Space Flight Mechanics

Prof. M Sinha

Department of Aerospace Engineering

Indian Institute of Technology, IIT Kharagur

Lecture No. # 33

Attitude Dynamics (Contd)

We have been discussing about attitude dynamics of the satellite. So, we continue with the topic. So, we were looking into the control flow.

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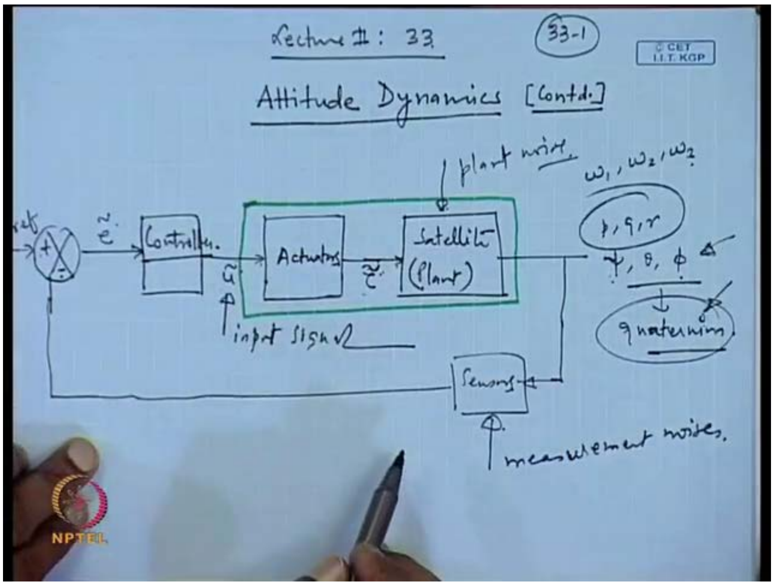

So, we had the control loop in, which we first we showed the plant here, which is the satellite. This is your plant and in the inside the satellite itself the actuators are present, but it is a safe shown as a separate bag actuators. And we showed this as tau as the torque, which is being given to the satellite and then the measurements were done. So, here outputs we are written as p q r and these are the angular rate. So, angular rates can also be written as omega one omega two and omega three, which is more general representation and then we had the angles phi theta phi instead of using this psi theta and phi we will be using the quaternion's. Because we will see that this representation which is called the pi these are the Euler's angles psi theta and phi.

So, they naturally have similarity in their representation therefore, the quaternion's representation we use quaternion representation, which is free from any kind of similarity. So, this is measured here and then. So, therefore, we have the sensors and sensors these are contaminated with measurement noise. Similarly, we can have the plant noise here then the major output it is a feedback. And then we have certain reference signal u reference which needs to be followed. So, we compare them this is the plus sign and here this is the minus sign and then the error is fed to a controller which is basically, a logic system. It maybe logic based just like in Fuzi logic or it may be totally a mathematical description. So, this is your controller and u is this is the input signal, for most of them, if you look into other control system. So, many times it happens that this block is combined together and can be represented as one single dynamical entity. And therefore, we can see that we are feeding if we consider the whole thing as the plants, then we are feeding this u tilde as the input to this plant.

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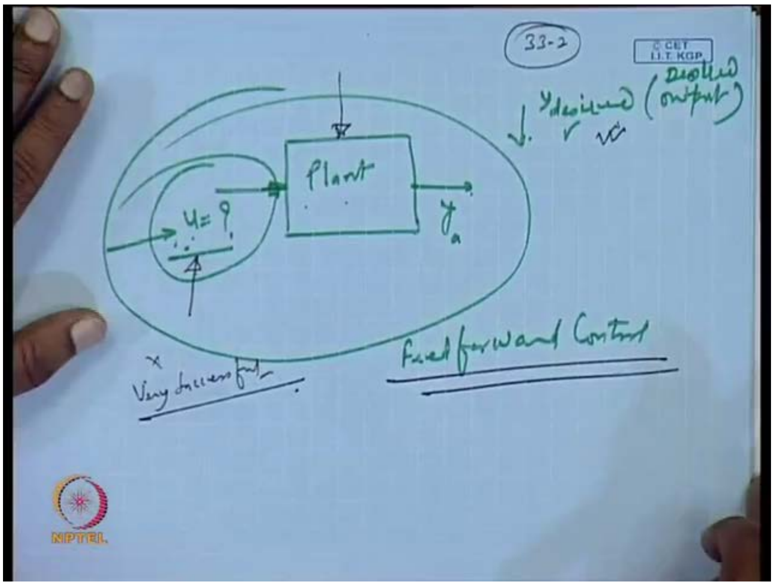

So, in the control system the objective remains given the plant and say desired output. So, y desired this is the output desired output and y say a is the actual output. So, you design the control inputs. So, basic objective is to design this inputs in such a way that you achieve the desired output here so; obviously, if your plant is a dynamical system. So, in that case you can design your inputs to the system or to the plant or priory and this is called the feed forward control.

So, if I have a this kind of control this will be called feed forward control what that disadvantage of this is if the plant parameter changes. If the there are disturbances entering into the plant, then your pre designed inputs to the system to the plant it will not lead to the desired output. And therefore, this kind of control system it is not very successful. So, eliminate this we have the feedback control system that we have shown earlier what we shown here? This is the feedback control system. So, as I earlier stated in the last lecture that we will not be dealing with the controls part in this course that, because this is out of syllabus.

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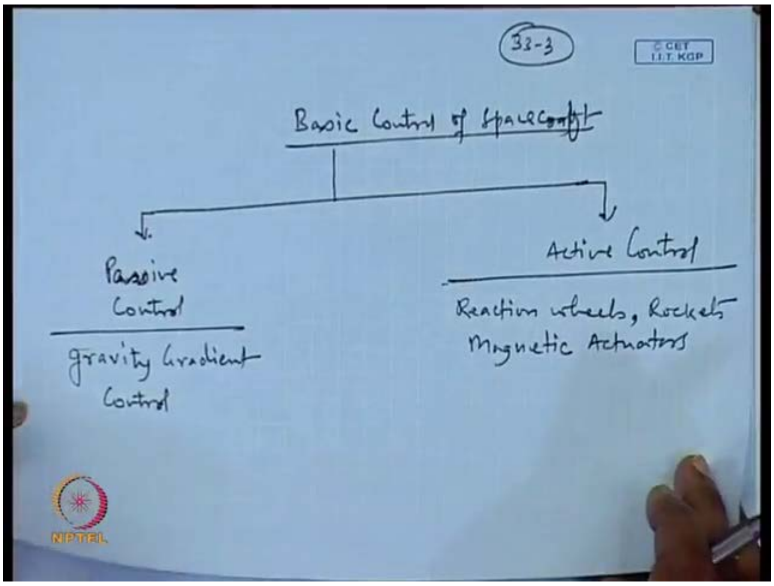

So, let us consider that some basic aspects of the satellite attitude control. So, we will have the basic control of spacecraft this we can broadly write has the passive control. So, in the passive control we have the gravity gradient control in the active control we can cut our eyes like the reaction wheels the rockets. So, rockets are of various types again then the magnetic actuators. And also we can list in this the dual spin dual spin system. So, we are going to discuss all of them briefly.

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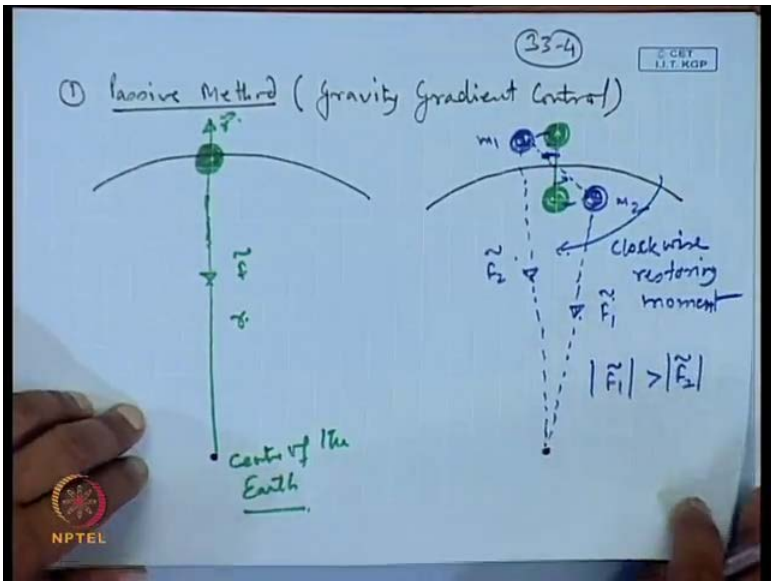

So, in the passive method we have the gravity gradient control suppose, this is the center of the earth and this is the orbit in which the satellite it is moving. So, this is your radius r and the gravitational force it is acting in this direction itself. So, radius vector r is directed outward, while the force vector let say directed toward the center of the earth. So, we have shown it by a small ball, but the satellite configuration may be of different type. So, again make it little good and let us consider a dimples x satellite we have one loop here, another loop here. The center of the earth is in this place, if we disturb this satellite from it is a original configuration.

So, the forces acting on this two loops this is say m one and this is the m two and we assume that this link is mass less. So, we can see from here this distance is smaller and this distance is larger and therefore, f tilde magnitude will be larger than F 2 tilde magnitude. So, this implies that, if the satellite is slightly disturbed from I it is original configuration then it will be the a restoring movement will be generated. So, this restoring movement is here, if we are disturbing it some this direction antilock wise. So, a restoring movement generated we tends to push it clockwise.

So, clockwise restoring movement so, in this configuration we are doing nothing just we have design the satellite such that they are two loops. And we are putting it in this configuration in the orbit, where the one loop is near to the earth and another loop is pointing away from the earth and therefore, this represents stable configuration it will automatically it is automatically stabilized.

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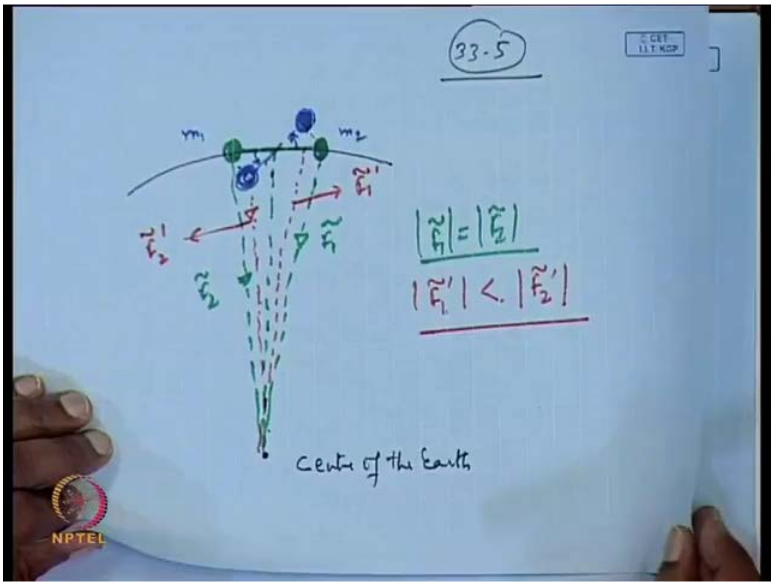

So, whenever some disturbance is coming on the satellite. So, automatically the restoring force is getting generated and it will get back into it is original configuration after some time. Now, consider the same satellite, but the initial configuration say these are the mass m one and m two. Now, if you have the initial configuration like this and if you disturb them from this position so, you move them in this direction. So, you can see that here in this case, the original case the initially they have the forces, which are acting this is you can tilde and F 2 tilde. So, F 1 tilde this is equal to F 2 tilde they are equal. But if this they are disturb by a small amount see you can see that a movement will be generated, which we will take it away from the so, we write this as F 2 prime this is the F 1 prime tilde.

We can observe here that F 1 prime tilde this is smaller in magnitude as compare to F 2 prime tilde. Therefore, in this configuration the satellite is not stable. So, it becomes very important to see the orientation of the satellite like, if we will always not have a satellite, which is spherical in snap rather it may be orbit or it may have difference shape. So, how to orient the satellite so, that it remains it points in a particular direction be it may be a need that it always rotates and only one phase of the satellite points to the toward the earth. So, depending on the need we will have the different orientation of the satellite, but one thing is clear from this place that the same satellite in certain orientation will not be a stable it will not remain in the same position in other orientation it will be a stable.

So, this is because use to the differential gravity, which is present and this is call the gravity gradient control. And you are not doing anything just you have design the two masses separated by certain distance and you have put this in the orbit. And therefore, under the whatever, the depending on the previous design it will, if you certain disturbance comes, it will, if it is in this position. It will tend to return back to original configuration or if it is in this configuration then it will deviate from the this position further more.

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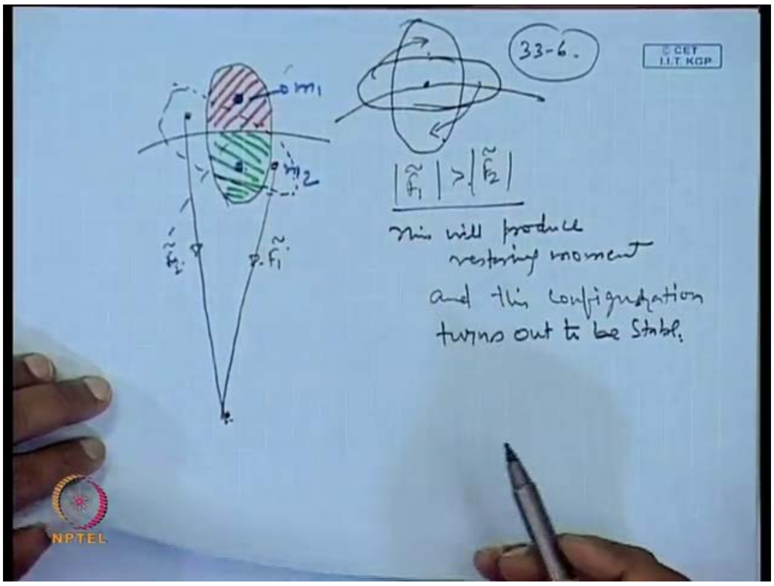

Similarly, look into a owlet shape satellite we can assume that this consist of two loops the center of mass of one lying at this point say this is the mass m one and this is the mass m two and, if this satellite is disturbed from this original configuration . So, immediately you can see that this mass will get this place into this position. And this mass will get this place into this position and this is the force F 1 tilde this is the force F 2 tilde acting on this. So, F 1 tilde magnitude is greater than F 2 tilde therefore, this will produce restoring movement and this configuration turns out to be stable.

The same thing, if you keep it in this way the same satellite, if you keep it like this. So, it will not sustain this configuration it will go and settle down into this configuration after some time it will move like this. So, this configuration we said this is the stable configuration similarly, this was the stable configuration this was the unstable, because this is was the green one was pointing here so, it is going away. So, this is the unstable configuration and we have this one was stable.

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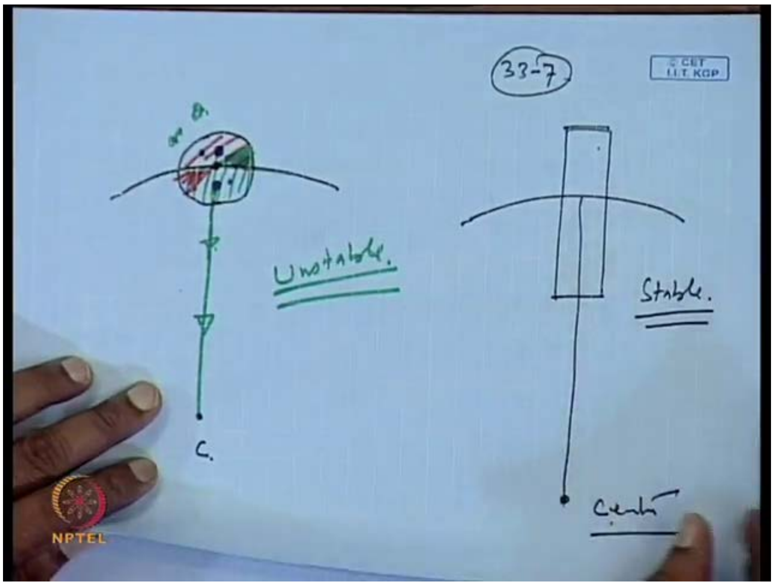

Now, consider another case, where we have a discover sphere and it is lying like this, this is the center of the earth. Now, these are the two half's one center is lying here another center is lying here. Now, you can see that because the symmetry in the distribution of mass about this point, if this satellites get disturbed by certain angle. So, this mass point moves from here to here suppose and this moves from here to here. So, that does not make in a difference in the configuration for the whatever, the portion as gone up suppose, this portion was red portion was here and then the red portion little bit comes down and green portion goes up.

So, if the mass distribution is uniformed so, it will not affect the center of mass of this two loops which is being divided by this line. So, over all we will see that this point is being attracted toward this and this point is also being attacked towards the center of the earth. So, wherever, whatever, configuration you take it if you rotate it y angle theta suppose your rotating it by going there and rotating it by angel theta y and then leaving it. So, if you do that it will remain in that same configuration and if you give it certain angular velocity then it will keep tumbling for all the time.

So, this we say this configuration is on a stable on the other hand if we have a rod sets satellite or the this is rectangular this is the center. So, this configuration is also stable by the same region. So, thus we see that by using the gravity gradient, which is the passive type control it is a possible that the satellite can maintain a particular direction. However, this kind of control this is only for the stability purpose only for pointing in a particular direction, if you keep the satellite, but not for suppose, you want next to reorient this. So, you cannot do it. Because if you do not have anything here any rocket or any reaction will on this to reorient it is not possible. So, the passive control it is an only meant for stabilizing the satellite nothing less.

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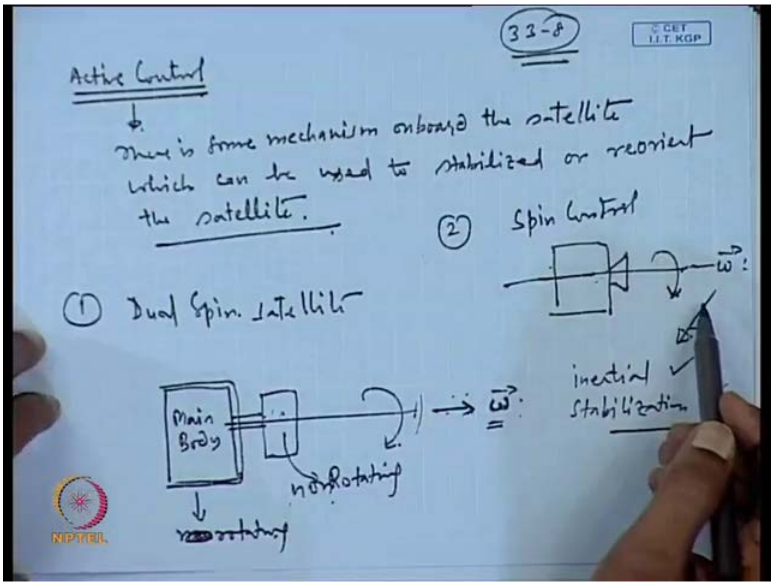

So, this passive control is over then we take the active control. So, active control implies that there is some mechanism on both the satellite, which can be use to stabilize or reorient the satellite there. So, in this category it is possible that we can bring this is the dual spin system. So, in the dual spin system what will happen? As we will see is dual spin satellite we will have the main body here is a non rotating. And to this one rotor may be attached, which is rotating or you can assume the different way that this part is non rotating and this part is rotating. So, if you are part some of the instrument, which needs to be point in a particular direction. So, you would like to make it non rotating suppose, this you there is an instrument, which you want that it does not rotate.

So, let us make it non rotating and make it rotating and this is the large body and if this rotates then the and suppose, this is rotating like this. So, you have the angular velocity vector which is directed like this. So, angular velocity vector directed in a particular direction this gives inertial stabilization, if you try to disturb it from this place. So, if you want to disturb the satellite you need certain amount of torque. So, if the angular velocity is large see the required large amount of torque to change the direction of this satellite. And therefore, if we assume that the disturbance torque are small and that we will not mix the satellite deviate much from this orientation. And therefore, this can use for the inertial pointing or the what we have call that inertial stabilization.

So, why it is done like this the actual configuration. We can take it as the another one the a spin control see in the spin control we will have only one body here and let say spinning about this acts. So, if it is spinning about this x and this is the angular velocity vector. So, it will be pointing in a inertial this is also for inertial stabilization, but the problem will be that, if you have certain component, which need to pointed in a particular direction then it will become difficult, because all the parts are rotating about a particular axis.

So, we take it further more here say this is the center of the earth suppose, this is the my satellite and this is the transponder, this transponder need to points toward the earth for the communication purpose this is the antenna. Now, you can see that if your satellite is rotating like this. And you have inertial stabilized it we have given a large spin about axis what will happen? This will try to maintain this orientation. There is no other rotation for the satellite. So, after some time we will see that this is coming half of this line so, as it goes in this direction, if it is in oriented in this direction only. So, the communication is lost very fast while, if you have an orientation, where the satellite is turning in this way instead of orienting like this.

It is also turning in this way then you will see that what the advantages, what if you are giving a very large spin about this. And then, if you want to make it turn also in this direction it becomes difficult. Because this is initially your stabilizing it and giving in a torque to rotate about this axis then you want to rotate about this axis. So, that it comes in this position. So, it will not impossible, but it becomes energy consuming, because you need energy to rotate it and for either omega vector is magnitude of the omega vector is large.

So; obviously, the amount of torque, which is required to rotate will be large and we will be unnecessarily wasting the energy and moreover the communication is lost. So, this is the limitation we can make it one and we can make it two. So, this puts the limitation on the use of this kind of the spacecraft. So, for spin control this is the fine for initial inertial stabilizes on, but it is not good for many cases. Similarly, the dual a spin one here the main body is rotating and then may be some portion of this, which is being used for a particular purpose. It is a non rotating so, will list some of the advantages and disadvantages of these two.

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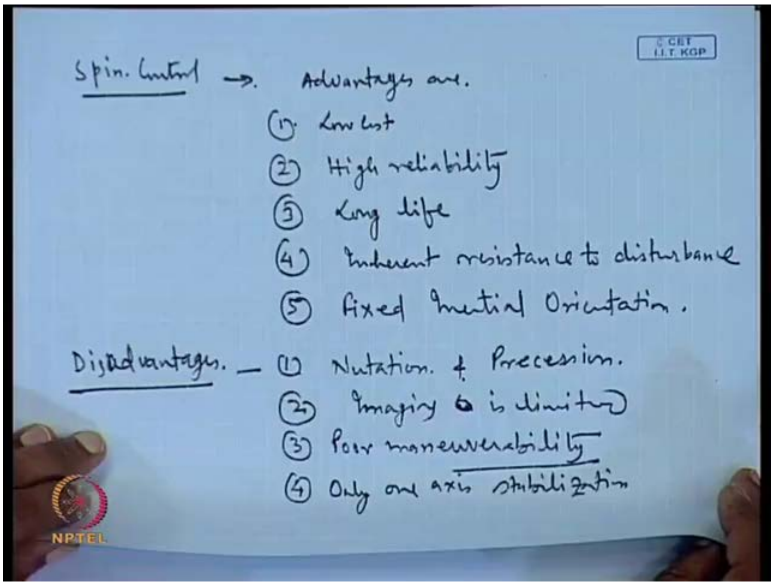

So, in the spin control advantages are may be low cost to design it high reliability long life invariant resistance to the fixed inertial orientation besides we have disadvantages also. This type of system under disturbance it will go notation and precession imaging is limited. You can see here that, if you this is your camera and this is rotating fast. So, if it is rotating you will see that you would not be able to picture it long, because your camera is directing it like this and you want to picture this area. So, as soon as it comes in this position this is pointing away from the field of view of the camera and here it is totally away from the field of view of the camera.

So, imaging is limited and as I told you it is resistance to the disturbance. So, also the poor maneuvers ability changing it is configuration changing it is orientation it becomes to role reorient spacecraft it becomes tough. This way you can do only one axis stabilization if you are rotating about this axis. So, it will stabilize only about this, but not about the other axis though the to a small torque it is stabilized in this direction. So, in naturally it turn to try to turn in other direction there may be problem, but a still you will see that it is a only one axis stabilization not about all the axis this is very easy to see. So, only one axis here in this figure you should note that, if I try to turn this vector from this position to this position.

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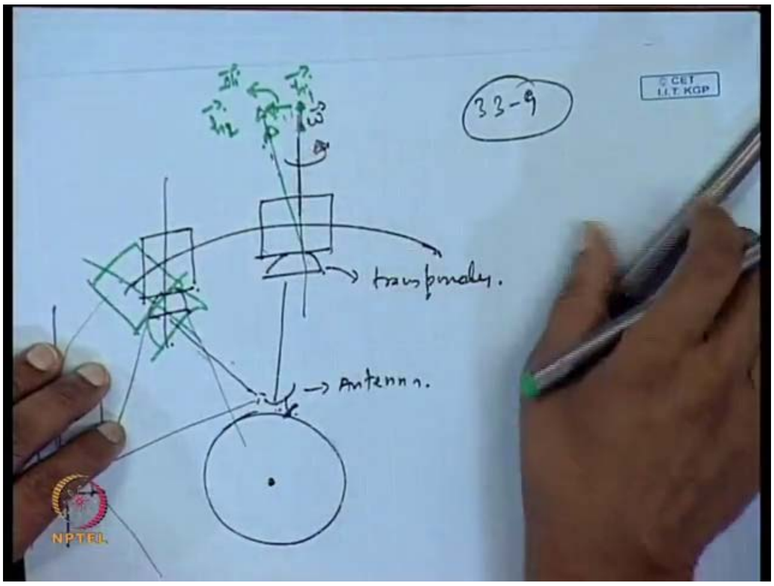

So, here suppose, the angular momentum vector is also pointing in this direction and next you have angular momentum vector say this is h 1 and this is h 2. So, after the orientation it gets reoriented. So, there is change in the angular momentum vector delta h. So, this delta h is produced from the external torque need to be applied to this to change this momentum angular momentum vector from this orientation to this orientation. So, if there is a disturbance acting on the satellite. So, it can go from this position to this position, if they provided the disturbances very large. So, if the disturbance is small.

So, the deviation will not be as large as I have shown in this figure for a small disturbance it will be deviating only various by a small quantity. Similarly, you can think of the disturbance giving been given in these planes and therefore, the omega will turn in for this axis also. So, this is the orientation inertial stabilization and if the orientated in a particular direction and there by it is orientation in other direction also say the other three axis. So, if one axis fixed towards one particular direction So, at and if it is resisting the motion from that orientation.

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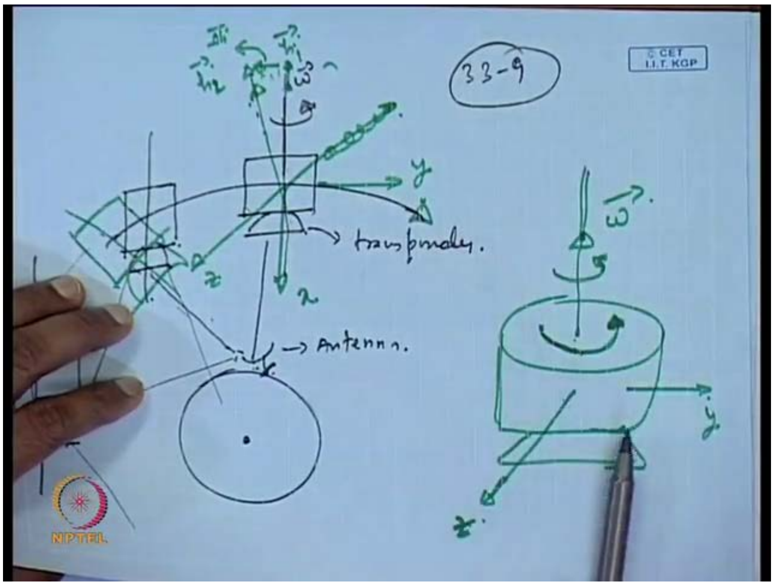

So, therefore, it implies that it will remain there, but say the I have this axis here and another the propend axis, which is perpendicular to this and let us name this as this axis as we can name this as x and suppose, the satellite is moving in this direction. So, we can write as this as y and this we can take as the z so, if it is rotating like this. Now, the whole satellite is rotating in this way this is your actual satellite in this we have shown as y and this direction we have showing as, if a torque is acting on this spacecraft such that is a tend to rotate it fast.

The torque is assisting this motion so; this will become rotate further at a higher angular rate. Now, the problem with this will be you do not what to do not, what that your system rotates at such a high angular rate though the rotating at a high angular rate; obviously, is beneficial to you. Because it is a pointing making it point more in more resistive way in this direction, but such thing, where the angular is speed is increasing for some or other reason. So, you must countered and for counteracting, if you do not device other things so, it cannot be done.

So, the alone the dual spin spacecraft though it is a stabilized about one axis it may be creating problem for you. So, in a sense here for we can say that the one axis stabilization it is say giving it is a fixed orientation, but it is not making it mu to rotation about it is an own axis and for counteracting that we must do some prevision. We must provide the reaction will saw any other thing. So, that is the angular speed is does not keep increasing.

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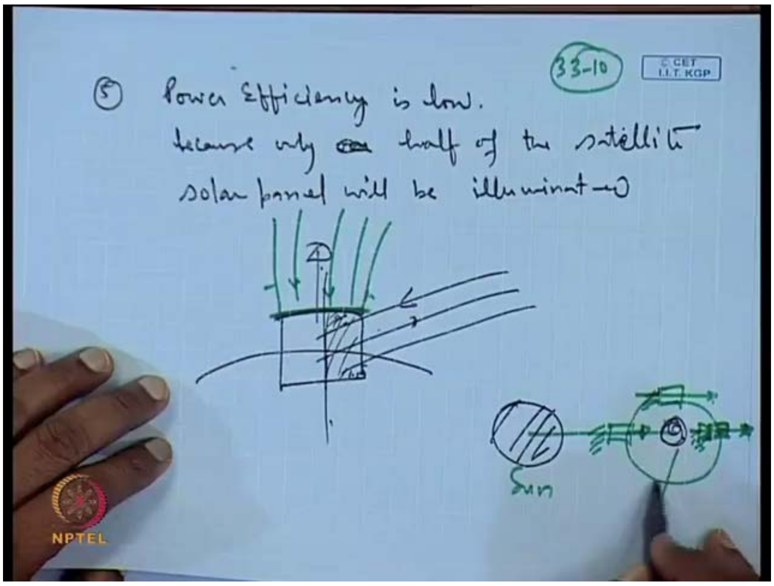

So, next we have is the fifth number we can list it as over maneuvers ability we have done already. One axis stabilization and then power efficiency is low, because only half of the satellite solar panel. So, if it is orientation is fixed and says it is getting eliminated from this direction. So, only this portion will get eliminated or let us say that it is getting eliminated from this direction. So, only this portion is getting eliminated as the portion will not get eliminated. So, for this we need to look into the configuration of the sun and the earth.

So, we have see sun here in this position and there is earth an around the earth this satellite is rotating this is your sun this is earth and the satellite is rotating around this for such satellite reaches oriented towards a particular direction. So, all the time it is oriented in a particular direction in this direction. So, you can see that only this part is getting eliminated all the time. So, it is power efficiency is very poor next we take the dual spin satellite.

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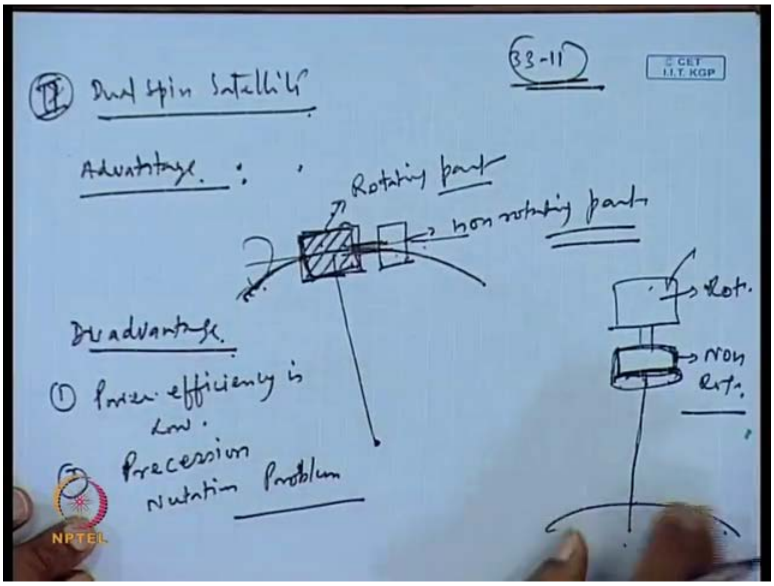

So, advantage of this. So, this is the rotating part and this is the non rotating part so, this non rotating part like this part is rotating to stabilize it along certain axis. So, because it say connected through one sat here and therefore, it will be it is a possible that it will rotate only about this axis. And if you oriented over this side down so, if you make it pointed in this direction so, this is rotating part and this is non rotating part. So, let this part rotate, but if you suppose, you are having a camera over this and you want to take a photograph on the earth, then it is a possible that you can get a good photograph.

Because if you are camera is rotating then the quality of the photograph will tend to blur similarly, for the as for the spin aircraft the power efficiency is low then for as per the spin aircraft the if there is a precession notation problem will be present. And you need some active control if you have to change the orientation; obviously, you require some active control.

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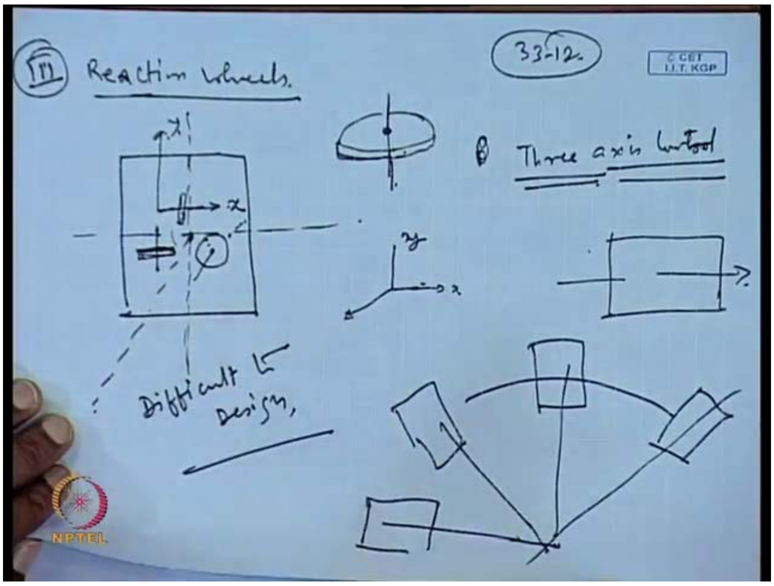

So, then we will have the reaction wheels and third we can list as the reaction wheels or the rocket motors will be the fourth one in the reaction wheels suppose, I have satellite here. So, I can have three reactions wheels one oriented like this, another oriented like this. So, these are the disk so, this is nothing but disk this is rotating on, which can rotate on itself. So, one disk can be fixed here this is the axis of the disk another one can be fixed like this. So, let us say this is x direction and this is y direction and in the z direction another disk can be fixed. So, we have the x y and z coming out here in this way. So, we can have a disk this is facing like so, this three disks can be rotated and as you rotate the disk in one direction. So, he known that the opposite reaction will come into picture.

So, that will tend to rotate the satellite in the opposite direction. The satellite then it will rotate about it is that particular x. So, we can device a plate form and keep it near the center and we will have that three disks, which will rotate at very high speed these are a small disk, but they rotate at very speed and therefore, you can provide three x control. And therefore, you can use this satellite as per your need if you want to make it point in a particular direction that is also possible the in inertial orientation. If you want to do it or either, if you want that your satellite as it moves in the orbit it keeps pointing toward the earth that is also possible with this. So, if you can complete your mission very easily using this what this is difficult to it is difficult to design.

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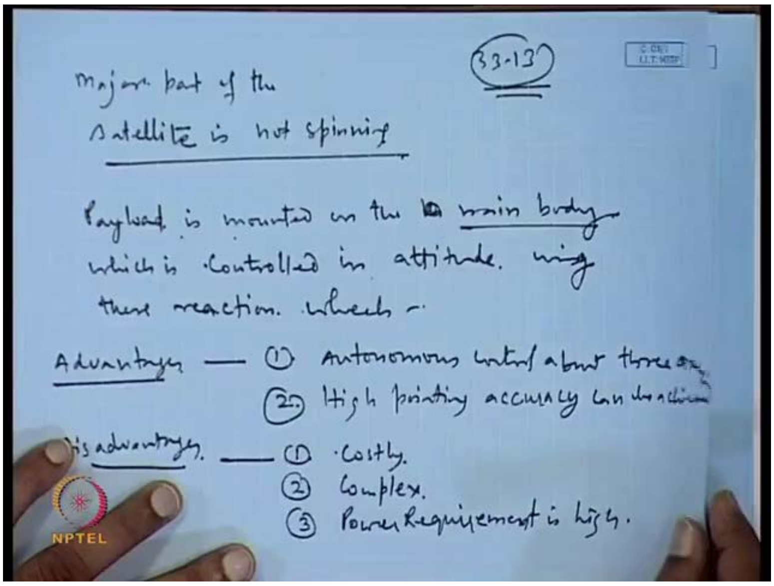

So, for reaction wheels satellite major part of the satellite is not a spin k load is mounted on the main body one load is control in attitude using this reaction wheels the one load is mounted on the main body, which is controlled. So, the main body controlled in attitude this reaction advantages are after normal control about three axis three axis. I pointing accuracy can be achieved this advantages are it is costly. So, instrument designing such instrument is a takes lot of money it is a complex power requirement is high the rockets.

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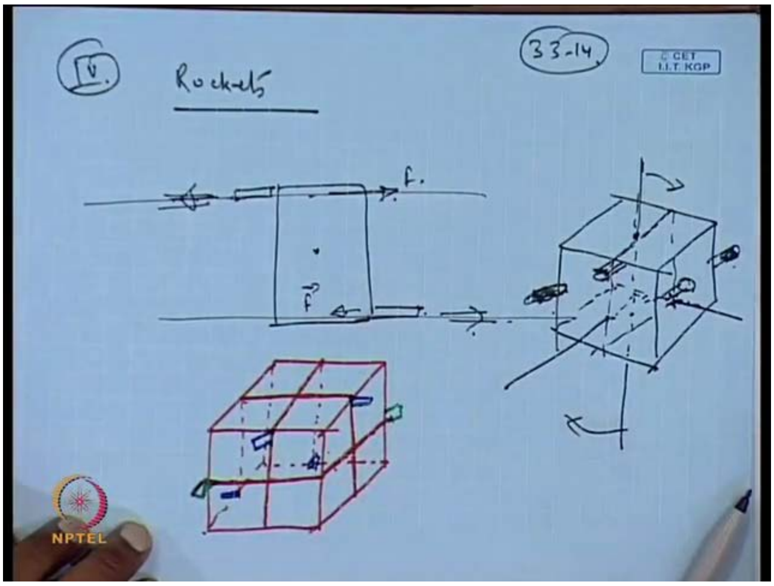

So, in the rockets, if you consider the use of the rockets for attitude orientation so, rockets are required in pairs say, if this is the rocket and if it is firing in this direction rejected mass in this direction. So, this can be used to provide the control about this vertical axis, if it is this two forces are once the mass are expelled in this direction. So, the force will be applied in this direction, if the mass rate expectation is same. So, all this forces will be acting like this we will provide torque about this axis. So, such three pairs can be install on the satellite main body say one of them can be installed here another can be another can be installed.

Here in this place this is on the another case, but on the bottom side k one you can install here in this case, another one you can install here in this place. So, these two together this will give orientation about it will rotation like this. This axis will go up or down, while this two it will rotate it like this. So, we have put in on this phase and we have put also on the vertical phase. So, what is remaining? The putting it on this phase and see here once you should remember that this needs to be fit this need to be fixed in proper position if we are putting about the center plane of symmetry.

So, if I have this is the plane of symmetry from here. To here you can see or I will make another graph. So, these are the plane of symmetry I am cutting this block into different blocks by using the plane of symmetry. So, one is particle then the horizontal one and similarly, I can cutting using this plane also. So, you need to out here rockets one here in this place another just you have put on the opposite place basically, going vertical down from here. So, you can put it here in this place similarly, one rocket you can put here in this place. So, another one you will be putting here downward here in this place.

So, this phase is covered this phase is covered and you need to so, this phase will give rotation like this phase will give rotation like this, we need to cover one this phase. So, we can put one here in this place an another one we can put here in this place. So, this three x we have three pairs of rockets and once you fire them in pair. So, you will be able to provide the three x control. So, this is the basic an atom of the spacecraft how the things are put and how the things are designed. So, we stop it at this point and continue in the next lecture. Thank you very much.