Vibration Control
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Module - 7
Principles of Active Vibration Control
Lecture - 9
Electro-Magnetics

This is Dr. S. P. Harsha from Mechanical and Industrial Department IIT, Roorkee. In the course of Vibration Control, we are mainly discussing about the control techniques, in which you see we discussed the two main phases, one the passive vibration control and in this module we are mainly discussing about the Active Vibration Control. So, this is the last leg of the our module in which we are going to discuss about the electromagnetic dampers.

So, we started this journey right from you see, the basics of active vibration controls in which we discussed that, if we have the main components like the sensor, like the actuator or along with you. See if we are coupling these two devices with the automatic control feature, then we can generate the cancellation force or the force, which we can act against the vibrating forces, through which the iterations are there in the system. And again it is absolutely depending on the location, the kind of sensor and how the actuation forces can be generated.

Sometimes we need to amplify the signals, because whatever the signals are there that is not even sufficient to counter attack the excitation feature, or sometimes we need to add some kind of you see the external sources. So, that we can supply at least this much energy to cancel out that force, so we found that, this is one of the excellent part by doing you see the active vibration control. But, the same time it absolutely depending on that what exactly the location, where we need to apply the control, what is the service condition, what exactly the operating features are there of the entire system is.

So, what I mean to say that just by adopting these three features it is not fulfilling our active vibration control part, so then the other part in the active vibration control started from the material side. There are various materials known as, the smart material through which the sensing and actuation features can be adopted straightaway. Just like you see the human body, which is one of the we can say the smart structure is there, where the sensing and the actuation straightaway there in the millisecond respond feature.

So, based on that, we categorise these materials under we can say the smart material or intelligent material started from the piezoelectric material. And even in that we discusses about the man made or the naturally available materials, but manmade materials based on mainly the ceramics, even the piezo materials means the piezoelectric ceramics material. Or the even the polymers are there which can be acted, as the piezoelectric material through which we can sense the vibration response.

And also at the same time they can be actuated the forces which are being required to suppress the vibrations. So, we discussed right from the piezoelectric accelerometers to the actuator part, and even whatever the profile surfaces even the this rectangular beam is there, circular profile is there, any kind of irregular surfaces are there, these PJT patches can be straightaway acted. So, that part we discussed in the beginning of the material, but sometimes, since this PJT patches which is starting from the lead only, because of the severity in the environmental features, even now a days there are various other materials which are like you know using instead of this PJT.

Then, the secondly part then we move to the electrorheological fluid and the magnetorheological fluids, so these fluids they can be act as the damper to suppress down the vibration. And also they can be act as the actuator part, based on the intensity of the applied field either the electrical or the magnetic field. Or even based on what the carrier fluid is there in which the entire molecules, the polarized molecules are being there we can simply add the viscosity by applying these fluxes, the magnetic flux or the electric field.

And they these polarised elements they can be symmetrically arranged, in such a way that the resistance can be provided in a stronger way, and even they can produce a high amount of the actuation forces as per the requirement. We discussed about that the electrorheological fluid and this magnetorheological fluid, according to their applications where you see right from, the aviation to our smart machineries, the computer numerical control machines these ER or MR fluids are absolutely we can say adoptable. Even now a days, even when the trains are being under the crushing action means when the impact loadings are there.

If we want to just provide a resistance in the this impact force this transmission these ER fluids have an excellent applications towards that, against the crushing, the crashing feature of these trains. And even where you see with the helicopters and many other applications these fluids are being actively applied. Then we discussed about the ship memory alloy, this is one of the excellent feature that even, sometimes we are discussing about the elastic reformation where we know that, when the loading and unloading conditions are there, there is no permanent set of reformation. And the whatever the you know like the specimen size or the shape is there is no change in that.

But, the shape memory alloys are such kind of materials they can recover their own shape when unloading is there, even they are at this inelastic or the plastic deformations. So, here this anthropoemic features along with all the mechanical properties, they have the excellent part with these shape memory alloy. So, in the last lecture we mainly discussed about the shape memory alloys and what exactly the applications are there, for vibration control. Even you see here they can be act as a straightaway damper, when they are just integrating themselves in the entire wire damper is there, and they can be coiled you see here as you know like the stiffness feature.

So, we have both the spring energy as well as the damping feature, towards suppression and means to the absorption of the energy or the dissipation of energy, and the same time to control the entire oscillation by absorbing features, or by we can say saving energy. They can straightaway save the energy and then we can say release the energy according to requirement, so what I mean to say that these shape memory alloys can be featured in both the way, they can be acted as the damper, they can be also acted as the actuator feature wherever it is being required.

So, that is why you see here many of the applications are there of the shape memory materials, towards the vibration and even for various biodynamical right from the bone to teeth to various other applications, these shape memory alloys materials have an they just showed their excellent we can say applications towards that. So, in the last lecture for this material side, active vibration control part the electromagnetic dampers are there, again we are going to use the electromagnetic feature as we discussed about the ER or the electrorheological and magnetorheological fluid; we discussed about the electrostrictive and magnetostrictive the materials. And then the third part with the same electro and magnetic part they can straightaway be acted as the electromagnetic damper, generally we are saying that the ED or EM part, the EM dampers.

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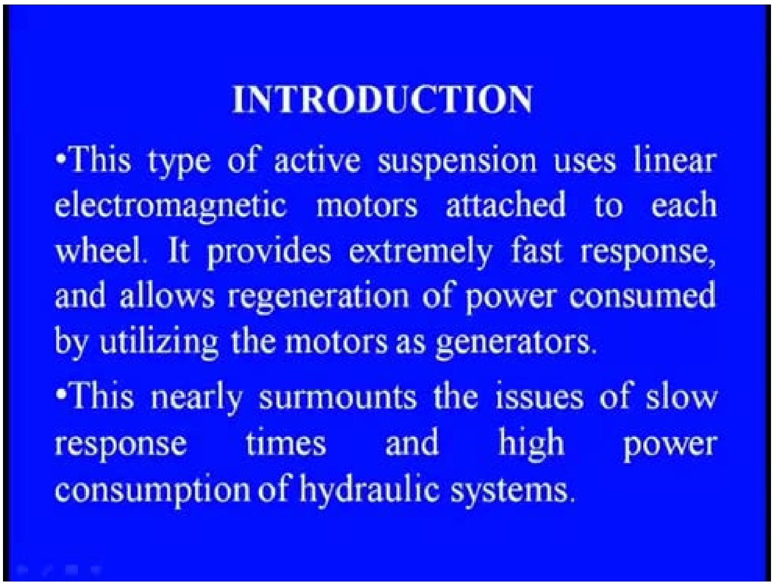

So, this type of active suspension simply uses for linear electromagnetic motors, which can be addressed to each of the wheels, wherever suspension is being required, where the absorption and the dissipation feature is essentially required against the shock loading. And these we can say the electromagnetic devices, like the motors just provides extremely fast response, because the response time is very, very less in these types. And they allow to regenerate the power consume by utilising motor as the generator, so here one of the important feature in the electromagnetic these motors, they can absorb the energy even at the resonant feature.

And whenever it is being required they can these motors can be acted as a generator, through which we can again reutilise whatever the consumed we can say the energy of the power is there in those devices. So, this means surmounts the issues of the slow response times and the high power consumption of the hydraulics system, so that is wherever we just want the immediate response, and even we can say these repower utilization. Then we can say this is one of the important device for such kind of applications.

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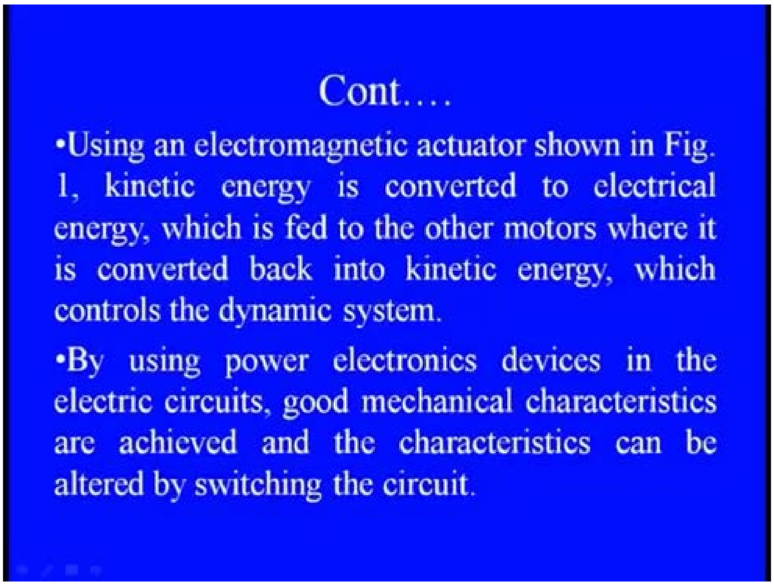

So, using of this electromagnetic actuator which I am going to show that in the next slide, the kinetic energy is mainly converted into the electrical energy. So, whatever the motion or when the shock features are being coming towards the vehicle they are simply absorbing the energy. So, this energy is mainly in the form of kinetic energy and then according to the design of this electromagnetic actuator. This entire kinetic energy is being converted into the electrical energy, which is then you see feeded to the other motors wherever it is being required to convert back to its kinetic energy with the control actions of the dynamic systems.

So, that is how the entire these electromagnetic these motors or generator means the devices are mainly working, first if any excitation is being there at any of the surface where these the devices are being attached to it, they can straightaway absorb the energy right from kinetic energy to electric energy. And then wherever it is required they can transfer this energy and this electric energy can be retransferred or retransmitted to the kinetic energy in terms of the generator. So, by using power electronic devices in electric circuits, good mechanical characteristics of these devices can be achieved. And the characteristics can be altered by the switching of the circuit, so that again the mechanical energy can be again reutilize, if the power electronic devices in terms of the electric energy. So, you see this is one of the beauty of the feature of this electromagnetic action there.

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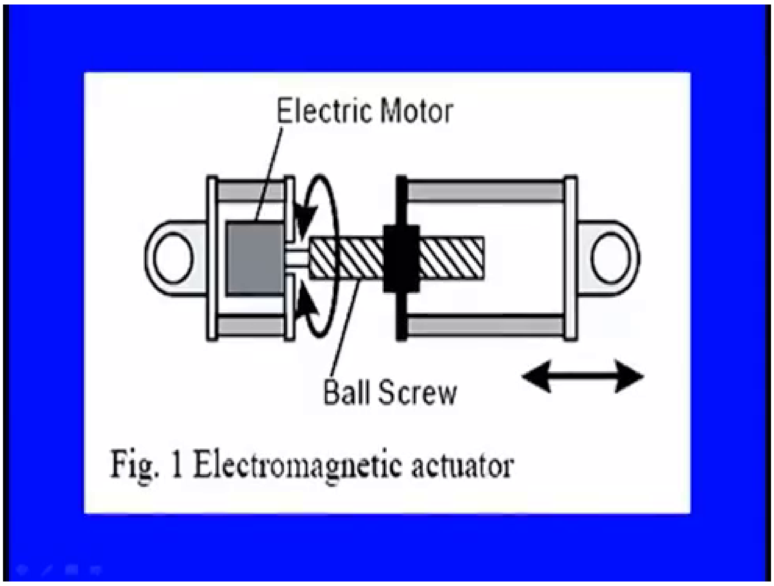

Fig. 1 Electromagnetic actuator

So, as you can see these electromagnetic actuators are there, we have this motor which the electric energy motor is there, and because of this magnetic action these dynamic actions are being happening means, this is the reciprocal motions are there. So, when this motion is there the entire kinetic energy which is being coming to the system, when it is being attached to any dynamic system, this can be straightaway absorbed here. And then this energy is being converted into the electrical energy, so here you see this absorbed energy will be retained in form of electric energy.

And then wherever it is required this again with this particular part where we have you see all the circular motion of this entire magnet part, it can be re back to this electric energy to the mechanical energy part. So, again they can be act as the actuator feature through these actions.

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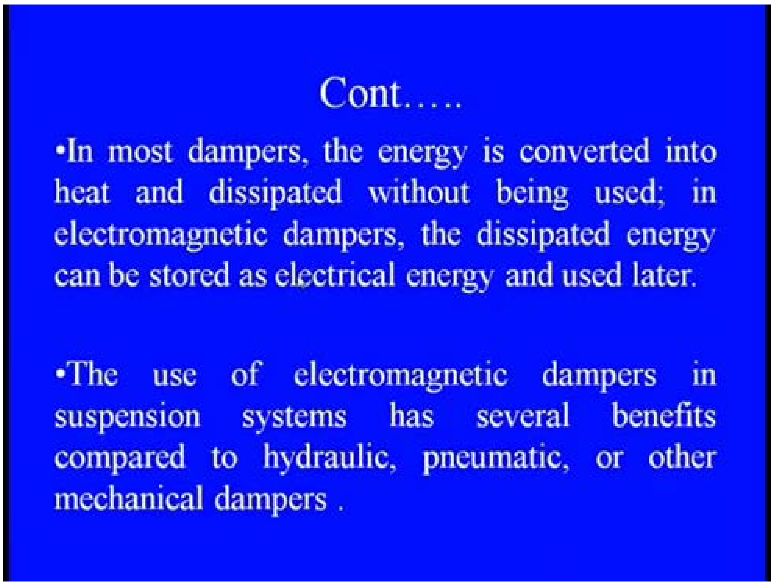

So, in most of these electromagnetic dampers, certainly we just want to see that what kind of actions can be happened, because this is what the electromagnetic the devices are there, in which there is a clear conversion of the kinetic to the electrical energy. But, the same time they are acting as the damper, so if you are talking about general damper feature then we know that the energy is converted into heat. And the dissipation features are being there without being used, so the entire energy can be transferred, in terms of the heat.

And in electromagnetic dampers the dissipated energy can be stored and the electrical energy, which is being the stored form can be used further, wherever it is being required. So, the use of this electromagnetic dampers in the suspension systems, have various we can say benefits as compared to this hydraulic pneumatic or any other mechanical dampers. Because, now a days in this particular case the main feature is that, if they are acting not only as the motor or generator part, they can be just store the energy, they can release the energy, wherever it is being required and though the spring can do this part.

But, whenever you we have the huge amount of energy at the resonant feature or even the shock loading is there, where we know that the impact kind of the loadings are there and certain amount of huge energies are being coming to the system. These electromagnetic dampers can be straightaway that in such a way that, whatever the energy which is coming in terms of the kinetic energy can be straightaway absorbed.

And convert into the electric energy, and they can this restore the energy for the highest time and with the quick response, they can immediately sent is release the energy in terms of the kinetic part, so this is one of the beauty part in this.

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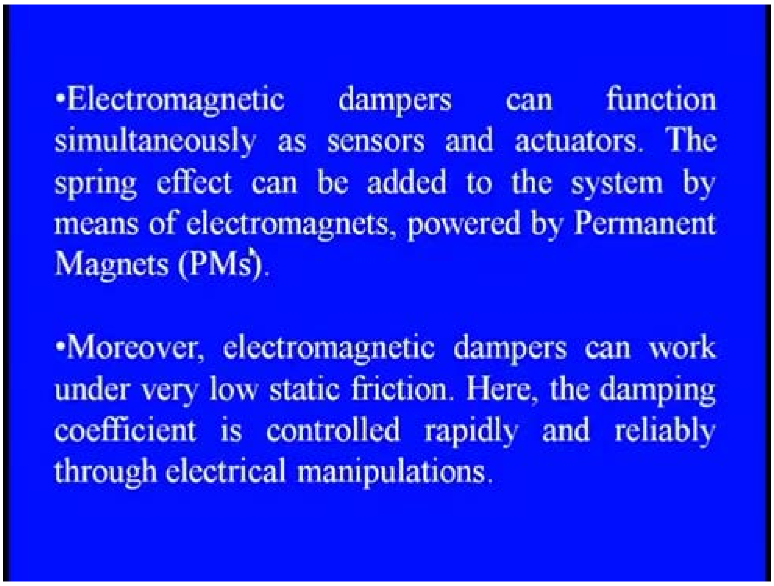

So, we can say that the electromagnetic dampers can function simultaneously as the sensor and the actuator, so the spring effect can be added to the system by means of the electromagnet, which are being powered by the permanent magnets. So, here you see here when we just want to sense the things, means whatever the sensing features are there. Then this electromagnet dampers can be act as with the inclusion of these permanent magnets the spring features.

So, this is what whatever the things are being coming, in terms of that is what I told you that, if you want to store the energy then they are simply acting as the spring part even whatever the highest energies are there. And when they are just saving the energy or we are saying that when they are storing the energy, this energies being absorbed with the simultaneous action of these the permanent magnets. And this kinetic energy is being converted into the electrical features, moreover this electromagnetic dampers can work under very low static frictions.

So, it is not that all the time, we need to know that highest amount of energies are being there and then can be used there. So, here the main thing is damping coefficient is being controlled rapidly and reliably through the electrical manipulators, so these manipulators which can allow them to even at whatever the damping coefficients are there, under the low static frictions.

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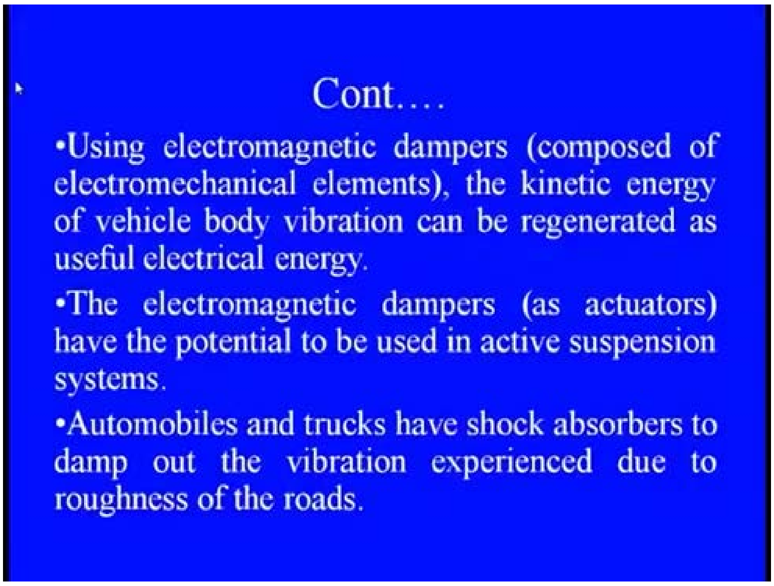

So, using electromagnetic dampers, which are being composed off this electromechanical elements, the kinetic energy of the entire vehicle body vibration can be generated as the useful electrical energy. And then these electrical energy can be stored and then it can be reutilised even in terms of the kinetic energy as well in the actuator feature. So, electromagnetic dampers for which we are saying that, when they are acting as the actuators, they have the potential to be used in the active suspension system effectively.

And efficiently they can actuate with the quick response time, as we are just setting that, what exactly the response time is being required to the system. So, automobiles and the trucks, they have shock absorber to damp out the vibration experienced due to roughness of the roads that is what I told you, wherever you see either that we have any irregular surface properties are there. Or when we have the bump kind of features, and when these vehicles are just travelling across that, whatever the shock or the sudden these impact energies are being coming or the impulsive forces are being acted towards the real system.

These electrodynamic dampers are able to suppress the energy, to store the energy, to absorb the energy and they can we can say that they can be reutilise this kinetic energy into, we can say the electric or electric energy to the kinetic energy in that.

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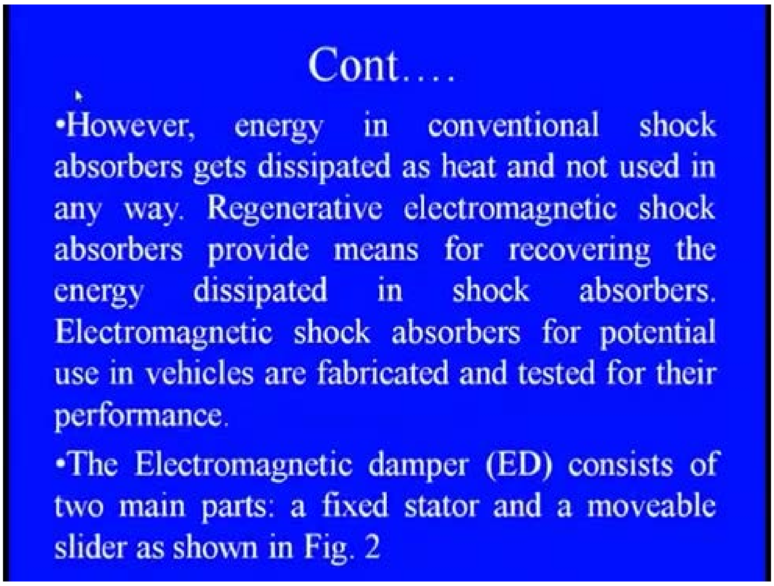

However, the energy in conventional shock absorber gets dissipated as heat, and cannot be used back in any way, that is what the shock absorber which we discuss in one of our passive vibration control. In which we have the clear arrangement of the dashpot in which the viscous damping are there, and our which we have the spring parts are there. So, spring can store the energy and transmitted this stored energy in the dashpot, and this dashpot is dissipation features are being occurred, some of the energy is being absorbed.

So, this is not an excellent feature in which the proper convergent energy, right from we can say like kinetic energy to strain energy and strain energy to kinetic energy can be done in the normal shock absorber. But, here whatever the kinetic energy is being to the system it can be regenerated, like right from the kinetic energy to electric energy and then electric energy to kinetic energy. So, the regenerative feature of the electromagnetic shock absorber provide, the means for recovering the energy dissipated in the shock absorbers.

And that is one of the unique feature, in which we can simply isolate the system and we can reutilise the entire energy part. So, electromagnetic shock absorber for, we can say because of these special feature they can used in the vehicles along with, we can say the dynamic systems are there, means wherever we know that the dynamic actions are being predominating. So, they can be attached or they can be fabricated and tested for their performance straightaway that, whether they can be sustained the huge amount of vibration, under you see the loading condition and the irregular surfaces are being there.

At higher speed, lower speed means whatever even the high amplitude or low amplitude of the oscillation is there. Or even the exciting frequencies of the low to high frequencies these electromagnetic dampers can be effectively used, at whatever the energy levels are. So, electromagnetic damper consist of the two main parts, as we discussed one the fixed stator is there in which we need to have a permanent kind of the magnets.

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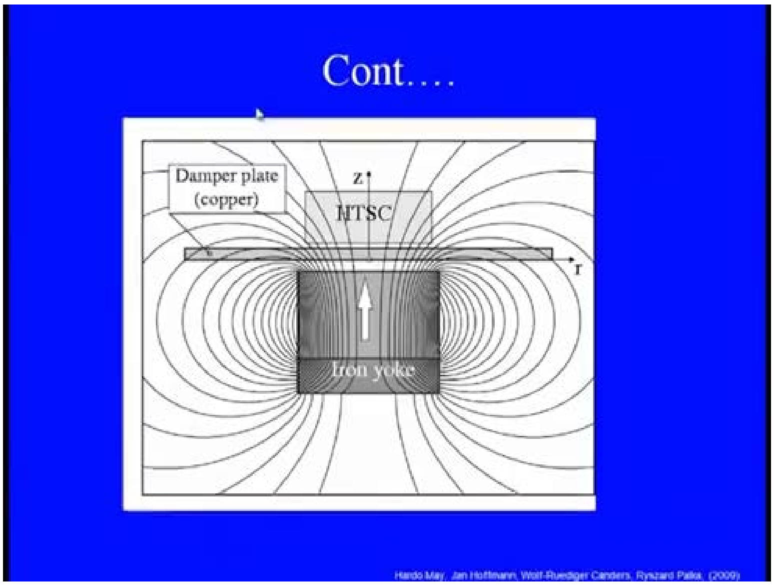

And second is the moveable slider, so in this part specially, when we are looking towards that the first thing is there that, when the magnetic moments are there all these the magnetic lines are being circulated all along the iron yoke. And then because of the intensity of this the entire feature is being, we can say whatever the moveable slider and the stator parts are there. These magnetic lines can be generated and the damper plate, which is you see on top of that you can see that this is what my damper plates are. They can be straightaway absorbed things, they can absorb whatever the kind of excitations are coming in that.

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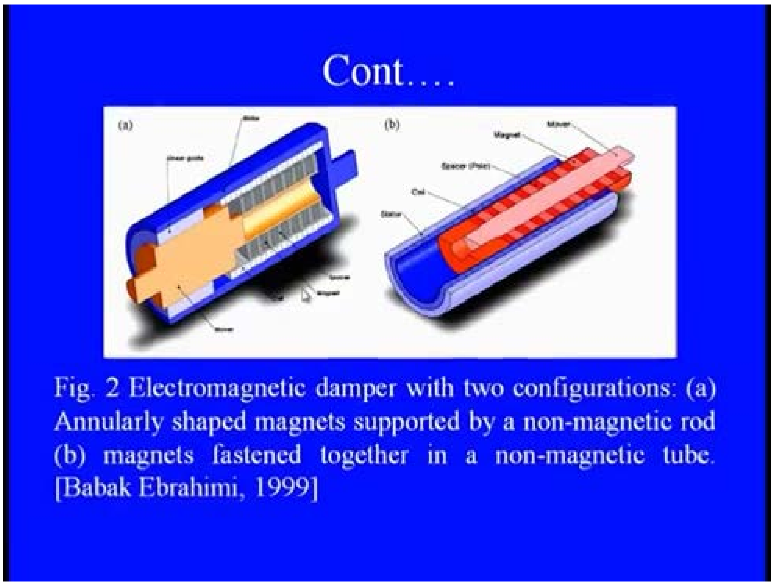

So, when we are looking the two main parts, you can see that we have cleared two parts here the electro electromagnetic damper, first the annularly shaped magnets supported by the non magnetic rod. So, that the non magnetic rods are being supported by this, so we have these all the coils are there, and that this is what my spacer. And in that this specially this part which is solid part is my magnets and with this straighter part which is being outside you see here, they are straightaway being supported by these non magnetic rod.

So, with these kind of things, whenever you see the magnet which is being fastened to gather with the non magnetic tube, then you see whatever the stator points are there. Means we can say that when the fixed point and the moveable points are there, then straightaway you see the magnetic fields can be generated, so we have this is what the moveable part which is absolutely inside the magnet. These red part which is clear you see, the coupled part from this mover is my magnets are there, and this is what my spacer.

The dark part in which this is my spacer, we have the coils all around and the stator part is there which is just providing outer caser feature there itself. So, when the stator and the these magnets, they when they make the outer casing the moveable part when they are just moving together under these magnetic fields, they can be straightaway you see. So, we have both the things, we have the stator which is if you look at that, at the outer part this is my stator just stator after that we have the coil part. So, this coils which are being supporting our spacer, and the magnet part which is straightaway coupled the mover part. We can say that, we can straightaway provide the electromagnetic field towards the part and whenever the kinetic energy through the movement of this part, the mover is coming to this system. They can be straightaway absorbed with the using of these magnets feature, so the straighter when we are talking about that they are simply the windings.

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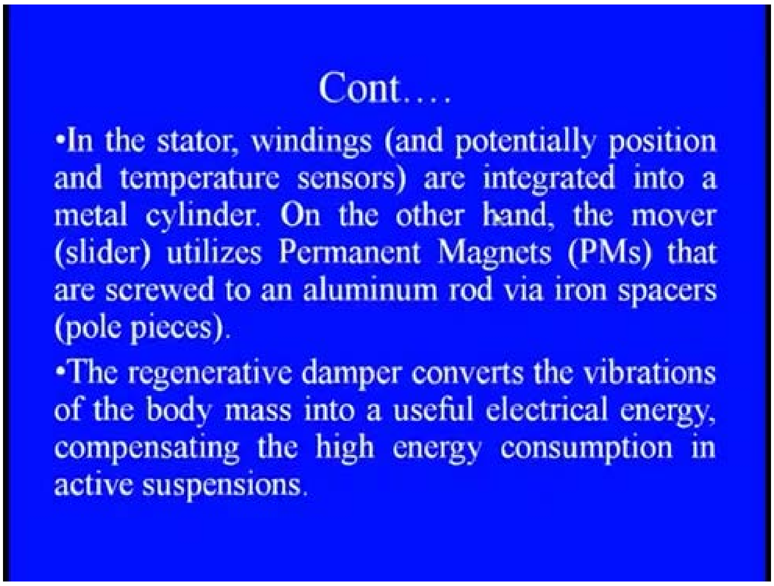

In which what we have, we have potentially position of this stator especially the windings, and they can be act as even the temperature sensor together. So, these windings are simply integrated into the metal cylinder, which is what you see the cylindrical features are there in the stator. And the mover which we are saying that the slider can be utilised in between the permanent magnets that are screwed to the aluminium rod via this spacer which we are saying that the pole pieces, just outside the red spots which I was showing there.

So, when these the mover or we can say the slider, which are being there which we are utilizing especially under the permanent magnets, the whatever the movement through these excitations when they are just coming to the system. The kinetic energy is being there and this kinetic energy is being now stored, because of this the all the windings are being there all around these mover part. So, they can be stored these entire kinetic energy, they convert first the electric energy, because of the environmental features all you see the magnetic environment.

And then these energy can be regenerate again back to the mechanical, so the regenerative damper converts the vibration of the body mass into the useful. We can say electrical energy compensating of high energy consumption is basically one of the special application of the active suspension. So, this is one of the feature, which is being happening there the mechanism, in which the entire stator windings which is being there together, when the movements are being there with our. We can say whatever the permanent magnets are there, they can be converted this kinetic energy into electrical energy. And then it can be way back to the system I can informs of the kinetic features.

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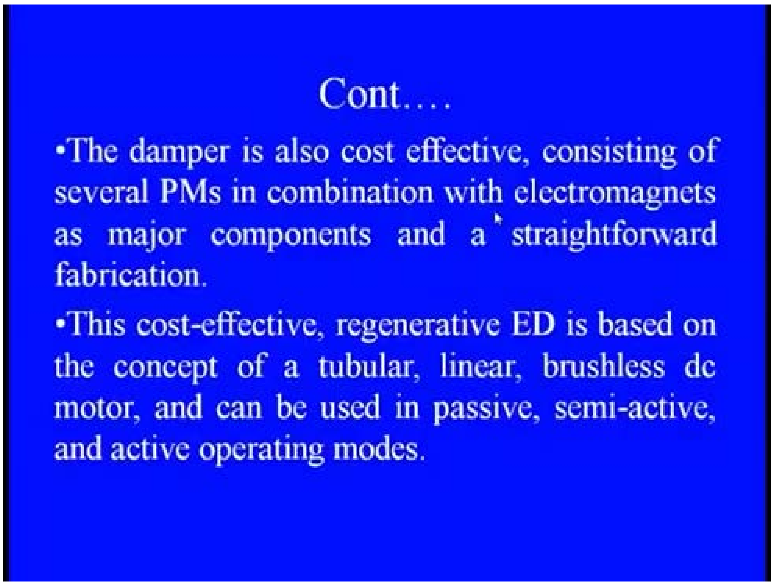

So, when we are talking about the electromagnetic damper, the damper is also we can say that just robust in the design, because it consisting the permanent magnets which in the combination with the electromagnets as the major component. And this is a uniform we can say structure in which not much the complexities are there, in the connection of these movable and the stator parts. So, this is somewhat the cost effective feature, and we can say that the regenerative electromagnetic damper is absolutely we can say that, either we can go with the tubular, we can go with the linear or the this brushless DC motor.

And that can be used straightaway when the active suspension system, so whenever we see that there is a clear vibration part, even we can straightaway used these as the passive or even the semi active devices. So, the ED part is really means the electromagnetic damper is an effective the utilisation of the energy, wherever it is being required.

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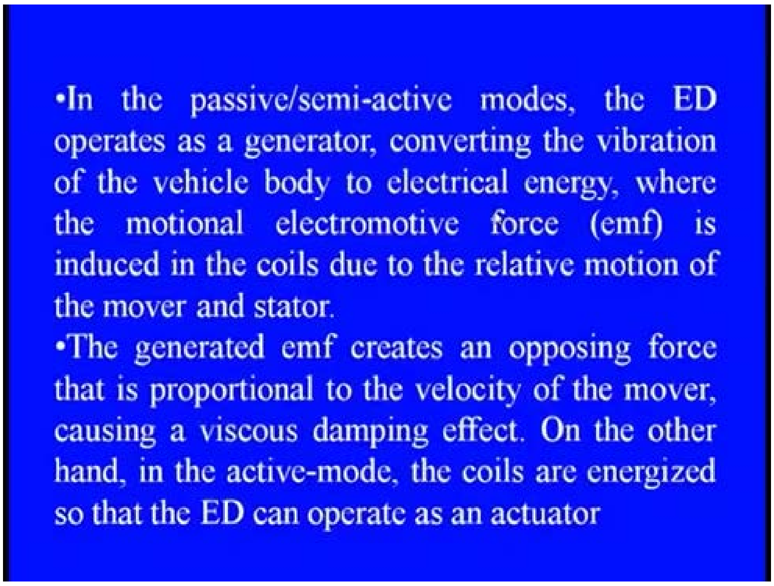

So, when we are talking about the passive or semi active modes of the vibration control, this electromagnetic damper operates as the generator, which is converting the vibration of the entire vehicle body. In terms of the continuous other shocking to electrical energy, and the motional electromagnetic forces EMF, which we are saying that EMF is basically induced to the coil due to relative motion of the mover in the stator part.

And this generated electromotive forces, even creates an opposing force that is proportional to the velocity of mover within the system, and this causing the viscous damping effect within the entire system. So, it is a clear resistant features are being there, because of the motion of this mover part within the electromagnetic field. So, we can say that this is what some kind of we can say, the passive features of that on the other hand in the active mode the coils are energized, so that the electromagnetic damper can operate as an actuator part.

So, instead of the dissipating or absorbing the energy, now we are transferring the energy back to the system and this can be even reacted as the actuator part in the system. So, this is what the working functions are, that when the vehicle body which is being generating the kinetic energy, and which is being converted into the electric energy. These the EMF forces which are being the generated in the coils, due to relative motion of the motion or the we can say the stator, is creating the opposing force there.

And this opposing force in the active vibration control, can be straightaway used as the actuator force back to the system to suppress the vibration. While if you are using this as the passive controller this force, when it is being moving with the velocity, whatever the velocity is there is simply causing the damping part. And with the damping they can be straightaway dissipated the energy, so that is why the passive was semi active when we cannot reutilise as the actuator feature in that. But, it is absolutely depending on the design features there.

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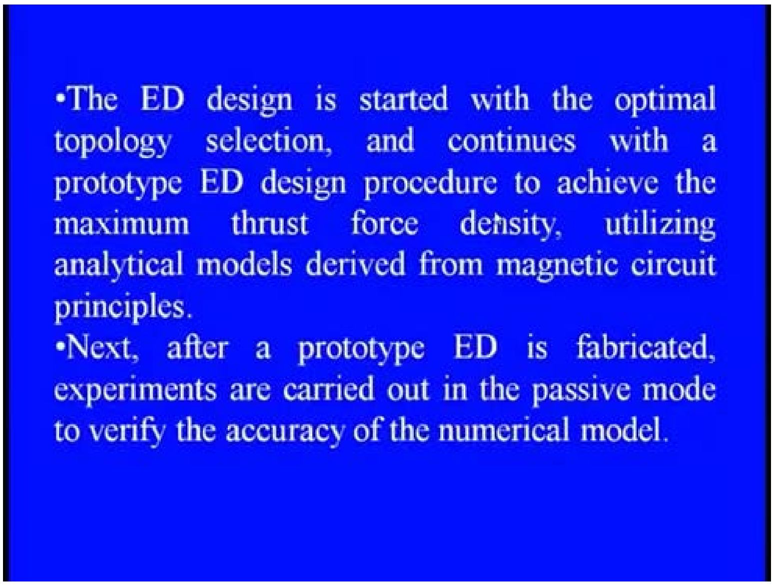

So, electromagnetic damper is designed, we can say it is just design on the basis of what the optimum topology features are there, means the selection the location part, what exactly the environmental features are there. And continuous with the prototype ED is designed, procedure to achieve the maximum thrust force density part there itself. And then can be utilised the various we can say, the application based on what exactly the magnetic circuit principles are there, along with the stator and moving features.

So, once you have the prototype ED, you can basically experiment those things, and then you can get how we can accurately redesign or how much electromagnetic forces are to be generated, through the like sensing feature. Whatever the things are being coming in terms of energy and how much force can be reacted towards the body itself, so this is one of the perfect ED design.

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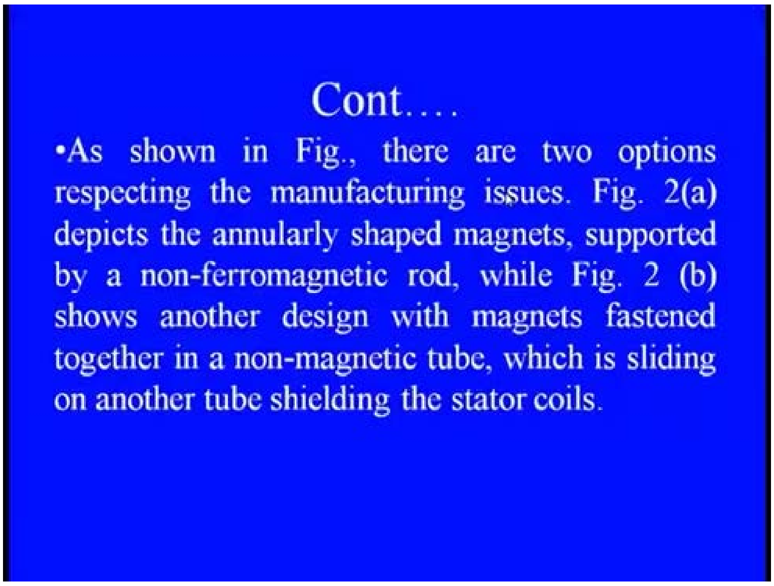

So, now we are going to show one more example in that, but previously when we show that the two main options, with respect to whatever the features are there one, which was depicts annularly shaped magnets, which were being supported by the non ferromagnetic rod. And the second was showing with the magnets fastened together with the non magnetic tube, in which you see the sliding motions are being there in the tube shielding to the stator coil.

So, these two the different types are there based on their manufacturing limitation and the issues, we can go with that and based on what the kind of forces which are being generated back to the system. For suppression of vibration these designs are to be there, whether we are going with the annularly shape, or whether we are going with these, when we are simply shielding the entire the stator coils to the non magnetic tube. So, what exactly the things are being required that can be done.

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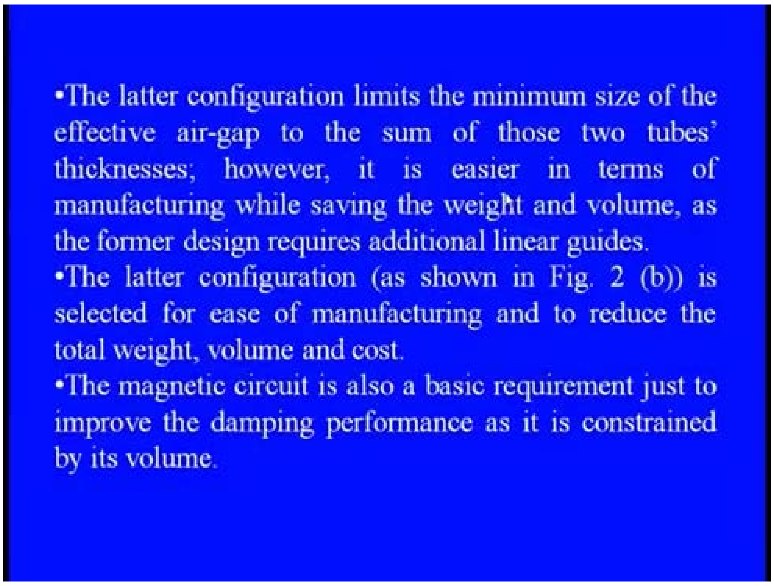

So, the configuration which limits the minimum size of this whatever the effective air gap, to the sum of those two tubes, that can be easily we can say that manufactured. And that can be, we can save the weight and the volume, in that case where the additional, this linear guides are required for supporting the entire annular feature. So, we can say that the configuration in which fastened features are being there, with these two parts means the, these two tubes absolutely.

And which minimum air gaps are there, the it is very easy to manufacture and also you see here it has very less weight, because we do not have any linear guides towards that. So, magnetic circuit which is also one of the basic requirement, we need to just improve the damping performance by putting this less volume towards that. So, that you see here there is no not many losses are there, because of the gap itself.

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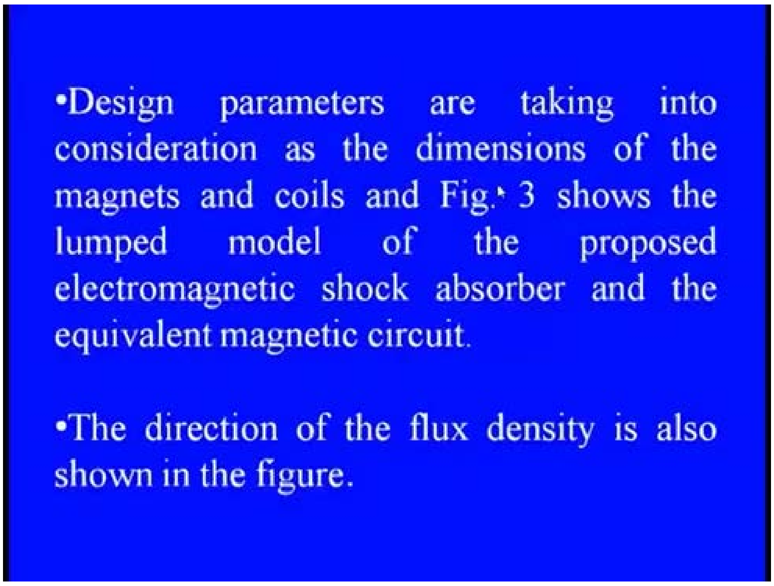

So, when we are talking about the design parameters, we need to consider the dimension of the magnets and the coils. And then we can show this especially towards the lumped model because ultimately you see, we need to use this as the damper feature. So, we can simply show on the lumped model of the proposed electromagnetic shock absorber, and what is the equivalent magnetic circuit is being required. But, one of the key issue in designing of such ED dampers are, the direction of flux density must be in the accordance, we will see here we just need the effective utilisation of the intensity of this magnetic field together.

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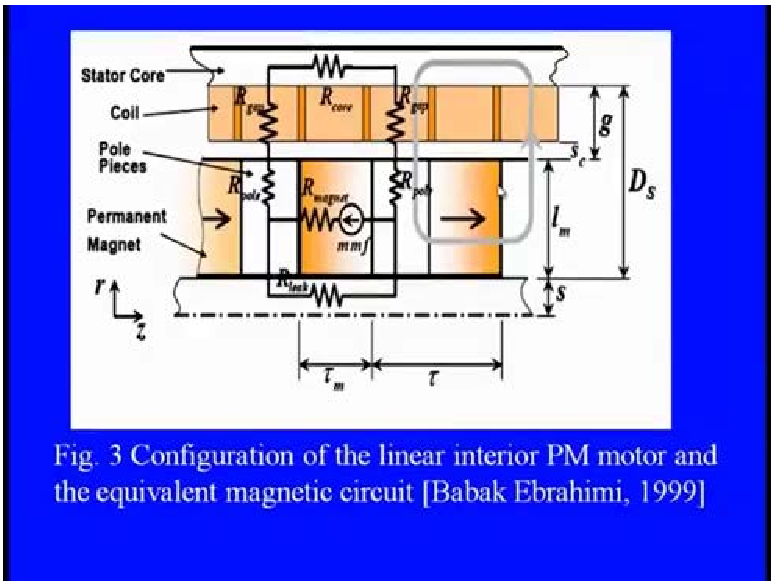

Fig. 3 Configuration of the linear interior PM motor and the equivalent magnetic circuit [Babak Ebrahimi, 1999]

So, as you can see here, we have the three main things, one outside you have the stator core, so this is outside the stator cores are there together. And when we are trying to make these discrete model, where we can say this linear lumped models are there, so lumped model is clearly showing that you see this is what my resistances. So, this is you see the first the gap feature is there R gap, this is my R the resistance of the pole part is there, this is my resistance magnet is there and this is resistance core is there.

So, in the coil particular, you can see that the coil is in such a way that it arranged with the gap of g and total in this permanent magnet motor part you see here. Or we can say the equivalent magnetic circuit which was shown by the Babak Ebrahimi, in 1991 it is clear that. These permanent magnets are being there and in between that, the entire feature, whatever you can say the electromagnetic force the EMF forces are generated. And they are straightaway you see EMF forces are generated and they are straightaway acting towards that, so we have the coil we have the pole places together. So, these pole places, which is clearly showing you see the white part in that, we have clear resistant feature in this.

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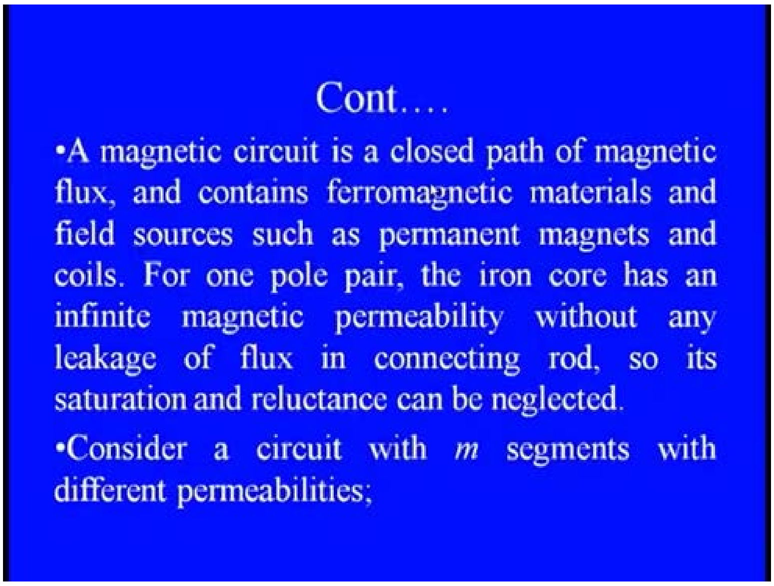

So, when we are talking about a magnetic circuit, which is closed which is closed path of the magnetic flux and there containing the ferromagnetic material and the field source, in such a way that the permanent magnet and the coils can be effectively utilised, in terms of their force generations. So, for one pole pair the iron core has an infinite magnetic permeability, without having any leakage flux that can be just adjust with the connecting rod, so it saturation or we can say its reluctance can be immediately neglected. So, when we are talking about this circuit, we can say that there are various segments, say m segments are there with the different permeability.

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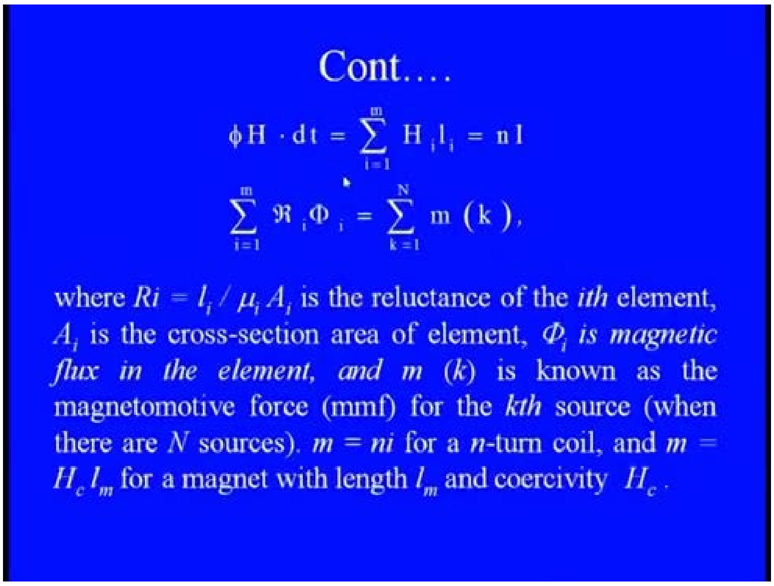

Then we can say the flux which is being generated phi into the magnetic flied phi H into d t is equals to entire summation of for the entire m segment summation of H i l i equals to n into i, where resistance r i is nothing but equals to l i by mu i a i. This is the we can say the reluctance of the i th element, and we can say that whatever the cross sectional area is there, this reluctance is absolutely depending on this area. And when we are talking about the magnetic flux which is the phi, in any of the element we can say that the total magnetic field which is somewhat we can say varying parameter with individual segment.

So, phi into H is nothing but the magnetic flux into whatever the magnetic field which is being available there is just with the delta time t, which just simply showing that whatever the forces are being there it is equals to n into i. And also when we are talking about individuals action, we have the reluctance r i at the i th element into whatever the magnetic flux in the i th element, the multiplication is clearly giving that how the variations are being there, along with m of k.

Where m we know that the total segments are there and this is nothing but the total force m of k when we are just going with the entire n part, the total force is being there which is nothing but the magneto motive force MMG force is there. So, when we are talking about of any source, when the total sources are there, we can just take the total amount of the sources and we can simply show that, how much you see the magneto motive forces are being generated along with the reluctance and the magnetic flux of these entire elements are there. So, when we are saying that, these two equations which are clearly showing the balance features for the individual section to the entire part. We can say that these lumped model, is just showing the linear propagation of these forces when they are being attached in the series way.

So, here we have m which is nothing but equals to the n I, n is nothing but the total number of coils, how many turns are there in the coils and m, N which we are showing here. As the source part particular in the forcing feature m of k which we are saying you know like nothing but the magneto motive force is nothing but equals to H c l m for a individual man made. Where l m is nothing but the total, this we can say the length of the magnet and H c is nothing but the coercivity in the flied part.

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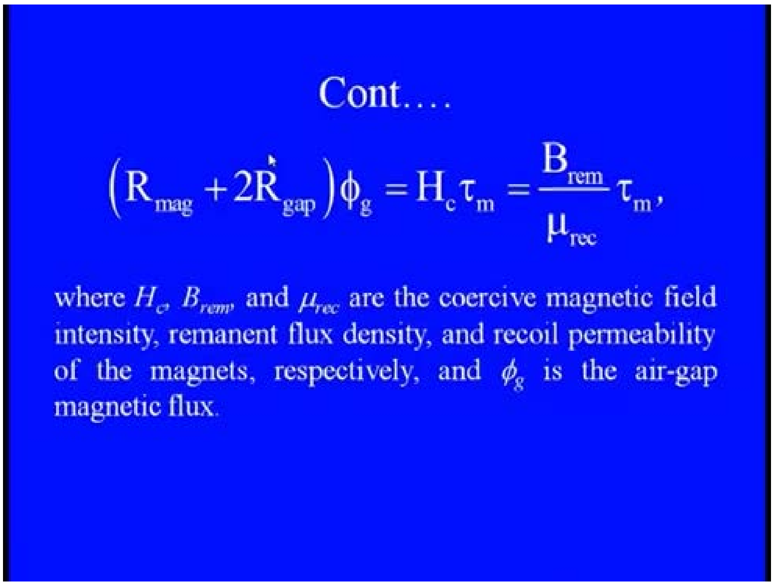

So, when we are using this the equation, then again we can rebalance this equation with the corrective magnetic field intensity. So, we are saying that the R magnet plus two times of the R gap into phi g and phi g is nothing but the air gap magnetic flux. Because, we know that this is one of the important task in that how much the air gap is there, through which magnetic flux is generated. So, R magnet plus two times or R gap when it is being multiplied with this flux, magnetic flux air gap, R phi gap is equals to H c tau m. And we know that H c is nothing but the corrective magnetic field intensity there which can be even multiplied with whatever the stresses which are being there, because of these force action of the magnet. Or else we can also equate to the B r e m divided by mu record into tau m and this B r e m is nothing but equals to remagnet flux density, because we need to just see that how much the magnetic effect is being there in that.

So, remagnet flux density and we know that mu r e m is the permeability in the recoiling of the magnets, so it is what the clear conversion, when the electromagnetic forces or the electric energy is repassing through that. And it is absolutely sensitive to that how much air gap is there in between this magnetic flux, so mu r e m by mu r a c into tau m is clearly we can say deciding that how much you see the phi g is being required in that. So, we can get to see the reluctance in the magnet and the gap part.

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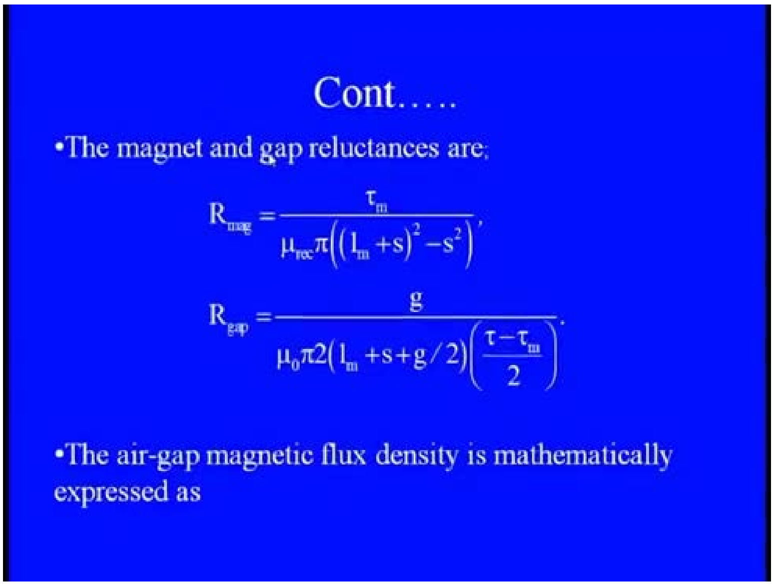

So, when we are talking about the magnetic reluctance r magnet which we shown previously, it is nothing but equals to tau m divided by mu r a c pi into l m plus S square minus S square, or even we can get the reluctance of the gap. So, gap reluctance is nothing but equals to its g that how much distance is there in the g, if you look at the diagram, this is what my g is there.

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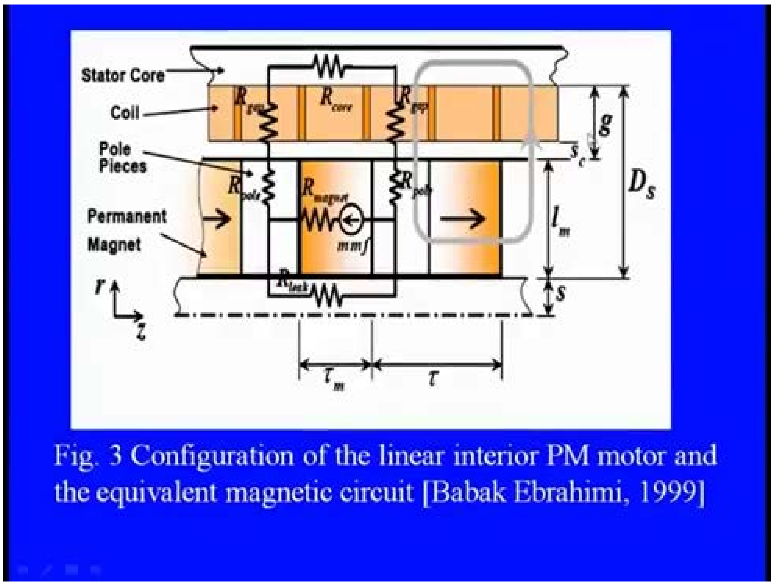

So, this g can be clearly relate with this l m which is nothing but the length of magnet and this gap is there as we can say S c or it is the total S is there. So, when we are just talking about the distance is tau m and tau S and this S c, we can straightaway relate these things together finding out that how much the gap reluctance or how much regenerative reluctances are there in that.

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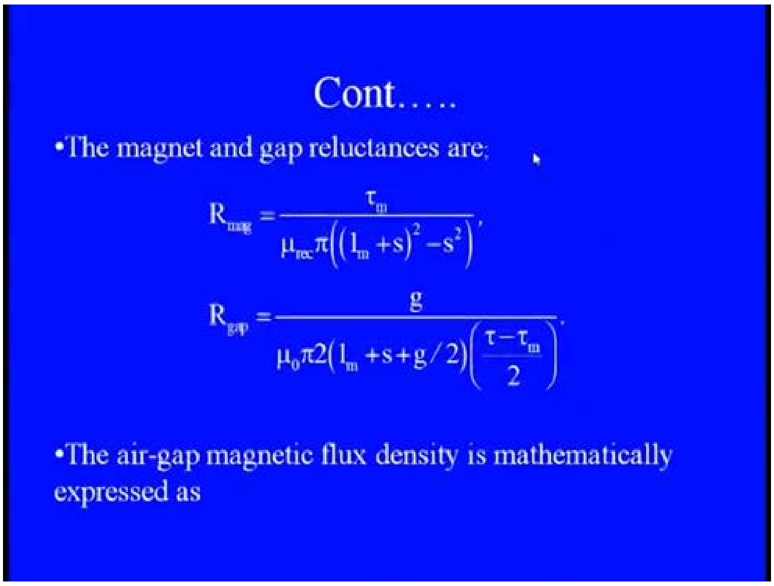

So, when we are just talking about the remagnet or when we are talking about the gap reluctance, then it is straightaway you see the magnet reluctance is nothing but equals to tau m which was you see the distance divided by this. And the g was vertical distance in divided by mu 0 pi square l m plus m plus g by 2 into tau minus tau m, means what is the total difference between tau and tau m is there divided by 2.

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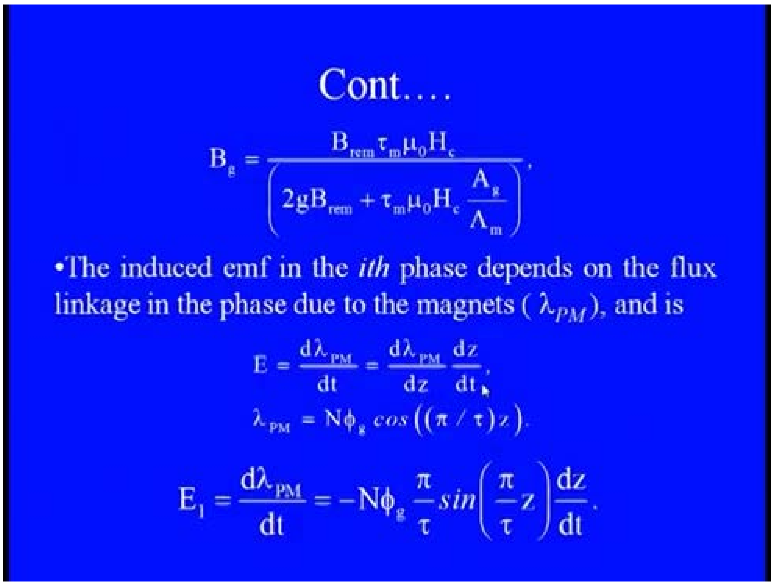

So, air gap magnetic flux density, which is the one of the important feature is there can also be get B g is equals to B r e m tau m mu 0 H c divided by 2 g e B r e m plus mu m tau 0 mu 0 tau m mu 0 H c a g by a m. So, here it is the cross sectional area, where you see the magnet and this g features are there, and the ratio is clearly giving that how much magnet the air gap magnetic flux are being there in that. And if you want to calculate now the electro motion force the EMF forces are there for any phase, say if you are talking about the i th phase.

Then certainly you see it is absolutely depending on what the flux linkages are there in between you see the magnets, so when we are talking about the this lambda PM, which is nothing but equals to the linkage feature in between the permanent magnets in the phase part. So, we can say this EMF part E is nothing but equals to d lambda PM divided by d t or else we can further go with the z part.

So, it is d lambda m by d z into d z by d t, here we can say that lambda PM which is something say the flux linkaging in the phase, due to the magnets is nothing but equals to the number of coils n into phi g cos pi divided by tau into z. And tau is the time constant, the tau is the distance in between these horizontal distances are there, in between this coil and other features. We can get you see here the EMF forces at the i th element is nothing but equals to d lambda divided by d t, or else even we can say that when we are just differentiating about this lambda PM, which we shown in the previous part this which is nothing but equals to minus n phi g pi by tau sin pi by tau z d z by d t.

So, this is the electromagnetic these forces are being generated when you see there is a conversion of the kinetic energy into the electric energy, the moment features are being there. So, even we can simply show the damping coefficient, which is one of the specific property of the electromagnetic dampers with the l m by D s ratio.

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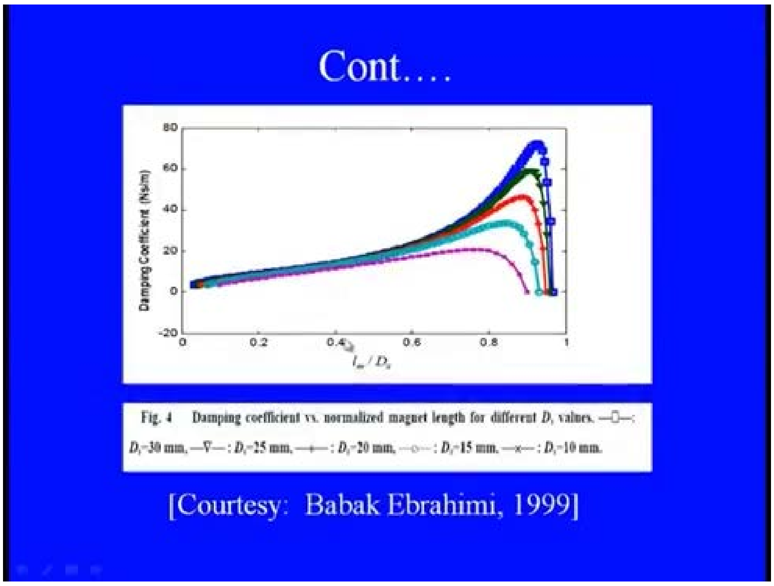

So, this is we can say the D m by l s ratio is nothing but the normalised magnet length with different values of the D s. So, we can see that when they are changing the D value means when the it is in the reducing from it is the bluest feature, and when it is just going down to this the pink part, it is the d value is down. And there is a clear part is there as the l m by D s ratio is increasing that damping coefficient is linearly increasing up to point l m by D s 0.5, and when it is going beyond 0.5, then there is a parabolic we can say expansions are there.

But, these expansion is quite rapid when the D value is high that means, when you know that the normalised magnet length for various D s value, means the damping value is being high. Then certainly you see here the variation for certain length is linear and then there is the non-linear features are being there together.

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We can even show the commercially that how is the ED's are simply looking towards that, so we have you see the stator, we look at these are the stator part and the mover in which pole and the magnets are being coupled together, they are being there within that. And through these permanent magnets these fields are generated and they can be acted effectively, in terms of we can say the damping devices. So, this is something which is now a days, a very much used especially towards the shock loading the electromagnetic dampers.

And even for the sophisticated control with the quick responses, in terms of the sensing to actuation these are effectively being used, especially against the shock loading part. So, in this lecture, we discussed about the main mechanism, we discussed about that what exactly the relations are there with the air gap, if the magnetic flux. Right from you see the magnet to the air gap to all the dimensional features, when we are taking these electromagnetic dampers as the lumped parameter, we can simply configure in the proper circuit.

And we can define the gap and then we can see that how much effective we can generate the magnetic flux, or how we can simply consume the kinetic energy, in terms of the electrical energy. And the how much the electromagnetic forces are being generated, when we just require the, this as the actuator force, so this is all about this lecture. In the next lecture now we are going to discuss about which is the last part, not basically from the material aspect of the vibration control or the passive vibration control.

But, this is the last part in this module in which we are going to discuss about the various numerical problems, which are being associated with the real machinery, how we can resolve those issues, how what exactly the parametric features are there, which we can simply you know like measure. And we can calculate rather and we can effectively like apply to the real features of the machine under the exciting forces.

Thank you.