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The thesis is dedicated to all of my parents, wife, children, brothers and sister whose love, guidance, sacrifices and encouragement is boundless

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ABSTRACT

Stress and strain measurements on frames and structures are mainly conducted by use of strain gauges. A measuring chain applied in such measurements usually consists of strain gauges, amplifiers and data acquisition and logging device. The applicability of such instrumentation, mainly depends on its sensitivity, measuring repeatability, accuracy and noiseless operation. The key point of this thesis is harmonization of measuring properties for the newly invented deformeter with the measuring electronics. Much alike a standard modeling of Mechatronic items, a very specific CLD (Close Loop Deformeter) is optimized throughout coupled modeling, bridging analysis of 3D virtual model and real design of laboratory prototype. Virtual experiment was developed to correspond with actual measurements on the test rig. The idea of rectification factor is introduced into concept of 3D modelling with an innovative CLD research. The focus of the research was kept on the output linearity, measuring range and resolution of the invente deformeter.

Keywords: CAD modelling, Close loop deformeter, Simulation, Strain gauge, Stress, Transducer.

Scientific field: Mechanical engineering.

Narrow scientific filed: Theory of Machine and Mechanisms.

UDC number: 620.172.2.087.45:004.94(043.3)

Apstrakt

Merenje naprezanja strukturnih elemenata konstrukcije uglavnom se izvodi korišćenjem mernih traka. Uobičajenu strukturu mernog lanca čine: merne trake, pojačivač i sistem za akviziciju podataka i njihovo memorisanje. Pouzdanost i efikasnost ovakvih merenja uglavnom zavisi od merne osetljivosti, ponovljivosti, tačnosti i nivoa šuma. Ključni doprinos ove doktorske teze je harmonizacija mernih karakteristika inoviranog deformetra sa mernom elektronikom. Slično kao kod modeliranja mehatroničkih komponenti, kroz oblikovanje i kompjutersku analizu 3D virtuelnog modela i dizajniranje realnog laboratorijskog prototipa, optimiziran je veoma specifičan deformetar sa zatvorenom petljom. Razvijen je virtuelni eksperiment koji odgovara aktuelnim merenjima na probnom stolu. U koncept 3D modeliranja uvedena je ideja faktora korekcije za odziv deformetra. Fokus istraživanja zadržan je na verifikaciji linearnosti izlaznog signala, mernog opsega, rezoluciji inoviranog deformetra i operativnoj primenjivosti CLD deformetra.

Ključne reči: CAD modeliranje, specijalni deformetar, simulacija, merna traka, naprezanje, senzor.

Naučna oblast: Mašinsko inženjerstvo

Uža naučna oblast: Teorija mehanizama i mašina.

UDK broj: 620.172.2.087.45:004.94(043.3)

Nomenclature

ε	Strain
L	Original length
ΔL	Change in length
σ	*Stress*
E	Elastic modus
R	Gauge resistance
ΔR	Resistance change due to strain
K	Gauge factor
e	Input voltage
e_o	output voltage
v	Poisson ratio
R_1-R_2-R_3-R_4	resistance
Q	Resistivity
ε_{CLD}	Deformeter strain
ε_{SG}	Beam strain
σ_{CLD}	Deformeter stress
σ_{SG}	Beam stress
U_A	Bridge input voltage
U_E	Bridge output voltage
B	Bridge factor
[B]	Strain displacement
[D]	Elasticity matrix
[K]	Global stiffness matrix of the structure
[N]	Matrix shape function
$\left[\underset{\sim}{K}\right]$	Global stuffiness matrix of the structure

$S_1^{(e)}$	Potion of the surface of the element
$\left[K^{(e)}\right]$	Element stuffiness matrix
$\vec{\underset{\sim}{Q}}$	Global vector of nodal displacement
$\vec{\underset{\sim}{Q}}^{(e)}$	Vector of nodal displacement degree of freedom
$V^{(e)}$	Volume of element
$\vec{U}$	Vector of displacement
$[T]$	Transformation matrix from local to global coordinate
$\vec{\phi}$	Vector of body force per unit volume
$\vec{\varepsilon}$	Strain vector
$\vec{\sigma}$	Stress vector
$\vec{\underset{\sim}{P}}$	Total vector nodal force
$\vec{\underset{\sim}{P}}^{(e)}$	Vector of element nodal force
$\vec{\underset{\sim c}{P}}$	Vector of concentered loads
$\vec{P}_i^{(e)}$	Vector of element nodal produced by initial strains
$\vec{P}_b^{(e)}$	Vector of element nodal forces produced by body force
$\vec{P}_s^{(e)}$	Vector of element nodal forces produced by surface forces
π_p	Potential energy
$\pi_P^{(e)}$	Potential energy of element

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CHAPTER 1

1 Introduction

Strain gauge is a core sensing element in many types of sensors. Substantially they are used for the stress-strain measurements on different kinds of frames and structures. A vast variety of strain gauges are available either for simple or verse specific measurements. Conventional design of deformeter is based on a resilient piece of metal flexible enough to detect induced stress.

Sometimes, placement of strain gauge (SG) is difficult, particularly in harsh ambient. Under such circumstances application of the deformeter, instead of a single strain gauge, becomes a real need.

An accurate picture of the load is created when the component loads are known by their size and excitation nature. The problem usually happens when the loads are unknown or just roughly approximated. It is possible to design a lighter and more efficient product by selecting lighter martial and making the thinner structure. But the safety of the product is compromised unless the required strength is maintained. By the same token, if only the strength is taken into consideration, the weight of the product increases and the economic feasibility is impaired. Thus, harmony between safety and economics is an extremely important factor in designing a structure. To design a structure which ensures the necessary strength while keeping such harmony, it is significant to know the Stress borne by each individual part. However, at the present scientific level, there is no technology which enables direct measurement and judgment of Stress**.** So, the Strain on the surface is measured in order to know the internal stress. Strain gauges are the most common sensing element to measure surface strain. Sometimes, placement of strain gauge (SG) is difficult, particularly in harsh ambient condition. Under such circumstances application of a deformation becomes a real need.

Deformeter is a simple sensing element containing one or more strain gauges. History of strain gauge invention is fractioned in two stages. Early, theoretical considerations were introduced by Charles Wheatstone as long ago as 1843, in his first publication on the bridge circuits [1], as well with William Thomson (1824-1905, Lord Kelvin after 1892) in his publication in 1856 [2]. Later on, in 1930s an applicable technical solution is engineered, based upon an idea of Charles Wheatstone [3].

This thesis is inspired by the former work on implementation of 3D modelling in design of omega deformeter [4]. The novelty of our investigation is a breaking through the concept of a Closed Loop Deformeter (CLD) developed by a fundamental Mechatronic approach [5]. That means, the virtual modeling and other techniques are utilized in order to create a satisfactory operation of the CLD, as the integral part of the measuring chain. Several improvements of CLD were introduced in the optimization process. 3D modeling was aimed not only on pure design, but also onto adjustment of its performance under the simulation. The conducted analysis went even a step further, generating a proportional signal on the output contacts of the embedded strain gauge.

Any given electrical conductor changes its resistance with mechanical stress, e.g. through tension or 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 as a result of microstructure change. This process is described by the relationship

$$\frac{dR}{R_0} = \varepsilon(1 + 2\upsilon) + \frac{dQ}{Q} \qquad (1.1)$$

R = Electrical resistance

ε = Strain

ν = Poisson's ratio

Q = Resistivity

CHAPTER 2

2 The Strain gauge operation- in principle

When a material receives a tensile force P, it has a stress σ that corresponds to the applied force. In the proportion to the stress, the cross-section contracts and the length elongate by ΔL from the length L the material had before receiving the tensile force.

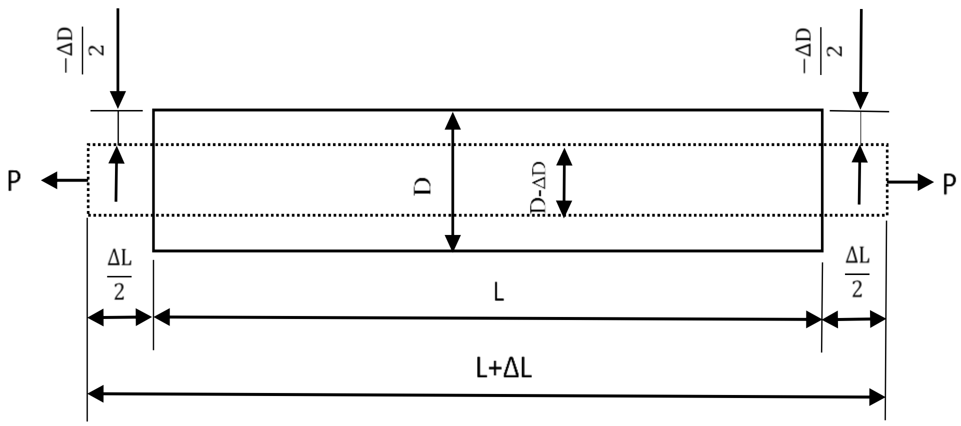


Figure 2.1 Tension force [6]

The ratio of elongation to the original length is called a tensile strain and is expressed as follows:

$$\varepsilon = \frac{\Delta L}{L} \tag{2.1}$$

ε- Strain

L- Original length

ΔL- Change in length

If the material receives a compressive force, it bears a compressive strain expressed as follows:

$$\varepsilon = \frac{-\Delta L}{L} \tag{2.2}$$

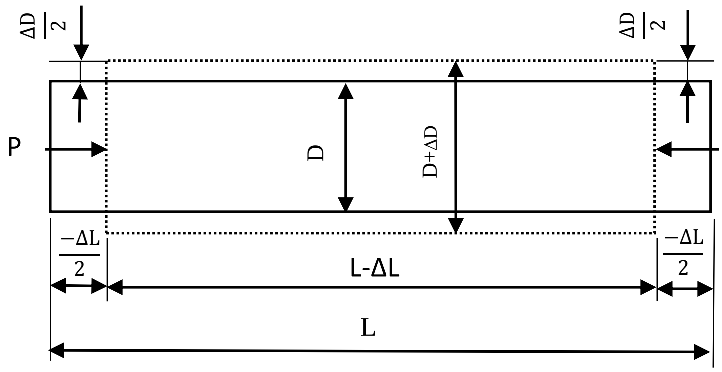


Figure 2.2 Compression Force [6]

Assuming that the cross sectional area of the material to be *A* and the applied force to be *P*, stress σ will be P/A, for a stress is a force acting on a definite cross sectional area. In a simple uniaxial stress field as illustrated above, strain ε is proportional to stress σ (Hooke's law), thus an equation

$$\sigma = E.\varepsilon \tag{2.3}$$

σ- Stress

ε- Strain

E- Elastic modulus

Is satisfied, assuming that the stress σ does not exceed the elastic limit of the material. An external force applied to a ferrous material generates physical deformation and electrical resistance change of the material. In the case that such a material is affixed into the test specimen over electrical insulation, the material produces a change of electrical resistance proportional to the deformation. Strain gauges consist of electrical resistance material and accordingly indicate a proportional change in the strain:-

$$\varepsilon = \frac{\Delta L}{L} = \frac{\Delta R / R}{K} \tag{2.4}$$

ε- Strain measured

R- Gauge resistance

ΔR- Resistance change due to strain

K- Gauge Factor

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

2.1 Types of strain gauges

Types of strain gauges include foil strain gauge, wire strain gauge and semiconductor strain gauge.

2.2 Structure of foil strain gauge

The foil strain gauge has metal foil photo – etched in a grid pattern in the electric insulating of the resin and gauge leads attached, as shown in Figure 2.3.

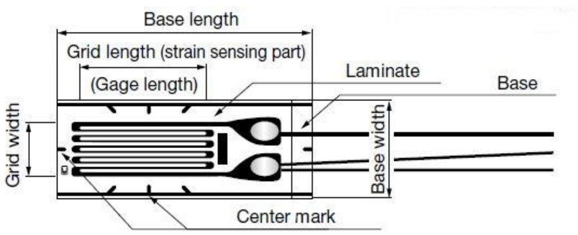


Figure 2.3 Strain Gauge Configuration [1]

The strain is bonded to the measuring object with a dedicated adhesive. Strain occurring on the measuring site is transferred to the strain sensing element via the gauge base. For accurate measurement, the strain and the adhesive should match the measuring material and operating conditions including temperature.

2.3 Principle of strain measurement

Strain – initiated resistance change is extremely small. Thus, for strain – measurement a Wheatstone bridge is formed to convert the resistance change to a voltage change, suppose in Figure 2.4 resistance (Ω) are R_1, R_2, R_3 and R_4 and the bridge voltage (V) is E. Then, the output e_o (V) is obtained with the following equation:

$$e_o = \frac{R_1R_3-R_2R_4}{(R_1+R_2)(R_3+R_4)} . E \qquad (2.5)$$

Suppose resistance R_1 is a strain gauge and it changes by ΔR due to strain. Then, the output voltage is,

$$e_o = \frac{(R_1+\Delta R)R_3-R_2R_4}{(R_1+\Delta R+R_2)(R_3+R_4)} . E \qquad (2.6)$$

If $R1=R_2=R_3=R_4=R$,

$$e_o = \frac{(R^2+R\Delta R)-R^2}{(2R+\Delta R)2R} . E \qquad (2.7)$$

Since R may be regarded extremely larger than ΔR,

$$e_o \cdot \frac{1}{4} . \frac{\Delta R}{R} \cdot E = \frac{1}{4} \cdot K \cdot \varepsilon \cdot E \qquad (2.8)$$

Thus obtained is an output voltage that is proportional to a change in resistance, i.e. a change in strain this microscopic output voltage is amplified analog recording or digital indication of the strain.

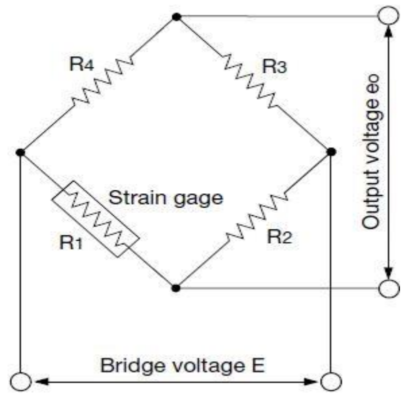


Figure 2.4 Wheatstone Bridge Circuit [2]

2.4 Gauge factor

When a metallic conductor is strained, it undergoes a change in electrical resistance, and it is this change that makes the strain gauge a useful device. The measure of this resistance change with strain is GAUGE FACTOR, GF. Gauge factor is defined as the ratio of the fractional change in resistance to the fractional change in length (strain) along the axis of the gage. Gauge factor is a dimensionless quantity, and the larger the value, the more sensitive the strain gage. Gage factor is expressed in equation form as:

$$K = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon} \qquad (2.9)$$

It should be noted that the change in resistance with the strain is not due solely to the dimensional changes in the conductor, but that the resistivity of the conductor material also changes with strain: The term gage factor applies to the strain gauge as a whole, complete with carrier matrix, not just to the strain-sensitive conductor. The gauge factor for constantan and nickel-chromium alloy strain gages is nominally 2, and various gauge and instrumentation specifications are usually based on this nominal value.

2.5 Wheatstone Bridge

The Wheatstone bridge is the most basic of a number of useful electrical bridge circuits that may be used to measure resistance, capacitance or inductance. It also finds applications in a number of circuits designed to indicate resistance changes in transducers such as resistance thermometers and moisture gages. In the circuit shown below it is apparent that the bridge can be imagined as two balanced circuits (composed of R1, R2 and R3, R4) connected so that the initial steady state voltages are cancelled in the measurement of e.

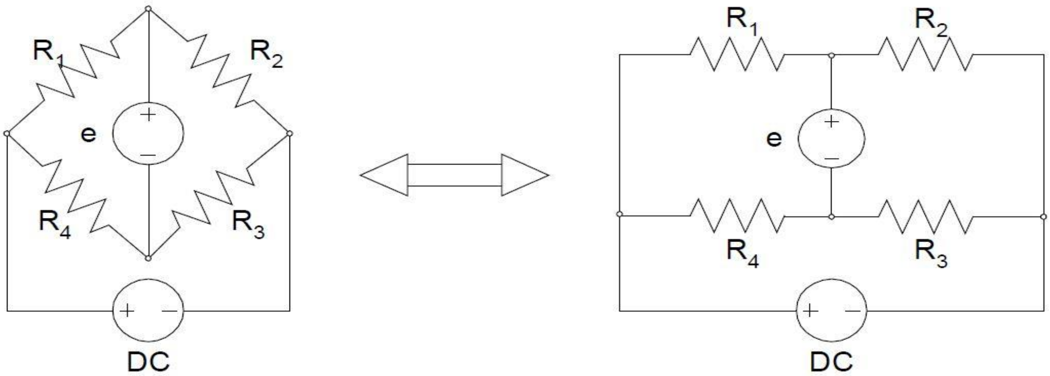


Figure 2.5 Wheatstone Bridge [2]

The output voltage can be written as the difference between two balanced circuits as:

$$e = \left[\frac{R2}{R1+R2} - \frac{R3}{R3+R4}\right]E = \frac{R2R4-R1R3}{(R1+R2)(R3+R4)}E \tag{2.10}$$

Clearly, an initial steady state voltage exists unless the numerator above is zero. Such a configuration with zero output voltage is termed a "Balanced Bridge" and is provided when:

R2 R4 = R1 R3

This relationship is not of direct concern here, but it is interesting to note that if any three of the four resistances are known, the fourth can be determined by rationing the values obtained at balance. For the present, however, we are concerned with the output produced by small changes in the resistance of the bridge arms. If we consider infinitesimal changes in each resistor then Ri ⇒ Ri + dRi and we can compute the differential change in the output voltage, e, as:

$$e = \frac{\partial e}{\partial R1}dR1 + \frac{\partial e}{\partial R2}dR2 + \frac{\partial e}{\partial R3}dR3 + \frac{\partial e}{\partial R4}dR4 \tag{2.11}$$

$$e = \left[\frac{R1R2}{(R1+R2)^2}\left\{\frac{dR1}{R1} - \frac{dR2}{R2}\right\} + \frac{R3R4}{(R3+R4)^2}\left\{\frac{dR3}{R3} - \frac{dR4}{R4}\right\}\right]E \tag{2.12}$$

If the bridge is balanced so that:

R = R1 = R2 = R3 = R4

Then, using this in the above equation for *de* yields:

$$de = \frac{1}{4}\left[\frac{dR1}{R1} - \frac{dR2}{R2} + \frac{dR3}{R3} - \frac{dR4}{R4}\right]E \quad (2.13)$$

We can use equation to express *due* in terms of the strains as:

$$de = [\varepsilon 1 - \varepsilon 2 + \varepsilon 3 - \varepsilon 4]E \quad (2.14)$$

Where ε_i, is the strain in the gage placed in the i-th arm of the bridge. Since the bridge is initially balanced, this is the only output and we have the desired result that:

$$e = [\varepsilon 1 - \varepsilon 2 + \varepsilon 3 - \varepsilon 4]E \quad (2.15)$$

This is the basic equation relating the Wheatstone bridge output voltage to strain in gages placed in each arm. Several remarks are in order:

• The equation identifies the first order effects only, and so this is the "linearized" form. It is valid only for small (infinitesimal) resistance changes. Large resistance changes produce nonlinear effects and these are shown in Figure 2.6 where finite changes in R (ΔR) in a single arm are considered for an initially balanced bridge.

• Output is directly proportional to the excitation voltage and to the Gage Factor. Increasing of either will improve measurement sensitivity.

• Equal strain in gages in adjacent arms in the circuit produces no output. Equal strain in all gages produces no output either.

• Fixed resistors rather than strain gages may be used as bridge arms. In this case the strain contribution is zero and the element is referred to as a "dummy" element or gage. Equations 14 and 16 along with the above remarks thus serve to describe the electrical behavior of a Wheatstone Bridge. The major intent here is not to suggest an electrical measurement techniques, but rather to describe the behavior in enough detail so that the effect of changes in any parameter can be directly assessed. While there are cases when the entire bridge circuit must be custom assembled, as for example in a special transducer, a majority of typical strain gage applications in structural testing involves measurement of strain in single gages, one at a time, with commercial equipment. Since all presently available strains measuring instruments employ the Wheatstone Bridge circuitry, our discussion on the relative effects of Gage Factor and strain changes in individual arms on the output indication is directly applicable.

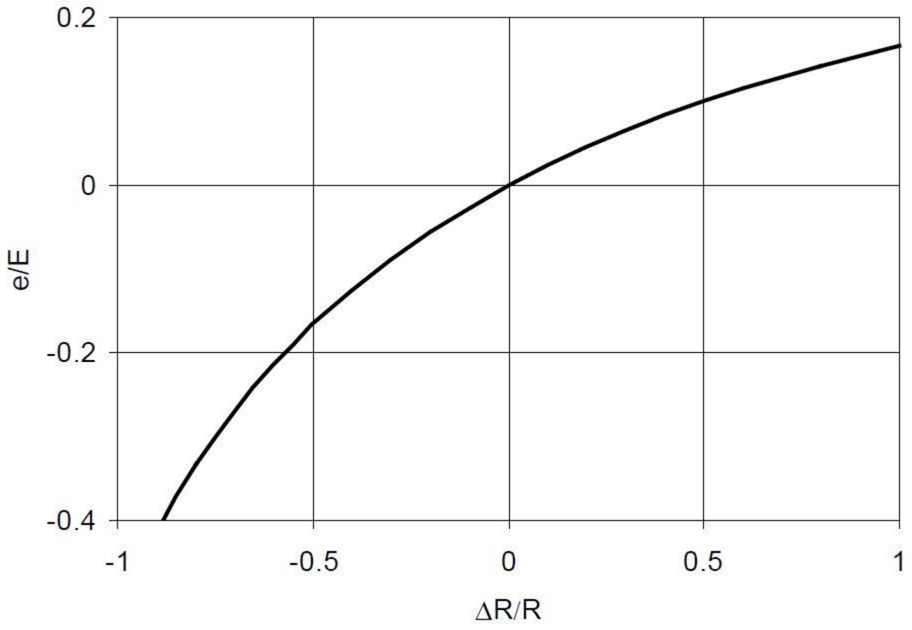
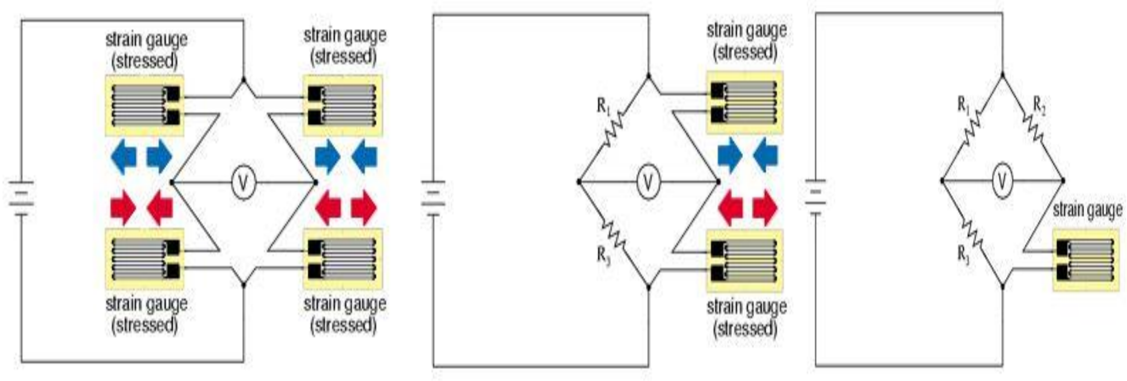


Figure 2.6 Wheatstone Bridge Output for Initially Balanced Bridge with Single Active Arm

2.6 Elementary circuits with strain gauges

The main fields of application of strain gauges are experimental stress analysis and the design and manufacture of transducers. Depending on the measurement problem on hand, one or more strain gauges are used at the actual measuring point. A designation such as "Full Bridge", "Half Bridge", or "Quarter Bridge" indicates such arrangements, although actually these are not correct. In fact, the circuit used for the measurement is always complete and is either fully or partially formed by the strain gauges on the specimen. It is then completed by fixed resistor, which are incorporated in the instruments.



Full bridge Half bridge Quarter bridge

Figure 2.7 Different version of the Wheatstone bridge circuit

Transducer generally have to comply with the more stringent accuracy requirement than measurement for stress analysis. Therefore, transducers should always have a full circuit with active strain gauges in all four arms.

Full bridge or half bridge circuits should also be used in stress analysis if different kind of interferences needs to be eliminated. An important condition is that cases of different stresses are clearly distinguished such as compressive or tensile stress, as well as bending, shear or torsional forces.

2.7 Wheatstone bridge circuit

The Wheatstone bridge is an electric circuit suitable for detection of minute resistance changes. It is therefore used to measure resistance changes of a strain gauge. The bridge is configured by combining four resistors as shown in Figure. 2.8.

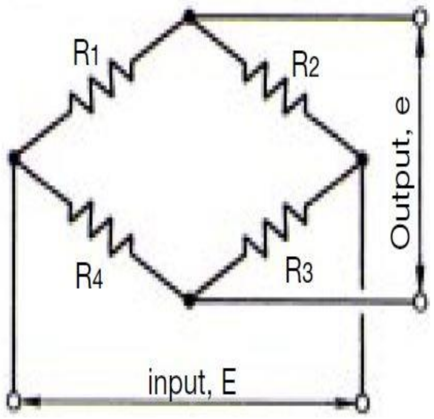


Figure 2.8 Wheatstone bridge configuration

Suppose:

R1 = R2 = R3 = R4, or R1 x R3 = R2 x R4.

Then, whatever voltage is applied to the input, the output, e, is zero. Such a bridge status is called "balanced." When the bridge loses the balance, it outputs a voltage corresponding to the resistance change.

As shown in Figure. 2.9, a strain gage is connected in place of R1 in the circuit. When the gauge bears strain and initiates a resistance change, ΔR, the bridge outputs a corresponding voltage, e.

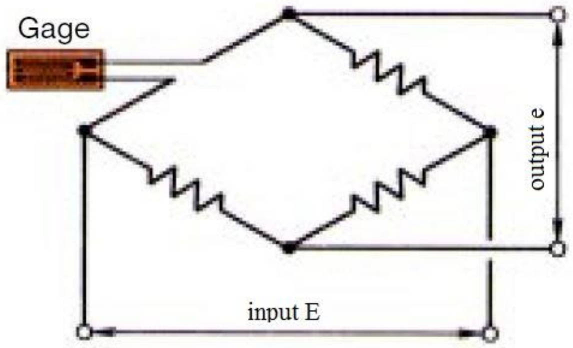


Figure 2.9 Strain gauge connlected to the circuit

$$e = \frac{1}{4} \cdot \frac{\Delta R}{R} \cdot E \qquad (2.16)$$

That is,

$$e = \frac{1}{4} \cdot K \cdot \varepsilon \cdot E \qquad (2.17)$$

Since values other than ε are known values, strain, ε, can be determined by measuring the bridge output voltage.

2.8 Bridge structures

The structure described above is called a 1-gauge system since only one gage is connected to the bridge. Besides the 1-gage system, there are 2- gauge and 4-gauge systems.

2.8.1 2-gage system

With the 2-gauge system, gauges are connected to the bridge in either of two ways, shown in Figure 2.10.

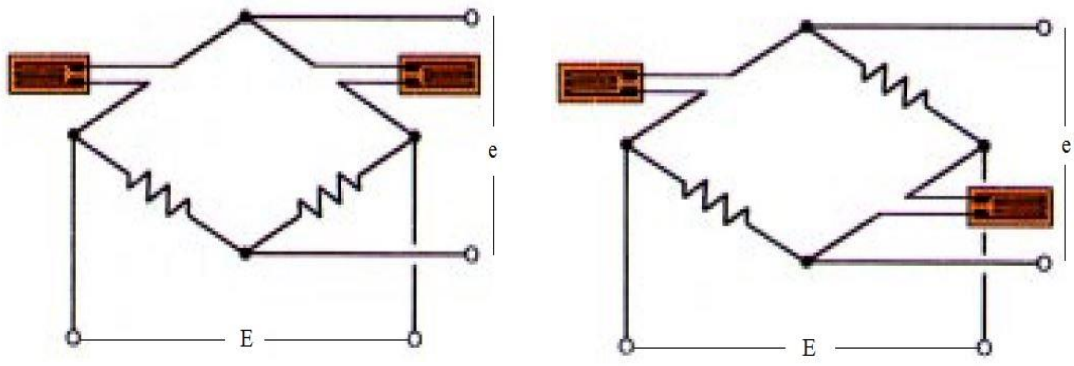


Figure 2.10 Two gauge system

2.8.2 Output voltage of 4-gage system

The 4-gage system has four gages connected one each to all four sides of the bridge. While this system is rarely used for strain measurement, it is frequently applied to strain-gage transducers.

When the gages at the four sides have their resistance changed to *R1* + Δ*R1*, *R2* + Δ*R2*, *R3* + Δ*R3* and *R4* + Δ*R4*, respectively, the bridge output voltage, e, is:

$$e = \frac{1}{4}\left(\frac{\Delta R1}{R1} - \frac{\Delta R2}{R2} + \frac{\Delta R3}{R3} - \frac{\Delta R4}{R4}\right)E \tag{2.18}$$

If the gages at the four sides are equal in specifications, including the gage factor, K, and receive strains, ε1, ε2, ε3 and ε4, respectively, the equation above will be:

$$e = \frac{1}{4} \cdot K(\varepsilon 1 - \varepsilon 2 + \varepsilon 3 - \varepsilon 4)E \tag{2.19}$$

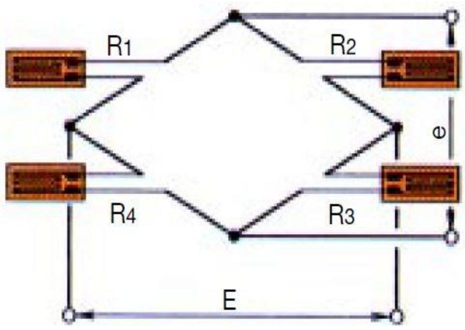


Figure 2.11 Output voltage 4 gauge system

2.8.3 Output voltage of 1-gage system

In the cited equation for the 4-gage system, the 1- gauge system undergoes resistance change, $R1$, at one side only. Thus, the output voltage is:

$$e = \frac{1}{4} \cdot K \cdot \frac{\Delta R1}{R1} \cdot E \tag{2.20}$$

Or,

$$e = \frac{1}{4} \cdot K \cdot \varepsilon \cdot E \tag{2.21}$$

In almost all cases, general strain measurement is performed using the 1-gage system.

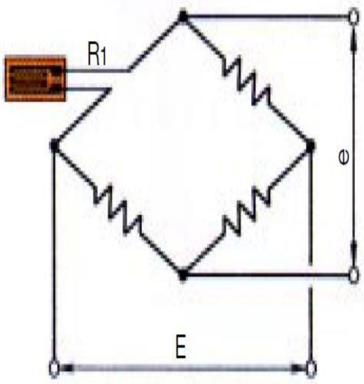


Figure 2.12 Output voltage 1 gauge system

2.8.4 Output voltage of 2-gage system

Two sides between the four initiate resistance change. Thus, the 2-gage system in the case of Figure 2.13 (a), provides the following output voltage:

$$e = \frac{1}{4}\left(\frac{\Delta R1}{R1} - \frac{\Delta R2}{R2}\right)E \tag{2.22}$$

Or

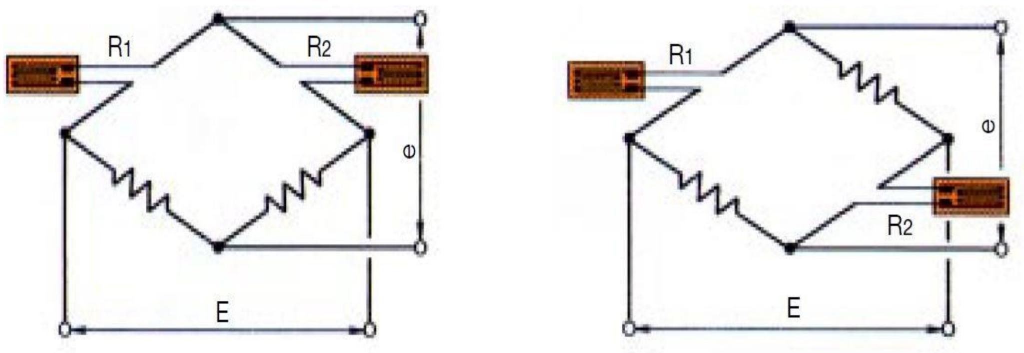
$$e = \frac{1}{4}K(\varepsilon 1 - \varepsilon 2)E \tag{2.23}$$

In the case of Figure 2.13 (b),

$$e = \frac{1}{4}\left(\frac{\Delta R1}{R1} + \frac{\Delta R2}{R2}\right)E \tag{2.24}$$

Or

$$e = \frac{1}{4}K(\varepsilon 1 + \varepsilon 2)E \tag{2.25}$$



Case (a) Case (b)

Figure 2.13 Output voltage 2 gauges system

That is to say, the strain borne by the second gage is subtracted from, or added to, the strain borne by the first gage, depending on the sides to which the two gages are inserted, adjacent or opposite.

2.9 Applications of 2-gage system

The 2-gage system is mostly used for the following cases. To separately know either the bending or tensile strain an external force applies to a cantilever, one gage is bonded to the same position at both the top and bottom, as shown in Figure 2.14. These two gages are connected to adjacent or opposite sides of the bridge, and the bending or tensile strain can be measured separately.

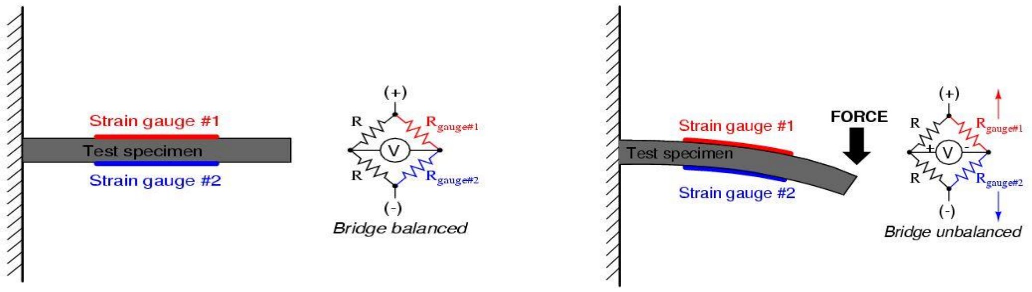


Figure 2.14 Illustrates a bending beam application

That is, gage 1 senses the tension (plus) strain and gage 2 senses the compressive (minus) strain. The absolute strain value is the same irrespective of polarities, provided that the two gages are at the same distance from the end of the cantilever. To measure the bending strain only by offsetting the tensile strain, gage 2 is connected to the adjacent side of the bridge. Then, the output, e, of the bridge as shown in equation (2.23).

Since tensile strains on gages 1 and 2 are plus and the same in magnitude, $(\varepsilon_1 - \varepsilon_2)$ in the equation is 0, thereby making the output, e, zero. On the other hand, the bending strain on gage 1 is plus and that on gage 2 is minus. Thus, ε_2 is added to ε_1, thereby doubling the output. That is, the bridge configuration shown in Figure 2.13 (a) enables measurement of the bending strain only.

If gage 2 is connected to the opposite side, the output, e, of the bridge as shown in equation (2.25).

Thus, contrary to the above, the bridge output is zero for the bending strain while doubled for the tensile strain. That is, the bridge configuration shown in Figure 2.13 (b) cancels the bending strain and enables measurement of the tensile strain only.

One of the problems of strain measurement is thermal effect. Besides external force, changing temperatures elongate or contract the measuring object with a certain linear expansion coefficient. Accordingly, a strain gage bonded to the object bears thermally-induced apparent strain. Temperature compensation solves this problem.

2.10 Active-Dummy Method

The active-dummy method uses the 2-gage system where an active gage, A, is bonded to the measuring object and a dummy gage, B, is bonded to a dummy block which is free from the stress of the measuring object but under the same temperature condition as that affecting the measuring object. The dummy block should be made of the same material as the measuring object.

As shown in Figure 2.15, the two gages are connected to adjacent sides of the bridge. Since the measuring object and the dummy block are under the same temperature condition, thermally-induced elongation or contraction is the same on both of them. Thus, gages A and B bear the same thermally-induced strain, which is compensated to let the output, e, be zero because these gages are connected to adjacent sides.

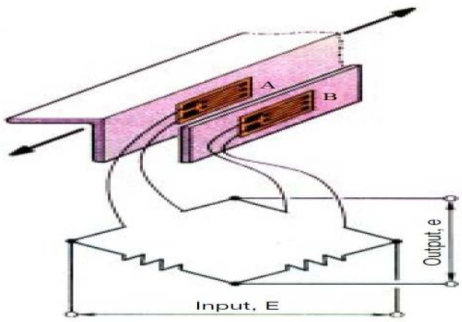


Figure 2.15 Active-Dummy strain gauges

2.11 Bridge balancing

In the previous discussions it has been assumed that the Wheatstone bridge circuit was initially balanced with all resistances equal. In reality, this is not the case due to inherent irregularities between even the most accurate of strain gages or dummy resistances. As a result, the bridge output voltage, e, is not zero, but instead may show an initial unbalance of as much as 0.1% of E, (i.e. up to 10 mV for E=10V). This may actually surpass the true strain-induced signal in many cases.

Fortunately; there is a relatively simple and straightforward method for eliminating this unbalance without adversely affecting the basic bridge circuit. It consists simply of some method for adding or subtracting from the resistance in any one arm so as to satisfy the balance requirement:

$$R1.R3=R2.R4$$

The adjustment may be made singly in one arm or relatively (differentially) in two or, more arms. Figure 2.16 shows several methods for accomplishing this. In Figure 2.16 (a) a small resistance is shown added in series with R_i to increase the arm resistance. The problem here is that this approach can only be used to increase the left-hand side of the above balance equation; thus one must know in advance which arm(s) have the lowest resistance.

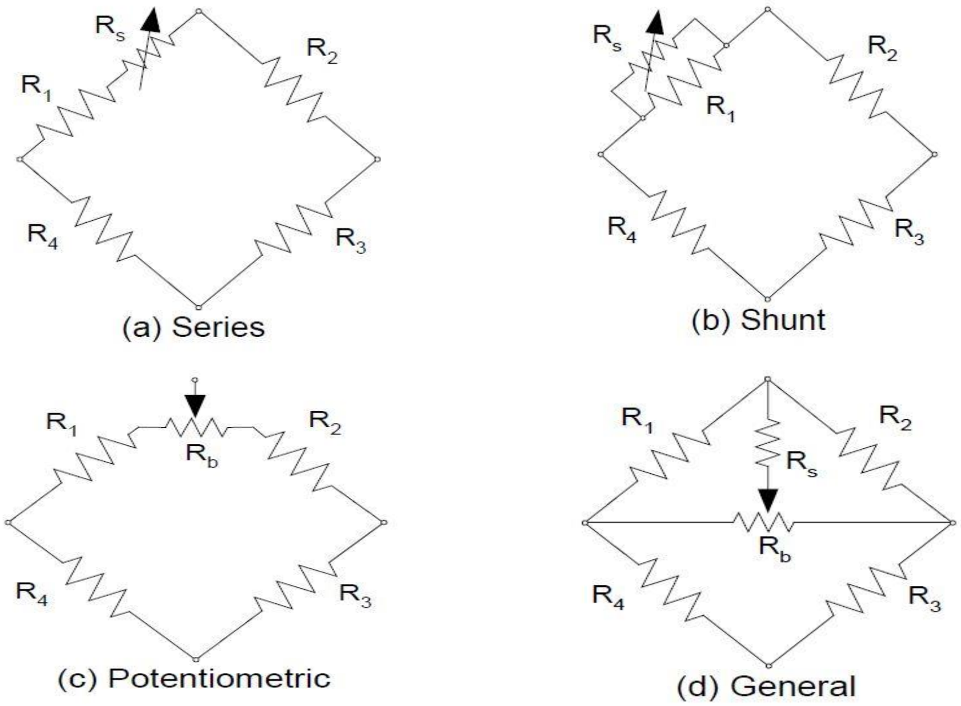


Figure 2.16 Strain Gauge Balancing Circuits

A second problem is that the added balance resistance must be extremely small in order not to unbalance the bridge in the opposite direction. The magnitude of this added balance resistance can be determined from the Wheatstone bridge equation. In order to cancel an initial unbalance voltage, a resistance change must be produced in one arm that is equal to the equivalent strain induced resistance change in a gage that would produce the same unbalance voltage. Using Eq. (2.14) for a single active arm (quarter bridge configuration) it follows that:

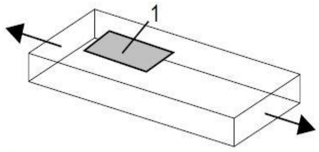
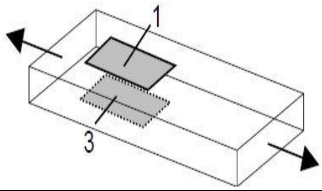
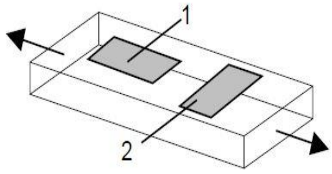
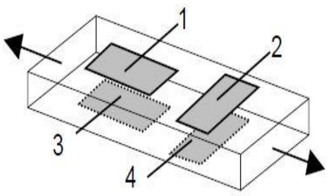
$$\Delta R1 = 4\frac{e_\circ}{E}R1 \tag{2.26}$$

2.12 Sensing Strain in a Member under Uniaxial Load

It is often necessary to measure the strain in a prismatic member (a bar) subjected to an axial load. A common example might be a truss element which is designed to carry axial load. In this case the application of a single strain gage oriented in the axial direction on the bar would appear to be sufficient. However, several problems arise. First, there is the problem of what to do about the other 3 arms of the Wheatstone bridge, but second, it is not always so easy to assume that a single gage will correctly sense the axial strain in the bar. For example, while the stress state may be uniaxial (consist of only a single nonzero stress), the strain state is not, and there are significant lateral strains that the gage might sense, especially if it is not accurately aligned.

Moreover, any slight bending in the member (due to initial eccentricities, for example) or other irregularities might cause the axial strain to vary across the cross section of the bar. Table 2.1 below summarizes some of the most common situations that might be encountered and provides wiring notes and K values.

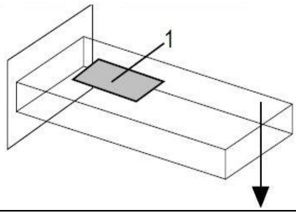
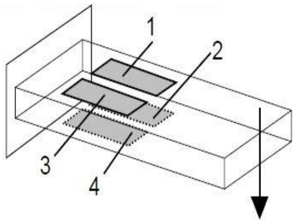
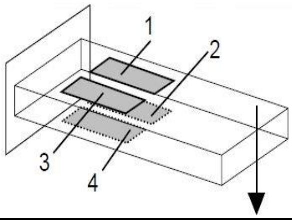
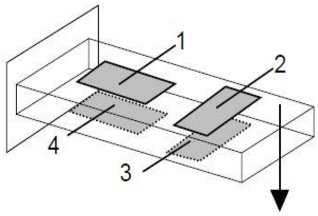
Table 2.1 Bridge Configurations for Uniaxial Members

No	K	Configuration	Notes
A-1	1		Must use dummy gage in an adjacent arm (2or 4) to achieve temperature compensation
A-2	2		Rejects bending strain but not temperature compensated; must add dummy gages in arms 2 & 4 to compensate for temperature.
A-3	(1+ν)		Temperature compensated but sensitive to bending strains
A-4	2(1+ν)		**Best**: compensates for temperature and rejects bending strain.

2.13 Sensing Strain in a Member under Bending Load

Quite the opposite of what was considered in the previous section can also be true. That is, it may be necessary to sense the bending induced strains in a prismatic member and NOT the strains due to axial loading. This is usually the case when dealing with beams or other so-called flexural elements. For these cases, the bridge can be wired so that the equal and opposite strains that are induced on the upper and lower surfaces of a simple beam will appear in adjacent arms where the strains will be combined. Even when the beam cross section is such that the centroid is not equal distances from the top and bottom surfaces (e.g., a 'tee' section), the strains will still be of opposite sign and will add constructively in the bridge equation. Table 2.2 below summarizes the most common configurations for flexural applications.

Table 2.2 Bridge Configurations for Flexural Members

No	**K**	**Configuration**	**Notes**
F-1	1		Also responds equally to axial strains; must use dummy gage in an adjacent arm (2 or 4) to achieve temperature compensation
F-2	2		Half-bridge; rejects axial strain and is temperature compensated; dummy resistors in arms 3 & 4 can be in strain indicator.
F-3	4		**Best**: Max sensitivity to bending; rejects axial strains; temperature compensated.
F-4	2(1+ν)		Adequate, but not as good as F-3; compensates for temperature and rejects axial strain.

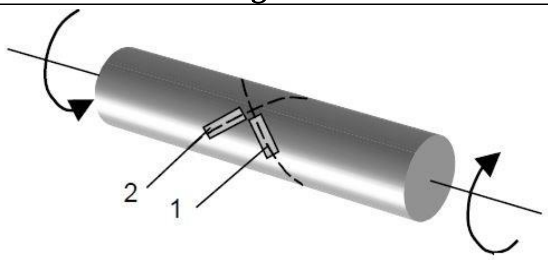
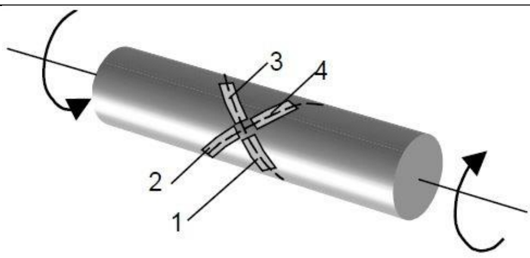
It should be noted that in Table 2.2, no consideration is given to the relative locations of the strain gages along the length of the beam. In practice the bending moment will vary and so will the strains. For example, case F-4 will be less sensitive if gages 2 and 3 experience less strain as a result of experiencing less bending moment (e.g., because they are closer to the load point in a cantilever configuration as illustrated).

One area of interest for flexural gage installations is in sensing the flexural deformation that accompanies buckling of a slender column. Mounting back-to-back gages near the midpoint of a column in a bridge configuration as shown in F-3, can result in a sensor that responds quite sensitively to small flexural movements as the column is loaded. In this case, a graphical extrapolation procedure such as that due to R.V. South well can be effective in indicating the buckling load well before it is reached and damage may occur. Also, it should be pointed out that the configurations for use on flexural elements may apply directly to thin plates when the objective is to sense the bending deformation and not the in plane stretching. Again, back-to-back mounted strain gages when properly wired into a Wheatstone bridge can often serve to effectively reject the in plane strains while responding to bending strains.

2.14 Sensing Torsion Strains in a Circular Shaft

Torsion presents an interesting challenge because the dominant stress is a shear stress, $\tau_{x\theta}$, and therefore it is usually necessary to measure the resulting shear strain, $\gamma_{x\theta}$. We have seen earlier that while strain gages can directly sense only an extensional strain, a rosette can be used to measure the strain state at a point and to thereby infer any particular 2D strain component. In the general case as treated earlier, it is necessary to apply at least 3 gages in a rosette to determine the 2D strain state. However, if some information is already known, it is usually possible to use fewer than 3 gages. This is the case when sensing the torsion strain in a circular shaft where the directions of principal strain are known in advance to be at 45° to the axial direction on the surface of the shaft. In view of this knowledge, a simple two-element “tee” or 90° rosette can be mounted such that the two individual gages are aligned in the principal strain directions. Table 2.3 below summarizes some of the possible configurations.

Table 2.3 Bridge Configuration for Torsion Members

No	K	Configuration	Notes
T-1	2		Half Bridge: Gages at ±45° to centerline sense principal strains which are equal & opposite for pure torsion; bending or axial force induces equal strains and is rejected; arms are temperature compensated.
T-2	4		**Best**: full-bridge version of T-1; rejects axial and bending strain and is temperature compensated.

It probably is obvious, but it should be noted that for rotating shafts, some form of commutation is needed to get the signals from the rotating gages. One approach involves use of mechanical slip rings to maintain electrical contact with rotating components. Radio telemetry is also a viable option given the availability of miniature electronics.

2.15 Sensing Strain in Rings

The thin ring is one of the most effective structural forms for converting loads and displacements into proportional strains. A structural analysis of the thin or thick ring subjected to various kinds of loadings is beyond the scope of the present notes. Instead, only a simple engineering analysis of the ring will be used to infer the behavior when instrumented with strain gages. The rings are very commonly employed as sensing elements in load cells and for this purpose, more detailed structural models may be required. The basic concept is to apply a diametric load to a thin ring and sense the flexural strains in the inner and outer surfaces of the ring. This is shown in Figure 2.17 below. A simple analysis of the deformation of the ring (not the initial shape, but rather just the change in shape) indicates that there will be four inflection points (where the curvature reverses) at roughly ±45° to the load axis. This means that the bending strains will reach local maximum values between the inflection points or roughly on the load axis and at 90° to it. As a result, these are good locations for strain gages, either on the inner or the outer surfaces of the ring. Since these are flexural strains, they will be nearly opposite in sign when located on opposite surfaces of the ring. This is illustrated in Figure 2.17 where gages are shown only at the middle locations. Using only the inner surfaces is often a better choice because it affords a measure of protection for the gage but it is often more difficult to install the gage.

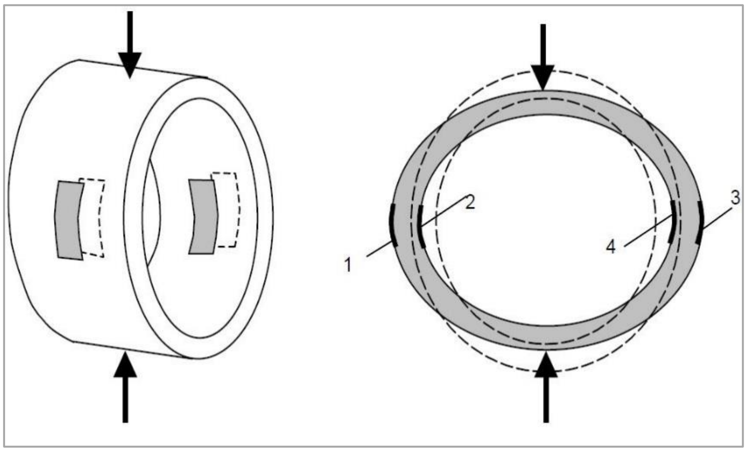


Figure 2.17 Simple Strain Gaged Ring

A variation of the ring gage involves use on only a half ring, sometimes called a "C" ring for obvious reasons, with the load applied across the opening of the C. Since this is a statically determinate configuration, it is actually easier to analyze as a structure. In any event, the behavior is similar to that of the full ring, but in this case the maximum strains are developed at the midpoint of the ring and this is where strain gages should be located. It should also be noted that rings are most commonly employed as load transducers so the strain gages sense the strain induced in the ring due to an applied load. With proper design, such devices are very effective load sensors. At the same time, however, if the ring is made as thin as possible, it eventually becomes so fragile that it is either a very sensitive load sensor with only a limited range. But at the same time, such a thin ring sensor can also be used as a displacement sensor with quite satisfactory performance. All that is necessary is to add two small spindles where the load is normally applied to transfer the deflection to a diametric change for the ring.

2.16 Multi-element Bridges

All of the configurations described above involve the use of up to 4 strain gages in a single Wheatstone bridge. There is no reason not to add more than one gage in an arm of the bridge provided balancing can still be achieved. Balancing is achieved when the products of the opposite arm resistances are equal ($R_1R_3=R_2R_4$). For example a total of 8 strain gages could be wired with 2 in each arm. If the gages are installed on the structure in such a way so that each pair of gages in a given arm experience strains with the same sign, the bridge will respond accordingly. In general this approach does not yield an improved bridge sensitivity (K factor) because the fractional change in resistance in the arm is still roughly the same. However, the effect is to average the strains in the pair. On the other hand, pairing gages which respond with opposite signs to an external input into a single arm will render the bridge insensitive to that kind of input, which may be the desired result. (This can also be achieved by placement of the gages in a bridge with single elements.) One key advantage of multi-element bridge arms is that the increased bridge resistance will allow use of a higher excitation voltage without inducing excessive thermal heating and drift. The only real drawbacks to multi-element bridge arms are that the increased bridge resistance may increase the noise level in the instrumentation somewhat and they may be incompatible with commercial strain instrumentation that is designed for balancing and calibration of 120 or 350 Ohm Bridges only.

CHAPTER 3

3 System Description

Signal conditioning of the strain gauge output Figure 3.1 develops over several consecutive blocks Figure 3.1. In the first step EMI (Electric Magnetic Impulse) unit suppresses high frequency noise. Then the signal undergoes significant amplification rate (500 times) over an instrumental amplifier. The main feature of this component is a low noise and low signal offset. Finally, low pass filter removes high frequency impurities from the signal. Operation of such a block composition is simulated in a dedicated software (Filter Lab and LTS piece) before completing the final design of the electronic circuit. After successful virtual verification, the design process continues with PCB manufacturing and component integration.

Much alike, this Mechatronic approach to measuring device development, an innovative CLD is optimized throughout 3D modelling and virtual testing and engineering.

The core idea is to investigate a substantially different design of a CLD, particularly, its behavior when exposed to selected loads. Unlike the standard deformeter shape, CLD has tied up opposed ends with a crossed position. In this concept, linear extension of a deformeter ends cause very intensive bending in its central part. Thus the measurement of subtle deformation becomes viable, producing a significant signal. The idea of 3D modeling and its verification in a virtual environment is overtaken from former researches in the same Laboratory [4]. The innovative design of CLD is, however, originally arranged as well the prototype is carefully tested, by its applicability, linearity and repeatability.

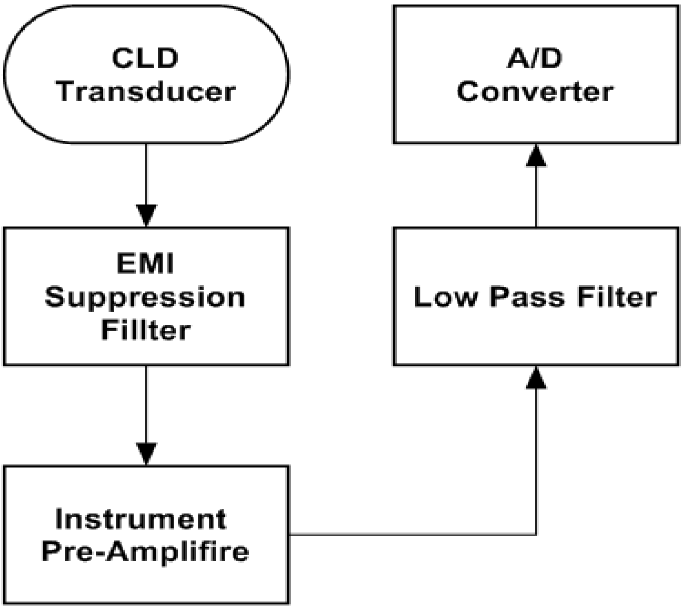


Figure 3.1 Signal Conditioning Block Composition

3.1 Signal conditioning composition

A fundamental parameter of the strain gauge is its sensitivity to strain. It is expressed as the gauge factor (K) depicting the ratio of relative change in electrical resistance to the relative change in length (strain).

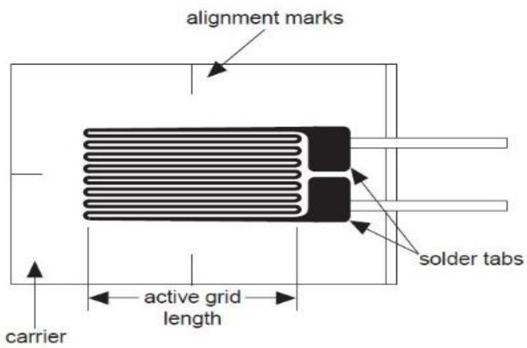


Figure 3.2 Strain gauge configuration

The Gauge Factor for metallic strain gauges is typically around 2. Regular strain measurements involve quantities in the range 0 – 10.000 ($\varepsilon \times 10^{-6}$). Therefore, a measurement with the strain gauge requires accurate detection of very small changes in resistance. That change of resistance ΔR is within overall span 480 $\mu\Omega$ – 2.4 Ω.

3.2 Bridge Completion

Unless full-bridge strain gauge sensor with, four active gauges are used for measurement, one will need to complete the bridge with reference resistors. Therefore, strain gauge signal conditioners typically provide half-bridge completion networks consisting of two high-precision reference resistors. Figure 3.3 diagrams the wiring of a half-bridge strain gauge circuit to a conditioner with completion resistors R_1 and R_2. The nominal resistance of the completion resistors is less important than how well the two resistors are matched. Ideally, the resistors are well matched and provide a stable reference voltage of $V_{EX} / 2$ to the negative input lead of the measurement channel.

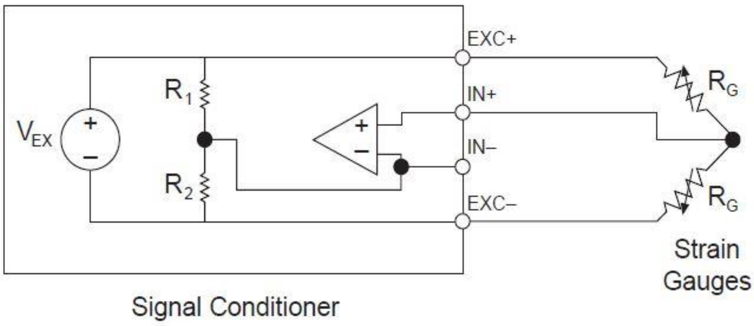


Figure 3.3 Connection of Half-Bridge Strain Gauge Circuit

3.3 Bridge Excitation

Strain gauge measurement involves sensing extremely small changes in resistance. Therefore, proper selection and use of the bridge, signal conditioning, wiring, and data acquisition components are required for reliable measurements. Strain gauge signal conditioners typically provide a constant voltage source to power the bridge. Most commonly the voltage level is either 3 V or 10 V. A higher excitation voltage generates a higher voltage signal, but also causes larger errors due to self-heating. It is of a crucial importance to have very accurate and stable excitation voltage. If the strain gauge circuit is located a distance away from the signal conditioner and excitation source, a significant error arises due to resistance in the connecting wires. It is advisable to have all electronic devices in the immediate vicinity.

3.4 Excitation Sensing

If the strain gauge circuit is located a distance away from the signal conditioner and excitation source, a possible source of error is voltage drops caused by resistance in the wires connecting the excitation voltage to the bridge. Therefore, some signal conditioners include a feature called remote sensing to compensate this error. Therefore, some signal conditioners include a feature called remote sensing to compensate for this error. Remote sensing wires are connected to the point where the excitation voltage wires connect to the bridge circuit, as seen in Figure 3.4. The extra sensor wires serve to regulate the excitation supply through negative feedback amplifiers to compensate for lead losses and deliver the needed voltage at the bridge.

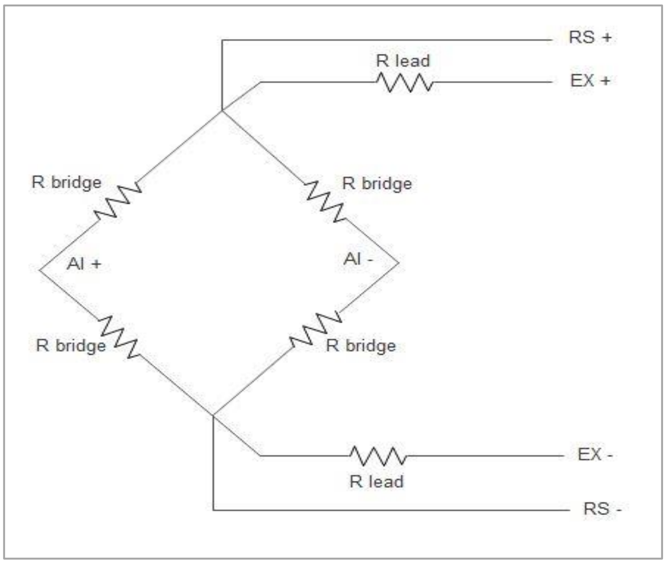


Figure 3.4 Remote Sensor Error Compensation

An alternative remote sensing scheme uses a separate measurement channel to measure directly the excitation voltage delivered across the bridge. Because the measurement channel leads carry very little current, the lead resistance has negligible effect on the measurement. The measured excitation voltage is then used in the voltage-to-strain conversion to compensate for lead losses.

3.5 Signal Amplification

The output of strain gauges and bridges is relatively small. In practice, most strain gauge bridges and strain-based transducers will output less than 10 mV/V (10 mV of output per volt of excitation voltage). With a 10 V excitation voltage, the output signal will be 100 mV. Therefore, strain gauge signal conditioners usually include amplifiers to boost the signal level to increase measurement resolution and improve signal-to-noise ratio.

In order to design a stable, harmonized measuring chain a brief analysis of crucial performance of each stage is conducted Table 3.1 shows several consecutive stages in signal generation and conditioning.

Table 3.1 Overview of Signal Degradation Rate within Measuring Chain

Device		Range	Resolution	Dynamic Range
Strain Gauge	Induced extension	0 – 0.1 mm	0.28 µm	1 : 300
	Proportional Strain	0 – 10000 µε	28 µε	1 : 300
CLD	Induced extension	0 – 10 mm	0.1mm	1 : 100
	Proportional Strain	0 – 3000 µε	28 µε	1 : 100
Pre-Amplifire	SG to AMP voltage	± 2.4 mV	0.6 µV	1 : 4.000
	AMP/SG output voltage	± 13.25 V	0.3 mV	
	CLD to AMP voltage	± 2.4 mV	0.6 µV	1 : 4.000
	AMP/CLD output voltage	± 7.95 V	0.3 mV	
Filter	Useful signal degrade		No effect	
Measuring instrument (ADC)	Input	± 1.25 V	0.3mV	1 : 4.000
	Output	± 32786	8	1 : 4.000

The main target in system development is to find out if there are weak points or any misconceptions. Since the CLD is conceived as a spring deformeter, and its core element is strain gauge, the output from these two is compared, in order to determine degradation extent. Later analysis, applied over 3D model and lab prototype showed that the 4 time signal drating is within acceptable margine. A very poor output signal from CLD must be significantly amplified and filtered in electronics. Table 3.1 shows obviously that the nature of the signal is preserved, and the filter makes no harm on it, while the AD block truly interprets a digital form of the signal. Measuring chain consists of the instrumentation amplifier LTR 1167 which is a high performance component with a low power, and low noise. When processing several signals in parallel a CMOS, 8 channel multiplexer is utilized (MAX 4617). It is a popular as a single voltage operated CMOS device with low leakage current (1 – 10 mA). The filter block is designed with modern components which have no effect on signal stability and intensity. Practically all the noise is removed, while the useful signal is kept untouched. Finally the signal is converted into a numerical record within A/D converter (LTC 1864). It is a 16 bit, 250ksps ADC.

3.6 LT1167 Amplifier

FEATURES

Single Gain Set Resistor: G = 1 to 10,000

Gain Error: G = 10, 0.08% Max

Input Offset Voltage Drift: 0.3µV/°C Max

Meets IEC 1000-4-2 Level 4 ESD Tests with

Two External 5k Resistors

Gain Nonlinearity: G =10, 10ppm Max

Input Offset Voltage: G = 10, 60µV Max

Input Bias Current: 350pA Max

PSRR at G = 1: 105dB Min

CMRR at G = 1: 90dB Min

Supply Current: 1.3mA Max

Wide Supply Range: ±2.3V to ±18V

1 kHz Voltage Noise: 7.5nV/$\sqrt{HZ}$

0.1Hz to 10Hz Noise: 0.28µVP-P

APPLICATIONS

Bridge Amplifiers

■ Strain Gauge Amplifiers

■ Thermocouple Amplifiers

■ Differential to Single-Ended Converters

■ Medical Instrumentation

The LTR1167 is a low power, precision instrumentation amplifier that requires only one external resistor to set gains of 1 to 10,000. The low voltage noise of 7.5nV/√Hz (at 1 kHz) is not compromised by low power dissipation (0.9 mA typical for ± 2.3V to ±15V supplies).

ABSOLUTE MAXIMUM RATINGS

Supply Voltage	±20V
Differential Input Voltage (Within the Supply Voltage)	±40V
Input Voltage (Equal to Supply Voltage)	±20V
Input Current	±20mA
Output Short-Circuit Duration	Indefinite
Operating Temperature Range	–40°C to 85°C
Specified Temperature Range LT1167AC/LT1167C	0°C to 70°C
Storage Temperature Range	–65°C to 150°C
Lead Temperature (Soldering, 10 sec)	300°C

3.7 Max-4617 Multiplexer

High-Speed, Low-Voltage, CMOS Analog Multiplexers/Switches.

The MAX4617/ is high-speed, low voltage, CMOS analog ICs configured as an 8-channel multiplexer (MAX4617). These CMOS devices can operate continuously with a +2V to +5.5V single supply. Each switch can handle rail-to-rail analog signals. The off-leakage current is only 1nA at T_A = +25°C and 10nA at T_A = +85°C.

All digital inputs have 0.8V to 2.4V logic thresholds, ensuring TTL/CMOS-logic compatibility when using a single +5V supply.

Features

Fast Switching Times 15ns t_{oN} 10ns t_{oFF}.

Guaranteed On-Resistance 10Ω max (+5V Supply) 20Ω max (+3V Supply).

Guaranteed 1Ω On-Resistance Match between channels (single +5V supply).

Guaranteed Low Off-Leakage Current: 1nA at +25°C.

Guaranteed Low On-Leakage Current: 1nA at +25°C +2V to +5.5V Single-Supply Operation.

TTL/CMOS-Logic Compatible.
Low Crosstalk: <-96dB.
High Off-Isolation: <-93dB.
Low Distortion: <0.017% (600Ω).

APPLICATIONS

Battery-Operated Equipment.
Audio/Video Signal Routing.
Low-Voltage Data-Acquisition Systems.
Communications Circuits.

ABSOLUTE MAXIMUM RATINGS

Voltages Referenced to GND.	
VCC, A, B, C, or Enable.	-0.3V to +6V
Voltage into Any Analog Terminal (Note1).	-0.3V to (VCC + 0.3V)
Continuous Current into Any Terminal.	±75mA
Peak Current, X, Y, Z (pulsed at 1ms, 10% duty cycle).	±200mA
Continuous Power Dissipation (T_A = +70°C).	
TSSOP (derate 9.4mW/°C above +70°C).	755mW
Narrow SO (derate 8.70mW/°C above +70°C).	696mW
Plastic DIP (derate 10.53mW/°C above +70°C).	842mW
Operating Temperature Ranges.	
Lead Temperature (soldering, 10sec).	+300°C
Soldering Temperature (reflow).	+260°C

Note 1: Voltages exceeding VCC or GND on any analog signal terminal are clamped by internal diodes. Limit forward-diode current to maximum current rating.

3.8 LTC11864 A/D Converter

Features

16-Bit 250ksps ADCs

Single 5V Supply

Low Supply Current: 850µA (Typ)

Auto Shutdown Reduces Supply Current to 2µA at 1ksps

True Differential Inputs.

1-Channel (LTC1864).

APPLICATIONS

High Speed Data Acquisition.

Portable or Compact Instrumentation.

Low Power Battery-Operated Instrumentation.

Isolated and/or Remote Data Acquisition.

The LTCR1864 is 16-bit A/D converter and operates on a single 5V supply. At 250ksps, the supply current is only 850µA. The supply current drops at lower speeds because the LTC1864 automatically power down between conversions. These 16-bit switched capacitor successive approximation ADCs include sample-and holds.

The LTC1864 has a differential analog input with an adjustable reference pin.

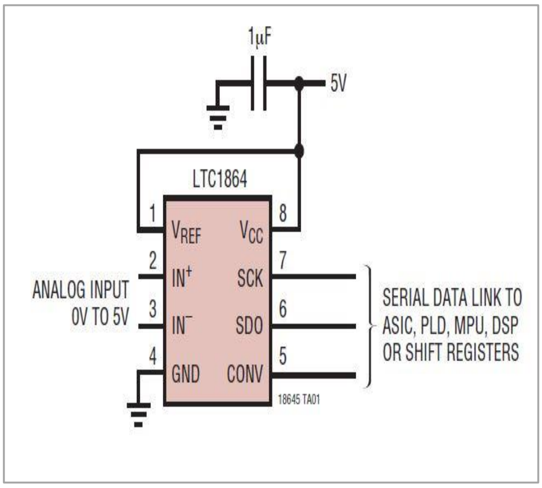


Figure 3.5 Single 5V Supply, 250ksps, 16-Bit Sampling ADC

3.9 Description of Dyna-Log-compact acquisition system

Performance:

- An instrument configuration of Dyna-log acquisition system consists of maximum two acquisition modules respectively 1 to 16 channels for acquisition task, one control module and user interface module.
- Digital signal processing (board) allows versatile and high processing speed together with high reliability, using fewer components.
- Application-specific Module concept.
- User interface module (Human Machine interface) for local operation and display.
- Local area interface connection to a windows PC.
- Datalog software application provides data visualization, measuring configuration selection and data exporting.
- Time synchronization between instruments.
- External battery supply.

Modules and units description:

- Accelerometer Acquisition module
  - Eight channels with configurable sensitivity for accelerometers.
  - One digital input for phase synchronization and rpm detection.
  - 16 bit ADC with external multiplexer.
  - Adaptable sampling rate up to 2ksampl/s for all channels.
  - PGA 1/32.
  - Selectable analogue high pass filter for each channel (1.6, 3.5, 5.1, 7.2, 11 Hz).
  - Configurable low pass filter for all channel (LP=k*f_{sampl}_rate, k= [0.35-1].

- Analogue Acquisition module
  - Eight channel for 4-20 mA or 0-10 v sensor.
  - One digital input for phase synchronization and rpm detection.
  - 16 bit ADC with external multiplexer.

- Up to 2ksampl/s for each channel.
- Signal condition per channel for pt100 (optionally pt1000) on request.
- 50V tolerant inputs.

- Strain Gauge Acquisition module
  - Eight input channels (0-10).
  - Eight signal conditioners for half bridge configuration with fixed gain, and trimmer for manual zeroing.
  - Strain Gauge resistance up to 1kohm.
  - 16 bit ADC with external multiplexer.
  - Up to 1ksamp/s for each channel.
  - 50V tolerant inputs.

- Control and log module
  - High speed communication with acquisition modules.
  - Time synchronization for acquisition module measurements.
  - Internal memory (8GB SD card) for data logging.
  - Real time clock.
  - Local arena network interface with Modbus RTU TCP/IP protocol (10 Mb/s).

- User interface module
  - Resistive touch screen.
  - Providing configuration for modules.
  - Starting and stopping measuring.
  - Sensor monitoring preview.
  - Simple measurement preview.

Range of application:

- Data acquisition.
- Site condition measurements.
- Strat up, coast down measurements.

- Trend records.
- Civil structure measurements.

CHAPTER 4

4 CLD 3D Modeling

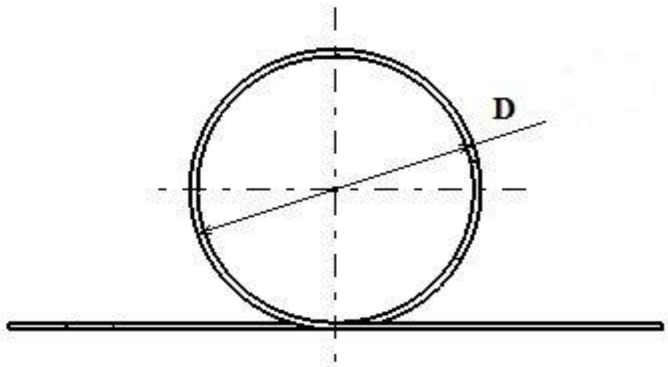
4.1 Shape and dimension

Close loop deformeter an original design leading to attempt of substituting conventional deformeter, deformeter is a type of sensor that can be replace strain gauge wherever and whenever are uncounted difficulties in attaching it.

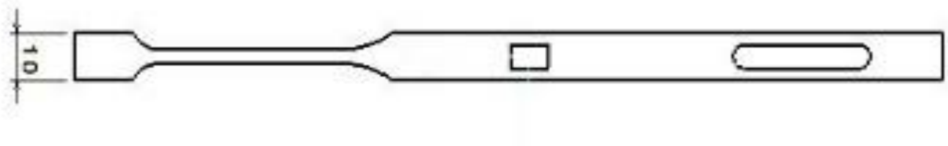
It is recognized that the strain gauge itself, bonded to a steel surface or any other material, dose not introduced additional tensing force if dose it is insignificantly small. A deformeter should fulfill prerequisite. Consequently, basic parameter for selecting shape an optimal shape of deformeter was stretching force .i.e. Reaction force which is present in the spring when deformed. As an acceptable value of the deformeter stiffness is defined K_o= 9 N/mm.

The close loop deformeter is around the spring steel plate and strain gauge. It is mounted with its probe pressed against structure. When displacement or force occurs in the structure. The plate spring is deformed and the amount of output proportional to the amount of displacement or force can be output [23].

In order to make a truly operational deformeter some design, analysis was carried out. Selected geometric parameters (spring thickness and loop diameter) were varied, to achieve an optimal stiffness. As a boundary acceptable deformeter stiffness it is defined k_o= 9 N/mm. Figure 4.1 shows final shape and size of CLD.



Final Closed Form



Spread Form

Figure 4.1 Final shape of CLD

Table 4.1 Range of CLDs diameters

Spring Model	D [mm]
1	30
2	40
3	50
4	60

Table 4.1 contains an overview of different diameters of CLDs.

During the CAD modelling quite a range of different diameters has been examined. Each CLD model was equipped with the bonded virtual Strain gauge of 10×5 mm dimension. CLDs have been stretched from unloaded, undeformed state to the maximal line extension of 10 mm. The margin of the least detectable extension was set to 0.01 mm. The material of the CLD is selected as structure spring steel which is easy to machine. Physical properties are listed in the table 4.2.

Table 4.2 Physical properties of CLD

Young's modulus	200000 MPa
Poisson ratio	0.3
Density	7850 kg/m^3

4.2 Meshing generation

The models are saved as an STP format in CATIA software [7] and imported back into ANSYS 16 for the analysis. Sizeing meshing is used 0.2 mm in CLD as shown in figure 4.2. Mesh study was performed on the FE model to refine the mesh for the accuracy of the calculated result depends on the competitive cost (CPU time). During the analysis, the specific variable and the mesh convergence was monitored and evaluated. The mesh convergence is based on the geometry, model topology and analysis objectives. For this analysis, the auto tetrahedral meshing approach is employed for the meshing of the solid region geometry. Tetrahedral mesh produces high quality meshing for boundary representation most of solids models imported from CAD systems. The tetrahedral elements (solid 187-3D) are used for the initial analysis based on the loading conditions [8] [9] [10] [11].

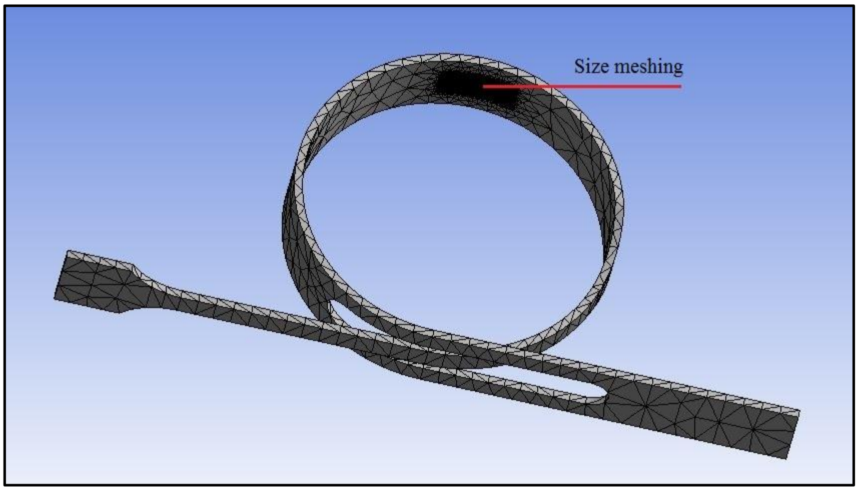


Figure 4.2 meshing of CLD

4.3 Boundary conditions

The boundary conditions are applied to the CLD model as shown in figure 4.3, one side displacement at x-axis, 0 at y & z axsis, fixed support is applied at opposite sides of the x-axsis and 0 at y & z axsis [11] [12].

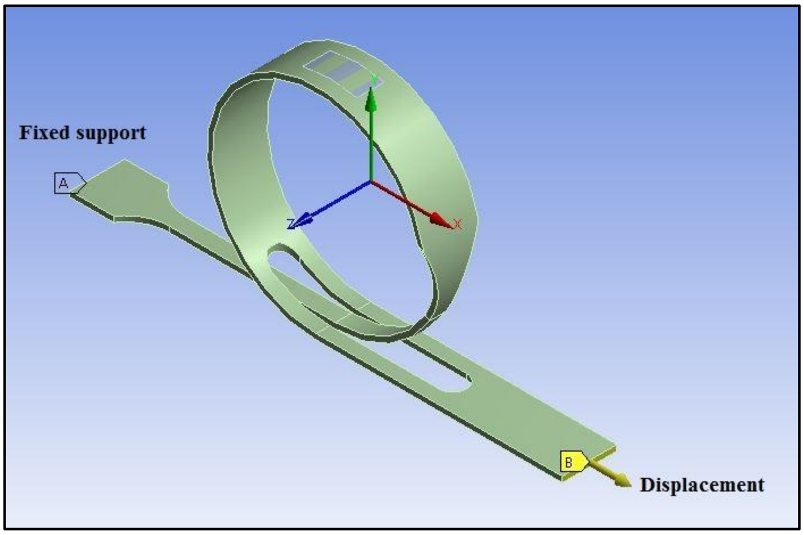


Figure 4.3 Boundary conditions on CLD

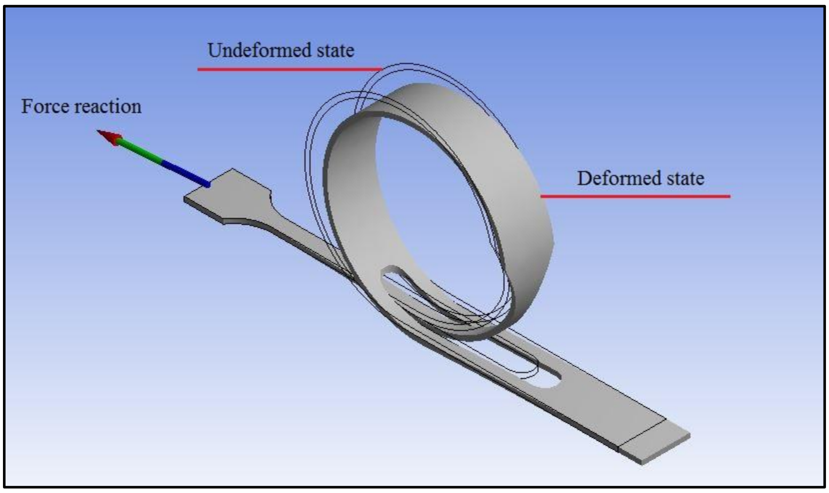


Figure 4.4 Undeformed and deformed CLD

4.4 CLD analysis simulation

Finite element analysis simulation is conducted using ANSYS SOFTWARE package [9], [11] [12].

The static performance of the CLD design is evaluated using static structural FEA. The simulations are carried out by applying an input displacement from (0.01 to 10 mm) to produce the stretching force. Table 4.3 shows the results of the line extension veres stretching force and stiffness.

Table 4.3 Stretching Force vs line extension

		Line Extension [mm]											
		0.01	1	2	3	4	5	6	7	8	9	10	Stiffness N/mm
Stretching Force [N]	Spring 1	0.07	7.26	14.51	21.76	29.02	36.27	43.53	50.78	58.04	65.3	72.55	7.2
	Spring 2	0.03	3.20	6.37	9.60	12.80	16.00	19.0	22.30	25.50	28.60	32.0	3.2
	Spring 3	0.02	1.67	3.34	5.01	6.68	8.35	10.02	11.69	13.36	15.03	16.7	1.6
	Spring 4	0.01	0.98	1.97	2.95	3.94	4.93	5.91	6.90	7.87	8.85	9.85	1.0

The simulations are carried out by applying an input displacement from (0.01 to 10 mm) to produce the stress. Table 4.4 shows the results of the line extension Veres stress.

Table 4.4 Stress vs Line Extension values

		Line Extension [mm]										
		0.01	1	2	3	4	5	6	7	8	9	10
Stress [MPa]	Spring 1	1.1	105.37	210.74	316.1	421.47	526.83	632.19	737.55	842.9	948.26	1053.6
	Spring 2	0.60	60.0	118.55	177.82	237.10	296.36	355.63	415.0	474.17	533.43	592.70
	Spring 3	0.38	38.00	76.01	114.01	152.01	190.01	228.01	266	304	342	379.99
	Spring 4	0.26	26.34	52.67	79.00	105.34	131.67	158	184.32	210.65	236.97	263.29

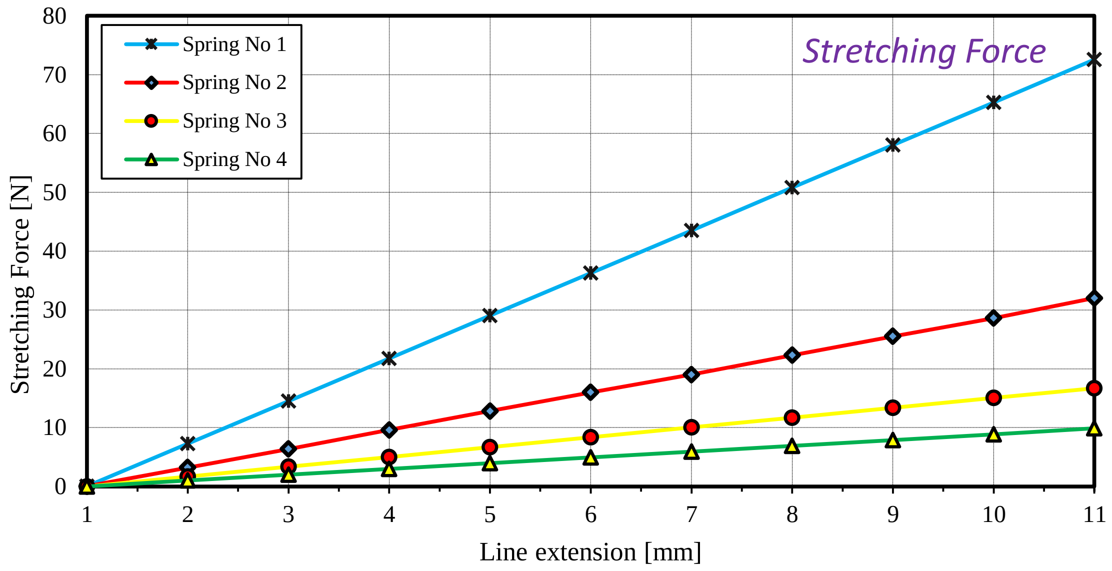


Figure 4.5 Stretching force vs line extension

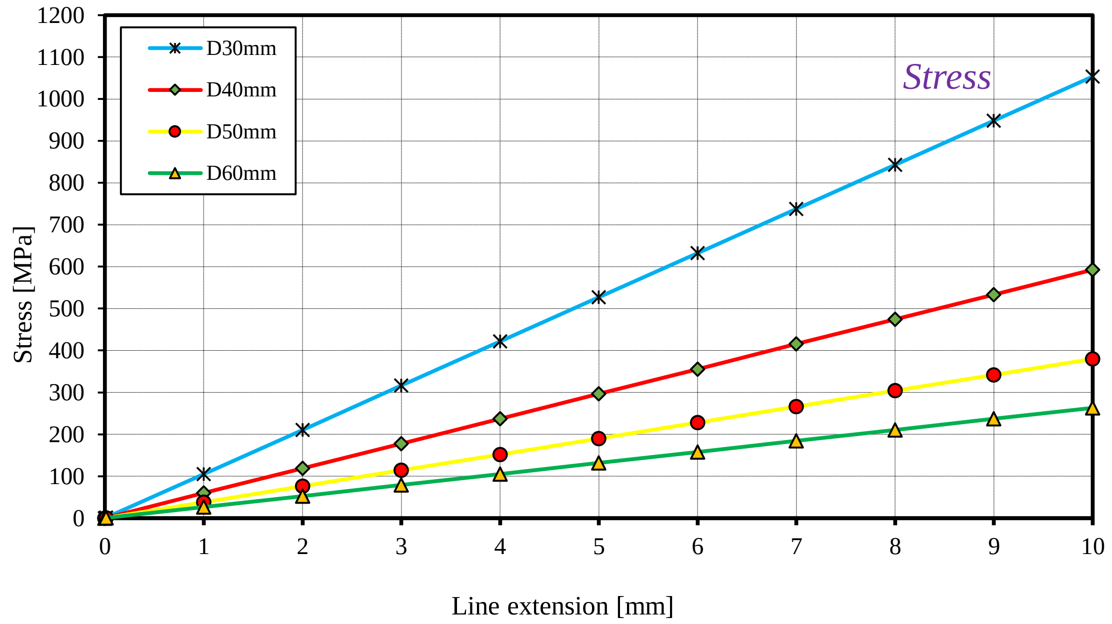
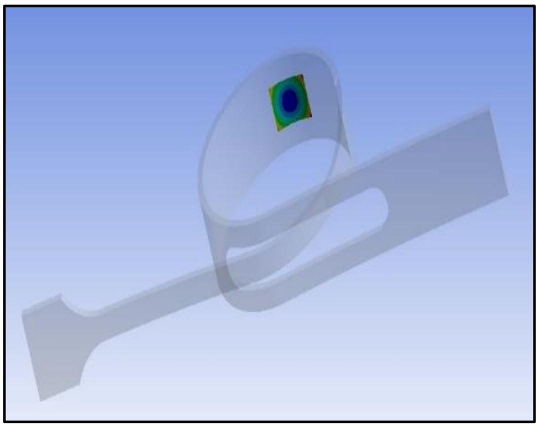
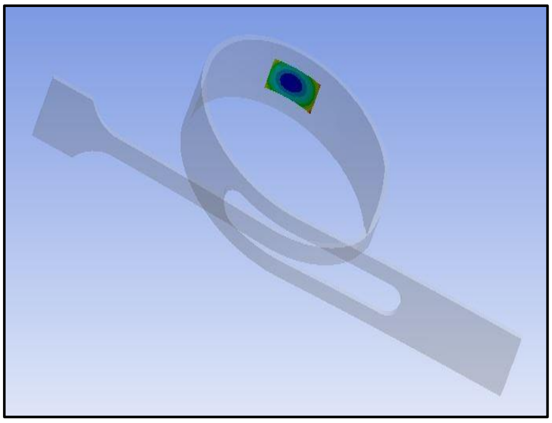


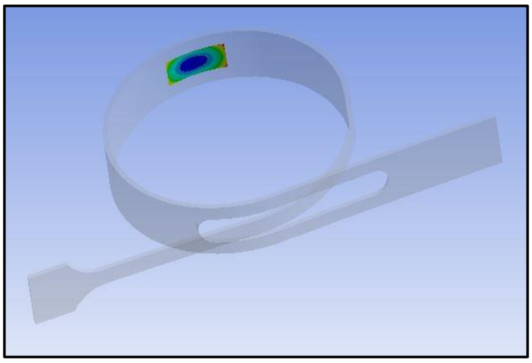
Figure 4.6 Stress vs line extension



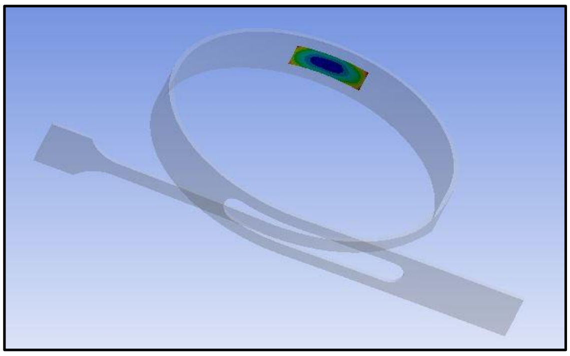
Model 1



Model 2



Model 3



Model 4

Figure 4.7 Von meshes stress FEM of the models

Any among the selected CLDs 1, 2, 3 and 4 fulfills the required stiffness margin $k_o \leq 9$ N/mm as shown in Figure 4.8 and table 4.3. The next parameter to verify was maximal stress, achieved in the spring by its full line extension. This parameter was important in order to induce redundant signal on the strain gauge, incorporated in CLD. Diagram, Figure 4.6 shows the proportion between introduced line extensions vs. stress created at the point of the bonded strain gauge. Springs are exposed up to the yield strength of the spring steel, $\sigma_{0.2}$ = 1080 Mpa, or up to the absolute line extension of 10 mm.

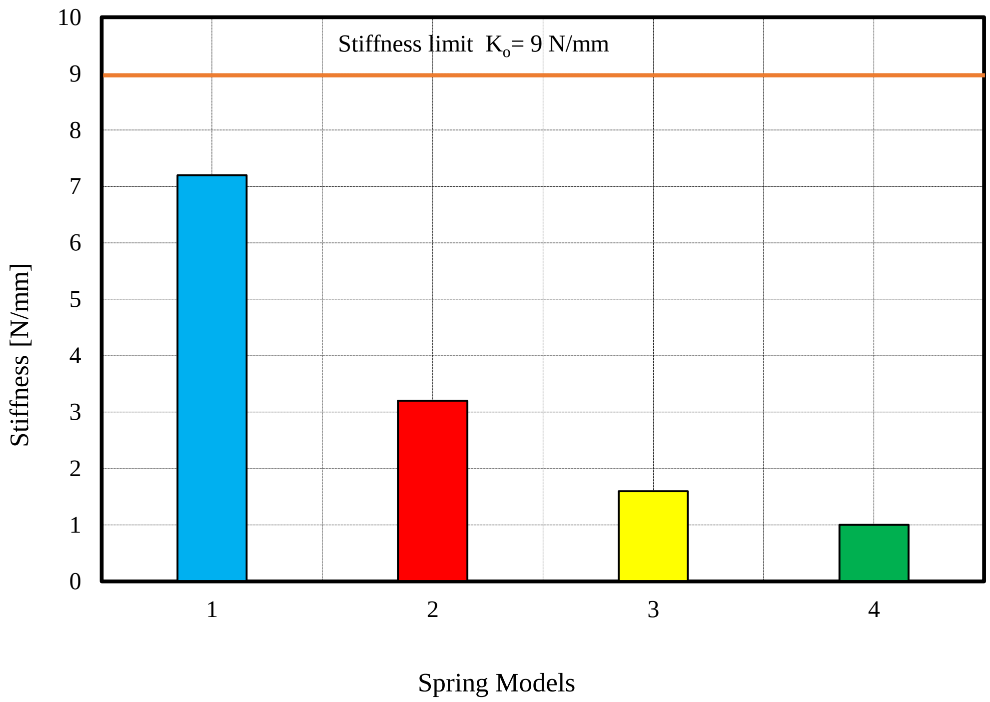


Figure 4.8 springs models vs. Stiffness

Except the spring no. 1, all other springs are far from the critical margin σ_{max} < 1080 MPa at the rate of 10 mm extension Figure 4.8. If mutually compared, the stresses on the strain gauges of virtual springs are very close, that is, neither spring is prominent by the signal intensity. From an operational point of view, a measurement resolution of 4.064×10^{-6} MV/V, which corresponds to 0.4Mpa strain, depicts an acceptable sensitivity threshold of the strain gauge. Therefore spring no. 3 and 4 doesn't satisfy this criterion Figure 4.10.

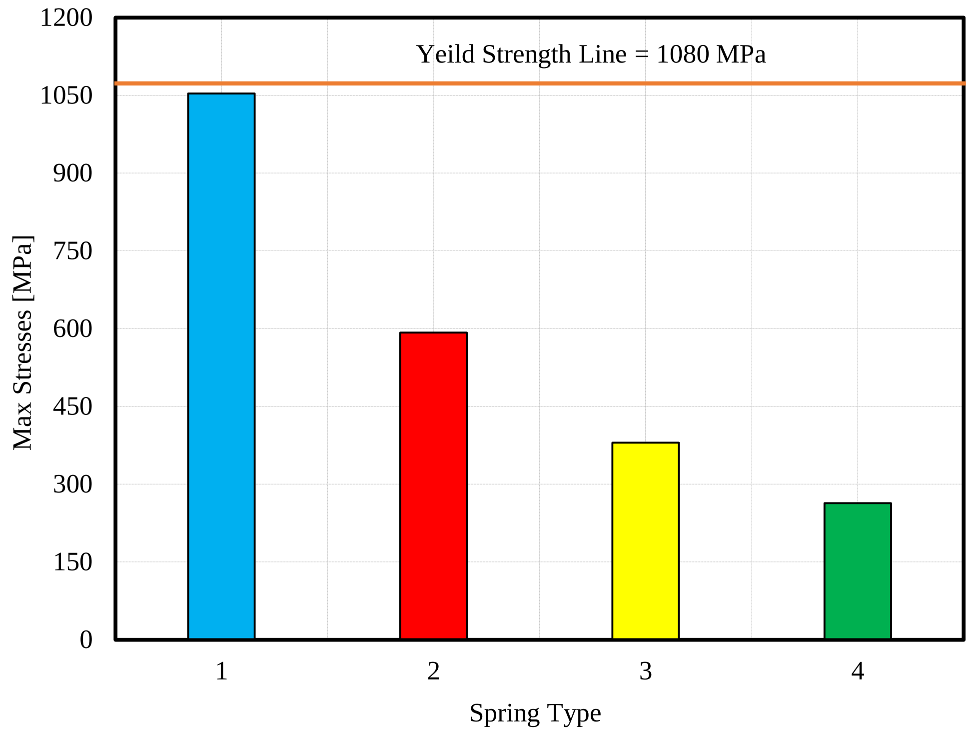


Figure 4.9 Maximum Stress on CLDs

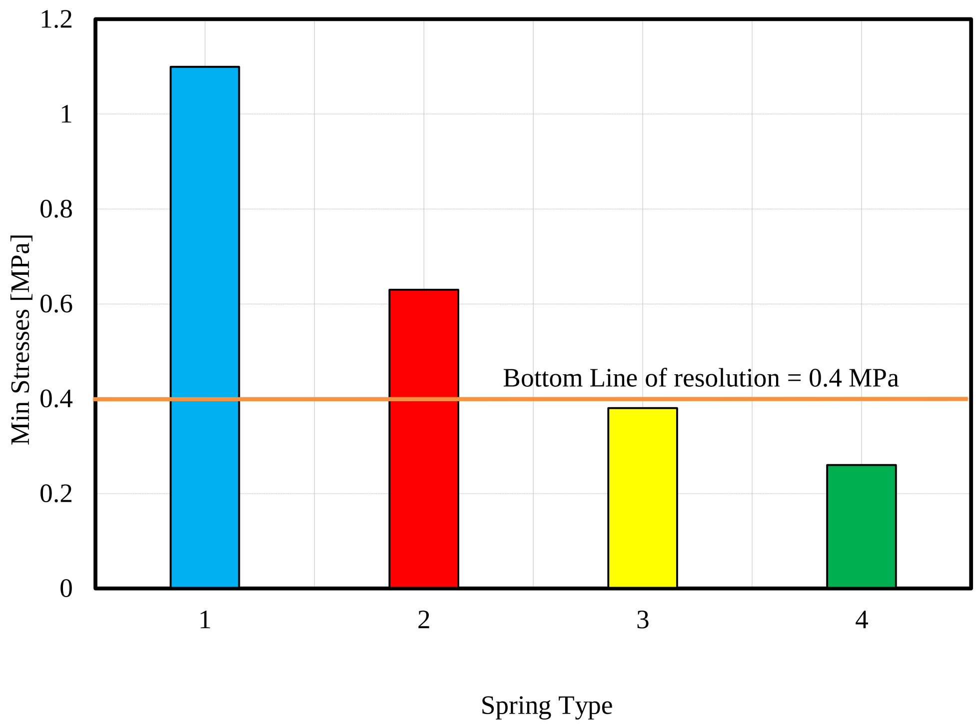


Figure 4.10 Bottom line of resolution

Further on, virtual testing in ANSYS [9, 10] was oriented to the spring 2 model, which is both resilient in the sense of measurement sensitivity and strong enough to resist possible overload.

Based on this preliminary analysis and stated arguments further virtual testing was oriented to just one model, NO 2.

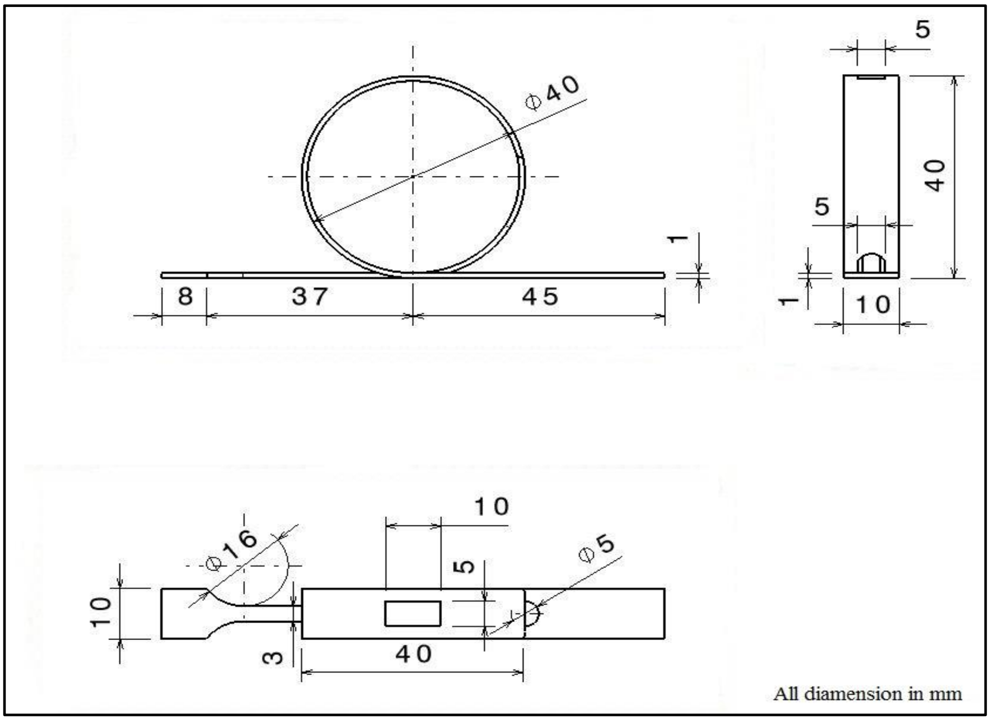


Figure 4.11 Model 2 dimension

4.5 Virtual experiment of CLD with simple beam

Virtual experiment is defined in such a manner that the CLD is placed on a simple beam, (cross-section square profile 30x30 mm, with 2 mm wall thickness) of a total length L = 4m, between supporting points. In the mid-span of the square beam, a virtual Strain gauge is fixed and above it a CLD. The static performance of the design is evaluated using static structural FEA. The simulations are carried out by applying an input force to produce stress. This set was loaded by a consecutively increasing force ranging from 10 to 200N.

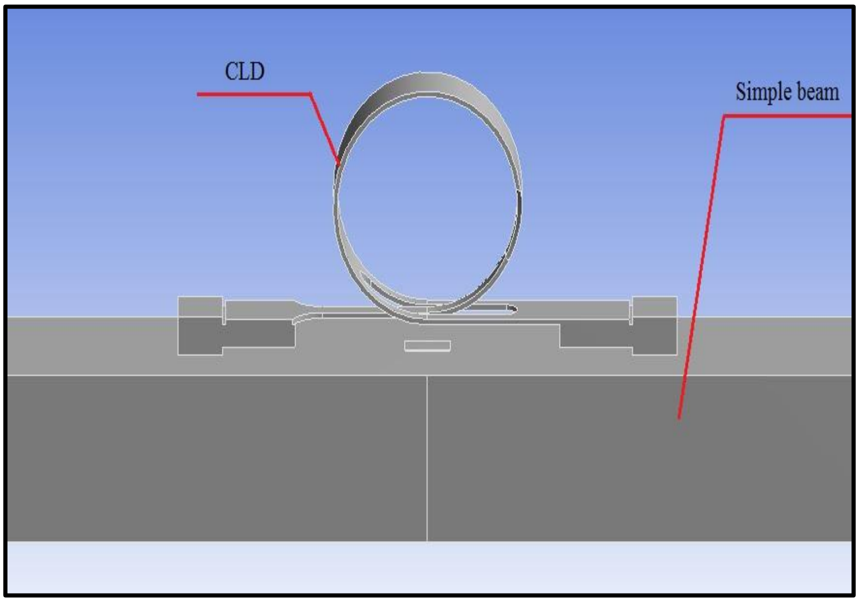


Figure 4.12 CLD and simple beam assembly

4.5.1 Mesh generation on CLD with beam

In this analysis mesh generation is the auto gerenration by the ANSYS software [9] [10], after that sizing of 0.2mm was given to the mid span beam and CLD. Tetrahedral 10-noded (sloid 187-3D) elements were used to the middel beam and CLD. Meshing generally falls in two categories depending on the geometry of the element. For a 3D machine element of regular shape, solid meshing is sufficient, but for irregular geometries we have to first use surface meshing and then solid meshing. The Tetrahedral 10-noded (sloid 187-3D) meshing was created using the imported CAD geometry. This was undertaken by using either manual or auto meshing techniques. Once the mesh has been created it is checked for free edge duplicates and normal. The element quality is also checked for aspect ratio, wrap angle, skew angle and taper. Once assured with a safe and sound surface meshing our next step is to import the model in ANSYS for solid meshing [12] [13].

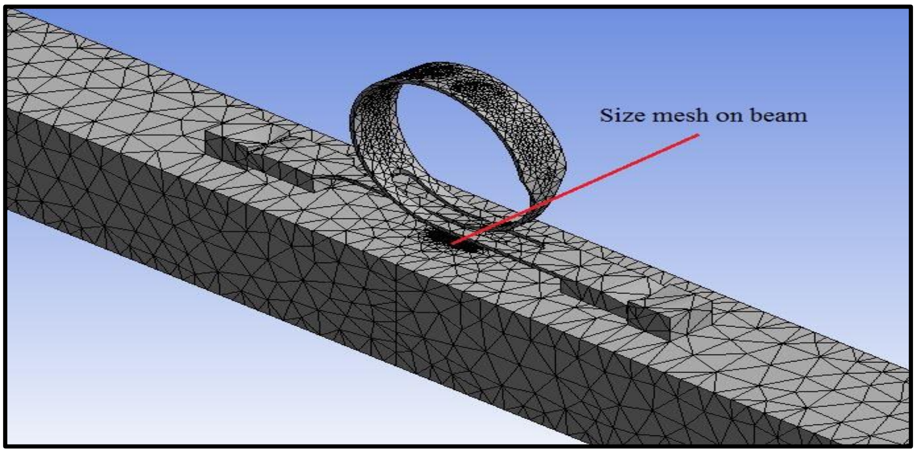


Figure 4.13 Sizing mesh on beam

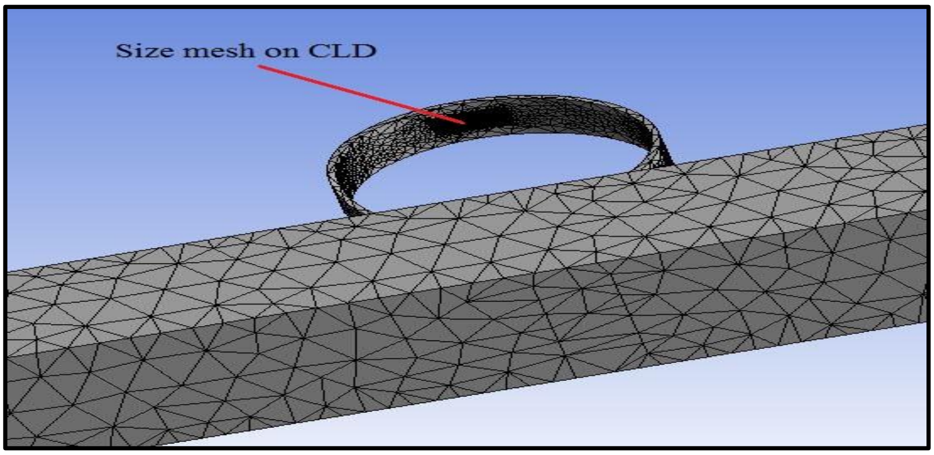
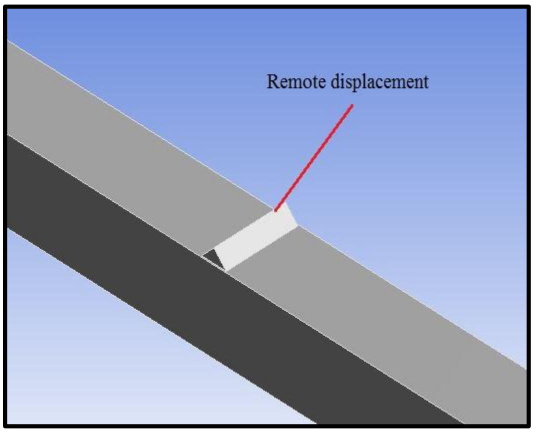


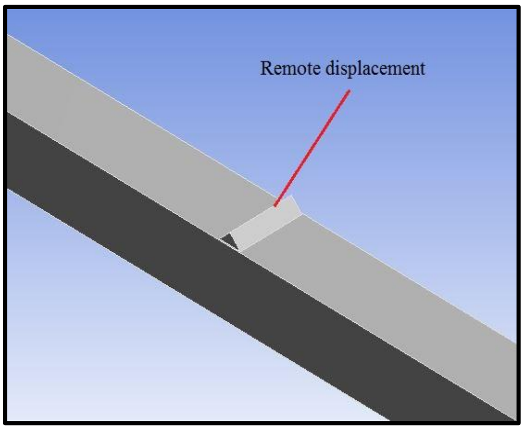
Figure 4.14 Sizing mesh on CLD

4.5.2 Boundary conditions on CLD with beam

The boundary condition was applied as remote displacement at two edges on a simple beam as shown in figure 4.15, and the applied force was concentrated in the mid of the beam as shown in figure 4.16. The boundary conditions are applied to the beam model as shown in figure 3.14, two side remote displacement, free at x-axis, 0 at y & z axsis, rotation 0 at x & 0 at y-axsis & free at z axsis.

The load was set by a consecutively increasing force ranging from 10 to 200N as shown in figure 4.16.





Simple beam –x-axsis   Simple beam +x-axsis

Figure 4.15 Boundary condition on simple beam

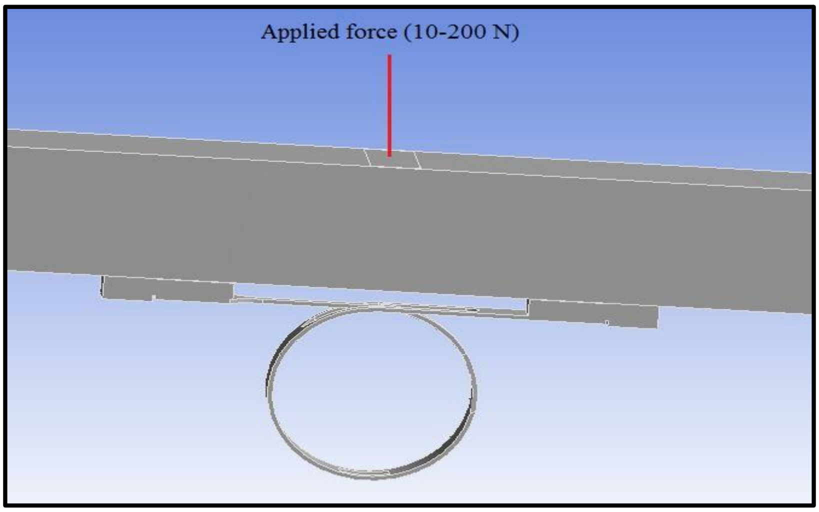


Figure 4.16 Applied forces on simple beam

4.5.3 Static structure analysis

The behavior of structure under static loading can be analyzed be employing different types of element within ANSYS [9] [10]. The nature of the structure dictates the type elements utilized in the analysis. Discrete or formed structure is suitable for modeling with rod- and beam- type elements. However, the modeling of continuous structure, usually requires a three-dimensional model with solid elements.

Under certain types of loading and geometric conditions, the three-dimensional type analysis can be analytically reduced to a two-dimensional analysis. If the component is subjected to in plane loading only and its thickness is small with respect to the other length dimensions, it is idealized as a plane stress condition. If the component with a uniform cross section is long in the depth direction and is subjected to a uniform loading along the depth direction, it is idealized as a plane strain condition. If the component has a circular cross section and is subjected to uniform and concentric loading, it can be considered as axisymmetric. If thin structural components are subjected to lateral loading, the plate and shell elements are suitable for analysis.

4.5.4 Equilibrium equations for linear static analysis

The overall equilibrium equations for linear structural static analysis are:

$$\left[\underset{\sim}{K}\right]\underset{\sim}{\vec{Q}} = \underset{\sim}{\vec{P}} \tag{4.1}$$

$$\left[\underset{\sim}{K}\right] = \sum_{e=1}^{E}\left[K^{(e)}\right] = assembled\ \ global\ \ stiffness\ \ matrix \tag{4.2}$$

$$\left[K^{(e)}\right] = \int_{V^{(e)}} [B]^T [D][B]\, dV \tag{4.3}$$

$[B]$- Strain-displacement matrix.

$[D]$- Elasticity matrix.

4.5.5 Formulation of finite element equation (static analysis)

The nodal degree of freedom is treated as unknowns in the present displacement formulation. The potential energy π_p has to be first expressed in terms of nodal degree of freedom [14]. After that the equilibrium equations can be by setting the first partial derivatives of π_p with respect to each of the nodal degrees of freedom equal to zero. The various steps involved in the derivation of equilibrium equations are given below:-

Step1: The solid body divided into E finite elements.

Step2: The displacement model within an element "e" is assumed as

$$\vec{U} = \begin{Bmatrix} u(x.y.z) \\ v(x.y.z) \\ w(x.y.z) \end{Bmatrix} = [N]\vec{Q}^{(e)} \tag{4.4}$$

Where $\vec{Q}^{(e)}$ Is the vector of nodal displacement degrees of freedom of the element, and $[N]$ is the shape function [14].

Step3: The element characteristic (stiffness) matrices and characteristic load factors are to be derived from the principle of minimum potential energy. The potential energy function of the body π_p is written as by considering the body and surface force.

$$\pi_p = \sum_{e=1}^{E} \pi_p^{(e)}$$

Where $\pi_p^{(e)}$ Is the potential energy of element e.

$$\pi_p^{(e)} = \frac{1}{2} \iiint_{V^{(e)}} \vec{\varepsilon}^T \, [D](\vec{\varepsilon} - 2\vec{\varepsilon_o})dV - \iint_{S_1^e} \vec{U}^T \, \vec{\Phi} \, dS_1 - \iiint_{V^{(e)}} \vec{U}^T \, \vec{\phi} \, dV \tag{4.5}$$

Where $V^{(e)}$ -is the volume of the element, S_1^e is the portion of the surface of the element over which distributed surface forces, and $\vec{\phi}$ is the vector of body forces per unit volume.

The strain vector $\vec{\varepsilon}$ appearing in equation (4.5) can be expressed in terms of the nodal displacement vector $\vec{Q}^{(e)}$ by differentiating equation (4.4)

$$\vec{\varepsilon} = \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{zz} \\ \varepsilon_{xy} \\ \varepsilon_{yz} \\ \varepsilon_{zx} \end{Bmatrix} = \begin{Bmatrix} \frac{\partial u}{\partial x} \\ \frac{\partial v}{\partial y} \\ \frac{\partial w}{\partial z} \\ \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \\ \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} \\ \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} \end{Bmatrix} = \begin{bmatrix} \frac{\partial}{\partial x} & 0 & 0 \\ 0 & \frac{\partial y}{\partial y} & 0 \\ 0 & 0 & \frac{\partial}{\partial z} \\ \frac{\partial}{\partial y} & \frac{\partial}{\partial y} & 0 \\ 0 & \frac{\partial}{\partial z} & \frac{\partial}{\partial y} \\ \frac{\partial}{\partial z} & 0 & \frac{\partial}{\partial x} \end{bmatrix} \begin{Bmatrix} u \\ v \\ w \end{Bmatrix} = [B]\vec{Q}^{(e)} \tag{4.6}$$

Where

$$[B] = \begin{bmatrix} \frac{\partial}{\partial x} & 0 & 0 \\ 0 & \frac{\partial}{\partial y} & 0 \\ 0 & 0 & \frac{\partial}{\partial z} \\ \frac{\partial}{\partial y} & \frac{\partial}{\partial x} & 0 \\ 0 & \frac{\partial}{\partial z} & \frac{\partial}{\partial y} \\ \frac{\partial}{\partial z} & 0 & \frac{\partial}{\partial x} \end{bmatrix}$$

$$\vec{\sigma}^{(e)} = [D](\vec{\varepsilon} - \vec{\varepsilon}_o) = [D][B]\vec{Q}^{(e)} - [D]\vec{\varepsilon}_o \tag{4.7}$$

Substitution equations (4.4) and (4.6) into equation (4.5) yields the potential energy of the element as

$$\pi_p^{(e)} = \frac{1}{2}\iiint_{V(e)} \vec{Q}^{(e)^T} [B\ ]^T\ [D]\ [B]\ \vec{Q}^{(e)}\ dV - \iiint_{V^{(e)}} \vec{Q}^{(e)^T}\ [B]^T\ [D]\ \vec{\varepsilon}_o\ dV - \iint_{S_1^{(e)}} \vec{Q}^{(e)^T}\ [N]^T\ \vec{\Phi}\ dS_1 - \iiint_{S_1^{(e)}} \vec{Q}^{(e)^T}\ [N]^T\ \vec{\phi}\ dV \tag{4.8}$$

In equations (4.5) and (4.8), only the body and surface forces considered. However, generally some external concentered forces will be also be acting at various nodes. If $\underset{\sim c}{\vec{P}}$ denotes the vectors of nodal forces acting in the directions of the nodal displacement, vector $\underset{\sim}{\vec{Q}}$ of the total structure or body. The total potential energy of the structure can be expressed as

$$\pi_p = \sum_{e=1}^{E} \pi_P^{(e)} - \underset{\sim}{\vec{Q}}^T \underset{\sim c}{\vec{P}} \tag{3.9}$$

Where $\underset{\sim}{\vec{Q}} = \begin{Bmatrix} Q_1 \\ Q_2 \\ . \\ . \\ . \\ Q_M \end{Bmatrix}$ *is the vector of nodal displacements of the entire structure.*

M is the total number of nodal displacement.

The summation of equation (4.8) and (4.9) give

$$\pi_p = \frac{1}{2} \underset{\sim}{\vec{Q}}^T \left[\sum_{e=1}^{E} \iiint_{V(e)} [B]^T [D][B] dV \right] \underset{\sim}{\vec{Q}} - \underset{\sim}{\vec{Q}}^T \sum_{e=1}^{E} \left(\iiint_{V^{(e)}} [B]^T [D] \vec{\varepsilon}_o \, dV + \iint_{S_1^{(e)}} [N]^T \vec{\Phi S_1} + \iiint_{V^{(e)}} [N]^T \vec{\phi} \, dV \right) - \underset{\sim}{\vec{Q}}^T \underset{\sim c}{\vec{P}} \tag{4.10}$$

The equation expresses the total potential energy of the structure in terms of the nodal degrees of freedom $\underset{\sim}{\vec{Q}}$. The static equilibrium configuration of the structures can be found by solving the following necessary conditions for minimization of potential energy [14].

$$\frac{\partial \pi_p}{\partial \underset{\sim}{\vec{Q}}} = 0 \, or \, \frac{\partial \pi_p}{\partial Q_1} = \frac{\partial \pi_p}{\partial Q_2} = \cdots = \frac{\partial \pi_p}{\partial M} = 0 \tag{4.11}$$

With the help of equation (3.10) and equation (3.11) cab be expressed as

$$\underbrace{\left(\sum_{e-1}^{E} \underbrace{\iiint_{V^{(e)}} [B]^T [D][B] dV}_{element stiffness matrix [K^{(e)}]}\right)}_{global or overall stiffness matrix of the structure [K]} \underbrace{\underset{\sim}{\vec{Q}}}_{global vector of nodal displacements} =$$

$$\underbrace{\underset{\sim c}{\vec{p}}}_{vector concentrated loads} + \sum_{e=1}^{E} \left(\underbrace{\iiint_{V^{(e)}} [B]^T [D] \vec{\varepsilon}_o \, dV}_{vector of element nodal forces produced by initial stains \vec{p}_i^{(e)}} + \underbrace{\iint_{S_1^{(e)}} [N]^T \vec{\Phi} \, dS_1}_{vector of element nodal forces produced by surface forces \vec{p}_s^{(e)}} + \underbrace{\iiint_{V^{(e)}} [N]^T \vec{\phi} \, dV}_{vector of element nodal forces produced by body forces \vec{p}_b^{(e)}} \right) \tag{4.12}$$

That is,

$$\left(\sum_{e=1}^{E} \left[K^e\right]\right) \underset{\sim}{\vec{Q}} = \underset{\sim c}{\vec{P}} + \sum_{e=1}^{E} \left(\vec{P}_i^{(e)} + \vec{P}_s^{(e)} + \vec{P}_b^{(e)}\right) = \underset{\sim}{\vec{P}} \tag{4.13}$$

Where

$$\left[K^{(e)}\right] = \iiint_{V^{(e)}} [B]^T [D][B] dV = element \;\; stiffness \;\; matrix \tag{4.14}$$

$$\vec{P}_i^{(e)} = \iiint_{V^{(e)}} [B]^T [D] \vec{\varepsilon}_o \, dV = elemnet \;\; load \;\; vector \;\; due \; to \; initial \;\; strains \tag{4.15}$$

$$\vec{P}_s^{(e)} = \iint_{S_1^{(e)}} [N]^T \vec{\Phi} \, dS = element \;\; load \;\; vector \;\; due \;\; to \;\; surface \;\; forces \tag{4.16}$$

$$\vec{P}_b^{(e)} = \iiint_{V^{(e)}} [N]^T \vec{\phi}\, dV = element\ load\ vector\ dut\ to\ body\ forces \quad (4.17)$$

The load vectors $\vec{P}_i^{(e)}, \vec{P}_s^{(e)}$ and $\vec{P}_b^{(e)}$ given in equation (4.15)-(4.17) are called kinematically consistent nodal vector [15]. Some of components of $\vec{P}_i^{(e)}$, $\vec{P}_s^{(e)}$ and $\vec{P}_b^{(e)}$ may be moments or even higher order quantities if the corresponding nodal displacements represent strains or curvatures. These load vectors are called kinematically consistent because they satisfy the virtual work (or energy) equation [24].

Step 4: The desired equilibrium equation of the overall structure or body expressed in equation (4.13).

$$\left[\underset{\sim}{K}\right]\vec{\underset{\sim}{Q}} = \vec{\underset{\sim}{P}} \quad (4.18)$$

Where

$$\left[\underset{\sim}{K}\right] = \sum_{e=1}^{E}\left[K^{(e)}\right] = assembled\ globle\ stiffness\ matrix \quad (4.19)$$

And

$$\vec{\underset{\sim}{P}} = \vec{\underset{\sim c}{P}} + \sum_{e=1}^{E}\vec{P}_i^{(e)} + \sum_{e=1}^{E}\vec{P}_s^{(e)} + \sum_{e=1}^{E}\vec{P}_s^{(e)} = assembled\ nodal\ load\ vector \quad (4.20)$$

Step 5 and 6: The solution for the nodal displacements and element stresses can be obtained after solving equation (4.1).

The following observation can be made from the derivation:

1. The formulation of element stiffness matrices. $\left[K^{(e)}\right]$. And element load vectors, $\vec{P}_i^{(e)}$, $\vec{P}_s^{(e)}$ and $\vec{P}_b^{(e)}$ which is basic to the finite element equations (4.1) requires integration to indicate in equations (4.14)-(4.17).

2. Formulate for the element stiffness and load vector in equations (4.14)-(4.17) remain the same irrespective of the type of element. However the orders of the stiffness matrix and load vector will change for different types of elements.

3. The element stiffness matrix given by equation (4.14) the assembled stiffness matrix given by (4.19) is always symmetric. In fact the matrix $[D]$ and the product $[B]^T[D][B]$ appearing in equation (4.2) are also symmetric [25] [26] [27].

4.5.6 Stress analysis

The stress results were calculated by ANSYS [9] [10] software package.
The normal stress in the simple beam is shown in figure 4.17 were calculated from simulation.

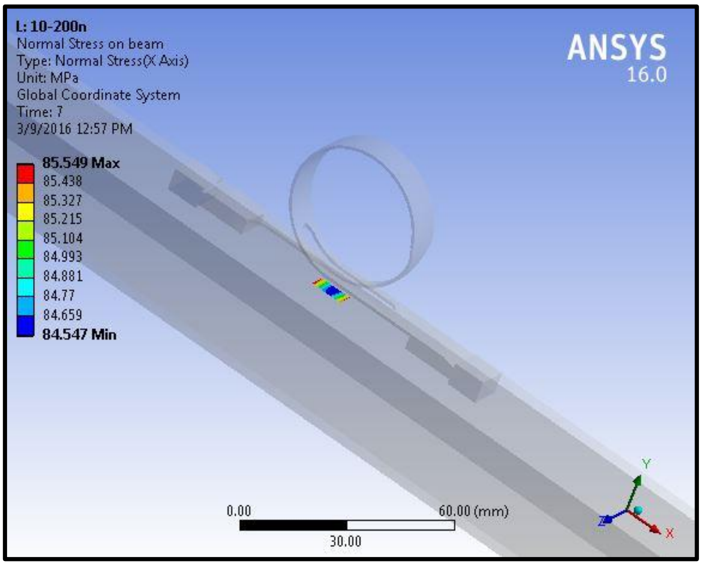


Figure 4.17 Normal stress on Beam

The normal stress results on CLD is shown in figure 4.18.

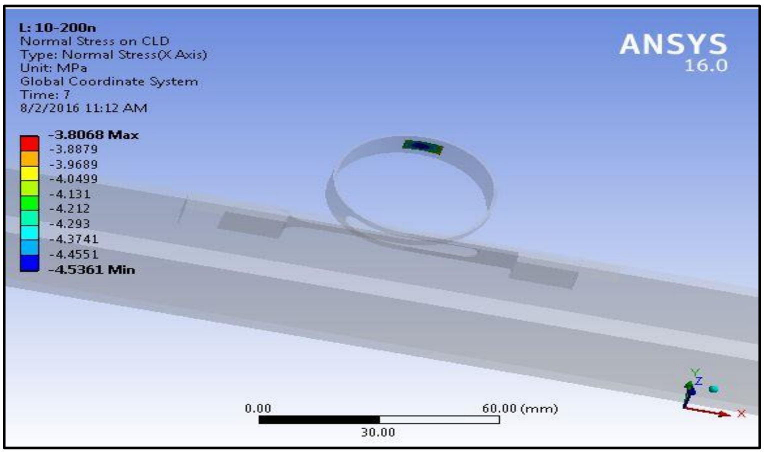


Figure 4.18 Normal stress on CLD

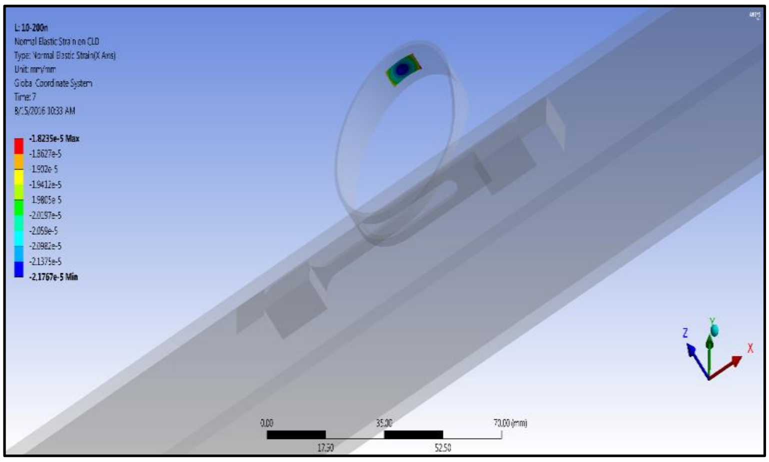


Figure 4.19 Maximum and minimum normal elastic strain on CLD

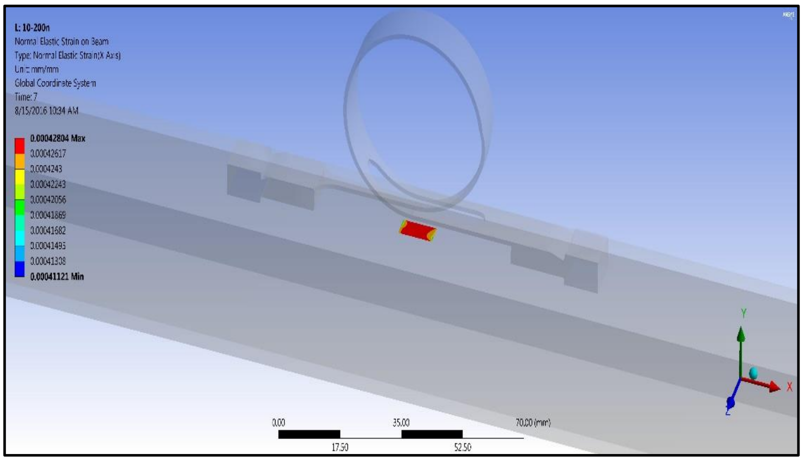


Figure 4.20 Maximum and minimum normal elastic strain on Beam

Table 4.5 Force Vs Stress on CLD & BEAM

Force [N]	Stress on **CLD** [Mpa]	Stress on beam **SG** [Mpa]
0	0	0
10	0.21318	4.2826
25	0.53295	10.707
50	1.0659	21.413
75	1.5989	32.12
100	2.1318	42.826
150	3.1977	64.239
200	4.2636	85.549

Figure 4.21 presents the results, read from the virtual Strain gauge on the beam (olive green line/ orange circle) and the virtual strain gauge on the CLD (blue line/ red square). At this point we are going to define a coefficient, which determines the relation between two graph lines (red and blue, Figure 4.21. That is actually a kind of Virtual Rectification Quotient (VRQ). Over the range of applied load simulation on the spring NO. 2, average value is equal VRQ = 20.10. Yellow line (green triangles) in the diagram, Figure 4.21 indicates the induced stress, rectified by VRQ. This virtual study proves a perfect compliance between originally measured stresses on the beam and ones detected by CLD.

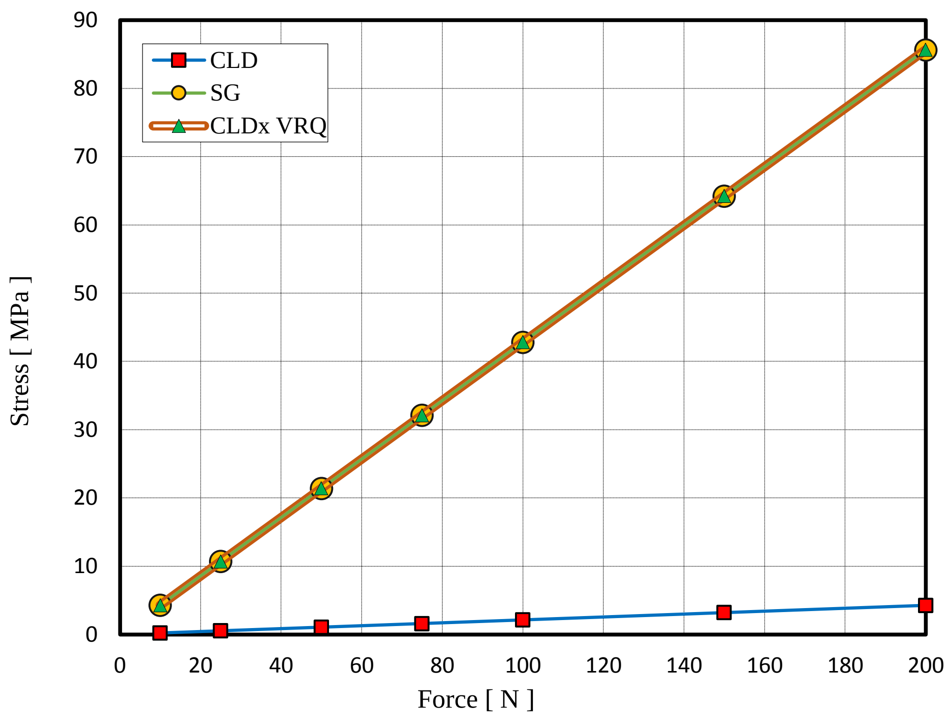


Figure 4.21 Stress Results by Force Applied

CHAPTER 5

5 Lab Measeurment

Having the virtual examination finished, a real CLD design is finalized in CATIA [7] and the prototype is manufactured, after spring 2 shape. Actual shape and dimension of the CLD is shown in the Figure 5.1.

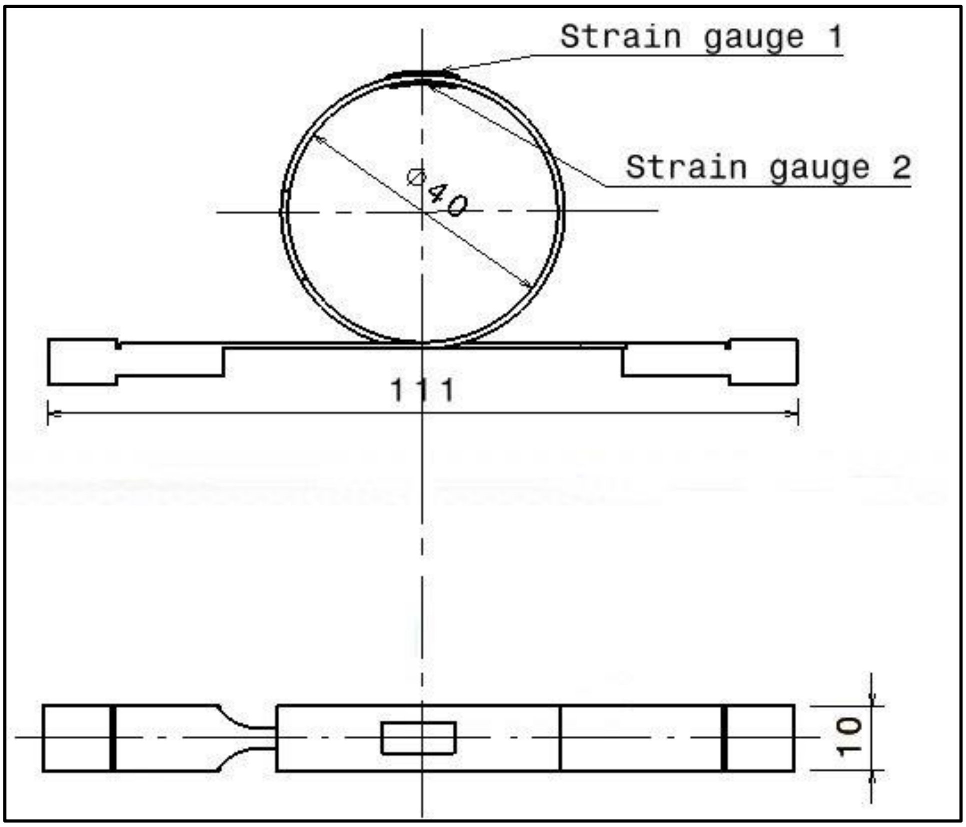


Figure 5.1 CLD design

CLD item is made of a spring steel. In order to simplify its fixing to the structure, at each end of CLD there is a mounting foot. For the Lab testing, a simple beam, of the same form as in a virtual 3D modeling is used. It is a steel made square profile, cross-section (30 × 30 mm/wall thickness 2mm), length L= 4 m. In the mid-span of the beam, a strain gauge pair is mounted (one active and one temp. ompensating strain gauge), configured as a half-bridge. Right above the active strain gauge, a CLD is fixed to the steel beam Figure 5.2.

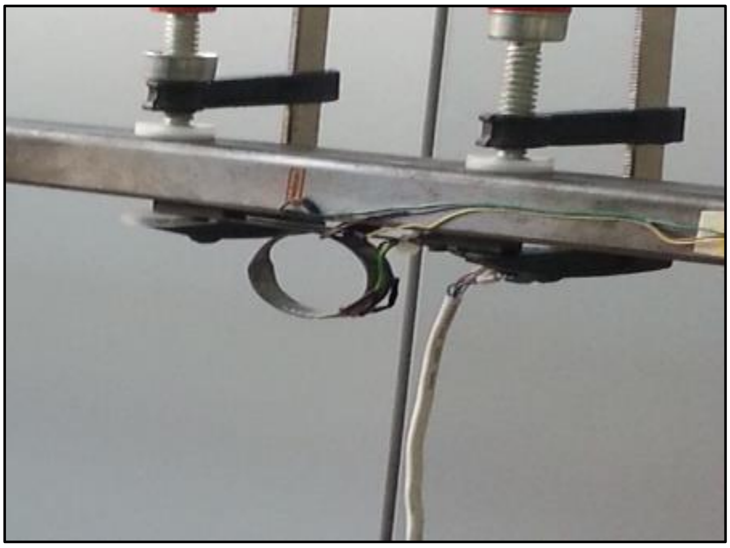


Figure 5.2 Set of Beam and CLD

5.1 Strain gauge setup

The surface of the beam and CLD are first cleaned with emery paper and solvent such as alcohol or acetone. The next step use scotch tape is used to position the gauges over the beam by allowing one end of the tape to stick. A small amount of adhesive is applied to the underside of the strain gauge. As well a small amount of glue is placed in the beam, surfaces are to be held tightly together for 2 minutes. Signal wires on each strain gauges are soldered and firmely fixed. Strain gauges are connected to the Dyna-Log instrument as shown in figure 5.5.

5.1.1 Soldering devices

The best and by far the most popular type of electrical connection between strain gages and measurement leads is soldering [16]. Similar excellent results can be obtained with crimp techniques, i.e. pressed connections. Screw terminal connections can cause changes in zero stability due to varying joint resistances. Temperature controlled, low voltage soldering irons, which are supplied from the line through a control unit, are recommended. Models with a fine, continuous electronic control and a high heating capacity of about 50W are preferred, because heat extracted from the point of the soldering iron is replaced immediately. The temperature control region for normally available soldering stations is between 120°C and 400°C; this is sufficient for the soft solders employed in strain gage techniques.

5.1.2 Lead material

The success of the measurement depends on the choice of the correct connecting leads and test cable, i.e. one suitable for the specific application. They should not only transfer the measuring signals between the link in a measurement system, i.e. transducer – amplifier – output, but they should also restrict interference signals to a minimum and resist operational stresses and the effects of environmental condition [16].

It is important that the core insulation has a high value which should not change significantly due to temperature, moisture, etc. When the half and full bridge circuits are connected, much depends on the symmetry of neighboring arms of the bridge with regard both to the resistance and also the cable capacitance between the cores. The cable covering should protect against external effects and should be resistant against moisture, water, oil, chemicals, both high and low temperatures and mechanical loading.

5.1.3 Methods of testing

Every strain gauge measurement should be checked for correct mounting and other important features measurement are made. Visual and electrical tests should be carried out [16].

5.1.3.1 Visual inspection

As an aid for checking purpose, a magnifying glass, giving about 6x enlargements is sufficient. Faults in the strain gauge bonding can be found in this way, such as for example:

- Air bubble under the strain gauge.
- Badly bonded edges.
- Unreliable solder connections.
- Flux residues.
- Positioning errors.

5.1.3.2 Electrical continuity

A good ohmmeter is sufficient with which the strain gauge resistance can be measured with an error of < ¼ %. The test should show whether the gauge resistance has altered as a result of improper mounting. Ohmmeter with a resolution down to 0.1 Ω are also suitable for use prior to mounting for finding a strain gauge correct resistance [16].

5.1.3.3 Insulation resistance

For the measurement of the insulation resistance between the gauge and the test object and between the cores of the cable and the screening instrument with a test voltage below 50 V and with a measurement range up to 20,000 MΩ or more are suitable [16].

5.2 Protection of the measuring point

Strain gauge measuring point must be protected against mechanical or chemical damage. Even under ideal conditions, e.g. in the laboratory, the characteristics of the measuring point would be influenced in the course of time if suitable countermeasures were not taken. The measures used to protect measuring points are as widely varied as the different influences on the strain gauge. In the laboratory where there is uniform dry air, light protection against contact, i.e. moisture of the hand, is sufficient, whereas in the rough rolling mill the protection must cover steam, water, oil, heat and mechanical effect [16]. In the former case a simple coating of varnish is sufficient, but in the latter case a number of layers of different protective materials are used to form a barrier.

5.3 Lab test

Two active strain gauges are glued to the CLD, one on the outer and one on the inner side of the loop. For the stress calculation on CLD, the following formula is applied [17].

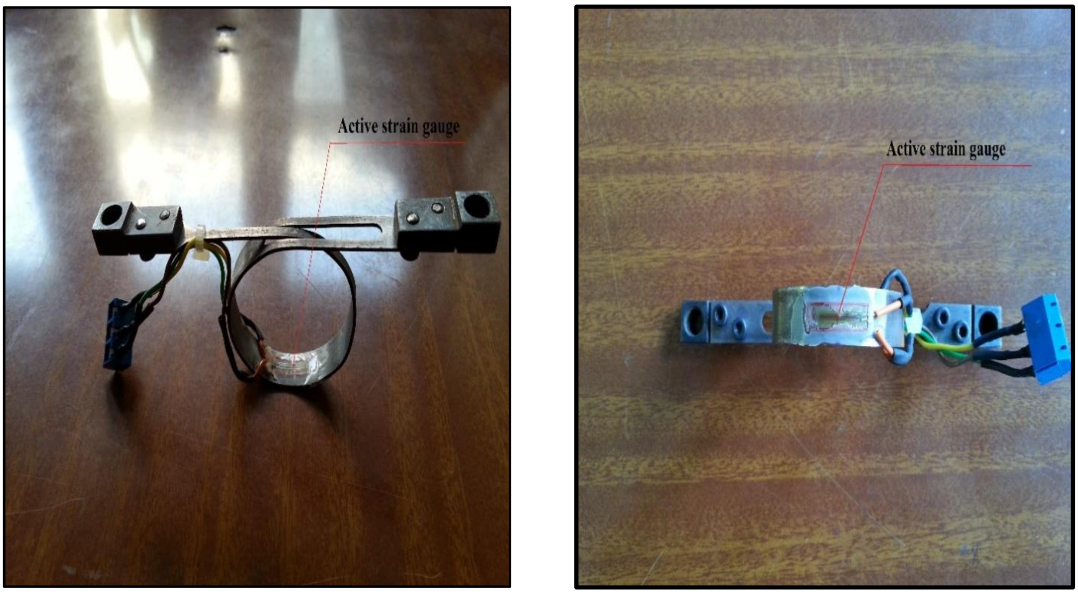


Figure 5.3 Two active stain gauges on CLD

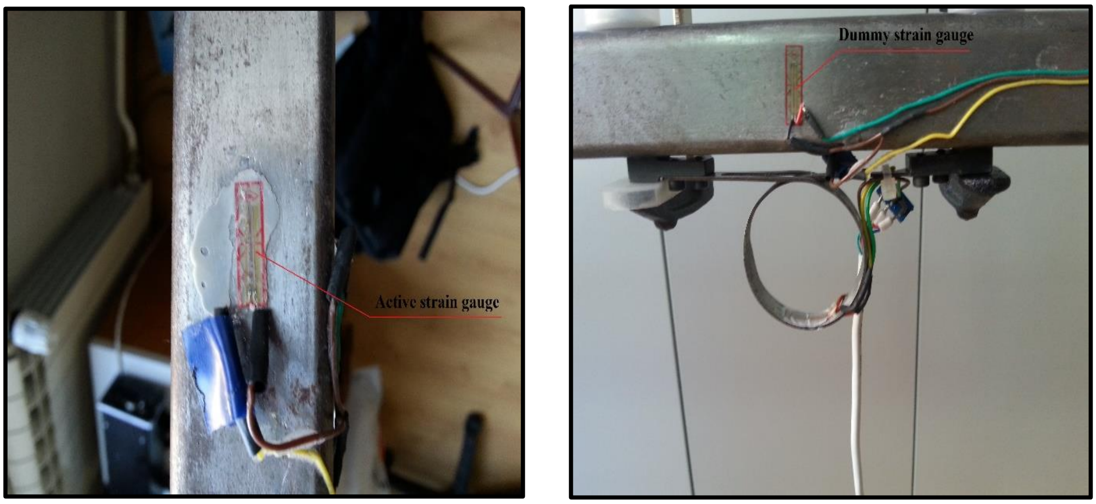


Figure 5.4 One active and one dummy strain gauges on the beam

$$\varepsilon = \frac{1}{B}\frac{4}{K}\frac{U_A}{U_E} \tag{5.1}$$

K is the gauge factor = 2.12, B is the bridge factor, U_A is the bridge output voltage, and U_E is the bridge input voltage.

The bridge factor = 2 for configuration with two active strain gauges. For the data acquisition a dedicated device, Dyna-Log instrument, RoTech (www.rotech.rs) make, was used. The device is a multi channel Data Logger, equipped with 16 bit resolution ADC Figure 5.5.

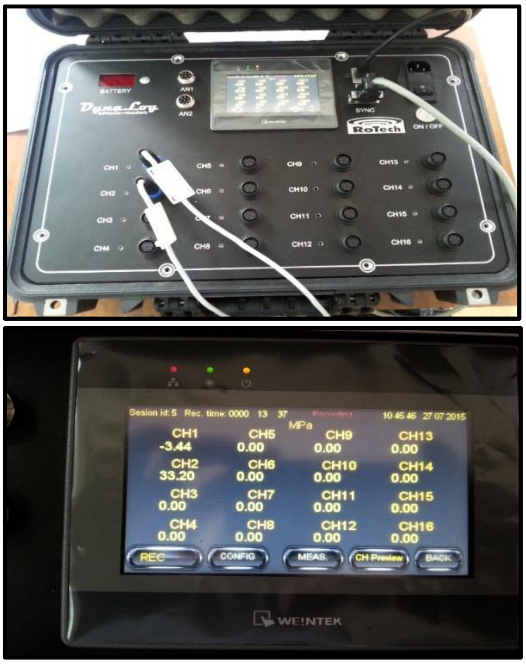


Figure 5.5 Dyna-Log Instrument

Since we didn't have the complete electronic circuit available integrate a microcontroller to the strain gauge. We use an acquisition device (Dyna-Log Instrument) to read the signal from the Wheatstone bridges. This device connected to a PC running windows we use the lab VIEW to collect the data. We built a VI (Virtual instrument) that can be calibrate signal by removing their offset when the strain gauge is at rest, and then display and collect the data of the two strain gauges.

Lab test is conceived in the same manner as the Virtual experiment. The size of the loading force was varied within the following range F1=7.56N; F2=15.25N; F3=23.02N; F4=30.88N; F5=46.35N. Placement of the weights is shown in the Figure 5.6. The steel beam is exposed to bending, induced by adding on lumped masses. As well a random load is applied to justify compliance between direct and CLD measurement Figure 5.6.

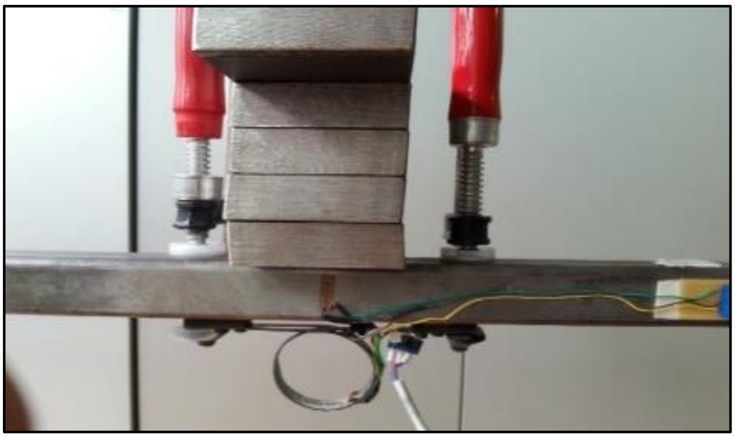


Figure 5.6 Weights Applied on Beam

After a series of repeated tests, it was determined experimentally that the Real Rectification Quotient (RRQ) of CLD is RRQ= 20.36. The outcome of the measurement is shown in the diagram Figure 4.12. Blue and red line present raw signals collected from the transducers. Light orange line depicts a rectified (RRQ= 20.36) output from CLD. Set of sampling points (range 1 - 45687), is generated by a stepping load. Correlation function was applied for the justification of signal compliance. The formula is:

$$Correl(x,y) = \frac{\sum (x - x^{-})(y - y^{-})}{\sqrt{\sum (x - x^{-})^2 . \sum (y - y^{-})^2}} \quad (5.2)$$

x = σ_{SG} –stress measured directly on the beam.

y = σ_{CLD}×RRQ –stress measured by CLD.

$x^{-} = \sum_{i=1}^{n} \frac{x_i}{n}$ – Average value of the σ_{SG}. (5.3)

$y^{-} = \sum_{i=1}^{n} \frac{y_i}{n}$ – Average value of the σ_{CLD} x RRQ. (5.4)

The degree of the correlation is:

Correl [σ_{SG}; σ_{CLD}× RRQ] = 0.99

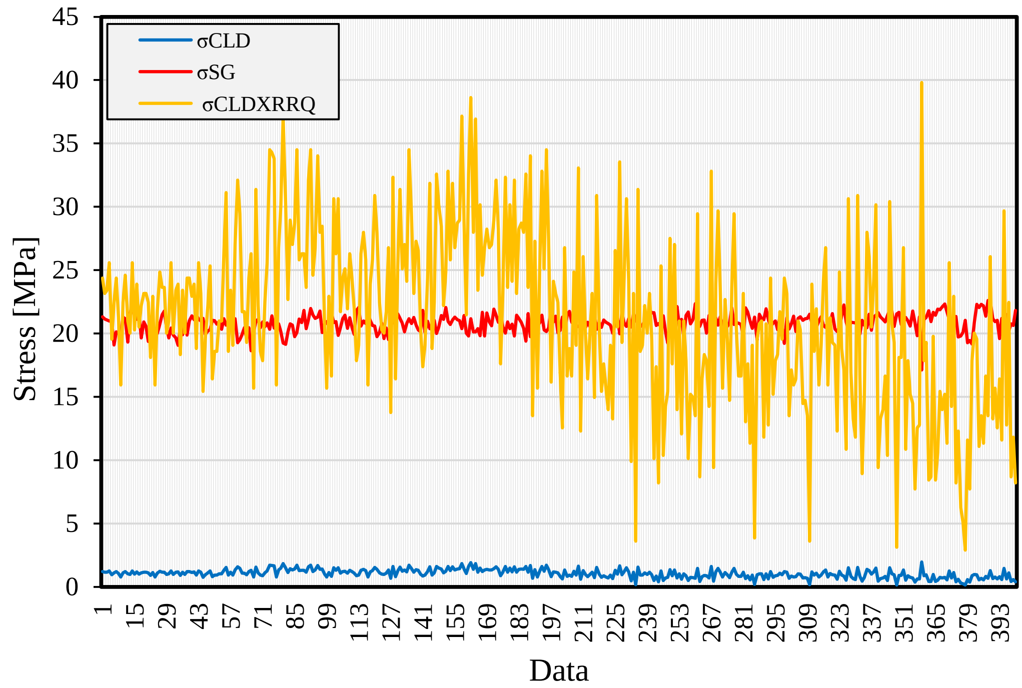


Figure 5.7 Comparison of SG and CLD Measurement at Force 7.56 N

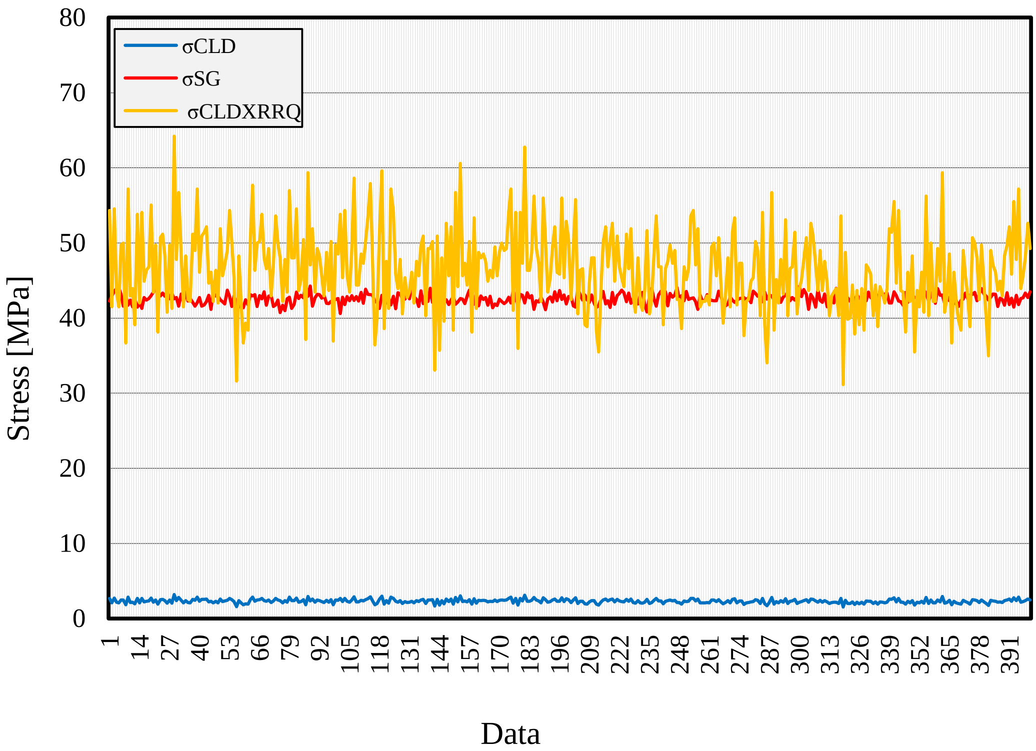


Figure 5.8 Comparison of SG and CLD Measurement at Force 15.25 N

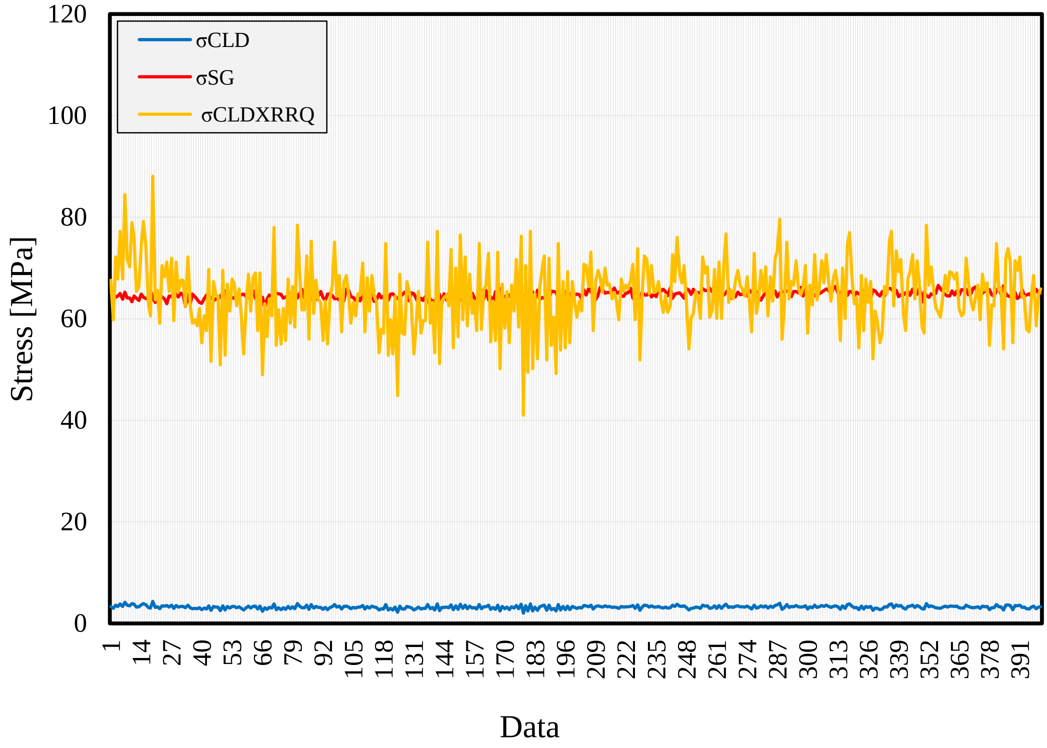


Figure 5.9 Comparison of SG and CLD Measurement at Force 23.02 N

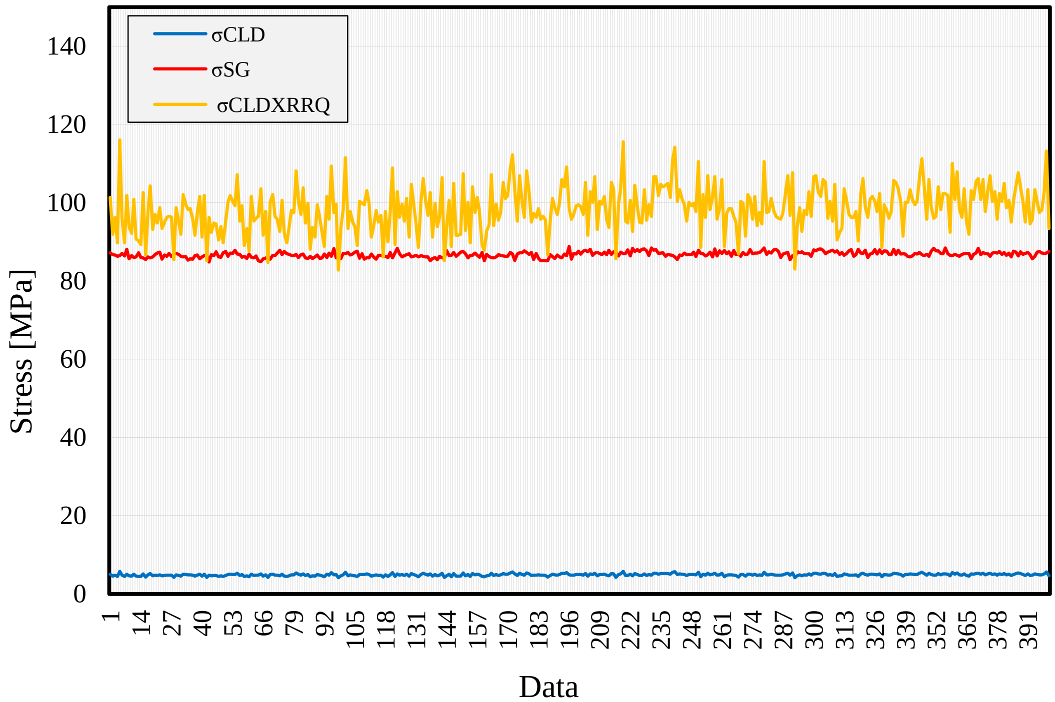


Figure 5.10 Comparison of SG and CLD Measurement at Force 30.88 N

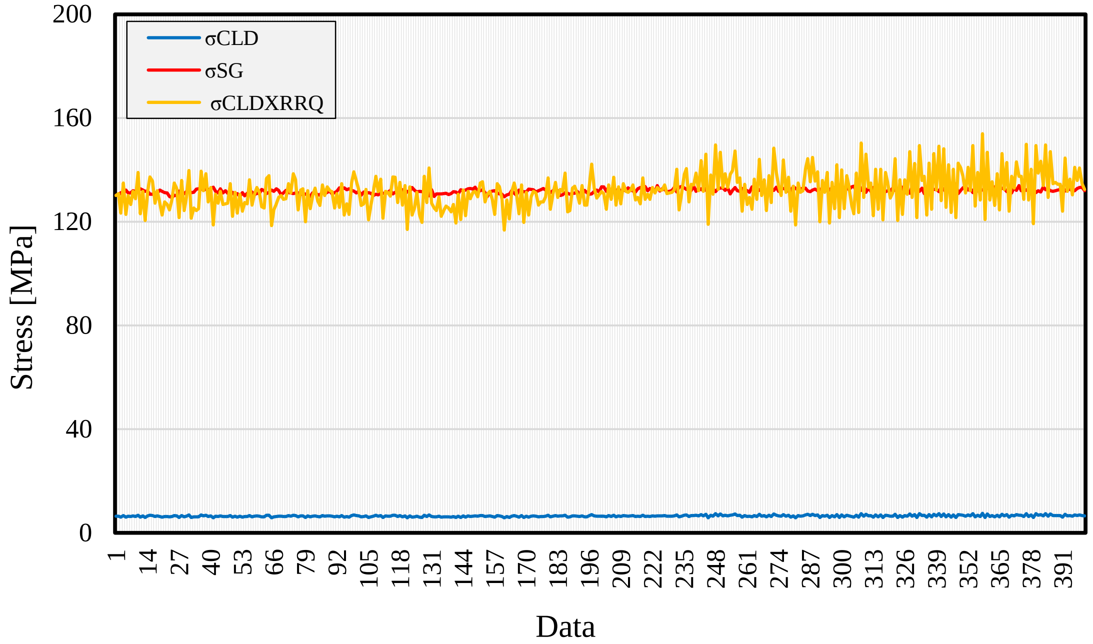


Figure 5.11 Comparison of SG and CLD Measurement at Force 46.35 N

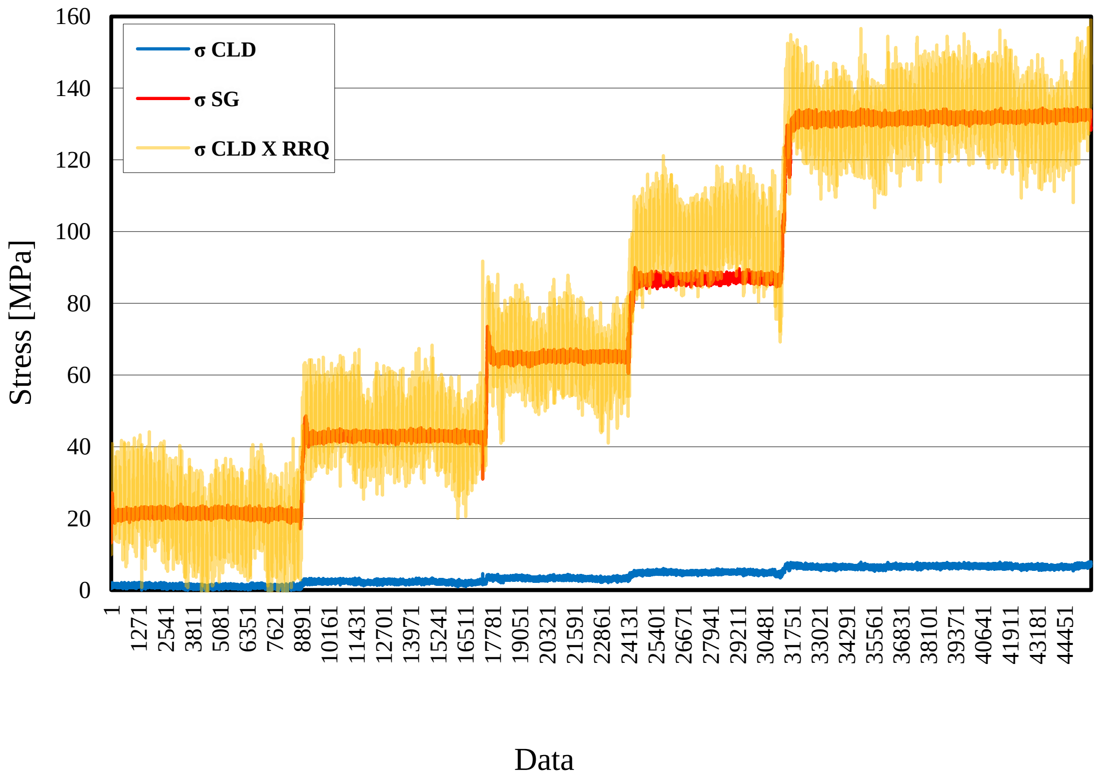


Figure 5.12 Comparison of SG and CLD Measurements with Applied Forces

CHAPTER 6

6 Result Analysis

In this chapter, the interpretation and analysis of data acquired using the acquisition system are presented. The data acquisition system was programmed to generate data in certain specified time intervals. Each acquisition consisted of data written in a text file, which included all strain gauge data. Data from each strain gauge acquired were analyzed to calculate resilient and permanent strain. The compilation of all acquisitions throughout the test generated the resilient and permanent strain histories for each strain gauge. The resilient and permanent strain histories were then analyzed to determine the strains and stress corresponding force level.

Lab measurements explicitly proved a linear output characteristic of CLD. It was also indicated in 3D modelling. Next is a functional compliance between stress and dilatation in CLD. The original stress on the surface of the beam is related by a constant factor to the one detected by CLD. This relation is depicted by a spring coefficient. Its value for the CLD spring 2 is VRQ = 22.7. In order to get the same order stress value after laboratory tests, it is necessary to convert detected voltage with the instrument into a physical value of the stress. Signal output, both from the strain gauge and CLD have been collected together.

Actual dilatation ε, is calculated applying formula (5.1). For the Wheatstone half bridge, with one active and one temp. Compensating strain gauge, bridge factor is B= 1. This kind of configuration on a steel beam, yields the equation:

$$\varepsilon_{SG} = \frac{4}{k} \cdot \frac{U_{A\,SG}}{U_{E\,SG}} \tag{6.1}$$

Unlike, on CLD a half bridge comprises two active strain gauges, so the Wheatstone bridge factor is B= 2 [17]. The corresponding dilatation then is:

$$\varepsilon_{CLD} = \frac{4}{2k} \cdot \frac{U_{A\,CLD}}{U_{E\,CLD}} \tag{6.2}$$

According to the Hook's law, stress is directly proportional to the dilatation so it makes no difference whichever parameter is used for the calculation of RRQ [18].

$$RRQ = \sum_{i=1}^{n} \frac{\varepsilon_{SG} / \varepsilon_{CLD}}{n} \qquad (6.3)$$

RRQ is derived as a mathematical average value from all collected points, considering just the points where either ε_{SG} or ε_{CLD} is greater than 0.001:

$\varepsilon_{SG} < 0.001 \wedge \varepsilon_{CLD} > 0.001$

Charts in Figure 6.6 show disipation of the RRQ around an average value points (1 - 4000). The light blue dots represent average coefficient value RRQ = 20.36, while the red dots are varying around, as the ratio of σ_{SG} and σ_{CLD} fluctuates in the Lab test. The output result from the DynaLog Instrument is 45687 consecutive data for the applied force ranging 7.56 N to 46.35 N. The RRQ value calculated around an average value for the selected points (1 - 4000). The data was chosen from the applied force at 7.56 N 400 data, the second applied force Was, 15.25 N and 200 data were chosen, the same thing for the entire forces 23.02 N, 30.88 N, 46.35N.

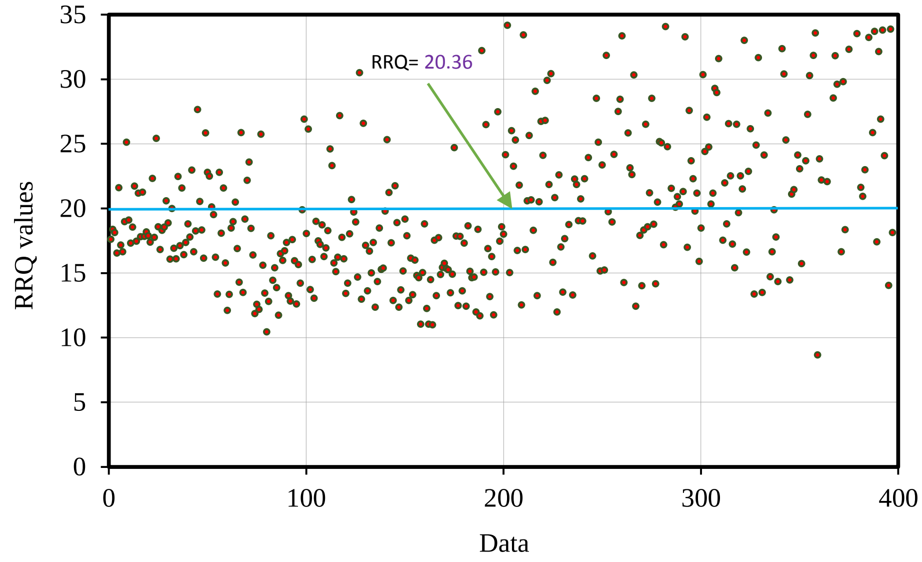


Figure 6.1 RRQ Values of Force 7.56 N

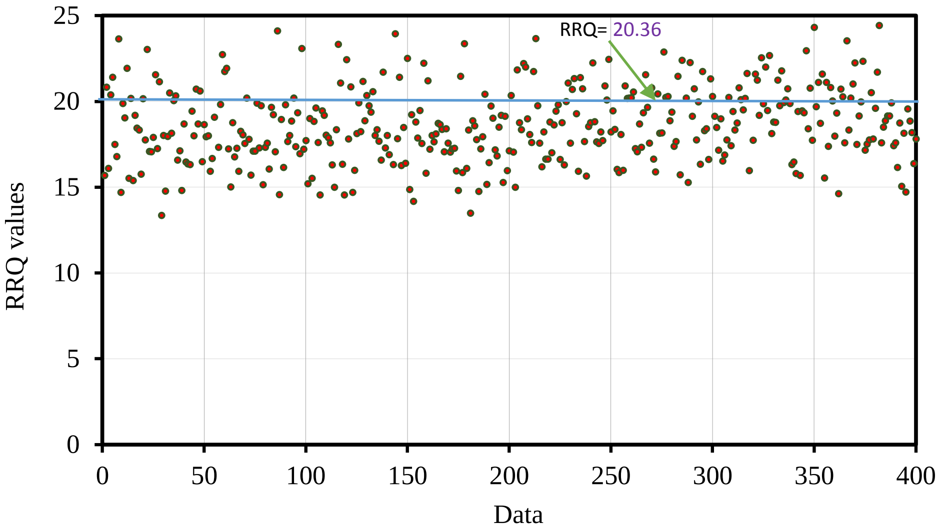


Figure 6.2 RRQ Values of Force 15.25 N

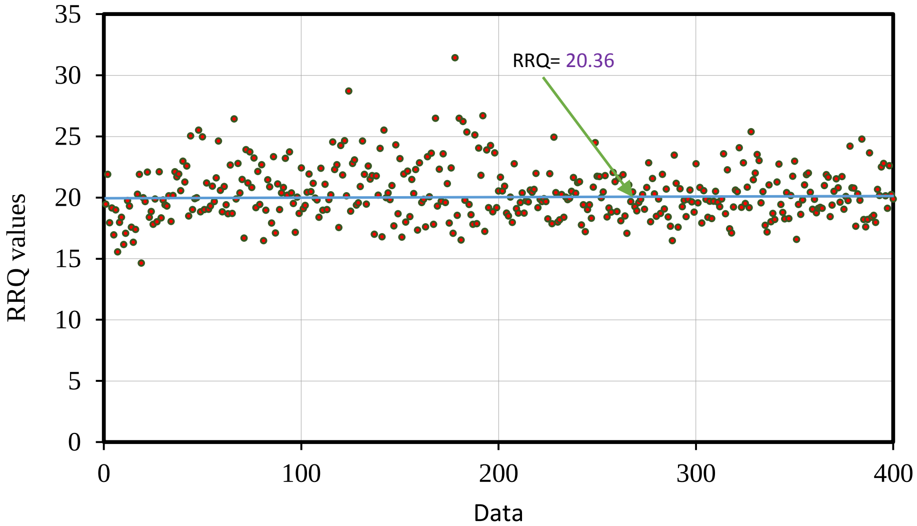


Figure 6.3 RRQ Values of Force 23.02 N

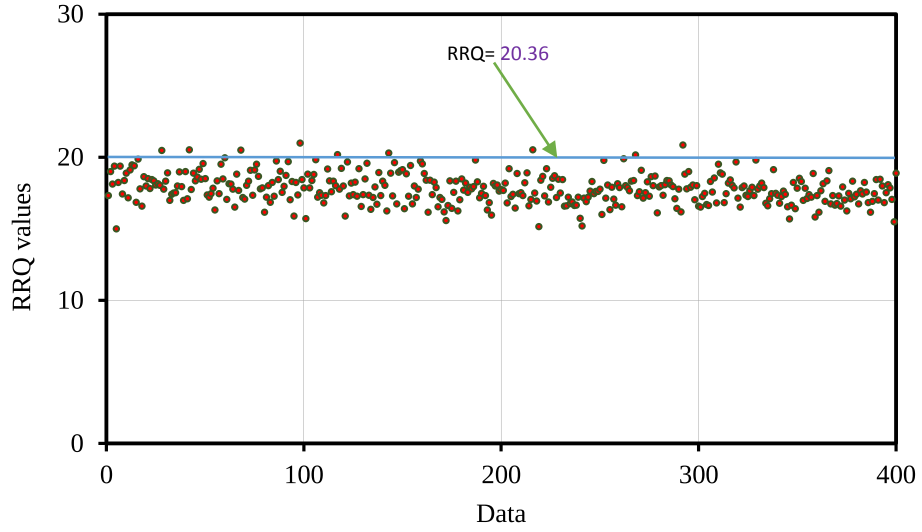


Figure 6.4 RRQ Values of Force 30.88 N

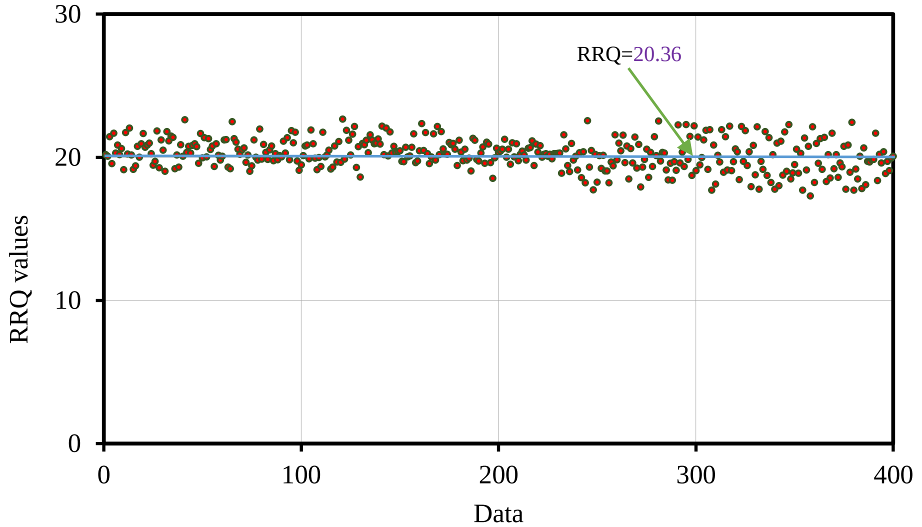


Figure 6.5 RRQ Values of Force 46.35 N

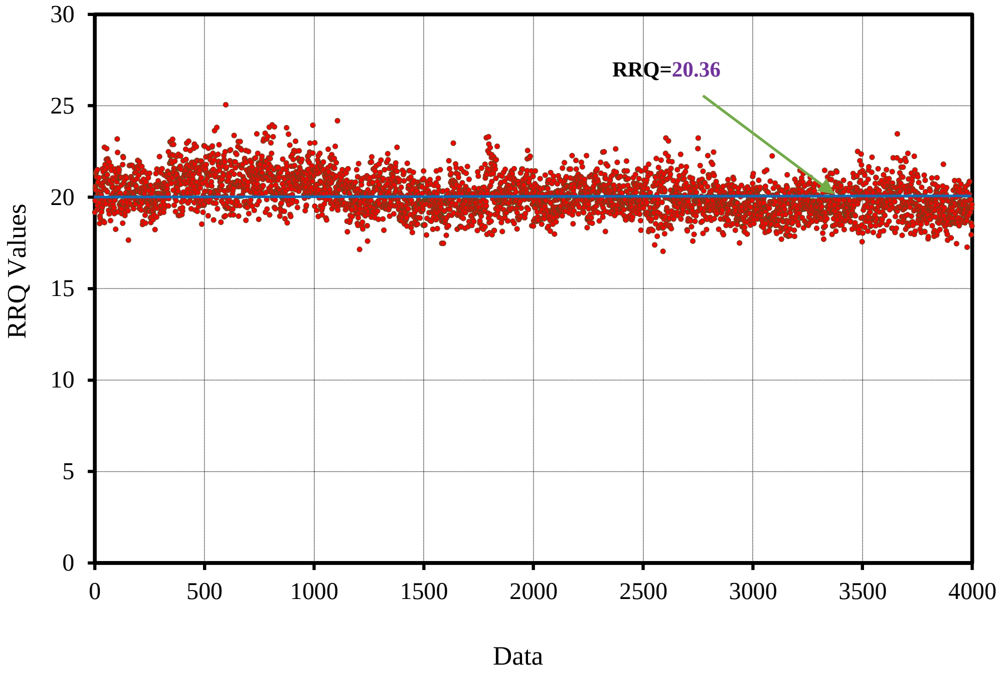


Figure 6.6 RRQ Values with Applied Forces

The 4000 data was chosen as shown in figure 5.6, for each force i chose the average of 800 data. All the results achieved the target as shown in the previous figures, and implementing RRQ in laboratory tests, almost perfect, 99% match is achieved between stress value from the original strain gauge and CLD.

CHAPTER 7

7 Conclusion

In this thesis the investigation started with search of available literature and existing solution. The methodology proposed by this thesis involves a Close Loop Deformeter, actually a pre-formed, resilient piece of steel metal with a fixed strain gauge. Commercially, there are various types of Deformeter are available in the market. They are described in the available literature. Usually a minimal span of such Deformeter is 50 mm or greater. Therefore, for shorter span a dedicated Deformeter must be developed. In order to design a multipurpose, widely, applicable liner Deformeter, with adjustable span, a new concept of Deformeter is explored. This thesis describes a research and development effort, invented into the creation of a new type of Deformeter.

Lord Kelvin first reported the relationship between electrical resistance and applied strain in wire conductors in 1856 [1]. However, it was not until the 1930's that commercial strain gauges came into effect. Their main purpose is to output a resistance, which changes in accordance with the strain experienced with the device. The difference in strain may be caused by the application of a compressive or tensile stress to the surface on which the sensor is attached. They are most commonly used in the automotive and aerospace industries, however, they have also found use in biomedical applications, for example, monitoring the performance of limb implants [2–4].
The design process was oriented an optimization of the original shape with dimension diameters and martial selection, design process started with 3D modeling (CATIA Software) of different type of Deformeter. Among several drafted shapes an optimal form is selected. Based on the 3D modeling (different diameters) with ANSYS Software final outcome results. Among discrete solutions an optimized mechanical structure is selected a prototype of a Close Loop Deformeter is shaped and heat treated.

The amplification facets of the electronics adapt to device a well-shaped and intensive signal.

Further virtual examination is conducted by ANSYS Software in order to select an optimal model of CLD. The ANSYS Software (Static Structure) performance of the CLD is tested. The optimal structure is verified. The static performance of the CLD design is evaluated using static structural FEA. The simulations are carried out by applying an input displacement from (0.01 to 10 mm) to produce the stretching force. The final shape of CLD with diameter 40 mm and stiffness 3.2 N/mm with maximum stress 592.7 MPa.

The virtual test of the structure is performed by creating a simple beam (cross-section square profile 30x30 mm, with 2 mm wall thickness) of a total length L = 4m, between supporting points. In the mid-span of the square beam, a virtual Strain gauge is fixed and above it a CLD. The static performance of the design is evaluated using static structural FEA. The simulations are carried out by applying an input force to produce stress. This set was loaded by a consecutively increasing force ranging from 10 to 200N.

Real laboratory was done. Lab test is conceived in the same manner as the Virtual experiment. CLD item is made of a spring steel. Two active strain gauges are glued to the CLD, one on the outer and one on the inner side of the loop. For the stress calculation on CLD, Two strain gauges are glued to the beam, one active and one dummy. The results of measurement were collected with DynaLog instrument, RoTech (www.rotech.rs) make, was used.

The size of the loading force was varied within the following range F1=7.56N; F2=15.25N; F3=23.02N; F4=30.88N; F5=46.35N. Steel beam is exposed to bending, induced by adding on lumped masses. As well a random load is applied to justify compliance between direct and CLD measurement. After a series of repeated tests, it was determined experimentally that the Real Rectification Quotient (RRQ) of CLD is RRQ= 20.36. Correlation function was applied for the justification of signal compliance, Correl = 0.99

During laboratory testing, it was revealed that RRQ is slightly different from the VRQ. It is assumed that detected the difference is a result of imperfection in either modelling or selected material properties. However, by implementing RRQ in laboratory tests, almost perfect, 99% match is achieved between stress value from the original strain gauge and CLD. Final conclusion would be that CLD is a type of sensor that could substitute strain gauge wherever arise difficulties in attaching it, as well when intended operation is in a harsh area with extensive deflections. Further investigations on CLD performance will be oriented to the site testing on different structures and more complex loadings [19].

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APPENDIXES

Appendix A: - Data & Strain

CLD [mV/V]	**Beam** [mV/V]	ε $_{CLD}$	ε $_{Beam}$
-6.16119E-06	5.42917E-05	-5.75812E-06	0.00010148
-5.85618E-06	5.38647E-05	-5.47307E-06	0.000100682
-5.91718E-06	5.36817E-05	-5.53008E-06	0.00010034
-6.4662E-06	5.34987E-05	-6.04318E-06	9.99975E-05
-4.94115E-06	5.33766E-05	-4.6179E-06	9.97694E-05
-5.67318E-06	4.86795E-05	-5.30203E-06	9.09897E-05
-6.16119E-06	5.13026E-05	-5.75812E-06	9.58927E-05
-5.36817E-06	5.09366E-05	-5.01698E-06	9.52085E-05
-4.02612E-06	5.05706E-05	-3.76273E-06	9.45244E-05
-5.67318E-06	5.42307E-05	-5.30203E-06	0.000101366
-6.22219E-06	5.39257E-05	-5.81513E-06	0.000100796
-5.30716E-06	4.92285E-05	-4.95997E-06	9.20159E-05
-5.06316E-06	5.50237E-05	-4.73192E-06	0.000102848
-6.4662E-06	5.64877E-05	-6.04318E-06	0.000105585
-5.12416E-06	5.42917E-05	-4.78893E-06	0.00010148
-6.03919E-06	5.38037E-05	-5.6441E-06	0.000100568
-5.18516E-06	5.51457E-05	-4.84594E-06	0.000103076
-5.61217E-06	5.00825E-05	-5.24502E-06	9.36122E-05
-5.85618E-06	5.32546E-05	-5.47307E-06	9.95414E-05
-5.85618E-06	5.24006E-05	-5.47307E-06	9.79451E-05
-5.67318E-06	4.93505E-05	-5.30203E-06	9.2244E-05
-4.57514E-06	5.10586E-05	-4.27583E-06	9.54366E-05
-5.79518E-06	5.14856E-05	-5.41606E-06	9.62347E-05
-4.02612E-06	5.11806E-05	-3.76273E-06	9.56646E-05
-5.49017E-06	5.09976E-05	-5.131E-06	9.53226E-05
-6.28319E-06	5.28276E-05	-5.87214E-06	9.87432E-05
-5.97818E-06	5.47187E-05	-5.58709E-06	0.000102278
-5.97818E-06	5.54507E-05	-5.58709E-06	0.000103646
-5.06316E-06	5.21566E-05	-4.73192E-06	9.7489E-05
-5.30716E-06	5.00825E-05	-4.95997E-06	9.36122E-05
-6.4662E-06	5.20346E-05	-6.04318E-06	9.72609E-05
-5.06316E-06	5.06316E-05	-4.73192E-06	9.46384E-05
-5.91718E-06	5.00825E-05	-5.53008E-06	9.36122E-05
-6.03919E-06	4.86185E-05	-5.6441E-06	9.08757E-05
-4.63614E-06	5.20956E-05	-4.33284E-06	9.7375E-05
-5.91718E-06	5.06926E-05	-5.53008E-06	9.47525E-05
-5.06316E-06	5.46577E-05	-4.73192E-06	0.000102164

-6.16119E-06	5.06316E-05	-5.75812E-06	9.46384E-05
-6.16119E-06	5.34987E-05	-5.75812E-06	9.99975E-05
-5.79518E-06	5.45357E-05	-5.41606E-06	0.000101936
-6.03919E-06	5.37427E-05	-5.6441E-06	0.000100454
-4.75815E-06	5.46577E-05	-4.44687E-06	0.000102164
-6.4662E-06	5.38647E-05	-6.04318E-06	0.000100682
-5.85618E-06	5.34987E-05	-5.47307E-06	9.99975E-05
-3.90412E-06	5.39867E-05	-3.64871E-06	0.00010091
-4.94115E-06	5.07536E-05	-4.6179E-06	9.48665E-05
-5.61217E-06	5.14856E-05	-5.24502E-06	9.62347E-05
-6.4052E-06	5.17296E-05	-5.98617E-06	9.66908E-05
-4.14813E-06	5.36207E-05	-3.87676E-06	0.000100226
-4.69715E-06	5.35597E-05	-4.38986E-06	0.000100112
-4.69715E-06	5.28276E-05	-4.38986E-06	9.87432E-05
-5.30716E-06	5.33766E-05	-4.95997E-06	9.97694E-05
-5.30716E-06	5.17906E-05	-4.95997E-06	9.68049E-05
-6.64921E-06	5.39257E-05	-6.21421E-06	0.000100796
-7.86924E-06	5.26446E-05	-7.35443E-06	9.84012E-05
-4.69715E-06	5.35597E-05	-4.38986E-06	0.000100112
-5.91718E-06	5.34987E-05	-5.53008E-06	9.99975E-05
-4.81915E-06	5.20346E-05	-4.50388E-06	9.72609E-05
-6.83221E-06	5.39257E-05	-6.38524E-06	0.000100796
-8.11325E-06	4.91065E-05	-7.58248E-06	9.17879E-05
-7.44223E-06	4.97165E-05	-6.95535E-06	9.29281E-05
-5.49017E-06	5.07536E-05	-5.131E-06	9.48665E-05
-5.49017E-06	5.20956E-05	-5.131E-06	9.7375E-05
-4.88015E-06	5.00215E-05	-4.56089E-06	9.34982E-05
-6.16119E-06	5.20956E-05	-5.75812E-06	9.7375E-05
-6.64921E-06	4.75205E-05	-6.21421E-06	8.88233E-05
-3.96512E-06	5.13026E-05	-3.70572E-06	9.58927E-05
-7.93024E-06	5.34987E-05	-7.41144E-06	9.99975E-05
-5.61217E-06	5.38037E-05	-5.24502E-06	0.000100568
-4.69715E-06	5.20956E-05	-4.38986E-06	9.7375E-05
-4.51414E-06	5.32546E-05	-4.21882E-06	9.95414E-05
-5.67318E-06	5.23396E-05	-5.30203E-06	9.78311E-05
-6.4662E-06	5.30716E-05	-6.04318E-06	9.91993E-05
-8.72327E-06	5.17906E-05	-8.15259E-06	9.68049E-05
-8.66227E-06	5.45357E-05	-8.09558E-06	0.000101936
-8.54026E-06	5.20346E-05	-7.98155E-06	9.72609E-05
-4.02612E-06	5.18516E-05	-3.76273E-06	9.69189E-05
-6.77121E-06	5.28886E-05	-6.32823E-06	9.88573E-05

-7.62524E-06	5.13026E-05	-7.12639E-06	9.58927E-05
-9.39429E-06	4.90455E-05	-8.77971E-06	9.16739E-05
-7.62524E-06	4.88015E-05	-7.12639E-06	9.12178E-05
-5.73418E-06	5.13026E-05	-5.35904E-06	9.58927E-05
-7.32023E-06	5.28886E-05	-6.84133E-06	9.88573E-05
-6.83221E-06	5.26446E-05	-6.38524E-06	9.84012E-05
-7.25922E-06	5.03266E-05	-6.78432E-06	9.40683E-05
-8.72327E-06	5.11806E-05	-8.15259E-06	9.56646E-05
-6.5272E-06	5.38647E-05	-6.10019E-06	0.000100682
-6.64921E-06	5.31326E-05	-6.21421E-06	9.93133E-05
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-7.07622E-06	5.54507E-05	-6.61329E-06	0.000103646
-7.19822E-06	5.11806E-05	-6.72731E-06	9.56646E-05
-5.30716E-06	5.28276E-05	-4.95997E-06	9.87432E-05
-3.96512E-06	5.33766E-05	-3.70572E-06	9.97694E-05
-5.79518E-06	5.23396E-05	-5.41606E-06	9.78311E-05
-4.20913E-06	5.50237E-05	-3.93377E-06	0.000102848
-7.74724E-06	5.31326E-05	-7.24041E-06	9.93133E-05
-6.64921E-06	5.33766E-05	-6.21421E-06	9.97694E-05
-7.74724E-06	5.05706E-05	-7.24041E-06	9.45244E-05
-5.49017E-06	5.21566E-05	-5.131E-06	9.7489E-05
-6.16119E-06	5.39257E-05	-5.75812E-06	0.000100796
-6.3442E-06	5.46577E-05	-5.92916E-06	0.000102164
-5.55117E-06	5.19736E-05	-5.18801E-06	9.71469E-05
-6.64921E-06	5.41087E-05	-6.21421E-06	0.000101138
-6.16119E-06	5.22176E-05	-5.75812E-06	9.7603E-05
-5.55117E-06	5.07536E-05	-5.18801E-06	9.48665E-05
-4.51414E-06	5.55727E-05	-4.21882E-06	0.000103874
-4.81915E-06	5.61827E-05	-4.50388E-06	0.000105014
-6.64921E-06	5.24616E-05	-6.21421E-06	9.80591E-05
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-6.5272E-06	5.29496E-05	-6.10019E-06	9.89713E-05
-4.02612E-06	5.47187E-05	-3.76273E-06	0.000102278
-6.03919E-06	5.36207E-05	-5.6441E-06	0.000100226
-6.5272E-06	5.25836E-05	-6.10019E-06	9.82871E-05

-7.80824E-06	5.24616E-05	-7.29742E-06	9.80591E-05
-7.07622E-06	5.03266E-05	-6.61329E-06	9.40683E-05
-5.67318E-06	5.11806E-05	-5.30203E-06	9.56646E-05
-5.12416E-06	5.30106E-05	-4.78893E-06	9.90853E-05
-5.06316E-06	4.99605E-05	-4.73192E-06	9.33842E-05
-5.49017E-06	5.20346E-05	-5.131E-06	9.72609E-05
-6.77121E-06	4.97775E-05	-6.32823E-06	9.30421E-05
-3.47711E-06	5.30716E-05	-3.24963E-06	9.91993E-05
-8.17425E-06	5.30716E-05	-7.63949E-06	9.91993E-05
-4.14813E-06	5.51457E-05	-3.87676E-06	0.000103076
-6.4052E-06	5.49017E-05	-5.98617E-06	0.00010262
-7.93024E-06	5.39867E-05	-7.41144E-06	0.00010091
-6.3442E-06	5.30106E-05	-5.92916E-06	9.90853E-05
-6.83221E-06	5.13026E-05	-6.38524E-06	9.58927E-05
-6.10019E-06	5.29496E-05	-5.70111E-06	9.89713E-05
-8.72327E-06	5.39257E-05	-8.15259E-06	0.000100796
-7.38123E-06	5.29496E-05	-6.89834E-06	9.89713E-05
-5.85618E-06	5.41697E-05	-5.47307E-06	0.000101252
-6.89321E-06	5.27056E-05	-6.44226E-06	9.85152E-05
-6.71021E-06	5.16686E-05	-6.27122E-06	9.65768E-05
-5.18516E-06	5.13636E-05	-4.84594E-06	9.60067E-05
-4.39214E-06	5.56337E-05	-4.1048E-06	0.000103988
-4.81915E-06	5.11806E-05	-4.50388E-06	9.56646E-05
-6.16119E-06	5.34377E-05	-5.75812E-06	9.98835E-05
-8.05225E-06	5.19126E-05	-7.52547E-06	9.70329E-05
-4.75815E-06	5.17906E-05	-4.44687E-06	9.68049E-05
-5.67318E-06	5.36207E-05	-5.30203E-06	0.000100226
-8.23525E-06	5.09366E-05	-7.6965E-06	9.52085E-05
-7.62524E-06	5.22786E-05	-7.12639E-06	9.7717E-05
-7.19822E-06	5.45967E-05	-6.72731E-06	0.00010205
-5.61217E-06	5.38037E-05	-5.24502E-06	0.000100568
-6.28319E-06	5.61827E-05	-5.87214E-06	0.000105014
-8.29626E-06	5.34377E-05	-7.75351E-06	9.98835E-05
-6.5272E-06	5.27666E-05	-6.10019E-06	9.86292E-05
-8.05225E-06	5.36817E-05	-7.52547E-06	0.00010034
-6.77121E-06	5.42307E-05	-6.32823E-06	0.000101366
-7.25922E-06	5.37427E-05	-6.78432E-06	0.000100454
-7.32023E-06	5.35597E-05	-6.84133E-06	0.000100112
-9.39429E-06	5.19126E-05	-8.77971E-06	9.70329E-05
-7.25922E-06	5.45967E-05	-6.78432E-06	0.00010205
-5.42917E-06	5.10586E-05	-5.07399E-06	9.54366E-05

-8.23525E-06	5.04486E-05	-7.6965E-06	9.42964E-05
-9.7603E-06	5.39257E-05	-9.12178E-06	0.000100796
-7.07622E-06	5.13026E-05	-6.61329E-06	9.58927E-05
-9.33329E-06	5.13026E-05	-8.7227E-06	9.58927E-05
-5.91718E-06	5.19126E-05	-5.53008E-06	9.70329E-05
-7.62524E-06	5.05096E-05	-7.12639E-06	9.44104E-05
-6.22219E-06	5.52067E-05	-5.81513E-06	0.00010319
-6.77121E-06	5.04486E-05	-6.32823E-06	9.42964E-05
-7.13722E-06	5.50847E-05	-6.6703E-06	0.000102962
-6.77121E-06	5.33156E-05	-6.32823E-06	9.96554E-05
-6.83221E-06	5.25226E-05	-6.38524E-06	9.81731E-05
-7.32023E-06	5.58777E-05	-6.84133E-06	0.000104444
-8.11325E-06	5.46577E-05	-7.58248E-06	0.000102164
-7.13722E-06	5.31936E-05	-6.6703E-06	9.94274E-05
-4.45314E-06	5.50237E-05	-4.16181E-06	0.000102848
-5.85618E-06	5.23396E-05	-5.47307E-06	9.78311E-05
-8.17425E-06	5.10586E-05	-7.63949E-06	9.54366E-05
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-7.62524E-06	5.19126E-05	-7.12639E-06	9.70329E-05
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-8.11325E-06	5.04486E-05	-7.58248E-06	9.42964E-05
-5.85618E-06	5.46577E-05	-5.47307E-06	0.000102164
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-7.07622E-06	5.19736E-05	-6.61329E-06	9.71469E-05
-8.23525E-06	4.94115E-05	-7.6965E-06	9.2358E-05
-5.97818E-06	5.49627E-05	-5.58709E-06	0.000102734
-8.60127E-06	5.03266E-05	-8.03857E-06	9.40683E-05
-3.41611E-06	5.50237E-05	-3.19262E-06	0.000102848
-6.89321E-06	5.19126E-05	-6.44226E-06	9.70329E-05
-3.96512E-06	5.25226E-05	-3.70572E-06	9.81731E-05
-6.28319E-06	5.30716E-05	-5.87214E-06	9.91993E-05
-8.29626E-06	5.46577E-05	-7.75351E-06	0.000102164
-6.3442E-06	5.16686E-05	-5.92916E-06	9.65768E-05
-8.72327E-06	5.13636E-05	-8.15259E-06	9.60067E-05
-6.89321E-06	5.20346E-05	-6.44226E-06	9.72609E-05
-4.08713E-06	5.61827E-05	-3.81974E-06	0.000105014
-6.10019E-06	5.33156E-05	-5.70111E-06	9.96554E-05
-5.85618E-06	5.44137E-05	-5.47307E-06	0.000101708
-5.67318E-06	5.11196E-05	-5.30203E-06	9.55506E-05
-4.27013E-06	5.16076E-05	-3.99078E-06	9.64628E-05

-3.1721E-06	5.42307E-05	-2.96458E-06	0.000101366
-6.77121E-06	5.09366E-05	-6.32823E-06	9.52085E-05
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-6.28319E-06	5.26446E-05	-5.87214E-06	9.84012E-05
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-8.35726E-06	5.24006E-05	-7.81052E-06	9.79451E-05
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-3.53811E-06	5.29496E-05	-3.30664E-06	9.89713E-05
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-7.74724E-06	5.24006E-05	-7.24041E-06	9.79451E-05
-6.10019E-06	5.39257E-05	-5.70111E-06	0.000100796
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-5.91718E-06	5.42917E-05	-5.53008E-06	0.00010148
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-4.81915E-06	5.19736E-05	-4.50388E-06	9.71469E-05
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-4.69715E-06	5.16076E-05	-4.38986E-06	9.64628E-05
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-1.06753E-05	0.000110596	-9.97694E-06	0.000206722
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-1.06753E-05	0.000105838	-9.97694E-06	0.000197829
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-1.24444E-05	0.000109254	-1.16303E-05	0.000204214
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-1.26274E-05	0.000108034	-1.18013E-05	0.000201933
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-1.19564E-05	0.000109742	-1.11742E-05	0.000205126
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-1.52505E-05	0.000168182	-1.42528E-05	0.000314359
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-2.63528E-05	0.000218814	-2.46288E-05	0.000408998
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-2.49498E-05	0.000221803	-2.33175E-05	0.000414585
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-2.48888E-05	0.000218265	-2.32605E-05	0.000407971
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-3.1416E-05	0.000333131	-2.93607E-05	0.000622675
-3.2758E-05	0.000332948	-3.0615E-05	0.000622333
-3.0867E-05	0.000332948	-2.88476E-05	0.000622333
-3.1416E-05	0.000333192	-2.93607E-05	0.000622789
-3.1843E-05	0.000333558	-2.97598E-05	0.000623473
-3.166E-05	0.000332521	-2.95888E-05	0.000621535
-3.1294E-05	0.000333192	-2.92467E-05	0.000622789
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-3.05619E-05	0.000337035	-2.85626E-05	0.000629973
-3.3429E-05	0.000336059	-3.12421E-05	0.000628148
-3.0928E-05	0.000336913	-2.89046E-05	0.000629745
-3.3307E-05	0.000338011	-3.11281E-05	0.000631797
-3.2575E-05	0.000338316	-3.04439E-05	0.000632367
-3.3185E-05	0.000337706	-3.1014E-05	0.000631227
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-3.41001E-05	0.000336303	-3.18692E-05	0.000628604
-3.42221E-05	0.000337218	-3.19832E-05	0.000630315
-3.227E-05	0.000334168	-3.01589E-05	0.000624614
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-3.3307E-05	0.0003349	-3.11281E-05	0.000625982
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-3.105E-05	0.000336181	-2.90187E-05	0.000628376

-3.40391E-05	0.000334107	-3.18122E-05	0.0006245
-3.3734E-05	0.000332887	-3.15271E-05	0.000622219
-3.2514E-05	0.000332643	-3.03869E-05	0.000621763
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-3.227E-05	0.000337096	-3.01589E-05	0.000630087
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-3.2758E-05	0.000336852	-3.0615E-05	0.000629631
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-3.1538E-05	0.000334412	-2.94747E-05	0.00062507
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-3.3063E-05	0.000339963	-3.09E-05	0.000635446
-3.1538E-05	0.00033551	-2.94747E-05	0.000627122
-3.3917E-05	0.000339536	-3.16982E-05	0.000634648
-3.2514E-05	0.000334412	-3.03869E-05	0.00062507
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-3.3734E-05	0.000338072	-3.15271E-05	0.000631911
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-3.40391E-05	0.000336486	-3.18122E-05	0.000628947
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-3.3429E-05	0.000337035	-3.12421E-05	0.000629973
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-3.54421E-05	0.000335022	-3.31235E-05	0.00062621
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-3.3063E-05	0.00034033	-3.09E-05	0.00063613
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-3.227E-05	0.00033856	-3.01589E-05	0.000632823
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-3.41611E-05	0.000336059	-3.19262E-05	0.000628148
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-3.3734E-05	0.000337096	-3.15271E-05	0.000630087
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-3.41001E-05	0.000335693	-3.18692E-05	0.000627464
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-3.41611E-05	0.000336059	-3.19262E-05	0.000628148
-3.3978E-05	0.000336913	-3.17552E-05	0.000629745
-3.3978E-05	0.000337462	-3.17552E-05	0.000630771
-3.1355E-05	0.000340086	-2.93037E-05	0.000635674
-3.65401E-05	0.000335815	-3.41497E-05	0.000627692
-3.3307E-05	0.00033673	-3.11281E-05	0.000629403
-3.44661E-05	0.000337767	-3.22113E-05	0.000631341
-3.2941E-05	0.000335754	-3.0786E-05	0.000627578
-3.56251E-05	0.000336303	-3.32945E-05	0.000628604
-3.43441E-05	0.000338499	-3.20973E-05	0.000632709
-3.55641E-05	0.00033917	-3.32375E-05	0.000633964
-3.40391E-05	0.000339597	-3.18122E-05	0.000634762
-3.349E-05	0.00033612	-3.12991E-05	0.000628262

Appendix B. Stress & RRQ values

σ_{CLD} [MPa]	σ_{SG} [MPa]	σ_{SG} / σ_{CLD}	$\sigma_{CLD} \times$ RRQ
1.2092	21.3108	17.6238	24.3748
1.1493	21.1431	18.3958	23.1682
1.1613	21.0713	18.1443	23.4095
1.2691	20.9995	16.5472	25.5815
0.9698	20.9516	21.6049	19.5481
1.1134	19.1078	17.1613	22.4442
1.2092	20.1375	16.6535	24.3748
1.0536	19.9938	18.9773	21.2375
0.7902	19.8501	25.1212	15.9281
1.1134	21.2868	19.1183	22.4442
1.2212	21.1671	17.3333	24.6162
1.0416	19.3233	18.5517	20.9962
0.9937	21.5981	21.7349	20.0308
1.2691	22.1728	17.4717	25.5815
1.0057	21.3108	21.1905	20.2721
1.1853	21.1192	17.8182	23.8922
1.0176	21.6460	21.2706	20.5135
1.1015	19.6586	17.8478	22.2028
1.1493	20.9037	18.1875	23.1682
1.1493	20.5685	17.8958	23.1682
1.1134	19.3712	17.3978	22.4442
0.8979	20.0417	22.3200	18.1001
1.1374	20.2093	17.7684	22.9268
0.7902	20.0896	25.4242	15.9281
1.0775	20.0177	18.5778	21.7202
1.2332	20.7361	16.8155	24.8575
1.1733	21.4784	18.3061	23.6508
1.1733	21.7657	18.5510	23.6508
0.9937	20.4727	20.6024	20.0308
1.0416	19.6586	18.8736	20.9962
1.2691	20.4248	16.0943	25.5815
0.9937	19.8741	20.0000	20.0308

1.1613	19.6586	16.9278	23.4095
1.1853	19.0839	16.1010	23.8922
0.9099	20.4487	22.4737	18.3415
1.1613	19.8980	17.1340	23.4095
0.9937	21.4544	21.5904	20.0308
1.2092	19.8741	16.4356	24.3748
1.2092	20.9995	17.3663	24.3748
1.1374	21.4065	18.8211	22.9268
1.1853	21.0952	17.7980	23.8922
0.9338	21.4544	22.9744	18.8241
1.2691	21.1431	16.6604	25.5815
1.1493	20.9995	18.2708	23.1682
0.7662	21.1910	27.6563	15.4454
0.9698	19.9220	20.5432	19.5481
1.1015	20.2093	18.3478	22.2028
1.2571	20.3051	16.1524	25.3402
0.8141	21.0474	25.8529	16.4108
0.9219	21.0234	22.8052	18.5828
0.9219	20.7361	22.4935	18.5828
1.0416	20.9516	20.1149	20.9962
1.0416	20.3290	19.5172	20.9962
1.3050	21.1671	16.2202	26.3055
1.5444	20.6642	13.3798	31.1322
0.9219	21.0234	22.8052	18.5828
1.1613	20.9995	18.0825	23.4095
0.9458	20.4248	21.5949	19.0655
1.3409	21.1671	15.7857	27.0295
1.5923	19.2755	12.1053	32.0976
1.4606	19.5149	13.3607	29.4429
1.0775	19.9220	18.4889	21.7202
1.0775	20.4487	18.9778	21.7202
0.9578	19.6346	20.5000	19.3068
1.2092	20.4487	16.9109	24.3748
1.3050	18.6529	14.2936	26.3055

0.7782	20.1375	25.8769	15.6868
1.5564	20.9995	13.4923	31.3736
1.1015	21.1192	19.1739	22.2028
0.9219	20.4487	22.1818	18.5828
0.8860	20.9037	23.5946	17.8588
1.1134	20.5445	18.4516	22.4442
1.2691	20.8319	16.4151	25.5815
1.7120	20.3290	11.8741	34.5109
1.7001	21.4065	12.5915	34.2696
1.6761	20.4248	12.1857	33.7869
0.7902	20.3530	25.7576	15.9281
1.3289	20.7600	15.6216	26.7882
1.4965	20.1375	13.4560	30.1669
1.8437	19.2515	10.4416	37.1656
1.4965	19.1557	12.8000	30.1669
1.1254	20.1375	17.8936	22.6855
1.4367	20.7600	14.4500	28.9602
1.3409	20.6642	15.4107	27.0295
1.4247	19.7543	13.8655	28.7189
1.7120	20.0896	11.7343	34.5109
1.2810	21.1431	16.5047	25.8229
1.3050	20.8558	15.9817	26.3055
1.3050	21.8375	16.7339	26.3055
1.1733	20.3769	17.3673	23.6508
1.5923	21.0952	13.2481	32.0976
1.7120	21.9812	12.8392	34.5109
1.2212	21.4784	17.5882	24.6162
1.3289	21.1910	15.9459	26.7882
1.6881	21.2868	12.6099	34.0282
1.3888	21.7657	15.6724	27.9949
1.4127	20.0896	14.2203	28.4775
1.0416	20.7361	19.9080	20.9962
0.7782	20.9516	26.9231	15.6868
1.1374	20.5445	18.0632	22.9268

0.8261	21.5981	26.1449	16.6521
1.5205	20.8558	13.7165	30.6496
1.3050	20.9516	16.0550	26.3055
1.5205	19.8501	13.0551	30.6496
1.0775	20.4727	19.0000	21.7202
1.2092	21.1671	17.5050	24.3748
1.2451	21.4544	17.2308	25.0988
1.0895	20.4009	18.7253	21.9615
1.3050	21.2389	16.2752	26.3055
1.2092	20.4966	16.9505	24.3748
1.0895	19.9220	18.2857	21.9615
0.8860	21.8136	24.6216	17.8588
0.9458	22.0530	23.3165	19.0655
1.3050	20.5924	15.7798	26.3055
1.3888	20.9995	15.1207	27.9949
1.2810	20.7840	16.2243	25.8229
0.7902	21.4784	27.1818	15.9281
1.1853	21.0474	17.7576	23.8922
1.2810	20.6403	16.1121	25.8229
1.5325	20.5924	13.4375	30.8909
1.3888	19.7543	14.2241	27.9949
1.1134	20.0896	18.0430	22.4442
1.0057	20.8079	20.6905	20.2721
0.9937	19.6107	19.7349	20.0308
1.0775	20.4248	18.9556	21.7202
1.3289	19.5388	14.7027	26.7882
0.6824	20.8319	30.5263	13.7561
1.6043	20.8319	12.9851	32.3389
0.8141	21.6460	26.5882	16.4108
1.2571	21.5502	17.1429	25.3402
1.5564	21.1910	13.6154	31.3736
1.2451	20.8079	16.7115	25.0988
1.3409	20.1375	15.0179	27.0295
1.1972	20.7840	17.3600	24.1335

1.7120	21.1671	12.3636	34.5109
1.4487	20.7840	14.3471	29.2015
1.1493	21.2629	18.5000	23.1682
1.3529	20.6882	15.2920	27.2709
1.3170	20.2811	15.4000	26.5469
1.0176	20.1614	19.8118	20.5135
0.8620	21.8375	25.3333	17.3761
0.9458	20.0896	21.2405	19.0655
1.2092	20.9755	17.3465	24.3748
1.5803	20.3769	12.8939	31.8562
0.9338	20.3290	21.7692	18.8241
1.1134	21.0474	18.9032	22.4442
1.6163	19.9938	12.3704	32.5802
1.4965	20.5206	13.7120	30.1669
1.4127	21.4305	15.1695	28.4775
1.1015	21.1192	19.1739	22.2028
1.2332	22.0530	17.8835	24.8575
1.6282	20.9755	12.8824	32.8216
1.2810	20.7121	16.1682	25.8229
1.5803	21.0713	13.3333	31.8562
1.3289	21.2868	16.0180	26.7882
1.4247	21.0952	14.8067	28.7189
1.4367	21.0234	14.6333	28.9602
1.8437	20.3769	11.0519	37.1656
1.4247	21.4305	15.0420	28.7189
1.0655	20.0417	18.8090	21.4788
1.6163	19.8022	12.2519	32.5802
1.9156	21.1671	11.0500	38.6136
1.3888	20.1375	14.5000	27.9949
1.8318	20.1375	10.9935	36.9243
1.1613	20.3769	17.5464	23.4095
1.4965	19.8262	13.2480	30.1669
1.2212	21.6699	17.7451	24.6162
1.3289	19.8022	14.9009	26.7882

1.4008	21.6220	15.4359	28.2362
1.3289	20.9276	15.7477	26.7882
1.3409	20.6164	15.3750	27.0295
1.4367	21.9333	15.2667	28.9602
1.5923	21.4544	13.4737	32.0976
1.4008	20.8797	14.9060	28.2362
0.8740	21.5981	24.7123	17.6175
1.1493	20.5445	17.8750	23.1682
1.6043	20.0417	12.4925	32.3389
1.1733	20.9276	17.8367	23.6508
1.4965	20.3769	13.6160	30.1669
1.1972	20.7361	17.3200	24.1335
1.5923	19.8022	12.4361	32.0976
1.1493	21.4544	18.6667	23.1682
1.4008	21.1910	15.1282	28.2362
1.4247	20.8558	14.6387	28.7189
1.3888	20.4009	14.6897	27.9949
1.6163	19.3952	12.0000	32.5802
1.1733	21.5741	18.3878	23.6508
1.6881	19.7543	11.7021	34.0282
0.6705	21.5981	32.2143	13.5148
1.3529	20.3769	15.0619	27.2709
0.7782	20.6164	26.4923	15.6868
1.2332	20.8319	16.8932	24.8575
1.6282	21.4544	13.1765	32.8216
1.2451	20.2811	16.2885	25.0988
1.7120	20.1614	11.7762	34.5109
1.3529	20.4248	15.0973	27.2709
0.8021	22.0530	27.4925	16.1695
1.1972	20.9276	17.4800	24.1335
1.1493	21.3586	18.5833	23.1682
1.1134	20.0656	18.0215	22.4442
0.8381	20.2572	24.1714	16.8935
0.6226	21.2868	34.1923	12.5494

1.3289	19.9938	15.0450	26.7882
0.8261	21.5023	26.0290	16.6521
0.9338	21.7418	23.2821	18.8241
0.8261	20.9037	25.3043	16.6521
1.2332	20.6642	16.7573	24.8575
0.9458	20.6403	21.8228	19.0655
1.6402	20.5685	12.5401	33.0629
0.6106	20.4248	33.4510	12.3081
1.2930	21.7657	16.8333	26.0642
0.9937	20.4727	20.6024	20.0308
0.8141	20.8797	25.6471	16.4108
0.9937	20.5445	20.6747	20.0308
1.1493	21.0474	18.3125	23.1682
0.7423	21.5741	29.0645	14.9628
1.5325	20.3290	13.2656	30.8909
1.0176	20.8797	20.5176	20.5135
0.7662	20.4966	26.7500	15.4454
0.8740	21.0713	24.1096	17.6175
0.7782	20.8797	26.8308	15.6868
0.6944	20.7840	29.9310	13.9974
0.9458	20.6642	21.8481	19.0655
0.6585	20.0417	30.4364	13.2734
1.3170	20.8558	15.8364	26.5469
1.0176	21.2150	20.8471	20.5135
1.6642	19.9699	12.0000	33.5456
0.9578	21.6460	22.6000	19.3068
1.2212	20.7840	17.0196	24.6162
1.5205	20.5685	13.5276	30.6496
1.1972	21.1671	17.6800	24.1335
0.4909	20.5206	41.8049	9.8947
1.1493	21.5741	18.7708	23.1682
0.1796	21.1671	117.8667	3.6200
1.5564	20.7121	13.3077	31.3736
0.9219	20.5445	22.2857	18.5828

0.9458	20.6642	21.8481	19.0655
1.1015	20.9995	19.0652	22.2028
0.9937	20.6164	20.7470	20.0308
1.1493	21.8854	19.0417	23.1682
0.9698	21.6220	22.2963	19.5481
0.5028	21.6460	43.0476	10.1361
0.8620	20.6403	23.9444	17.3761
0.4071	20.7840	51.0588	8.2054
1.2571	20.5206	16.3238	25.3402
0.5148	21.4065	41.5814	10.3774
0.7064	20.1614	28.5424	14.2388
0.7662	19.2515	25.1250	15.4454
1.3648	20.7121	15.1754	27.5122
0.8740	20.4248	23.3699	17.6175
1.3409	20.4248	15.2321	27.0295
0.6944	22.1249	31.8621	13.9974
1.0416	20.5685	19.7471	20.9962
0.5986	21.1192	35.2800	12.0668
1.0416	19.7543	18.9655	20.9962
0.8860	21.4305	24.1892	17.8588
0.5028	21.6939	43.1429	10.1361
0.7543	20.7600	27.5238	15.2041
0.7423	21.1192	28.4516	14.9628
0.6705	22.3643	33.3571	13.5148
1.4606	20.8558	14.2787	29.4429
0.4310	20.5685	47.7222	8.6881
0.8141	21.0474	25.8529	16.4108
0.9099	21.0713	23.1579	18.3415
0.8860	20.0417	22.6216	17.8588
0.7064	21.4305	30.3390	14.2388
1.6282	20.2572	12.4412	32.8216
0.4669	21.3108	45.6410	9.4121
1.1853	21.2389	17.9192	23.8922
1.4726	20.6642	14.0325	29.6842

1.1613	21.3108	18.3505	23.4095
0.7782	20.6403	26.5231	15.6868
1.1254	20.9276	18.5957	22.6855
0.9698	20.5685	21.2099	19.5481
0.7303	20.8319	28.5246	14.7214
1.1733	22.0291	18.7755	23.6508
1.4606	20.7121	14.1803	29.4429
1.0176	20.8558	20.4941	20.5135
0.8261	20.8079	25.1884	16.6521
0.8261	20.7121	25.0725	16.6521
1.1493	19.7783	17.2083	23.1682
0.6465	22.0291	34.0741	13.0321
0.8740	21.6699	24.7945	17.6175
0.5627	20.9995	37.3191	11.3427
0.9458	20.4009	21.5696	19.0655
0.1916	21.2868	111.1250	3.8614
0.9698	19.4910	20.0988	19.5481
1.0296	21.5263	20.9070	20.7548
1.0416	21.1910	20.3448	20.9962
0.5866	21.0952	35.9592	11.8254
1.0296	21.9573	21.3256	20.7548
0.6345	21.1192	33.2830	12.7908
1.2092	20.5685	17.0099	24.3748
0.7543	20.8079	27.5873	15.2041
0.8860	20.9995	23.7027	17.8588
0.9099	20.3051	22.3158	18.3415
1.0775	21.3347	19.8000	21.7202
0.9698	20.5445	21.1852	19.5481
1.2092	19.2276	15.9010	24.3748
1.1493	21.2389	18.4792	23.1682
0.6705	20.3530	30.3571	13.5148
0.8500	20.7600	24.4225	17.1348
0.7902	21.3826	27.0606	15.9281
0.8141	20.1614	24.7647	16.4108

1.0416	21.1910	20.3448	20.9962
1.0057	21.3108	21.1905	20.2721
0.7183	21.0474	29.3000	14.4801
0.7303	21.1671	28.9836	14.7214
0.6705	21.1910	31.6071	13.5148
0.1796	21.5263	119.8667	3.6200
1.1853	20.8079	17.5556	23.8922
0.9219	20.2572	21.9740	18.5828
1.0895	20.4966	18.8132	21.9615
0.7902	20.9995	26.5758	15.9281
0.9458	21.3108	22.5316	19.0655
1.1972	20.6403	17.2400	24.1335
1.3289	20.4966	15.4234	26.7882
0.7902	20.9516	26.5152	15.9281
1.0536	20.7361	19.6818	21.2375
0.9578	21.5741	22.5250	19.3068
0.9458	20.3530	21.5190	19.0655
0.6106	20.1614	33.0196	12.3081
1.2332	20.4966	16.6214	24.8575
0.9338	21.3586	22.8718	18.8241
0.8500	22.2446	26.1690	17.1348
0.5388	20.9037	38.8000	10.8601
1.5205	20.3290	13.3701	30.6496
0.8381	20.8797	24.9143	16.8935
0.6585	20.8558	31.6727	13.2734
0.5866	20.8319	35.5102	11.8254
1.5325	20.7121	13.5156	30.8909
0.8261	19.9459	24.1449	16.6521
0.4430	21.0474	47.5135	8.9294
0.7543	20.6642	27.3968	15.2041
1.3888	20.4487	14.7241	27.9949
1.2930	21.5263	16.6481	26.0642
1.0176	20.2572	19.9059	20.5135
1.1972	21.3108	17.8000	24.1335

1.4965	21.4544	14.3360	30.1669
0.4669	21.6460	46.3590	9.4121
0.6585	21.3108	32.3636	13.2734
0.6944	21.1192	30.4138	13.9974
0.8261	20.9037	25.3043	16.6521
0.5148	21.4305	41.6279	10.3774
1.5085	21.8136	14.4603	30.4082
1.0296	21.7418	21.1163	20.7548
0.9578	20.5685	21.4750	19.3068
0.1556	21.5502	138.4615	3.1374
0.8979	21.6699	24.1333	18.1001
0.8979	20.7121	23.0667	18.1001
1.3289	20.9037	15.7297	26.7882
0.5388	21.2629	39.4667	10.8601
0.8860	20.9995	23.7027	17.8588
0.7543	20.5924	27.3016	15.2041
0.7183	21.7657	30.3000	14.4801
0.3831	20.8319	54.3750	7.7227
0.6226	19.8262	31.8462	12.5494
0.6345	21.3108	33.5849	12.7908
1.9754	17.1204	8.6667	39.8203
0.8860	21.1192	23.8378	17.8588
0.9578	21.2629	22.2000	19.3068
0.4190	21.7896	52.0000	8.4467
0.4310	20.9516	48.6111	8.6881
0.9817	21.6699	22.0732	19.7895
0.4190	21.4544	51.2000	8.4467
0.5268	21.9333	41.6364	10.6187
0.7662	21.8854	28.5625	15.4454
0.6944	22.1009	31.8276	13.9974
0.7543	22.3404	29.6190	15.2041
0.5627	21.6939	38.5532	11.3427
1.2691	21.1192	16.6415	25.5815
0.7064	21.0713	29.8305	14.2388

1.1374	20.8797	18.3579	22.9268
0.4071	21.3347	52.4118	8.2054
0.6106	19.7304	32.3137	12.3081
0.3113	19.8022	63.6154	6.2747
0.2514	20.1135	80.0000	5.0680
0.1437	21.0474	146.5000	2.8960
0.5747	19.2755	33.5417	11.5841
0.3831	19.4431	50.7500	7.7227
0.8860	19.1797	21.6486	17.8588
0.9937	20.8079	20.9398	20.0308
0.9698	22.3164	23.0123	19.5481
0.5507	22.0530	40.0435	11.1014
0.6705	22.2925	33.2500	13.5148
0.5627	22.1728	39.4043	11.3427
0.8261	21.3826	25.8841	16.6521
0.6705	22.6038	33.7143	13.5148
1.2930	22.5319	17.4259	26.0642
0.6585	21.1671	32.1455	13.2734
0.7782	20.9516	26.9231	15.6868
0.6226	21.0474	33.8077	12.5494
0.8141	19.6107	24.0882	16.4108
0.5747	21.1910	36.8750	11.5841
1.4726	20.6882	14.0488	29.6842
0.6345	21.5023	33.8868	12.7908
1.1134	20.2093	18.1505	22.4442
0.4310	20.7600	48.1667	8.6881
0.5866	20.6403	35.1837	11.8254
0.4071	21.8375	53.6471	8.2054
2.6938	42.2623	15.6889	54.3004
2.0592	42.8849	20.8256	41.5096
2.7057	43.5793	16.1062	54.5417
2.1550	43.9145	20.3778	43.4403
2.0592	44.0821	21.4070	41.5096
2.4663	43.1483	17.4951	49.7150

2.4783	41.5919	16.7826	49.9564
1.8198	43.0286	23.6447	36.6829
2.8374	41.7116	14.7004	57.1964
2.1311	42.3821	19.8876	42.9576
2.1790	41.4961	19.0440	43.9230
1.9395	42.5497	21.9383	39.0963
2.6698	41.4482	15.5247	53.8177
2.0832	42.0229	20.1724	41.9923
2.6818	41.2806	15.3929	54.0591
2.2269	42.7173	19.1828	44.8883
2.2987	42.4060	18.4479	46.3363
2.3226	42.5976	18.3402	46.8190
2.7297	43.0046	15.7544	55.0244
2.1550	43.4596	20.1667	43.4403
2.4663	43.7948	17.7573	49.7150
1.8916	43.5793	23.0380	38.1309
2.5142	42.9567	17.0857	50.6804
2.5381	43.3398	17.0755	51.1630
2.3945	42.8849	17.9100	48.2670
2.0233	43.6032	21.5503	40.7856
2.4663	42.5497	17.2524	49.7150
2.0473	43.2920	21.1462	41.2683
3.1846	42.5497	13.3609	64.1951
2.3705	42.7173	18.0202	47.7843
2.8135	41.5679	14.7745	56.7137
2.4064	43.2201	17.9602	48.5084
2.0592	42.1905	20.4884	41.5096
2.3945	43.4596	18.1500	48.2670
2.1071	42.2623	20.0568	42.4750
2.0952	42.5976	20.3314	42.2336
2.5381	42.0708	16.5755	51.1630
2.4304	41.5919	17.1133	48.9910
2.8374	42.0468	14.8186	57.1964
2.2867	42.7173	18.6806	46.0950

2.5262	41.5919	16.4645	50.9217
2.5501	41.7356	16.3662	51.4044
2.5860	42.2144	16.3241	52.1284
2.2149	43.0286	19.4270	44.6470
2.2867	41.1369	17.9895	46.0950
2.0952	43.4117	20.7200	42.2336
2.2987	42.9567	18.6875	46.3363
2.0832	42.9088	20.5977	41.9923
2.5741	42.4299	16.4837	51.8870
2.2628	42.1905	18.6455	45.6123
2.3346	41.8792	17.9385	47.0603
2.4304	43.7230	17.9901	48.9910
2.6938	42.9088	15.9289	54.3004
2.4902	41.5440	16.6827	50.1977
2.2508	42.9328	19.0745	45.3710
1.5684	41.7356	26.6107	31.6149
2.3945	41.4961	17.3300	48.2670
2.0952	41.5440	19.8286	42.2336
1.8198	41.3524	22.7237	36.6829
1.9515	42.4299	21.7423	39.3376
1.9036	41.7356	21.9245	38.3723
2.5022	43.1243	17.2344	50.4390
2.8614	42.9567	15.0126	57.6791
2.2987	43.1243	18.7604	46.3363
2.4783	41.5440	16.7633	49.9564
2.4902	43.0046	17.2692	50.1977
2.6698	42.5497	15.9372	53.8177
2.3825	43.4835	18.2513	48.0257
2.3107	41.7116	18.0518	46.5777
2.4424	42.8849	17.5588	49.2324
2.1311	43.0286	20.1910	42.9576
2.3346	41.5440	17.7949	47.0603
2.6579	41.7595	15.7117	53.5764
2.4783	42.4060	17.1111	49.9564

2.3825	40.7299	17.0955	48.0257
2.0952	41.6877	19.8971	42.2336
2.3705	40.9693	17.2828	47.7843
2.1550	42.5497	19.7444	43.4403
2.8255	42.7891	15.1441	56.9551
2.3825	41.2806	17.3266	48.0257
2.3825	41.8553	17.5678	48.0257
2.7057	43.4356	16.0531	54.5417
2.1670	42.5976	19.6575	43.6816
2.2388	43.0286	19.2193	45.1297
2.5022	42.6933	17.0622	50.4390
1.8437	44.4652	24.1169	37.1656
2.9452	42.9088	14.5691	59.3684
2.3346	44.2497	18.9538	47.0603
2.5741	41.5919	16.1581	51.8870
2.1550	42.6694	19.8000	43.4403
2.4424	43.1483	17.6667	49.2324
2.3945	43.1243	18.0100	48.2670
2.2628	42.6454	18.8466	45.6123
2.1311	43.0525	20.2022	42.9576
2.4184	41.9750	17.3564	48.7497
2.1670	41.9032	19.3370	43.6816
2.4902	42.2384	16.9615	50.1977
1.8318	42.2863	23.0850	36.9243
2.4663	42.4539	17.2136	49.7150
2.4064	42.6215	17.7114	48.5084
2.6698	40.6102	15.2108	53.8177
2.2508	42.7652	19.0000	45.3710
2.6938	41.8074	15.5200	54.3004
2.2747	42.8370	18.8316	45.8537
2.1550	42.2863	19.6222	43.4403
2.4424	42.9807	17.5980	49.2324
2.9093	42.3581	14.5597	58.6444
2.2029	42.8609	19.4565	44.4057

2.2029 2.4064	42.2623 43.4117	19.1848 18.0398	44.4057 48.5084
2.3466	41.9750	17.8878	47.3017
2.4902	43.8187	17.5962	50.1977
2.6459	43.1483	16.3077	53.3351
2.8734	43.1004	15.0000	57.9204
2.3466	43.0765	18.3571	47.3017
1.8078	42.1666	23.3245	36.4416
1.9994	42.1187	21.0659	40.3030
2.5262	41.2806	16.3412	50.9217
2.9572	43.0286	14.5506	59.6098
1.9156	42.9807	22.4375	38.6136
2.3585	42.0229	17.8173	47.5430
2.0473	42.6933	20.8538	41.2683
2.8374	41.7356	14.7089	57.1964
2.6818	42.8849	15.9911	54.0591
2.2747	41.2567	18.1368	45.8537
2.1790	43.3877	19.9121	43.9230
2.3705	43.2201	18.2323	47.7843
2.0114	42.5736	21.1667	40.5443
2.2508	42.5018	18.8830	45.3710
2.1191	43.1004	20.3390	42.7163
2.1550	42.5736	19.7556	43.4403
2.2867	44.2976	19.3717	46.0950
2.0832	42.8609	20.5747	41.9923
2.3585	42.4778	18.0102	47.5430
2.2628	41.5440	18.3598	45.6123
2.4663	43.6272	17.6893	49.7150
2.5262	41.9032	16.5877	50.9217
1.9994	43.4117	21.7126	40.3030
2.4424	42.2384	17.2941	49.2324
2.4424	43.9863	18.0098	49.2324
2.4902	42.0708	16.8942	50.1977
1.6402	42.1426	25.6934	33.0629

2.5262	41.2327	16.3223	50.9217
1.7719	42.4299	23.9459	35.7176
2.3825	42.5018	17.8392	48.0257
1.9635	42.0468	21.4146	39.5790
2.6100	42.4299	16.2569	52.6110
2.2628	41.8074	18.4762	45.6123
2.5860	42.3821	16.3889	52.1284
1.9036	42.8370	22.5031	38.3723
2.8135	41.8313	14.8681	56.7137
2.1909	42.1187	19.2240	44.1643
3.0051	42.6215	14.1833	60.5751
2.2628	42.5257	18.7937	45.6123
2.3466	41.9271	17.8673	47.3017
2.2029	42.8849	19.4674	44.4057
2.4902	43.6990	17.5481	50.1977
1.8916	42.0468	22.2278	38.1309
2.6459	41.8313	15.8100	53.3351
2.0473	43.4117	21.2047	41.2683
2.4184	41.6158	17.2079	48.7497
2.3825	42.9328	18.0201	48.0257
2.4064	42.4539	17.6418	48.5084
2.3585	42.7173	18.1117	47.5430
2.2269	41.6877	18.7204	44.8883
2.2987	42.8849	18.6562	46.3363
2.2508	41.3524	18.3723	45.3710
2.4543	41.8792	17.0634	49.4737
2.2628	41.6637	18.4127	45.6123
2.4184	42.5018	17.5743	48.7497
2.4783	42.2384	17.0435	49.9564
2.4304	41.9032	17.2414	48.9910
2.4424	42.1666	17.2647	49.2324
2.6818	42.7652	15.9464	54.0591
2.8374	42.0229	14.8101	57.1964
2.0353	43.6751	21.4588	41.0270

2.6818	42.5257	15.8571	54.0591
1.7839	41.6877	23.3691	35.9589
2.6818	43.1483	16.0893	54.0591
2.3466	43.0286	18.3367	47.3017
3.1128	41.9989	13.4923	62.7471
2.2987	43.3877	18.8750	46.3363
2.2987	42.6933	18.5729	46.3363
2.4184	43.0046	17.7822	48.7497
2.7896	41.1369	14.7468	56.2311
2.4543	42.2863	17.2293	49.4737
2.3466	42.1187	17.9490	47.3017
2.0952	42.7891	20.4229	42.2336
2.7776	42.1426	15.1724	55.9897
2.5022	41.1130	16.4306	50.4390
2.1550	42.5257	19.7333	43.4403
2.2508	42.8131	19.0213	45.3710
2.4543	42.1426	17.1707	49.4737
2.5860	43.4835	16.8148	52.1284
2.2867	42.2863	18.4921	46.0950
2.2747	43.6511	19.1895	45.8537
2.7776	42.4539	15.2845	55.9897
2.2508	43.0525	19.1277	45.3710
2.6219	41.8792	15.9726	52.8524
2.5022	42.8609	17.1292	50.4390
2.1071	42.8849	20.3523	42.4750
2.4424	41.6398	17.0490	49.2324
2.7656	41.4722	14.9957	55.7484
2.0114	43.9145	21.8333	40.5443
2.2987	43.1483	18.7708	46.3363
2.3107	42.4060	18.3523	46.5777
1.9395	43.0765	22.2099	39.0963
1.9275	42.4299	22.0124	38.8549
2.2149	42.0708	18.9946	44.6470
2.3825	43.0765	18.0804	48.0257

2.3825	41.9511	17.6080	48.0257
1.9036	41.4003	21.7484	38.3723
1.7599	41.6398	23.6599	35.4763
2.1550	42.5497	19.7444	43.4403
2.4783	43.5314	17.5652	49.9564
2.5860	41.8792	16.1944	52.1284
2.3226	42.3102	18.2165	46.8190
2.4902	41.4243	16.6346	50.1977
2.6100	43.4117	16.6330	52.6110
2.2269	41.8553	18.7957	44.8883
2.5262	42.9807	17.0142	50.9217
2.3226	43.2680	18.6289	46.8190
2.2508	43.7230	19.4255	45.3710
2.1909	43.3877	19.8033	44.1643
2.5381	42.1905	16.6226	51.1630
2.3107	43.3398	18.7565	46.5777
2.5741	41.9750	16.3070	51.8870
2.1311	42.5976	19.9888	42.9576
2.0233	42.6454	21.0769	40.7856
2.3825	41.8792	17.5779	48.0257
2.0832	43.1243	20.7011	41.9923
2.0353	43.4117	21.3294	41.0270
2.1670	41.8074	19.2928	43.6816
2.5621	40.8257	15.9346	51.6457
2.0114	43.0286	21.3929	40.5443
2.1191	43.9624	20.7458	42.7163
2.4064	42.5018	17.6617	48.5084
2.6579	41.5919	15.6486	53.5764
2.3226	43.0765	18.5464	46.8190
2.3226	43.5793	18.7629	46.8190
1.9395	43.1483	22.2469	39.0963
2.3107	43.4835	18.8187	46.5777
2.3585	41.6158	17.6447	47.5430
2.4663	43.2680	17.5437	49.7150

2.3466	42.7652	18.2245	47.3017
2.4304	43.0765	17.7241	48.9910
2.1071	44.0342	20.8977	42.4750
2.1071	42.3342	20.0909	42.4750
1.9156	43.0046	22.4500	38.6136
2.3226	42.3102	18.2165	46.8190
2.2388	43.5314	19.4439	45.1297
2.3107	42.4539	18.3731	46.5777
2.6579	42.6215	16.0360	53.5764
2.6938	42.6933	15.8489	54.3004
2.3346	42.1905	18.0718	47.0603
2.5741	41.1609	15.9907	51.8870
2.0592	43.0525	20.9070	41.5096
2.0952	42.2623	20.1714	42.2336
2.0952	42.3102	20.1943	42.2336
2.1311	43.1004	20.2247	42.9576
2.0712	42.5497	20.5434	41.7510
2.4543	42.3581	17.2585	49.4737
2.4783	42.2863	17.0628	49.9564
2.2628	42.2863	18.6878	45.6123
2.5142	43.5793	17.3333	50.6804
2.2149	42.8370	19.3405	44.6470
1.9515	42.0708	21.5583	39.3376
2.1191	41.6398	19.6497	42.7163
2.3825	41.8553	17.5678	48.0257
2.0592	42.8131	20.7907	41.5096
2.5501	42.4060	16.6291	51.4044
2.6459	42.0708	15.9005	53.3351
2.0712	42.3342	20.4393	41.7510
2.3466	42.5976	18.1531	47.3017
2.3466	42.6454	18.1735	47.3017
1.8677	42.7173	22.8718	37.6483
2.0952	42.4060	20.2400	42.2336
2.1071	42.7412	20.2841	42.4750

2.2269	42.0468	18.8817	44.8883
2.2508	43.6032	19.3723	45.3710
2.4902	43.2920	17.3846	50.1977
2.4304	42.9088	17.6552	48.9910
1.9994	42.9328	21.4731	40.3030
2.6818	42.1666	15.7232	54.0591
1.9395	43.4356	22.3951	39.0963
1.6881	42.5018	25.1773	34.0282
2.1311	43.0525	20.2022	42.9576
2.8135	42.9567	15.2681	56.7137
1.9036	42.3821	22.2642	38.3723
2.2388	42.8370	19.1337	45.1297
2.0832	43.1962	20.7356	41.9923
2.3705	42.0708	17.7475	47.7843
2.1430	42.8131	19.9777	43.1990
2.6339	43.0286	16.3364	53.0937
1.9994	43.4596	21.7365	40.3030
2.3107	42.2863	18.3005	46.5777
2.3226	42.7412	18.4021	46.8190
2.5501	42.3821	16.6197	51.4044
2.0114	42.8609	21.3095	40.5443
2.1790	44.2258	20.2967	43.9230
2.2388	42.8370	19.1337	45.1297
2.3705	43.7948	18.4747	47.7843
2.5142	43.1483	17.1619	50.6804
2.1670	41.1369	18.9834	43.6816
2.6100	43.1483	16.5321	52.6110
2.5262	42.6454	16.8815	50.9217
2.3346	41.4722	17.7641	47.0603
2.1670	43.8427	20.2320	43.6816
2.4304	42.3581	17.4286	48.9910
2.1670	42.0708	19.4144	43.6816
2.3585	43.2201	18.3249	47.5430
2.2149	41.4961	18.7351	44.6470

1.9994	41.5679	20.7904	40.3030
2.1311	42.8609	20.1124	42.9576
2.1550	42.0229	19.5000	43.4403
2.1790	43.9863	20.1868	43.9230
1.9994	43.2680	21.6407	40.3030
2.6579	42.4539	15.9730	53.5764
1.5444	42.0229	27.2093	31.1322
2.4184	42.8849	17.7327	48.7497
1.9754	42.6694	21.6000	39.8203
1.9874	42.2144	21.2410	40.0616
2.2029	42.2623	19.1848	44.4057
1.8797	42.3821	22.5478	37.8896
2.1670	43.0286	19.8564	43.6816
1.9395	42.6933	22.0123	39.0963
2.1790	42.4060	19.4615	43.9230
1.9036	43.1483	22.6667	38.3723
2.3346	42.3102	18.1231	47.0603
2.3107	43.4596	18.8083	46.5777
2.2747	42.7173	18.7789	45.8537
1.9994	42.4778	21.2455	40.3030
2.2029	43.5075	19.7500	44.4057
1.9275	41.9750	21.7764	38.8549
2.1909	43.6990	19.9454	44.1643
2.1430	43.0286	20.0782	43.1990
2.0832	43.1962	20.7356	41.9923
2.1790	43.3159	19.8791	43.9230
2.5741	41.9989	16.3163	51.8870
2.5501	42.0229	16.4789	51.4044
2.7536	43.4835	15.7913	55.5071
2.2149	43.0046	19.4162	44.6470
2.6938	42.2623	15.6889	54.3004
2.1670	42.1666	19.4586	43.6816
2.1550	41.6877	19.3444	43.4403
1.8916	43.4117	22.9494	38.1309

2.2867	42.0947	18.4084	46.0950
2.0952	43.5075	20.7657	42.2336
2.3945	42.4778	17.7400	48.2670
1.7599	42.7891	24.3129	35.4763
2.1670	42.6694	19.6906	43.6816
2.0592	43.4835	21.1163	41.5096
2.2867	42.8370	18.7330	46.0950
2.0233	43.6990	21.5976	40.7856
2.7896	43.3398	15.5365	56.2311
1.9994	42.2144	21.1138	40.3030
2.4783	43.0765	17.3816	49.9564
2.0952	43.6032	20.8114	42.2336
2.0952	41.9511	20.0229	42.2336
2.4424	43.9145	17.9804	49.2324
2.2269	43.0286	19.3226	44.8883
2.9452	43.0525	14.6179	59.3684
2.0233	41.9271	20.7219	40.7856
2.1191	42.9567	20.2712	42.7163
2.4064	42.3102	17.5821	48.5084
1.8198	42.8131	23.5263	36.6829
2.2867	41.9032	18.3246	46.0950
2.0952	42.3342	20.2057	42.2336
1.9754	41.5200	21.0182	39.8203
1.9036	42.3342	22.2390	38.3723
2.4304	42.5257	17.4975	48.9910
2.2628	43.3398	19.1534	45.6123
2.1311	42.5736	19.9775	42.9576
1.9275	43.0765	22.3478	38.8549
2.5142	43.1483	17.1619	50.6804
2.4783	43.4117	17.5169	49.9564
2.3825	42.2863	17.7487	48.0257
2.1071	43.2201	20.5114	42.4750
2.4663	43.9145	17.8058	49.7150
2.2029	43.1962	19.6087	44.4057

1.9754	42.8849	21.7091	39.8203
1.7360	42.4060	24.4276	34.9936
2.4304	42.7652	17.5961	48.9910
2.3346	43.1962	18.5026	47.0603
2.2867	43.1483	18.8691	46.0950
2.1670	41.5200	19.1602	43.6816
2.2269	42.6454	19.1505	44.8883
2.1311	42.4539	19.9213	42.9576
2.3945	41.7116	17.4200	48.2670
2.4663	43.3638	17.5825	49.7150
2.5860	41.7834	16.1574	52.1284
2.2747	42.6454	18.7474	45.8537
2.7536	41.4722	15.0609	55.5071
2.3705	43.0286	18.1515	47.7843
2.8374	41.7834	14.7257	57.1964
2.1790	42.6215	19.5604	43.9230
2.2628	42.6694	18.8571	45.6123
2.3825	43.3159	18.1809	48.0257
2.6100	42.7412	16.3761	52.6110
2.4424	43.4835	17.8039	49.2324
3.3523	65.2492	19.4643	67.5738
2.9691	65.0337	21.9032	59.8511
3.5797	64.2675	17.9532	72.1592
3.3642	64.4830	19.1673	67.8152
3.8311	64.9858	16.9625	77.2272
3.3642	63.8844	18.9893	67.8152
4.1903	65.2253	15.5657	84.4673
3.5678	64.1238	17.9732	71.9179
3.4839	64.1238	18.4055	70.2285
3.9150	63.3336	16.1774	78.9166
3.7713	64.4830	17.0984	76.0205
3.2445	64.0759	19.7491	65.4018
3.2924	63.6210	19.3236	66.3671
3.6875	64.8900	17.5974	74.3312

3.9269	64.2435	16.3598	79.1579
3.6755	64.0041	17.4137	74.0899
3.1487	63.9083	20.2966	63.4711
3.0051	65.7999	21.8964	60.5751
4.3699	64.0520	14.6575	88.0873
3.1607	63.2379	20.0076	63.7125
3.2565	64.1238	19.6912	65.6431
2.9332	64.8182	22.0980	59.1271
3.4959	64.2914	18.3904	70.4698
3.3882	63.9323	18.8693	68.2978
3.5318	62.9505	17.8237	71.1938
3.2445	64.5069	19.8819	65.4018
3.5678	64.3393	18.0336	71.9179
2.9572	65.4408	22.1296	59.6098
3.5318	64.8182	18.3525	71.1938
3.2445	64.2914	19.8155	65.4018
3.3523	65.0577	19.4071	67.5738
3.3523	64.7224	19.3071	67.5738
3.1008	62.4716	20.1467	62.5058
3.5797	64.6745	18.0669	72.1592
3.1128	62.8547	20.1923	62.7471
2.9332	64.8661	22.1143	59.1271
2.9691	64.4590	21.7097	59.8511
2.9093	63.7886	21.9259	58.6444
3.0769	63.2618	20.5603	62.0231
2.7417	63.0463	22.9956	55.2657
3.0051	63.9801	21.2908	60.5751
2.8614	64.6506	22.5941	57.6791
3.4600	64.0280	18.5052	69.7458
2.5621	64.2196	25.0654	51.6457
3.3403	63.5731	19.0323	67.3325
3.2086	63.9083	19.9179	64.6778
3.1966	63.8844	19.9850	64.4365
2.5262	64.4590	25.5166	50.9217

3.4480	64.9858	18.8472	69.5045
2.6219	65.4887	24.9772	52.8524
3.3163	63.0702	19.0181	66.8498
3.0529	64.7224	21.2000	61.5404
3.3642	64.1238	19.0605	67.8152
3.3163	64.0759	19.3213	66.8498
3.1008	64.9379	20.9421	62.5058
3.2684	64.3393	19.6850	65.8845
2.9931	64.7464	21.6320	60.3338
2.6339	64.8661	24.6273	53.0937
3.1248	64.3393	20.5900	62.9885
3.4121	64.2914	18.8421	68.7805
3.0529	63.8844	20.9255	61.5404
3.3762	65.6084	19.4326	68.0565
3.4241	64.0041	18.6923	69.0218
2.8614	64.8661	22.6695	57.6791
3.4241	64.0999	18.7203	69.0218
2.4304	64.2435	26.4335	48.9910
3.1248	62.1603	19.8927	62.9885
2.8015	63.8604	22.7949	56.4724
3.1727	64.6745	20.3849	63.9538
3.0051	64.5548	21.4821	60.5751
3.8671	64.5548	16.6935	77.9512
2.7177	65.0098	23.9207	54.7831
3.0649	64.9619	21.1953	61.7818
2.7297	64.8182	23.7456	55.0244
3.0769	64.0759	20.8249	62.0231
2.7656	64.2914	23.2468	55.7484
3.3642	64.5548	19.1886	67.8152
2.9332	64.9619	22.1469	59.1271
3.2924	64.0520	19.4545	66.3671
2.8973	65.7520	22.6942	58.4031
3.8910	64.0999	16.4738	78.4339
3.4241	64.9379	18.9650	69.0218

3.0649	65.7999	21.4687	61.7818
3.0649	64.0520	20.8984	61.7818
3.5917	64.3872	17.9267	72.4005
2.7776	64.8661	23.3534	55.9897
3.7354	63.8844	17.1026	75.2965
3.0290	64.0041	21.1304	61.0578
3.3523	63.7886	19.0286	67.5738
3.1607	64.4590	20.3939	63.7125
3.1368	65.3450	20.8321	63.2298
2.7656	64.1956	23.2121	55.7484
3.1487	63.5970	20.1977	63.4711
2.7297	64.8422	23.7544	55.0244
3.1846	64.9140	20.3835	64.1951
3.3044	64.5548	19.5362	66.6085
3.7234	63.9083	17.1640	75.0552
3.1966	64.0999	20.0524	64.4365
3.4001	63.6449	18.7183	68.5392
2.8494	63.9323	22.4370	57.4377
3.3283	63.5731	19.1007	67.0912
3.4001	65.8957	19.3803	68.5392
3.2086	65.6084	20.4478	64.6778
2.9332	64.3633	21.9429	59.1271
3.1368	64.2675	20.4885	63.2298
3.0051	63.5970	21.1633	60.5751
3.2206	64.3154	19.9703	64.9191
3.2086	63.5491	19.8060	64.6778
3.5199	64.7703	18.4014	70.9525
2.8494	63.8125	22.3950	57.4377
3.3762	64.0999	18.9858	68.0565
3.0529	64.4351	21.1059	61.5404
3.4001	64.6506	19.0141	68.5392
3.1966	63.4055	19.8352	64.4365
3.1487	63.6689	20.2205	63.4711
2.6459	64.9619	24.5520	53.3351

2.8734	64.0999	22.3083	57.9204
2.8374	64.4111	22.7004	57.1964
3.7114	65.1295	17.5484	74.8139
2.6219	63.6449	24.2740	52.8524
2.9691	64.8661	21.8468	59.8511
2.6339	64.9619	24.6636	53.0937
3.1966	64.4111	20.1498	64.4365
2.2269	63.9801	28.7312	44.8883
3.4121	64.4351	18.8842	68.7805
2.8374	64.6745	22.7932	57.1964
2.8255	65.2492	23.0932	56.9551
3.3403	64.7703	19.3907	67.3325
3.2445	63.5252	19.5793	65.4018
3.1128	65.1055	20.9154	62.7471
2.6339	64.9140	24.6455	53.0937
2.9212	63.9801	21.9016	58.8858
3.2445	63.1900	19.4760	65.4018
2.8374	64.0759	22.5823	57.1964
2.9572	63.5970	21.5061	59.6098
2.9572	64.4590	21.7976	59.6098
3.7234	63.2857	16.9968	75.0552
2.9332	63.9083	21.7878	59.1271
3.1368	63.4055	20.2137	63.2298
2.6459	63.5731	24.0271	53.3351
3.8311	64.3154	16.7875	77.2272
2.5381	64.8182	25.5377	51.1630
3.1487	62.9505	19.9924	63.4711
3.1846	64.9140	20.3835	64.1951
3.2086	63.6449	19.8358	64.6778
3.1008	65.0577	20.9807	62.5058
3.6516	64.5548	17.6787	73.6072
2.6938	65.4887	24.3111	54.3004
3.4720	64.8900	18.6897	69.9872
2.8015	64.9858	23.1966	56.4724

3.7952	63.6928	16.7823	76.5032
2.9691	65.1295	21.9355	59.8511
3.5797	64.4830	18.0134	72.1592
2.9093	64.4830	22.1646	58.6444
3.4121	62.9984	18.4632	68.7805
3.0290	65.0577	21.4783	61.0578
3.1487	64.0280	20.3346	63.4711
2.8614	63.8365	22.3096	57.6791
3.7114	64.4351	17.3613	74.8139
2.8734	65.6323	22.8417	57.9204
3.2565	63.8365	19.6029	65.6431
3.3044	65.6084	19.8551	66.6085
3.6156	63.7168	17.6225	72.8832
2.7536	64.2914	23.3478	55.5071
3.1487	63.2139	20.0760	63.4711
2.7656	65.3450	23.6277	55.7484
3.6276	64.6267	17.8152	73.1245
2.4902	65.9915	26.5000	50.1977
3.3163	64.0280	19.3069	66.8498
2.8853	64.4590	22.3402	58.1618
3.2445	63.9562	19.7122	65.4018
2.7417	64.6506	23.5808	55.2657
3.3044	64.8182	19.6159	66.6085
3.0529	64.6027	21.1608	61.5404
3.5558	63.7407	17.9259	71.6765
2.8973	64.9619	22.4215	58.4031
3.7833	64.6745	17.0949	76.2619
2.0353	64.0041	31.4471	41.0270
3.4959	64.8661	18.5548	70.4698
2.4543	65.0577	26.5073	49.4737
3.8311	63.3336	16.5313	77.2272
2.4902	65.3210	26.2308	50.1977
3.2206	63.7168	19.7844	64.9191
2.5860	65.6323	25.3796	52.1284

3.2804	63.7886	19.4453	66.1258
3.4480	64.1956	18.6181	69.5045
3.5917	64.0280	17.8267	72.4005
2.5741	64.6745	25.1256	51.8870
3.5678	63.7646	17.8725	71.9179
2.7177	65.4168	24.0705	54.7831
2.9931	65.3450	21.8320	60.3338
2.4424	65.2492	26.7157	49.2324
3.7114	63.9801	17.2387	74.8139
2.6698	63.8125	23.9013	53.8177
3.3403	64.0520	19.1756	67.3325
2.6938	65.3929	24.2756	54.3004
3.4361	64.7464	18.8432	69.2632
2.7417	64.9140	23.6769	55.2657
3.3403	64.0520	19.1756	67.3325
3.1487	64.6745	20.5399	63.4711
2.9931	64.8661	21.6720	60.3338
3.1487	64.7224	20.5551	63.4711
3.0529	63.9083	20.9333	61.5404
3.5079	65.7042	18.7304	70.7112
3.4959	64.6745	18.5000	70.4698
3.2924	66.0154	20.0509	66.3671
3.6276	65.2253	17.9802	73.1245
2.8614	65.1534	22.7699	57.6791
3.3403	63.8125	19.1039	67.3325
3.4480	64.6027	18.7361	69.5045
3.3762	66.1831	19.6028	68.0565
3.2325	65.8718	20.3778	65.1605
3.4720	65.0337	18.7310	69.9872
3.3044	65.1774	19.7246	66.6085
3.3163	65.1774	19.6534	66.8498
3.1727	65.4168	20.6189	63.9538
3.2325	66.0394	20.4296	65.1605
3.1487	65.0816	20.6692	63.4711

2.9691	65.2732	21.9839	59.8511
3.3642	64.5788	19.1957	67.8152
3.2445	64.4590	19.8672	65.4018
3.3044	65.0337	19.6812	66.6085
3.2684	65.1295	19.9267	65.8845
3.3523	65.9915	19.6857	67.5738
3.5079	64.0759	18.2662	70.7112
2.9691	65.2013	21.9597	59.8511
3.6635	65.4408	17.8627	73.8485
2.5741	64.2435	24.9581	51.8870
3.1966	65.2492	20.4120	64.4365
3.5917	64.6506	18.0000	72.4005
3.5558	64.6745	18.1886	71.6765
3.2206	65.2492	20.2602	64.9191
3.4959	64.3154	18.3973	70.4698
3.2325	64.7943	20.0444	65.1605
3.2445	64.3872	19.8450	65.4018
3.3403	66.5901	19.9355	67.3325
3.1846	65.3689	20.5263	64.1951
3.0410	65.8239	21.6457	61.2991
3.2086	65.3450	20.3657	64.6778
3.0410	64.5788	21.2362	61.2991
3.1008	66.0633	21.3050	62.5058
3.6037	64.0520	17.7741	72.6419
3.3403	64.8661	19.4194	67.3325
3.7713	64.9858	17.2317	76.0205
3.4241	65.1055	19.0140	69.0218
3.3283	64.6267	19.4173	67.0912
3.4959	64.0759	18.3288	70.4698
3.1607	65.9676	20.8712	63.7125
2.6818	65.7042	24.5000	54.0591
2.9811	64.8182	21.7430	60.0924
3.0290	65.8239	21.7312	61.0578
3.2445	64.8661	19.9926	65.4018

3.1846	65.2013	20.4737	64.1951
2.9811	65.0337	21.8153	60.0924
3.5797	65.9197	18.4147	72.1592
3.4241	65.5605	19.1469	69.0218
3.4839	65.5844	18.8247	70.2285
2.9931	66.0154	22.0560	60.3338
3.0649	65.3210	21.3125	61.7818
3.4600	65.2971	18.8720	69.7458
2.9811	64.3872	21.5984	60.0924
3.5318	64.0041	18.1220	71.1938
2.9811	65.2492	21.8876	60.0924
3.4959	64.6985	18.5068	70.4698
3.8072	65.1055	17.1006	76.7446
3.1368	65.9915	21.0382	63.2298
3.2565	64.0759	19.6765	65.6431
3.1727	64.9379	20.4679	63.9538
3.3403	64.3154	19.2545	67.3325
3.4480	65.2253	18.9167	69.5045
3.3044	64.7464	19.5942	66.6085
3.2684	64.8900	19.8535	65.8845
3.1966	64.7703	20.2622	64.4365
3.3882	64.5309	19.0459	68.2978
3.1487	65.6084	20.8365	63.4711
2.8494	65.1534	22.8655	57.4377
3.6156	65.2013	18.0331	72.8832
3.0290	65.3210	21.5652	61.0578
3.1727	64.4351	20.3094	63.9538
3.4480	63.6928	18.4722	69.5045
3.2445	64.5788	19.9041	65.4018
3.4839	65.1534	18.7010	70.2285
3.0051	65.7999	21.8964	60.5751
3.3882	64.6267	19.0742	68.2978
3.1487	65.2253	20.7148	63.4711
3.5558	65.4887	18.4175	71.6765

3.6396	64.2914	17.6645	73.3659
3.9509	65.1295	16.4848	79.6406
2.7776	65.2253	23.4828	55.9897
3.0889	65.3689	21.1628	62.2645
3.7234	65.4408	17.5756	75.0552
3.1727	65.7281	20.7170	63.9538
3.3403	64.3633	19.2688	67.3325
3.3044	65.3689	19.7826	66.6085
3.5438	65.3450	18.4392	71.4352
3.2804	65.1295	19.8540	66.1258
3.2086	66.1831	20.6269	64.6778
3.2804	64.4830	19.6569	66.1258
3.4959	65.7520	18.8082	70.4698
2.8374	64.6506	22.7848	57.1964
3.3044	64.6985	19.5797	66.6085
3.1128	64.8661	20.8385	62.7471
3.6037	64.5788	17.9203	72.6419
3.1607	65.0577	20.5833	63.7125
3.2684	64.9140	19.8608	65.8845
3.5438	65.2253	18.4054	71.4352
3.3283	65.5605	19.6978	67.0912
3.6037	65.8957	18.2857	72.6419
3.3283	65.6323	19.7194	67.0912
3.1487	64.6027	20.5171	63.4711
3.3642	66.0394	19.6299	67.8152
3.4480	66.3746	19.2500	69.5045
3.2684	64.9858	19.8828	65.8845
2.7656	65.2253	23.5844	55.7484
3.4720	64.9140	18.6966	69.9872
2.9811	66.3986	22.2731	60.0924
3.6995	64.6027	17.4628	74.5725
3.8192	65.3450	17.1097	76.9859
3.4001	65.3929	19.2324	68.5392
3.1248	64.4830	20.6360	62.9885

3.1846	65.2253	20.4812	64.1951
2.6938	64.8661	24.0800	54.3004
3.4001	65.3210	19.2113	68.5392
2.8614	65.4168	22.8619	57.6791
3.3642	65.7042	19.5302	67.8152
3.1368	65.4408	20.8626	63.2298
3.3403	64.0759	19.1828	67.3325
2.5860	65.7042	25.4074	52.1284
3.0529	65.4887	21.4510	61.5404
2.9452	64.8422	22.0163	59.3684
2.7417	64.5069	23.5284	55.2657
2.8374	65.3689	23.0380	57.1964
3.2924	64.4590	19.5782	66.3671
3.2206	66.0154	20.4981	64.9191
3.7234	66.0154	17.7299	75.0552
3.8311	65.8718	17.1938	77.2272
3.1008	65.2732	21.0502	62.5058
3.6396	65.6084	18.0263	73.3659
3.4361	64.3393	18.7247	69.2632
3.5558	64.7464	18.2088	71.6765
3.0410	64.6985	21.2756	61.2991
2.8614	65.1055	22.7531	57.6791
3.3642	65.4647	19.4591	67.8152
3.4361	64.6027	18.8014	69.2632
3.6037	65.8478	18.2724	72.6419
3.1727	64.7464	20.4075	63.9538
3.5438	64.8422	18.2973	71.4352
3.2804	66.2070	20.1825	66.1258
2.9093	63.3097	21.7613	58.6444
2.8374	65.2492	22.9958	57.1964
3.8910	64.5548	16.5908	78.4339
3.3044	64.2196	19.4348	66.6085
3.4839	64.9140	18.6323	70.2285
3.2684	64.7464	19.8095	65.8845

3.0889	65.0098	21.0465	62.2645
3.0410	66.5662	21.8898	61.2991
2.9931	65.9197	22.0240	60.3338
3.1966	65.3689	20.4494	64.4365
3.4001	64.7464	19.0423	68.5392
3.2445	64.4830	19.8745	65.4018
3.4361	64.4830	18.7666	69.2632
3.4241	65.5126	19.1329	69.0218
3.3642	64.6506	19.2171	67.8152
3.4241	65.4887	19.1259	69.0218
3.0769	64.6027	20.9961	62.0231
3.0051	65.7760	21.8884	60.5751
3.0290	65.6802	21.6838	61.0578
3.5678	65.7999	18.4430	71.9179
3.3403	64.7703	19.3907	67.3325
3.1607	64.8661	20.5227	63.7125
3.0649	65.9915	21.5312	61.7818
3.1846	66.2788	20.8120	64.1951
3.3044	64.8422	19.6232	66.6085
2.9691	64.5069	21.7258	59.8511
3.4121	65.0337	19.0596	68.7805
3.2565	65.4168	20.0882	65.6431
3.3283	65.7520	19.7554	67.0912
2.7177	65.7760	24.2026	54.7831
3.1128	64.7703	20.8077	62.7471
3.1008	64.4351	20.7799	62.5058
3.7114	65.5365	17.6581	74.8139
3.2565	66.1112	20.3015	65.6431
3.2804	64.8661	19.7737	66.1258
2.6818	66.4943	24.7946	54.0591
3.5678	64.9619	18.2081	71.9179
3.6635	64.4830	17.6013	73.8485
3.5318	64.3393	18.2169	71.1938
2.7417	64.8661	23.6594	55.2657

3.5438	65.2013	18.3986	71.4352
3.4480	63.9562	18.5486	69.5045
3.5797	64.3633	17.9799	72.1592
3.1846	65.8239	20.6692	64.1951
3.1966	64.4830	20.1723	64.4365
2.8734	64.6745	22.5083	57.9204
2.8494	64.9619	22.7983	57.4377
3.1966	64.4351	20.1573	64.4365
3.4001	65.0577	19.1338	68.5392
2.9093	65.8239	22.6255	58.6444
3.2086	65.0337	20.2687	64.6778
3.2684	64.9858	19.8828	65.8845
5.0284	87.2065	17.3429	101.3607
4.5615	86.7515	19.0184	91.9487
4.7770	86.6557	18.1404	96.2927
4.4537	86.3445	19.3871	89.7766
5.7587	86.4402	15.0104	116.0822
4.7650	87.0389	18.2663	96.0514
4.4537	86.3684	19.3925	89.7766
5.0523	88.1164	17.4408	101.8434
4.6572	85.6261	18.3856	93.8793
4.5734	86.4402	18.9005	92.1900
5.0044	85.9853	17.1818	100.8781
4.5016	86.1290	19.1330	90.7420
4.4777	87.2065	19.4759	90.2593
4.4298	85.9853	19.4108	89.2940
5.0882	85.8895	16.8800	102.5674
4.2981	85.4825	19.8886	86.6393
4.8368	86.1290	17.8069	97.4994
5.1720	85.8895	16.6065	104.2568
4.6213	86.1768	18.6477	93.1553
4.8129	86.7276	18.0199	97.0167
4.7051	87.1107	18.5140	94.8447
4.8967	87.3501	17.8386	98.7060

4.6333	85.5303	18.4599	93.3967
4.7171	86.6557	18.3706	95.0860
4.7770	86.3445	18.0752	96.2927
4.7889	87.0389	18.1750	96.5340
4.7770	86.2487	18.0551	96.2927
4.2382	86.8952	20.5028	85.4326
4.8967	87.0628	17.7800	98.7060
4.7291	86.7994	18.3544	95.3274
4.5615	86.3205	18.9239	91.9487
5.0643	86.1050	17.0024	102.0847
4.9446	86.2008	17.4334	99.6714
4.8727	85.3627	17.5184	98.2234
4.8847	85.6740	17.5392	98.4647
4.7530	85.5543	18.0000	95.8100
4.5495	86.4642	19.0053	91.7073
4.8248	86.6318	17.9553	97.2580
5.0404	85.6740	16.9976	101.6021
4.5255	86.1050	19.0265	91.2247
5.0523	86.4881	17.1185	101.8434
4.2262	86.7515	20.5269	85.1913
4.7770	84.8359	17.7594	96.2927
4.5854	86.7276	18.9138	92.4313
4.7051	86.4642	18.3766	94.8447
4.6932	87.4699	18.6378	94.6034
4.4896	86.1050	19.1787	90.5007
4.6572	86.0811	18.4833	93.8793
4.4537	87.2065	19.5806	89.7766
4.7291	87.5656	18.5165	95.3274
4.9685	86.3205	17.3735	100.1541
5.0523	87.0867	17.2370	101.8434
4.9805	87.0628	17.4808	100.3954
4.9206	87.8530	17.8540	99.1887
5.3157	86.8473	16.3378	107.1528
4.7291	86.8234	18.3595	95.3274

4.9206	86.0332	17.4842	99.1887
4.4178	86.3205	19.5393	89.0526
4.6333	85.6980	18.4961	93.3967
4.3460	86.8712	19.9890	87.6046
5.0404	86.0571	17.0736	101.6021
4.7291	85.9374	18.1722	95.3274
4.7650	86.4163	18.1357	96.0514
4.7889	85.1951	17.7900	96.5340
5.1361	84.9078	16.5315	103.5327
4.5495	85.6740	18.8316	91.7073
4.8488	85.8416	17.7037	97.7407
4.2023	86.2008	20.5128	84.7086
4.9685	85.5303	17.2145	100.1541
5.0643	86.5839	17.0969	102.0847
4.7889	86.4881	18.0600	96.5340
4.7530	87.1586	18.3375	95.8100
4.5974	87.8290	19.1042	92.6727
4.9925	86.7276	17.3717	100.6367
4.5734	87.4938	19.1309	92.1900
4.4537	86.9431	19.5215	89.7766
4.6453	86.7994	18.6856	93.6380
4.8608	86.5360	17.8030	97.9820
4.8368	86.4881	17.8812	97.4994
5.3636	86.7994	16.1830	108.1181
4.9925	85.9853	17.2230	100.6367
4.8129	86.7515	18.0249	97.0167
5.1481	86.8712	16.8744	103.7741
4.7051	85.8656	18.2494	94.8447
4.9565	85.7219	17.2947	99.9127
4.3699	86.3445	19.7589	88.0873
4.6453	85.7458	18.4588	93.6380
4.5255	86.1290	19.0317	91.2247
4.9326	86.6318	17.5631	99.4301
4.7650	85.7219	17.9899	96.0514

4.5854	85.9374	18.7415	92.4313
4.4058	86.8473	19.7120	88.8113
5.0404	85.9613	17.0546	101.6021
4.7530	87.0867	18.3224	95.8100
5.4235	86.3205	15.9161	109.3248
4.8368	88.3079	18.2574	97.4994
4.9446	85.9374	17.3801	99.6714
4.1065	86.2487	21.0029	82.7779
4.6453	85.6980	18.4485	93.6380
4.8727	87.0628	17.8673	98.2234
5.5312	86.9431	15.7186	111.4968
4.6333	87.3262	18.8475	93.3967
4.8488	86.6318	17.8667	97.7407
4.7291	86.9191	18.3797	95.3274
4.6453	87.3501	18.8041	93.6380
4.4178	87.6375	19.8374	89.0526
4.9805	85.7937	17.2260	100.3954
4.9565	86.9910	17.5507	99.9127
4.9326	85.6022	17.3544	99.4301
5.1122	85.9613	16.8150	103.0501
4.9565	85.9135	17.3333	99.9127
4.5255	86.8473	19.1905	91.2247
4.6812	86.0332	18.3785	94.3620
4.8608	85.5543	17.6010	97.9820
4.7171	86.5121	18.3401	95.0860
4.8009	86.5600	18.0299	96.7754
4.2741	86.3445	20.2017	86.1566
4.8488	86.2966	17.7975	97.7407
4.4657	85.9613	19.2493	90.0180
4.8488	87.3262	18.0099	97.7407
5.3995	85.9135	15.9113	108.8421
4.4298	87.1825	19.6811	89.2940
5.1002	88.3558	17.3239	102.8087
4.7770	86.9431	18.2005	96.2927

4.9446	86.1050	17.4140	99.6714
4.7291	86.4881	18.2886	95.3274
5.0164	86.7036	17.2840	101.1194
4.5255	86.9431	19.2116	91.2247
5.1960	86.1050	16.5714	104.7394
4.9565	86.2966	17.4106	99.9127
4.6812	86.5600	18.4910	94.3620
4.3938	86.1290	19.6022	88.5700
4.9805	86.4402	17.3558	100.3954
5.2678	86.2966	16.3818	106.1874
5.0044	86.1290	17.2105	100.8781
4.8009	86.1050	17.9352	96.7754
5.0882	85.1951	16.7435	102.5674
4.5255	85.7219	18.9418	91.2247
4.9565	85.9613	17.3430	99.9127
4.6572	85.4106	18.3393	93.8793
4.7770	86.2966	18.0652	96.2927
5.2798	85.9135	16.2721	106.4288
4.2262	85.8656	20.3173	85.1913
4.6453	87.7811	18.8969	93.6380
4.9925	86.4402	17.3141	100.6367
4.4058	86.5839	19.6522	88.8113
5.2080	87.3262	16.7678	104.9808
4.5495	86.3205	18.9737	91.7073
4.5495	86.7994	19.0789	91.7073
4.5615	87.3980	19.1601	91.9487
5.3277	87.4938	16.4225	107.3941
4.6093	86.9431	18.8623	92.9140
4.9685	85.9374	17.2964	100.1541
4.4537	86.5839	19.4409	89.7766
5.1601	86.5121	16.7657	104.0154
4.8368	87.1346	18.0149	97.4994
5.0284	86.5600	17.2143	101.3607
4.8368	86.0571	17.7921	97.4994

4.4178	87.2783	19.7561	89.0526
4.3579	85.1951	19.5495	87.8460
4.5974	86.8234	18.8854	92.6727
4.6812	86.2247	18.4194	94.3620
5.3157	85.9613	16.1712	107.1528
4.6692	85.9374	18.4051	94.1207
4.9446	86.1050	17.4140	99.6714
4.7410	86.7036	18.2879	95.5687
4.8368	86.5360	17.8911	97.4994
5.2199	86.3924	16.5505	105.2221
5.0164	86.3205	17.2076	101.1194
5.0523	86.2966	17.0806	101.8434
5.3875	87.3262	16.2089	108.6008
5.5671	86.8712	15.6043	112.2208
5.1242	85.2430	16.6355	103.2914
4.7291	86.8952	18.3747	95.3274
5.3037	87.2304	16.4470	106.9114
4.9685	87.2065	17.5518	100.1541
4.7770	87.6614	18.3509	96.2927
5.3636	87.2783	16.2723	108.1181
5.0882	86.7994	17.0588	102.5674
4.7171	87.3262	18.5127	95.0860
4.8248	85.4585	17.7122	97.2580
4.7770	87.0389	18.2206	96.2927
4.8847	85.8177	17.5686	98.4647
4.7530	85.1472	17.9144	95.8100
4.7889	85.2430	17.8000	96.5340
4.7410	85.1712	17.9646	95.5687
4.2981	85.1712	19.8162	86.6393
4.7410	86.7515	18.2980	95.5687
5.0164	86.2247	17.1885	101.1194
4.8967	85.6980	17.5012	98.7060
4.8129	86.6079	17.9950	97.0167
4.9685	86.1290	17.3349	100.1541

5.2559	85.8656	16.3371	105.9461
5.1601	86.9191	16.8445	104.0154
5.4115	86.4881	15.9823	109.0835
4.8847	88.8587	18.1912	98.4647
4.7530	85.5782	18.0050	95.8100
4.8129	87.0149	18.0796	97.0167
4.9206	86.8952	17.6594	99.1887
4.9326	87.6375	17.7670	99.4301
4.9087	86.8952	17.7024	98.9474
4.8129	87.6135	18.2040	97.0167
5.2199	87.8290	16.8257	105.2221
4.5495	87.4699	19.2263	91.7073
5.1002	88.1403	17.2817	102.8087
4.9685	86.5839	17.4265	100.1541
5.2918	87.0867	16.4570	106.6701
4.6213	87.2783	18.8860	93.1553
4.9805	87.0389	17.4760	100.3954
4.9446	86.7515	17.5448	99.6714
5.0404	87.3980	17.3397	101.6021
4.7530	86.7036	18.2418	95.8100
4.6453	87.8769	18.9175	93.6380
5.2199	86.7994	16.6284	105.2221
5.1242	87.4699	17.0701	103.2914
4.2502	87.2544	20.5296	85.6740
4.9326	86.4163	17.5194	99.4301
5.1481	87.3501	16.9674	103.7741
5.7347	86.9910	15.1691	115.5995
4.7291	87.0628	18.4101	95.3274
4.7051	87.9248	18.6870	94.8447
4.9925	86.4163	17.3094	100.6367
4.5974	88.3319	19.2135	92.6727
5.1840	87.5177	16.8822	104.4981
4.9087	88.0206	17.9317	98.9474
4.7171	87.5177	18.5533	95.0860

4.7051	88.1164	18.7277	94.8447
5.1242	88.1882	17.2103	103.2914
4.7410	87.6614	18.4899	95.5687
4.9326	86.4402	17.5243	99.4301
4.7889	88.4037	18.4600	96.5340
5.2918	87.8530	16.6018	106.6701
5.2918	88.0206	16.6335	106.6701
5.0523	87.0628	17.2322	101.8434
5.1960	87.1586	16.7742	104.7394
5.1601	87.1825	16.8956	104.0154
5.1840	86.3205	16.6513	104.4981
5.2080	86.7755	16.6621	104.9808
5.0284	86.6318	17.2286	101.3607
5.4953	86.5121	15.7429	110.7728
5.6629	86.1050	15.2051	114.1515
4.9805	85.4825	17.1635	100.3954
5.1242	86.6318	16.9065	103.2914
5.0164	86.4402	17.2315	101.1194
4.9326	87.1107	17.6602	99.4301
4.7291	86.7036	18.3342	95.3274
4.9685	86.7755	17.4651	100.1541
4.9206	86.7036	17.6204	99.1887
4.9565	87.3501	17.6232	99.9127
4.8488	86.2247	17.7827	97.7407
5.4833	87.8290	16.0175	110.5315
4.3938	87.0389	19.8093	88.5700
5.0643	86.9431	17.1678	102.0847
4.7770	86.3924	18.0852	96.2927
5.3037	86.7036	16.3476	106.9114
4.8727	87.3501	17.9263	98.2234
5.0404	86.1529	17.0926	101.6021
5.2918	88.1643	16.6606	106.6701
4.7530	86.3684	18.1713	95.8100
4.8967	87.6854	17.9071	98.7060

5.2559	87.0389	16.5604	105.9461
4.4058	87.7572	19.9185	88.8113
4.8248	86.9670	18.0248	97.2580
4.8847	87.4459	17.9020	98.4647
4.8847	86.3205	17.6716	98.4647
4.7889	87.8051	18.3350	96.5340
4.7171	86.7036	18.3807	95.0860
4.3100	86.9910	20.1833	86.8806
4.9805	86.3205	17.3317	100.3954
4.9565	87.2783	17.6087	99.9127
4.5375	86.7036	19.1082	91.4660
5.0643	86.8952	17.1584	102.0847
5.0164	88.0445	17.5513	101.1194
4.7530	86.9670	18.2972	95.8100
5.0404	87.1586	17.2922	101.6021
4.6692	87.1346	18.6615	94.1207
4.8368	87.2544	18.0396	97.4994
4.6932	87.8051	18.7092	94.6034
5.4833	88.4276	16.1266	110.5315
4.8368	86.7755	17.9406	97.4994
4.8488	87.4459	18.0346	97.7407
5.0164	87.1346	17.3699	101.1194
4.8608	87.9727	18.0985	97.9820
4.7889	88.0924	18.3950	96.5340
4.7650	87.4938	18.3618	96.0514
4.7530	85.9613	18.0856	95.8100
4.8368	86.8712	17.9604	97.4994
5.0882	87.0867	17.1153	102.5674
5.3037	87.2783	16.4560	106.9114
4.8009	85.4106	17.7905	96.7754
5.3397	86.4881	16.1973	107.6354
4.1185	85.9374	20.8663	83.0193
4.6453	87.5417	18.8454	93.6380
4.8967	87.2065	17.8093	98.7060

4.5974	87.4699	19.0260	92.6727
4.8608	87.0628	17.9113	97.9820
4.8129	86.9670	18.0697	97.0167
5.1002	86.9431	17.0469	102.8087
4.7889	86.3445	18.0300	96.5340
5.2918	87.9009	16.6109	106.6701
5.3037	87.6614	16.5282	106.9114
5.1002	88.1164	17.2770	102.8087
5.0404	88.1643	17.4917	101.6021
5.2559	87.8530	16.7153	105.9461
5.2199	86.9431	16.6560	105.2221
4.7650	87.3501	18.3317	96.0514
4.9805	87.6375	17.5962	100.3954
4.7291	87.8290	18.5722	95.3274
5.1960	87.3741	16.8157	104.7394
4.4896	87.7093	19.5360	90.5007
4.5854	86.7994	18.9295	92.4313
4.6333	87.2783	18.8372	93.3967
5.1361	86.5360	16.8485	103.5327
4.9805	87.0389	17.4760	100.3954
4.8129	87.6614	18.2139	97.0167
4.7770	88.0445	18.4311	96.2927
4.7770	86.2966	18.0652	96.2927
4.8488	86.7276	17.8864	97.7407
4.4777	88.1164	19.6791	90.2593
5.0763	87.1346	17.1651	102.3261
5.2678	87.0628	16.5273	106.1874
4.9087	87.8530	17.8976	98.9474
4.7770	85.9853	18.0000	96.2927
5.0044	86.8473	17.3541	100.8781
5.0404	87.0389	17.2684	101.6021
4.9805	88.0445	17.6779	100.3954
4.8488	86.8712	17.9160	97.7407
5.0763	87.9727	17.3302	102.3261

4.3938	87.0628	19.8147	88.5700
4.9326	87.7333	17.7864	99.4301
4.8608	87.5896	18.0197	97.9820
4.7650	86.7755	18.2111	96.0514
4.8488	86.7515	17.8914	97.7407
5.2439	88.0685	16.7945	105.7048
5.2199	86.8234	16.6330	105.2221
5.1361	87.8530	17.1049	103.5327
4.9685	86.8473	17.4795	100.1541
4.5375	86.9431	19.1609	91.4660
4.9685	86.9191	17.4940	100.1541
4.9685	86.2247	17.3542	100.1541
5.1242	86.1529	16.8131	103.2914
5.0044	86.3924	17.2632	100.8781
4.9326	87.0389	17.6456	99.4301
4.9805	86.8473	17.4375	100.3954
5.2678	87.2544	16.5636	106.1874
5.5192	86.7515	15.7180	111.2555
5.1840	86.4402	16.6744	104.4981
4.7530	86.8234	18.2670	95.8100
5.2559	86.3445	16.4282	105.9461
4.9087	87.6375	17.8537	98.9474
4.7650	88.3798	18.5477	96.0514
4.7889	87.7333	18.3200	96.5340
5.1601	87.6854	16.9930	104.0154
4.8727	87.0149	17.8575	98.2234
5.0763	86.9910	17.1368	102.3261
5.0763	88.4037	17.4151	102.3261
5.0523	86.9910	17.2180	101.8434
4.5854	86.5600	18.8773	92.4313
5.4594	86.4881	15.8421	110.0488
5.0044	86.8234	17.3493	100.8781
5.3516	86.5600	16.1745	107.8768
4.8847	86.3445	17.6765	98.4647

4.7770	86.8234	18.1754	96.2927
5.1361	86.9431	16.9277	103.5327
4.7410	87.0389	18.3586	95.5687
4.5615	87.0628	19.0866	91.9487
5.1122	85.6740	16.7588	103.0501
5.0044	86.7994	17.3445	100.8781
5.2319	87.1586	16.6590	105.4634
5.2678	88.3558	16.7727	106.1874
5.0044	86.6797	17.3206	100.8781
5.2559	87.2783	16.6059	105.9461
4.8488	86.9910	17.9407	97.7407
5.1122	86.9910	17.0164	103.0501
5.3037	86.3205	16.2754	106.9114
4.9805	87.0867	17.4856	100.3954
5.1002	87.2783	17.1127	102.8087
4.7530	87.1586	18.3375	95.8100
5.0763	87.5417	17.2453	102.3261
4.9805	86.8234	17.4327	100.3954
5.2080	87.2544	16.7540	104.9808
4.8967	86.5121	17.6675	98.7060
4.9925	87.0867	17.4436	100.6367
4.7171	86.1529	18.2640	95.0860
4.9805	87.6375	17.5962	100.3954
5.1840	87.3741	16.8545	104.4981
5.3397	86.3684	16.1749	107.6354
5.1601	87.4459	16.9466	104.0154
4.9685	86.7994	17.4699	100.1541
4.7171	87.0628	18.4569	95.0860
5.1242	87.2544	17.0280	103.2914
4.6932	86.6797	18.4694	94.6034
4.7530	85.6261	18.0151	95.8100
5.1242	86.2726	16.8364	103.2914
4.9805	87.3501	17.5385	100.3954
4.8368	87.4938	18.0891	97.4994

4.8727	87.0867	17.8722	98.2234
5.1002	87.0389	17.0657	102.8087
5.6150	87.0867	15.5096	113.1862
4.6333	87.5417	18.8941	93.3967
6.4531	130.2590	20.1855	130.0796
6.4890	130.2350	20.0701	130.8036
6.1179	131.1928	21.4442	123.3222
6.6925	130.8815	19.5564	134.9063
6.0939	132.2464	21.7014	122.8396
6.4531	131.0492	20.3080	130.0796
6.2855	131.1210	20.8610	126.7009
6.5369	131.9351	20.1832	131.7690
6.3932	131.7675	20.6105	128.8729
6.8961	131.9830	19.1389	139.0090
6.1059	132.6774	21.7294	123.0809
6.5369	132.2464	20.2308	131.7690
5.9742	131.7675	22.0561	120.4262
6.5369	131.8393	20.1685	131.7690
6.8123	130.5703	19.1670	137.3197
6.7285	130.5703	19.4057	135.6303
6.3094	131.1210	20.7818	127.1836
6.5489	131.0252	20.0073	132.0103
6.3094	132.1985	20.9526	127.1836
6.0819	131.7196	21.6575	122.5982
6.3334	131.1689	20.7108	127.6663
6.2855	131.0970	20.8571	126.7009
6.1777	129.7322	21.0000	124.5289
6.3813	129.3012	20.2627	128.6316
6.6925	130.2350	19.4597	134.9063
6.5848	129.9238	19.7309	132.7343
6.0341	131.7914	21.8413	121.6329
6.7404	129.9956	19.2860	135.8716
6.1658	130.7858	21.2117	124.2876
6.4172	131.5759	20.5037	129.3556

6.9320	131.8633	19.0225	139.7330
6.0221	131.2407	21.7932	121.3915
6.2136	131.3844	21.1445	125.2529
6.1658	132.5577	21.4990	124.2876
6.2017	132.7253	21.4015	125.0116
6.9200	132.9408	19.2111	139.4917
6.5489	132.0548	20.1645	132.0103
6.8721	132.7013	19.3101	138.5263
6.3334	132.2943	20.8885	127.6663
6.6087	132.7492	20.0870	133.2170
5.8904	133.2999	22.6301	118.7369
6.4770	131.7675	20.3438	130.5623
6.3094	131.0731	20.7742	127.1836
6.5369	132.7253	20.3040	131.7690
6.2855	131.0492	20.8495	126.7009
6.2974	131.9830	20.9582	126.9423
6.3094	131.0013	20.7628	127.1836
6.6806	130.9294	19.5986	134.6650
6.0580	131.3125	21.6759	122.1155
6.5129	130.0674	19.9706	131.2863
6.1179	130.7858	21.3777	123.3222
6.4770	129.7801	20.0370	130.5623
6.1538	131.1689	21.3152	124.0462
6.3214	129.9477	20.5568	127.4249
6.2974	131.0013	20.8023	126.9423
6.7524	130.7379	19.3617	136.1130
6.2735	131.5041	20.9618	126.4596
6.4651	130.3069	20.1556	130.3209
6.6087	130.9534	19.8152	133.2170
6.5129	130.8576	20.0919	131.2863
6.2376	132.4140	21.2284	125.7356
6.2136	132.0069	21.2447	125.2529
6.7763	130.8576	19.3110	136.5957
6.8362	131.3844	19.2189	137.8023

5.8784	132.2464	22.4969	118.4955
6.1777	131.6717	21.3140	124.5289
6.2974	132.7013	21.0722	126.9423
6.4172	132.0788	20.5821	129.3556
6.4531	130.3787	20.2041	130.0796
6.3813	131.0492	20.5366	128.6316
6.3932	132.0788	20.6592	128.8729
6.6806	131.2647	19.6487	134.6650
6.5010	131.1449	20.1731	131.0449
6.8721	130.7858	19.0314	138.5263
6.7524	131.1210	19.4184	136.1130
6.1777	131.1449	21.2287	124.5289
6.5608	131.2647	20.0073	132.2516
6.5848	130.4026	19.8036	132.7343
5.9502	130.7618	21.9759	119.9435
6.5489	130.2111	19.8830	132.0103
6.2017	129.7082	20.9151	125.0116
6.4411	131.0492	20.3457	129.8383
6.5968	131.0013	19.8584	132.9756
6.3573	130.5224	20.5311	128.1489
6.2615	130.2829	20.8069	126.2182
6.6566	131.5520	19.7626	134.1823
6.4531	130.7618	20.2635	130.0796
6.6207	131.3604	19.8409	133.4583
6.5489	131.8154	20.1280	132.0103
6.5249	130.7618	20.0404	131.5276
6.2136	131.2407	21.1214	125.2529
6.4890	131.7675	20.3063	130.8036
6.2256	133.0366	21.3692	125.4942
6.6806	132.5098	19.8351	134.6650
6.0819	133.0366	21.8740	122.5982
6.2974	132.3422	21.0152	126.9423
6.0939	132.6534	21.7682	122.8396
6.6925	132.1027	19.7388	134.9063

6.9080	131.8872	19.0919	139.2503
6.7285	131.0492	19.4769	135.6303
6.5489	131.8393	20.1316	132.0103
6.2615	130.2111	20.7954	126.2182
6.2974	131.4083	20.8669	126.9423
6.5728	130.8815	19.9126	132.4930
5.9862	131.1689	21.9120	120.6675
6.2496	130.9294	20.9502	125.9769
6.5249	130.1632	19.9486	131.5276
6.8242	130.5703	19.1333	137.5610
6.5249	130.4026	19.9853	131.5276
6.7644	130.9534	19.3593	136.3543
6.0221	131.0013	21.7535	121.3915
6.5369	130.9534	20.0330	131.7690
6.5129	131.3125	20.1618	131.2863
6.4411	132.0548	20.5019	129.8383
6.8123	130.7379	19.1916	137.3197
6.8003	131.3125	19.3099	137.0783
6.3214	131.4323	20.7917	127.4249
6.7045	131.8872	19.6714	135.1476
6.2735	132.3661	21.0992	126.4596
6.6446	130.5703	19.6505	133.9410
5.8066	131.7196	22.6845	117.0475
6.6207	131.6717	19.8879	133.4583
6.0819	133.2042	21.9016	122.5982
6.2256	132.0309	21.2077	125.4942
6.5129	131.4083	20.1765	131.2863
6.0939	131.7435	21.6189	122.8396
5.9383	131.5999	22.1613	119.7022
6.8242	131.7675	19.3088	137.5610
6.3214	131.1210	20.7424	127.4249
6.9799	129.9956	18.6244	140.6984
6.3094	132.2943	20.9677	127.1836
6.2136	129.7561	20.8825	125.2529

6.1658	130.7618	21.2078	124.2876
6.4291	130.6900	20.3277	129.5969
6.0580	130.6900	21.5731	122.1155
6.1658	130.7858	21.2117	124.2876
6.2496	130.9294	20.9502	125.9769
6.2136	130.5224	21.0058	125.2529
6.1418	130.7858	21.2943	123.8049
6.2855	131.6238	20.9410	126.7009
5.9263	131.5041	22.1899	119.4609
6.4770	130.7618	20.1885	130.5623
5.9981	132.2943	22.0559	120.9089
6.5608	131.9112	20.1058	132.2516
6.0700	132.2464	21.7870	122.3569
6.5369	132.6774	20.2967	131.7690
6.3932	132.7971	20.7715	128.8729
6.5129	132.5577	20.3529	131.2863
6.5369	133.2760	20.3883	131.7690
6.4291	131.5999	20.4693	129.5969
6.6925	132.0069	19.7245	134.9063
6.7165	132.3661	19.7077	135.3890
6.3334	131.1689	20.7108	127.6663
6.4770	129.7561	20.0333	130.5623
6.5369	131.4562	20.1099	131.7690
6.3693	131.8393	20.6992	128.3903
6.0939	131.9590	21.6542	122.8396
6.6806	131.1449	19.6308	134.6650
6.6207	130.6660	19.7360	133.4583
6.3813	130.5703	20.4615	128.6316
5.7946	129.5885	22.3636	116.8062
6.3693	130.4026	20.4737	128.3903
6.0101	130.6181	21.7331	121.1502
6.5129	131.9830	20.2647	131.2863
6.6925	130.9534	19.5671	134.9063
6.5010	130.1871	20.0258	131.0449

6.1059	132.1985	21.6510	123.0809
6.6566	131.8872	19.8129	134.1823
5.9383	131.6238	22.1653	119.7022
6.5129	131.5041	20.1912	131.2863
6.0819	132.5577	21.7953	122.5982
6.4291	132.4379	20.5996	129.5969
6.5369	132.3422	20.2454	131.7690
6.5010	131.4323	20.2173	131.0449
6.2735	131.9830	21.0382	126.4596
6.3334	132.3182	20.8922	127.6663
6.3334	132.7971	20.9679	127.6663
6.4291	132.2224	20.5661	129.5969
6.7883	131.9830	19.4427	136.8370
6.1897	131.2647	21.2070	124.7702
6.4770	131.9112	20.3660	130.5623
6.7045	132.5098	19.7643	135.1476
6.4172	132.0069	20.5709	129.3556
6.5728	130.1632	19.8033	132.4930
6.5369	130.4026	19.9487	131.7690
6.8841	131.2168	19.0609	138.7677
6.1418	131.0013	21.3294	123.8049
6.1658	130.6421	21.1883	124.2876
6.5968	130.9534	19.8512	132.9756
6.6327	131.0252	19.7545	133.6996
6.4890	131.7435	20.3026	130.8036
6.3094	130.7618	20.7249	127.1836
6.6446	130.1871	19.5928	133.9410
6.2735	132.1027	21.0573	126.4596
6.2735	131.2647	20.9237	126.4596
6.6566	130.6421	19.6259	134.1823
7.0517	130.6660	18.5297	142.1464
6.5968	131.7196	19.9673	132.9756
6.4052	132.2224	20.6430	129.1143
6.4651	131.4562	20.3333	130.3209

6.5249	133.4197	20.4477	131.5276
6.4890	133.4436	20.5646	130.8036
6.1897	131.6957	21.2766	124.7702
6.6566	133.2760	20.0216	134.1823
6.3813	131.2647	20.5704	128.6316
6.8003	132.7492	19.5211	137.0783
6.2735	131.8633	21.0191	126.4596
6.6207	132.7013	20.0434	133.4583
6.2974	131.8872	20.9430	126.9423
6.6806	132.0788	19.7706	134.6650
6.5369	132.0788	20.2051	131.7690
6.5129	133.1084	20.4375	131.2863
6.5608	132.2943	20.1642	132.2516
6.6566	131.8872	19.8129	134.1823
6.3693	131.5041	20.6466	128.3903
6.4172	132.7013	20.6791	129.3556
6.2974	133.2281	21.1559	126.9423
6.7883	131.9112	19.4321	136.8370
6.3813	133.5394	20.9268	128.6316
6.4770	132.0069	20.3808	130.5623
6.3813	132.8450	20.8180	128.6316
6.6087	132.2943	20.0181	133.2170
6.5010	131.4323	20.2173	131.0449
6.6087	133.9465	20.2681	133.2170
6.5608	131.7914	20.0876	132.2516
6.5608	132.6774	20.2226	132.2516
6.6566	132.4619	19.8993	134.1823
6.4890	131.5280	20.2694	130.8036
6.5010	131.7435	20.2652	131.0449
6.5129	132.0548	20.2757	131.2863
6.5608	133.1563	20.2956	132.2516
6.9559	131.5041	18.9053	140.2157
6.1777	133.2999	21.5775	124.5289
6.4890	133.5873	20.5867	130.8036

6.8482	133.0844	19.4336	138.0437
6.9679	132.4140	19.0034	140.4570
6.3334	132.8929	20.9830	127.6663
6.6686	132.0788	19.8061	134.4236
6.6566	133.6352	20.0755	134.1823
6.8841	131.6478	19.1235	138.7677
6.5489	133.1323	20.3291	132.0103
7.1235	132.3182	18.5748	143.5944
6.5369	133.2999	20.3919	131.7690
7.2433	132.0309	18.2281	146.0077
5.9024	133.1802	22.5639	118.9782
6.8482	132.2464	19.3112	138.0437
6.4770	132.7013	20.4880	130.5623
7.4228	131.5999	17.7290	149.6277
6.5728	132.8689	20.2149	132.4930
7.2792	132.9168	18.2599	146.7317
6.6087	133.0126	20.1268	133.2170
6.8721	132.1027	19.2230	138.5263
6.6087	133.0844	20.1377	133.2170
6.8601	130.7379	19.0576	138.2850
6.9320	132.1027	19.0570	139.7330
7.3031	133.1323	18.2295	147.2144
6.7045	131.9112	19.6750	135.1476
6.7883	131.7675	19.4109	136.8370
6.1538	132.8211	21.5837	124.0462
6.6686	132.2943	19.8384	134.4236
6.2855	131.9112	20.9867	126.7009
6.4172	131.3365	20.4664	129.3556
6.1897	133.4676	21.5629	124.7702
6.7644	132.7492	19.6248	136.3543
6.3813	132.7492	20.8030	128.6316
7.1475	132.1027	18.4824	144.0770
6.4531	133.0126	20.6122	130.0796
6.7524	132.4858	19.6206	136.1130

6.1658	132.1027	21.4252	124.2876
6.8362	131.5999	19.2504	137.8023
6.3214	132.1027	20.8977	127.4249
7.3630	132.0788	17.9382	148.4211
6.8961	133.2999	19.3299	139.0090
6.6327	131.6478	19.8484	133.6996
6.4531	132.7732	20.5751	130.0796
7.1355	132.7971	18.6107	143.8357
6.5129	132.4858	20.3419	131.2863
6.8003	131.7196	19.3697	137.0783
6.1538	131.9830	21.4475	124.0462
6.6327	133.5155	20.1300	133.6996
5.8904	132.7971	22.5447	118.7369
6.6925	132.1745	19.7496	134.9063
6.5129	132.5337	20.3493	131.2863
6.5489	132.9408	20.2998	132.0103
6.9559	132.9408	19.1119	140.2157
7.1595	131.8872	18.4214	144.3184
6.7165	131.6238	19.5971	135.3890
7.1834	132.1745	18.4000	144.8010
6.7285	132.5816	19.7046	135.6303
6.9080	131.9830	19.1057	139.2503
5.9502	132.5337	22.2736	119.9435
6.7404	132.1506	19.6057	135.8716
6.5129	132.7253	20.3787	131.2863
6.8961	133.4676	19.3542	139.0090
5.9263	132.1506	22.2990	119.4609
6.7045	133.0844	19.8500	135.1476
6.2017	133.1084	21.4633	125.0116
7.0397	131.8393	18.7279	141.9050
6.0341	134.0183	22.2103	121.6329
6.9440	132.4858	19.0793	139.9743
6.2017	132.8450	21.4208	125.0116
6.8362	133.1563	19.4781	137.8023

6.6207	132.3182	19.9855	133.4583
6.2855	133.3957	21.2229	126.7009
6.1059	133.6352	21.8863	123.0809
6.8841	131.9112	19.1617	138.7677
6.1298	134.4253	21.9297	123.5636
7.4588	132.1027	17.7111	150.3518
6.4172	133.8267	20.8545	129.3556
7.2433	131.3365	18.1322	146.0077
6.6087	133.1802	20.1522	133.2170
6.6925	131.7675	19.6887	134.9063
6.0700	133.1802	21.9408	122.3569
6.9559	131.9112	18.9639	140.2157
6.1897	132.7971	21.4545	124.7702
6.9559	133.0605	19.1291	140.2157
5.9862	132.7253	22.1720	120.6675
6.8961	131.5280	19.0729	139.0090
6.6925	131.9112	19.7102	134.9063
6.4052	131.9351	20.5981	129.1143
6.5129	132.8929	20.4044	131.2863
7.1595	132.1027	18.4515	144.3184
5.9742	132.4140	22.1643	120.4262
6.7524	133.2281	19.7305	136.1130
6.0939	133.3239	21.8782	122.8396
6.7524	131.1449	19.4220	136.1130
6.4770	132.1506	20.4030	130.5623
7.2912	131.0013	17.9672	146.9731
6.4172	133.7549	20.8433	129.3556
7.0637	132.6295	18.7763	142.3877
6.0341	133.5155	22.1270	121.6329
7.4109	131.7196	17.7738	149.3864
6.7404	132.8929	19.7158	135.8716
6.8242	130.7858	19.1649	137.5610
6.0819	132.6534	21.8110	122.5982
7.0756	132.5337	18.7310	142.6290

6.1897	132.2703	21.3694	124.7702
7.2552	132.4140	18.2508	146.2491
6.5608	132.5098	20.1971	132.2516
7.3989	131.5280	17.7767	149.1451
6.3573	133.4197	20.9868	128.1489
7.3510	132.4858	18.0228	148.1797
6.2256	131.5041	21.1231	125.4942
7.0397	132.1267	18.7687	141.9050
6.1298	133.4676	21.7734	123.5636
6.9559	132.4140	19.0361	140.2157
6.0341	134.5211	22.2937	121.6329
7.0756	130.8576	18.4941	142.6290
6.9799	132.0788	18.9228	140.6984
6.8242	133.0366	19.4947	137.5610
6.5010	133.7310	20.5709	131.0449
6.9918	132.1745	18.9041	140.9397
6.5489	132.8450	20.2852	132.0103
7.4109	131.2407	17.7092	149.3864
6.2496	133.4436	21.3525	125.9769
6.8961	131.8393	19.1181	139.0090
6.3693	132.3422	20.7782	128.3903
7.6383	132.2464	17.3135	153.9718
5.9981	132.7971	22.1397	120.9089
7.2792	132.7732	18.2401	146.7317
6.3693	133.5873	20.9737	128.3903
6.7165	131.6238	19.5971	135.3890
6.2615	133.4915	21.3193	126.2182
6.8721	131.6478	19.1568	138.5263
6.1777	132.1506	21.3915	124.5289
7.2552	132.8929	18.3168	146.2491
6.5728	132.7492	20.1967	132.4930
7.0876	131.5759	18.5642	142.8704
6.1538	133.5394	21.7004	124.0462
6.8242	131.1449	19.2175	137.5610

6.5968	133.2042	20.1924	132.9756
7.0996	132.0788	18.6037	143.1117
6.8242	133.8746	19.6175	137.5610
6.8242	131.9590	19.3368	137.5610
6.3813	132.6295	20.7842	128.6316
7.4348	132.1027	17.7681	149.8691
6.3693	132.9408	20.8722	128.3903
6.9559	131.9590	18.9707	140.2157
5.9143	132.7971	22.4534	119.2195
7.4109	131.2407	17.7092	149.3864
6.8841	132.0069	19.1757	138.7677
7.1116	131.5041	18.4916	143.3530
6.6446	133.4436	20.0829	133.9410
7.4228	132.2943	17.8226	149.6277
6.4172	132.6534	20.6716	129.3556
7.2912	131.9112	18.0920	146.9731
6.6806	131.7196	19.7168	134.6650
6.7045	131.9112	19.6750	135.1476
6.6686	132.2464	19.8312	134.4236
6.6686	132.4619	19.8636	134.4236
6.1538	133.4915	21.6926	124.0462
7.1714	131.8154	18.3806	144.5597
6.5369	132.1745	20.2198	131.7690
6.7644	132.5816	19.6000	136.3543
6.4651	131.7914	20.3852	130.3209
6.9918	132.0069	18.8801	140.9397
6.7404	132.8689	19.7123	135.8716
6.9799	133.1323	19.0738	140.6984
6.6806	133.2999	19.9534	134.6650
6.5728	131.9351	20.0729	132.4930

Прилог 1.

8 Изјава о ауторству

Потписани Giuma Ali Shneba

број индекса D39 / 2013

Изјављујем

да је докторска дисертација под насловом

LINEARITY OF THE CLOSE LOOP DEFORMETER

Мерна линеарност специјалног деформетра

- резултат сопственог истраживачког рада,
- да предложена дисертација у целини ни у деловима није била предложена за добијање било које дипломе према студијским програмима других високошколских установа,
- да су резултати коректно наведени и
- да нисам кршио/ла ауторска права и користио интелектуалну својину других лица.

Потпис докторанда

У Београду, December 2017

____

Прилог 2.

9 Изјава о истоветности штампане и електронске верзије докторског рада

Име и презиме аутора Giuma Ali Shneba

Број индекса D39 / 2013

Студијски програм Theory of Machine and Mechanisms

Наслов рада Мерна линеарност специјалног деформетра

Ментор проф. Др Љубомир Миладиновић

Потписани/а ____

Изјављујем да је штампана верзија мог докторског рада истоветна електронској верзији коју сам предао/ла за објављивање на порталу **Дигиталног репозиторијума Универзитета у Београду.**

Дозвољавам да се објаве моји лични подаци везани за добијање академског звања доктора наука, као што су име и презиме, година и место рођења и датум одбране рада.

Ови лични подаци могу се објавити на мрежним страницама дигиталне библиотеке, у електронском каталогу и у публикацијама Универзитета у Београду.

Потпис докторанда

У Београду, December 2017

____

Прилог 3.

10 Изјава о коришћењу

Овлашћујем Универзитетску библиотеку „Светозар Марковић“ да у Дигитални репозиторијум Универзитета у Београду унесе моју докторску дисертацију под насловом:

LINEARITY OF THE CLOSE LOOP DEFORMETER

MERNA LINEARNOST SPECIJALNOG DEFORMETRA

која је моје ауторско дело.

Дисертацију са свим прилозима предао/ла сам у електронском формату погодном за трајно архивирање.

Моју докторску дисертацију похрањену у Дигитални репозиторијум Универзитета у Београду могу да користе сви који поштују одредбе садржане у одабраном типу лиценце Креативне заједнице (Creative Commons) за коју сам се одлучио/ла.

1. Ауторство

2. Ауторство - некомерцијално

3. Ауторство – некомерцијално – без прераде

4. Ауторство – некомерцијално – делити под истим условима

5. Ауторство – без прераде

6. Ауторство – делити под истим условима

(Молимо да заокружите само једну од шест понуђених лиценци, кратак опис лиценци дат је на полеђини листа).

Потпис докторанда

У Београду, ________________________

____

1. Ауторство - Дозвољавате умножавање, дистрибуцију и јавно саопштавање дела, и прераде, ако се наведе име аутора на начин одређен од стране аутора или даваоца лиценце, чак и у комерцијалне сврхе. Ово је најслободнија од свих лиценци.

2. Ауторство – некомерцијално. Дозвољавате умножавање, дистрибуцију и јавно саопштавање дела, и прераде, ако се наведе име аутора на начин одређен од стране аутора или даваоца лиценце. Ова лиценца не дозвољава комерцијалну употребу дела.

3. Ауторство - некомерцијално – без прераде. Дозвољавате умножавање, дистрибуцију и јавно саопштавање дела, без промена, преобликовања или употребе дела у свом делу, ако се наведе име аутора на начин одређен од стране аутора или даваоца лиценце. Ова лиценца не дозвољава комерцијалну употребу дела. У односу на све остале лиценце, овом лиценцом се ограничава највећи обим права коришћења дела.

4. Ауторство - некомерцијално – делити под истим условима. Дозвољавате умножавање, дистрибуцију и јавно саопштавање дела, и прераде, ако се наведе име аутора на начин одређен од стране аутора или даваоца лиценце и ако се прерада дистрибуира под истом или сличном лиценцом. Ова лиценца не дозвољава комерцијалну употребу дела и прерада.

5. Ауторство – без прераде. Дозвољавате умножавање, дистрибуцију и јавно саопштавање дела, без промена, преобликовања или употребе дела у свом делу, ако се наведе име аутора на начин одређен од стране аутора или даваоца лиценце. Ова лиценца дозвољава комерцијалну употребу дела.

6. Ауторство - делити под истим условима. Дозвољавате умножавање, дистрибуцију и јавно саопштавање дела, и прераде, ако се наведе име аутора на начин одређен од стране аутора или даваоца лиценце и ако се прерада дистрибуира под истом или сличном лиценцом. Ова лиценца дозвољава комерцијалну употребу дела и прерада. Слична је софтверским лиценцама, односно лиценцама отвореног кода.