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# Ring-shaped strain gauges and their application

***Abstract**. This paper provides a description of a designed and constructed ring-shaped strain gauge. Such a gauge, intended for measuring transverse strain of a concrete supporting column, can be used for monitoring the state of the latter. The electric resistance element of the gauge is thoroughly sealed in a watertight manner, thereby making it possible to flood it with poured concrete and then use in a humid environment. The paper also discusses the effects of an exemplary application of ring-shaped strain gauges under laboratory conditions.*

***Streszczenie.** W artykule przedstawiono zaprojektowany i skonstruowany tensometr pierścieniowy. Jest on przeznaczony do pomiaru odkształceń poprzecznych betonowych kolumn wsporczych, w celu monitorowania ich stanu. Elektryczne uzwojenie oporowe tensometru jest starannie zahermetyzowane, przez co może on być zalewany płynną mieszanką betonową i użytkowany w środowisku wilgotnym. W artykule umieszczono również wyniki przykładowego zastosowania tensometru pierścieniowego w warunkach laboratoryjnych. (**Tensometr pierścieniowy i jego zastosowanie)***

**Keywords:** strain gauges, metrology, concrete supporting columns.
**Słowa kluczowe:** tensometry, metrologia, betonowe kolumny wsporcze.

## Introduction

Testing of cylindrical rocks and concrete samples in the uniaxial state of stress is a standard procedure performed in numerous laboratories. Often, the only parameter determined in such a test is the value of stress (referred to as compressive strength and denoted by $R_c$) destructive to the sample. For this purpose, a simple testing machine equipped with a load cell is sufficient. Sometimes, however, there occurs a need to determine stress-strain characteristics as well. To this end, it is necessary to measure the strains of the sample. Fig. 1 presents a cylindrical sample with two strain gauges glued on its surface, halfway up its height. The gauge denoted by $SG_L$ is intended for measuring longitudinal strain, the gauge denoted by $SG_T$ for measuring transverse strain.

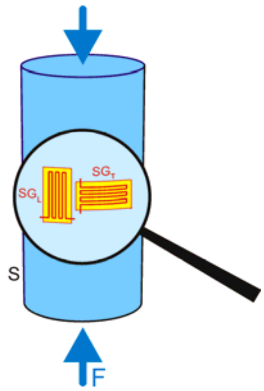


Fig. 1. A cylindrical rock or concrete sample tested in the uniaxial state of stress. *S*-sample, *F*-load, $SG_L$-longitudinal strain gauge, $SG_T$–transverse strain gauge

Fig. 2 presents two stress-strain characteristics of a concrete sample. It can be noticed that the stress vs. transverse strain characteristics lose their linearity at a stress which is lower than in the case of the stress vs. longitudinal strain characteristics. The loss of linearity is caused by microcracks which occur in the mass of the sample due to the process of its destruction. Therefore, transverse strain measurement is a more accurate procedure when it comes to detecting the defects of the sample. When the value of transverse strain becomes greater than half the value of longitudinal strain, the Poissons ratio of the sample exceeds 0.5. It means that, due to internal empty cracks, the volume of the sample becomes greater than at the beginning of the experiment. In the example provided, it occurs at the value of stress equal to 44.7 MPa, when the longitudinal strain is equal to 1.56 ‰, and the transverse strain is equal to 0.78 ‰.

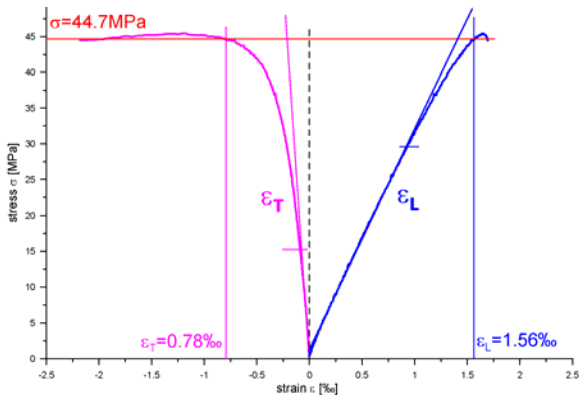


Fig. 2. Stress vs. longitudinal strain ($\varepsilon_L$) and stress vs. transverse strain ($\varepsilon_T$) characteristics of a concrete sample. Ticks at the curves mark limits of their linearity

Concrete columns, as supporting elements of bridges, trestles or viaducts, not only resemble the samples in shape, but they are also loaded in a similar way. For monitoring their state, ring-shaped strain gauges can be used (Fig. 3). Such gauges can be placed inside the columns when the latter are being constructed, close to the surface. The gauges should be watertight, given the fact that the columns are often exposed to humidity, or they are immersed in water. For the sake of simplicity, ring-shaped strain gauge is referred to as RSSG in the paragraphs that follow.

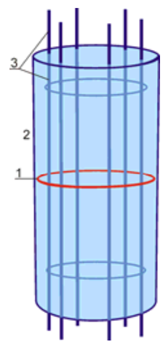


Fig. 3. An example of a potential application of a ring-shaped strain gauge *1*, *2* a column fragment, *3* its reinforcement

**Determining the metrological parameters of the wire Cuprothal 49**

The RSSGs for measuring transverse strains of concrete columns were constructed with the use of bare resistance wire made of the alloy Cuprothal 49 with the diameter equal to 0.3mm. The composition of that alloy is very similar to the composition of constantan, the basic material used in the production of wire and thin-film strain gauges [1]. It contains 44.5% Cu, 44% Ni, 1% Mn, and 0.5% Fe [2]. Since that wire was to be used for the construction of strain gauges, its constant *k*, also referred to as the coefficient of elastoresistivity, had to be determined. This constant is defined according to the formula:

$$\varepsilon = k\frac{\Delta R}{R} \tag{1}$$

where: $\varepsilon$ - measured strain, *k* – constant, coefficient of elastoresistivity, $\Delta R$ - increase of the resistance of the strain gauge, *R* - resistance of the strain gauge.

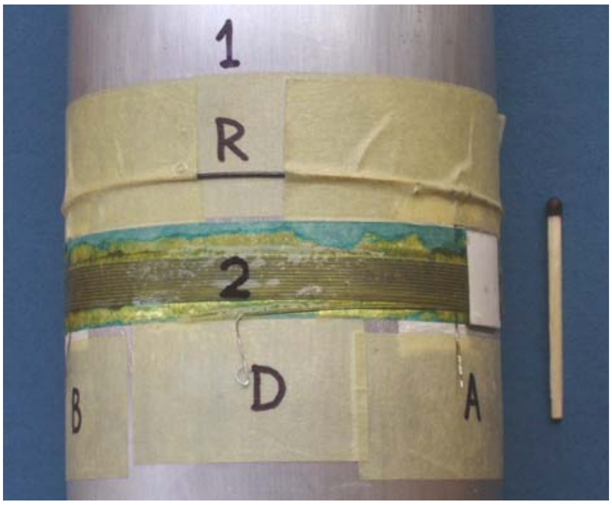


Fig. 4. A tool used for determining the constant *k* of the wire. *1*-a tube, *2*- 12 turns of Cuprothal 49 wire, *R* common rail, *A*, *B*-free terminals of 2 strain gauges, *D* free terminal of the winding

For this purpose, a tool was constructed, whose photo is presented in Fig. 4. The tube *1* is made of aluminum. Halfway up its height, 3 bonded wire strain gauges were glued, at the intervals of 120 ˚. The gauges were long enough to cover almost the entire circumference of the tube. Subsequently, in the same place on a tissue washer and on the strain gauges, 12 turns *2* of the wire under examination were wound around. After winding, the turns, separating thread and the washer, were glued together. All the upper terminals of the strain gauges and of the winding were soldered to the common rail *R*. In the photo, one can see only the terminals of two strain gauges; the free ones are denoted by *A* and *B*. *D* is the free terminal of the winding. During each of the 5 tests, the tube was uniaxially compressed in a press and its transverse strains were measured with a 4-channel strain meter connected both to the strain gauges and to the winding. All the tests exhibited a slightly greater constant *k* of the winding, equal to 2.16, than the constant *k* of strain gauges, equal to 2.15. Thus, not only does the material of the wire Cuprothal 49 have a composition similar to that of constantan, but also its coefficient of elastoresistivity is almost identical. Its temperature coefficient for the ambient temperature 293 K is about 20 ppm/1K [2].

**Structure of the RSSG**

Fig. 5 presents the structure of the RSSG. A winding *2* of 6 turns of Cuprothal 49 wire was wound on a tissue washer about 10 mm wide, fixed on a specially prepared spool. The turns were separated with a thin thread. Subsequently, the winding was covered with tissue tape and saturated with epoxy resin. Once the resin had hardened sufficiently, the winding was carefully removed from the spool. Then, the two terminals of the PVC-coated single-core cables *5* were soldered to both ends of the wire. To improve resin adhesion, the ends of the PVC-coating were tightly wrapped with a thread, as it is presented in Fig. 5b. At first, the winding was flooded with epoxy resin in a special mould in order to be sealed. Unfortunately, this method gave bad results. The ready for use RSSG was too thick, and the sealing was fragile and vulnerable to cracking when flooded with poured concrete. A better method proved to be wrapping the winding (with the washer and the covering tissues *3*) in a cotton band *4* and subjecting it to vacuum saturation with epoxy resin, as it is presented in Fig. 5a.

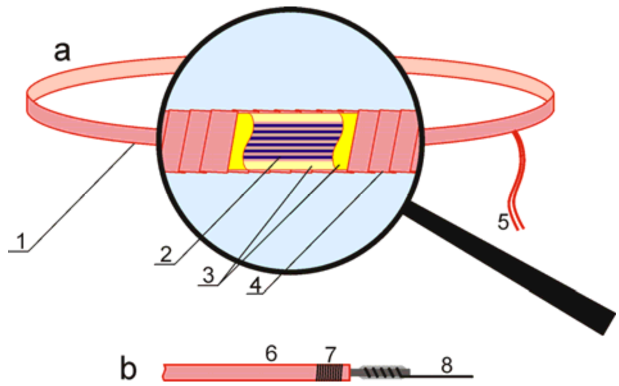


Fig. 5. Details of construction of the RSSG (a) and sealing of one of its terminals (b). *1*-the RSSG, *2*-winding, *3*-washer and covering tissues, *4*-cotton band wrapping, *5* terminals, *6*-PVC-coated cable, *7* thread wrapping, *8* Cuprothal 49 wire

Once the resin had hardened, the leak tightness of the RSSG was tested by measuring possible electric leakages in a metal vessel filled with 2% solution of caustic soda NaOH. Any untight places (detected by electrolysis) were additionally covered with resin. Fig. 6 presents the RSSG ready to be flooded in concrete.

Fig. 6. The RSSG ready to use.

**Preparing RSSGs for measuring strains of steel-concrete supporting elements**

The first application of RSSGs, whose construction is described above, was laboratory testing of supporting columns in the form of Concrete Filled Steel Tubes (CFST) [4,5]. The outer surface of such columns is easily accessible, and measuring the strains of the tubes can be performed e.g. by using bounded strain gauges. The core being the concrete mix that fills the tubes is accessible only at the ends that contact the plates of a testing press, which has no application in the process of measuring the strains. Therefore, the measurement transducers should be flooded in the concrete when the columns are still under construction.

It seemed that using RSSGs for measuring transverse strains of the concrete cores was the best choice. However, the gauges had to meet strict requirements. As a rule, poured concrete contains more water, which is subsequently consumed in the process of its setting. Drying of the excess water in the case of CFST elements is a very slow process. Thus, the concrete remains wet for a long time after its setting. Apart from this, for the sake of proper measurement, the diameter of the RSSGs should be slightly smaller than the inner diameter of the steel tubes (by 4 mm maximally). The moisture, as well as the proximity of an electrically conducting surface, make it necessary that RSSGs are absolutely watertight.

For research purposes, 24 columns were used, made with the use of tubes 1.5 m long, with the outer diameter of 168 mm and diversified thickness of the wall: 5 mm and 10 mm. Those tubes were made of 2 grades of steel: R35 and R45 [3], differing in the yield point. Concrete of 4 grades of endurance was used, with the diversified sort of aggregate. According to the assumptions, in the case of each tube, transverse strains should be measured at 3 levels: halfway up its height and at the distance of 0.3 m from its both ends.

The main goal of the research was not only to measure the transverse strains of the concrete cores during uniaxial tests of the elements, but also to determine the interaction between the steel tubes and the concrete cores. Instead of gluing bonded strain gauges for measuring the transverse strains of the tubes, windings similar as for sealed RSSGs were wound on the tubes at the levels corresponding to the ones at which RSSGs should be placed in the concrete (*8*, *9*, *10*, Fig. 7). In the places where the windings were wound, rust and dirt were removed from the tubes. Obviously, insulating tissue washers were also used. Subsequently, windings and washers were saturated with epoxy resin and cable terminals were soldered. For convenient winding, a special supporting device was made, which made is possible to rotate the tubes. Additionally, halfway up the height of each tube, three bonded strain gauges for measuring the longitudinal strains were glued (*11*, Fig. 7). Thus, every column was equipped with 9 gauges: 6 for measuring longitudinal and transverse strains of the tube, and 3 RSSGs for measuring transverse strains of the core.

For a correct placement (Fig. 7) of the 3 RSSGs *2*, *3*, *4* inside a tube, they were all tied together with a holding *1* and a weight ring *5* by means of 6 thin cords *6*. Both the holding and the weight ring were made of steel rods, wherein the latter one was thicker (and heavier), its diameter being 8 mm. The holding ring *1* was hanged on the upper brim of the tube *7*. The electric terminals were passed through small holes, bored close to the upper and lower brim of a tube.

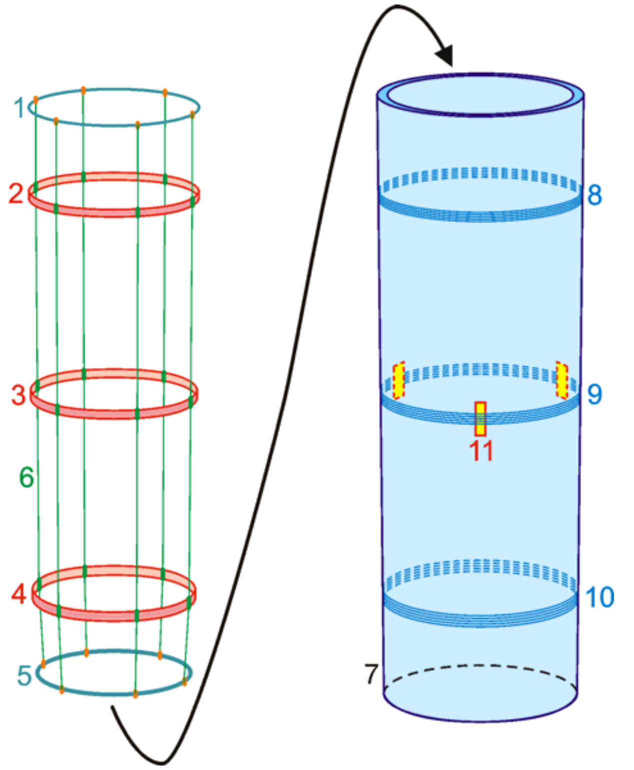


Fig. 7. A column equipped with all gauges. *1*-holding ring, *2*, *3*, *4*-sealed RSSGs, *5*-weight ring, *6*-thin cords, *7* a steel tube, *8*, *9*, *10* windings on the tube, *11* three bonded strain gauges

Each of the gauges both those wound on a tube and the RSSGs had been equipped with a dummy strain gauge, i.e. a resistor made of the same wire wound on a small steel spool. Its resistance was obviously the same as that of the gauges. Similarly, dummy strain gauges glued on a small steel plate were added to each bonded strain gauge for measuring longitudinal strains. All the active and dummy strain gauges were arranged in pairs so as to constitute half-bridges [6]. Before the start of the experiment, all the dummy gauges together with the entire column under examination had been thermally insulated from the environment.

**Results of an exemplary experiment of uniaxial compression of a tube-concrete column**

After the construction of CFST columns, i.e. flooding tubes together with RSSGs with concrete, 28 days were allowed to pass till the concrete got fully set. During that time, the gauges were periodically checked with respect to possible appearance of a measurable electric leakage between the gauges and the tubes, which would indicate a loss of the watertightness of the gauges. On the day of the experiment, the CFST columns were successively placed in a hydraulic press and subjected to an uniaxial compression test. All the measuring half-bridges were connected to three 4-channel strain meters (only 3 channels of each meter were used). The values of strains of tubes and concrete were automatically measured and recorded every 6 seconds. The press was controlled in order to obtain a linear increase of load, with velocity of 0.8 kN/s. Fig. 8, 9, 10 present the result of the examination of a CFST column marked 3D10, made with the use of a tube with a ten-millimeter thick wall.

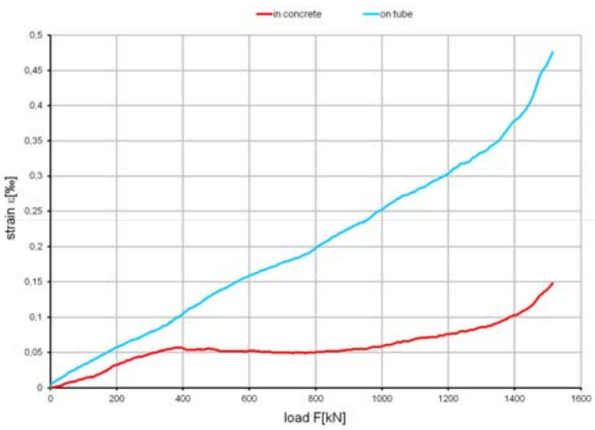


Fig. 8. Transverse strains measured by the upper RSSG (in concrete) and the upper winding (on tube)

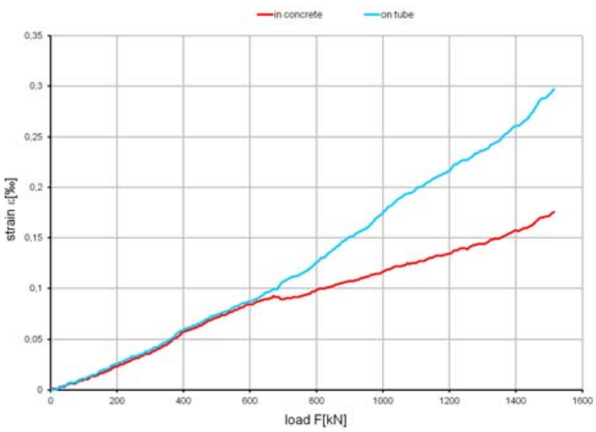


Fig. 9. Transverse strains measured by the middle RSSG (in concrete) and the middle winding (on tube)

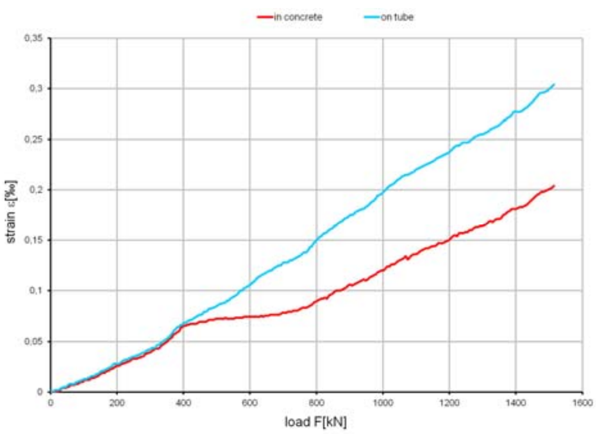


Fig. 10. Transverse strains measured by the lower RSSG (in concrete) and the lower winding (on tube)

The diagrams of transverse strains depict how the tube and the concrete core interact with each other. For the middle RSSG and winding, strains are almost identical for the load smaller than about 630 kN. Subsequently, the increase in the strain of the tube becomes greater, which indicates that the tube loses contact with the concrete. A similar process can be observed for the lower outer and inner gauges, though here the loss occurs at an earlier stage, at the load of about 400 kN. An interesting fact is a complete lack of interaction of the tube and the concrete at the place where the upper gauges were situated. This phenomenon can also be observed during the examination of other columns. It might result from the heterogeneity of concrete composition, caused by the sedimentation of aggregate during the flooding of the tubes.

**Summary**

The experiment presented in the last paragraph was conducted for all the 24 CFST columns prepared beforehand. For most of them, similar results were obtained. Therefore, the experiments proved the usefulness of the RSSGs developed by the author, as well as of the proposed method of measuring the strains of the tube and the concrete core of the CFST column. Additionally, the experiments determined the conditions of interaction between concrete and the tube: in these conditions, the concrete core is loaded under a complex stress state. The experiments also provide some experience as to the construction of RSSGs designed for functioning in water or in a moist environment.

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