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Structural Health Monitoring Through Non-Destructive Evaluation

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Abstract:- **Indian Infrastructure development is very rapid in the present decade. Over the next decade, an estimated $1.5 trillion is required for the development, overhauling and refurbishing of new and existing civil infrastructure. Structural Health Monitoring (SHM) is an essential field for sustainable infrastructure management, which is very relevant as India competes in the global market. It is a known fact that there are numerous new and archaic buildings/ engineering structures that have known or unknown deficiencies, that require immediate attention. It will be too little and too late to wait for a disaster to incur irreparable monetary or human loss. SHM is a multi-disciplinary field where civil, electrical, computer engineering, material science and seismology can work together to increase the durability of such engineering structures. There is a dire need for society for realizing SHM systems that can automatically and quantitatively analyse the real-time condition of building structures. Among many issues, development of sensor technology, damage detection and techniques for modal parameters are the most paramount. Shortcomings of global health monitoring in damage detection have led to increasing demand for localised and Non-Destructive Evaluation techniques for fault detection systems. Relevant non-destructive evaluation (NDE) is based on minimal invasive testing and evaluation of discontinuities, without compromising the integrity of the structure. The latest development in NDE techniques utilizes smart in-situ materials capable of detection and estimation of possible damage incurred in structures due to external factors. Semiconductor nanocrystals with exceptionally advanced properties of photoluminescence and electroluminescence are the promising candidate in the development of such economic systems, for real-time stress and strain analysis. This paper highlights the immense potential of semiconductor nanocrystals as NDE materials to monitor engineering structures.**

Key words: Structural Health Monitoring, Non-Destructive Evaluation, Semiconductor Nanocrystals.

INTRODUCTION

With the advancement of material science and invention of new building materials, there is a rapid increase in the diversity of architectural style and designs of structures. Because of this structures are becoming more ambitious and complex. Due to extensive modelling, multiplex and ambitious designs of structures it's crucial to continuously monitor the present as well as future state of the structure. In a well-defined system a localised failure is one of the major reasons for an immediate or a progressive collapse. Therefore these localised damages should be detected timely to take preventive measures. Exponentially increasing structural failures of dams, bridges and other critical buildings are major threats all across the globe. Infrastructure development is one of the major contributors to the economic development of any country. Structural failures may have huge impact on economic development due to monetary and human losses.

Degradation in strength of a civil infrastructure after catastrophic events may have several deleterious effect. Hence there is an extreme need of inspecting the percentage retained strength after such events which could be used as an effective tool for better understanding of the structures, optimizing their performance and physical health. Physical harm that impairs the material or geometric properties of the structural system including changes to the boundary conditions is termed as damage. This can adversely affect the systems performance and reduces its functionality. Development of internal stress or strain inside the static civil structures leads to continuous deterioration of strength after construction. It is mainly due to loading and harsh environmental impacts. At the time of construction it is impossible to keep a check on quality and strength of every section, both quantitatively and qualitatively. Hence, there is a variation of physical parameters in different elemental segments of the structure. Continuous increase in the variation of physical parameters will usher the way towards failing of structures. But integration of such systems endows us with the ability to differentiate that whether the low life and decreased serviceability of the structure is due to inferior material or faulty construction.

Structural health monitoring aims to provide a novel system for detecting and communicating material damage. It is a process in which certain strategies are implemented for determining the presence, location and severity of damages. It refers to the integrated elemental system that can mathematically and computationally sense the abnormal characteristics and change in performance due to deterioration or damages of the infrastructure using NDE techniques. It involves observation of a system over time using dynamic responses from an array of sensors, on a periodic basis. The extraction of damage sensitive features from the measurements helps in determining the present scenario or specifically the health of the structure. This is an effective tool in determining the current status of building along with the detailed knowledge of its integrity and lifetime.

Until now visual inspection by trained person has been a common and widely used tool to identify external damages. One major requirement of this type of monitoring system was the accessibility to the region of concern. Moreover this was a non- reliable method as the efficiency of such monitoring totally depends on the experience of the inspector. Over the last few decades several researches have been reported to replace such traditional methods of damage detection. Hence, there was an urgent need of developing smart sensory system to resolve the emerging global problem. The idea of smart structure was proposed to be an alternative because of their inherent smartness and improved susceptibility to environmental changes. The concept of smart and intelligent diagnosis system has led to the idea of developing advanced in-situ methodologies for evaluation and detection of failing structural components. It will offer the ability to reliably detect and track structural damage like overloading, seismic induced damage etc. as it accumulates over time.

Despite of continuous effort of researchers in developing such systems for early stage fault detection, we were unable to develop reliable, robust and economic method that can be used as a health analysis tool. Nanotechnology have emerged as a revolutionising array for the development of new sensory mechanisms, overcoming the deficiencies of present technology. Nano crystals popularly termed as quantum dots are seen as an alternative smart material with surpassing ability to be used as Nano-sensors for localised and precise health monitoring tool. This paper will emphasize on recent advancements in the field of SHM using Nano technology.

1.2 Structural health monitoring

Ideally, health monitoring of civil infrastructure consists of determining, measured parameters like severity and location of the damage. Structural health monitoring consist of primarily two parts Global health monitoring and Local health monitoring (1). Taking particularly global health monitoring into picture the state-of-the-art method of health monitoring do not give sufficiently accurate information to determine the extent of the damage. Currently, these methods can only determine whether or not damage is present in the entire structure. Such methods are referred to as ‘‘Global health monitoring’’ methods (2). They are important because often just knowing that damage has occurred is all that one needs so that further examination of the structure to find the exact location and severity of the damage. Global health monitoring is further divided into two types’ Global static based technique and Global dynamic based technique.

1.2.1 Global static repose

This technique is based involves applying static forces on the structure and measuring corresponding displacements. This technique has number of shortcomings especially in the way of practical implementation, which is not an easy task. As measurement of displacement on a large real life structures are hard to measure. Employing several load cases and computational approach is itself challenging issue. The application of large loads requires high measuring and power input, which are costly and tedious to evaluate a timely and cost effective assessment. Another method is global dynamic response based technique.

1.2.2Global Dynamic Response Based Techniques

Modal parameters like frequencies, the mode shapes, modal damping are function of various physical properties. Any significant change in the physical properties resulting from damage will cause detectable change in the modal parameter. If we consider modal parameters into pictures the techniques can be divided into four types which is based on changes in frequency, mode shape, modal damping and updating of structural modal parameters. A thorough review was done by Salawu on frequency change as a parameter for damage detection. Damage is considered to be section that is localised to a very specific region. On the other hand the modal frequency is not a local parameter. This has lead to several drawbacks such as the overall change in natural frequency becomes quite negligible, same level of damage may cause change in frequencies which could be quite different. Cawley and Adams extended the method of frequency shift to composite material. A further extensive research was done by Stubbs and Osegueda in 1990 in which modal frequency was used to design a damage detection method. But the fact which should be kept in mind is that the frequency alone cannot determine the severity and location of damages. Mode shape techniques are another effective tool for structural analysis it can be divided into two categories one is the displacement mode shape change and the other is the strain mode shape change. In 1984 West proposed the

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modal assurance criteria (MAC) under the method of displacement mode change for detecting and locating damages within in a structure. In this method change in MAC across different positions of mode shape is used to localize structural damage. In 1992 Fox did an intensive investigation on the concept of MAC and termed it as relatively insensitive to damages.. In 1992 Mayes introduced the idea of structural translational and rotational error checking (STRECH) to detect damages and structural integrity by calculating the ratios of relative modal displacement and assessing the structural stiffness accuracy between two different degrees of freedom. When only resonant frequencies and mode shapes are examined the relative change in mode shapes by graphical comparison is proved to be the most suited technique.

On the other hand taking curvature mode shape for damage detection into consideration, it uses the relationship between curvature and flexural stiffness of beams. If the flexural stiffness of the beam decreases the curvature increases. Damping is a phenomena which exist in all civil infrastructures, it is phenomena which is predominant wherever there is an energy dissipation, and damping ultimately leads to the decay of amplitude for a particular system under consideration. This is where the concept of Modal Damping comes into picture. Modal damping rises with the increase in damage, hence it can be used to characterize the presence of damage within a system. The utilisation of modal damping is rarely seen because of difficulty in accurately measuring damping ratio. Hence it is only used as an additional test for damage detection along with the few which are mentioned above. Updating of structural parameters is another effective way of damage detection. The phenomena of updating of modal parameter has no specific rule to be followed for updating. Rather there are certain objectives for updating in this case it is for damage detection. Hence if the component under consideration is damaged then properties like mass, stiffness and, damping change (5). Hence these parameters are perturbed and a resulting model is created. The damage is then detected by comparing the data of modelled structure and the real one.

1.2.3 LIMITATIONS OF GLOBAL TECHNIQUES

Some of the critical issues associated with the global techniques are summarized below:

1. These techniques depend on prior test which are done for damage detection if prior data are not available then it is highly impractical to generate the original data
2. These techniques are used by considering the assumption of linear structure model. But in reality the damage is far from linear at failure level.
3. For monitoring huge structures the number of sensors used may be very large and are critical issues. .
4. These techniques are not suitable for detecting small damages and hence are confined to damages which are already predominant.
5. These techniques demand expensive hardware and sensors and considering the monitoring of mega structures could cost a huge amount
6. A major drawback which is to be kept in mind is interference of enveloping mechanical noise which falls in low frequency range, these waves are in addition to the electrical and electromagnetic noise associated with the detection system itself.
7. The functioning of these techniques is degraded when are prone to multiple damages while detection of damages.

1.2.4 LOCAL TECHNIQUES

Local health monitoring is concerned about detection of damages at a localised level hence have a very confined influence. Local health monitoring techniques are broadly classified into two categories one is through conventional techniques and the other by using smart materials

Conventional techniques

Some of the methods in conventional techniques category are discussed here briefly. Technique using smart materials is main concern of this paper and discussed in detail.

Ultrasonic Technique

Ultrasonic techniques are more prone to damage sensitivity when compared to methods of global health monitoring. It is based on the principle of elastic propagation of wave through the medium and reflection within it. A piezoelectric probe is used to generate high frequency waves into the material. These waves propagates and reflects whenever a crack is encountered. The location of the damage is precisely determined by estimating the time difference between the applied and reflected wave.

However these techniques poses a few limitation which includes the high cost factor, the data collected requires complex processing which involves an experienced professional to interpret the data and their inability to detect transverse surface cracks(Giurgiutiu and Rogers, 1997)

Eddy Currents Technique

In this technique a coil is used to generate eddy current in the system under consideration. The system inturn induces a current in the main coil itself which undergoes variation in the presence of damage. The main advantage of the technique is the simplicity in the application part and not sophisticated hardware are required. However it poses a major disadvantage of confining its application in only conductive materials since this technology is dependent on electric and magnetic fields. Further research in those arena has led to the development of magneto-optic imaging to capture the image of defects (Ramuhalli et al., 2002).

Impact Echo Technique
In this technique a source is used to generate a stress pulse into the component to be monitored. These waves propagates through the structure and gets reflected by cracks in the considered component. These waves are then analysed and characterised for the location of cracks and damages. This technique is only limited to detection of large voids effectively but not the small sized cracks (Park et al., 2000a).

Magnetic field technique
This technique comprises of a coating the component to be tested with a liquid containing iron powder. The given component is then observed under U.V light which makes the cracks visible. Technique is restricted to magnetic materials only and also the component should be first detached and then should be tested under U.V light which narrows its field of application.

Penetrant dye test
In penetrant dye test a coloured liquid is allowed to penetrate inside the crack by applying the dye over the surface of the component and then the surface is washed off. A chalk suspension is then applied which enhances the coloured line along the cracks in the tested components and makes it visible to the naked eyes. The major drawback of the technique is that it is labour intensive and it can't be used where accessibility is not possible.

X-ray technique
In this technique the test component is stimulated with an X-Ray beam and then are again re-captured on a film which demarked as black lines. This technique is highly efficient in determining large and moderate size cracks but is inefficient in determining of small cracks as these defects are difficult to capture. The advancement in this field has led to the usage of computer tomography which was earlier confined to medical diagnosis. This has led to widening the application to components with have varying density. The drawback of this technique which is quite prominent in this case is the physical movement of equipment around the test component for damage detection. The movement of such equipment for detection of damages totally depends on the prior experiences and visual inspections Sometimes it would lead to removal of finishes or cover over the test components which may lead to interruption in the detection. The other major factor which should be kept in mind is the high equipment cost (Boller, 2002).

1.3 Techniques Based on 'Smart Materials and Smart System'

Smart materials are those materials which have the ability to change their physical properties such as the shape, stiffness, viscosity, etc. in a specific manner under specific stimulus input. Smart materials are one of the components of smart structures. The piezoelectric materials and optical fibers are examples of smart material. Smart structures have ability to sense change in their environment, optimally adjust themselves, and take appropriate action.

1.3.1Nano-technology and S.H.M

After more than two decades of research in nanotechnology and immensely increased focus in R&D have changed our vision and prospective towards accomplishing technological development in vast array of application oriented goals. It has revolutionised the whole industrial sector and has immense potential in answering most of the questions raised, from well-established to budding areas. The whole technology revolves around the possibility of tailoring the particles and their unique size dependent properties. It is widely used in the fabrication of materials and devices with better electrical properties, enhanced photoluminescence properties, self-cleaning ability, superior catalytic properties, etc . It finds it application from electronics and IT to civil and environmental engineering.

QDs are novel class of zero dimensional nanomaterials with unique physicochemical properties which arises due to quantum confinement effect. The confinement of particles, usually electrons or holes, to a low dimensional structure usually leads to dramatic changes in their behaviour and to the manifestation of size effects that usually fall into the category of quantum-size effects. They obey quantum mechanical principles' of quantum mechanics. Because of their unique, tunable, size dependent properties, an understanding of their mechanism and economic solutions for their synthesis are yet a major concern that needs to be addressed. These are magic sized versatile materials having more than 80% of the atom on its surface and white light emission capability [6]. High surface to volume ratio of QDs, just like other nanoparticles have significant effect on its surface properties which in turn affect their structure. These materials have radii smaller than bulk exciton Bohr radius, due to which they fall in the category of strong confinement which further gives them better properties. Because of the three dimensional confinement of both electrons and holes, there is an effective increase in the size of band gap of QDs with decreasing crystallite size. Consequently, there is an observable blue shift (i.e., shift towards higher energy) [7] in both optical absorption and emission spectra, as we go on reducing the size of QDs. Thus, the electronic properties of QDs lies in between those of bulk semiconductors (SCs) and those of discrete molecules of comparable size, and can be easily tuned as a function of its shape and size for a given composition. All of these are direct consequence of discrete energy levels of QDs.

Here we are specifically targeting the possibility of using nano-crystals for developing smart in-situ material with capability of empowering building structure by providing vision for sensing defects. According to the research findings of Vanderbilt University it is possible to develop reliable sensing technology for investigating and communicating dynamic load conditions, in-order to access any specific region of building infrastructure without using physical sensors [9]. New smart, in-situ materials with potential of judging material's intrinsic state with varying environmental and load conditions would be a major break-through in the constantly developing field of SHM and NDE. The researchers' at Vanderbilt University have introduced the concept of using ultrasmall CdSe quantum dots [8] for achieving a prospering health monitoring system with ability of visual detection. CdSe has already finds application in optoelectronic industry and spectroscopy. Now they have emerged as an alternative for replacing the technology that involves modification in polymer chain structures that acts as an optical sensing system in response to external stimuli like stress or strain, temperature, shear etc. Epoxy samples containing varying percent weights of CdSe nanocrystals can act as nano-sensors based on the fundamental physics of photoluminescence [10].

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