that is, the more significant loss of the light intensity, can be for a given rail deformation observed for a laser light of higher wavelength and *vice versa*. It immediately implies that for a given rail the higher mass sensitivity can be achieved by using the laser light of higher wavelengths.

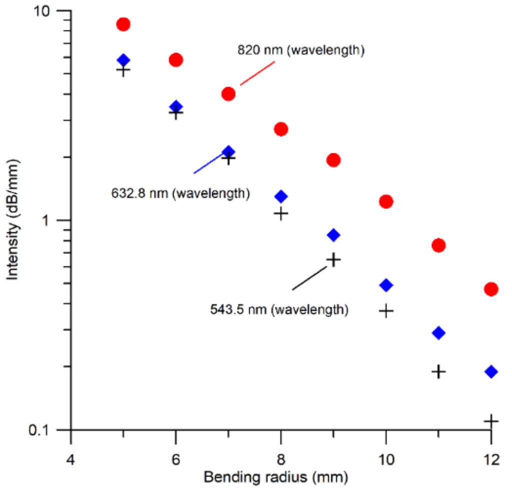


Figure 2: Dependency of changes in light intensity on bending radius for three different sources of laser lights (wavelength of 820 nm, 632.8 nm and 543.5 nm).

We have performed preliminary testing and the results of this test are summarized in Table 1. As expected, the light intensity changes depend on the rail deformation.

Laser source	Light itensity			
	No train	Car - empty	Car – loaded	Engine
450nm/ 15W	0.113	0.108	0.108	0.0827
532nm/ 4W	0.134	0.133	0.124	0.132

Table 1: Experimentally determined changes in the light intensity observed for two different lasers and different track loading conditions.

4 Conclusions and Contributions

We have proposed novel optomechanical weighting system utilizing the bend loss of the fiber. The mathematical model of the optomechanical system that accounts for the rail deformations caused by the wheel of the passing train, has been developed. Based on the computational results, the final optical detection system has been proposed. We have also shown that for a given rail the higher mass sensitivity can be easily achieved by using the higher wavelength lasers. These theoretical predictions have been supported by the recent preliminary experimental results.

Overall, the main advantages of the proposed dynamic weighting system can be summarized as follows: 1) low cost; 3) applicable to also the highly polluted environments such as a heavy industry; and, 4) the achievable mass sensitivity can be modulated by the wavelength. On the other hand, the reliability of the system is still under long-term testing. Hence, we can only foresee that the optical methods can be, due to a low cost of fiber optic technology, a suitable candidate for fast and yet accurate dynamic weighting of railways carriages.

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