

T.C.
ISTANBUL AYDIN UNIVERSITY
INSTITUTE OF GRADUATE STUDIES



**A REVIEW ON CURRENT EXTENSOMETER USE IN
INDUSTRIAL APPLICATIONS, ITS DEFICIENCIES AND A
PROPOSAL FOR IMPROVEMENT**

MASTER'S THESIS
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Department of Mechanical Engineering
Mechanical Engineering Program

JUNE, 2023

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JUNE/2023

APPROVAL PAGE

DECLARATION

I hereby confirm and assert that the Master's thesis titled " A Review On Current Extensometer Use in Industrial Applications, Its Deficiencies and a Proposal for Improvement" is entirely my own work, adhering to scientific ethics and conventions. Throughout the entire process, from the initial project phase to the completion of the thesis, I have not received any form of unauthorized assistance. The referenced works cited in the thesis accurately represent the sources from which I have obtained information. (01/06/2023)

Gassim Fauzi Naddi

FOREWORD

In the realm of materials testing, structural monitoring, and engineering research, the accurate measurement of strain and displacement is vital for understanding the behavior, performance, and integrity of various structures and materials. Bolt-on extensometers, as a specific type of extensometer, have emerged as valuable instruments for capturing precise deformation data during mechanical testing processes.

The primary objective of this thesis is to provide a detailed examination of bolt-on extensometers, with a particular emphasis on their failure modes and the measures for mitigating such failures. By identifying and understanding the reasons behind potential failure modes, researchers and practitioners can implement appropriate strategies to enhance the reliability and accuracy of measurements obtained from bolt-on extensometers.

This thesis also investigates the various challenges associated with bolt-on extensometers, such as structural failures, installation and alignment issues, environmental factors, and calibration and maintenance considerations. By exploring these challenges in depth, readers will gain insights into the factors that can impede accurate measurements and the strategies to overcome these hurdles.

Furthermore, this research aims to inspire further advancements in the field of bolt-on extensometers. By shedding light on their failure modes and potential solutions, it encourages the development of improved designs, calibration techniques, and maintenance protocols that will contribute to more reliable and accurate measurements.

July 2023

Gassim Fauzi Naddi

**A REVIEW ON CURRENT EXTENSOMETER USE IN INDUSTRIAL
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ABSTRACT**

Extensometers are mechanical devices used to measure changes in length or strain in materials under stress or deformation. They provide valuable data for evaluating material properties, structural integrity, and mechanical behavior. One specific type of extensometer is the bolt-on extensometer, which is easily mounted onto the surface of a specimen using bolts or clamps.

This thesis project aims to investigate and analyze the role of extensometers and bolt-on extensometers in measuring strain and deformation in materials, focusing on their advantages and potential failure modes. Extensometers are widely used mechanical devices in engineering, material testing, and research to assess material properties and structural behavior. Bolt-on extensometers, a specific type of extensometer, offer the advantage of easy installation without damaging the specimen.

The study begins with an in-depth literature review to understand the theoretical background, working principles, and applications of extensometers and bolt-on extensometers. The advantages of extensometers lie in their ability to provide accurate and reliable measurements of strain. They aid in the design, optimization, and safety assessment of structures.

The thesis project also investigates the specific advantages of bolt-on extensometers, which include non-destructive testing capabilities and versatility in measuring strain in delicate or composite materials. The easy installation and removal

of bolt-on extensometers make them suitable for various testing scenarios, both in laboratory settings and in the field.

However, the research also delves into the potential failure modes of bolt-on extensometers. Mechanical issues such as arm or jaw failures, contact point discrepancies, or central body malfunctions can lead to inaccurate or inconsistent measurements. Calibration problems and environmental factors, such as extreme temperatures or corrosive substances, can also affect the performance of these devices.

Keywords: extensometer, bolt-on extensometer, measurement failure, correction methods, advantages and failure.

**ENDÜSTRİYEL UYGULAMALARDA MEVCUT EKSTANSOMETRE
KULLANIMI, EKSİKLİKLERİ VE İYİLEŞTİRME ÖNERİSİ ÜZERİNE BİR
İNCELEME**

ÖZET

Ekstansometreler, gerilim veya deformasyon altındaki malzemelerde uzunluk veya gerinimdeki değişiklikleri ölçmek için kullanılan mekanik cihazlardır. Malzeme özelliklerini, yapısal bütünlüğü ve mekanik davranışı değerlendirmek için değerli veriler sağlarlar. Spesifik bir ekstansometre türü, cıvatalar veya kelepçeler kullanılarak bir numunenin yüzeyine kolayca monte edilen cıvatalı ekstansometredir.

Bu tez projesi, ekstansometrelerin ve cıvatalı ekstansometrelerin malzemelerdeki gerinim ve deformasyonun ölçülmesindeki rolünü, avantajlarına ve potansiyel arıza modlarına odaklanarak araştırmayı ve analiz etmeyi amaçlamaktadır. Ekstansometreler, malzeme özelliklerini ve yapısal davranışı değerlendirmek için mühendislik, malzeme testi ve araştırmalarda yaygın olarak kullanılan mekanik cihazlardır. Belirli bir ekstansometre türü olan cıvatalı ekstansometreler, numuneye zarar vermeden kolay kurulum avantajı sunar.

Çalışma, ekstansometrelerin ve cıvatalı ekstansometrelerin teorik arka planını, çalışma ilkelerini ve uygulamalarını anlamak için derinlemesine bir literatür taraması ile başlar. Ekstansometrelerin avantajları, doğru ve güvenilir gerinim ölçümleri sağlama yeteneklerinde yatmaktadır. Yapıların tasarımına, optimizasyonuna ve güvenlik değerlendirmesine yardımcı olurlar.

Tez projesi ayrıca, tahribatsız test yetenekleri ve hassas veya kompozit malzemelerdeki gerinim ölçümünde çok yönlülüğü içeren cıvatalı ekstansometrelerin belirli avantajlarını da araştırmaktadır. Cıvatalı ekstansometrelerin kolay kurulumu ve çıkarılması, onları hem laboratuvar ortamlarında hem de sahada çeşitli test senaryoları için uygun hale getirir.

Bununla birlikte, araştırma cıvatalı ekstansometrelerin olası arıza modlarını da araştırıyor. Kol veya çene arızaları, temas noktası tutarsızlıkları veya merkezi gövde arızaları gibi mekanik sorunlar hatalı veya tutarsız ölçümlere yol açabilir. Kalibrasyon sorunları ve aşırı sıcaklıklar veya aşındırıcı maddeler gibi çevresel faktörler de bu cihazların performansını etkileyebilir.

Anahtar Kelimeler: ekstansometre, geçmeli ekstansometre, ölçüm hatası, düzeltme yöntemleri, avantajlar ve başarısızlık.

TABLE OF CONTENTS

DECLARATION.....	I
FOREWORD.....	II
ABSTRACT.....	III
ÖZET.....	V
TABLE OF CONTENTS.....	VII
LIST OF FIGURES	XI
I.INTRODUCTION	1
A. General Introduction	1
B. Report Outline.....	2
II.EXTENSOMETERS.....	3
A. Introduction.....	3
B. Extensometer.....	3
C. Types of Extensometers	3
1. Contact Extensometers.....	3
a. Clip-on extensometer	4
b. Sensor arm extensometer	5
2. Non-contact extensometer.....	5
a. Video extensometer.....	6
b. Laser extensometer.....	7
D. Working Principle of Extensometer.....	7
1. Magnetic extensometer	8

2.	Electrical extensometer	9
3.	mechanical extensometer	10
4.	Soil extensometer	10
III.BOLT-ON EXTENSOMETERS.....		12
A.	Introduction	12
B.	Bolt-on Extensometers	12
C.	Types of Bolt-on Extensometers	12
1.	Structural monitoring extensometers	12
a.	Vibrating Wire Extensometers:.....	14
b.	Linear Variable Differential Transformers (LVDTs)	15
c.	Capacitive Extensometers	16
2.	Geotechnical extensometers.....	17
a.	Convergent Extensometers.....	17
b.	Rod Extensometers.....	18
c.	Tape Extensometers	19
d.	Settlement Extensometers	20
e.	Borehole Extensometers.....	21
3.	Automotive testing extensometer.....	22
4.	Bolt-on Strain Gauges	22
5.	Bolt-on LVDT Extensometer	23
a.	Single-Point Bolt-On LVDT Extensometers	25
b.	Multiple-Point Bolt-On LVDT Extensometers.....	25
c.	Customized Bolt-On LVDT Extensometers	26
D.	Models of Bolt-on Extensometers.....	27

1.	XT50 extensometer (flintec)	28
2.	VT1 Extensometer (flintec).....	30
3.	Model 178 extensometer (VPG transducers Company).....	31
E.	Measurement Accuracies	34
1.	Structural Monitoring Bolt-on Extensometers.....	34
2.	Geotechnical Bolt-on Extensometers.....	35
3.	Automotive Testing Bolt-on Extensometers.....	35
4.	Bolt-on Strain Gauges	36
5.	Bolt-on LVDT Extensometers (Linear Variable Differential Transformers).....	36
F.	Failure of Bolt-on Extensometers	36
G.	Advantages of Bolt-on Extensometers.....	38
IV.OVERCOME THE FAILURES IN MEASUREMENTS OF BOLT-ON EXTENSOMETERS.....		42
A.	Introduction	42
B.	Mechanical Failures	42
C.	Theoretical failures.....	44
D.	Correction Methods.....	46
1.	Mechanical Approach	46
2.	Theoretical Approach.....	47
V.CONCLUSION.....		50
VI.REFERENCES		52
APPENDIX A		56
APPENDIX B		57

APPENDIX C	58
RESUME.....	59

LIST OF FIGURES

Figure 2-1: clip-on extensometer.	4
Figure 2-2:Sensor arm extensometer.	5
Figure 2-3:video extensometer.....	6
Figure 2-4: laser extensometer.	7
Figure 2-5: magnetic extensometer.....	8
Figure 2-6: electrical extensometer.....	9
Figure 2-7: mechanical extensometer.	10
Figure 2-8: soil extensometer.....	11
Figure 3-1: The Vibrating Wire Inline Extensometer.	15
Figure 3-2 Linear Variable Differential Transformers (LVDTs).....	16
Figure 3-3:convergent extensometer.....	18
Figure 3-4:Rod extensometers.	19
Figure 3-5:settlement extensometer or settlement gauge.....	20
Figure 3-6: borehole extensometer.	21
Figure 3-7: bolt-on strain gauge.....	23
Figure 3-8: Bolt-on LVDT Extensometer.....	24
Figure 3-9: XT50 extensometer.	29
Figure 3-10: VT1 Extensometer.	31
Figure 3-11: Model 178 Extensometer.	33

I. INTRODUCTION

A. GENERAL INTRODUCTION

Extensometers are essential tools used in engineering, material testing, and research to measure strain and deformation in various materials under stress. They provide valuable data for understanding material behavior, evaluating structural integrity, and optimizing design. Among the different types of extensometers, bolt-on extensometers have gained popularity due to their convenience and non-destructive testing capabilities. This thesis aims to investigate the role of extensometers and specifically focus on bolt-on extensometers, analyzing their advantages and potential failure modes.

Bolt-on extensometers offer unique advantages that make them particularly valuable in certain applications. Their non-destructive nature allows for easy installation and removal without altering or damaging the material being tested. This makes bolt-on extensometers ideal for delicate structures, composites, or samples that require subsequent testing or analysis. The versatility of bolt-on extensometers enables their use in various engineering disciplines, including structural, civil, mechanical, and aerospace engineering.

This thesis will investigate extensometers and bolt-on extensometers in-depth, focusing on their advantages and potential failure modes. Experimental investigations will be conducted to validate the advantages of extensometers and assess their failure modes under controlled loading conditions. The findings of this research will contribute to a better understanding of extensometers, specifically bolt-on extensometers, their advantages, and the factors that can lead to failure.

B. REPORT OUTLINE

This report is composed of four chapters in addition to this one. Chapter 2 is a literature review about the extensometer, types, classification of extensometers and the working principles of extensometers. Chapter 3 explain bolt-on extensometer, its types and uses in addition will be explained the accuracies, failures and advantages. Chapter 4 will explain how to overcome the failures in measurement of bolt-on extensometers Finally, the general conclusion presented in chapter 5.

II. EXTENSOMETERS

A. INTRODUCTION

In this chapter, will be explained what is an extensometer, the classifications, types of extensometers and the working principles.

B. EXTENSOMETER

An extensometer is a device used by geologists and civil engineers to measure changes in length with great precision. It is utilized for stress-strain measurements and tensile testing. In other word is used for measuring the deformation of a material under stress.

Extensometers immediately measure strain on the specimen. This reduces measurement impacts from other testing components and improves accuracy.

C. TYPES OF EXTENSOMETERS

There are two main different types of extensometers, each one has a specific application, these types are; contact extensometers, and non-contact extensometers.

1. Contact Extensometers

Contact extensometers are mounted directly into the specimen; this type of extensometer has been used for many years. There are 2 categories of contact extensometers; clip-on extensometer and sensor arm extensometer.

a. Clip-on extensometer

Those extensometers are used where high precision and accuracy is needed, it can measure from very small to relatively large (from 1 mm to more than 100 mm or 0.1m).

The mechanical elements that convey extension from the specimen to the internal transducer through knife edges are short and strong. Because there is almost no relative movement between the specimen and the extensometer, measurement accuracy is quite good.



Figure II-1: clip-on extensometer.

b. Sensor arm extensometer

Sensor arm extensometers have the advantages of being automated and having a vast measuring range with excellent measurement accuracy. Precision designs with highly smooth and balanced mechanical action apply the specimen with the least amount of loading. Superimposed bending stresses are mainly mitigated since the sensor arms are in touch with both sides of the specimen.

The disadvantage of the sensor arm extensometer is that because of the direct contact with the specimen, the extensometer can be damaged or even destroyed at the failure point of high elasticity.

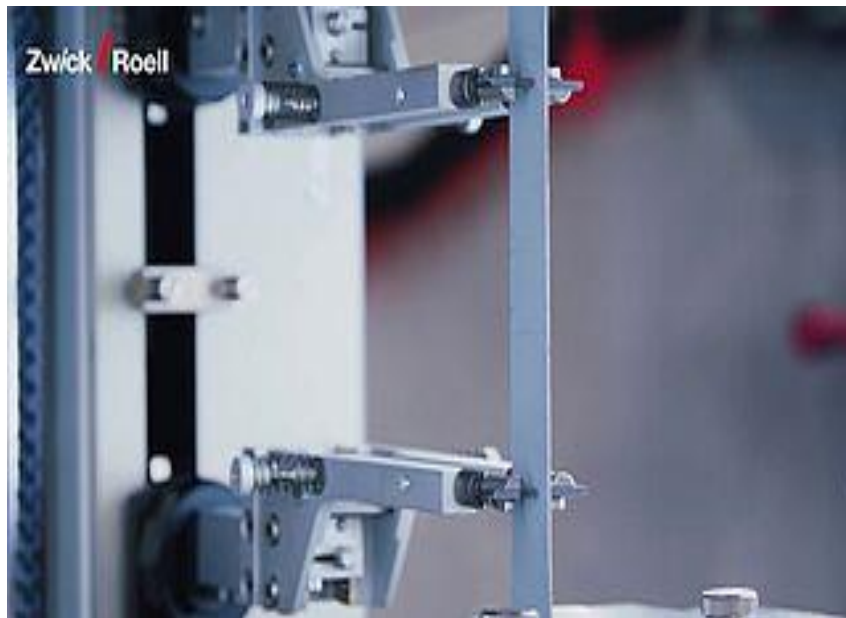


Figure II-2: Sensor arm extensometer.

2. Non-contact extensometer

As the name implied those extensometers are not mounted directly to the specimen, and for certain application non-contact extensometers are becoming more common because they can be used in places where it is difficult to use contact

extensometers. There are two types of non-contact extensometer; laser extensometer and video extensometer.

a. Video extensometer

A video extensometer is a device that can assess the stress and strain on a given material by taking continuous pictures of the specimen while it is being tested with a frame grabber or a digital camera connected to a computer.

Typically, the specimen of the substance being tested is sliced into a specified form and tagged with specialized markers (usually special stickers or with pens that distinguishes the marker from the specimen color and texture in the captured image). While the test subject is being stretched or compressed, the recorded video continuously tracks the distance in pixels between these markers in the picture. To directly detect strain and, if necessary, manage the testing machine in terms of strain control, this pixel distance can be monitored in real-time and mapped against a calibration value.

Noncontact video extensometers have the major benefit of being able to test specimens that display whiplash up to the point of material failure without suffering any damage. The capacity to more precisely calculate strain and use strain as a control loop mechanism for test samples experiencing significant deformations is another benefit.

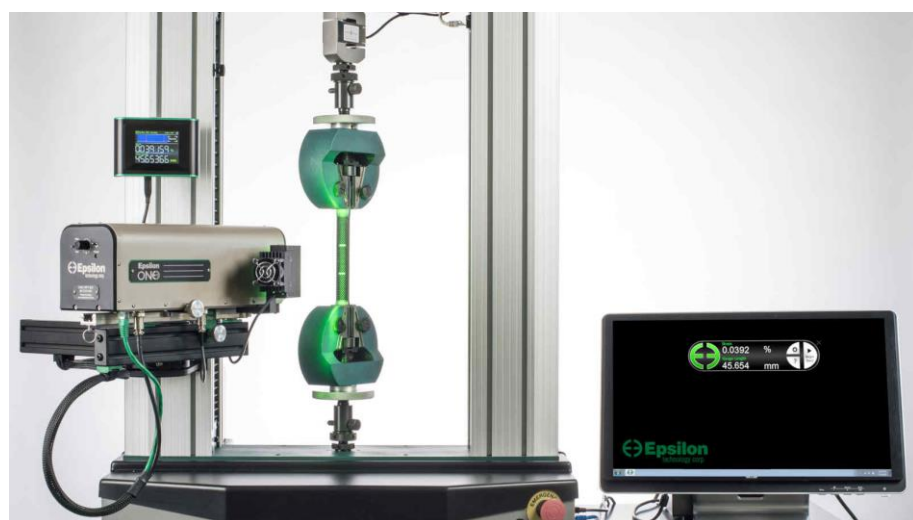


Figure II-3:video extensometer.

b. Laser extensometer

Extensometers using the most recent extensometer technology employ a non-contacting device and don't need measuring markings. The laser extensometer creates a virtual measuring mark by using the surface of a specimen as a fingerprint. When laser light is focused on certain measurement locations, it reflects in different ways that correlate to the surface's topography, producing a particular pattern of speckles. Direct extension values are generated by continuously monitoring a set of measurement locations. Throughout specimen deformation, the alteration in the surface structure, which forms the foundation of the speckle pattern, is continually assessed. A CCD camera then captures the reflections from the specimen surface, which are then subjected to sophisticated algorithms for processing.

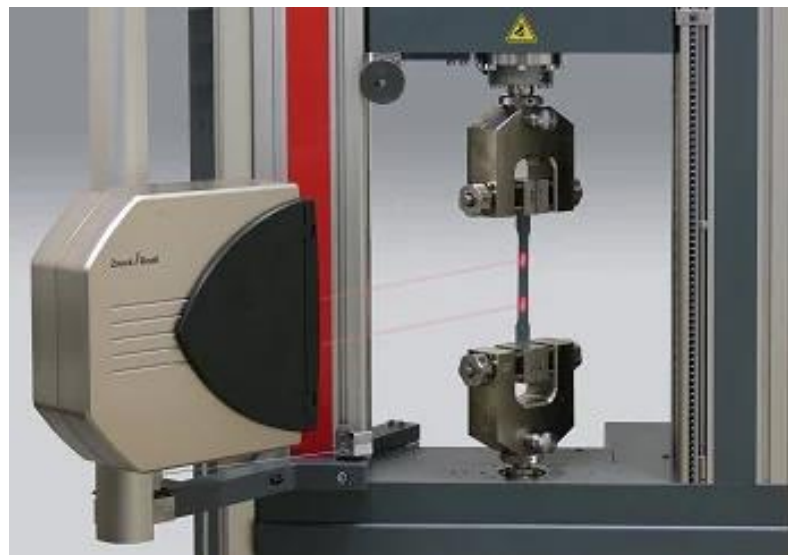


Figure II-4: laser extensometer.

D. WORKING PRINCIPLE OF EXTENSOMETER

Extensometers' operating principles vary depending on their type and region of application. Some of them, such as soil extensometers and magnetic, electrical,

mechanical, and other extensometers, will be discussed in this part. These extensometers all operate on various principles.

1. Magnetic extensometer

The magnetic extensometer system is made to measure the heave or settlement of soft ground caused by loading or unloading when embankments, fills, buildings, and other structures and building.

Monitoring the position of magnetic targets positioned above a near-horizontal access tube allows for the evaluation of lateral movement at any level within a soil mass. A consolidation-induced settlement can occur in embankments and foundations, while lateral ground movement can occur in abutments, foundations, or embankments.



Figure II-5: magnetic extensometer.

2. Electrical extensometer

Electrical extensometers are instruments that allow obtaining the state of deformation with a high degree of accuracy, thanks to its ease of installation and low cost. Most electrical extensometers use a linear variable differential transformer (LVDT) to convert a small movement into a voltage that is recorded.

The principle of operation of an electrical extensometer is based on the changes in electrical resistance that a conductor undergoes when it is subjected to changes in its length.

A vibrating wire transducer is incorporated into the electrical borehole extensometer for the purpose of measuring displacement.

A vibrating wire transducer is incorporated into the electrical borehole extensometer for the purpose of measuring displacement. Fiberglass or AISI 410 stainless steel connecting rods of the appropriate length are connected to a groutable reinforced bar anchor.

From the factory, connecting rods made of fiberglass come in one length. Heavy-duty protective tubing surrounds the connecting rods, allowing for free movement. Using a lock nut and a link plate, the displacement sensor is connected to the connecting rod.

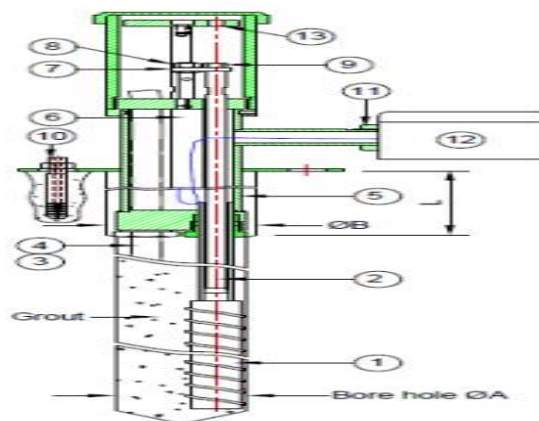


Figure II-6: electrical extensometer.

3. Mechanical extensometer

Mechanical extensometers are based on the measurement of the variation of length (ΔL) of a body of length L , since the values of ΔL to be measured are very small, extensometers of this type use mechanical devices to achieve amplification of said length variation and that can be detected with accuracy by the device.

The borehole extensometer showed in figure 7 measures the lengthening (displacement) of a rock mass over time in a single or multiple boring holes. It basically consists of a reference plate and one or more anchors. The anchor or anchors are anchored in either the same borehole or adjacent boreholes.



Figure II-7: mechanical extensometer.

4. Soil extensometer

The soil extensometer monitors displacement with a vibrating wire sensor. To monitor the horizontal movement of the surrounding soil, the system consists of a

sensor assembly with flanges that are mounted between two anchors with adaptors, an adjustment unit, sockets, and extension rods.

Telescopic PVC tubing with appropriate "O" ring seals surrounds the system to prevent water ingress and eliminate friction between the rods and soil.

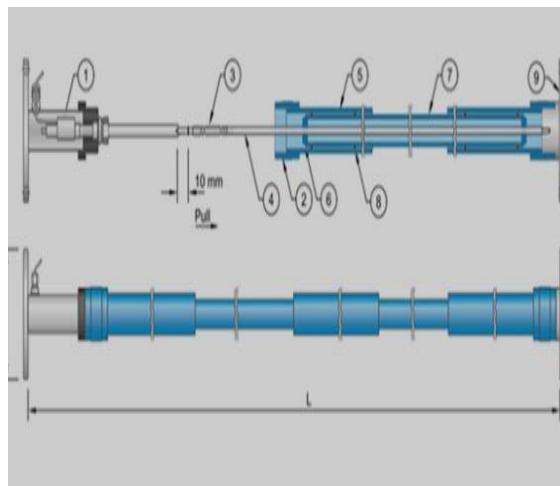


Figure II-8: soil extensometer.

III. BOLT-ON EXTENSOMETERS

A. INTRODUCTION

In this chapter, will be explained what is a bolt-on extensometer, some types and uses of bolt-on extensometers, accuracies, failures and advantages and finally the reason of failures.

B. BOLT-ON EXTENSOMETERS

The bolt-on extensometer is used to measure the change in length or displacement of vehicles, builds, bridges, excavators, big machinery etc. as it undergoes stress, allowing the calculation of strain or deformation. A bolt-on extensometer is a device used to measure strain or deformation in materials, typically metals, under mechanical loading. It is designed to be bolted directly onto the surface of the specimen or test material.

Bolt-on extensometers are commonly used in applications for quality control, research and development, and material testing labs. They give engineers and scientists a non-destructive way to measure strain or deformation, enabling them to examine the mechanical characteristics and behavior of materials under various circumstances.

C. TYPES OF BOLT-ON EXTENSOMETERS

Bolt-on extensometers come in a variety of designs, each designed to a particular application's measuring needs. Here are some common types:

1. Structural monitoring extensometers

Structural monitoring extensometers are specialist instruments used to monitor and measure strain or deformation in structures including buildings, bridges, tunnels, dams, and other types of civil infrastructure. To offer continuous monitoring

and data collecting, these extensometers are intended to be permanently or semi-permanently placed on the structure. In order to track changes in strain over time, they are often fastened or affixed to particular points on the structure.

The primary purpose of Structural Monitoring Extensometers is to assess the structural health and behavior of the monitored structures. By measuring strain or deformation, these extensometers can provide valuable insights into the structural performance, load distribution, and response to external forces. The collected data can be used for a variety of purposes, including:

- **Structural Health Monitoring:** Structural Monitoring Extensometers help in assessing the integrity and condition of the structure over its lifetime. They can detect and quantify changes in strain, deformation, or displacement that may indicate structural damage, deterioration, or excessive loading.
- **Load Monitoring:** These extensometers can measure strain or deformation caused by live loads, temperature variations, or environmental factors. By monitoring these changes, engineers can gain a better understanding of how the structure responds to different load conditions and ensure it operates within design parameters.
- **Safety Assessments:** Continuous monitoring of strain or deformation allows for early detection of structural anomalies or abnormal behavior. By identifying potential safety risks, engineers can take proactive measures to address any issues and ensure the safety of the structure and its occupants.
- **Performance Evaluation:** Structural Monitoring Extensometers provide valuable data for evaluating the performance of structures, including the effectiveness of design, construction techniques, and material properties. The collected information can be used to validate and improve future structural designs.
- **Research and Analysis:** The data collected from these extensometers can be utilized for research purposes, allowing engineers and researchers to gain insights into the behavior and performance of

different structural systems. This information can contribute to the development of improved design methodologies and construction practices.

Overall, Structural Monitoring Extensometers play a crucial role in assessing the structural integrity, safety, and performance of various civil infrastructure. By providing real-time data on strain and deformation, they enable engineers to make informed decisions regarding maintenance, repairs, and structural modifications, ensuring the longevity and safety of the monitored structures. There are several types of Structural Monitoring Extensometers used for assessing the behavior and performance of structures. Here are some common types:

a. Vibrating Wire Extensometers:

These extensometers are specialized instruments used to measure displacement or deformation in various structures. These extensometers employ vibrating wire technology, which provides accurate and reliable measurements in a wide range of engineering applications.

The bolt-on design allows for easy installation and secure attachment to the structure being monitored. The extensometer is typically mounted onto the structure using bolts, ensuring a stable connection and reliable measurements.

Inside the extensometer, a vibrating wire sensor is utilized to measure the displacement or deformation of the structure. The vibrating wire sensor consists of a tensioned wire that vibrates at a specific frequency. When the structure undergoes displacement or deformation, the tension in the wire changes, resulting in a change in its resonant frequency. This change in frequency is converted into an electrical signal, which is then measured and recorded by the extensometer.



Figure III-1: The Vibrating Wire Inline Extensometer.

b. Linear Variable Differential Transformers (LVDTs)

LVDTs are displacement transducers commonly used in structural monitoring. They consist of a movable core connected to the structure and a coil assembly. Changes in displacement result in a corresponding change in the voltage output of the LVDT, providing a measurement of structural movement. Linear Variable Differential Transformers (LVDTs) are not typically considered as bolt-on extensometers in the traditional sense. LVDTs are displacement transducers that are commonly used to measure linear displacements or movements. They are often used in applications where precise position measurements are required, such as in control systems or automation. LVDTs are typically installed by mounting them onto a structure or attaching them to a moving component. They may use bolts or other fasteners for secure attachment, but their primary function is to measure displacement rather than strain or deformation directly.

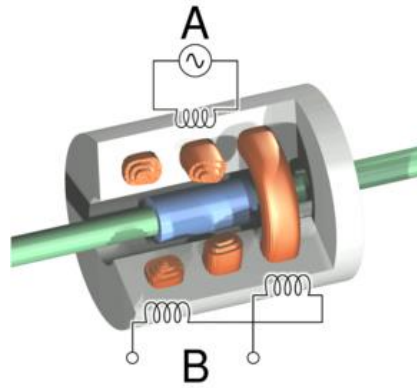


Figure III-2 Linear Variable Differential Transformers (LVDTs).

c. Capacitive Extensometers

Capacitive extensometers measure changes in capacitance resulting from structural deformation. They consist of capacitive plates or sensors attached to the structure, and the variation in capacitance is correlated with the deformation or strain experienced by the structure.

In a capacitive extensometer, two conductive plates are placed in close proximity to each other, with a small gap between them. When the structure experiences strain or deformation, the distance between the plates changes, leading to a corresponding change in capacitance.

To install a capacitive extensometer, the two conductive plates are typically attached or bolted onto the surface of the structure. The extensometer is carefully positioned and securely fastened to ensure accurate strain measurements. The bolt-on design provides stability and maintains the proper alignment of the plates during testing or monitoring.

By measuring the change in capacitance, the capacitive extensometer determines the strain or deformation experienced by the structure. This enables precise and reliable strain measurement in various mechanical testing or structural monitoring applications.

2. Geotechnical extensometers

Geotechnical Extensometers are specialized devices used to measure the movement or changes in soil or rock. These instruments are employed in geotechnical engineering and monitoring to evaluate the stability and behavior of soil or rock masses.

Geotechnical Extensometers usually comprise of mechanical or electronic measuring tools that are installed at specific depths or locations of importance within the ground or rock. They are built to endure the challenging and rigorous conditions typically found in geotechnical settings.

The primary purpose of Geotechnical Extensometers is to measure changes in displacement or deformation within the soil or rock mass over time. By monitoring these changes, engineers and geotechnical experts can evaluate the performance and stability of slopes, embankments, tunnels, excavations, retaining walls, and other geotechnical structures. The collected data provides insights into the behavior and movement of the ground, helping in the assessment of potential hazards, designing appropriate mitigation measures, and ensuring the safety of nearby structures and personnel.

Geotechnical Extensometers can be categorized based on their installation method and measurement principle:

a. Convergent Extensometers

Convergent extensometers consist of multiple anchor points installed at different depths or locations in the ground or rock. These anchor points are connected to a common reference point on the surface, and changes in distance between the anchors and the reference point indicate deformation or displacement. Convergent extensometers are not typically considered as bolt-on extensometers. Convergent extensometers are devices used to measure strain and deformation in materials or structures. They employ a converging point system, where two arms with contact points converge towards a central point on the specimen.

To install a convergent extensometer, the arms with contact points are typically attached or clamped onto the surface of the material or structure being

measured. However, the installation method may vary depending on the specific design of the convergent extensometer.



Figure III-3:convergent extensometer.

b. Rod Extensometers

Rod extensometers consist of a series of rods installed in boreholes or installed directly into the ground or rock. These rods are equipped with displacement sensors that measure the changes in length or displacement of the rods, providing information on ground movement. Rod extensometers are devices used to measure strain and deformation in soil or rock formations. They typically consist of a series of rods or bars that are installed vertically or horizontally into the ground or rock.

To install a rod extensometer, the rods are usually anchored or bolted to the surrounding soil or rock. This bolt-on attachment ensures that the extensometer remains securely in place during measurements. The rods are often fitted with displacement transducers or other sensors that measure the relative movement or deformation of the rods, providing information about the strain in the surrounding soil or rock.

By using a bolt-on attachment method, rod extensometers offer stability and accurate strain measurements in geotechnical monitoring applications.

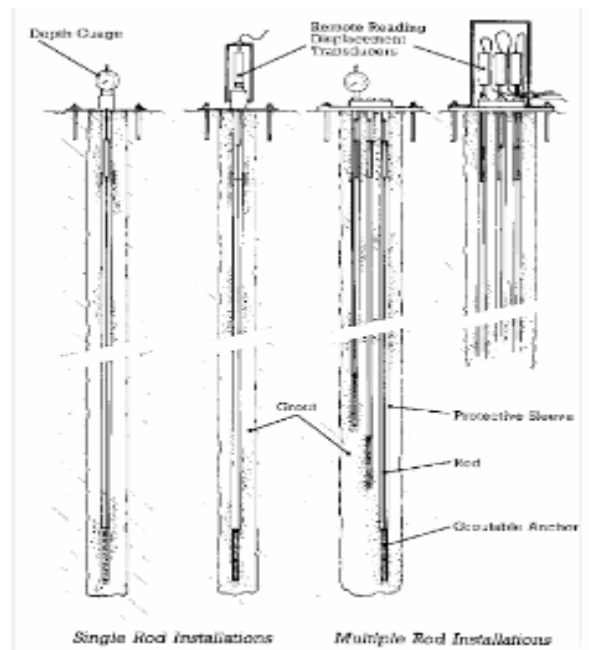


Figure III-4:Rod extensometers.

c. Tape Extensometers

Tape extensometers use a flexible measuring tape that is attached to a fixed reference point on the surface and anchored at various depths or locations in the ground or rock. Changes in the length of the tape indicate deformation or displacement. Tape extensometers are not typically considered as bolt-on extensometers. Tape extensometers are devices used to measure strain and deformation in geotechnical applications, specifically in soil or rock formations.

Tape extensometers consist of a steel tape or wire that is anchored at one end and attached to a reference point. The other end of the tape is connected to a displacement transducer or sensor that measures the elongation or contraction of the tape as the soil or rock undergoes deformation.

Unlike bolt-on extensometers that directly attach to a structure using bolts or adhesive bonding, tape extensometers are typically installed by burying or embedding the tape in the soil or rock. The tape is placed in a pre-drilled hole or borehole and secured to the surrounding material using grout or other stabilization methods. This

installation method allows the tape extensometer to measure strain or deformation in the surrounding soil or rock.

d. Settlement Extensometers

Settlement extensometers are used to measure vertical settlement or compression of soil or rock. They typically consist of a series of rods or sensors that are installed vertically in the ground or rock and provide measurements of settlement over time. Settlement extensometers are commonly considered as bolt-on extensometers. Settlement extensometers are instruments used to measure vertical or horizontal movements, settlement, or subsidence of soil or structures.

In the case of settlement extensometers, they are typically installed by attaching them directly to a structure or embedding them in the soil. The extensometer is secured in place using bolts, clamps, or other fastening mechanisms. The bolt-on attachment ensures that the extensometer remains fixed and provides accurate measurements of settlement or movement.

The settlement extensometer consists of a reference point or anchor that remains fixed, and a moving portion that measures the relative displacement. The displacement is often measured using sensors or transducers connected to the moving portion of the extensometer.

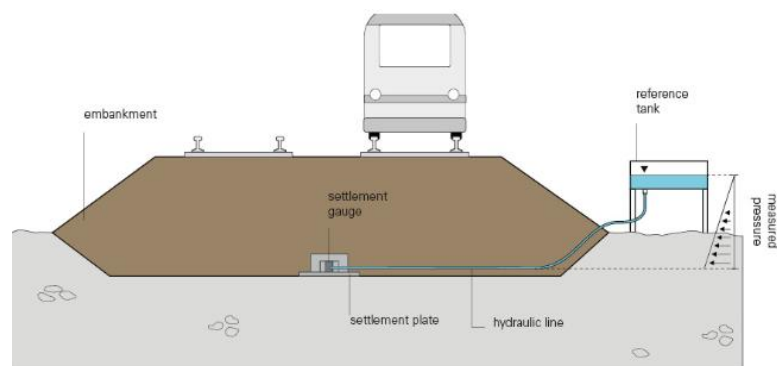


Figure III-5: settlement extensometer or settlement gauge.

e. Borehole Extensometers

Borehole extensometers are installed in boreholes and measure displacement or deformation in the surrounding soil or rock. They can be installed as multiple anchor points or as single-point displacement sensors. Borehole extensometers are instruments used to measure strain and displacement in geotechnical applications, particularly in boreholes or deep excavations.

To install a borehole extensometer, it is typically anchored or bolted to the sidewalls of the borehole or excavation. The extensometer is secured in place using bolts, clamps, or other fastening mechanisms, ensuring a stable and reliable attachment.

Borehole extensometers often consist of a central anchor or reference point that remains fixed, and one or more rods or wires that connect to displacement sensors or transducers. The sensors or transducers measure the relative movement or displacement of the rods, providing valuable information about the strain and deformation in the surrounding soil or rock.



Figure III-6: borehole extensometer.

3. Automotive testing extensometer

Automotive Testing Extensometers are specialized instruments utilized in the automotive industry to measure strain, deformation, or displacement in various automotive components or materials. These extensometers are specifically engineered to endure the demanding conditions and dynamic forces experienced during automotive testing and evaluation. These extensometers are designed to be directly attached to the surface of the automotive part using bolts or adhesive bonding techniques.

Automotive testing extensometers typically feature a sensing element, such as a strain gauge or LVDT (Linear Variable Differential Transformer), that undergoes changes in electrical resistance or displacement when subjected to strain. The extensometer is securely attached to the component using bolts, ensuring good contact and accurate strain measurement.

The main objective of Automotive Testing Extensometers is to evaluate the mechanical properties and performance characteristics of automotive components, materials, and structures.

4. Bolt-on Strain Gauges

Bolt-on strain gauges are specialized sensors employed in engineering to measure the strain or deformation occurring in mechanical structures. These gauges are named "bolt-on" because they are typically affixed to the surface of a structure using bolts or adhesive bonding methods.

Bolt-on strain gauges consist of a sensing element made of a thin metallic foil or wire, accompanied by a backing material that provides mechanical support. The sensing element is designed to exhibit changes in electrical resistance in response to applied strain. As the structure experiences deformation or strain, the strain gauge undergoes a corresponding deformation, leading to a modification in its electrical resistance.

To install a bolt-on strain gauge, the surface of the structure is prepared by cleaning and roughening it to ensure proper adhesion. The strain gauge is then securely

attached using bolts or adhesive bonding techniques, ensuring optimal contact with the surface. The strain gauge is connected to a measurement device, such as a data acquisition system or strain indicator, which quantifies the change in electrical resistance and calculates the associated strain.

Bolt-on strain gauges find widespread use in various engineering applications, including structural monitoring, material testing, and load measurements. By providing precise and reliable strain measurements, these gauges enable engineers to assess the structural behavior, integrity, and performance of mechanical systems under different load conditions.

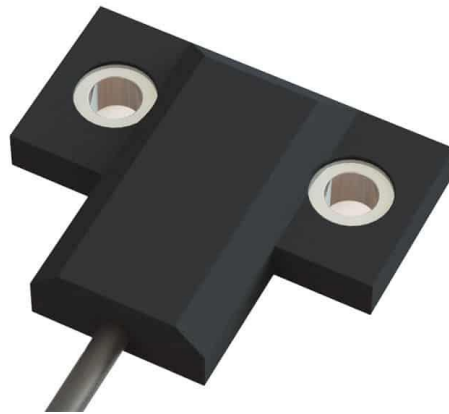


Figure III-7: bolt-on strain gauge

5. Bolt-on LVDT Extensometer

Bolt-On LVDT (Linear Variable Differential Transformer) extensometers are specialized engineering instruments utilized for quantifying the displacement or deformation in mechanical structures. These extensometers derive their name from their ability to be firmly affixed to the surface of a structure using bolts.

LVDTs are transducers that convert mechanical displacements into electrical signals. They consist of a primary coil and two secondary coils wound around a hollow core. The primary coil is energized by an alternating current, generating a magnetic field that induces voltages in the secondary coils. The relative displacement of the core, resulting from the deformation of the monitored structure, alters the coupling between the primary and secondary coils, causing a variation in the induced voltages.

Bolt-on LVDT extensometers typically incorporate a threaded rod or stud that is fastened to the structure using bolts. The LVDT body is mounted onto the threaded rod, ensuring a secure and stable connection. As the structure experiences deformation, the LVDT measures the displacement of the threaded rod, which directly corresponds to the deformation of the structure.

LVDT extensometers offer exceptional accuracy, linearity, and reliability in displacement measurements. They find widespread application in scenarios where precise and continuous monitoring of structural deformations is essential, such as in civil engineering, geotechnical engineering, and mechanical testing. Bolt-on LVDT extensometers present a robust and dependable solution for monitoring structural behavior under diverse loading conditions.



Figure III-8: Bolt-on LVDT Extensometer.

There are several types of Bolt-On LVDT (Linear Variable Differential Transformer) extensometers commonly used in engineering applications. These types include:

a. Single-Point Bolt-On LVDT Extensometers

This type consists of a single LVDT sensor attached to the structure using bolts. It measures the displacement or deformation at a specific point on the structure. Single-Point Bolt-On LVDT (Linear Variable Differential Transformer) Extensometers are specialized instruments used for measuring displacement or deformation at a specific point on a mechanical structure. These extensometers are designed to be securely attached to the surface of the structure using bolts, providing a stable and reliable connection.

The extensometer consists of an LVDT sensor, which is a type of position transducer. The LVDT sensor typically includes a primary coil and two secondary coils wound around a hollow core. An alternating current is passed through the primary coil, creating a magnetic field. The displacement or deformation of the structure being monitored causes a relative movement of the core, which changes the coupling between the primary and secondary coils. As a result, the induced voltages in the secondary coils vary proportionally to the displacement or deformation.

The LVDT sensor is mounted onto the structure using bolts, ensuring a secure and stable attachment. It is positioned at the specific point where the displacement or deformation needs to be measured. As the structure undergoes deformation, the LVDT sensor detects the corresponding displacement, providing accurate and reliable measurements at that specific point.

Single-Point Bolt-On LVDT Extensometers are commonly used in various applications, including structural monitoring, mechanical testing, and quality control in engineering fields. They offer precise and continuous measurement of displacement or deformation at a single location, allowing engineers to assess the performance and behavior of structures under different loading conditions.

b. Multiple-Point Bolt-On LVDT Extensometers

This type consists of multiple LVDT sensors arranged at different points along the structure. It allows for the measurement of displacement or deformation at multiple locations simultaneously. Multiple-Point Bolt-On LVDT Extensometers are

specialized instruments used for measuring displacement or deformation at multiple locations on a structure. They consist of multiple LVDT (Linear Variable Differential Transformer) sensors that are securely attached to the surface of the structure using bolts.

Each LVDT sensor is positioned at a specific location of interest on the structure. These sensors are interconnected to a central data acquisition system, which allows for simultaneous measurement and monitoring of displacement or deformation at multiple points.

Multiple-Point Bolt-On LVDT Extensometers provide a comprehensive view of the structural behavior by capturing data from multiple locations. This type of extensometer is commonly used in applications where it is essential to monitor the behavior and performance of a structure at multiple critical points, such as in civil engineering, structural testing, and geotechnical monitoring.

By capturing data from multiple locations, engineers and researchers can gain a better understanding of how a structure responds to different loading conditions and environmental factors. This information is valuable for structural analysis, research, quality control, and making informed decisions regarding maintenance, repair, or retrofitting of the structure.

Overall, Multiple-Point Bolt-On LVDT Extensometers offer a versatile and efficient solution for monitoring and analyzing the behavior of structures at multiple key locations simultaneously.

c. Customized Bolt-On LVDT Extensometers

In addition to the standard types mentioned above, Bolt-On LVDT extensometers can be customized to suit specific applications. Customization may involve modifications in sensor configuration, size, range, or mounting arrangement to meet the specific measurement requirements of the structure being monitored. Customized Bolt-On LVDT Extensometers refer to LVDT-based extensometers that are tailored or modified to meet specific measurement requirements of a particular application or structure. These extensometers are designed and configured according

to the specific needs of the user, considering factors such as size, range, mounting arrangement, and sensor configuration.

The customization options for Bolt-On LVDT Extensometers can vary depending on the manufacturer or supplier. Some common customization possibilities include:

- **Sensor Configuration:** Modifying the number and arrangement of LVDT sensors to accommodate specific measurement points or patterns on the structure.
- **Size and Range:** Adapting the physical size and measurement range of the extensometer to fit within the available space and meet the required measurement range.
- **Mounting Arrangement:** Customizing the mounting mechanism, such as bolt hole patterns, stud lengths, or alternative mounting options, to ensure secure attachment to the structure.
- **Output and Compatibility:** Incorporating specific signal conditioning or output options to match the requirements of data acquisition systems or monitoring equipment.
- **Environmental Considerations:** Enhancing the extensometer's design to withstand extreme temperatures, corrosive environments, or other challenging conditions specific to the application.

D. MODELS OF BOLT-ON EXTENSOMETERS

there are likely many models of bolt-on extensometer available from different manufacturers. Here will be provided for you some common models that are widely used in various industries.

1. XT50 extensometer (flintec)

The XT50 extensometer is an engineering device specifically designed for bolt-on applications in measuring force and deformation in rigid structures. It is constructed from high-quality stainless steel and features a fully welded design, ensuring durability and reliability.

One of the key advantages of the XT50 extensometer is its exceptionally low activation force requirement. This makes it particularly suitable for use in structures with high stiffness, where minimal force is required to accurately measure the deformation. The extensometer offers a high-gain analogue output signal that is directly proportional to the elastic deformation experienced by the structural component to which it is attached. Unlike some extensometers that rely on structural adhesives for installation, the XT50 extensometer eliminates the need for such adhesives. This simplifies the installation process and ensures a secure and dependable attachment to the structure. The XT50 extensometer is designed to withstand harsh operating conditions commonly encountered in industrial, agricultural, and construction equipment applications. Its hermetically sealed construction protects it from environmental factors and ensures reliable performance even in challenging environments.

The extensometer incorporates a full Wheatstone strain gauge bridge, which enhances its accuracy and sensitivity to detect even subtle deformations. This technology enables the extensometer to deliver a high-gain output signal, providing precise and reliable measurements of the elastic deformation of the substrate part it is bolted to. In summary, the XT50 extensometer is a robust and versatile engineering instrument designed for bolt-on applications. With its low activation force requirement, high-gain output signal, and resistance to harsh conditions, it is well-suited for use in various industries and applications where accurate measurement of force and deformation is essential.



Figure III-9: XT50 extensometer.

2. VT1 Extensometer (flintec)

The VT1 extensometer is an engineering device specifically tailored for applications involving silo inventory monitoring and other similar processes within the process weighing industry. It is meticulously designed to meet the specific requirements of these applications.

Featuring a fully welded construction and made from high-quality stainless steel, the VT1 extensometer ensures exceptional durability and reliability even in demanding environments. It is a bolt-on device, meaning it can be securely attached to rigid structures without the need for extensive modifications.

One notable advantage of the VT1 extensometer is its exceptionally low activation force requirement. This attribute makes it particularly well-suited for accurately measuring force in rigid structures where minimal force can be applied. This low activation force capability allows for precise and reliable measurements in challenging industrial environments.

The VT1 extensometer boasts an electro polished finish, which is specifically chosen to meet the stringent hygienic standards required in food processing environments. This finish ensures optimal cleanliness, corrosion resistance, and easy maintenance, making it suitable for use in clinical food processing applications.

Similar to other extensometer models, the VT1 provides a high-gain analogue output signal that directly correlates with the elastic deformation experienced by the structural component to which it is mounted. This output signal allows for accurate and reliable measurement of structural deformation or strain.

Additionally, the VT1 extensometer eliminates the need for structural adhesive during installation. This simplifies the installation process and ensures a secure and dependable attachment to the structure. The absence of structural adhesive also minimizes the risk of contamination or interference with the monitoring process.

In summary, the VT1 extensometer is a highly specialized engineering device designed for silo inventory monitoring and process weighing applications. With its fully welded stainless steel construction, low activation force requirement, electro polished finish, and high-gain analogue output signal, it offers precise and reliable

measurement capabilities in rigid structures. Its suitability for food processing environments further enhances its versatility and applicability in various industries.



Figure III-10: VT1 Extensometer.

3. Model 178 extensometer (VPG transducers Company)

The Model 178 extensometer is an advanced load sensor meticulously engineered to facilitate precise force measurement on a wide range of load-bearing structures. This extensometer offers a comprehensive solution for various applications, including weighing systems, level control, stress analysis, and fatigue monitoring.

With its innovative design, the Model 178 extensometer enables the installation of multiple sensors for permanent mounting, enabling more intricate stress profiling and comprehensive analysis of structural behavior. This capability allows for a deeper understanding of the complex forces and stresses acting upon the structure, facilitating informed decision-making and optimization of performance.

The Model 178 extensometer particularly excels in non-intrusive level measurements, especially for materials that are prone to uneven buildup, bridging, or sidewall collection. In scenarios where direct contact level measurement is impractical or undesirable, such as with liquids or wetted materials, the Model 178 extensometer presents an ideal solution. Its non-contact measurement approach ensures accurate level assessment without compromising the integrity of the material being measured.

Furthermore, the design of the Model 178 extensometer makes it highly suitable for retrofitting onto existing structures. This retrofitting capability enables the integration of the extensometer into pre-existing vessels or structures without compromising their integrity. This feature offers significant cost and time savings compared to constructing entirely new measurement systems.

The Model 178 extensometer incorporates cutting-edge engineering principles and materials to ensure exceptional performance and durability. Its robust construction guarantees long-term reliability in harsh operating conditions and allows for precise and repeatable force measurements over an extended period.

In summary, the Model 178 extensometer represents a state-of-the-art load sensor that provides an all-inclusive solution for force measurement in load-bearing structures. Its versatility, multiple sensor capability, non-intrusive level measurement capability, retrofitting compatibility, and robust construction make it a valuable asset for a wide range of engineering applications. By offering accurate and reliable data, the Model 178 extensometer contributes to enhanced structural integrity, optimized performance, and informed decision-making in various industries.



Figure III-11: Model 178 Extensometer.

E. MEASUREMENT ACCURACIES

The measurement accuracy of bolt-on extensometers is a critical aspect that varies depending on several factors inherent to the specific extensometer model, design characteristics, measurement range, instrument quality, and the testing environment. This comprehensive understanding of the measurement accuracies associated with different types of bolt-on extensometers is crucial for ensuring reliable and precise deformation or strain measurements in various engineering applications.

In engineering, the accuracy of a bolt-on extensometer refers to its ability to provide measurements that closely correspond to the true values of deformation or strain. It is expressed as a percentage or a specific value in units of displacement or strain, signifying the maximum allowable deviation between the measured value and the actual value.

However, it is important to note that achieving the specified measurement accuracy relies on various factors that must be carefully considered. Calibration, installation technique, environmental conditions, and the quality of the extensometer itself significantly impact the overall measurement accuracy. Proper installation procedures, regular calibration routines, and adherence to manufacturer guidelines are crucial to ensure accurate and reliable measurements.

For more demanding or critical applications, advanced bolt-on extensometers may offer higher measurement accuracies, typically in the range of $\pm 0.05\%$ or better. These extensometers are specifically designed to meet the stringent accuracy requirements of precision engineering projects or research applications. However, I can provide you with a general overview of the typical measurement accuracies associated with different types that we explain of bolt-on extensometers:

1. Structural Monitoring Bolt-on Extensometers

- **Measurement Accuracy:** The measurement accuracy of structural monitoring bolt-on extensometers can vary depending on the specific model and manufacturer.

- **Accuracy Specification:** It is common to see accuracy specifications within $\pm 0.1\%$ to $\pm 0.5\%$ of the full-scale range or within a specified fraction of the measured value.
- **Factors Affecting Accuracy:** Accuracy can be influenced by factors such as installation technique, bonding quality, temperature variations, and the overall stability of the measurement system.

2. Geotechnical Bolt-on Extensometers

- **Measurement Accuracy:** Geotechnical bolt-on extensometers are designed for measuring strain or deformation in geotechnical applications such as soil or rock monitoring.
- **Accuracy Specification:** Accuracy can vary depending on the specific model and manufacturer. Typical accuracy specifications range from $\pm 0.1\%$ to $\pm 1\%$ of the full-scale range, depending on the measurement requirements and environmental conditions.
- **Factors Affecting Accuracy:** Accuracy can be affected by factors such as installation technique, proper alignment, ambient temperature variations, and the type of material being monitored.

3. Automotive Testing Bolt-on Extensometers

- **Measurement Accuracy:** Automotive testing bolt-on extensometers are used for measuring strain or deformation in automotive components and structures.
- **Accuracy Specification:** Accuracy can vary depending on the specific model and manufacturer. Typical accuracy specifications range from $\pm 0.1\%$ to $\pm 0.5\%$ of the full-scale range or within a specified fraction of the measured value.
- **Factors Affecting Accuracy:** Accuracy can be influenced by factors such as proper installation technique, vibration, temperature variations, and the quality of the measurement system.

4. Bolt-on Strain Gauges

- **Measurement Accuracy:** Bolt-on strain gauges are specialized sensors used to measure strain or deformation in mechanical structures.
- **Accuracy Specification:** Accuracy can vary depending on the specific model and manufacturer. Typical accuracy specifications range from $\pm 0.1\%$ to $\pm 0.5\%$ of the full-scale range.
- **Factors Affecting Accuracy:** Accuracy can be affected by factors such as proper installation technique, bonding quality, temperature variations, and the overall stability of the measurement system.

5. Bolt-on LVDT Extensometers (Linear Variable Differential Transformers)

- **Measurement Accuracy:** Bolt-on LVDT extensometers are used to measure linear displacement or deformation in mechanical structures.
- **Accuracy Specification:** Accuracy can vary depending on the specific model and manufacturer. Typical accuracy specifications range from $\pm 0.1\%$ to $\pm 0.2\%$ of the full-scale range.
- **Factors Affecting Accuracy:** Accuracy can be influenced by factors such as proper installation technique, alignment, temperature variations, and the quality of the LVDT and measurement system.

F. FAILURE OF BOLT-ON EXTENSOMETERS

Failure of bolt-on extensometers can occur due to various reasons, impacting their performance and reliability. Understanding the potential failure modes is crucial for ensuring accurate and consistent measurements. Here are some common failure modes and the reasons behind them:

1. Structural Failure:

- **Overloading:** Bolt-on extensometers can experience failure if subjected to excessive loads beyond their designed capacity. This can lead to permanent deformation or even fracture of the extensometer components.
- **Material Fatigue:** Repeated cyclic loading can cause fatigue failure in the extensometer. Over time, the repeated stress cycles can weaken the material, resulting in cracks or failure of critical components.

2. Installation and Alignment Issues:

- **Improper Installation:** Incorrect installation of bolt-on extensometers can lead to measurement errors and potential failure. Inadequate attachment, misalignment with the specimen, or incorrect positioning can compromise the extensometer's performance.
- **Insufficient Tightening:** Inadequate tightening of the bolts or clamps used to secure the extensometer to the specimen can result in slippage or movement during testing. This can introduce measurement errors or even lead to detachment of the extensometer.

3. Environmental Factors:

- **Temperature Effects:** Bolt-on extensometers may experience failure due to temperature variations during testing. Differential thermal expansion or contraction between the extensometer and the specimen can cause mechanical stress, leading to deformation or failure.
- **Corrosion:** Exposure to corrosive environments, such as high humidity or aggressive chemicals, can degrade the extensometer's materials over time. Corrosion can weaken the components, impair the extensometer's functionality, and lead to failure.

4. Mechanical Interference:

- **Contact with Surrounding Structures:** In some cases, bolt-on extensometers may come into contact with adjacent structures or equipment during testing. This can cause interference, misalignment, or damage to the extensometer, compromising its accuracy and potentially leading to failure.
- **Specimen Movements:** Vibrations, movements, or deformation of the specimen itself during testing can impact the performance of bolt-on extensometers. Excessive specimen movements can result in dislodgment or misalignment of the extensometer, affecting its measurements.

5. Calibration and Maintenance Issues:

- **Lack of Calibration:** Failure to calibrate the extensometer regularly or using incorrect calibration procedures can result in inaccurate measurements. Without proper calibration, the extensometer may provide unreliable data or fail to meet the required accuracy standards.
- **Inadequate Maintenance:** Neglecting routine maintenance, such as cleaning, lubrication, and inspection of the extensometer, can contribute to its failure. Dirt, debris, or wear in the moving parts can hinder its functionality and compromise measurement accuracy.

G. ADVANTAGES OF BOLT-ON EXTENSOMETERS

Bolt-on extensometers offer several advantages that make them valuable tools for a wide range of applications. some advantages are listed below:

1. **Ease of Installation:** Bolt-on extensometers are designed for easy installation and attachment to the test specimen or structure. They typically feature a simple and straightforward mounting mechanism, such as bolts, clamps, or adhesive, which allows for quick and secure attachment. This ease of installation reduces setup time and enables efficient testing processes.

2. **Non-Destructive Testing:** Bolt-on extensometers facilitate non-destructive testing (NDT) of materials and structures. Unlike other extensometer types that require surface preparation or specimen modification, bolt-on extensometers can be attached directly to the test surface without altering its integrity. This non-destructive nature enables repeated measurements on the same specimen and minimizes potential damage or disruption to the structure.
3. **Wide Range of Applications:** Bolt-on extensometers are versatile instruments suitable for various applications across different industries. They can be used in material testing, structural monitoring, geotechnical engineering, automotive testing, and more. Their adaptability allows researchers, engineers, and technicians to employ them in a diverse range of projects and experiments.
4. **High Accuracy and Precision:** Bolt-on extensometers are capable of providing accurate and precise measurements of strain or displacement. They are designed to minimize measurement errors and maintain consistent performance throughout the testing process. With proper installation, calibration, and adherence to best practices, bolt-on extensometers can achieve high accuracy levels required for demanding applications.
5. **Reliability and Durability:** Bolt-on extensometers are constructed using robust materials that ensure durability and long-term reliability. They are designed to withstand the rigors of testing environments, including high loads, temperature variations, and potential mechanical impacts. The materials used, such as stainless steel or high-strength alloys, enhance their resistance to corrosion, wear, and fatigue, ensuring reliable performance over an extended period.

6. **Compatibility with Different Specimen Sizes:** Bolt-on extensometers are available in various sizes and configurations to accommodate different specimen dimensions. They can be customized or adjusted to fit specific testing requirements, allowing for flexibility in choosing the appropriate extensometer for the application at hand. This compatibility ensures accurate measurements across a wide range of specimen sizes and shapes.
7. **Cost-Effectiveness:** Bolt-on extensometers often offer a cost-effective solution compared to other types of extensometers. They generally have lower upfront costs and require minimal additional equipment or modifications for installation. Moreover, their durability and reusability contribute to long-term cost savings by eliminating the need for frequent replacements or repairs.
8. **Real-Time Monitoring Capability:** Some bolt-on extensometers are equipped with advanced features, such as digital data output and connectivity options, enabling real-time monitoring of strain or displacement. This capability allows for immediate analysis of test data, early detection of anomalies or failures, and timely decision-making in critical situations.
9. **Non-Intrusive Measurement:** Bolt-on extensometers provide non-intrusive measurement capabilities, especially when compared to extensometers that require direct contact with the specimen surface. This non-intrusive nature eliminates the risk of altering the material behavior or introducing stress concentrations, ensuring more accurate and representative measurements.
10. **Standardization and Compatibility:** Bolt-on extensometers are often designed and manufactured according to recognized industry standards, ensuring compatibility with commonly used testing

equipment and protocols. This standardization simplifies integration into existing testing setups, promotes interoperability, and facilitates data comparison and sharing between different laboratories or research institutions.

IV. OVERCOME THE FAILURES IN MEASUREMENTS OF BOLT-ON EXTENSOMETERS

A. INTRODUCTION

In this chapter, will be explained more deeply the mechanical and theoretical failures and the correction methods.

B. MECHANICAL FAILURES

Mechanical failures in the measurement of bolt-on extensometers can occur due to various factors and components involved in the device's construction. These failures can lead to inaccurate or inconsistent measurements of strain and deformation in materials. Let's explore some of the potential mechanical failure modes in detail:

1. **Arm or Jaw Failures:** Bolt-on extensometers typically consist of arms or jaws that attach to the surface of the specimen. These arms or jaws may experience mechanical failures such as bending, deformation, or breakage under excessive or uneven loading. Such failures can introduce errors in the measurement by causing misalignment of the contact points or compromising the stability of the extensometer.
2. **Contact Point Discrepancies:** The contact points or pins at the end of the arms are crucial for accurately measuring strain. Mechanical failures can occur if the contact points wear out, become misaligned, or lose their shape due to repeated usage or improper handling. These discrepancies can result in inconsistent or erroneous readings, affecting the reliability of the extensometer.
3. **Central Body Malfunctions:** The central body of the bolt-on extensometer houses components responsible for transmitting and

measuring displacement. Failures in the central body, such as misalignment of internal mechanisms, loose connections, or damaged components, can impair the overall functionality of the extensometer. These malfunctions can lead to unreliable measurements or complete failure of the device.

4. **Inadequate Stiffness or Rigidity:** Bolt-on extensometers rely on their stiffness and rigidity to maintain accurate contact with the specimen surface during loading. If the extensometer lacks sufficient stiffness or rigidity, it may deform or deflect under stress, resulting in inaccurate measurements. This failure mode can be attributed to the design or material selection of the extensometer.
5. **Insufficient or Inconsistent Clamping:** Bolt-on extensometers rely on clamps or bolts for secure attachment to the specimen. If the clamping mechanism is inadequate or inconsistent, it can lead to slippage or movement of the extensometer during testing. This slippage can introduce measurement errors and compromise the reliability of the results.
6. **Wear and Tear:** Over time, continuous usage of bolt-on extensometers can result in wear and tear of the mechanical components. This can include issues such as fatigue, material degradation, or corrosion. Such wear and tear can affect the overall performance and accuracy of the extensometer, necessitating regular inspection, maintenance, and replacement of worn-out parts.
7. **Calibration Issues:** Calibration is essential to ensure accurate measurements with bolt-on extensometers. Mechanical failures can occur if the calibration process is not performed correctly or if the extensometer drifts out of calibration over time. Inaccurate calibration

can lead to significant measurement errors and affect the reliability of the data obtained.

C. THEORETICAL FAILURES

Theoretical failures in the measurement of bolt-on extensometers can occur due to various factors related to the theoretical principles and assumptions underlying their design and operation. These failures can impact the accuracy and reliability of strain and deformation measurements. Some potential theoretical failure modes are explained below:

1. **Inadequate Linearity:** Bolt-on extensometers typically assume linearity in the relationship between applied force and resulting deformation. However, if the material being tested exhibits non-linear behavior, such as plastic deformation or material instability, the assumption of linearity may not hold true. This can result in inaccurate strain measurements, especially at higher loads or in materials with complex stress-strain curves.
2. **Poor Gauge Length Selection:** The gauge length is the section of the extensometer where strain is measured. If the gauge length is not appropriately chosen for the specific material or application, it can lead to inaccurate measurements. For example, selecting a gauge length that is too short may not capture the representative strain behavior, while selecting a gauge length that is too long may result in reduced sensitivity to localized strain variations.
3. **Sensitivity and Resolution Limitations:** The sensitivity and resolution of bolt-on extensometers can be limited by design factors such as the size of the contact points, the spacing of the arms, or the mechanical constraints of the device. Inadequate sensitivity or resolution can hinder the detection and measurement of small strain

changes, particularly in materials that exhibit low strain levels or require high precision measurements.

4. **Transverse Sensitivity:** Bolt-on extensometers are designed to measure strain along a specific axis. However, they can be susceptible to transverse sensitivity, meaning they may also measure strains in unintended directions due to the influence of forces acting perpendicular to the primary measurement axis. Transverse sensitivity can introduce errors and inaccuracies in strain measurements, especially in materials subject to complex loading conditions.
5. **Temperature Effects:** Temperature variations can affect the performance of bolt-on extensometers. Materials can exhibit thermal expansion or contraction, which can introduce strains and affect the accuracy of measurements. Additionally, temperature variations can influence the mechanical properties of both the extensometer and the specimen, leading to deviations from expected strain values.
6. **Environmental Interference:** Environmental factors such as vibrations, electromagnetic fields, or electrical interference can impact the performance of bolt-on extensometers. These external influences can introduce noise or disturbances in the measurement signal, leading to erroneous readings or reduced measurement accuracy.
7. **Assumptions of Homogeneity and Isotropy:** Bolt-on extensometers assume that the material being tested is homogeneous and isotropic, meaning it has uniform properties in all directions. However, if the material exhibits significant heterogeneity or anisotropy, such as composite materials or highly textured metals, the assumptions of homogeneity and isotropy may not hold true. This can result in

inaccurate strain measurements and misinterpretation of material behavior.

D. CORRECTION METHODS

Measurement failures in bolt-on extensometers can compromise the accuracy and reliability of strain or displacement measurements. Therefore, it is crucial to implement mechanical strategies to address these failures and ensure precise and consistent results. Here is a detailed explanation of how to overcome failures in the measurement of bolt-on extensometers, focusing on both the mechanical and theoretical aspects:

1. Mechanical Approach

1) Proper Installation:

- Ensure the extensometer is installed following the manufacturer's guidelines and recommendations.
- Thoroughly clean and prepare the surface where the extensometer will be attached to ensure proper adhesion.
- Use appropriate tools, such as torque wrenches, to achieve the recommended tightening torque.
- Verify that the extensometer is aligned correctly and securely attached to the structure.

2) Secure Fastening:

- Use high-quality fasteners, such as bolts, screws, or clamps, that are appropriate for the specific application and load requirements.
- Ensure the fasteners are tightened to the specified torque to prevent slippage or loosening during operation.
- Consider using additional locking mechanisms, such as lock nuts or thread-locking compounds, to maintain fastener integrity.

3) Vibration and Shock Mitigation:

- Evaluate the environment where the extensometer will be used and implement measures to mitigate vibrations and shocks.
- Use vibration isolation materials, such as rubber or elastomeric pads, to reduce the impact of external vibrations.
- Consider mounting the extensometer on a separate vibration-damped platform or utilizing shock-absorbing techniques to minimize disturbances.

4) Environmental Protection:

- Shield the extensometer from harsh environmental conditions, such as moisture, dust, chemicals, or extreme temperatures.
- Employ protective enclosures, covers, or coatings to prevent direct exposure to damaging elements.
- Regularly inspect and clean the extensometer to remove any debris or contaminants that could affect its performance.

5) Regular Maintenance:

- Establish a maintenance schedule to inspect, calibrate, and perform necessary repairs or replacements on the extensometer.
- Conduct periodic checks for wear, damage, or calibration drift and address any issues promptly.

2. Theoretical Approach

1) Calibration:

- Perform calibration of the extensometer to establish its measurement accuracy.
- Follow the calibration procedure provided by the manufacturer or accredited calibration laboratories.

- Apply known strains or displacements to the extensometer and compare the readings to reference standards.
- Adjust or calibrate the extensometer based on the calibration results to improve its measurement accuracy.

2) Linearity Compensation:

- Some extensometers may exhibit non-linear response characteristics.
- Employ appropriate linearity compensation techniques, such as polynomial fitting or lookup tables, to correct for non-linearity and improve measurement accuracy across the entire measurement range.

3) Temperature Compensation:

- Changes in temperature can affect the performance of extensometers, especially those made of materials with different coefficients of thermal expansion.
- Apply temperature compensation techniques to mitigate the influence of temperature variations on measurement accuracy.
- Use compensation coefficients or active temperature control systems to minimize temperature-related errors.

4) Signal Conditioning:

- Implement effective signal conditioning techniques to improve the quality of the measured signals.
- Use high-quality amplifiers, filters, and shielding techniques to minimize noise, interference, and signal degradation.
- Optimize signal conditioning parameters to enhance the accuracy and reliability of the measured data.

5) Data Analysis and Validation:

- Employ robust data analysis techniques to identify and handle outliers, anomalies, or inconsistent measurements.

- Apply statistical methods, such as data averaging, outlier rejection algorithms, or data validation checks, to ensure the reliability and accuracy of the collected data.
- Perform data validation against known or expected behavior to verify the integrity of the measurement results.

V. CONCLUSION

In conclusion, bolt-on extensometers have been extensively studied and utilized in various fields for measuring deformation and strain in structures. They offer several advantages, including ease of installation, versatility, and the ability to provide valuable insights into the behavior of materials under load. However, like any measurement instrument, bolt-on extensometers are not immune to failures that can affect their accuracy and reliability.

Throughout my thesis research, I have identified and analyzed various failures associated with bolt-on extensometers. These failures can arise from factors such as installation errors, environmental conditions, mechanical limitations, and signal distortions. Understanding these failures is crucial for ensuring accurate and meaningful measurements.

To overcome these failures, several corrective methods have been explored and implemented. Proper installation techniques, including precise alignment and secure attachment, are essential for minimizing measurement errors. Regular calibration procedures, following recognized standards, help establish a reference for accurate measurements and correct any deviations in the extensometer's response. Additionally, employing appropriate compensation techniques, such as linearity and temperature compensation, can enhance measurement accuracy across a wide range of conditions.

Signal conditioning plays a vital role in overcoming failures by reducing noise, mitigating interference, and enhancing signal quality. This includes using high-quality amplifiers, filters, and shielding techniques to ensure robust and reliable measurements. Careful consideration of environmental factors, such as temperature, humidity, and chemical exposure, is necessary to protect the extensometer and maintain its performance.

Furthermore, thorough data analysis and validation techniques are essential for identifying and addressing measurement anomalies. Statistical analysis, outlier detection, and data quality checks help ensure the reliability and accuracy of the measured data, providing confidence in the results obtained from the bolt-on extensometer.

Overall, my research findings highlight the importance of understanding the failures, advantages, and methods for overcoming challenges associated with bolt-on extensometers. By implementing proper installation practices, calibration procedures, compensation techniques, signal conditioning measures, environmental considerations, and robust data analysis, the failures can be mitigated, and the advantages of bolt-on extensometers can be fully realized.

In conclusion, bolt-on extensometers are valuable tools in the field of deformation and strain measurement, and by addressing their failures and optimizing their performance, we can confidently rely on them for accurate and reliable data, facilitating advancements in structural engineering, materials science, and various other disciplines.

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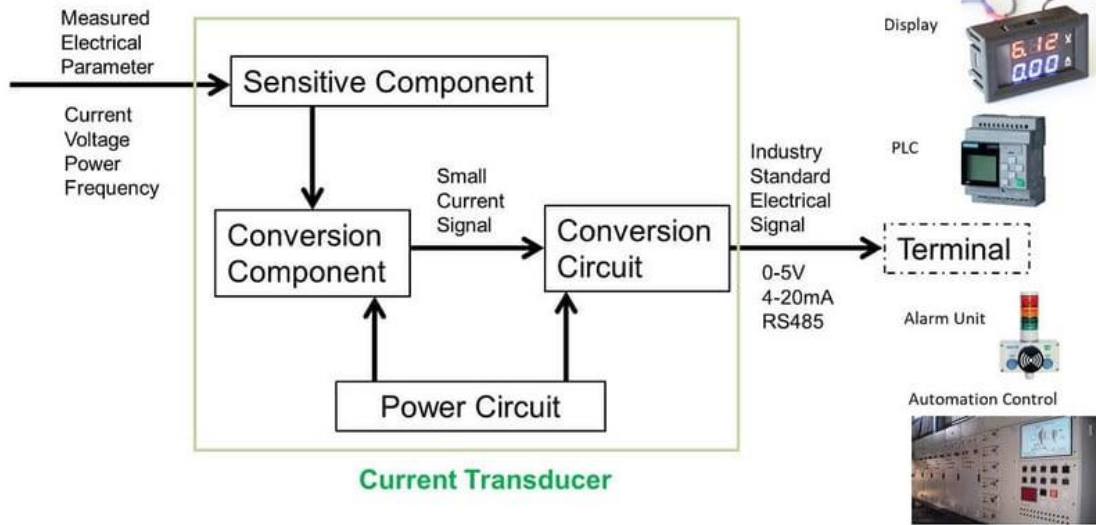
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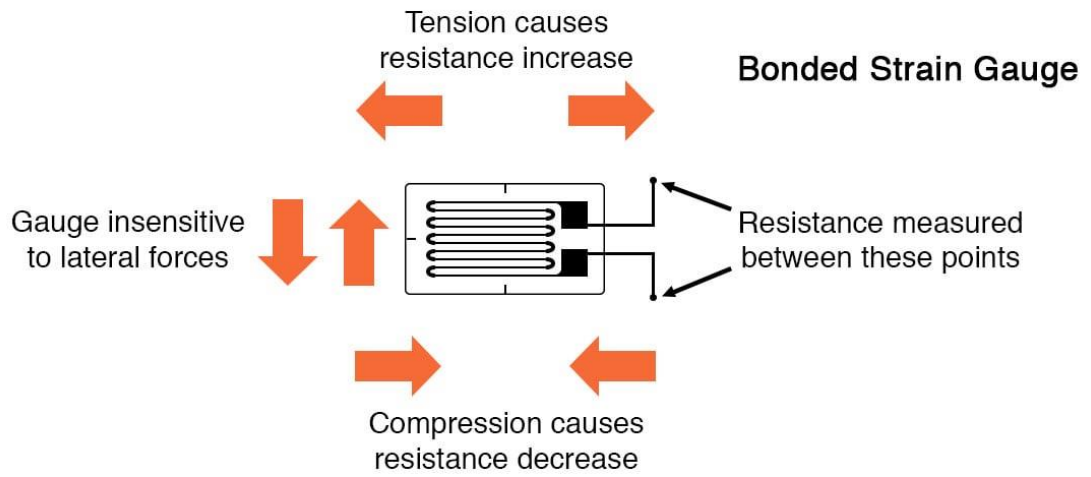
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APPENDICES

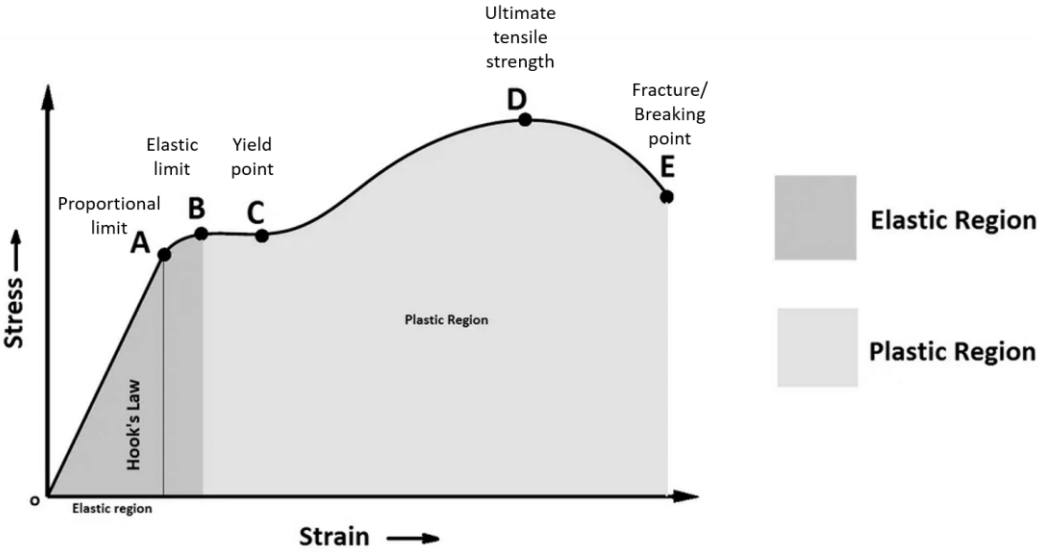
APPENDIX 1: TRANSDUCERS



APPENDIX B: STRAIN GAUGES



APPENDIX C: STRESS-STRAIN



RESUME

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