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Structural Health Monitoring Of Steel Sections Using EMI Technique

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ABSTRACT: Electro-mechanical impedance method (EMI) is a cutting-edge non-destructive evaluation technique that is gaining significant recognition in the field of structural health monitoring. It's becoming increasingly popular due to its ability to assess the condition of structures without causing any damage. Health monitoring of structures has become a key focus for researchers in the field of damage detection. The Structural Engineering Community is increasingly adopting the Electro-Mechanical Impedance (EMI) technique to monitor the health of structures. This technique involves using Piezoelectric (PZT) patches that are bonded to the structure, along with instruments like Impedance analyzer/LCR meter and wired/wireless connections. The change in conductance/impedance/susceptance signature in comparison with the healthy signature defines the presence of damage. In this work, various types of damages induced on steel sections to obtain readings of conductance and susceptance. Taken one specimen of I-section and applied load on it using UTM. Additionally, taken four specimens of channel section, out of which two specimens have been induced with corrosion, with or without epoxy, and two specimens have been induced with damage by cutting and creating hole. The fracture analyzed model was then monitored in the same way as a healthy model with the help of the PZT patch. The conductance signature so obtained was then compared with the baseline (healthy) signature, the change in which identified the presence of a crack on the joint. Root mean squared deviation (RMSD) values have been calculated for computing the change in conductance values for respective frequency ranges.

KEYWORDS: Structural Health Monitoring, PZT Patch, EMI Technique.

I. INTRODUCTION

There is continuous deterioration of strength after construction of any civil, mechanical and aerospace structure due to loading and environmental impacts. Structures consist of an assembly of various members like columns, beams, slabs etc. At the construction time, it is impossible to ensure a uniform quality and strength at every section. Hence, there is variation of strength from section to section. However, if this variation is under a certain threshold limit, structure can be considered to be damage free. If this variation increases beyond the threshold limit due to certain reasons like excessive loads or fatigue, it would result into damage. If again this limit increases and crosses certain value, it can be said that the element has failed. Hence, damage and failure are relative terms and vary from structure to structure. For example, in case of aerospace structure, failure threshold is much lower as compared to civil structures. Structural health monitoring (SHM) is a process in which certain strategies are implemented for determining the presence, location and severity of damages and the remaining life of structure after the occurrence of damage. This term is usually referred to aerospace, civil and mechanical engineering infrastructure. It is the continuous measurement of the loading environment and the critical responses of a structural system or its components. Health monitoring is typically used to track and evaluate the performance, symptoms of operational incidents and anomalies due to deterioration or damage as well as health during and after extreme events.

EMI TECHNIQUE USING PIEZO SENSORS

The recent developments in the area of smart materials and systems have ushered new openings SHM and non-destructive evaluation (NDE). Smart materials, such as the piezo-ceramics, and the fibre-optic materials can facilitate the development of non-obtrusive miniaturized systems with higher resolution and faster response. These smart materials possess immense capabilities of damage diagnosis because of their inherent stimulus- response and energy transduction capabilities. The EMI technique is essentially a vibration based technique operating in the frequency range of 30-400 kHz excited by an impedance analyzer/ LCR meter. Under external field excitation, the bonded patch induces deformations in the host structure (converse effect), whose response is transferred back to the patch (direct effect) in the form of admittance signature, consisting of conductance (the real part) and susceptance (the

imaginary part). Any damage to the host structure affects the structural parameters, which in turn leads to change in the admittance spectrum. Hence a plot of conductance signature serves as a diagnosis of structural health.

II. RELATED WORK

To evaluate the effectiveness of EMI technique in damage detection with PZT materials in the structural health monitoring experimentation is conducted on steel sections. (i.e 1 I-section and 4 channel section). In this experiment the same piezoelectric patch behaves as an actuator and as a sensor also. Signature (Plot of Conductance (G) Susceptance (B) and Admittance with frequency) was obtained for several stages i.e. firstly for the healthy state of host structure and then for damaged states of structure. Then, a damage quantification system based on the Root Mean Square Deviation index is used for each stage. The damage index indicates the severity of damages at each condition. The frequency range adopted for the experimentation is 30 kHz – 400 kHz.

MATERIAL AND SPECIMEN

The test was carried out on:

1. Steel I-Section

Name: ISLB 125

Table 1 Properties of I-Section

Properties	Values
Weight per Meter	11.90 Kg/m
Sectional Area	15.12 cm ²
Depth of Section	125mm
Width of Flange	75mm
Thickness of Flange	6.50mm
Thickness of Web	4.40mm
Moment of Inertia	406.80cm ⁴
Moment of Inertia	43.40cm ⁴
Radius of Gyration	5.19cm
Radius of Gyration	1.69cm

Steel Channel Section

Name: ISMC 100

Common Name: Indian Standard Medium Channel Beam 100

Table 2 Properties of Channel Section

Properties	Values
Weight per Meter	9.2 Kg/m
Sectional Area	11.70 cm ²
Depth of Section	100mm
Width of Flange	50mm
Thickness of Flange	7.5mm
Thickness of Web	4.7mm
Moment of Inertia	186.7cm ⁴
Moment of Inertia	25.9cm ⁴
Radius of Gyration	4.00cm
Radius of Gyration	1.49cm

This experiment was performed to analyse the effectiveness of PZT patch for damage and corrosion in steel structure. This experiment essentially involves an ISLB 125 steel beam is bonded with PZT patch using epoxy from 260mm of end of I-section. The instrument required to obtain signatures are digital Impedance Analyzer (LCR meter) and its connecting fixture and a USB cable. This test was performed in two stages i.e. in the first stage signatures for healthy condition of the beam and in second stage for the damaged condition of beam is obtained. In the first stage, Impedance Analyzer

through Connecting Fixture of LCR meter. Then the frequency was swept through 30 kHz to 400 kHz i.e. the PZT patch transfers this vibrations to the structure through adhesive bond layer. These vibrations are transferred to structures and reflected back from the same PZT patch through waves, which will indicate the health of the structure. The required parameter i.e. Conductance (G) and Susceptance (B) is directly measured through LCR meter for all the values of frequency. From the obtained data, the graph of Conductance versus Frequency and Susceptance versus Frequency is plotted. These graphs are said to be the Conductance Signature or just a signature shown by particular sensor for specimen. This data is saved in excel format and can be available as and when required. In the second stage, damage was introduced in the form of significant visible damage by loading the I-section under Universal Testing Machine (UTM) and then the same damaged specimen with PZT patch was reanalyzed for damage state by using the same procedure as previously adopted. The PZT patch again acts as an actuator and sensor. Then the data for healthy state and damaged state was compared.

The experiment described presents a meticulous approach to understanding the corrosion behaviour of channel section ISMC100 specimens under different conditions. By subjecting one specimen to anti-corrosion paint while leaving the other untreated, the study aims to elucidate the protective efficacy of the coating in a corrosive environment. This differential treatment allows for a direct comparison between the corrosion rates of coated and untreated specimens, shedding light on the practical utility of anti-corrosion measures. The immersion of both specimens in a 5% NaCl solution for a standardized period of 30 days serves as a representative simulation of a corrosive environment, mimicking real-world conditions where such materials might be exposed to saline solutions. By establishing a consistent testing duration, the study ensures comparability across the specimens, facilitating reliable conclusions regarding the impact of corrosion on the materials. The inclusion of readings for conductance and susceptance further enriches the analysis by exploring the electrochemical properties of the specimens post-immersion. Conductance and susceptance measurements offer valuable insights into the underlying corrosion mechanisms, potentially revealing nuanced aspects of the corrosion process beyond mere surface degradation. By quantifying these electrical properties, the study can uncover correlations between corrosion behaviour and material characteristics, contributing to a deeper understanding of the factors influencing material degradation in saline environments.

Overall, this comprehensive experimental design provides a robust framework for assessing the corrosion resistance of channel section ISMC100 specimens and elucidating the interplay between anti-corrosion coatings, environmental exposure, and material properties.

The experimental setup outlined here delves into the structural health monitoring of channel section ISMC100 specimens using PZT (Lead Zirconate Titanate) patches, which are commonly employed for their piezoelectric properties. By affixing PZT patches at specific locations on both specimens with epoxy, the study aims to assess the structural integrity of the materials under varying conditions. The strategic placement of the PZT patches—one near the left end and the other close to the right end—allows for localized monitoring of structural responses. This positioning likely enables the detection of asymmetrical loading or damage patterns, providing valuable insights into the distribution of stresses or strains along the length of the specimens.

Before inducing damage, initial readings are taken from both specimens to establish a baseline for comparison. This step is crucial as it provides a reference point for evaluating changes in structural behaviour post-damage induction. By capturing "healthy" readings, the study ensures that any subsequent deviations can be attributed to the induced damage rather than inherent variability in the material properties or measurement process. The deliberate introduction of damage, achieved by drilling a hole in one specimen and cutting another to a specific length, serves to simulate common types of structural compromise encountered in real-world scenarios. By employing controlled methods of damage induction, the study can systematically evaluate the response of the specimens to different forms of structural degradation.

The subsequent comparison of readings between the pre-damage and post-damage states facilitates a quantitative assessment of the extent of structural deterioration. The Root Mean Square Deviation (RMSD) calculation provides a robust statistical measure to quantify the overall deviation between these states, offering a concise summary of the structural changes induced by the damage. In essence, this experimental approach enables a comprehensive evaluation of the structural health of channel section ISMC100 specimens under controlled conditions, leveraging PZT-based monitoring technology to assess the effects of induced damage and providing valuable insights into the materials' mechanical behaviour.

III. METHODOLOGY

Five specimens were selected for structural health monitoring of a steel structure. One specimen was an I-section, and the other four were channel sections with the same specifications. Two PZT (Lead Zirconate Titanate) patches were attached to the I-section for collecting healthy readings. Load was applied to the structure, and the damage readings were recorded. For the channel sections, one section was coated with anti-corrosion paint, while the other section was left untreated. After collecting the healthy readings, corrosion was induced in the channel sections and after 30 days damage readings recorded. For specimen 4 two PZT patches were attached and damage was induced by creating and its readings were recorded. Similar procedures were followed for the other channel section, including creating a cut and recording the readings. The healthy conductance, damage conductance, and susceptance values were compared for all the specimens. The Root Mean Square Deviation (RMSD) was calculated to evaluate the differences between the healthy and damaged conductance and susceptance values.

IV. EXPERIMENTAL RESULTS

RESULT FOR SPECIMEN 1

The beam was subjected to frequency range of 30 kHz – 400 kHz. In this range, the corresponding conductance and susceptance values were recorded by LCR meter. Then the corresponding admittance was calculated. Firstly, healthy signature of intact specimen was taken then the damage was introduced in the beam and corresponding damaged signature was taken. This procedure is repeated for all the beams. The conductance, susceptance and RMSD graphs are then plotted. For beam 1 all these plots are as shown in respective figures below.

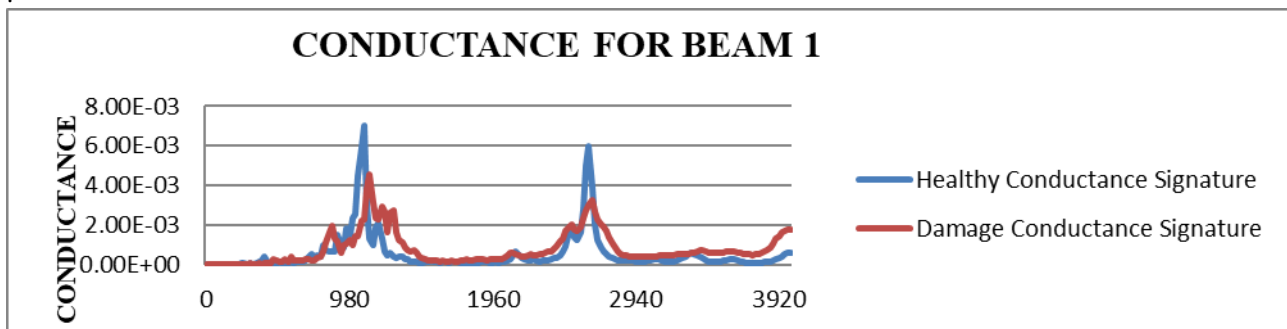


Fig.1: Conductance for Beam 1 by PZT patch 1 its comparison with damage

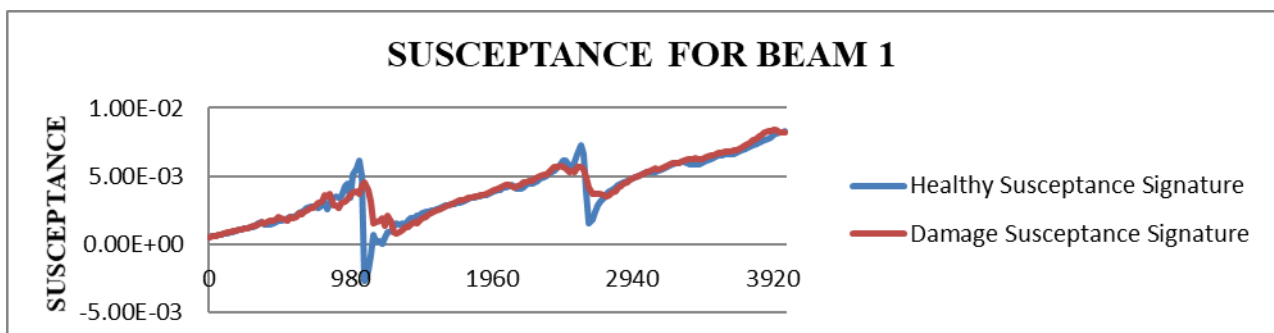


Fig.2: Susceptance for Beam 1 by PZT patch 1 its comparison with damaged

RESULT FOR SPECIMEN 2

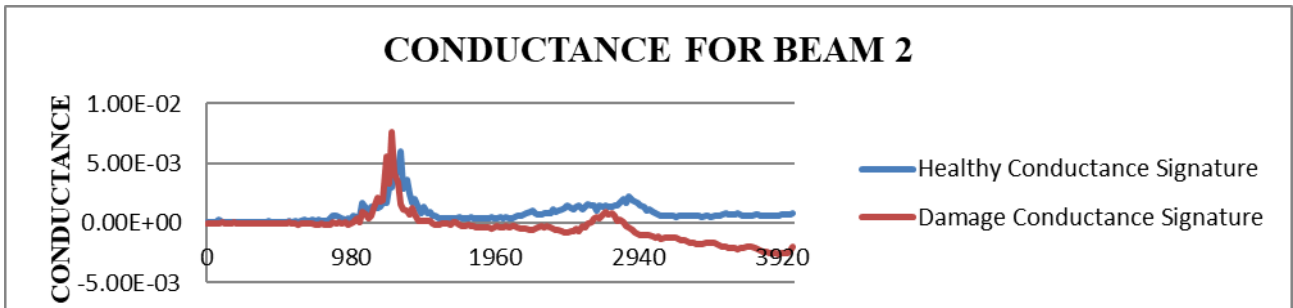


Fig.3: Conductance for Beam 2 by PZT patch its comparison with damaged

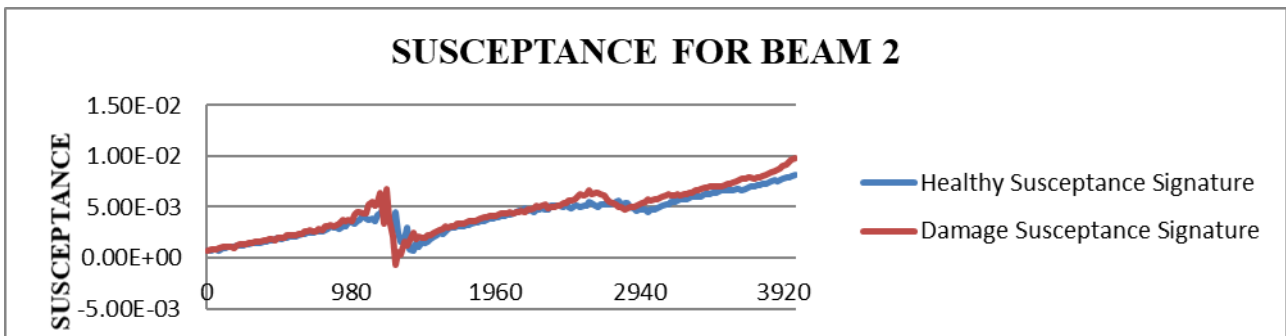


Fig.4: Susceptance for Beam 2 by PZT patch its comparison with damaged

RESULT FOR SPECIMEN 3

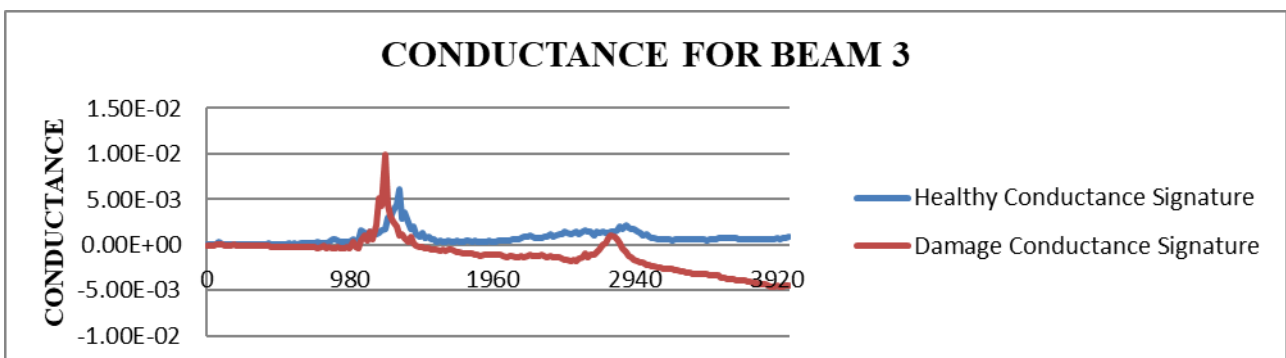


Fig 5: Conductance for Beam 3 by PZT patch its comparison with damaged

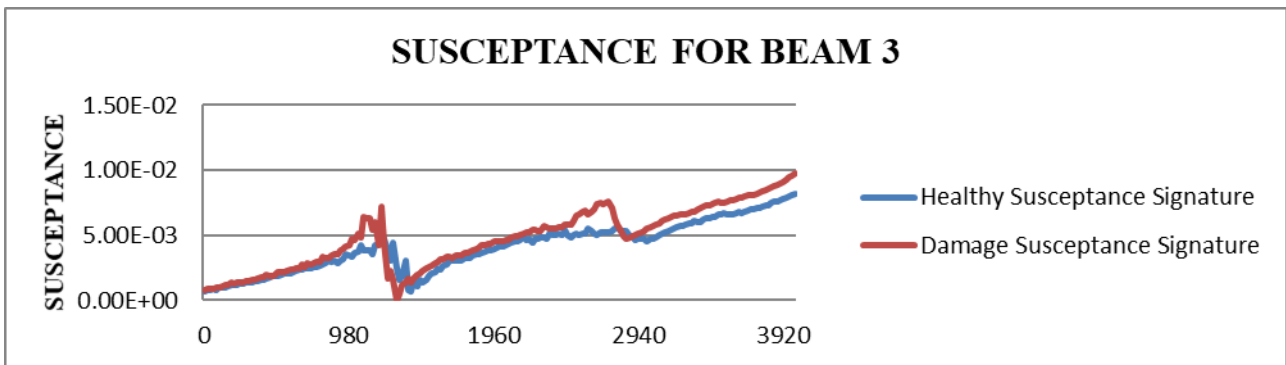


Fig.6: Susceptance for Beam 3 by PZT patch its comparison with damaged

RESULT FOR SPECIMEN 4

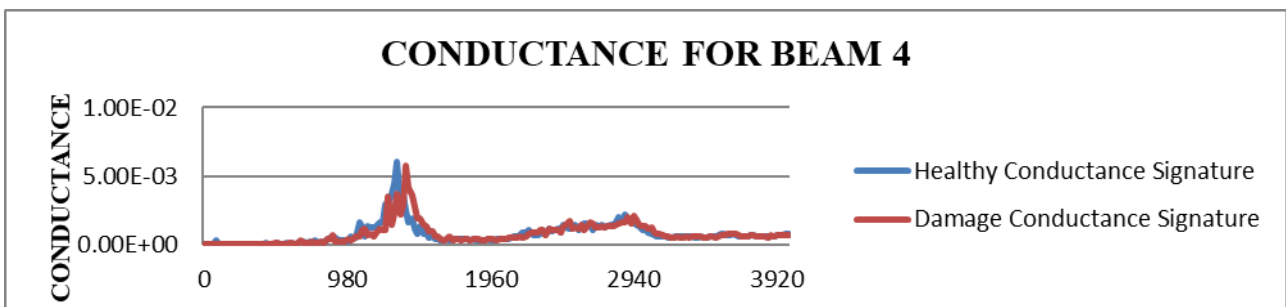


Fig.7: Conductance for Beam 4 by PZT patch 1 its comparison with damaged

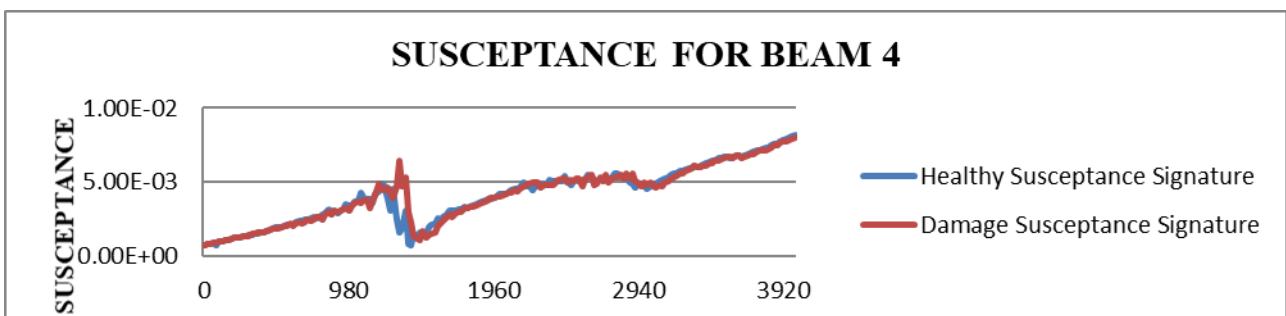


Fig.8: Susceptance for Beam 4 by PZT patch 1 its comparison with damaged

RESULT FOR SPECIMEN 5

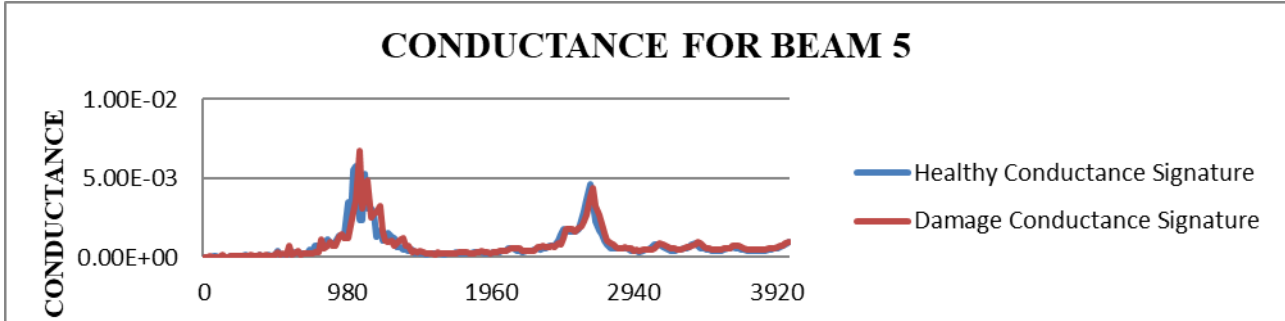


Fig.9: Conductance for Beam 5 by PZT patch 1 its comparison with damaged

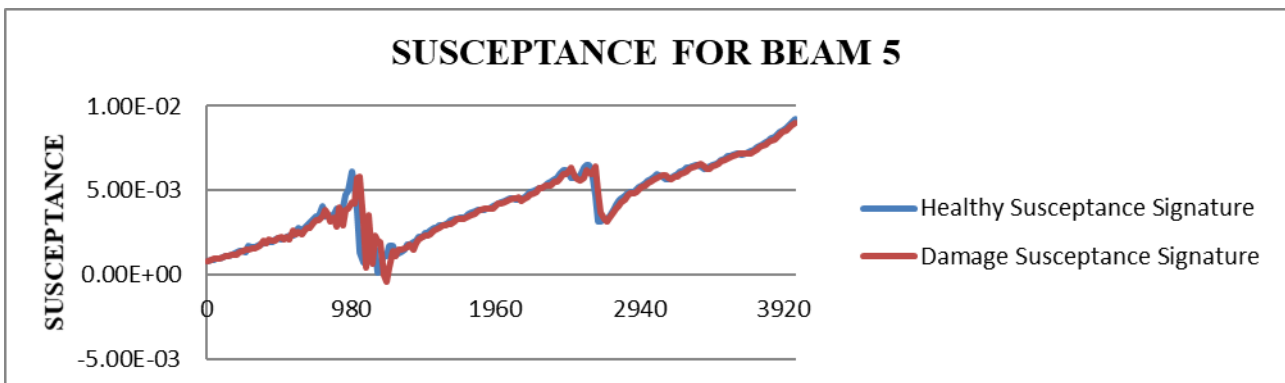


Fig.10: Susceptance for Beam 5 by PZT patch 1 its comparison with damaged

In the experimental protocol, all specimens underwent a rigorous regimen of induced damages, with particular emphasis on the application of various stressors to assess their structural integrity. Notably, a centrally applied load was employed on beam 1, serving as a benchmark for subsequent analyses. Comparative evaluations between the readings obtained from pristine and impaired specimens underscored the heightened sensitivity of conductance measurements over susceptance, illuminating its efficacy across the entire spectrum of specimens examined. Focusing specifically on beams 2 and 3, corrosion was deliberately induced to simulate real-world scenarios. Beam 2 received a protective epoxy coating, while beam 3 remained untreated, serving as a control. Conductance analyses unveiled that the untreated beam exhibited discernibly heightened levels of structural degradation, as evidenced by a noteworthy root mean square deviation (RMSD) discrepancy of 0.85. Furthermore, even in instances where minimal damages were intentionally introduced to specimens 4 and 5, conductance emerged as a dependable diagnostic tool, demonstrating its robustness and reliability in detecting subtle structural alterations. This underscores the versatility and efficacy of conductance as a sensitive indicator of structural integrity in diverse experimental settings.

V. CONCLUSION

Through conducting experiments on steel beams under two conditions – undamaged and damaged – and analyzing the responses of their bonded PZT patches using a high-frequency LCR meter, were it is concluded that:

As a smart material, piezoelectric substances are highly responsive to structural damages occurring at high frequencies. This characteristic makes them well-suited for implementation in Electromagnetic Interference (EMI) techniques within structural health monitoring systems, particularly for serving as sensors and actuators.

Due to its high-frequency nature, this technique minimizes noise interference, allowing the signatures to stand out distinctly without being muddled by background noise. This clarity in the signals leads to more precise and accurate results, as evidenced by the data presented in all the graphs.

The study on damage detection indicates that changes in peak shifts vertically and laterally, along with alterations in conductance values between healthy and damaged conditions, can effectively identify damage. Moreover, it's evident that PZT patches are capable of detecting various types of damage such as corrosion, scraping, and the presence of holes.

It can be concluded that, PZT patch is location sensitive as it shows higher damage sensitivity when positioned near the damage zone.

Root Mean Square Deviation is found out to be the best possible method for the damage quantification, because it directly utilizes conductance values.

By monitoring the change in conductance and susceptance signatures for damaged and baseline signatures, it can be found that conductance is more sensible to damages than the susceptance values. Hence, conductance values are used for damage quantification.

The damage specification criteria is dependent on the conductance values only and does not include any physical dimension, hence the change in sizing will not affect the damage specification criteria as established on beam results.

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