Smart Structures
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Week 01
Lecture No: 03
Introduction to Smart Structures (continued)
Part 01

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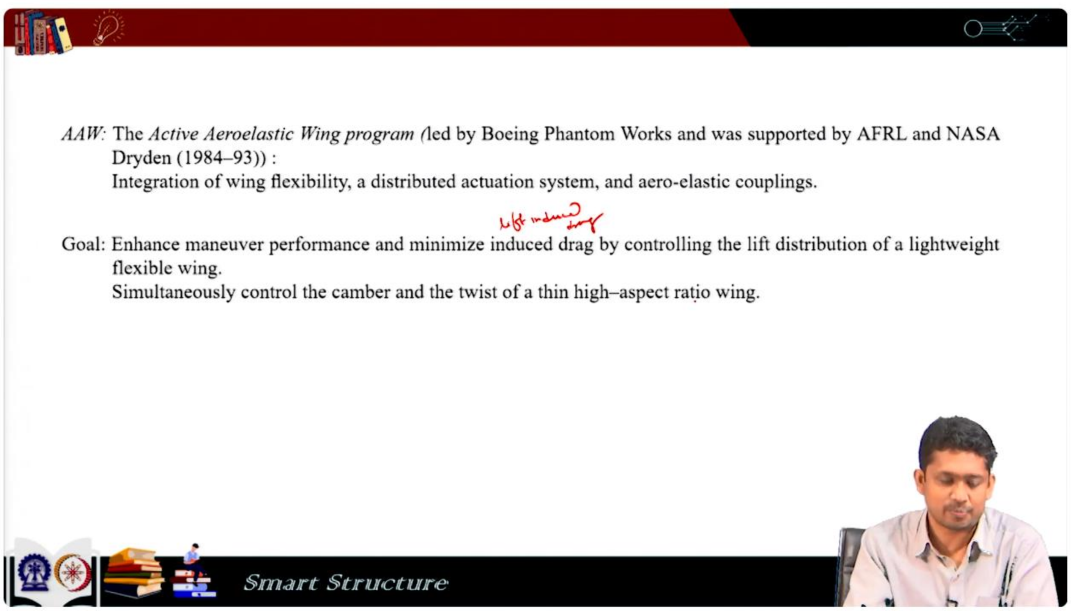

We will continue with the applications AAW the Active Aeroelastic Wing Program. It was led by Boeing Phantom Works and was supported by AFRL and NASA Dryden. It was about integration of wing flexibility or distributed actuation system and aero elastic coupling. Here the goal was to enhanced maneuver performance and minimize induced drag by controlling the lift distribution of a lightweight flexible wing. Induced drag is also known as lift introduced drag and it can be controlled by controlling the deep distribution and that is what they did. Simultaneously control of camber and the twist of high aspect ratio wing was also the goal.

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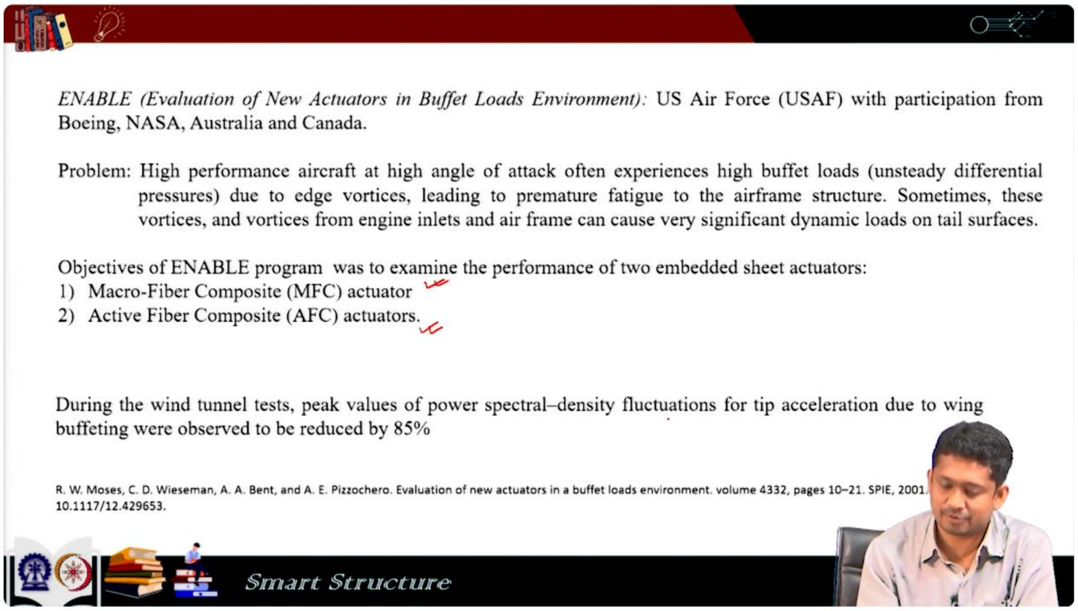

Control is evaluation of new actuators in buffet load environment. It was initiated by US Air Force and other participants were from Boeing, NASA, Australia and Canada. Its goal was to address a very relevant problem, very practical problem that is encountered by high performance aircrafts. So, this high-performance aircraft when they are at high angle attack, they often experience something called buffet loads. Those are unsteady differential pressure and that happens due to edge vertices and it leads to premature fatigue of the air frame. And sometimes these vertices they coupled with other vertices that come from engine inlets and air frames and that can be even more significant. Here the goal was to examine the performance of two sheet actuators and they are macro fiber composite actuator and active fiber composite actuator. So, these are composite actuators. So, here direction dependent actuation is possible. Macro fiber composite was invented by NASA, it is a piezoelectric composite and it was then commercialized by smart materials in Germany. And during the wind tunnel test they observed that power spectral density fluctuations for tip acceleration due to wing buffeting were reduced by almost 85 percent.

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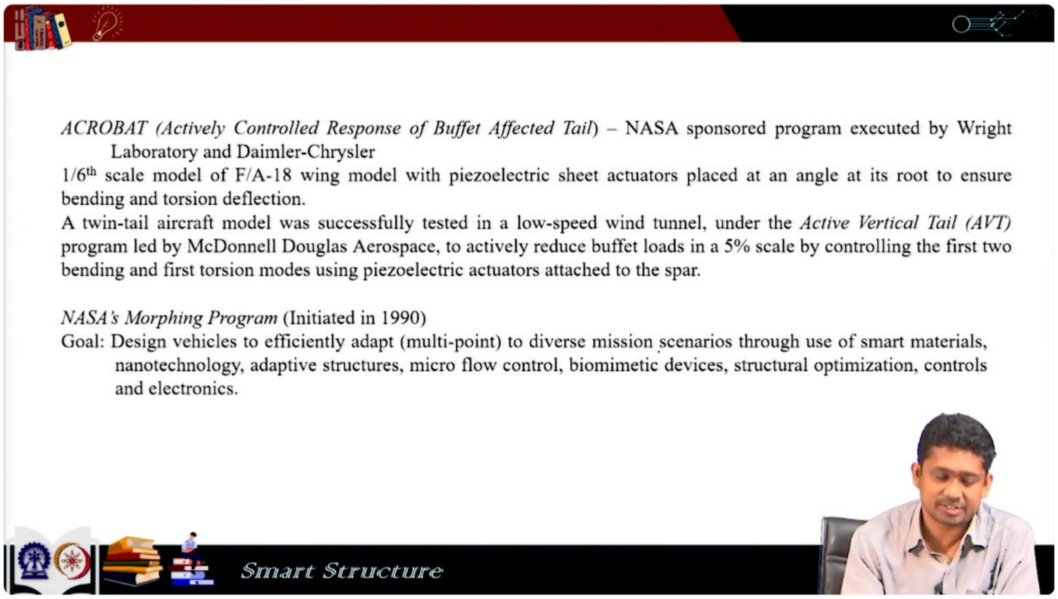

Acrobot that stands for actively controlled response of buffet affected tail. It was a NASA sponsored program and executed by Wright laboratory and Daimler-Prisler.

It used a one sixth model of F A 18 wing with piezoelectric sheet actuators that was placed at an angle at its root. So, it was placed at an angle to ensure both bending and torsional deflection. A twin tail aircraft model was successfully tested in a low-speed wind tunnel under the active vertical tail program led by McDonald Douglas aerospace to actively reduce buffet loads in a 5 percent scale by controlling the first two bending and first torsion boards using piezoelectric actuators attached to a spur. Then NASA had a morphing wing program that was initiated in 1990. Where the goal was to design vehicles to efficiently adapt to diverse mission scenarios through the use of smart materials, nanotechnology, adaptive structures, micro flow control, biomimetic devices, structural optimization, controls and electronics.

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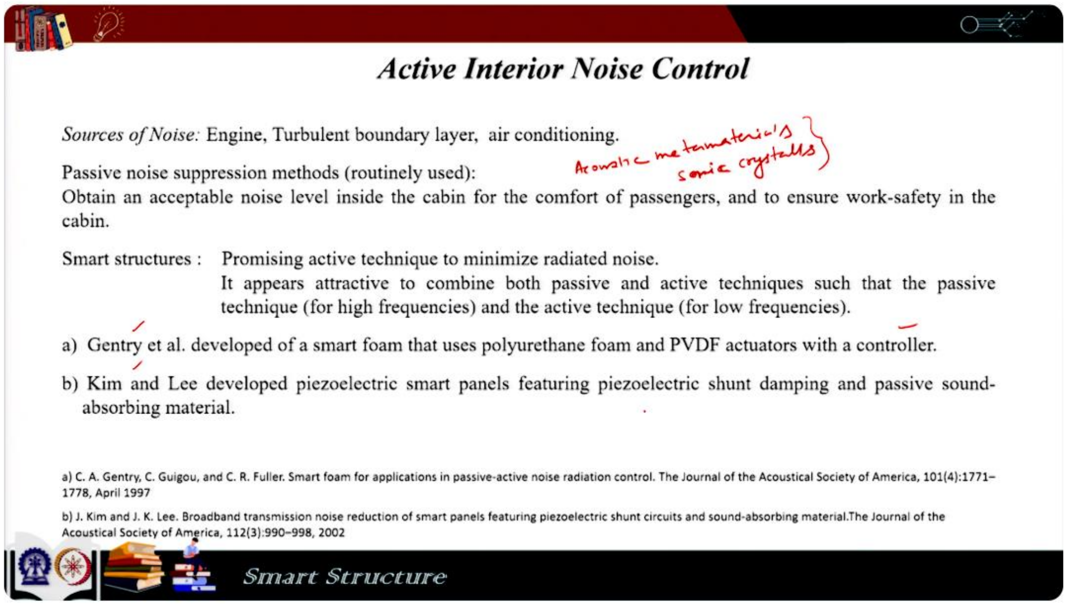

Now we will talk about noise control in aircraft. So, noise is something where lot of research goes on. So, noise control is an issue. Noise comes from engine turbulent boundary layer, air conditioning and so on. Now most of the noise control methods are passive and they are and those passive techniques has been quite successful noise has been reduced by a by a satisfactory amount. And there are two items where lot of research is going on one is called acoustic beta materials and sonic crystals. So, these are based on the beta materials concepts where lot of research has been done and has been found to be quite useful. But the idea is that if some kind of active component is of component is added to the solutions, then the efficiency can be further improved. That is what has been done by in these two papers we can see. So, Gantry and others they developed smart foam that uses polyurethane foam and PVDF actuators with a controller.

Steve and Lee they developed piezoelectric smart panels featuring piezoelectric shunt damping and passive sound absorbing material.

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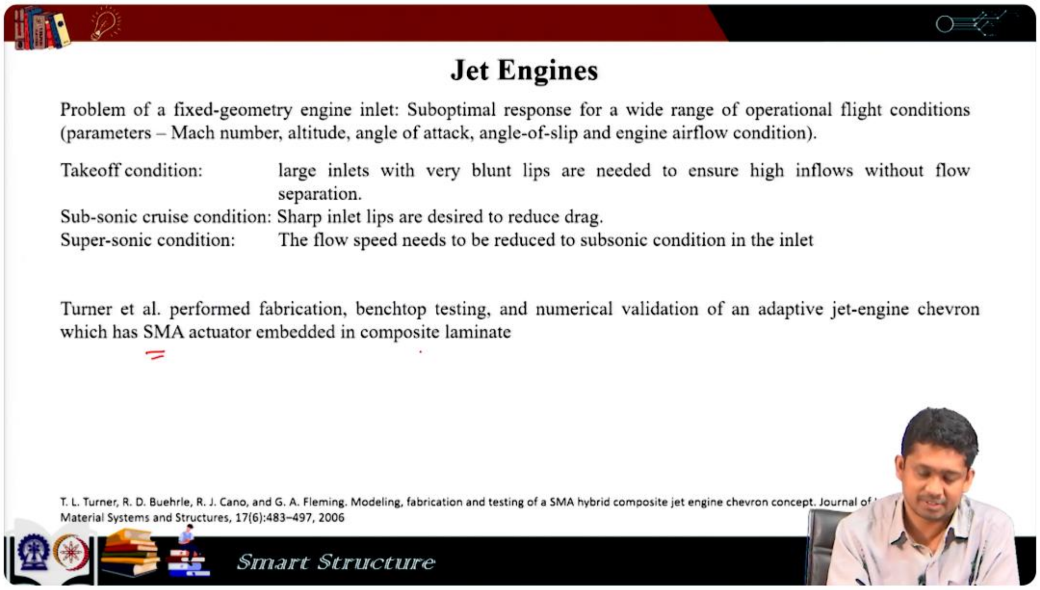

Now, we will talk about jet engines. In jet engines the problem is that if the jet engine has a fixed geometry in inlet, then it does not act it does not work optimally in a wide range of wind speed. Because at different wind speed the requirement is different. For example, in the takeoff condition large inlets with very blunt leaves are needed this ensures high inflow without flow separation. In the subsonic cruise condition sharp inlet leaves are desired to reduce the drag. Whereas, in supersonic condition the requirement kind of changes the flow speed needs to be reduced to subsonic condition in the inlet. So, the solution lies in some kind of adaptive inlet geometry which can adapt to the changing wind speed. Turner and others performed fabrication, bench top testing and numerical validation of an adaptive jet engine chevron which has shape memory alloy actuators embedded in a composite laminate. Now, composite laminates can be made shape adaptive just by orienting the plies in a sequencing the ply orientation in a proper way.

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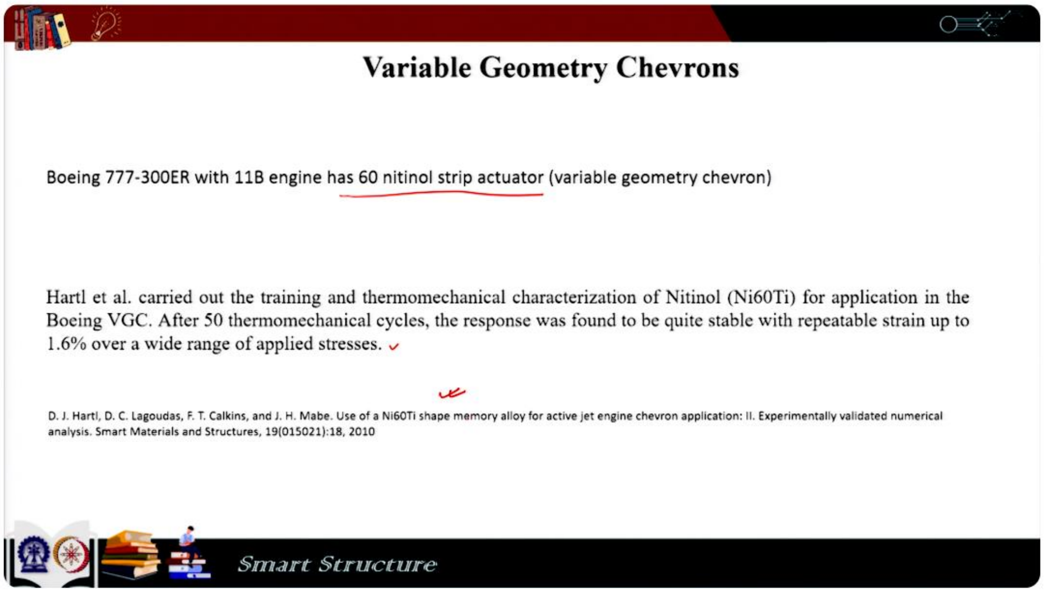

So, we will talk about it when we discuss composite materials in more details. Now, again if some active component is added to it here it has been done with the help of shape memory alloy actuators it can be even more shape adaptive. Boeing 777-300ER with 11B engine which has a variable geometry chevron which it has 60 Nitinol strip actuators. Now, Hartle and others they carried out training and thermo mechanical characterization of nitinol for application in the Boeing variable geometry chevron. So, after 50 thermo mechanical cycles the response was found to be quite stable with repeatable strain up to 1.6 percent over a wide range of applied stresses. So, shape memory alloys they need something called training where loading and unloading is done in a cyclic manner. We will talk about it again when we discuss shape memory alloy in more details. So, that is what was done here and the observations are mentioned more details can be found here.

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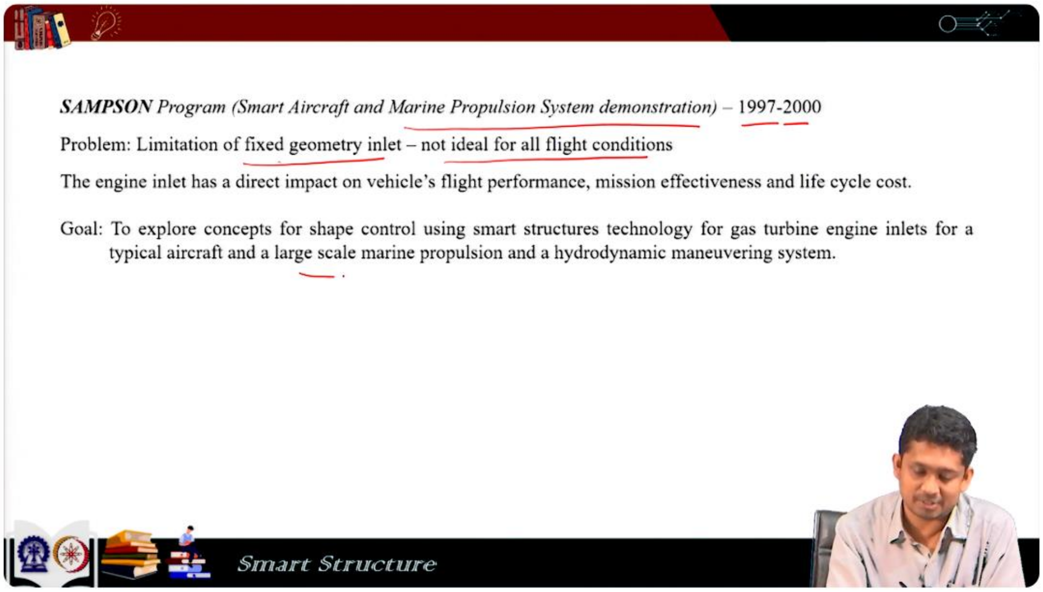

Samsung program has kind of similar goal it is smart aircraft and marine propulsion system demonstration. It was between 1997 to 2000. The problem they addressed is similar the limitation of fixed geometry inlet which is not ideal for all flight conditions. And the engines inlet has a direct impact on vehicles flight performance mission effectiveness and life cycle cost. So, the goal here was to explore concepts for shape control using smart structures technology for gas turbine engine inlets for a typical aircraft and large marine propulsion and hydrodynamic maneuvering system as well.

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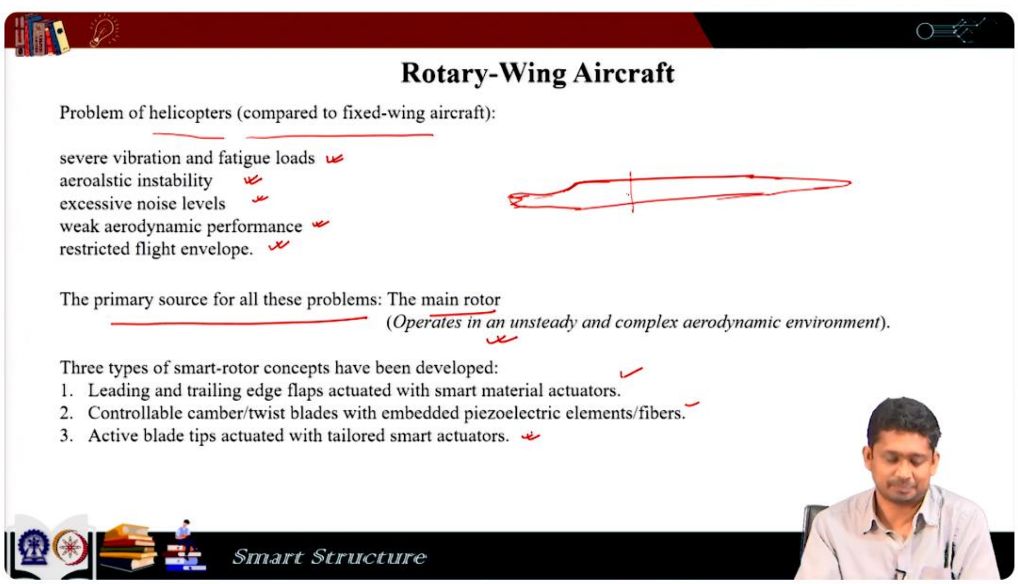

In rotary wings aircraft so, for example, helicopter has a rotor. So, this rotor adds to significant complexity. First of all, a rotor has complex motion. Now, a rotor can have edge wise vibration, it can have flap wise vibration, it can have twist and again there are several modes where these all these motions are coupled. It is connected to hub the hub itself has its own complicated kinematics. So, that makes the vibration of the rotors quite complicated and it is in complex aerodynamic environment. So, there are significant complexities that comes severe vibration and fatigue loads, aero elastic instability, excessive noise, weak aerodynamic performance and restricted flight envelope. And as mentioned the primary source for all these problems are the rotor. So, three types of smart rotor concepts was developed leading and trailing edge flaps actuated with smart material actuator, controllable camber twist blades with embedded visual electric elements fibers, active blade tips actuated with tailored smart structures.

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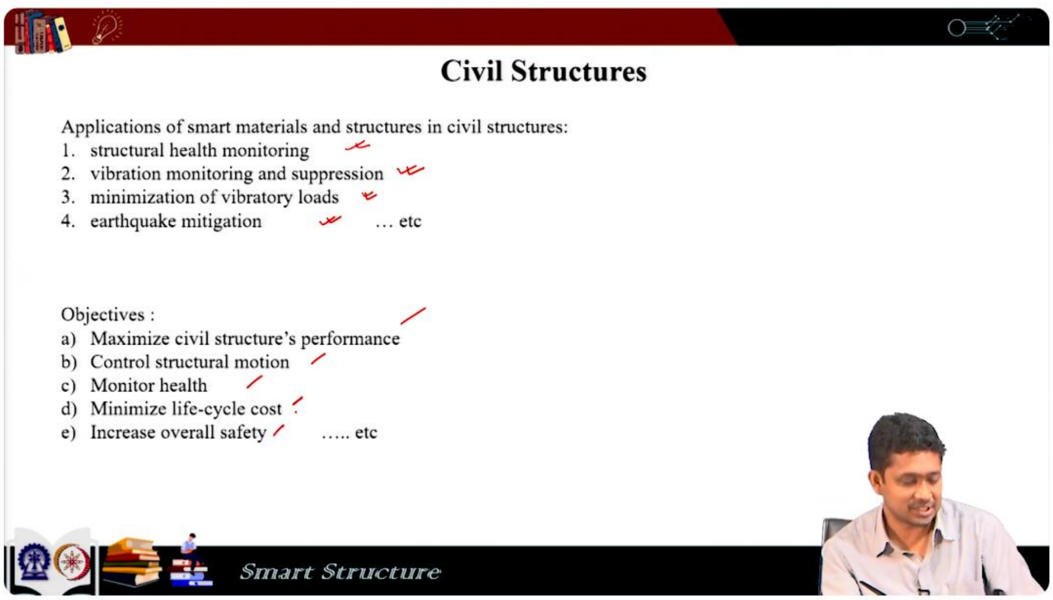

Now, we will talk about civil structures. The applications are diverse in civil engineering structures as well, structural health monitoring, vibration monitoring and suspension separation, minimization of vibratory loads, earthquake mitigation.

The objective here is to maximize civil structure performance, to control structural motion, monitor health, maximize life cycle minimize life cycle cost and most importantly increase the overall safety.

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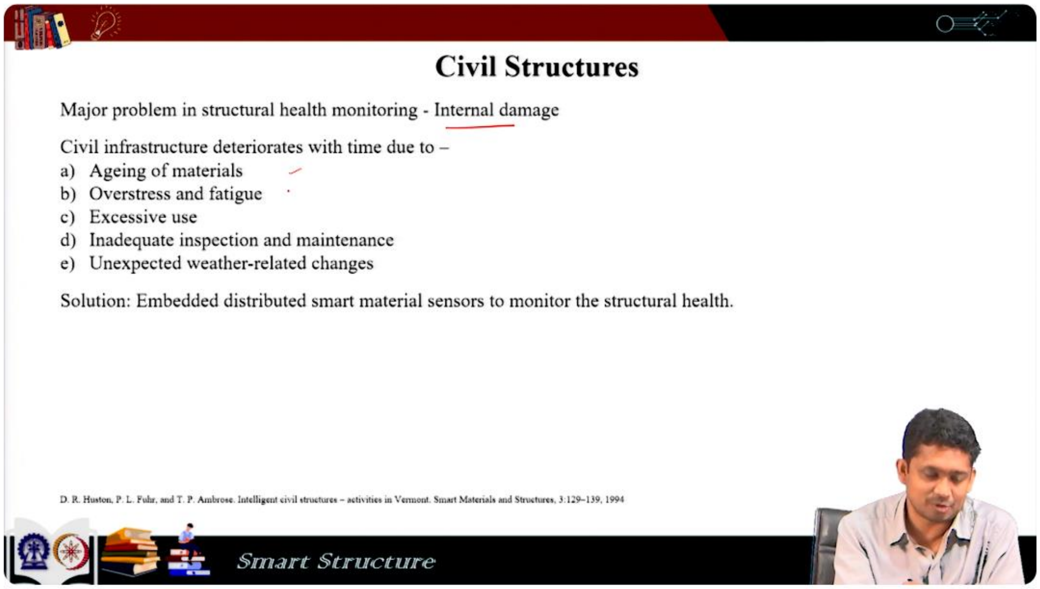

Now, major problem in the structural health monitoring is internal damage. Civil structures deteriorate with time due to several factors aging, over stress, fatigue, excessive use, inadequate inspection and maintenance, unexpected weather-related problems. So, embedded distributed smart materials sensors to monitor the structural health is a solution.

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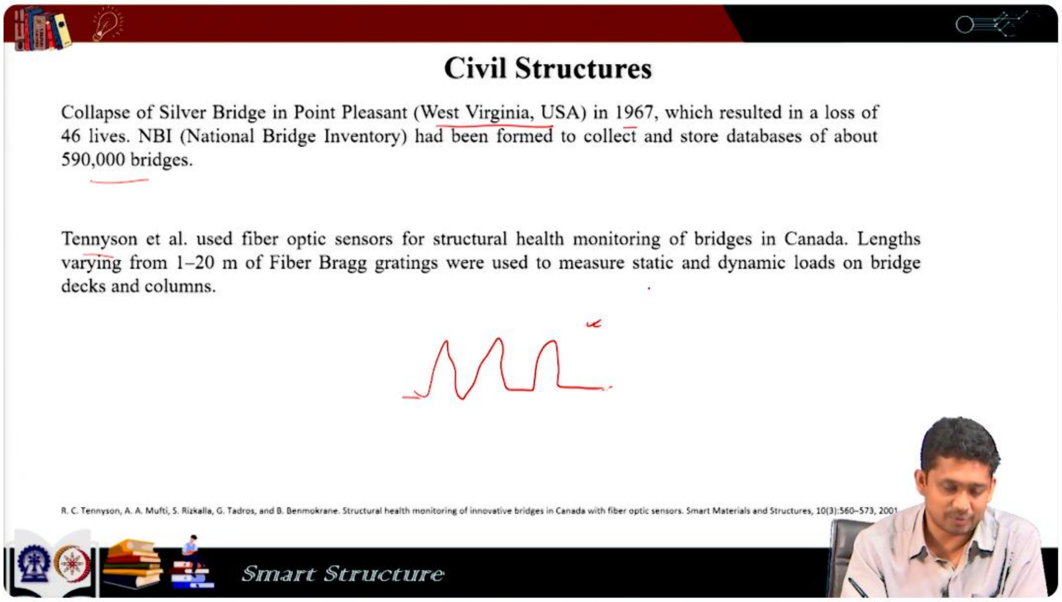

So, there has been in the history there has been several collapses of structures. So, here is just one example that is taken from the book collapse of silver bridge in Point Pleasant that was in West Virginia USA in 1967. Now this resulted in loss of 46 lives. So, for all these things NBI national bridge inventory was formed, the goal was to collect and store database of about 5,90,000 bridges. So, there was a study by Tennyson and others they used fiber optic sensors to provide an overview of structural fiber optic sensors to in the past there has been several structural failures. Here is one example taken from the book the collapse of silver bridge in Point Pleasant that was in West Virginia USA in 1967 and that resulted in loss of 46 lives. So, NBI national bridge inventory was formed to collect and store database of about 5,90,000 bridges. There is an there is a study by Tennyson and others they used fiber optic sensors for structural health monitoring. Now so, they with the fiber optic sensors they monitor the strain at various parts of the bridge and as the vehicles passed by it and strain variation like this was found. Now with this kind of strain variation if it is monitored on a regular basis then any anomaly can be detected that was the goal of this kind of works and strain monitoring is used a lot with the help of fiber optic sensors for civil engineering structures. Suspension bridges and cable strain bridges they all are they all have these cables as a major component of the structure.

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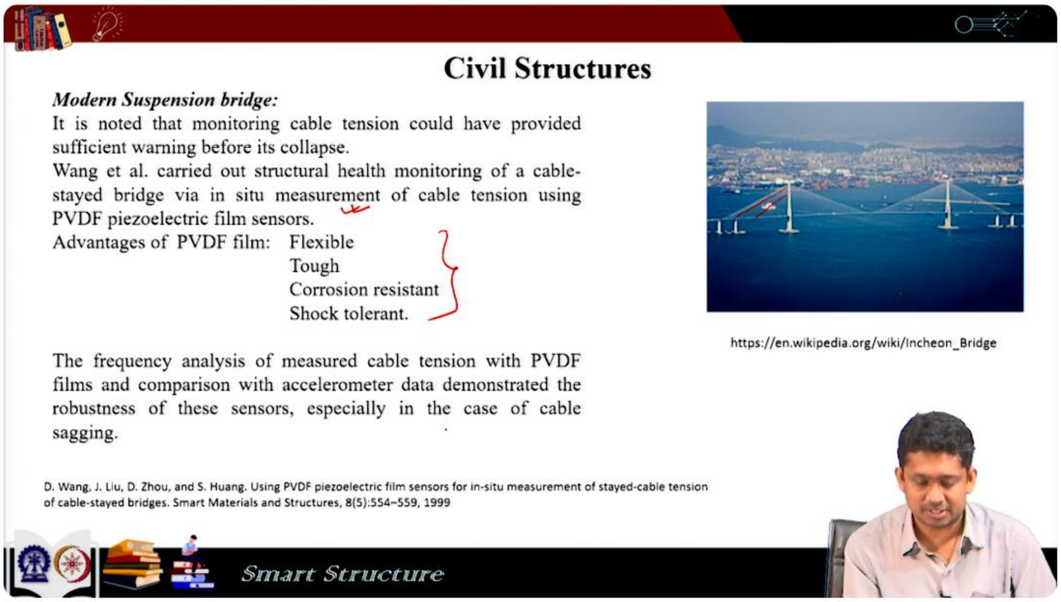
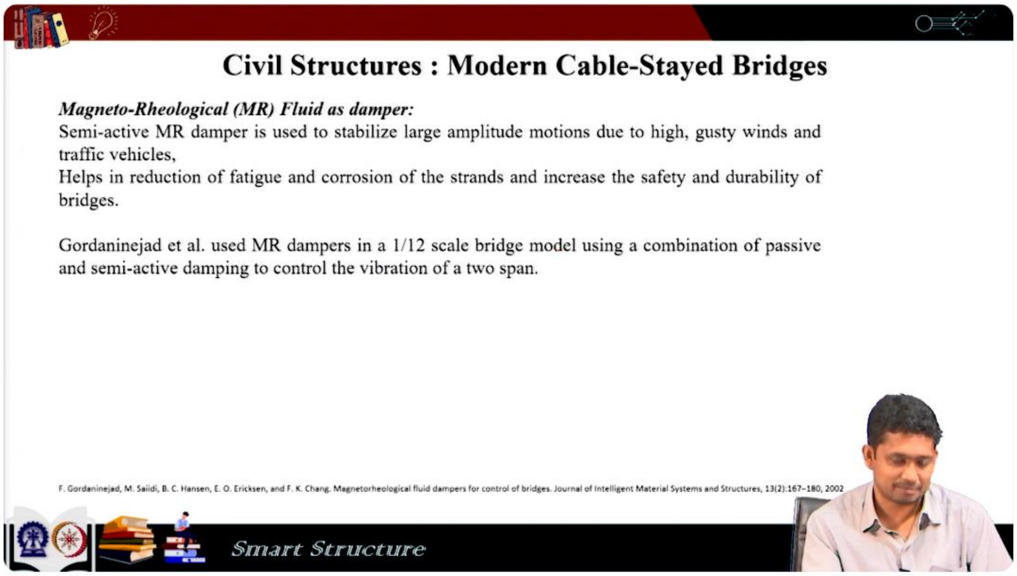


Now apart from the loads due to the traffic or the earthquake load wind load also cause a lot of severity in these structures. So, because of complicated interaction between the wind and the structure phenomena like vortex induced vibration flutter they happen. An example is the failure of the Takoma Narrows bridge in USA. Now it was observed that if the tension in the cable can be monitored that can help a lot for monitoring of this bridges. So, that was the goal of this study carried out by Wang and others. So, they measured the tension in the cable using PVDF piezoelectric film sensors. So, as was mentioned while comparing different smart materials it was it was seen that PVDF has much low elastic modulus as compared to PZT. Now because this because these cables are somewhat flexible. So, PVDF was found to be a better solution here. And it was observed that the frequency analysis of measured cable tension with PVDF films and comparison with accelerometer data demonstrated the robustness of the sensors specially in the case of cable sagging. (Refer Slide Time: 19:45)



Now, vibration control is also another aspect. So, magnet rheological fluid is quite a lot used for this kind of applications. Semi active MR damper is used to stabilize large amplitude motions due to high gusty winds and traffic vehicles. It helps in reduction of fatigue and corrosion of the strands and increase the safety and durability of the bridges. So, Gordany and Hazard they used MR dampers in a 1 by 12 scale bridge model using a combination of passive and active damping to control the vibration of two span. So, MR dampers are finding growing applications in this in this civil engineering structures. So, a extensive and extensive study on MR damper for seismic and wind excited buildings can be found here. And here we can find some optimization also to for proper usage of these dampers.

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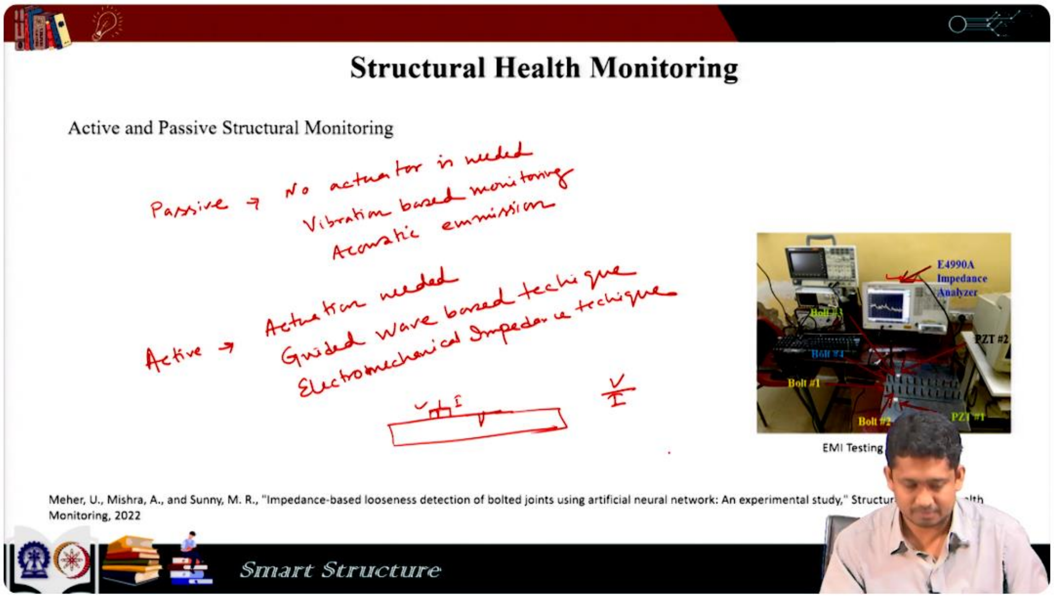

Now, we will spend some time on structural health monitoring because it is a very cross disciplinary problem. Aerospace structures, civil structures, mechanical structures, marine structures everywhere the monitoring of the health is needed to enhance safety and efficient use of these structures. Structural health monitoring is basically based on the principle of looking at the structural response to some known or unknown excitation. And from the response the response data is analyzed and some information about the structural health is assessed. So, it can be structural health monitoring can be passive. So, in a passive generally no actuator is needed. So, whatever the structural data is obtained from the because of the ambient condition that is used to find out the structural damage status. So, examples can be in passive examples can be vibration-based monitoring. Now, vibration can base monitoring can be done with known vibration also by heating it with a impact hammer or shaker, but when the vibration based monitoring is done just by looking at the ambient vibration due to the ambient load condition that is a passive monitoring. Acoustic emission these are all passive techniques. Active techniques involved actuation. So, some known signal is given to the structure and the structural response is looked into. So, it can be guided wave-based technique, electro mechanical impedance technique these are all active health monitoring techniques. So, in an electro mechanical impedance based technique if I have a structure then if I have some piezoelectric patch fitted to it, if I apply some voltage to it, I can measure the current also across this patch. So, the V by I is this ratio is the electro mechanical impedance of the electro mechanical impedance obtained here. It is electro mechanical because this impedance depends on the structural property also. If there is some flaw in the structure this impedance changes and from this change structural health can be assessed. Now, here is one example here we hear an experimental experiment is being done in our lab to find out any looseness in bolts. So, it has it has a impedance analyzer and it has bolts it has bolts the looseness of which is being monitored and it has piezoelectric patches.

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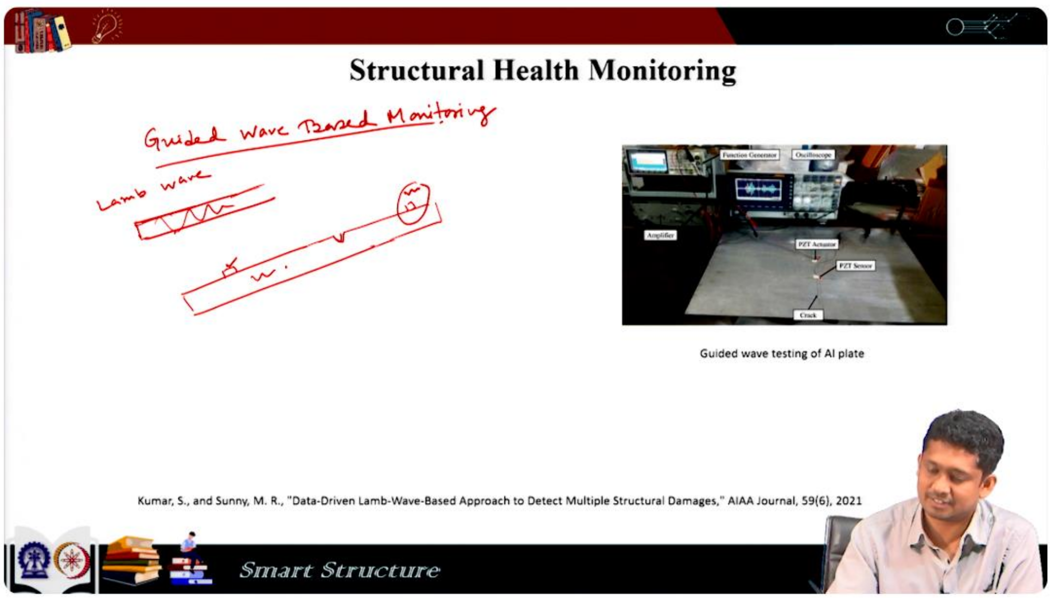

Guided wave-based monitoring. So, in guided wave-based monitoring guided waves are waves that travel by I mean that that is travelling of which is guided by some wave guides. So, one of the examples is lab wave where the wave guide is the wave guide is the two opposite surfaces of a thin structure like a thin plate as can be seen here. So, the wave remains confined within this thin boundary and travels. So, these waves can travel long distance. So, that is why they are quite useful because with small number of actuators a long a larger area can be scanned. Now a very simple schematic view of a guided wave-based system can be like this. So, if I have a piezoelectric patch here, if I have a piezoelectric patch here, if I excite it here the wave propagates and it the wave is sensed here. Now during propagation if it encounters any damage the sensing response that we get here changes and from that change again we can find out if there is any problem in the structure or not. So, here is one experiment guided wave-based experiment shown here. So, we can see a plate here is a there is a piezoelectric actuator which is excited by a function generator and these are sensor the data is collected through to a through an oscilloscope and it tries to find out any problem in the structure along this dimension. So, now we will look into how guided wave propagates ok.

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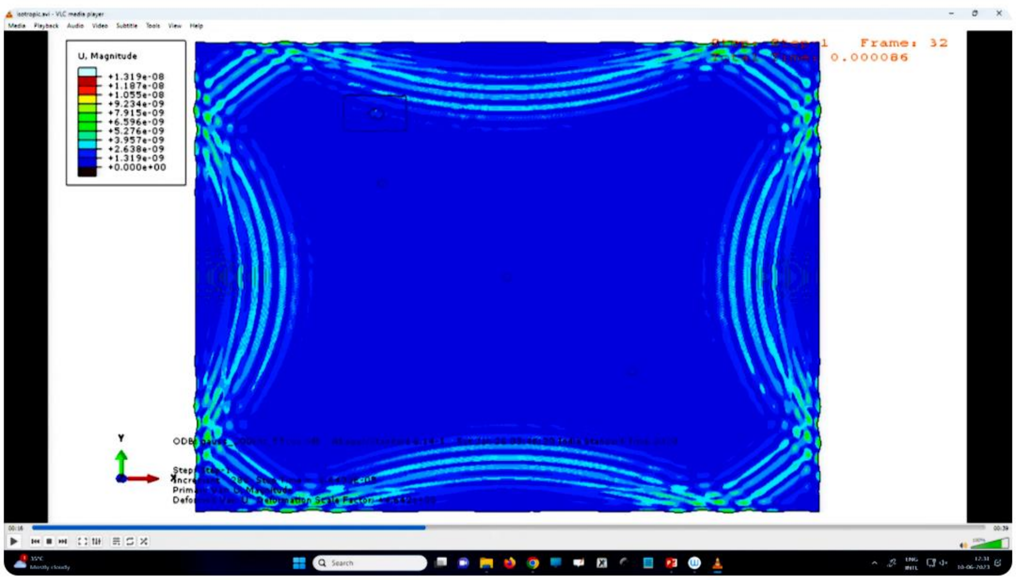

This video shows propagation of guided wave which is generated by piezoelectric patch in the structure. So, the wave is generated here and we can these isotropic materials we can see that the wave is propagating uniformly across all the dimensions. So, it propagates uniformly along all the directions and then when it encounters any damage here, we can see that this damage again scatters the wave and the wave propagating pattern changes. So, the wave propagating pattern that we see here is kind of different from that we see here because we have a damage here. So, whatever we have placed a sensor here. So, whatever this a sensor senses can be quite different than a than any sensor if it is placed here. So, this video shows the propagation of guided wave the guided wave is generated by a piezoelectric patch which is placed at the center. Now because this structure is isotropic and the piezoelectric patch that we used by circular here. So, the wave is propagating uniformly across all the directions and we will see how damage is changing the propagation pattern. So, once the wave is reaching here, we have put some damage here we can see that because of this damage the wave is wave is getting scattered. So, the wave propagation pattern here is somewhat different from the wave propagation pattern here. So, any sensor that is placed here the reading that it gets will be different from any sensor that is placed here where there is no damage. So, the wave propagation pattern also incorporates information about damage and the goal is to extract the damage information from the wave propagation pattern. Now it has several complexities for example, when the wave hits the edges again it comes back. So, there are lots of reflections. So, it needs lots of advance processing to find out the damage from this wave propagation. So, that was just to give an idea about the application of this piezoelectric materials for damage detection using guided waves.

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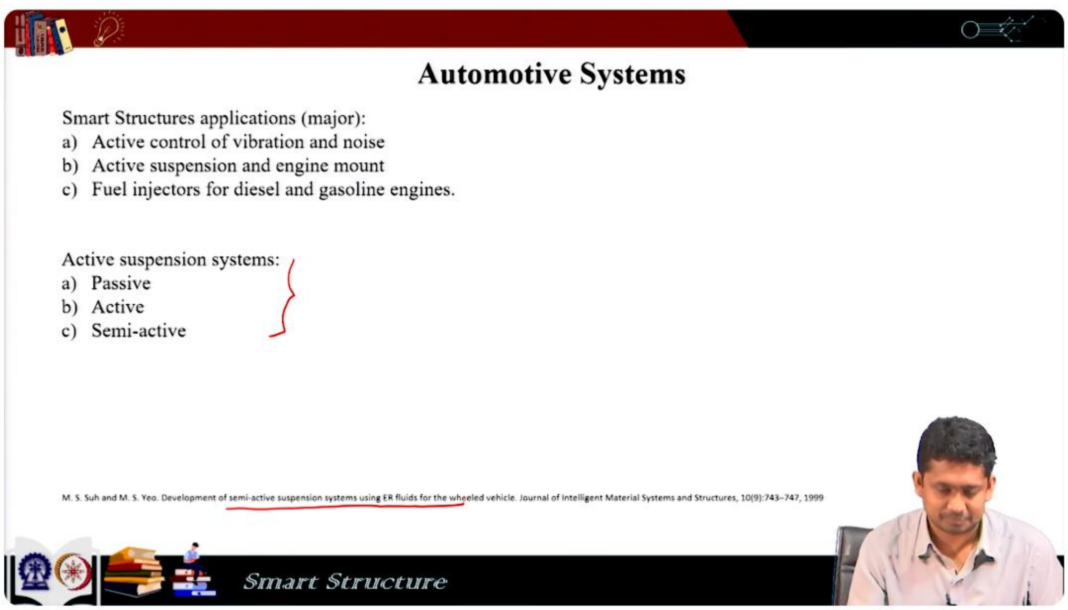

In automotive system also smart materials find lot of use. It is generally in active control of vibration, active suspension and engine mount, fluid injectors for diesel and gasoline engines. Active suspension can be passive active or semi active. In this paper a development of semi active suspension system using ER fluid can be found.

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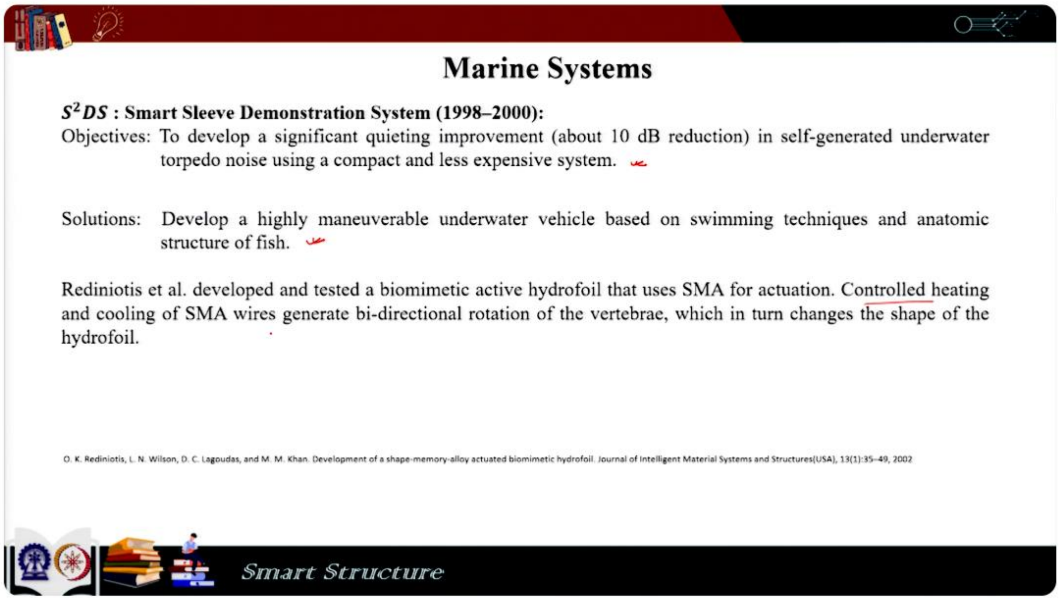

Here one marine system application is shown that is S2DS smart slip demonstration system. The objective was to develop a significant quieting quiet environment improvement of about 10 decibel reduction in self-generated underwater torpedo, torpedo noise using a compact and less expensive system. So, the solution came in the form of the development of a highly maneuverable underwater vehicle based on swimming techniques and anatomic structure of fish. Radinitis and others developed and tested a biomimetic active hydrofoil that uses shape memory alloy for actuation. Controlled heating and cooling of shape memory alloy wires generate bidirectional rotation of the vertebrate and this in turn changes the shape of the hydrofoil.

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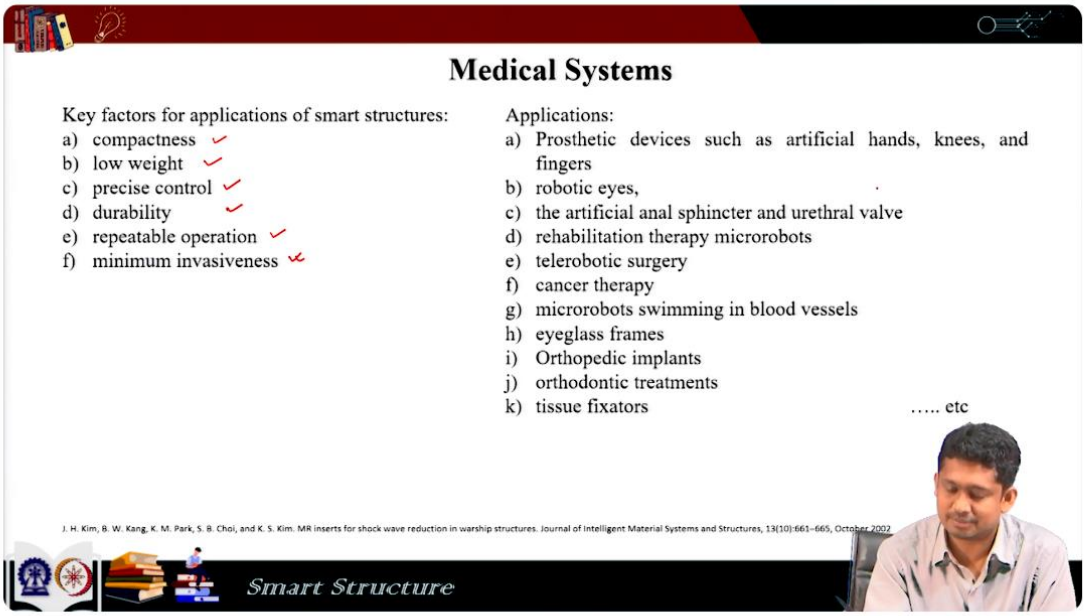

There is growing use of smart materials for medical systems also. In medical systems here the requirement is compactness, low weight, precise control has to be there, durability and repeatable operation is needed and minimum invasiveness that is also required for surgeries. Applications that we applications they involve prosthetic devices such as artificial hands, knees and fingers, robotic eyes, artificial and sphincter and urethral valve, rehabilitation therapy, micro robots, telerobotic surgery, cancer therapy, micro robot swimming in blood vessels, eye glass frames, orthopedic implants, orthodontic treatments, tissue fix t-shirt fixators.

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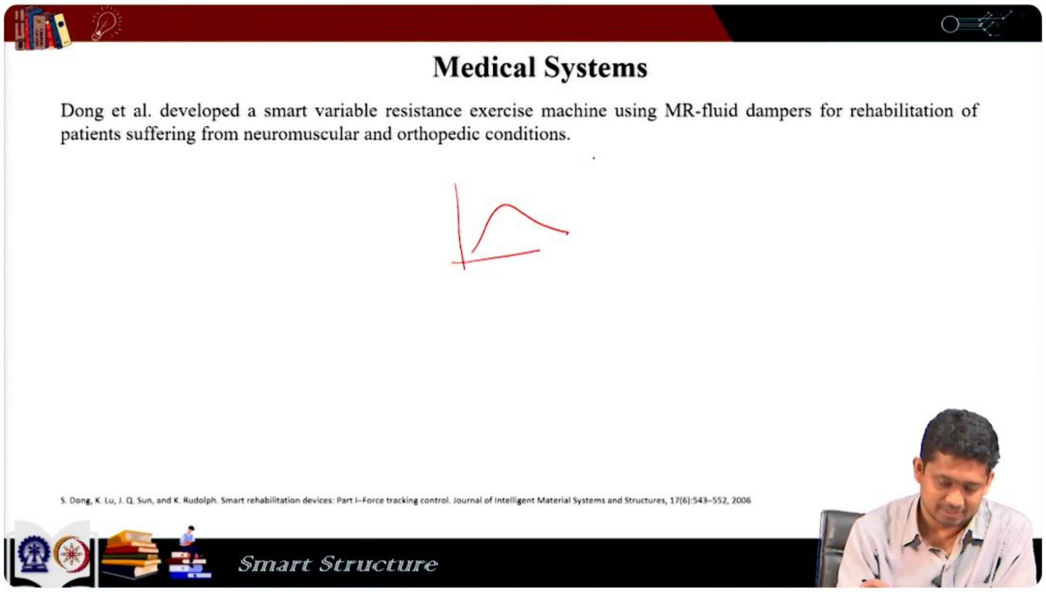

There is a study by Dong and others they developed smart variable resistance exercise machine using MR fluid dampers for rehabilitation of patients suffering from neuromuscular and orthopedic conditions. So, in an exercise equipment generally the resistance offered is not so properly tuned. So, that is what they wanted to address here. So, when a during the stretching the maximum force, I mean during the stretching at the beginning and the end the force is not maximum generally the force is somewhat low and the maximum force is achieved somewhere in between. So, that is what they wanted to do in through this work the strength offered by the resistance offered by this exercise equipment was tailored in such a way that when required it offers the maximum resistance.

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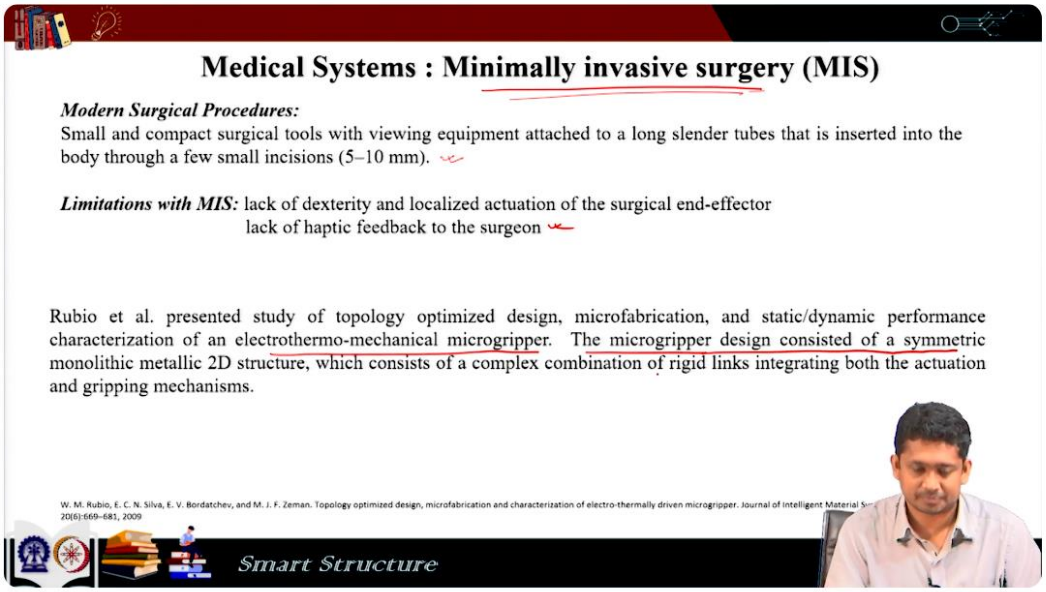

Minimally invasive surgery is quite popular now because of its several benefits less difficulty to the patients. Now small and compact surgical tools with viewing equipment attached to a long slender tube that is inserted into the body through a few small incisions about 5 to 10 millimeters are generally used for this. Now the limitations of these tools are lack of dexterity and localization actuation of the surgical end effectors and lack of haptic feedback to the surgeon. So, because of that Rubio and others they presented study of topology optimized design micro fabrication and static dynamic performance characterization of a electro thermo mechanical micro gripper. The micro gripper design micro gripper design consists of consisted of a symmetric monolithic metallic 2D structure. This consist of a complex combination of rigid links integrating both the actuation and gripping mechanisms.

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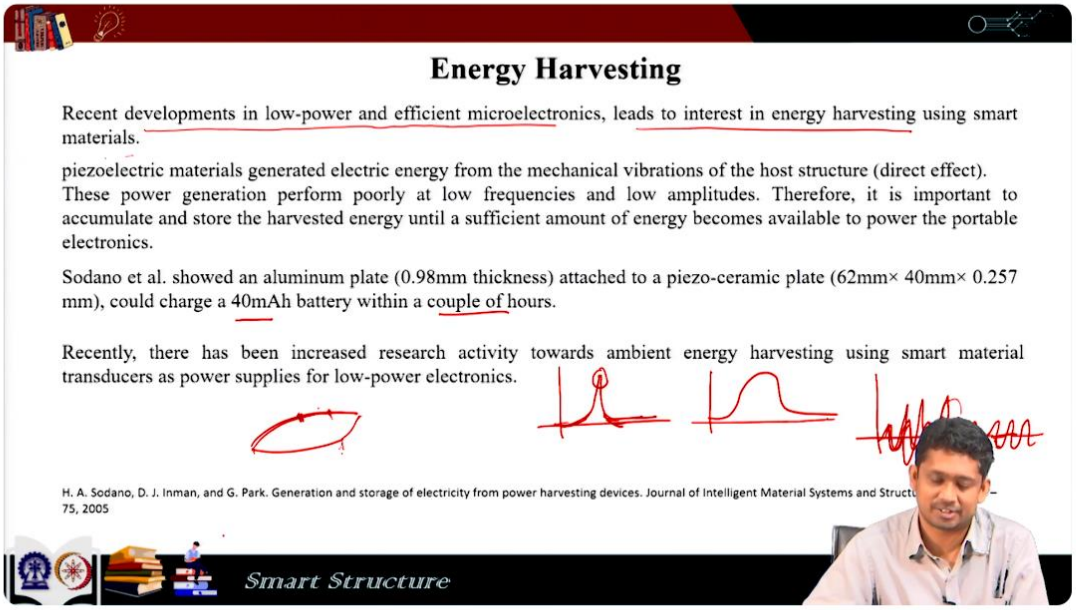

Now finally, we will talk about energy harvesting applications as was mentioned earlier that energy harvesting offers wants to offer some smart solution to power requirement, power requirement sensors and the electronic equipment's associated. Here the motivation is that recent developments in low power and efficient microelectronics leads to interest in energy harvesting using smart materials. So, piezoelectric materials using the direct effect the energy associated with mechanical vibration part of it can be harvested. Now there are several works in this area for example, Sodano and others they showed an aluminum plate attached to a piezoelectric piezoceramic plate could charge a 40 milli ampere hour battery within a couple of hours. Now when it comes to energy harvesting there are lot of observations for example, in linear systems the energy harvested is maximum when the frequency of oscillation when the frequency of oscillation is very close to the resonance frequency. So, the moment we are away from the resonance frequency the harvesting efficiency is quite low. So, that is why in a non-linear system we can do a more broadband energy harvesting. So, there are good amount of work in this area and there have also there has also been observation that in bi-stable systems the energy harvesting is even better. So, bi-stable systems can have small scale small vibration within one potential well I mean with respect to one stable configuration there can be large amplitude vibration with respect to one stable configuration and there can be large vibration where it shifts from one configuration to another configuration. So, when it does that even more energy can be harvested and in specially in aeroelastic systems if the system is prone to flutter, then instead of dissipating the extra energy it can be meaningfully harvested for some special purpose. So, as was said that a flutter is a growing oscillation. So, the system starts the structural system starts taking energy from the aerodynamic system.

So, instead of dissipating the energy by using properly designed energy harvester the energy can be absorbed. So, the extra energy can be absorbed with this stabilize the structure as well as the absorbed energy can be used for used can be useful for some meaningful purpose. So, the three are endless possibilities. Now with this several with these discussions on this several applications it is clear that with smart materials and smart structures the possibilities is endless, but at the core of it lies proper material modeling and proper analysis of the structures and that is what this course is about. So, now, we will gradually move into various piezoelectric materials from the from the next lecture we will start discussing about. So, with this discussion on these diverse applications we can see that there is endless possibility with smart materials and smart structures, but at the core of it lies proper material modeling and proper analysis. So, that is what this course is about. Now we will gradually move into various smart materials and smart structures from the next class we will start discussing about piezoelectric materials. Now, so, with this we finish this introduction. Thank you.