Smart Structures

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Abstract- A structure is an assembly that serves an engineering function. It is reasonable to expect that all engineering design should be smart, and not dumb. But one can still make a distinction between smartly designed structures and smart structures. The latter term has acquired a specific technical meaning over the last few decades. A smart structure is that which has the ability to respond adaptively in a pre-designed useful and efficient manner to changes in environmental conditions, including any changes in its own condition; the response is adaptive in the sense that two or more stimuli or inputs may be received as anticipated and yet there is a single response function as per design.

Smartness ensures that the structure gives optimum performance under a variety of environmental conditions. While structures with some degree of smartness have been designed from times immemorial, the current activity and excitement in this field derives its impetus from the level of sophistication achieved in materials science, information technology, measurement science, sensors, actuators, signal Processing, nanotechnology, cybernetics, artificial intelligence, and biomimetics. In this field we will discuss about smart structures, some of the materials used for making of smart structures and some applications areas of these structures.

I. INTRODUCTION

The new field, termed "smart materials and structures" refers to structures that can assess their own health, perform self repair or can make critical adjustments in their behavior as conditions change. This has become possible due to team activities involving inputs from manufacturing, measurement systems, instrumented structures, and supplemented by performance tests on components. The human body is a self-regulating network of cells controlled by our subconscious mind. This network has numerous feedback loops for precise control.

A feedback control system is a self-regulating device build within the psychosomatic network of all living creatures and is continually being used for adaptation to environment and consequent survival. In such a control system, the information about the outcome of any process or activity is transmitted to source (mostly brain) for appropriate modification in order to meet the desired goal. A feedback mechanism is easily seen when we see a baby first learning to walk, or a child to riding a bicycle. Smart structures deal with structures which are "adaptable" in some sense; perhaps like a biological system. The design of smart structures involves more challenges because the structural behavior is not "fixed" but depends on environment.

What are smart structures?
Smart structures have the capability to sense, measure, process, and diagnose at critical locations any change in selected variables, and to command appropriate action to preserve structural integrity and continue the intended functions."

II. SMART STRUCTURE MATERIALS

What are smart materials?
A smart material is a material which can sense a change in its Environment, produce a change in response to an external stimulus or both, i.e. it can sense and actuate. A system comprising a smart material, a smart structure and intelligent processing is called a smart system.

Smart Structure Classification

Passively Smart

Structures have the ability to respond to a stimulus in a useful manner, without assistance of electronic controls or feedback systems.

Example: A helicopter blade in which composite layers are arranged to tailor the stiffness of the blade to produce twisting when the blade bends (Bend-twist coupling). The coupling is used to reduce aerodynamic loads on the blade when it bends.

Actively Smart
Structures utilize feedback loops which accelerate the recognition and response process.

Example: A helicopter blade with piezoceramic patches sensor that detects the vibrations of the blade and active fiber composite actuators that are controlled to suppress vibrations of the blade.
Very Smart (or Intelligent) Structures utilize nonlinear properties of the sensor, actuator, memory and/or feedback systems to tune the response behavior.

III. COMPONENTS OF A SMART STRUCTURE.

Two functions are important for smart materials are sensing and actuation.
Sensing: structural displacement, strains, vibrations, and wave propagation can be used to control or performance monitoring or for determining the integrity of the structure. It is called Structural Health Monitoring (SHM).

Actuation: used to suppress vibration or to change the shape of structures to improve their performance.

Examples: morphing wings to improve aerodynamic performance of an aircraft and active noise reduction in a helicopter cabin.
Based on the above functions, the general components of a smart structure are

Sensor(s): Monitor environmental changes and generate signals proportional to the changing measured parameters.

Actuator(s): Used to change the properties of the smart structure in order to achieve desired response.

Control system(s): Continually monitors the sensor's signal, processing the information in order to determine if action is required. If an action is required, then a signal is applied to the appropriate actuator(s).

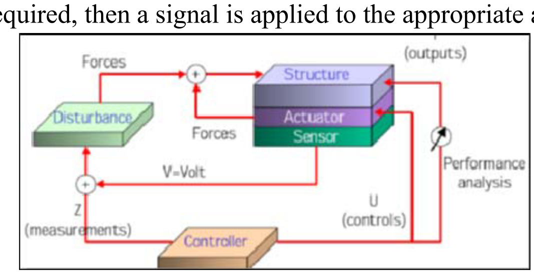


Figure 1: components of a smart structure

Smart Materials:

Common characteristic of smart materials is that they have one or more properties that can be altered using thermal, optical, electrical, and magnetic fields. Some of the smart materials are:
1. Piezo electric materials (piezoceramics (pzts),
piezopolymers, pvdfs),
2. Electrostrictive ceramics (pmns)
3. Magnetostrictives
4. Shape memory alloys (smas)

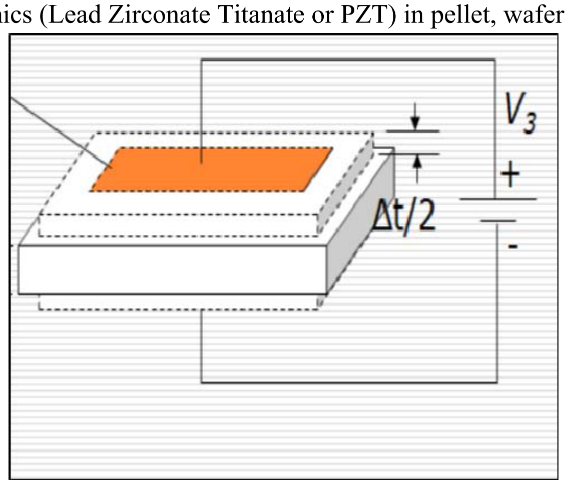
5. Electro rheological fluids (erfs)
6. Magneto rheological fluids (mrfs)
7. Polymer gels

The Actuator/sensor capabilities of these materials are summarized in the table below

	Actuator	Sensor
PZT X	X	X
PMN	X	
M AGNETOSTRICTIVE	X	
SMA	X	X
ERF	X	
MRF	X	
GELS	X	X

IV. PIEZOELECTRIC MATERIALS/ACTUATORS

THese materials can be deformed when a voltage is applied across them or in the reverse manner can produce electric charge when mechanically deformed by external forces. This unique property can be utilized to produce very effective solid state sensors and actuators. They can be integrated into structures as embedded sensors and actuators to come up with active or smart structures. They are available in natural form (Quartz) or can be manufactured as sintered ceramics (Lead Zirconate Titanate or PZT) in pellet, wafer or fiber forms.



Electro rheological (ER) And Magneto rheological (MR) Fluids

ER/MR fluids use electric/magnetic field to change the effective viscosity (or rheological behavior) of a fluid. ER/MR fluids contain fine particles (1-10 µm size) of dielectric/magnetic materials. The fluid must be nonconducting. Electric/magnetic field caused the dielectric/magnetic particles

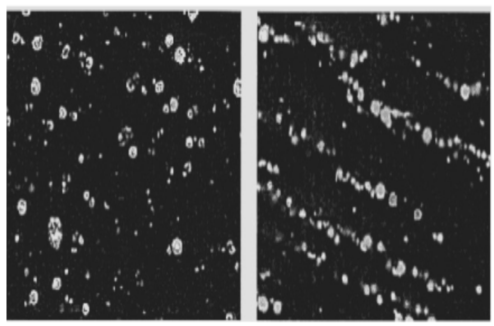


Figure 3: Magnetorheological (MR) Fluid: Before and after a magnetic field is applied.

V. SHAPE MEMORY ALLOY

Shape Memory Alloys (SMAs) are a unique class of metal alloys that can recover apparent permanent strains when they are heated above a certain temperature. The SMAs have two stable phases - the high-temperature phase, called *austenite* and the low-temperature phase, called *martensite*. In addition, the martensite can be in one of two forms: *twinned* and *detwinned*. A phase transformation which occurs between these two phases upon heating/cooling is the basis for the unique properties of the SMAs. The key effects of SMAs associated with the phase transformation are *pseudo elasticity* and *shape memory effect*. Upon cooling in the absence of applied load the material transforms from austenite into twinned (self-accommodated) martensite. As a result of this phase transformation no observable macroscopic shape change occurs. Upon heating the material in the martensitic phase, a reverse phase transformation takes place and as a result the material transforms to austenite.

Four characteristic temperatures are defined in SMA:

Martensitic start temperature (*M0s*), which is the temperature at which the material starts transforming from austenite to martensite;

Martensitic finish temperature (*M0f*), at which the transformation is complete and the material is fully in the martensitic phase;

Austenite start temperature (*Aos*) at which the reverse transformation (austenite to martensite) initiates; and

Austenite finish temperature (*Aof*) at which the reverse phases transformation is completed and the material is the austenitic phase.

Example of Shape Memory Alloys is Nitinol, a Nickel - Titanium alloy. SMAs are capable of very high strains and high actuation forces but have low bandwidth (slow response time) due to time needed for heating and cooling.

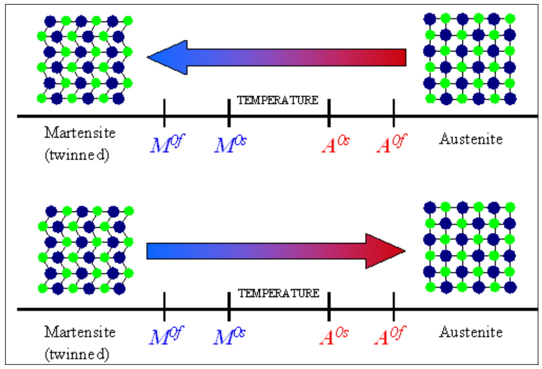


Figure 4 : properties of SMA

If a mechanical load is applied to the material in the state of twinned martensite (at low temperature) it is possible to detwin the martensite. Upon releasing of the load, the material remains deformed. A subsequent heating of the material to a temperature above A0f will result in reverse phase transformation (martensite to austenite) and will lead to complete shape recovery. The above described process results in manifestation of the Shape Memory Effect (SME).

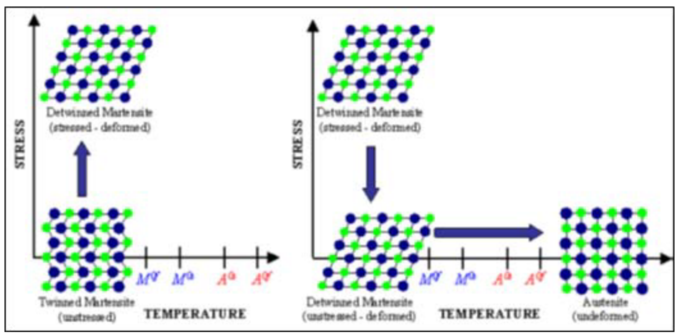


Figure 5: properties of SMA

A comparison table of the properties of different smart materials is given below

VI. EULER-BERNOULLI BEAM THEORY

The Euler-Bernoulli beam model often called as the classical beam model for plane beams rests on the following assumptions

Planner symmetry: The longitudinal axis is straight and the cross section of the beam has a longitudinal plane of symmetry. The resultant of the transverse loads acting on each section lies on that plane. The support conditions are also symmetric about this plane.

Cross section variation : The cross section is either constant or varies smoothly.

Normality : The Euler-Bernoulli beam equation is based on the assumption that the plane cross section normal to the neutral axis after deformation or bending. This assumption is valid if length to thickness ratio is large and for small deflection of beam. The total rotation will be due to the bending stress alone.

Strain energy : The internal strain energy of the number accounts only for the bending deformation and all other contributions such as the transverse shear and the axial forces are ignored.

Linearization : Transverse deflections, rotations and deformations are considered so small that the assumptions of the infinitesimal deformations apply.

Material Model: The material is assumed to be elastic, slender thin and long.

EXPERIMENTAL SETUP

The experimental set-up for smart structure control is shown in Figure 1. This consists of a cantilever beam made of aluminum bonded with one pair of collocated piezoelectric patches as sensor/actuator at the fixed end. To apply disturbance a piezoelectric patch is bonded at the free end of the beam. The conditioned piezo sensor output was given as analog input to dSPACE controller board. The control algorithm was developed using SIMULINK and implemented in real time on dSPACE system using RTW and dSPACE Real Time Interface tools. The controller output was directed to piezoelectric actuator through driving amplifier. The dimensions and properties of the beam and piezoelectric patches are given in Tables 1 and 2.

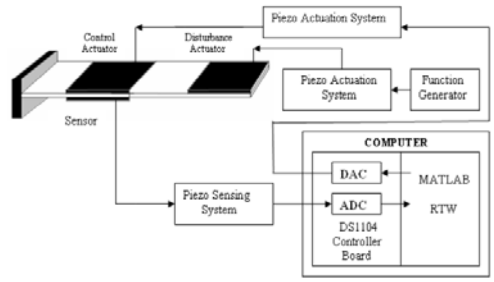


Table 1: Properties and dimensions of the Aluminum beam

Length (m)	l	0.3
Width (m)	b	0.0127
Thickness (m)	t_b	0.0023
Young's modulus (Gpa)	E_b	71
Density (kg/m^3)	ρ_b	2700
Natural frequencies (Hz)	f	31.7, 200
Damping ratio	ξ	0.0524
Damping constants	α , β	2.8676 , 4.5231×10^{-4}

Table 2: Properties and dimensions of piezoelectric sensor/actuator

length (m)	l_p	0.0765
Width (m)	b	0.0127
Thickness (m)	t_a	0.005
Young's modulus (Gpa)	E_p	47.62
Density (kg/m^3)	ρ_p	7500
Piezoelectric strain constant (m V^{-1})	d_{31}	-247×10^{-12}
Piezoelectric stress constant (V m N^{-1})	g_{31}	-9×10^{-3}

VII-APPLICATIONS OF SMART STRUCTURE

Space structures

Large space structures are subject to a variety of dynamic perturbations produced by the crew, the docking of other spacecraft, transient thermal states during the orbit, micrometeorities, and so on. The vibration amplitude of the perturbations has to be dampened in time to avoid further nonstability in the space structure. In addition to that, the dampening of the flexible models is a necessary ingredient in achieving robust attitude control of the spacecraft.

Airplanes

Smart wings: Airplanes that have smart wings will control surfaces that can reshape themselves on the fly. Airplane wings will flex themselves like fish tails. With the help of smart structures, airfoil will be shaped and the aircraft's

lift will be improved. This improved lift will help to get a single-engine fighter off the deck of an aircraft carrier without a catapult.
Replacing current (and heavy) hydraulic control systems with light-weight, high-performance smart materials could increase aircraft payloads by as much as 30 percent and flight range by 50 percent.
Adaptive surfaces would replace stiff structures designed as a compromise among ideal wing shapes for various maneuvers. Eventually vertical tails, ailerons, and stiff structures could be eliminated.

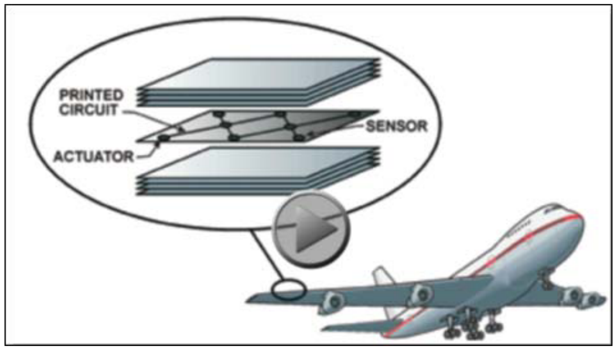


Figure 6: smart materials in aircraft

Helicopters

Figure 7: Active helicopter blades

Active helicopter blades adjust shape continuously to respond to vibration engendering pressure changes in the air. These fluctuations knock the machinery out of alignment and cause a lot of down time. A helicopter's maintenance schedule is approximately 15 percent of its time. In the helicopter project, piezoelectric patches on blade surfaces function both as sensors and as actuators, or as generators of counter-force. Flutter suppression is a particularly important problem. Recent experiments in NASA wing tunnels with unoptimized smart structure designs have shown a 70 percent decrease in displacement and a 20 percent increase in blade speed by utilizing active vibration control concepts. Active noise suspension for helicopter cabins promise greatly decreased acoustic noise/vibration intensities. This reduces stress upon crew members involved in increasingly longer duration missions

Submarines and ships

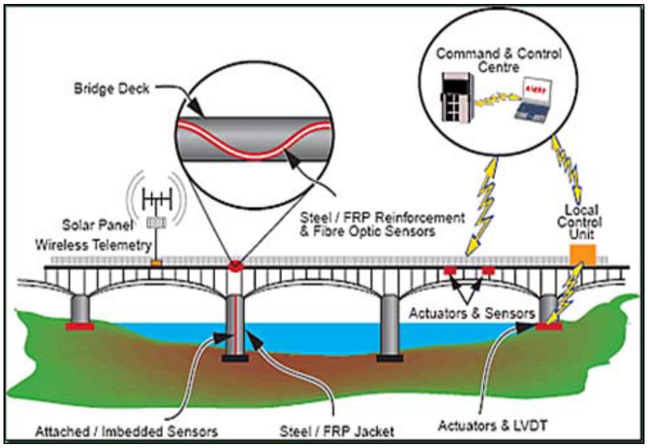
Stealth submarines using smart skins. Smart materials technology may result in stealth submarines. Their acoustically hypersensitive smart skins would detect the pressure of an incoming sonar wave, and then automatically generate an equal but opposite counter-pressure to cancel out the ping. With nothing reflected back to enemy boat, the submarine would be invisible.

Cars

The automotive industry also is eager to incorporate intelligent materials technology. Some of the areas where smart material will be used are:

Smart car seats: Researchers are working on an industry-sponsored project to develop smart car seats that can identify primary occupants and adapt to their preferences for height, leg room, back support, and so forth.
Maintenance information: The technology exists to enable cars to tell owners how much air pressure tires have, when oil changes are needed, and other maintenance information.
Suspension and transmission: Smart materials that can change their viscosity (inherent thickness or resistance to flow) when exposed to electric or magnetic fields. This kind of smart material will lead to new kinds of auto suspensions and transmissions.

Structural health monitoring



Smart Structures has for the past some years been advancing the technology of bridge and building monitoring. Also known as structural health monitoring (SHM) we have systems world-wide and an impressive affiliate list. The SHM process involves the observation of a system over time using periodically sampled dynamic response measurements from an array of sensors, the extraction of damage-sensitive features from these measurements, and the statistical analysis of these features to determine the current state of system health. For long term SHM, the output of this process is periodically updated information regarding the ability of the structure to perform its intended function in light of the inevitable aging and degradation resulting from operational environments. After extreme events, such as earthquakes or blast loading, SHM is used for rapid condition screening and aims to provide, in near real time, reliable information regarding the integrity of the structure.

Floating Bridge –Dubai.

With a total length of 365 metres and a width of 22 metres, the pontoon bridge features six lanes on two identical,mirrored decks spanning the entire Dubai Creek. For each direction an independent supporting structure has been constructed.The parallel structures were designed to accommodate three lanes and one footwalk each.Between the two floating pontoons made of concrete, each 115 metres long and 22 metres wide, a hydraulically driven rotating middle section made of steel is positioned to allow for undisturbed navigation.To compensate for differences in level as well as for transverse inclinations (heeling) and longitudinal displacements resulting from traffic loads and wave action acting on the ramp, another two rows of 28 transitory elements are installed between the floating pontoons and the transitory ramp on either bank. The structure so formed dynamically distributed energy from waves and pressure from vehicles across the length and breadth of the platform in such a way that they canceled each other out. 23 standard elements filled with highly resistant polystyrene plates serve as the actual floating body supporting several thousands of tons of the heavy bridge on water level.

Structure of a bridge

VIII.CONCUSION

Smart materials and structures technology represents an emerging field of study that is finding many applications in several areas. These applications include structural control, condition/health monitoring, damage assessment, structural repair, integrity assessment and more recently in asset management, preservation, and operation of civil infrastructure. The potential benefit of this technology may be improved system reliability, longevity, enhanced system performance, improved safety against natural hazards and vibrations, and a reduction in life-cycle costs in operating and managing civil infrastructure systems.

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