Vibration Control

Prof. Dr. S. P. Harsha
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Module - 7
Principles of Active Vibration Control
Lecture - 3
Piezoelectric Material-II: Applications

Hi, this is Dr. S P Harsha from Mechanical and Industrial Department IIT Roorkee, in the course of Vibration Control, now we are discussing about the Principles of Active Vibration Control. So, in last two lectures we mainly discussed about the basics of vibration control means how do we adopt the sensing feature, and how we coupled this sensing and actuator part, with the automatic control unit. And also you see we discussed about, the various part of the materials aspect through which we can coupled both the sensor and actuator right from the material itself.

So, you know like we discussed various parts like the shape memory alloys, the electro rheological or magneto rheological fluid, the electrostrictive fluids or even you see here the piezoelectric materials. So, in the last lecture we mainly discussed about the formation of the piezoelectric part, that how the piezoelectric you know like these crystals which has you see the crystalline features, can simply give the electrical output when the mechanical input is there or vice versa when the mechanical output is there how the electrical input can generate such kind of things.

Means we can have a clear strain feature, which can be you know like sensed or even we can have the electrical charged feature when the mechanical forces are there. So, we discussed you know like main right from the curie brothers in 1880 that how they you know like featured out this part, when you know like when they say that when any this crystalline material is being there, in the stress field. Then the voltages are being generated or when they are under the electric field, then the strain feature is being there within those materials.

So, based on their internal stiffness feature the actuation forces are being generated, and based on you see these, whatever the molecular motions. Whatever you see either we can say the silicon oxide or anything you see, the sensing features can be adopted using that. So, this piezoelectric material can be used directly as the sensor or the actuator according to the requirement, but one of the drawback of this piezoelectric material which was discussed that when the static force is there, then certainly you see here we cannot featured out this sensing part from this material.

And you see here, we discussed in the last lecture about the manmade or the naturally occurred piezoelectric part in the materials. And we found that, there are lots of drawbacks when we are really going in the actuator part, when we are using the naturally occurred material. So, one of the best use in the sensor and actuator part from the piezoelectric material is the PZT patch or the PZT material.

In which we have the lead, the zirconium and the titanium part and they you know like coupled feature is giving an excellent property, they are exhibiting excellent property which is being required for sensing and actuating application for active vibration controlled part. But, sometimes even you see here, the lead which is not you know like the environmentally compatible feature there is a clear demand that you see here the lead free kind of system should be adopted in these ceramics part.

So, you see here the sodium or the potassium based these materials are now being evolved, but still you see lots of things are being you know like requiring to be done in this particular part. But, still the PZT part is commercially used and still is being you know like in the use of in the application various applications are there, and we are using that. So, as far as the application part is concerned now in this lecture, we are going to discuss about the principles of active vibration control. And you see here in this particular piezoelectric material what the applications are there in that.

So, when we are talking about these piezoelectric material applications, we know that first thing is coming there are various application, and the first is the high voltage and the power sources. So, under this category the direct piezoelectricity of sub substance like the quartz or many other, can generate the potential difference of the thousands of volts even. So, we can say that even the high voltage part can also be adopted as per the applications, and the best known application is the electrically cigarette charger, the electrically cigarette lighter.

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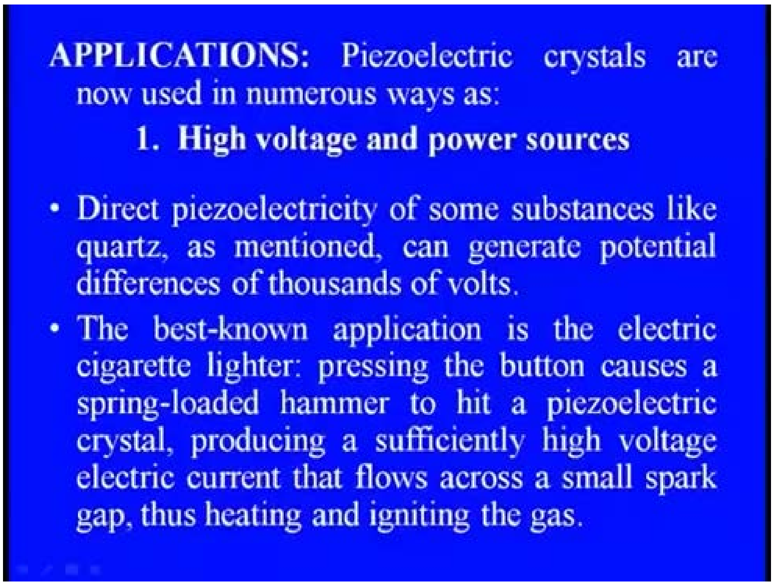

We are pressing the button it is causing the spring loaded hammering action, and when this hammer is hitting the piezoelectric crystal they are producing a sufficiently high voltage electric current, abruptly at that point. And which flows all across the small spark gap and because of this heating part the gas is being ignited, and we have the lightening feature. So, this is one of the basic principle in which you see here, the high voltage electric current is being generated, and that is being flowing to generate or to we can say ignite the gas by heating part.

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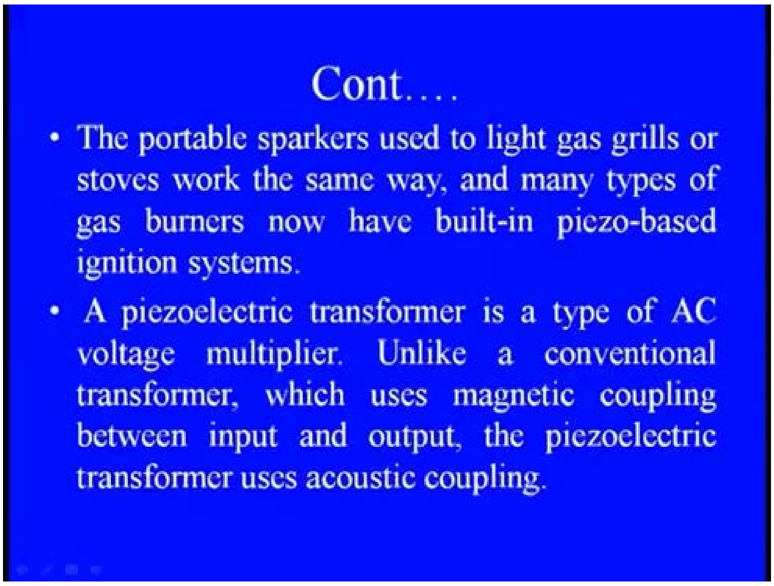

So, this piezoelectricity is directly coupled along with whatever you see you know like the elements are there. And that is being generating high voltage part there itself or even we can say that, a portable speakers which is used to light the gas grills or the stove working on the same way, and many types of these gas burners now is being built based on the piezo-based ignition systems and that is one of the unique feature of that. So, piezoelectric transformer is a type of AC voltage multiplier, so unlike a conventional transformer which uses magnetic coupling between the input and output this piezoelectric transformer uses the acoustic coupling.

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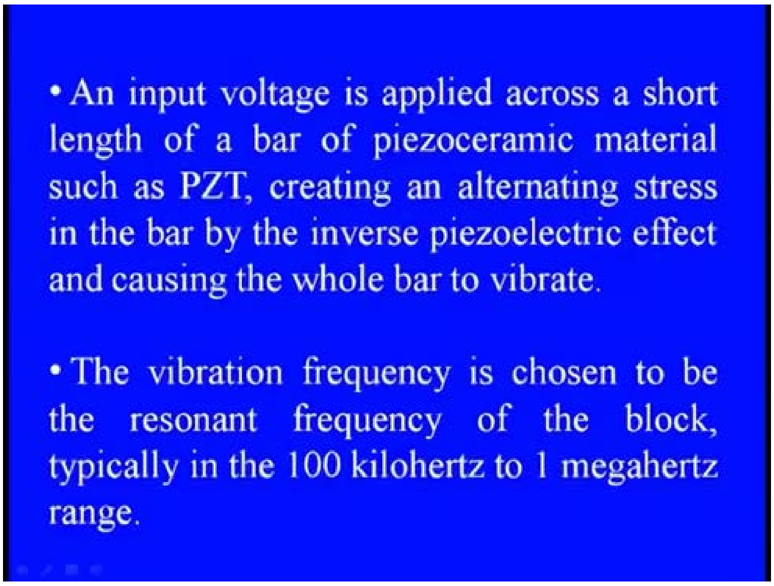

And an input voltage, which is being coupled across the short length of bar of piezoelectric material, like you know like the PZT, which we discussed, through that we can create an alternative stress in the bar by inversing the piezoelectric effect, and then we can you know like cause the whole bar to vibrate. So, this vibration frequency can be chosen to be resonant frequency of the block within you see right from the 100 kilohertz to 1 megahertz range even. So, this is what you see the huge vibration excitations can be there according to the input voltage there itself.

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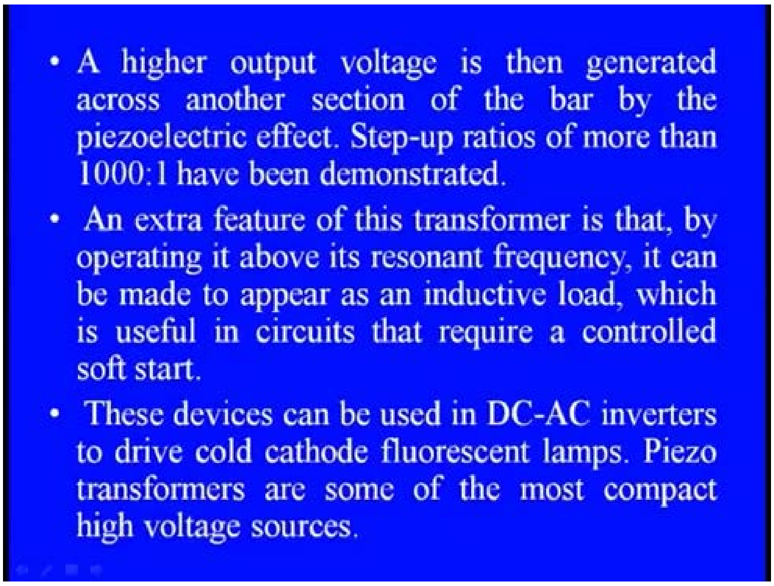

So, a higher output voltage can be generated all across the another section of the bar just using the piezoelectric effect. And this step up ratio which is of more than 1000 is to 1 can be straightly demonstrated using this, and an extra feature of this transformer is that by operating it above the resonant frequency it can be even made up to appear as an inductive load, which is useful in circuit that require a controlled soft shaft starting part. So, these devices can be used in DC-AC inverters to drive the cold cathode fluorescent lamps.

So, this is again you see one of the important specific use of this, and these piezo transformers are some of the most compact high voltage sources. And nowadays they have lots of good applications in these because these you know like the transformers or straightaway we can say that are just a AC voltage multiplier. So, this is one of the important application of these piezoelectric part, the piezoelectric materials just to generate the high voltage or the high level of power sources right from the electric lighter to even we have seen that the generators or the transformers.

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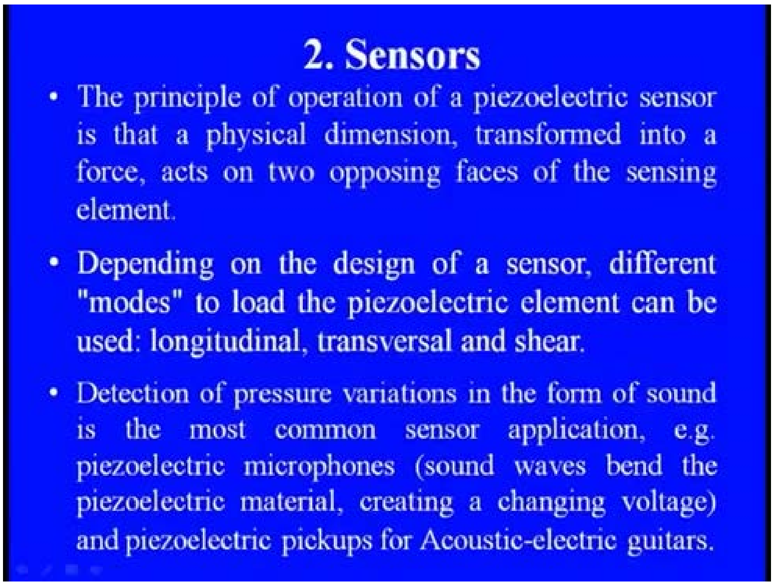

Second as we discussed from the vibration point of view is the sensor, and the principle of operation of the piezoelectric sensor is simply that the physical dimension is transformed into the force, and can act the two opposing faces of the sensing elements. And depending on the design of sensor, the different modes to load the piezoelectric element can be used, as we discussed there were three different modes, the longitudinal, the transverse, and the shear.

And whenever we are just going with the sensing elements part specially, then the transverse feature or transverse mode gives a proper feature of this sensing element. So, detection of the pressure variation in form of the sound is the most common sensor applications, like we are using the piezoelectric microphones. In which the sound waves bend, the piezoelectric material and creating the changing voltage this is what the applications. Because, we know that the sound waves have a sufficient power and through that, we can simply deform or we can provide the mechanical strain part, through that you see the voltage can be generated. And piezoelectric pickups for acoustic electric guitars have a excellent applications towards that.

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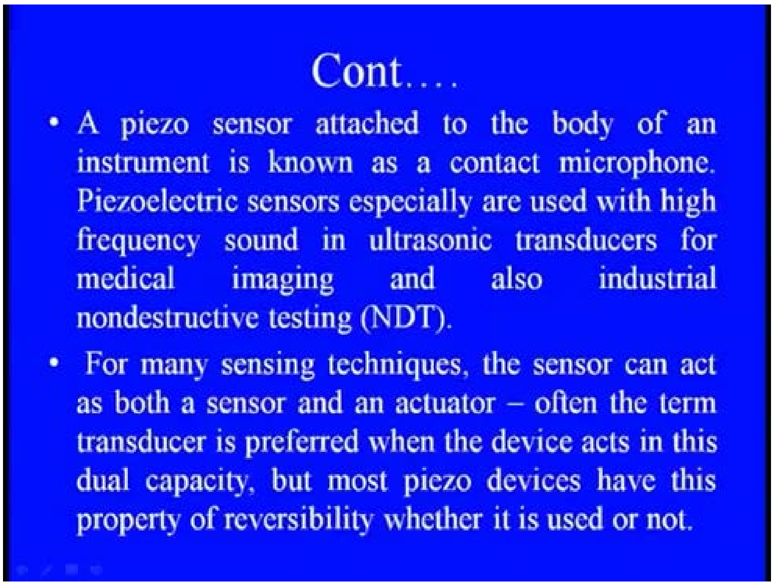

So, when we are talking about the piezo sensor which is to be attached to the body of the instrument on this particular guitar part is known as the contact microphone. And this piezoelectric sensor especially which is being used for high frequency sound, in ultrasonic transducers for medical imaging or even for industrial, we can say this nondestructive testing NDT part has a greater applications towards that.

So, when we are talking about the sensing techniques, the sensor can be act both as a sensor, and actuator feature often termed as a transducers which is preferred when the devices you know like acts in this dual capacity. But, most piezo devices have this property of reversibility whether we are using as a sensor or actuator in the reverse phenomena or not.

So, when we are talking about the ultrasonic transducers which can inject you see, the ultrasonic waves into body receive the returned wave, and convert it into the electrical signals just like the voltage part. So, most of the medical ultrasound transducers are of piezoelectric based only because it has a great applications when such actions are being required under the ultrasonic transducers.

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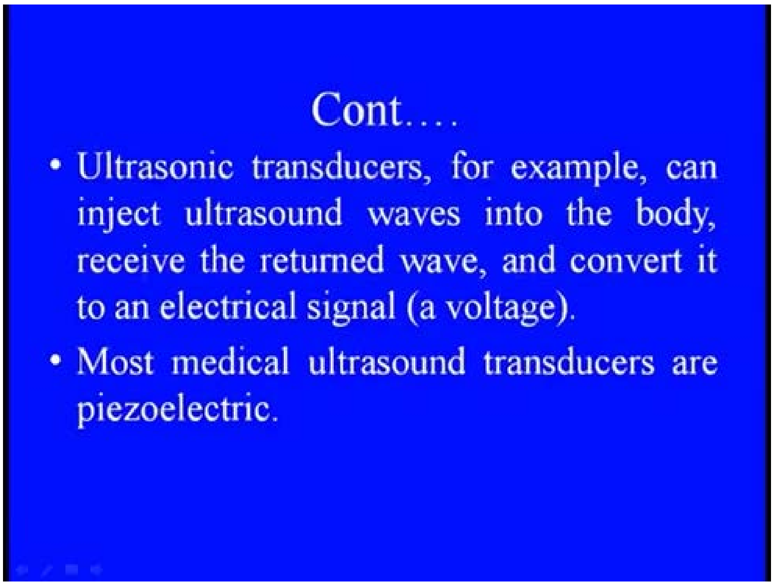

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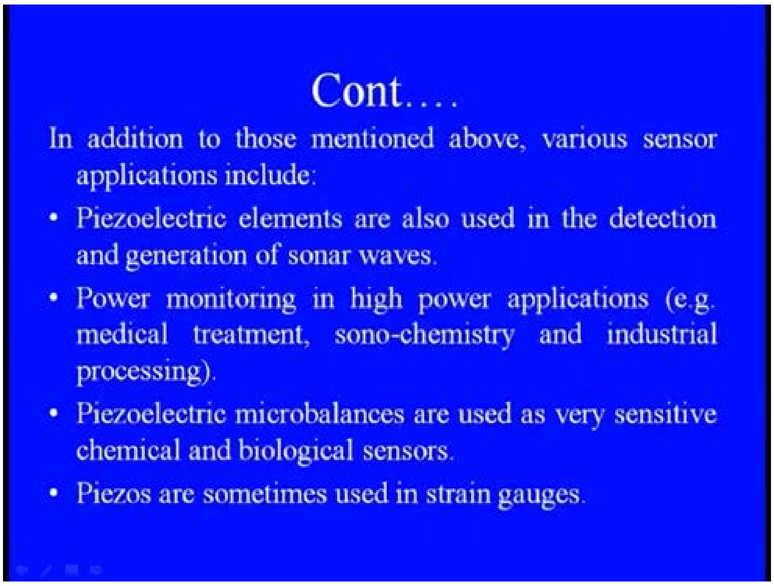

So, in addition to these mentioned the various sensor application can also be there like the piezoelectric elements are just using in detection, and generation of the sonar waves. The power monitoring in a high power applications like you see, the medical treatment or you see the sonochemistry or industrial processing features, these are the clear applications of these piezoelectric sensors, the piezoelectric microbalances, which are just used as very sensitive chemical and biological sensors. And even the piezo's are sometimes used as the strain gauges, where a clear you know like we can say the deformation measurement can be there in that even the micron level.

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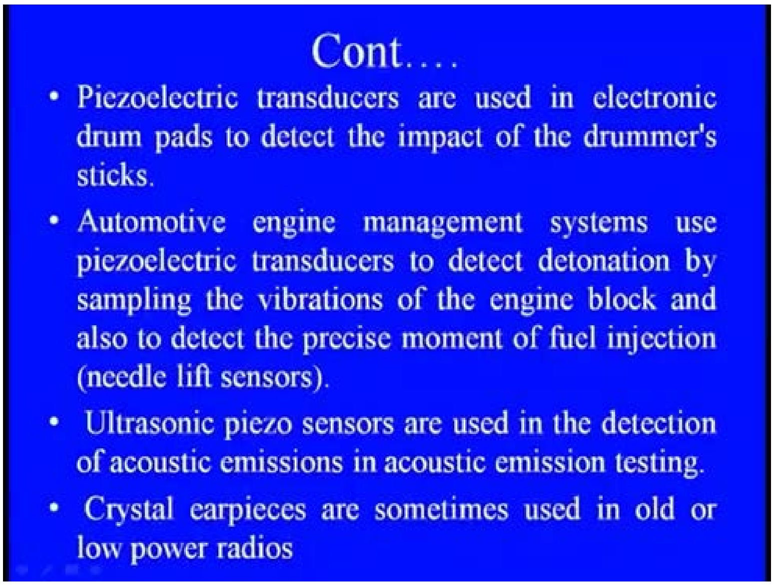

So, these transducers the piezoelectric transducers are used in electronic drum pads to detect the impact of drummer's sticks. The automobile engine which has you see here a clear you know like use of piezoelectric transducers, to detect the detonation by sampling, the vibrations of the entire engine block. And also detect the precise moment of fuel injection, which has a clear needle lift sensors are there.

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And even we can say that, the ultrasonic piezo sensors are used in detection of acoustic emission in the acoustic emission testing where it is required for the IC engine part. And the crystal ear pieces are sometimes used in we can say, old or low power radios where you see we just want to see that what exactly the impacts are there under the ear pieces.

So, as you can see that the piezoelectric disc which is you know like straightaway applied there, and you see here it can be act as you can say you know like whatever the sensing features are being coming out as an sound. And that is that is immediately you know like the pickup part is there under the guitar pick up.

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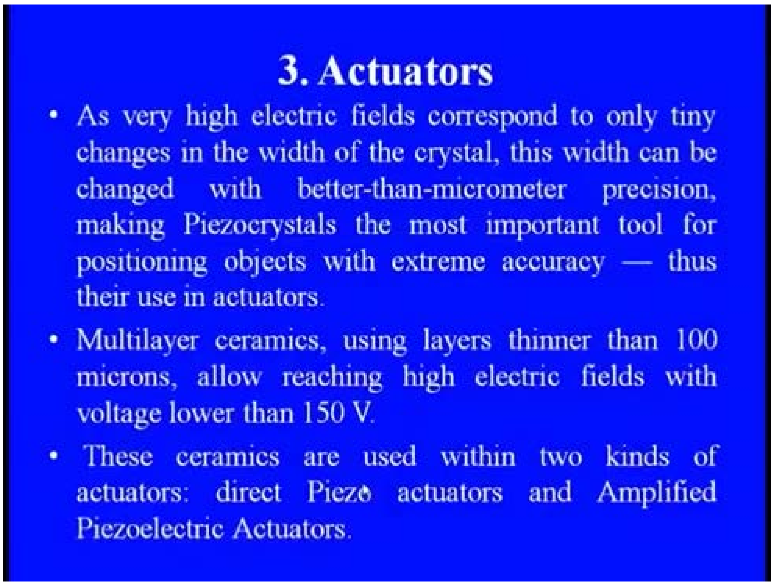

So, this is you see one of the best part of the piezoelectric material is these sensing feature, the sensing application. But, also you see here as we know that this man-made piezoelectric part can also be used as the actuator, so as very high electric fields corresponding to only a tiny changes in the width of the crystal. And this width can be changed with the better we can say you know like in the better than the micro meter precision, making piezo crystal most important tool for positioning object with the extreme accuracy, and thus we can use this as the actuators in that.

So, when we are talking about the ceramics there are you know like various layers are there in the ceramics. And using these layers thinner than the 100 microns which allow you see reaching them the higher electrical fields, even more than we can say you know like the voltage of 150 volt. The ceramics are used clearly for you know like exciting the features right from whatever the within the ceramics part right from you know like when these intermolecular features are there. So, these ceramics are used within the two kinds of actuators we can say, a direct piezo actuator or we can say the amplified piezoelectric actuators. So, you know like in these two types a different actions are being there, and we can use straightaway as a actuator of this ceramics part.

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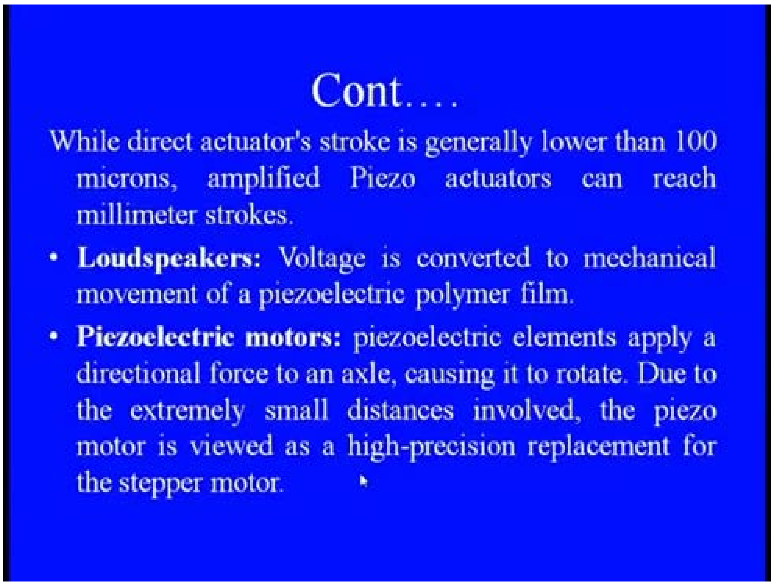

So, while we are talking about the direct actuators, the stroke is generally lowered than the 100 microns. And amplified to the piezo we can say it just going towards the amplified piezo actuators can reach to the millimeter stroke in the actuation part just like you see the loudspeakers. But, the voltage is converted to the mechanical movement of piezoelectric polymer film, the piezoelectric motors in which the piezoelectric element is being applied to a directional force to an axle which is causing to rotate.

So, due to this extremely you know like small disturbances being involved at the microns levels of these piezo motor, we can viewed this a high precision replacement for a stepper motor. Because, you see here you know like at the molecular level all these small disturbances are being occurred in the piezoelectric motors, and we can straightaway use in at the you know like micro level precised motion there.

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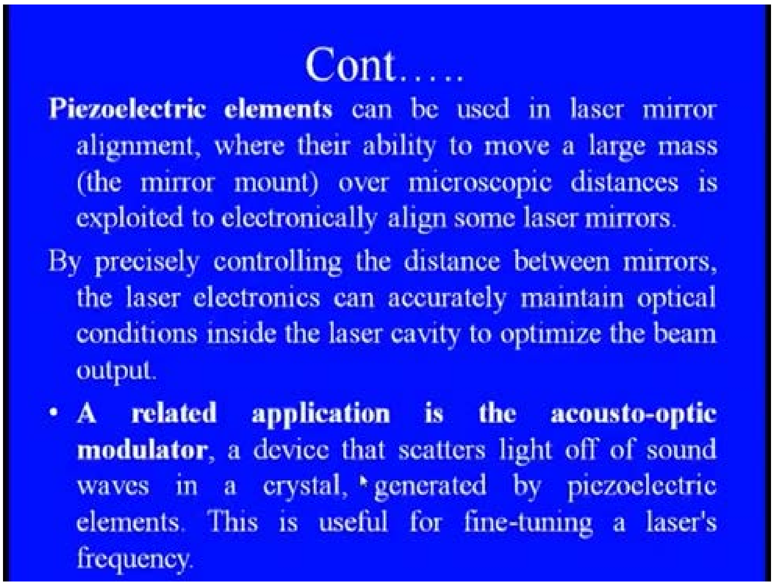

The piezo electric element can be used in the laser mirror alignment because we know that wherever you see you know like the laser mirrors are there for proper alignment these piezoelectric element. Because, they have the ability to move a larger mass the mirror mount you see here or microscopic distances, and that can be exploited to electronically aligned some of the laser mirrors. And by precisely controlling the distance between the mirrors, and the laser electronic can accurately maintain the optical condition inside the laser cavity to optimize the beam output.

So, this is one of the specific we can say application of the piezoelectric element, as a actuator to just you know like put a proper balance or you know like just give a clear mirror balancing part, in this part where the laser mirrors are being there to align the things. A related application can also be adopted in the acousto-optic modulator, in which you see a device that is scattered a light of the sound waves in the crystal can be generated by the piezoelectric element, and this is useful for fine tuning a laser frequencies.

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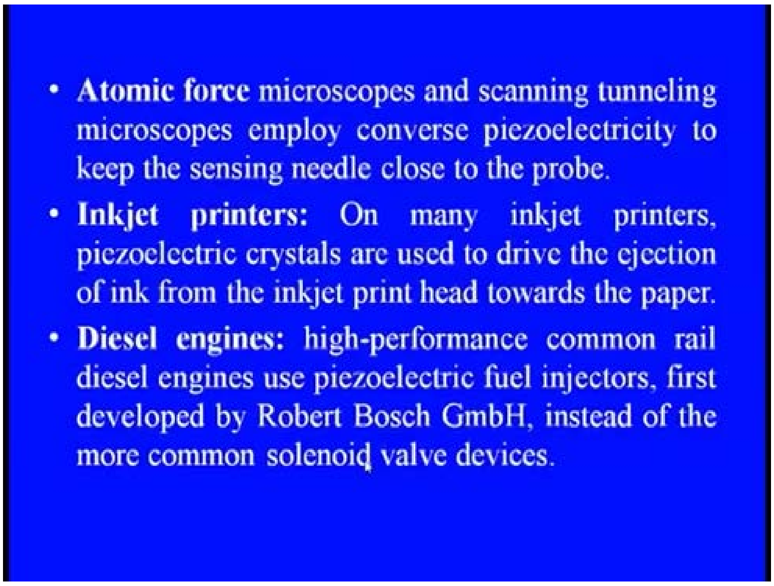

Even we can see in our atomic force microscopic or any scanning tunneling microscopes can straightaway employ to converse the piezoelectricity to keep the sensing needle close to the probe for that. And even the inkjet printers in which the piezoelectric crystals are just used to drive the ejection of the ink inject print head towards the paper, even the in the mechanical devices. The diesel engine the high performance common real diesel engines are just using the piezoelectric fuel injectors. And they are straightaway using instead of this solenoid valve devices, they have a clear actuation features as per the requirement these fuel injectors are being adopted. And they are absolutely based on this piezoelectric part.

So, active control of vibration using this amplified actuators can be straightaway used in these way, the X-ray shutters. And you can see that you see the metal disc with the piezoelectric disc attached is used as the buzzer part, as you can see on the screen.

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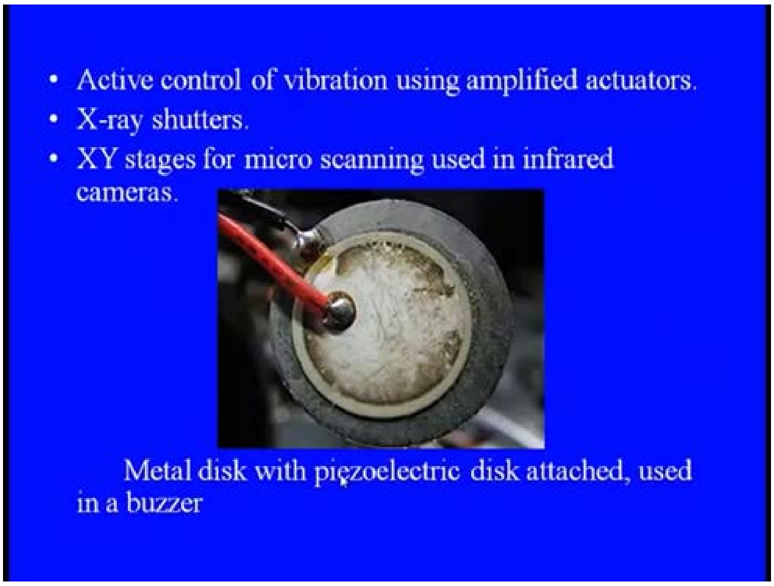

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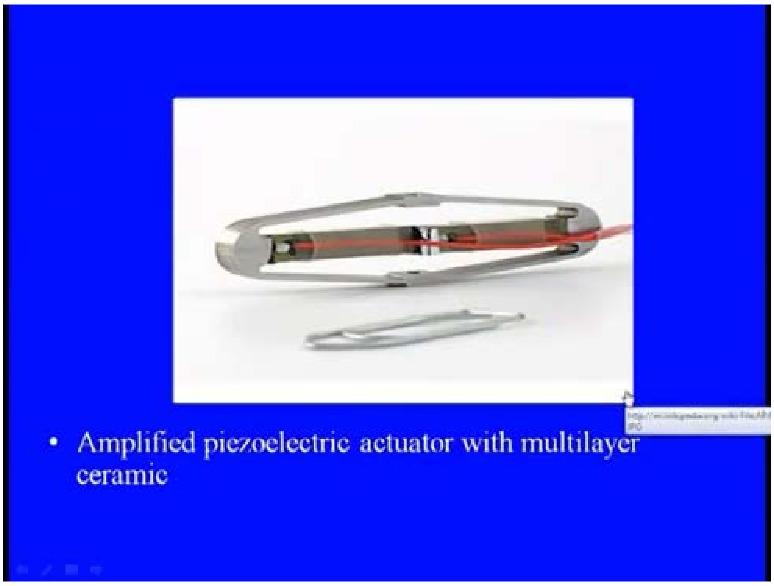

And even you see here, the amplified piezoelectric actuator with the multilayer ceramics is being there. And you see these ceramics can be you know like applied to many of the applications, where it is being required.

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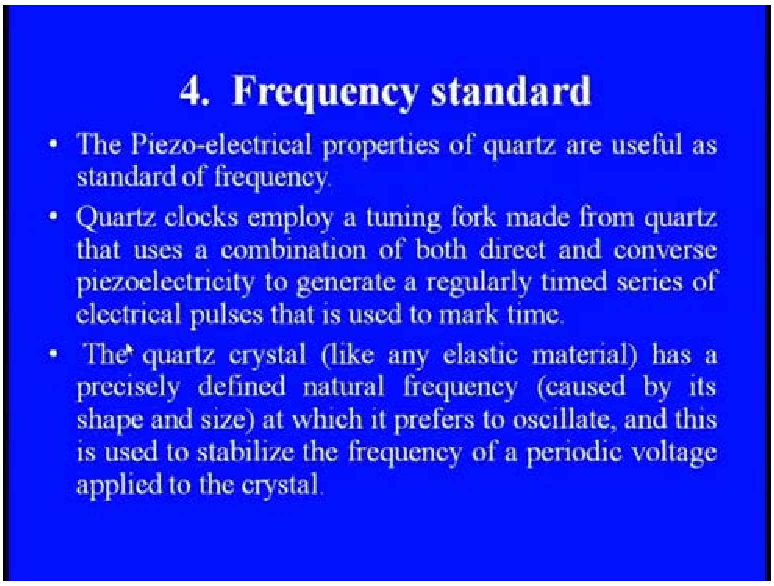

Another application part from this piezoelectric material the smart material is the frequency standard. Because, we know that the piezoelectric properties of the quartz or any material is useful to standardize the frequencies, and the these quartz clocks which employ this tuning fork can be made from you like the quartz, as the combination of the both the direct and converse piezoelectricity to generate.

The regularly timed series of the electric pulse that can be used to mark according to the time of this quartz clocks or we can say even the crystal quartz, which is we can say you know like one of the elastic material. Has precisely defined the natural frequency according to it is shape and size you see here, at which we know that the oscillation is being happened that can be even used to stabilize the frequency of the periodic voltage, when it is being applied to such kind of crystals. So, when we are talking about the frequency standard, we need to check it out that what exactly the properties of the piezoelectric parts is really you know like just to be useful to standardize the frequency.

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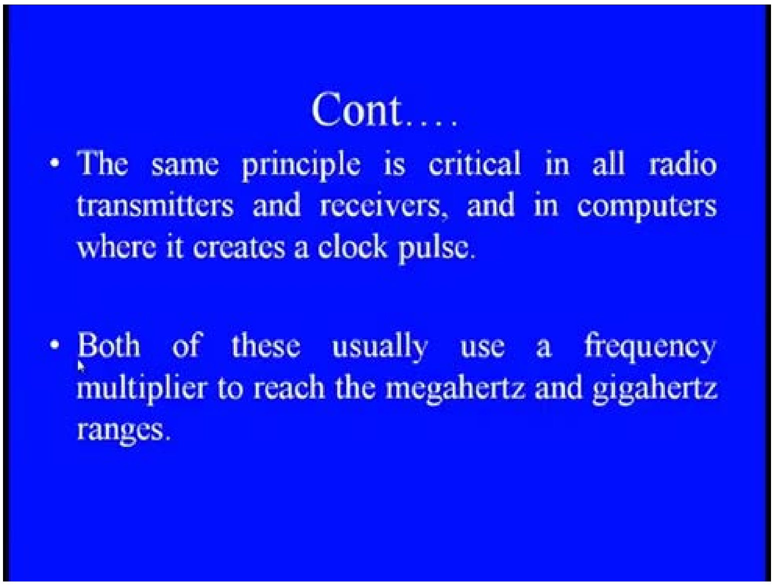

So, the same principle is critical in all the radio transmitted, whatever you see the radio transmission features are there in the receiver, in computers wherever you see it creates the clock pulse. So, both of these usually use the frequency multiplier to reach the megahertz and gigahertz range of frequencies, which is to be you know like standardized according to the exciting part.

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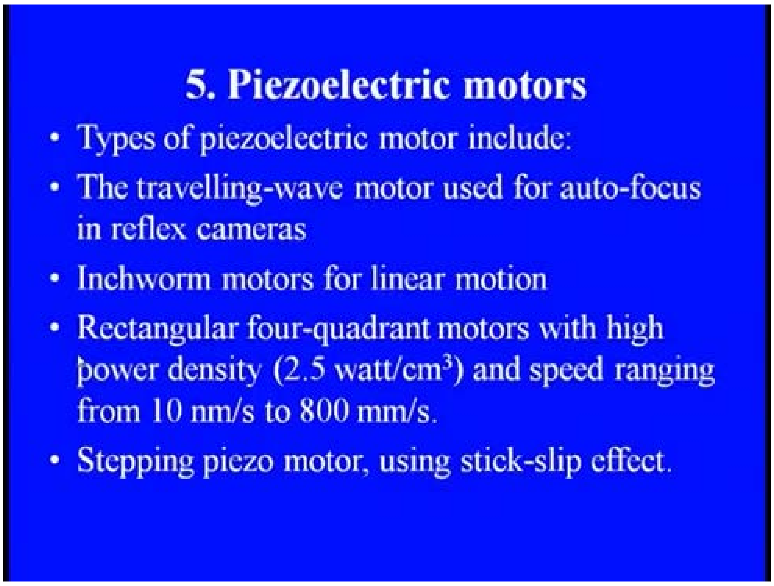

And then we have the piezoelectric motors, these type of piezoelectric motors is just you know like showing that you see how the actuations are there. And wherever we require the actions from the motor, these piezoelectric based motors are just giving like the travelling wave motor used for auto focus in reflexes cameras. There you see we cannot even adopt the actual motors, the piezoelectric featured motor are straightaway used for the auto focus part.

Even the inchworm motors is being straightaway used piezoelectric motor for their linear actuation or the motoring actions, the rectangular four quadrant motors with high power density means if we are requiring you see even up to 2.5 watt per centimeter cube power requirement. And the speed which is ranging from 10 nanometer per second to 800 millimeter per second, these you know like the quadrant motors can be straightaway used these piezoelectric motors.

And this stepping piezo motor which is used for you know like the stick slip effect is always being you know like based on this piezo motors. So, what I mean to say that the various types of motors, which are being available and the applications if we are just going to for higher speed ranging or you know like high power density or for any kind of stepping part or even for you know like the linear motions inside, you see the cameras or wherever you know like the requirement is there it is clear application of these motors are…

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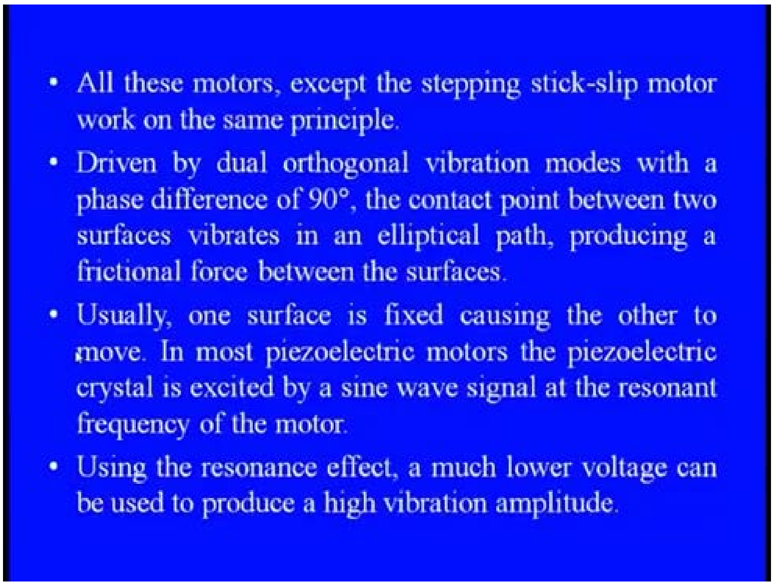

And all these motors just based on the same principle as our piezo features, which is been driven by the dual orthogonal vibration modes with a phase difference of 90 degree.

And the contact between the two surfaces, are simply vibrate in an a elliptical path according to feature you see here, which can produce the frictional force between these surfaces. And we know that, one surface is fixed causing the other to move, and in this piezoelectric feature, the piezoelectric motor is just you know like we can say excites the piezoelectric crystal.

And then by a sine wave is generated at the resonant frequency of the motor, and using this resonantial feature a much lower voltage can be used to produce a high vibration amplitude. So, that is one of the beauty of the system because in that you see here we are using the orthogonal vibrational mode, in the multi degree of freedom system. So, when we are talking about the orthogonal feature in the vibration mode, we know that there is a clear phase differences are there, at these two contact points vibrating surfaces.

And because of that we can generate the elliptical path in between these two, you know like the surfaces at the frictional forces. And because of that we can say that whenever the resonant frequencies are there of the motor, even we have a lower voltage through which these entire thing the dual orthogonal vibration modes are being there is really generating the high vibration amplitudes.

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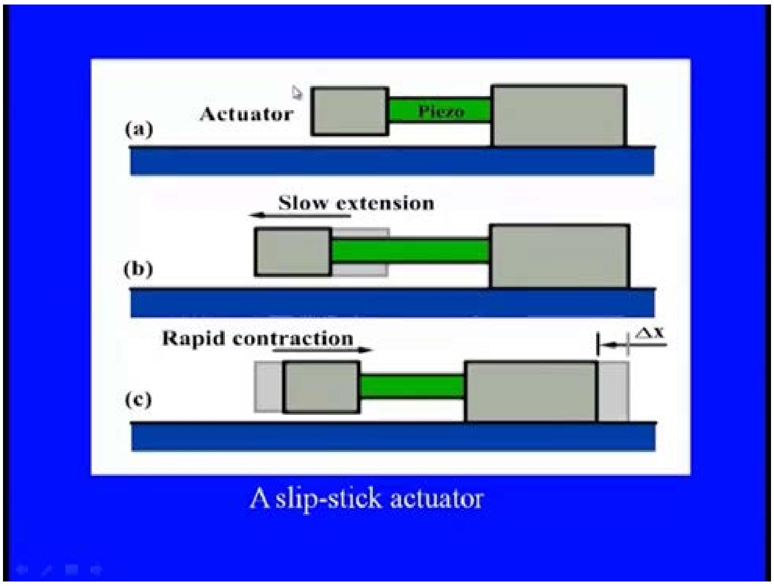

So, you can see this is one of the beauty of this you know like the slip stick we can say actuator, this is what it is there you see here we have the piezo feature here and these you know like the this sticky part is being there. So, when we have a slow excitations this piezo is clearly creating you see you know like the change in that even whatever we can say a small voltages are there.

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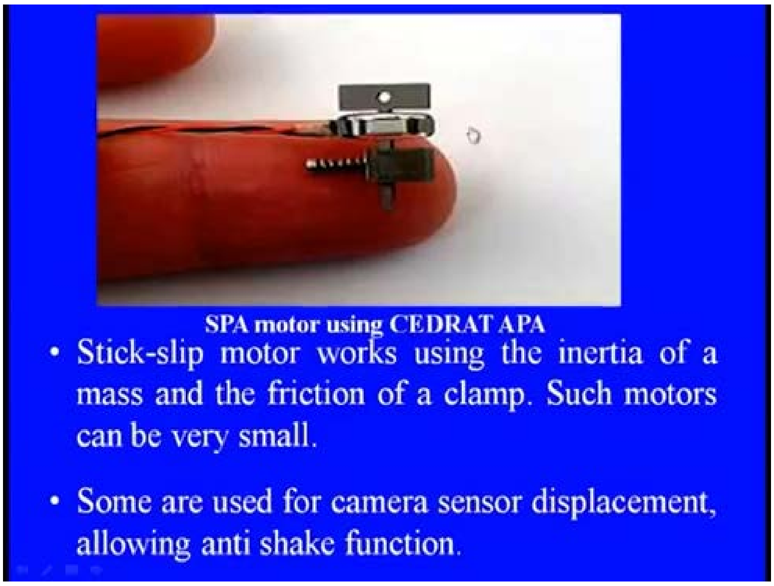

And this rapid contraction the slow extension rapid contraction is clearly featured, the high vibration excitations even at the low voltage side or even we can see that this is what you see the actual motor part, it is where you see you know like just the in a small micron size. And this stick slip motor is absolutely works on the using the inertia of the mass, and the friction of the clamp.

So, that is why you can see that they are absolutely small which through which we can generate the high vibration amplitude. And some are used for camera sensor displacement which are just you know like putting a anti shake functions, so now, a day's whenever you see you know like we are buying the camera, the anti-shake you know like the functions is being there within the inbuilt part is absolutely coming through this stick slip motors, which is based on the piezoelectric materials. So, we know that you see even with this is particular small part, this SPA motor we can clearly you know like put, the anti-shake function in the cameras.

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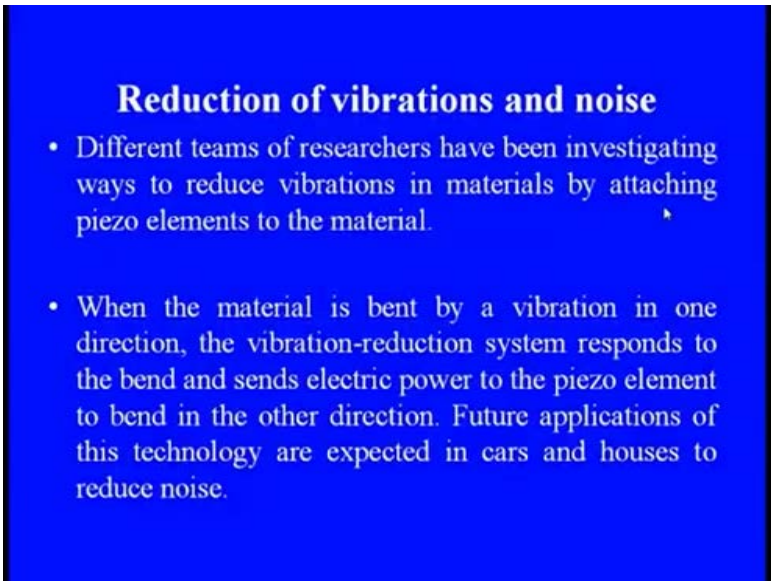

So, especially when we are talking about the piezoelectric application in the reduction of vibration and noise, the various researcher investigated, the various ways to reduce the vibration in the material by attaching the piezo elements towards the material part. And when the material is bent by the vibration in one direction, the vibration reduction system respond to bend, and send the electric power to the piezo element.

And this technology can be you know like expected, just that you see here that whenever we are just standing these you know like whatever the electric power part through this piezo element is to be you know like used to bend in other directions as well. So, what does it means that you see here, whenever we are just trying to reduce or we just want to divert, the whatever the propagation path towards the propagation path of these you know like the waves, the sound waves or the vibration phenomena this is one of the specific use. Because, we know that when the material is bent by this vibration in one direction, it can be respond to bent, and even sends the electric power towards the piezo element to needs to bent in other direction. So, you see there is a clear variation there, and we are using this concept in cars and houses to reduce the noise part.

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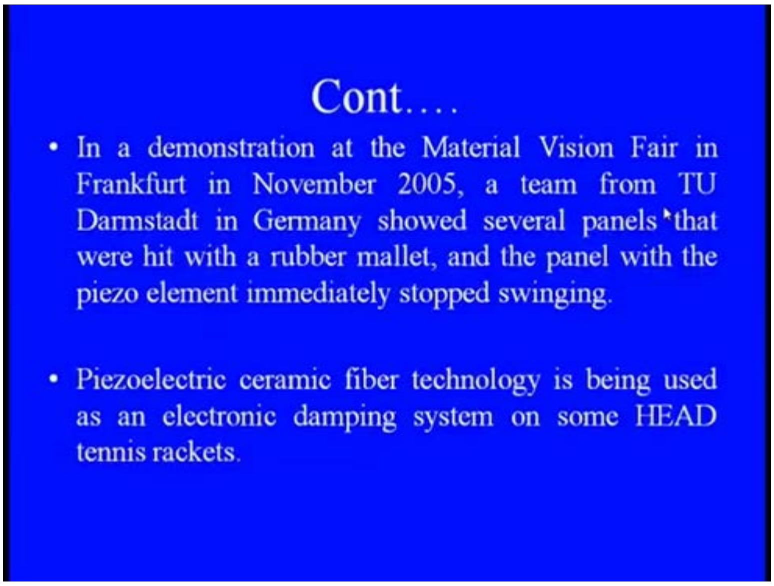

So, you see here you know like in somewhere in 2005 in the Frankfurt, in the laboratory of this material vision part at the Darmstadt the TU university, they shows various panels through which there is a clear hitting in the vibration part. Means through the vibration part on the rubber mallet and the panel with the piezo element is immediately stopping all the swing feature there itself.

So, these piezo electric ceramics fiber which are just being used there you know like as an electronic damping system, on some head tennis racket we can see that there is a effective control on the swimming feature using this piezo element part. So, when we are talking about you see the vibration control, the first thing is coming the measurement of that, and these the sensing part particular and these sensing feature straightaway there based on the piezoelectric accelerometer.

So, this piezoelectric accelerometer is utilizes the piezoelectric effect of the certain material to measure, the dynamic changes in their mechanical variables like the acceleration or the vibration magnitude or the mechanical shocking. So, as with the all the transducer, the piezoelectric accelerometer convert one form of energy into another and provide an electric signal in respond to a quantity, property or the condition that is being measured based on you see what kind of you know like the dynamic actions are.

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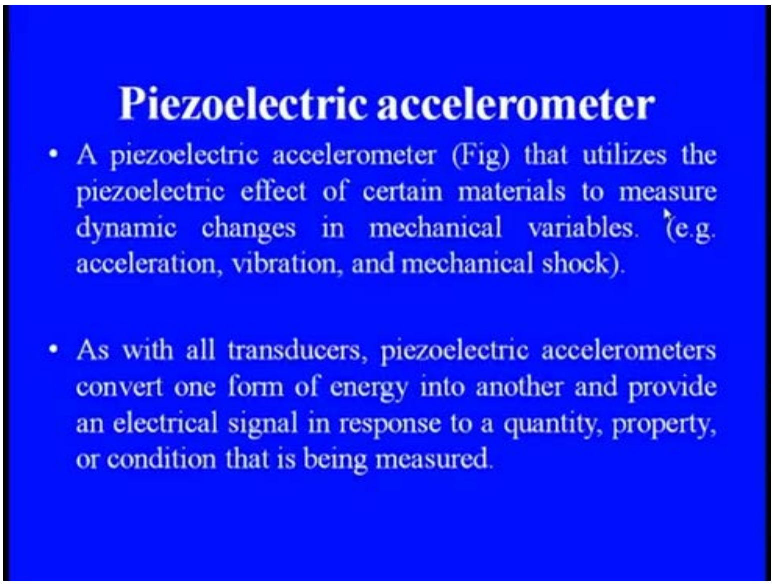

So, these piezoelectric accelerometers can straight away provide not only you see, you know like the magnitude in one direction. But, even bi or tri directions as well means in all three directions we can get the proportion of the acceleration at the same point.

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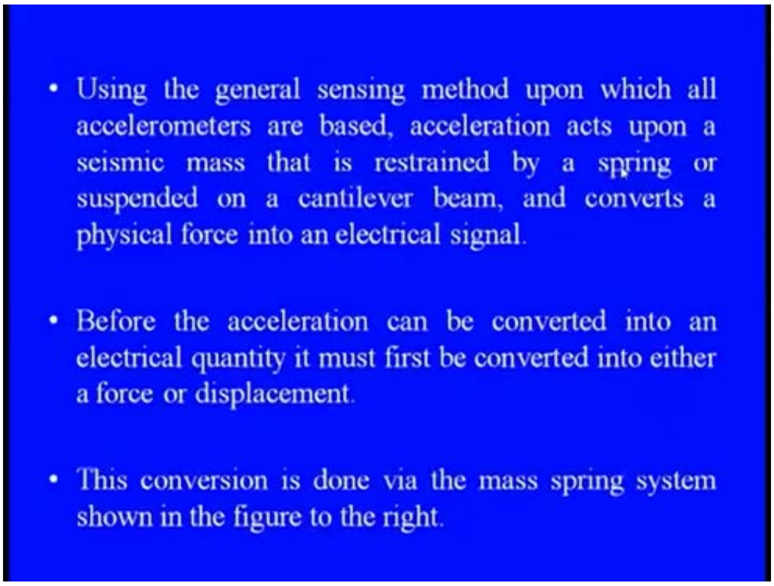

So, using the general sensing method upon which all the accelerometers are based, the acceleration acts upon the seismic mass that is being restrained by a spring or we can say suspended on the cantilever beam, and that converts the physical force into electrical signal. So, before the acceleration can be converted into the electric quantity, it must first be converted into either the force or the displacement part.

So; that means, you see here whatever the acceleration feature is there under the you know like we can say the movement of or the dynamic movement of this mass, first it has to convert into the force or the displacement part. And this conversion is done by the mass spring system, as we can simply show there.

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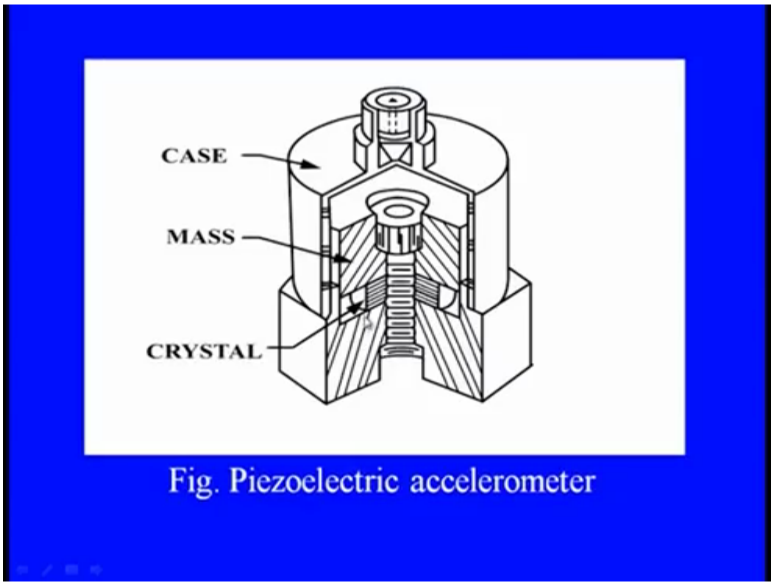

So, when it is being converted there you see this is what it is we have a piezoelectric accelerometer, in which the crystal feature is there in this way, this is what my crystal feature, this is the added mass is and there this is what my casing part. So, when we are saying that we are trying to know measure the acceleration, so first this acceleration has to converted into the electric quantity, and before that you see here first the force or displacement has to be coming out.

So, you see here when we have seen this mass this is basically you know like putting this acceleration into we can say force as the inertia force, rather we can say or the displacement part. And the piezoelectric these accelerometers, then you see just giving whatever the outcome is there in terms of the electric features, whatever the voltage changes.

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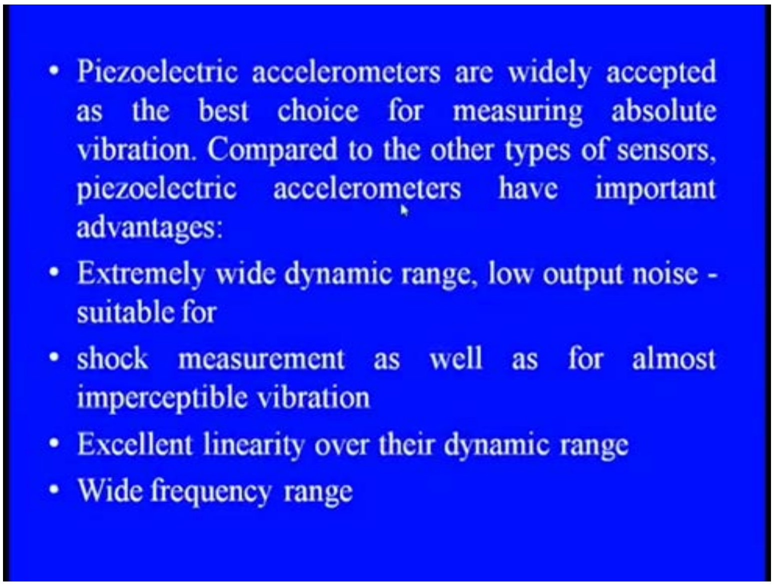

So, these accelerometers are widely accepted as the best choice for measuring an absolute vibration, in terms of the acceleration. Because, we know that the acceleration is not only depending on the amplitude, but also it is depending on the frequency features, how many number of times the repetitions are there. So, the compared to other types of sensors, the piezoelectric accelerations have the great advantage.

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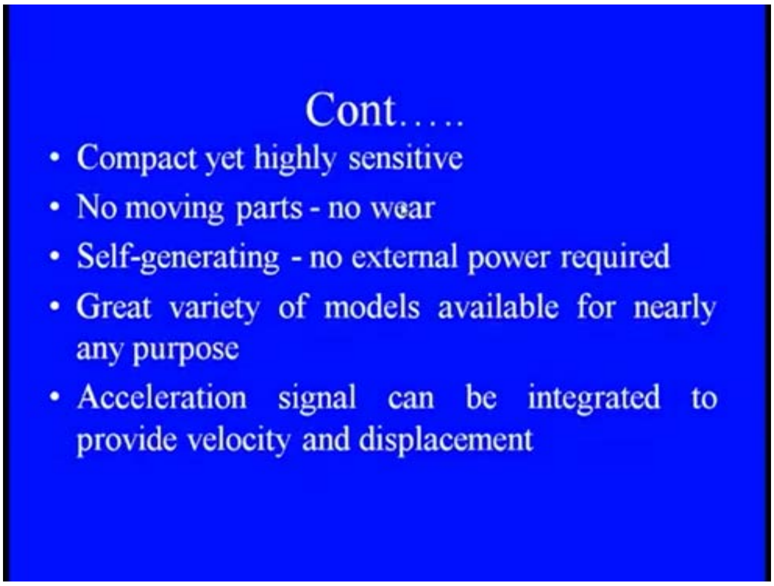

Because, we can apply for the wide range of dynamic range means for the low frequency, high frequency, low output noise or whatever you see you know like the high output features are there for the shock measurement. As well as for all type of you see the imperceptible vibrations, excellent linearity you know like in measurement over the various huge dynamic range, the wide frequency range can be straightaway measured.

It is especially you see you know like compact even, you can find a small part for even you know like the higher frequency range with the high sensitivity. And we know that since, all the robustness is there in that manufacturing part, so there is no moving part there is no wear and tear. And everything is self-generating, so no external power source is required for that, and since the great variety of models are available. So, you see here we can straightaway use based on their linearity property, an acceleration signal can be integrated to provide the velocity or displacement. So, that is why you see here, the acceleration feature is one of the significant feature to measure the vibrations.

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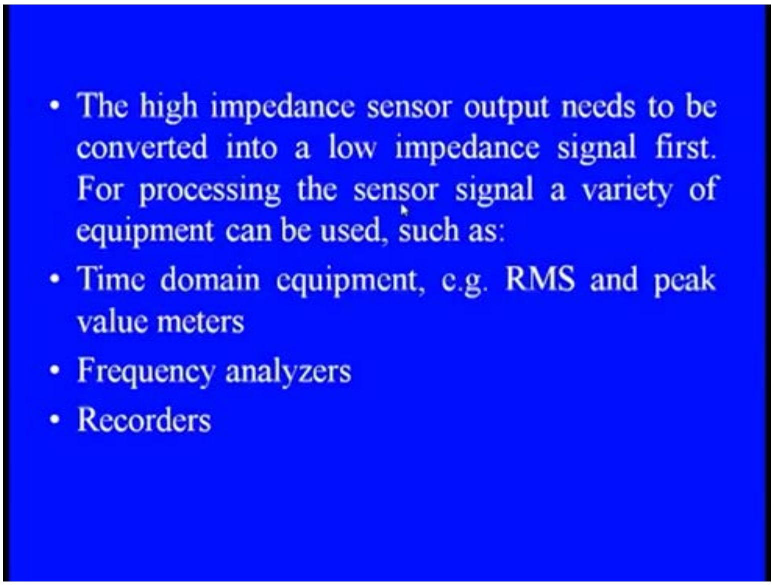

The high impedance sensor output needs to be converted to the low impedance signal first, and for processing the sensor signal to a variety of the equipment that can be even used in the time domain equipment. Where you see the root p square or the peak amplitudes are meters are being there, the frequency analysis straightaway we can convert this acceleration. And then we can straightaway analyze the frequency the exciting frequency with the amplitude, and the recorders also can be used straightaway.

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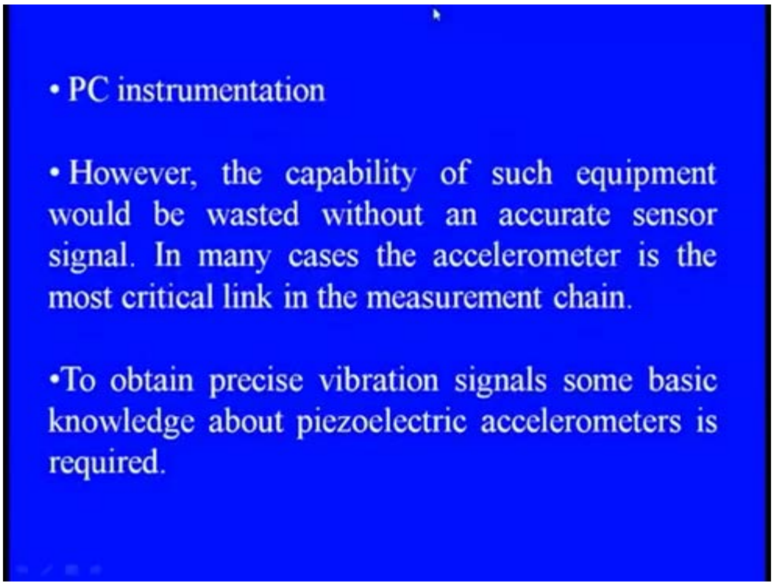

Even in the PC instrumentation, even for the capability of these equipment would be even wasted without an accurate sensing signal. And in many cases the accelerometer is the most critical link between the measurement chain, and to obtain the précised vibration signal. The vibration accelerometers are absolutely even from the weight side that you see you know like even the less weight, the less weight accelerometer piezoelectric accelerometers are there or even you see here. Whenever we are going for an higher operating range with the sophisticated sensitive part, these piezoelectric accelerometers are well available in the market.

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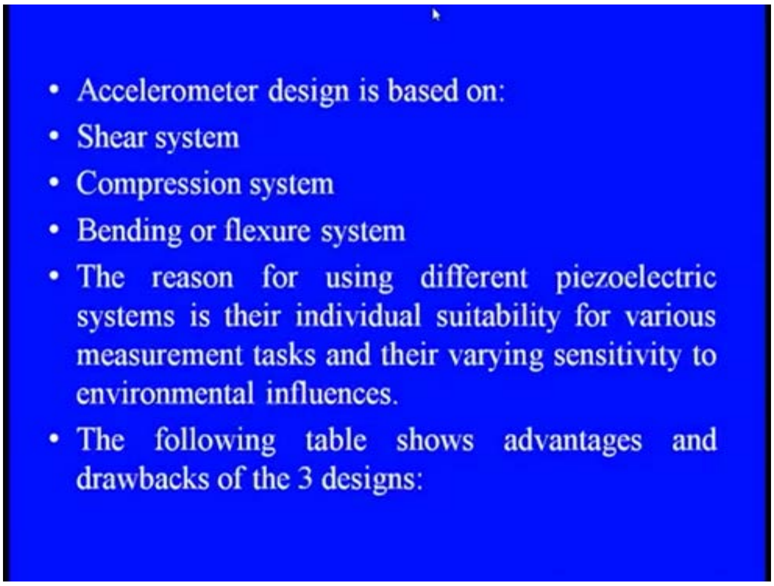

So, when we are talking about this accelerometers the design of the accelerometer is absolutely based on the various features, like it is based on the sharing system, whether the mode is here or the mode is compression or the mode is bending or the flexure one. So, the reason for using the different piezoelectric system is the individual suitability for various measurements tasks, and their varying sensitivity to the environmental influences. So, we can say that there are you see you know like drawbacks or the advantage of such systems.

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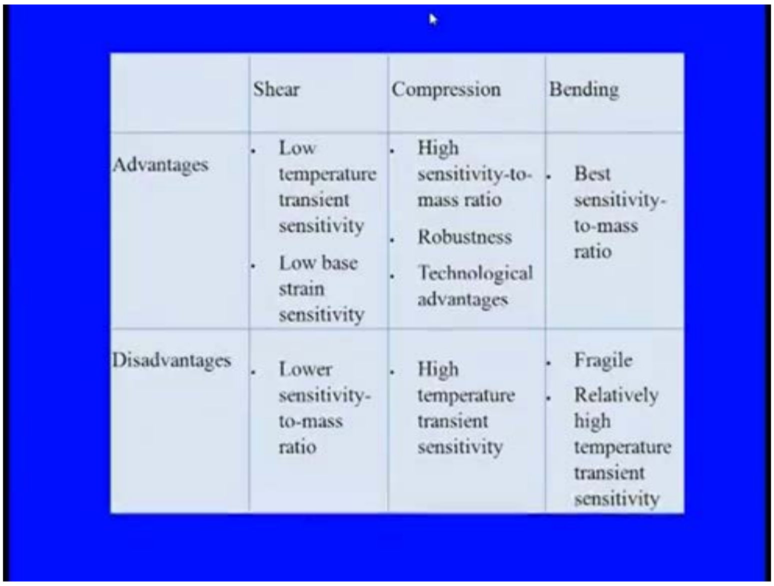

	Shear	Compression	Bending
Advantages	• Low temperature transient sensitivity • Low base strain sensitivity	• High sensitivity-to-mass ratio • Robustness • Technological advantages	• Best sensitivity-to-mass ratio
Disadvantages	• Lower sensitivity-to-mass ratio	• High temperature transient sensitivity	• Fragile • Relatively high temperature transient sensitivity

So, when we are using the three different systems like the shear or compression or bending or flexure we can say, the advantage is when we are using the shear feature. The shear system we can say, the low temperature transient sensitivity, and even it has the low base strain sensitivity together. But, that the disadvantage is it has a lower sensitivity to the mass ratio, whatever the you know like the added and the vibration mass ratio.

And if we are using the compression system, the advantage is it is very sensitive to the mass ratio, which is drawback of the shear system is even it has good robustness in the design part, and great technological advantage from this feature. But, the main problem comes when we are using the compression feature, compression system in this piezoelectric accelerometer is the high temperature you know like we can say the transient sensitivity. So, whenever we have you see the transient nature due to the temperature variation, the inaccuracies are coming in the measurements.

And when we are going towards the flexure or the bending system in this you know like accelerometer, it is always best suited for the mass ratio sensitivity. But, again you see the various drawbacks are there in that as it is very fragile in it is nature, it is relatively high temperature transient temperature sensitivity. So, you see here with this concept certainly we would like to find out that what is the you know like the applications and where do we just want to apply that.

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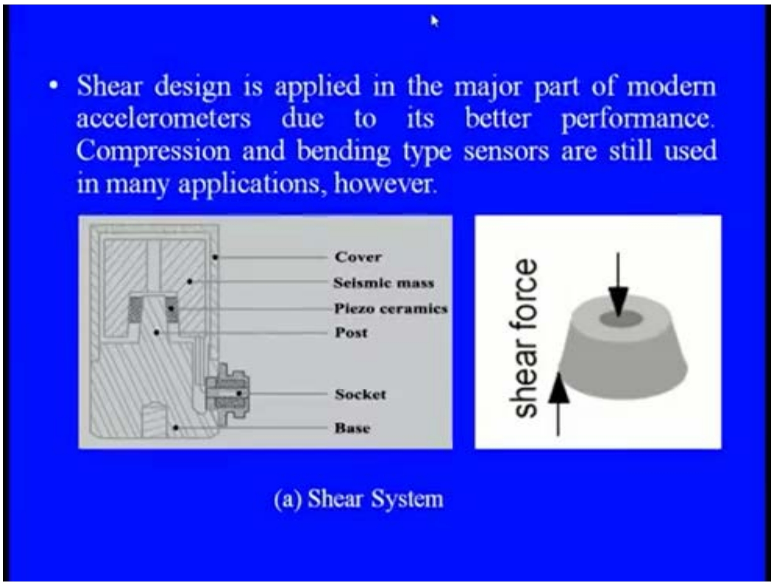

So, if we are going towards these design of this you can see the first sheared design, which is to be applied in major part of the modern accelerometer due to it is better performance as per the compression and the bending part. And you see that, we have you know like the shear forces as you can see that, the shear forces are there all along the plane. And due to this shearing action, whatever you see you know like the things are being coming can be straight away measured as we have seen in our basic concept.

You can see in the construction feature of that, this is what our covering part the seismic masses are there because you see we just want to first convert the acceleration into the force or the displacement. So, this is what the seismic seismic mass and this is what you see the shearing feature of this piezo ceramics part is there, and then this is what the base where the excitation features are being coming or any you know like these mechanical accelerations are being featured out. So, what I mean to say that when these forces are being acting here, it is absolutely in the shearing feature, and it has a great application because of the shearing force there is a clear voltage generations are there in between that.

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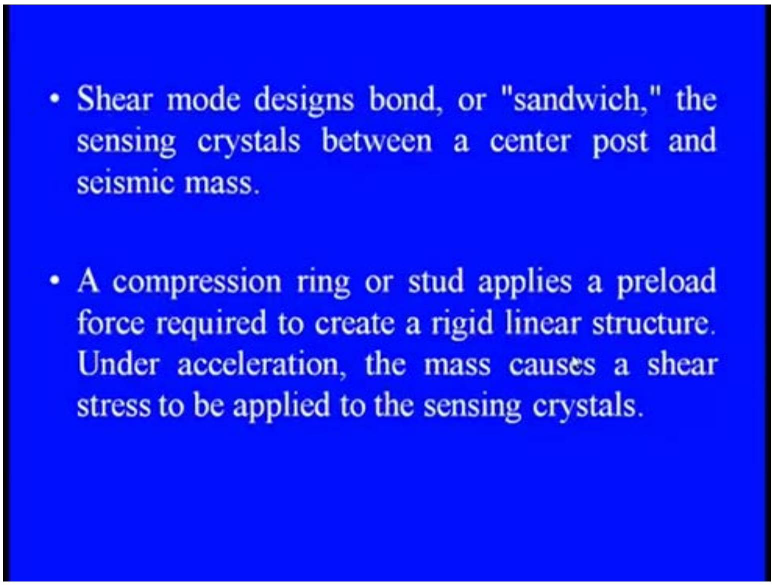

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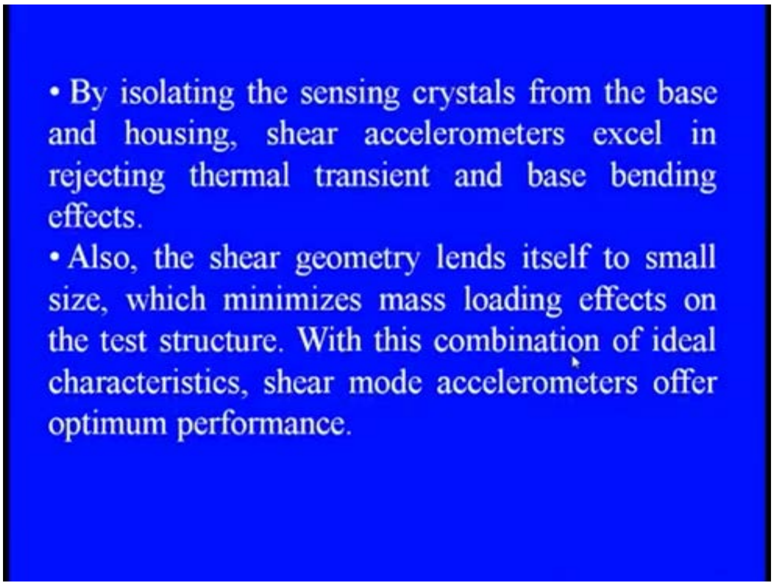

And this shear more design, either we can say the sandwich form or we can say you know like the bonding form is just sensing the crystals between, the center post and the seismic mass, as we show by the dark region. And the compression ring or the we can say the stud in between you see you know like the things are being there, apply the preload force which is required to create it a linear region in the entire structure. And under the acceleration this mass causes the shearing stresses, which is being to be applied to the stressing crystals.

So, while isolating the sensing crystals from the base or the housing, the shear accelerometers excel in resulting the thermal transient, whatever you see you know like the temperature transient features are there. And the base bending effects, and that is one of the unique feature in these shear mode shear base accelerometer that you see here, it is always being comfortable under the, you know like working feature of the thermal or we can say the bending effect at the base part, we can apply these things, also the shear geometry length itself to small size, which minimizes the mass loading part or the inertial features on that, on the test structure.

So, that is why you see here we have a small you know like these sensing devices are there, which has all the features which is been required with the cancellation of you know like the transient thermal and the bending part. And with this combination, the ideal characteristics the shear mode accelerometer offer the optimum performance in the recent time.

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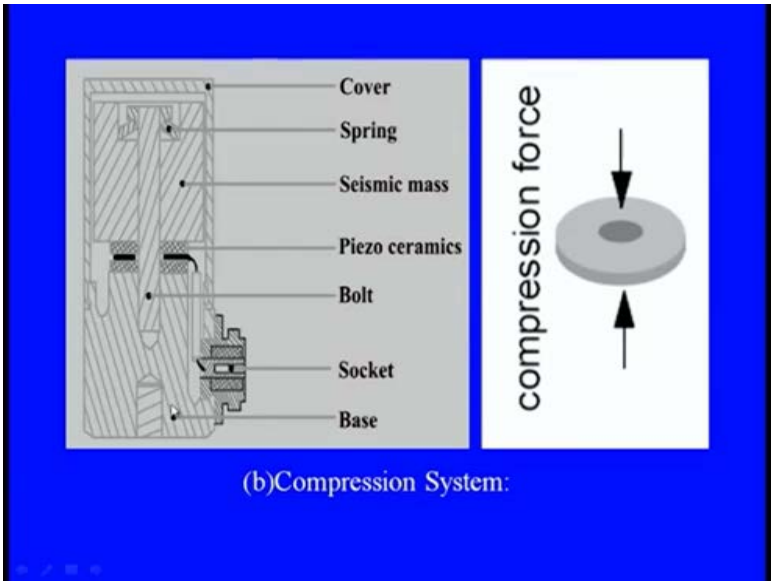

And if we are going to the compression part you can see that it is a clear compression part is there on the piezoelectric material. So, again this output cover you see with the base, when you know like the excitation is coming, and these bolts are being provided under which you see we can say that the seismic mass is with this particular piezo ceramics part is there. So, it is well you know like we can say balanced part and you see because you know like it can contain the high compression features there itself.

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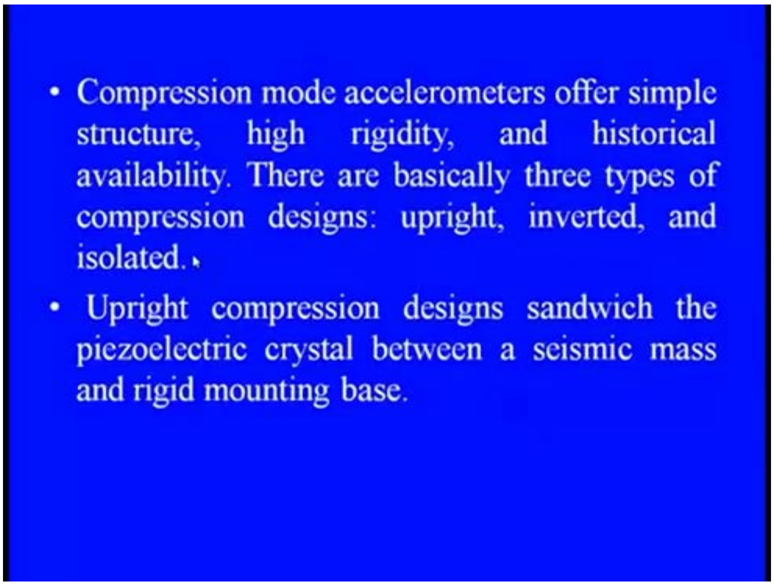

So, compression mode accelerometers is simply offering a simple structure we do not have to you know like go with the different combination seismic mass, and entire you know like the feature, it has a good rigidity part. And we can say that it is simple base because you see you know like because of the simplicity part its very much available. So, we can say that even there are three basic types of the compression designs are there, like upright, inverted, and isolated part and there all available with this.

So, upright compression which designs you see you know like based on the sandwich part of the piezoelectric crystal between the seismic mass and rigid mounting base is very much available in this markets. And they have good we cans say the compatibility as per the requirements.

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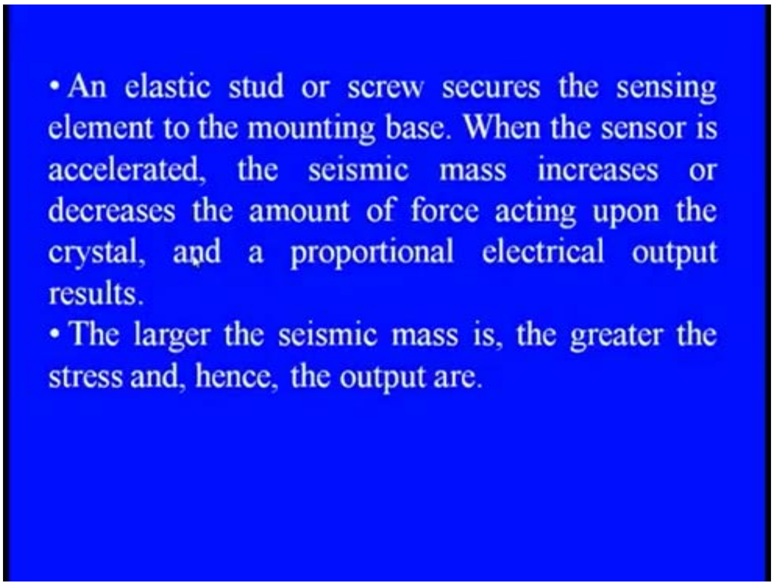

So, an elastic or the screw sensors means you see when we are saying the stud or the screw, which is there in the you know like in this particular device is always secures the sensing element to the mounting base. So, when the you know like we can say the sensor is being accelerated, the seismic mass increases or we can say whatever we you know like the decrease or increase of this mass, amount of force acting upon the crystal and a proportional electrical output is being there.

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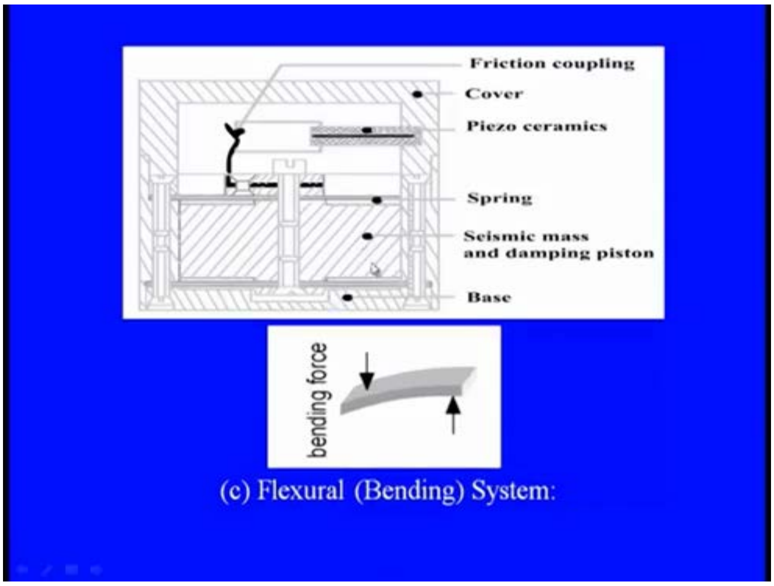

So, whatever you see the acceleration part which is being you know like coming to the system, the seismic mass is just converted into the force and accordingly you see the electrical output is being there from this crystal part. So, the larger seismic mass the greater stress and; obviously, the greater outputs are there from these upright compression systems.

And when we are going to the flexure feature, means the bending force you can see that, this is what you know like the piezoelectric part the bending features are there. And you see this piezoelectric sensors which is being there you see here, and there is a frictional coupling is there along with this part, and we have the spring element. So, this seismic mass along with the this damping mass being added with these piezo ceramics, and you see here when at the base excitations are coming on that.

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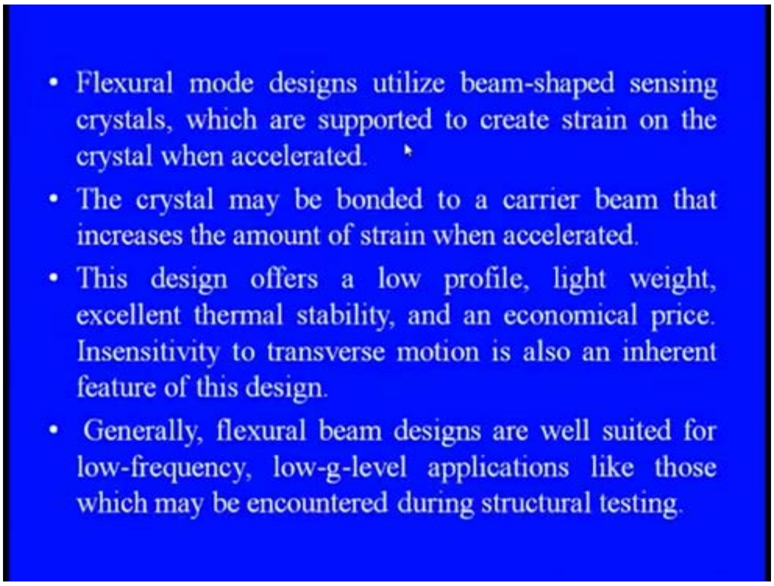

The flexural mode part is there according to their beam shaped sensing design with crystal part, which is even then supported to create the strain on the crystal when the accelerations are there. So, in this the crystal may be bonded to a carrier beam, which is then increases the amount of strain under the high accelerations, so this design certainly offers a low profile light weight, excellent thermal stability part.

And you see here, since you know like it is a simplicity in the design, it is they are quite inexpensive too. So, in sensitivity to transverse motion is also one of the inherent feature of this design, so generally we can say the flexural beam design are well suited for the low frequency, the low gravitational acceleration level application. And that can be straight away you know like adopt along with the structure, which is being tested at their low frequency part.

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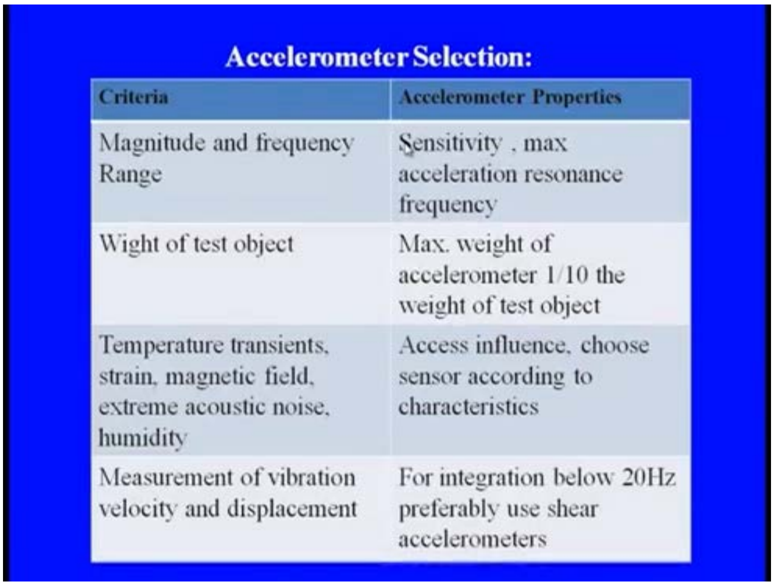

So, when we are talking about accelerometer selection we need to go with the two main part, what is the criteria and what accelerometer properties are there being along with that. So, when we are talking about the criteria first the magnitude and the frequency these are the two basic part of the vibration, in this particular annual acceleration, so we need to check it out what is the sensitivity level, in the accelerometer, what is the maximum acceleration responses is there from that, and what is the resonant frequency the maximum resonant frequencies are there from that.

The second criteria is the weight of the test object, so if we have the maximum weight of these you know like the things are there, we can go the accelerometer rate 1 10 of the object weight. Then only we can say that there is a compatibly according to the inertia forces being generated, and then you see here at the base excitation it can be immediately sensed out towards that. The third which is most important criteria is the temperature transient, the strain, the magnetic field or you see what the extreme acoustic conditions are there in the surrounding and the humidity part.

Because, they have the clear influence on that, so excess influence choose the sensor according to the characteristic that you see whether, we are going with the shear or whether we are going with the longitudinal or whether we are going with the, we can say you know like these bending features of that. And then we have the measurement of vibration velocity and the displacement. So, we need to check it out that whether you see the integration is a perfect part or not along with the shear accelerometer, and we need to check it out even sometimes below 20 hertz, whether it is really preferable to use this one or not.

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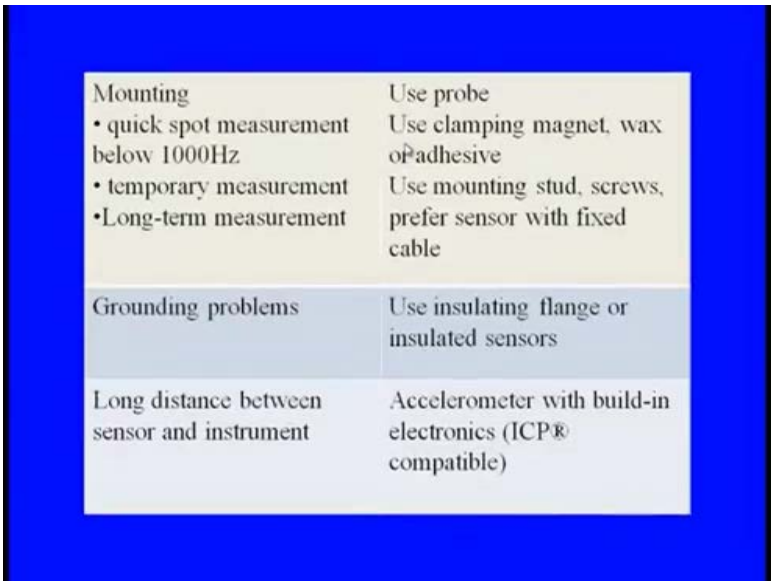

Then the mounting which is one of the important part in the accelerometer, the quick spot measurement below 100 below 1000 hertz, the temporary measurement and the long term measurement. When such kind of things are there, we need to see the property in the accelerometer that whether we are using the probe, which is a quick part, whether we are using you know like the magnetic feature or the wax or any additive part means the adhesive feature is there.

So, that we can permanently or temporary you know like make an arrangement or use the mounting stud with screws or we can say you know like simply prefer the sensor with the fixed cables. The other you know like we can say criteria's are grounding problems means you see what exactly the grounding parts are there, which is simply you know like using the insulating flange or the insulating sensors or the long distance between the sensors, and the instrument where the entire measurement is recording.

So, we need to see nowadays which is perfect use you see the accelerometer with inbuilt electronics is the ICP kind of compatible part. Because, when we are using the ICP type of you know like these piezoelectric sensors, then you see here we can you know like integrate the highly sensitive feature, and even that can be maintained up to the distance the long distance between the measuring and the recoding part.

So, in this part you see here the piezoelectric sensors and the actuators and the various applications which we have discussed. Especially when we are going towards the various you know like those rotating machinery or any kind of vibrating generating feature, we know that the piezoelectric application in the material can be immediately acted, as an sensor or an actuator to suppress these vibrations. And you see here, we can rather use even for many other applications of these piezoelectric feature in the materials.

So, this is you see you know like this chapter was mainly dedicated towards, the applications of the piezoelectric materials. Now, you see in the next lecture we are going to discuss about the application of you see you know like these piezoelectric part especially in terms of accelerometer and many other part, under the active vibration control.

Thank you.