Satellite Attitude Dynamics and Control
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Lecture - 57
Control Moment Gyro (Contd.)

Welcome to lecture number 57. So, we have been discussing about the Control Moment Gyros, the satellite actuator with control moment gyros. So, we will continue with that ok. So, it is a basically a gyroscope put on the satellite, but there are certain modifications ok. So, let us discuss about that, but before that I want to discuss about few fertilities which I told in the last lecture, which is quite important ok.

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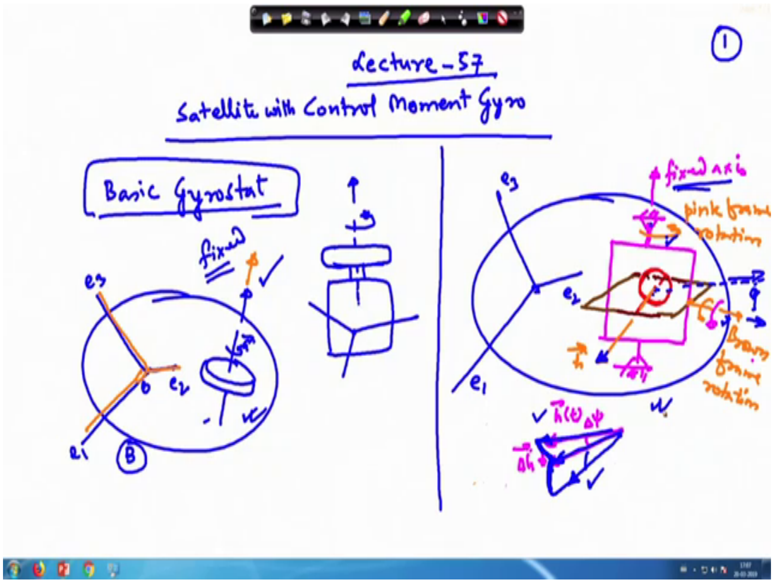

So, in a basic gyrostat what we have that there is a satellite body main body which we have written as B, and inside this there is a wheel which is rotating on it is axis, but this axis remains fixed which we are showing, as a or either we are considered at the same thing can be something like this. I have a satellite and outside this there is a wheel. So, this wheel is rotating about this axis ok. So, it is rotating this wheel is rotating.

So, these 2 cases are same only thing here, this is outside and this is located inside. In both the cases with respect to the satellite main body, if you see that if I fix anybody frame here ok. So, this axis of rotation which is here in this direction which is here in this direction with respect to this frame it remains fixed. It is not changing ok. So, this is the characteristic of a basic gyrostat. Now once we are we were discussing about the control moment gyros, so that difference there was that I have a satellite here ok, inside this there is a control moment gyros, which we have made it something like this. Say we have shown one outer frame, and this frame is reported in this satellite. So, this axis is fixed in the satellite. This axis is fixed ok, so, the fixed axis.

Then we have the inner frame or the inner gimbal. And there after we have a wheel which is rotating here. So, this is a wheel which will be rotating about this axis this 1 by dotted line insects on the back of this figure ok. So, here in this case what we see that the angular momentum of this wheel, let us show it by some other color this wheel is rotating about this axis ok. So, it is angular momentum I can show it by h. In this case with respect to this body axis this is the body axis. So, with respect to this axis this direction is fixed, but here in this case what happens this is one gimbal.

So, satellite can rotate about this, sorry this frame the brown frame this is the brown frame is rotating here brown frame rotation here. And in this place this the pink frame rotation takes place. So, this way you can see that this vector the h vector which is looking here like this. Because of this pink frame rotation, it will rotate to this direction. And it will become like this ok. Say this is initially horizontal. So, it will come to this position. So, the change position will look like it has gone from this position to this position ok. So, this changes taking place is the delta h. Initially this is h. Now after this once we rotate about this axis ok, once we are rotating about this the brown frame rotation axis ok so, in that case this will then go down what you have seen here. So, better I will make the figure little bit I will change it.

So, let us say this is the h vector initially. And from here then it is changing to this position. So, this is your delta h removing this ht plus delta t ok. Thereafter what is happening that because of the rotation about the brown frame? So, this rotation has taken place. So, this angle is say the psi or delta psi whatever. So, brown frame rotation will take it down. Once we have given this rotation and there after we are giving the brown frame rotation. So, that we can indicate by some other colors say this is going and down ok.

So, this is 1 plane movement and thereafter this is going down. This vector is from this place to this place. It comes here in this plane and then it is going down we can see that how it is looking ok. So; that means, this from this h vector has changed from this place to this place finally,. While here in this case in the so, this rotation is with respect to the body frame which I can fix here in this place. Let us say this is our e 1 e 2 and e 3 direction; so (Refer Time: 07:58) here this is e 1 e 2 and e 3 direction ok.

So, in the gyrostat, this direction remains fixed. So, this is fixed while here in this case this axis is fixed, but this axis is not fixed you considered this axis will also rotate if you rotate it like this. So, this axis will move from this place to it will go to this side. From here to here it will look something like this it will move from this place to this place by psy angle.

So, neither this axis is fixed neither the, this rotation vector or the h vector which I am associating with the angular momentum of the this wheel ok. This is neither remaining phase because this will change due to this also and due to this also because of this and because of this also. So, this case becomes complicated as compared to the gyrostat. So, this is the difference between the cmg and the gyrostat motion vise. And there are other things also which are different. So, I will point out the related mathematics and it is very important what I told yesterday the last class.

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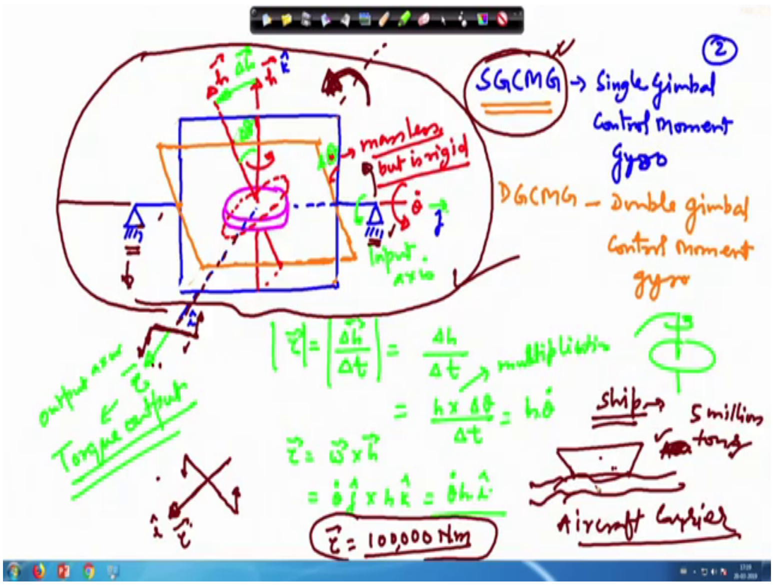

So now let us look into the what? We have been discussing about the single frame control moment gyros or for single gimbal single gimbal control moment gyro. This is also called we can write as single gimbal control moment gyro. So, for the single frame or the single remote control moment gyro, what we have looked at this is rotating on certain axis ok. And there is a wheel this wheel rotates about this axis. And here let us say this is rotating about this axis. So, it is angular momentum vector this is h. And we will assume for the time being that this is mass less ok, but is it this is an idealization mass less first digit. So, as a result what will happen? That as soon as you rotate about this axis this frame will tilled ok. It will come from this place to it will rotate about this. So, it will look something like this part will go inside it will go inside from here to here. This will come outside and this part will go inside. So, this is the part which is inside here this is the part which is coming outside.

So; that means, if I rub this part, and there is a break I am showing that it is going from the back. So, you will find on the Google the single SGCM and the DGCM means double gimbal control moment gyros, DG CMG. This we call as the double gimbal control moment gyro. So, as shown as we are rotating. So, this will also tilled ok. It is a rotation vector it will tilt from this place to it will come from here to here. And this will go from this place to this place. Means the rotation axis will come to this place. And then your this wheel be oriented like this means the h vector now it is a tilted ok.

So, this is now the h vector and assuming that the wheel is rotating at a constant speed. This angle we can show this is the theta angle. So, here theta dot will be present here in this case. So, what happens here that the change which has taken place this is your this place to this place. So, better we can show here in this place. So, this is your delta h. And as I told you the corresponding torque generated as we have been discussing that will be delta h divided by delta t ok. Here this is not because of the speeding of the wheel, wheel is rotating at a constant speed ok, but the rotation axis is getting tilted ok. You are tilting the rotation axis. So, if you tilt the rotation axis. So, magnitude vise what we have seen and also the vector vise I have shown you this can be written as if I right here in this direction say if I take fix one axis to the this frame the blue frame. So, this axis I take it outside to the blue frame and this axis is going here. If I right here I cap j cap and in this direction k cap ok. So, delta h by delta t we can write as theta dot j cap cross magnitude vise first let me repeat what I have written last time.

So, that I have ok. So, this delta h we have written as delta h magnitude basically this is delta h divided by delta t magnitude vise. So, delta h is nothing but this h vector times this angle which is delta theta ok. Or here this is delta theta ok. So, we write here as delta theta this one. Divided by delta t this is times not cross this is multiplication simple multiplication. So, this is h time theta dot ok. And the same thing in the vector notation can be written as omega cross h, were omega here in this case is theta dot j cap, and h here in this case say it is in the k direction right now. So, we can write here h times k cap. And therefore, theta dot h j times k cross k that becomes i cap. So, this is basically here in this direction. So, the torque generated lies along this direction ok. So, this is your tau this is the torque output. So, we apply certain torque about this axis you have to apply here torque. So, this is called the input axis and this is the output axis so; that means, this torque as you can see this will be a result of this torque. I can show it like this because this is coming here in this direction. So, this is going down one force is going down and one force is coming up. So, here the force is going down and this is coming up say something like this say. one side force is going down and one side the force is coming up and this is the i axis.

So, the torque produced is along this axis. You can see that this is the using the right hand rule. So, tau is here in this direction ok, but you can see that from this figure, this figure little this is slanted it is I cannot show you in the 2 d like this. So, this is a better view here in this place. So, this one actually this line and this line there will be parallel to each other ok. So, this means if you look from the if I tell you that basically this will be perpendicular to the page at the centre of the rotation wheel. This tau vector it will come it will come out from the page at the centre of the wheel and that will be perpendicular to the page.

So; that means, this the axis which is shown here this axis it will be perpendicular to this ok. So, but here this 2 axis are fixed to the satellite ok. This 2 axis are not free to rotate and therefore, if this is inside a satellite say this is the satellite body, ok. So, this whole thing will make that will be torque about this axis means this blue axis which is this shown here it is going like this and it is coming here in this direction ok. So, the this whole satellite will then rotate about this axis because there is a output torque about this axis. So, we have applied a torque about this axis and as a consequence we are getting torque output along this direction.

So, this is the principal of the control moment gyros. So, this is single gimbal control moment gyro. In the double gimbal control moment gyro, I hope this is clear that because of this constant this is a digit constant. So, it is not free to rotate this cannot go down and this cannot go up ok. It cannot go down and this cannot go up. And therefore, it cannot rotate about this axis. So, where this torque will then go? This torque will then therefore, it will be acting on this whole body. And it will move the whole body about this axis. So, using the control moment gyros, we can reorient the satellite. And the single gimbal control moment gyro is can it can produce very last torque. I

n the terrestrial light for the ship ok. There are big control moment gyros too say this is the ship and going in the water ok. There are very large control movement gyros which are used for controlling the ship. Because it is a million of terms it is a weight is there. And such a big ship like the aircraft carrier, aircraft carrier which are there aircraft carrier aircraft carrier, this are very heavy something like the 5 million tones. 5 million or 5 lakh let me call it is a 5 million ton. So, this is quiet heavy. So, to control this if the waves come and these get disturbed. So, to control this you require very large amount of torque ok. So, that torque is generated using this control moment gyros on the ship. And those are those control moment gyros are very large in size and they can produce enormous torque. Single gimbal control moment gyros it is somewhere 100 thousand newton what we call as the 1 lakh, 1 lakh newton meter torque can be generated ok for the terrestrial case using this single control moment gyros. It is a very large ok. In the double gimbal control moment gyros as we have discussed that we have the outer frame which is devoted in the satellite.

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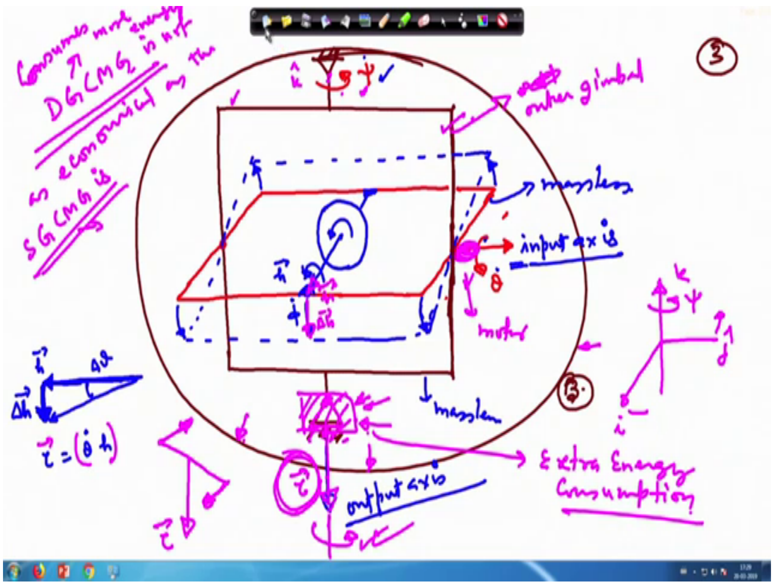

So, this is in the satellite body (Refer Time: 22:34) this is an exaggerated figure ok. It does not consume so much of space. There after we have the inner gimbal which I have shown like this. So, this is the gimbal axis here you rotate by theta here and about this by psi. So, there is a motor which can motor fixed to this one, is the brown one is outside. So, brown one is outside this is inside. And then we have the rotor ok. So, this is pivoted here it will rotate about this axis, this will rotate here and this will rotate here. So, theta dot we can show here psi dot we can show here. And then phi dot we can show here in this place. So, this figure earlier also we have made, but how the actuation takes place today we are discussing about this. So, say I call this again as the input axis. If I do this, so, if I apply a torque a torque is applied using a motor about this axis. So, what will happen? This will go down this will go down. So, we have to show this will come from this place to this place like this and on the upper side it will go like this. And then we need to join this to get the respective frame position.

So, this is the new frame position ok. Now in this situation what is happening that, as the h vector which is say here in this case if I show this axis like this. So, this is your h vector for this rotor. And as usual this is we are assuming mass less. And this ring also we are the inner frame also we are having mass less. So, this is vector which is here this is the corresponding h vector for this rotor which is rotating like this ok. So, this will go down. This goes down by angle here delta theta ok. So, if we look from the horizontal positions. So, this will be almost like a vertical ok. So, this is your delta h. So, but we have discussed earlier along the same line the torque produced will be theta dot times h, but this time the direction is vertically downward ok. Means the output axis is along this direction. So, this is. So, as result of this rotation, this vector the vector which was here the h vector this tilts from this position to and it comes to this position. So, this is your delta h. So, delta h is basically here in this direction. So, this is your torque direction.

So, this quantity, we can write as theta times h. And if I right here say in the outer frame if I define this as the k. And so, with respect to outer frame, the outer frame this direction is k and this we are showing as i and this as j as. So, the outer frame if it rotates y side. So, this will rotate. It will rotate from this position to this position this will go from this place to this place. So, this torque if you look. So, this torque is using the right hand rule, this torque is going down like this ok. And using the right hand rule, how we can produce this torque this is tau. So, this is equivalent to force applied like this in the horizontal plane ok. So, this is the force applied in the horizontal plane.

Means it will covers this external gimbal or this is the outer gimbal, it will covers this outer jumble to process. And so, how those satellite will be then controlled how you can change it is orientation that the question. So, the solution is you do not allow the rotation area in this place using a motor. Whenever it is required you release it and whenever it is not required you use the motor that this torque is nullified ok. So, large amount of torque will be needed to cancel this ok. The torque about this axis. So, you will need a motor here, in this place either here in this place or either here in this place to cancel this torque ok.

So, if you cancel this torque means it is becoming something like a rigid frame it is a fixed instead of here a gimbal, it is becoming fixed here ok. It is becoming fixed it is not a gimbal no more rotating ok. So, this torque will be directly transferred to the satellite then ok. So, as compared to your single gimbal you can see that you will have to use a motor to restrain it. So, that this frame does not rotate and this torque generated here it gets transferred to the satellite main body ok so that the satellite can rotate about this axis. So, the therefore, the satellite can rotate about this axis as shown by this figure ok.

So, the extra motor that you use here in this place one motor you are using here in this place which I am showing let us say this is one motor and one motor we are using here in this place. So, this extra motor here it consumes extra energy extra energy consumption. And therefore, this double gimbal control moment gyro, this is not as economical as your single gimbal control moment gyro is. So, this is not as economical as the single gimbal control moment gyro is. Means this is consuming more energy, consumes more energy also torque vise because if you try to produce a larger torque. So, you need to produce a put a bigger motor here in this place to restrain it. So, that is not good. And therefore, the torque production capacity of the double gimbal control moment gyro it is a lesser than it is a less as compared to the single gimbal control moment gyro. So, this is the basic principle involved for the control moment gyros. Now we can discuss the related mathematics. So, we will continue discussing about this topic about the control moment gyros.

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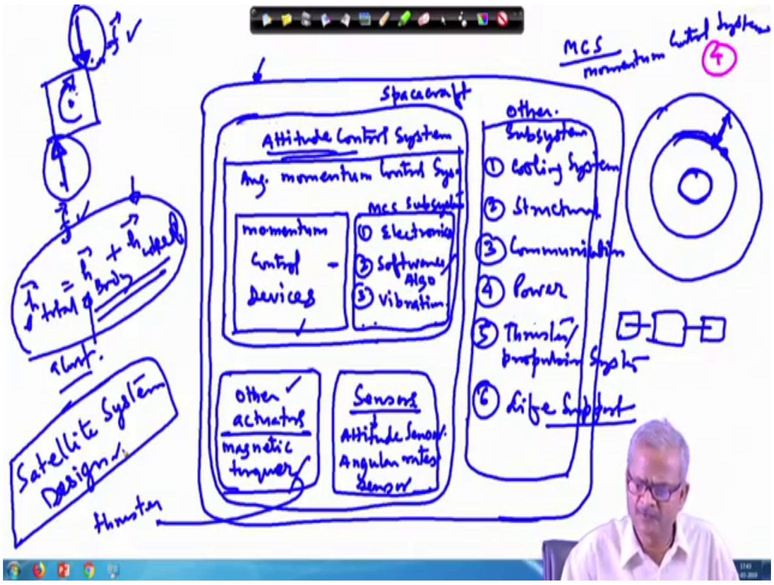

Say this is a block diagram. I am showing this is the spacecraft. So, this is your spacecraft. There after I have one block here.

So, in this case the, for the spacecraft, this is the spacecraft and then for this you have the attitude control system. Remember that your control moment gyros is internal to the system. And therefore, there is no external torque acting on the system as a hole. If you think that a gravity gradient itself acting for a short time in the short run if you are just looking. So, you can ignore that, there are dynamic torque then the other like the solar radiation torque and so on. So, we can neglect those things. So, if we neglect. So, the system it becomes free from the external torque (Refer Time: 34:04) ok. And in that case the system angular momentum will remain conserved. So, your attitude control system which is inside the body just like the control moment gyros and all this. While there is a difference between this type momentum transfer this are call the momentum transfer devices. While here if we will look for the thruster. So, I can have thruster here in this place, I can have a thruster, in this place this produces thrust and this produces thrust. So, using this I can create. So, say if this is producing thrust here in this direction. So, this thrust goes here in this direction by arrow and this thrust it is here in this direction. So, I can produce a motion about this axis which is going inside or coming outside it does not matter this rotation is taking place like this.

So, this thrust they act likes a external torque ok. This forms a couple ok. So, this force let us say this is f and this is minus f. So, they cancel each other, but the torque remains. And this kind of arrangement is used on the spacecraft if you are using the thrusters ok because this does not require any internal moving devices ok. You can have one chamber of propellant and that propellant can be expelled to create the necessary force or generate the necessary force. And which will result in the corresponding torque. So, these are acting as the external force here. While here the control and therefore, acting as a external torque also. While the control moment gyros gyrostat what we have looked in this are all angular momentum conserved system.

Means whatever is there it is inside ok. You can see that the satellite is speeding up, but just opposite to that because the total angular momentum is conserved h total this will be h body and plus h will this is going to remain constant ok. This is not going to change the total quantity. Not the right hand side left hand side is constant if you speed up the wheel. So, this will also speed up, but as a hole angular momentum is going to be a constant if there is no external torque. So, the attitude control system now this consist of we can put it outside and make a box here. So, this whole thing is a attitude control system and out of this these are the subsystems.

So, attitude control system and then you have the momentum angular momentum basically angular momentum control system. Inside this we will have the momentum control devices which is angular momentum control devices. One or many can be there. So, we can write here devices. And to support this device then we can have the corresponding this we can write as the MCS. MCS is your momentum control system. So, MCS, this is sub subsystem. Means what are the things are required to drive this ok. So, what are the other things we can expect? The basic electronics, then the corresponding software or the algorithm, software less algorithm, this can be like that control algorithm. Then vibration control subsystem, vibration control even for this. And of course, other things associated things can be here in this place, but for this system attitude control system to run you need to know the attitude of the satellite also. So, for this then you need the sensors. So, this sensor can consist of like the attitude sensor ok. What is latitude and also the angular momentum sensor, angular velocity sensor angular rates sensor means along the different axis, your measuring the angular rates. And here is the other actuator actuators can be there such as say the magnetic torque it can be thruster. So, thruster can also be there.

So, whatever you can expect. So, in the other actuator we can put it ok. And there are other things other subsystems which are other subsystems. One very important thing for the satellite is the cooling system, which we call as a thermal system. Say thermal protection and cooling one side of the satellite which is away from the sun. So, this is facing very low temperature extremely low temperature and though the side which is facing the sun it will face a very high temperature. And if the satellite is rotating slowly in 1 minute it is rotating on it is axis only one time. So, for 1 minute it will be facing the sun almost one side or say for the half minute. So, if we look this way. So, satellite undergoes the cooling of the structure and heating of the structures, of this generates these are called the thermal stresses ok. So, you need proper management for that otherwise many system cancel. In the case of the Chandrayaan the same thing happened in the case of the Chandrayaan exactly if it is a why it failed once it was put in the orbit.

So, there was the temperature control problem. And because of that some of the sensors failed. And those sensor once it failed. So, satellite attitude cannot be known it is a. Therefore, it become it become very difficult to manage. So, what they did they (Refer Time: 42:42) they increase they increase the orbital radius. Means here this is the moon. So, initially the satellite is in this here this orbit. So, there is the orbit from this place to this place. And there after whatever the data could have been transferred. So, they got it, but the purpose of the satellite was lost. So, they could not control the satellite because of the failure of the sensor ok. So, these things are very important. So, the subsystem then the structural subsystem many things associated things can be there ok. Then the communication you need to communicate with the ground then your power system unit on board power.

So, on the satellite, if this is your satellite or we will put solar panels on both the sides or other designs can be there. Then this actuator system here inside that the propellants and other things you are storing ok. So, we can write here as the thruster or the propulsion system thruster slash propulsion system. And if man is going in the satellite that vehicle. So, then the life support system should also be there. So, it is a very complicated if you look on national geography or any of the discovery channel. So, you find out the how complicated the structure inside the satellite is. So, this is a basic idea about fabricating a satellite what are the things you can expect. So, you can find many books available on the satellite system design satellite system design. So, that gives you a fairly good idea about what are the design requirements ok. What are the problems you are going to face while you are designing the spacecraft? So, everything will be there ok. It will not discuss their the attitude control system in details, but this to give a brief idea about what the attitude control system is ok. So, we will stop here and then we will continue in the next lecture.

Thank you very much.