Mladen M. Regodić
Teaching Assistant
University of Belgrade
Faculty of Mechanical Engineering

Goran B. Šiniković
Assistant Professor
University of Belgrade
Faculty of Mechanical Engineering

Emil A. Veg
Assistant Professor
University of Belgrade
Faculty of Mechanical Engineering

Zorana V. Jeli
Assistant Professor
University of Belgrade
Faculty of Mechanical Engineering

Nenad Gubeljak
Full Professor
University of Maribor
Faculty of Mechanical Engineering
Slovenia

Application of "Omega" Deformer for Stress Measuring in Dynamic Loading of the Structure

Strain gauge is a basic tool used to measure the stress of the material. In industry, it has been in use for more than seventy years. The area of application of the strain gauges is very wide. They are used to measure the stress of mechanical and building constructions, individual machine parts, devices and aids in medicine, etc. Straing gauges are made of different materials, in different shapes and dimensions. In spite of the wide presence, the aplication of the straing gauges can be difficult in certain weather conditions. Low temperature and high humidity significantly negativly affect the materials used for placing the gagues on the surface of the part to be tested. In order to overcome these problems, deformeters are used. This study examines the possibility of using a specially designed deformeters in the form of a letter omega (Ω). Tests were carried out in laboratory conditions, on a freebeam, under the action of dynamic loads. The main objective of the test was to determine the degree of correlation between the results obtained by direct reading from the strain gauge and the results read by the deformeter. The analysis of the results of comparative tests showed a high degree of correlation, which confirmed the possibility of using "Omega" deformeter on the structures that are exposed to dynamic load.

Keyword:Strain gauge, Stress, "Omega" Transducer, Dynamic Load

1. INTRODUCTION

The strain gauges are often used in industry. A large number of sensors uses the strain gauges as a „core sensing" element [1-6].There is a wide variety of shapes and dimensions of the strain gauges in the market, and the possibility of application is very diverse [7-8]. Sometimes, in difficult weather conditions, strain gauges application can be difficult. In such an environ–ment, there is a need for the use of a deformer with strain gauges.

Strain gauge type transducers electrically measure physical quantities such as load and displacement. They operate by converting the physical quantities into mechanical stress, and then detecting that stress with a strain gauge.

The deformeter is most often made of a metal part that is flexible enough to detect the imposed stresses. Deformers contain one or more strain gauges.

The history of the application of strain gauges can be divided into two phases. Charles Charles Wheatstone gave his first theoretical assumptions about the working principles of the strain gauges in his publications in 1843 [9]. This effect is the change of resistance in a conductor due to the effects of mechanical stress. William Thomson (1824-1905, Lord Kelvin after 1892) went further with some work published in 1856 [10]. However, the use of strain gauges began only in the 1930s (in the 1930s).

The basic idea of this paper was to examine the linearity and degree of correlation of the specially designed "Omega" deformeter in the case of dynamic stress of the construction[11-15].

2. STRAIN GAUGE PRINCIPLES

Any electrical conductor changes its resistance with mechanical stress, e.g. through tensionor compression forces. The resistance change is partially due to the conductor's deformation and partially due to the change in the resistivity Q of the conductor material as a result of microstructural changes. This process is described by the relationship (1):

$$\frac{dR}{R_0} = \varepsilon\left(1+2\nu\right)+\frac{dQ}{Q} \tag{1}$$

where R is the electrical resistance, ε is the strain, ν is the Poisson's ratio and Q is the resistivity.

External force applied to an elastic material gene–rates stress, which subsequently generates deformation of the material. At this time, the length L of the material extends to $L+\Delta L$ if applied force is a tensile force. The ratio of ΔL to L, that is $\Delta L/L$, is called strain (Precisely, this is called normal strain or longitudinal strain). On the other hand, if compressive force is applied, the length L is reduced to $L- \Delta L$. Strain at this time is $(-\Delta L)/L$. Strain is usually represented as ε.

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Correspondence to: Dr Emil Veg, Assistant Professor,
Faculty of Mechanical Engineering,
Kraljice Marije 16, 11120 Belgrade 35, Serbia
E-mail: eveg@mas.bg.ac.rs
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where e is the voltage output, E is the exciting voltage, R_1 is the gauge resistance, $R_2 \sim R_4$ is the fixed resistance

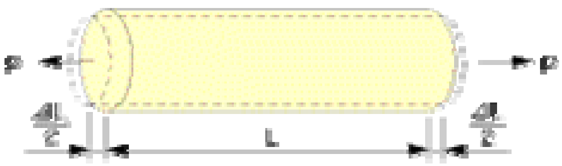

Figure 1. Dilatation of elastic material [3]

$$\varepsilon = \Delta L / L \tag{2}$$

where ε is the strain, L is the original length, ΔL is the change of length.

Supposing the cross sectional area of the material to be A and the applied force to be P, stress σ will be P/A, since a stress is a force working on a definite cross sectional area. In a simple uniaxial stress field as illustrated below, strain ε is proportional to stress σ, thus an equation

$$\sigma = E \cdot \varepsilon \tag{3}$$

is satisfied, provided that the stress σ does not exceed the elastic limit of the material. "E" in the equation is the elastic modulus (Young's modulus) of the material.

External force applied to a ferritic material generates physical deformation and electrical resistance change of the material. In case that such material is sticked onto test specimen via electrical insulation, the material produces a change of electrical resistance corresponding to the deformation. Strain gauges consist of electrical resistance material and measure proportional strains to the resistance changes.

$$\varepsilon = \frac{\Delta L}{L} = \frac{\frac{\Delta R}{R}}{K} \tag{4}$$

which ε is the strain measured, R is the Gauge resistance, ΔR is the resistance change due to strain and K is the gauge factor.

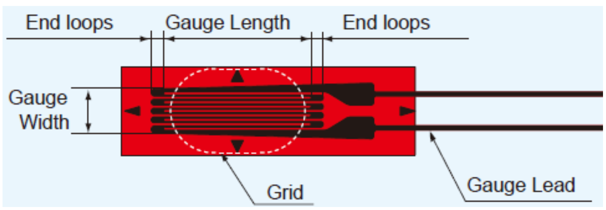

Figure 2. Strain gauge construction [3]

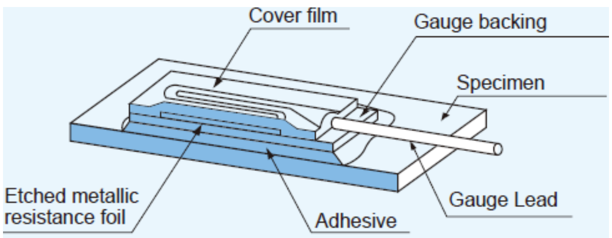

Figure 3. Strain gauge configuration

Normally, this resistance change is very small and requires a Wheatstone bridge circuit to convert it to voltage output.

$$e = \frac{R_1 R_3 - R_2 R_4}{(R_1 + R_2)(R_3 + R_4)} E \tag{5}$$

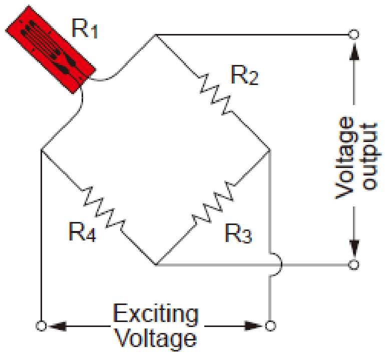

Figure 4. Wheatstone bridge circuit

3. DEFORMETER

The tested deformeter has a form of a letter "Omega". The figure 4 shows the shape and dimension of the deformeter.

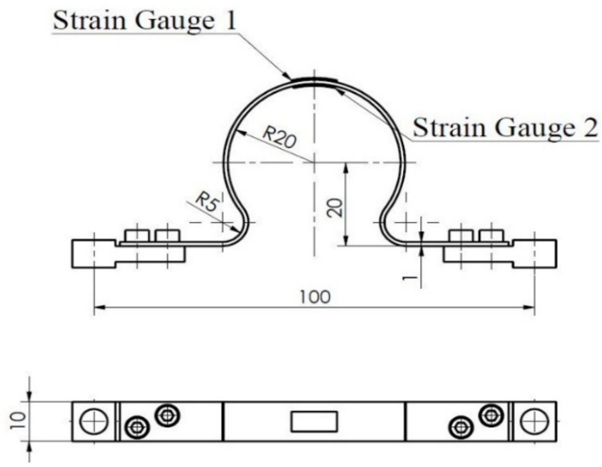

Figure4. Dimensions and shape of Omega deformeter

The deformeter is made of steel tin sheet in the shape of a letter the "Omega" and two steel footings used to bond it to the substrate. The material of the steel tin sheet is spring steel. On the central part of the deformeter, there are two strain gauges fixed, as shown in Fig. 4. For such a configuration of the strain gauges, “Bridge factor" has a value of 2 (B = 2) [5]. The following formula is used to calculate the stress in the deformeter:

$$\varepsilon = \frac{4}{B \cdot k} \cdot \frac{U_A}{U_{EA}} \tag{6}$$

where ε is the Strain, B is the bridge factor, k is the gauge factor, UE is the bridge input voltage and UA is the bridge output voltage.

Due to the deformation construction itself, the voltage that occurs in it does not correspond to the actual voltage on the structure we measure, but these voltages are in direct correlation. In order for the measured voltage to fit the real one, it is necessary to introduce the correction coefficient RRQ. Based on the calculation and experiments, it is determened that for the tested deformeter this coefficient is RRQ = 12.49.

Based on the experiments carried out under static stresses, a high degree of Correlation [σSG; σΩ x RRQ] is determined and it is 0.99, which is described in [12].

4. TESTING IN LABORATORY CONDITIONS

The deformeter test was carried out on a steel shaft on a square cross-section of 30x30 mm, wall thickness of 2 mm and a length of 4 m. Figure 5 shows the experiment setting. In the centre of the beam there are 2 fixed strain gauges of which the first one is active while the other is passive and is used for temperature compensation. Strain gauges are placed in a half bridge configuration. The spot where the strain gauges is fixed is taken as the reference measuring point. "Omega" deformeter is placed above the active strain gauge.

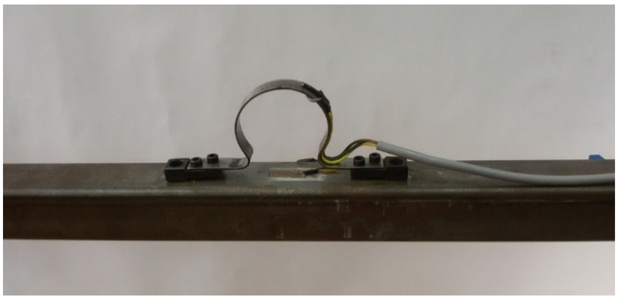

Figure5 Set of a beam and Omega Deformeter

The dynamic load was introduced by a device made up of an electric motor with a rotor controlled by a frequency regulator. A concentrated mass was placed on the rotor by means of which we introduced the unbalance. When rotating an unbalanced rotor, a dynamic force is generated whose frequency is proportional to the number of rotor rotations. The device is rigidly linked to the steel beam, which instantly transmits the initiative to it. The constant value of the angular speed of the rotor provides a dynamic drive of constant frequency. The frequency regulator can achieve full control and fine tuning of the dynamic drive frequency. DynaLog (RoTech, Serbia) device was used for signal acquisition.

The device has a 16-bit AD converter with a sampling rate of up to 2000 Hz. Figures 6 and 7 give graphical representations of test results.

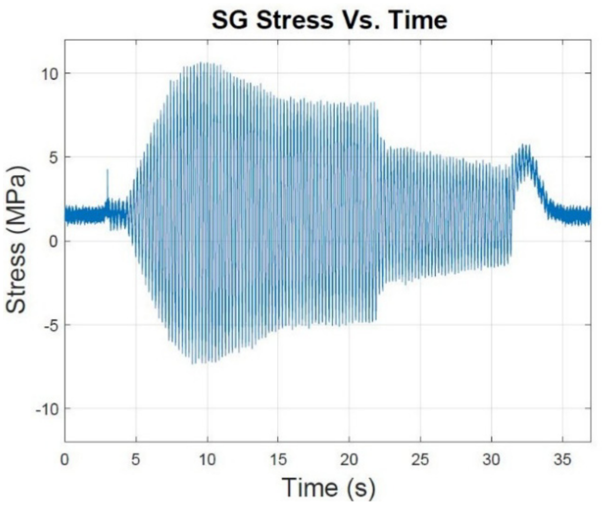

Figure 6. Strain gauge RAW signal

At the beginning of the test, the beam was in a state of rest. After three seconds of the experiment, a dyna–mic load was initiated by starting an electric motor that lasted until the 22ndsecond when the engine was switc–hed off. At the very end of the test, the beam osci–llations were compulsively dimmed. The crude signals are filtered using the "Moving Average" function. After filtering and zeroing the signal,their comparative disp–lay is shown in Figure 8.

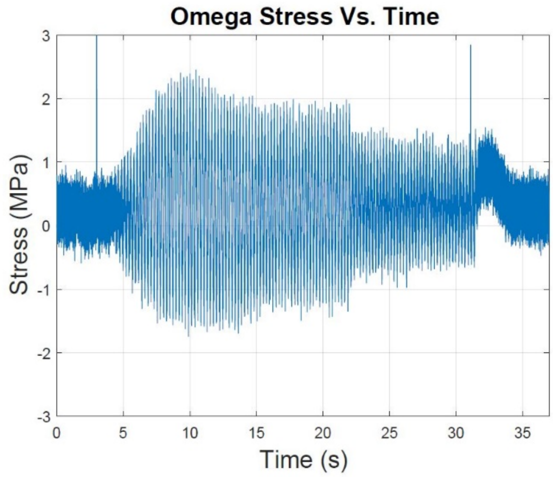

Figure7. Omega deformeter RAW signal

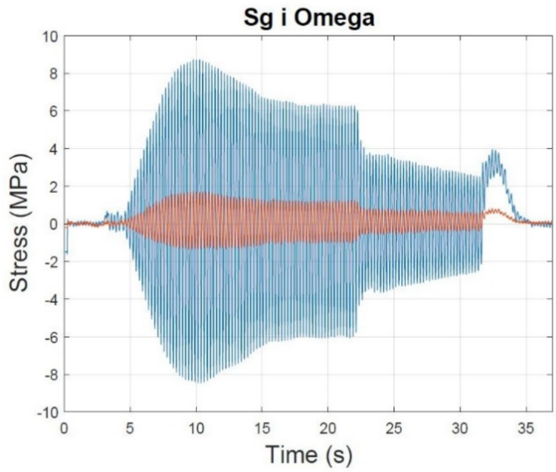

Figure 8. Strain gauge and Omega deformeter visual comparation

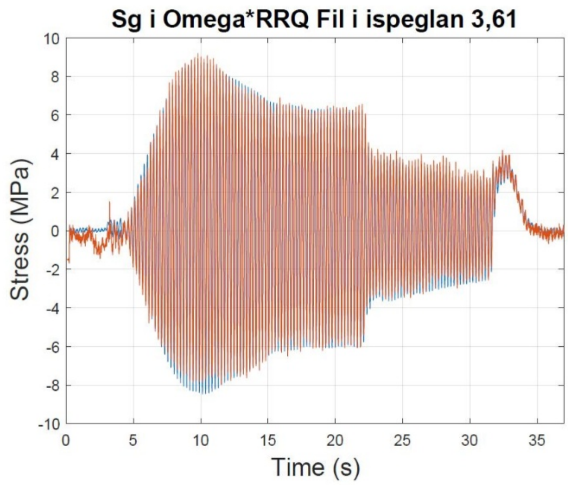

Figure9. Strain gauge and corrected Omega deformeter visual comparation

As already mentioned, signal from the deformeter is weaker than the actual signal. It is necessary to correct such a signal by introducing the correction coefficient RRQ. After correction of the Omega deformeter signal, a comparison of both signals is given in Figure 9.

Figure 10 shows the part of the signal between the 15thand 22ndsecond of the experiment.

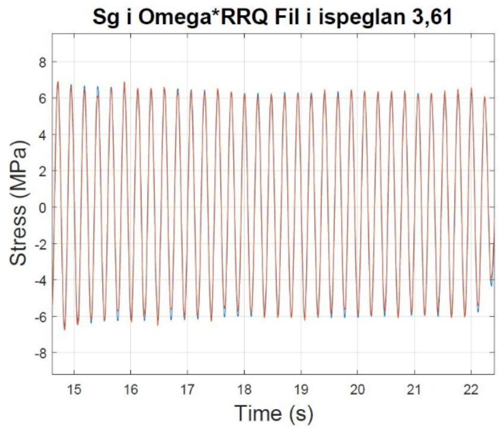

Figure10. Strain gauge and corrected Omega deformeter visual comparation

After the filtering and correction of the signal, a numerical comparison of the obtained results was also arranged. For the comparison of given signals, the correlation method and the following formula were used:

$$correl(X,Y) = \frac{\sum (x-\bar{x})\cdot(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \cdot \sum (y-\bar{y})^2}} \quad (7)$$

x = σSG – values of stress on the beam

y = σΩ x RRQ – values of stress on the Omega deformeter

$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$ – average value of the σSG

$\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n}$ – average value of the σΩ x RRQ

The degree of correlation is:

Correl [σSG ; σΩ x RRQ] = 0.94

5. RESULTS ANALYSIS

In the previous paper, the relationship between the voltage in the beam and the voltage in the Omega deformeter is explained, and it has been shown that this deformeter, in static motions, can faithfully transmit deformations from the desired measuring point. During dynamic testing of the deformeter, the same signal comparison method as in static testing was used. The source voltage signals from the strain gauges and omega deformeter are simultaneously sampled. Dilatation is calculated using formula (8). For Wheatstone's half-bridge, with one active gauge and one temperature compensatinggauge, the Bridge factor is B = 1. This configuration is on the beam.

$$\varepsilon = \frac{4}{k}\cdot\frac{U_{ASG}}{U_{ESG}} \quad (8)$$

On the omega deformeter, a different configuration of Wheatstone's half-bridge is set, with two active strain gauges. For such a configuration, the bridge factor is B=2 [5], and the corresponding dilation is calculated using the following formula:

$$\varepsilon_{\Omega} = \frac{4}{2\cdot k}\cdot\frac{U_{A\Omega}}{U_{E\Omega}} \quad (9)$$

According to Hook's law, the voltage and dilatation are in direct proportions. Thanks to this fact, when comparing the signal from the beam and omega deformeter we can also use the dilatation. The 94% correlation rate is at a satisfactory level, bearing in mind that the equipment used to acquire the signal has a 16-bit ADC embedded in it. With ADC of a lesser resolution, the signal strength is increased. In Figure 9 it can be seen that in the first 5 seconds of the experiment there is a very weak signal with a lot of noise. Such a signal multiplied by RRQ leads to greater deviation of the result. After the introduction of the dynamic initiative, the signal from the strain gauge and the Omega deformeter have a very good match. Even after the expiry of the dynamic initiation effect, in the phase of forced damping, the signal from the Omega deformeter is followed by a reference signal from the strain gauge.

6. CONCLUSION

The tested Omega deformeter is a type of sensor that can replace the strain gauge if there is a difficulty in implementing the strain gauge itself. In the previous paper [12], the application of Omega deformeter with the static load of the construction, is presented. Studies have shown that in the case of static load, the degree of correlation is 99%.

In this paper, a deformeter testing is carried out in the dynamic load of the construction. The signal from The Omega deformeter is corrected using the RRQ correction factor as well as static testing. The main objective of the study is to perform a comparative analysis of the voltage obtained from the signal from the strain gauges and voltage that is read on the Omega deformeter. The results of the study showed a high degree of correlation and itwas 94%. In this way it is confirmed that Omega deformeter application was possible both for static and for dynamic loadings of constructions.

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ПРИМЕНА ОМЕГА ДЕФОРМЕТРА ЗА МЕРЕЊЕ НАПРЕЗАЊА ПРИ ДИНАМИЧКОМ ОПТЕРЕЋЕЊУ КОНСТРУКЦИЈА

М. Регодић, Г. Шиниковић, Е. Вег, З. Јели, Н. Губељак

Мерне траке су основни алат који се користи за мерење напрезања материјала. У индустрији се примењују већ више од седамдесет година. Област примене мерних трака је веома широка. Користе се за мерења напрезања машинских и грађевинских конструкција, појединачних машинских делова, уређаја и помагала у медицини итд. Мерне траке се израђују од различитих материјала, у различитим облицима и димензијама. И поред широке заступљености, примана мерних трака може бити отежана у одређеним временским условима. Ниска температура и повећана влажност ваздуха веома неповољно утичу на материјале помоћу којих се мерне траке постављају на површину дела кaји се испитује. Да би се превазишли наведени проблеми користе се деформетри. У раду је испитана могућност примене специјално дизајнираног деформетра у облику слова омега (Ω). Испитивања су изведена у лабораторијским условима, на простој греди, при дејству динамичких оптерећења. Главни циљ испитивања био је утврђивање степена корелације резултата добијених директним очитавањем са мерних трака и резултата очитаних са деформетра. Анализа резултата упоредних испитивања показала су висок степен корелације чиме је потврђена могућност примене „Омега" деформетра на конструкцијама које су изложене динамичком оптерећењу.