

Designing an overhead gantry crane

School of Engineering Portfolio

Stress Analysis and Dynamics

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ACMA5010

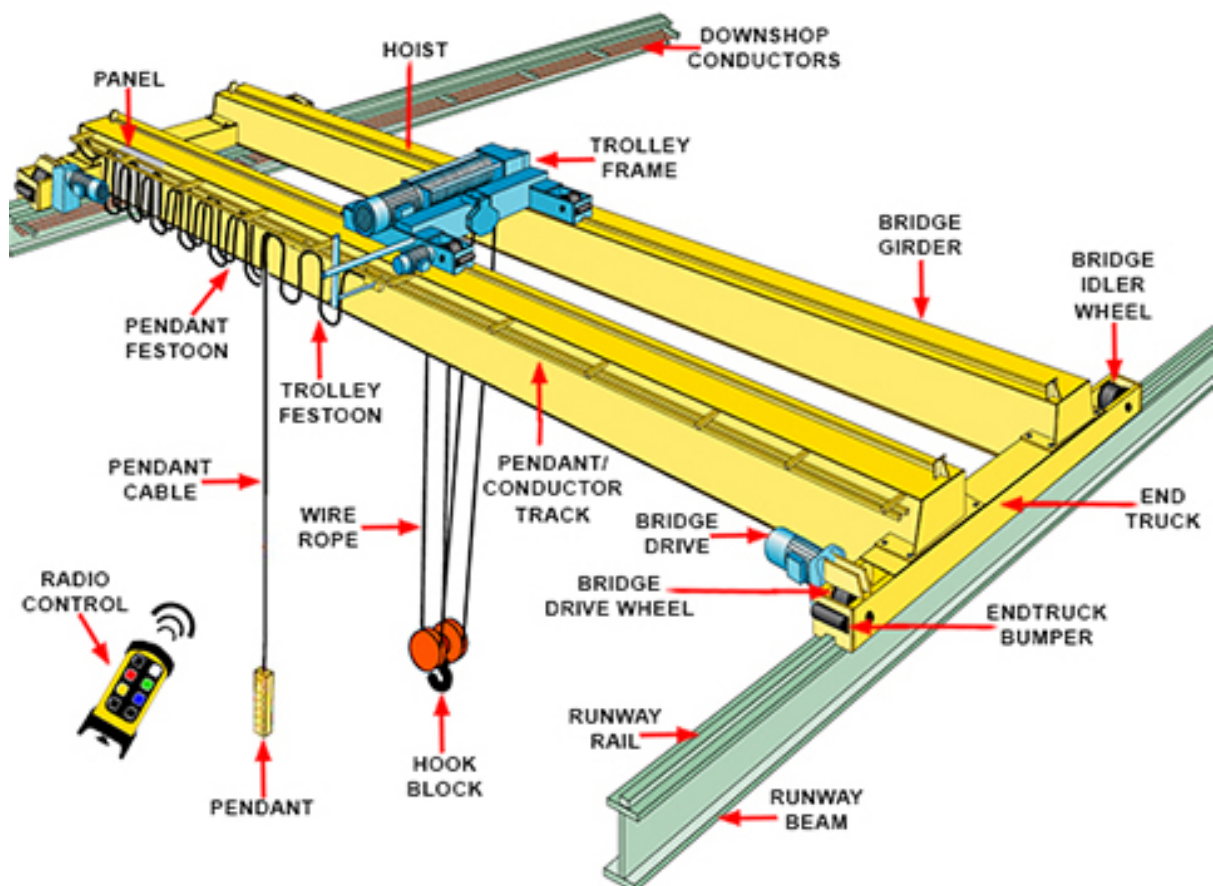


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1.0 INTRODUCTION

In this report, I will be evaluating the design of an overhead gantry crane using slope and deflections of beams theory. Also included in this report is a historical section about strain gauges, the different types of strain gauges available and why they are so important in our everyday applications. Furthermore, I will discuss the type of strain gauges I believe are suitable for use in the design, where it should be used on the gantry crane and how the readings from the strain gauge should be interpreted.

2.0 SECOND MOMENT OF AREA CALCULATION

To find my Second Moment Of Area of the beam (I) we can use the double integration method and derive our

$$\text{formula: } Y_{(\max)} = \frac{-wL^3}{48EI}$$

$Y_{(\max)} = 10 \text{ mm}$ This is the maximum allowable deflection for the beam.

$w = 5 \times 9.81 \text{ KN}$ This is the weight of the load acting at the centre of the beam.

$L = 10 \text{ m}$ This is the length of the beam that for the purposes of my calculation I'm assuming as 10 m.

$E = 210 \text{ GNm}^2$ This is the Young's Modulus of the material

Now using all known and assumed values we can input into this equation to find our Second Moment Area (I):

$$0.01 = \frac{-(-49.05 \times 10^3)(10)^3}{48(210 \times 10^9)(I)}$$

$$I = \frac{-(-49.05 \times 10^3)(10)^3}{48(210 \times 10^9)(0.01)}$$

$$I = \frac{49050000}{100800000000}$$

$$I = 4.866 \times 10^{-4}$$

$$I = 0.00049 \text{ m}^4$$

We now have a value for (I) that satisfies our equation to give us a max deflection of 10 mm.

The (American Nation Standard, 2006) states that "the active load on the crane should be no less than 100% and no more than 125% during testing unless recommended by the manufacturer". If we were to implement this standard into our design then this would mean our max load is $w = 61312.5 \text{ N}$ and this would give us a Second Moment Of Area (I) value of $= 6.083 \times 10^{-4}$

$$I = 0.00061 \text{ m}^4$$

To keep this design cost effective and within our specified tolerances I have chosen British Steel as my steel structure manufacturer. They are BES 6001 certified as mentioned in (British Steel, 2021) and I trust their standards when choosing a suitable steel section from their product list.

The beam I recommend is serial size: 457mm x 191mm x 133kg/m with a second moment of area (I): 64058 cm^4

$$\text{This would give me: } Y_{(\max)} = \frac{-(-49.05 \times 10^3)(10)^3}{48(210 \times 10^9)(64058 \times 10^{-8})} = 7.6 \times 10^{-3} = 7.6 \text{ mm}$$

My reason for choosing this beam structure is that it also satisfies the 25% increase in load with a maximum deflection of 9.5mm. This falls just under our set limit of 10mm. If I chose the next beam structure in the list which is heavier then this would also satisfy these conditions however it wouldn't be cost effective. The increase in weight of the beam would increase the overall cost of manufacturing it and the other components to be able to support a weighty structure. If I opted for the beam structure before my chosen structure, then this would've only satisfied one of my conditions and the 25% increase in load would have exceeded the 10mm allowable deflection limit which would cause the beam to fail under max load.

2.1 ASSUMPTIONS AND CONSIDERATIONS

The first assumption made is about the idler wheel of the crane. The idler wheel cannot translate side to side. However, there is no frictional resistance acting on it and this allows it to rotate along the longest axis. The idler wheel is free rolling and that makes the overall system a restrained system. If the crane is not fitted with stop brakes, the idler wheels can start to rotate whilst under load. This could increase the overall strain experienced as it introduces acceleration. The greater the mass of an object the greater the inertia. If the load starts accelerating, resulting in an increased force acting on the steel girder then this further results in an increase in deflection which could exceed past the allowable limit.

The second assumption I considered is the material used to manufacture the crane. The Young's modulus value (E) is according to the manufacturer's standards. If the Young's Modulus of the beam was not true to the manufacturer's standard, then this could result in failure of the beam under load. A smaller Young's modulus would increase the deflection in the beam. Over a prolonged period, this excess strain experienced could lead to failure under load.

3.0 HISTORY OF THE STRAIN GAUGE

Early in the 20th century, scientists were experimenting heavily in order to keep us advancing as a society. In 1938, two scientists simultaneously invented the strain gauge. The first, Edward E. Simmons of Caltech was investigating the stress-strain behaviour of metals under shock loads as mentioned by (Keil, 2017).

Simmons invented the principle of a strain gauge. Simmons inventive idea was to use a dynamometer, which is a small measuring device that can measure force and equip this with fine resistance wires that were made from constantan.

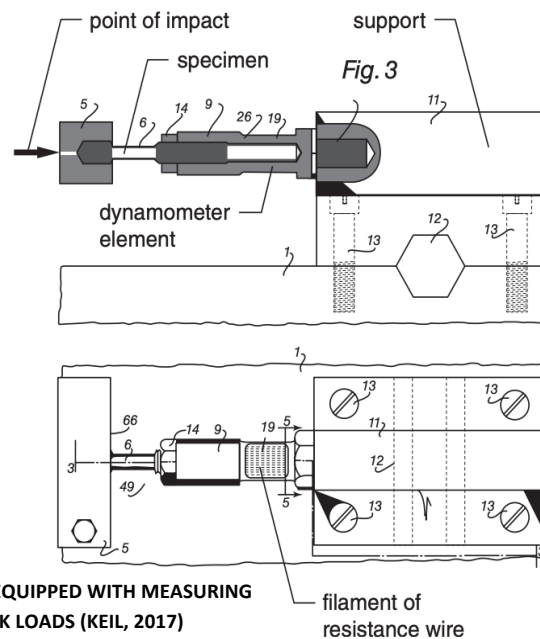


FIGURE 1 - E.E. SIMMONS'S DYNAMOMETER EQUIPPED WITH MEASURING WIRES FOR THE MEASURING OF SHOCK LOADS (KEIL, 2017)

The second scientist, Professor of Seismology Arthur C. Ruge from MIT discovered the strain gauge whilst helping his student complete a thesis. They were investigating the stresses experienced by modelled water towers using a tabletop earthquake simulator that Professor Ruge designed. Whilst performing their tests, any stress on the surface could now be detected using Ruge's invention. The design of Ruge's strain gauge consisted of 4 tungsten filament wires fixed onto a rigid base in diamond formation as described by (Feder, 2000). The stress can be measured from the changes in the electrical resistance of the current running through the wires.

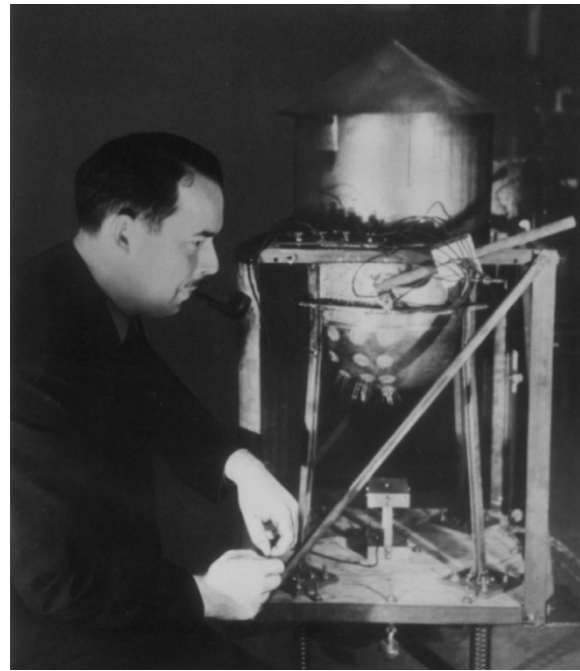


FIGURE 2 - A.C. RUGE CARRYING OUT EXPERIMENTS USING THE TABLETOP SIMULATOR AND MODEL WATER TANKS IN 1938 (KEIL, 2017)

3.1 WHEATSTONE BRIDGE

The Wheatstone bridge is a measuring device that is used to measure the electrical resistance in a circuit. This device was initially invented by Samuel Hunter Christie in 1833. However, in 1843 Charles Wheatstone further added to Christie's work by creating simple and practical formulae in accordance with Ohm's Law, that can calculate current and resistance. He popularized the device and its arrangement along with its many applications that we implement in the modern era.

The device is made up of 4 elements usually referred to as arms/legs (resistors), a voltmeter or a galvanometer to measure voltage or current (used to indicate zero value running through the circuit) and a battery. The bridge is used to measure an unknown resistance in a circuit with high accuracy and precision. (Schweber, 2018) describes the formation of the bridge as two known resistors, one variable resistor and an unknown resistance. In order to achieve a balanced bridge, the variable resistor needs to be altered until a zero value is achieved. The unknown resistance can now be calculated and based on what the unknown element is e.g., a strain gauge, further implications can be made based on the resistance value achieved i.e., how much deflection has the bridge girder experienced.

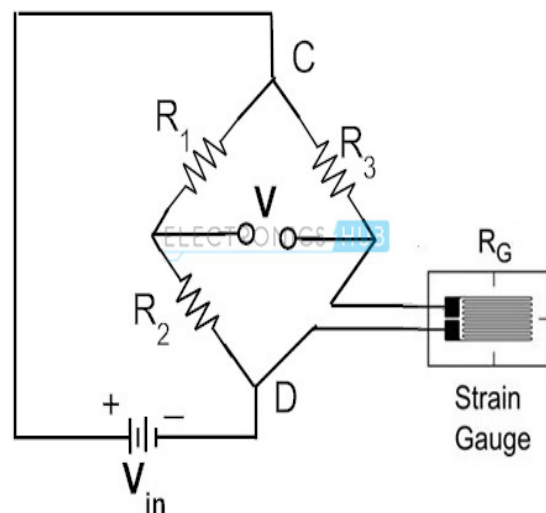


FIGURE 3 - WHEATSTONE BRIDGE FOR STRAIN MEASUREMENT (ELECTRONICS HUB, 2019)

This device is widely used in several fields and when used effectively can achieve accurate results. This type of device can be used with a strain gauge when monitoring the strain experienced in load bearing components in aerospace applications. Technology is advancing at a rapid rate and the need for precise and accurate instrumentation is growing alongside this.

3.2 EXTENSOMETER

The extensometer is a highly precise monitoring device used heavily in the geotechnical field. Geologists and civil engineers use this device to measure changes in length of an object under stress, specifically tensile stress. The readings achieved from the instrument can help determine multiple factors of the object under stress i.e., tensile strength of the object or the yield point elongation as described by (Encardio Rite, 2020).

This device is versatile due to its use across multiple fields. They can be used in various fields such as magnetic, electrical, mechanical and even soil. The variations of this device are contact, non-contact, laser and video. A unique and innovative device that when implemented correctly can achieve accurate results. Epsilon's deflectometer model 3540 is an example of an extensometer that is used to measure deflection.



FIGURE 4 - EPSILON DEFLECTOMETER MODEL 3540

3.3 PNEUMATIC GAUGE

The biggest development of air gauging occurred around the 1940s with an increase in military demands. The automobile industry also implemented the use of air gauging instrumentation into their processes. Adding this instrument to their arsenal allowed for much greater control and precision with any complex machining processes.

Air gauging was innovative and beneficial before electronic gauging became the more reliable measuring system in the workshop as described by (Burrows, 2013). This method of measuring has many benefits that make it desirable. If compressed air is readily available then using this instrument will bring precise measurements, easy operation, zero preparation for use and many other cost reducing benefits.

This form of instrumentation would be an excellent choice as part of a design that needs displacement measurements. The instrument configuration is a platen that has an air nozzle mounted within. This is simply run along the testing area which will be the steel girder. The deflection can be measured according to the rate of air that escapes from the device under pressure. This instrument is reliable and super sensitive resulting in very accurate readings. However, the extra cost would be to add a compressed air supply to the design of the gantry crane. The extra cost isn't feasible to use this as our method of testing when there are other reliable sources of testing.

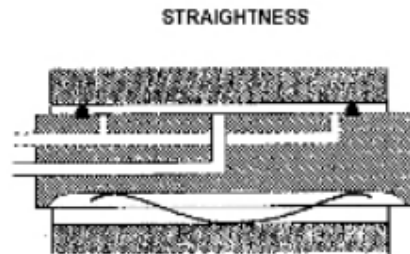


FIGURE 5 - AIR ELECTRIC MEASUREMENT FOR STRAIGHTNESS (BURROWS, 2013)

3.4 CAPACITANCE GAUGE

This type of strain gauge is common and is used instead of a standard resistance gauge. Resistance gauges tend to introduce other elements that affect the overall resistance of the assembly. This gives a false resistance reading and would not be reliable in conditions with increased temperature exposure. Capacitance strain gauges do not dissipate any energy resulting in more reliable and accurate strain readings.

If the testing application has certain conditions as shown by (Tarasenko, Heerens and Tarasenko, 2012) in figure 5, then it is important to consider all of these factors when choosing a capacitance or resistance strain gauge for optimal results. For our design, the main problem area would be the lead connection troubles to be able to smoothly operate this type of strain gauge unless a three-terminal a.c. system is used. The gantry crane will be large, and this means long cables will need to be used in order to ensure the circuit assembly has power running through it. This in my opinion seems like a lot of unnecessary work and wouldn't be cost effective.

Influence on measurement results of	Resistive or semiconductor strain gauges	Uniplanar capacitive strain gauge
Hysteresis	Exist	Can exist, excludable in simple design
Creep	Exist	Can exist, excludable in simple design
Orthogonal contractions or elongations	Exist	Absent
Temperature-induced changes in absolute sensitivity via changes in dimensions	Exist, removable by second gauge	Absent
Zero shift by temperature-induced length variations	Exist in all directions, removable by second gauge	Exist only in gauge direction, removable by second gauge
Chosen value of resistivity	Exist, gauge needs to be trimmed	Absent, gauge needs no trimming
Temperature changes of resistivity	Exist, removable by second gauge	Absent
Measure of deformation	Exist	Absent
Connection lead resistance troubles	Exist	Absent
Long connecting cable problems	Exist	Absent for three-terminal a.c. system
Electrostatic residual effect	Exist above 50 V	Absent for three-terminal a.c. system
Effect of external electric fields	Hardly exist	Exist, easy to eliminate
Nuclear radiation problems	Negligible	Absent
Zero drift due to extreme high-temperature exposure	As a rule exist	Excluded in simple design
Drift due to fatigue testing	Exist	Absent

FIGURE 6 - A COMPARISON OF POSSIBLE INFLUENCES ON GAUGE CHARACTERISTICS (TARASENKO, HEERENS AND TARASENKO, 2012)

3.5 INDUCTANCE GAUGE

Another innovative variation of a strain gauge related to measuring the inductance experienced in an element. This type of strain gauge is applied in systems to measure displacement, pressure, vibration, force and even thickness. A simple inductance transducer is measuring the displacement in an assembly. When the mechanical element moves, the flux path permeance that is generated from the circuit is altered proportionally. This small change in inductance and output of the circuit can be measured against the input value and a calculation of displacement can be made as described in (ELPROCUS, 2018). A very innovative and useful measuring system that can come in a two-coil setup. The principle of this type of transducer is one coil that is excited during application whilst the other coil is used to record the output of the application. The input and output are directly proportional, making this type of device very easy to use and reliable in a suitable field.



FIGURE 7 - INDUCTIVE TRANSDUCER (SIMPLE) (ELPROCUS, 2018)

3.6 ACOUSTIC GAUGE

Surface Acoustic Wave (SAW) devices have been used for multiple applications since the 1970s. The device consists of two interdigital transducer arrays (IDTs) on a piezoelectric substrate such as quartz as described in (Technical, 2009). The IDTs consist of metal electrodes that are fabricated using integrated circuit technology. This is used to receive and emit waves. The electrical signal is converted into an acoustic wave and then back into an electrical signal. Signals can be generated when mechanical stress is applied, and the strain is measured in the frequency change that the sensor technology uses. Some applications of this device are in the automotive sector specifically measuring torque or tyre pressure.



FIGURE 8 - BASIC TORQUE SENSOR MODEL RWT310

3.7 WHY THESE HAVE BEEN DEVELOPED

Strain gauges were developed to further our understanding of elements undergoing changes in behaviour when conditions are changed. The strain gauges today are extremely accurate and from a business perspective, this is necessary. This form of instrumentation can allow for increased capability for businesses and an increased lifespan of equipment which is a benefit to the manufacturer and the customer. This creates a feeling of satisfaction as the strain gauge can help determine a great deal of probabilities. Strain gauges can also determine a range of applications such as the likelihood of an underground cavity collapsing. This can be determined with the use of an extensometer. Other applications that a strain gauge is utilised in is measuring bridges or dam structures to detect early deformations. In the aerospace field the use of a strain gauge is utilised in the wings to measure wing deflection.

These applications of the strain gauge show just how useful they are in our everyday lives without us even noticing. We unknowingly put our safety in the hands of these devices when boarding a plane or travelling on a train. The devices are monitored heavily and in the chance of a potential failure, the problem would be flagged up well in advance to avoid catastrophic scenarios such as the Minneapolis steel truss bridge in 2007 leading to 13 fatalities as mentioned in (Sensing system, 2016).

3.8 FUTURE OF THE STRAIN GAUGE

For the medical industry especially, incorporating this sort of instrumentation into medical devices is a powerful attribute. After a thorough testing and prototyping period, (Hottinger, 2013) goes on to explain the multiple uses of strain gauges in critical and non-critical medical procedures. Some of these procedures range from high-precision robotic surgery to medical pump pressure and flow measurements.

The device introduces a completely new dynamic for monitoring accurately and efficiently. Industries will continue to use them to improve overall performance. Monitoring for faults that arise over prolonged periods is vital in most fields of application and with current advancements in technology, the need for super sensitive instrumentation is dire.

4.0 USE OF STRAIN GAUGES IN THE DESIGN

So, for my design I have chosen two types of strain gauge that I believe would be cost effective and easy to install on the steel girder. The purpose of two different types is to achieve two values of deflection and taking an average. This eliminates inconsistencies. Any anomalies can be addressed by a calibration and not taken as the true value. This is very common in big industries where they are over reliant on a single instrument and cross referencing this against another device of the same nature is not completed. This would increase the overall cost of the design however I believe the long-term benefits far outweigh the initial cost. The two types are a deflectometer model 3540 (Figure 4) which is manufactured by Epsilon and a vibrating wire strain gauge (Figure 9) manufactured by RST instruments.

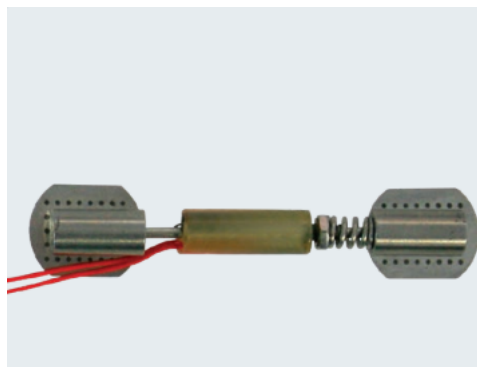


FIGURE 9 - VIBRATING WIRE SPOT WELDABLE STRAIN GAUGE (VWSG-S-3000)

Epsilon's device has a single extensometer arm with a spherical contact tip that is used to measure deflection. This device can be configured with a spring-loaded arm acting downward or upward depending on application. This is extremely useful for the design of the gantry crane as it allows for multiple ways to implement onto the steel girder. The device will be installed at the centre of the beam with the arm pressing downward. The magnetic base allows for easy mount and dismount of device. The strain is measured by the small spring force exerted against the test surface whilst it undergoes deflection. This measurement can be read as the total deflection experienced by the steel girder under load therefore no further calculation is needed.

In figure 10, the vibrating wire strain gauges are located (1) and (2). These are placed in the centre of the steel girder running parallel with the beam. This placement gives a resultant bending moment under load along the shown axis (YY). Having the strain gauges at this location makes protecting the gauges and running cables easier. To interpret the readings from these gauges it is important to firstly record readings whilst there is 0 load present. This would be your initial calibration before any load tests are performed. The subsequent readings following this initial reading will be used to calculate the true strain experienced by the gauge as described by (Elm, 2020).

Strain is calculated using the formula: $\mu\epsilon_{\text{true}} = R_1 - R_0$.

R_0 is the initial reading when installed and R_1 is the subsequent strain reading which will occur when under load. If the true strain calculation comes back as positive, then the strain experienced is tensile. If the result is negative, this strain is compressive. In our scenario the strain these gauges will experience will be tensile. A simple gauge factor can be used to calculate the final deflection experienced by the beam.

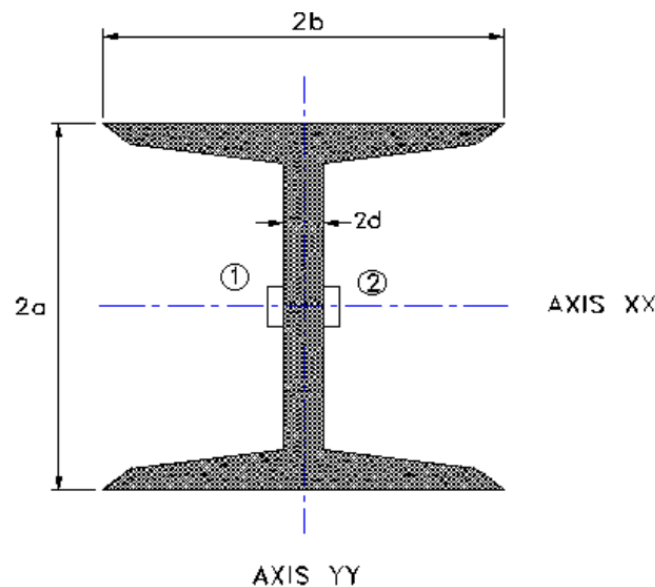


FIGURE 10 - DIAGRAM SHOWING POSITIONING OF THE STRAIN GAUGES AND THE AXIAL STRAIN ALONG (YY) AXIS.

5.0 CONCLUSION

To conclude my design of a cost-effective gantry crane, I will use the steel section 457mm x 191mm x 133kg/m manufactured by British steel to achieve my allowable maximum deflection with specified load and 125% of the specified load. My design will incorporate the use of two different strain gauges that will monitor the strain experienced by the beam accurately and flag any possibilities of failure.

6.0 REFERENCE LIST

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