Satellite Attitude Dynamics and Control
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Lecture – 69
Satellite Attitude Control using Thruster

Welcome to the lecture number 69. So we will discuss about the Attitude Control of the Satellite using Thruster. So, it is a very simple problem.

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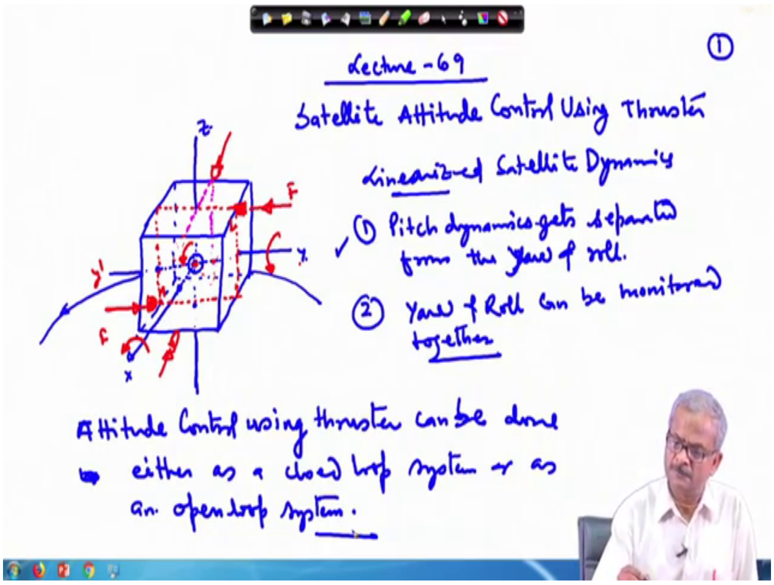

So if we have the thruster located just above the y axis here in this place and this is the c g of the satellite. So, one thruster is located here in this place and another thruster on the opposite side here in this place ok. So, this is along the y axis, this is y prime and this is we are dropping perpendicular here and we are dropping perpendicular here. So, this angle is 90 degree and this angle is also 90 degree. So, these are two thrusters.

So, if you locate your thruster this way, so what is the benefit that this will produce thrust like this and this will produce thrust like this. So, this will be the direction of the thrust and because they fall in the same plane, this is the plane, it is going like this and then it is coming like this and from here to here this is a one plane and this plane passes through the centre of gravity. Therefore, if you have two such pair of the thrusters which produce the same thrust ok, so there would not be any acceleration of the centre of gravity. Centre of gravity will not accelerate.

However, these two forms this is F and this is F. So, these forms a couple and it will produce a torque here in this case which is along the x direction. Similarly, if we have thrusters over this axis and one is located here and another we have to locate on the bottom side here which I cannot show here or either show let me about this c g. So, another thruster I can locate just below this here in this place. So, you have another thruster here. So, they fall in the x z plane and it will produce torque about the y axis.

So, if this thrust goes from this side and the thrust from this side, so this will be along the negative y direction. If we on the other hand if we put the thruster here in this place one thruster here and one thruster just below this here in this place ok, so this thruster will be like this and this thruster will be like this. So, this will form a couple which will produce torque along this direction. So, depending on where you are locating the thruster, so accordingly the thrust where this torque direction will be decided ok.

So, I am removing this part and keeping just these two. The same way you can do for the x axis, y axis and z axis we have to do and control using this is very simple at least in the case of the satellite dynamics which is linearized ok.

So, for linearized satellite dynamics your pitch dynamics gets separated from the yaw and roll ok. So, this can be controlled separately if you are doing for a small angular deviation and yaw and roll can be monitored together. So, this is your orbit in which the satellite is going and location of in which direction you want to choose the x axis x orbital y orbital. As I have shown you it is flexible as you choose the axis notation. So, accordingly you are changing the equation of motion. There is nothing great in all these things ok. So, attitude control can be done either as a closed loop system or as an open loop system.

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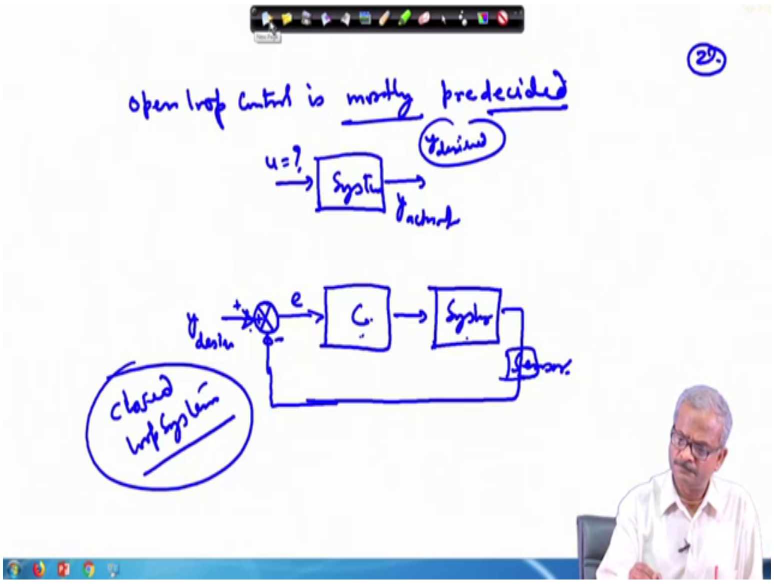

So, open loop system open loop control is mostly pre decided ok. That means, you have a system here what you want to do with this y desire here, you should have this is the actual output of the system design this control u. So, this you are putting in the open loop. If we do the same thing in the closed loop means I will put y desired here in this place ok.

So, this becomes my reference value, this plus and here minus and we design a controller here as we have done earlier also and here is your system and there maybe sensor also. So, sensor we are not showing here ok. So, its feedback is taken and controller is appropriately designed and the system is controlled. So, this constitutes your close loop system. I hope I am clear to you because these are from your linear control system which is prerequisite for this course.

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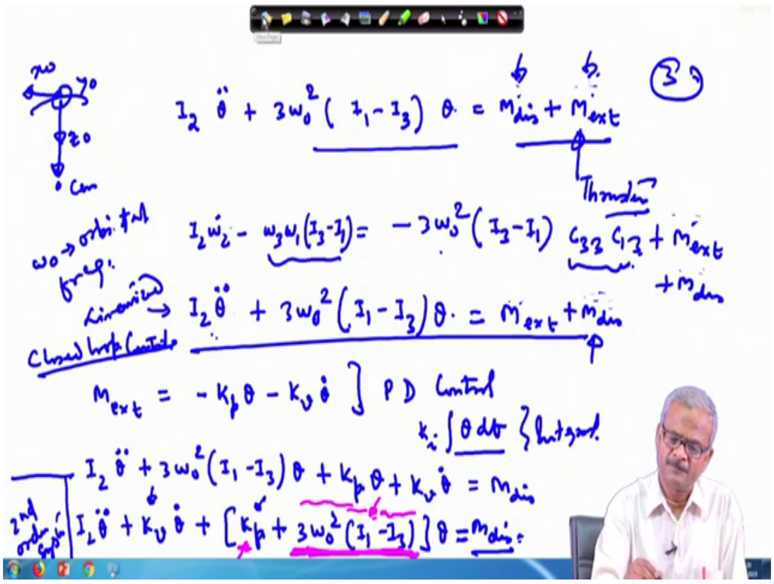

So, for the pitch dynamics if you remember already we have written I 2 times theta double dot plus 3 omega 0 s square. This was on the right hand side. So, this comes on the left hand side I 1 minus I 3 times theta the external torque. Basically, this is the disturbance torque and this is the external torque which will be applied.

So, here M external due to the thruster will come here and the gravity gradient part if you remember we have written like this if it is I 2. So, we had I 2 times omega 2 dot minus I 2 times omega 2 dot minus omega 3 omega 1 times I 3 minus I 1 on this side and on the right hand side, then you had the this torque comes due to gravity gradient external one whatever they were.

So, the same sequence also follows here in this case and then there was C3 depending on in which direction you are choosing. If you are choosing this, this is the centre of the earth and if you choose this has the we have taken this as the x 0 as this direction and z 0 is this in our analysis for the gravity gradient and y 0 going inside x 0 y 0 z 0. So, in that case it appeared as C 33 and C 13.

So, this we have reduced it, so, this appears here in this format. So, if you bring here on this side this part vanished ok. For the case we have discussed you go back and look into that. So, for a linearized dynamics only we get this term and plus 3 omega 0 is square and this term minus theta appears from here. So, this one is I 1 minus I 3 times theta and on the right hand side, then it remains M external and plus M disturbance.

So, we write here M external plus M disturbance. Omega 0 is the orbital frequency orbital. So, now this M external if you ignore the case will become very simple and M external you can choose in the form of because this is only along the y axis. So, this vector notation we can drop here, this can be dropped; this can be dropped; all this can be dropped ok. So, M external then becomes for the closed loop control we can put this as minus k p times theta minus k v times theta dot.

So, this is your PD control ok. If you want to improve on this, then you can put a i d part means we have to add a k i times theta d t. So, this is I part integral part, this is the integral part. So, if we insert here in this particular equation, so in the linearized form this one is appearing as theta 2 theta double dot ok. Theta 2 in this case is theta double dot. So, this is the linearized case and then M externally we insert here in this place, bring it on the left hand side k p times theta plus k v times theta dot there equal to on the right hand side, then only M disturbance will appear.

So, I 2 times theta double dot plus k v times theta dot and then we can write it as k p plus 3 omega 0 square I 1 minus I 3 times theta this equal to M disturbance. If there is more have naturally the disturbance it remains there and that disturbance, but over a short period of time you can ignore ok.

Until unless it is a very high disturbance, like the aerodynamic torque and then the solar radiation torque, they are very feeble ok. So, for over a short period of time you can ignore it, but if you are looking for the stability analysis of the system, so at that time we take into account and we do it quite often because whether under the action of disturbance your system is stable or not stable. So, that becomes important. This kind of disturbance they input energy into the system ok.

So for and some of them may have potential for destabilizing the system. So, therefore it is quite often in most of the cases almost for its a customary to take the disturbance and model it where the what will be the highest value of the disturbance. Its magnitude is taken for the analysis in the what is done that you are trying to proof this stability of the system. So, we will assume that the maximum distance disturbance amplitude will be this much ok. So, based on that then the analysis is carried out.

So, this system if we look it is a second order system. So, by appropriately choosing this k p and k v you can place the poles of the system in desired location and therefore, you will get the desired result from the system. The term which is the gravity gradient one this particular one this is will be quite a small as compared to this is in your hand ok, but this is not in your hand. However, this quantity is small as compared to this.

So, if you are not doing stability analysis rather you are just doing some temporary control. So, this can be well it can be dropped out and only with this part, then you can do the control that may consist of reorienting the satellite ok. So, the same way then you can proceed for the yaw and the roll one, but they are coupled. So, little care is required for that ok.

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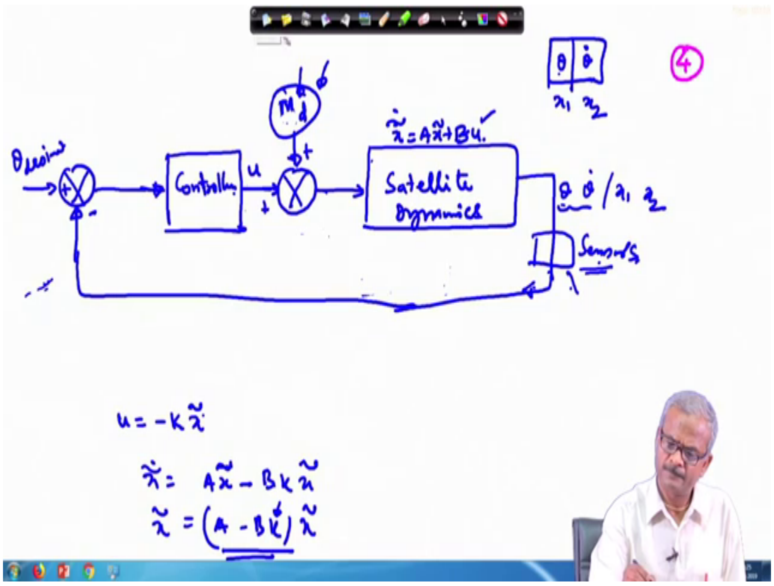

And the control proof for the magnetic actuated satellite I will be uploading that will also will applied to this cases. In that case we are averaging the system by putting it in a standard format. You do not put the system in the standard format, take it as it is and then apply the same kind of the same Lyapunov function and then workout.

So, the here in this case, so our control block it looks like this. This is your satellite dynamics or the satellite system which in the linearized form it can be written as Ax plus B u ok. Here in this case you have already taken u. So, for u is taken as say minus k times x tilde. These are all x tilde u equal to minus k times x tilde as in this case and x tilde is the state. So, here in this case theta and theta dot this constitutes your states two variables. This is the single variable, but in the feature space you get these two, you can write as x 1 and x 2 ok.

So, from there we have then the r dot equal to A x tilde minus B times k x tilde and obviously, you know this must, you must be aware of all these things. So, by using the proper k we will be able to place the pole of the system poles of the system in proper place. So, without sensor this is the situation, this is the controller here in this case controller.

So, this control input we have written as u. The same external this is nothing, but here u here in this case. So, this is the control input going to this system. So, this u and then to this the disturbance will be added. So, torque due to t disturbance, this plus plus and here you have the difference value theta desired you want to achieve certain value of the theta. So, this composes the closed loop system ok.

So, if you are adding the here the this is not the thrust, this is the torque or here M disturbance we have written M d, this is your M d. So, if disturbance is also present, so you need to take into account that also and some disturbance rejection filter may be required also. The sensor you are measuring here the sensors are there say so for this sensor here theta and theta dot these are the two outputs you are getting here we say x 1 and x 2 ok. So, this will be measured by the sensors ok. So, sensors can also get in the noise. So, this noisy input goes here in this place. So, all these things must be taken care of while designing the control.

So, we are not a this is not a control design course and therefore, we are not discussing those issues, but how to go about doing all these things you can carry out using this kind of block diagram a simple control you can always design ok.

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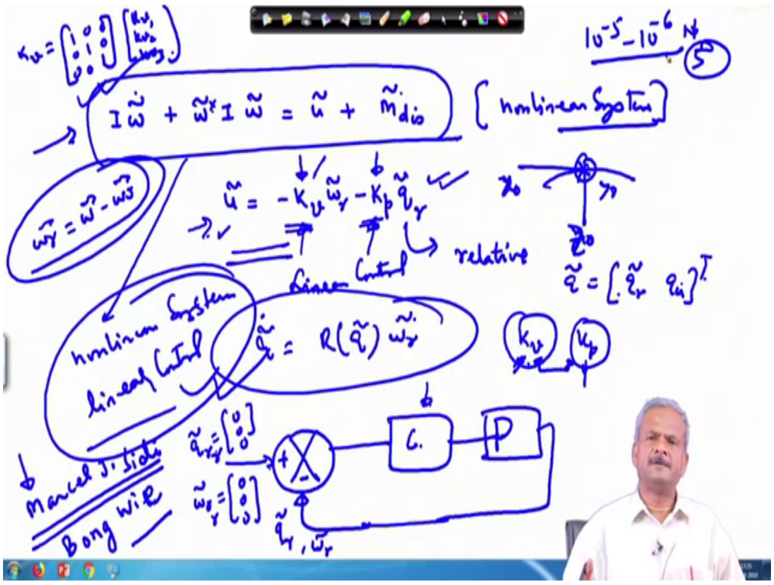

So, this is your non-linear system; if you are looking for dealing with this system. So, still you can u is the same kind of formulation k p times one is omega tilde r. If you are trying to do with respect to the orbital frame, this is your orbital frame x 0. And this is z 0 and y 0 going inside.

So, if you are looking for orientation of your space craft with respect to the orbital frame, so for you can do it in the same way as we have done for the magnetically actuated satellites. So, this is k v times omega r minus k p times the altitude. So far if you are doing for the non-linear system, so it is better to do in terms of q r where q r this is the relative referring to the q tilde which is the quadrenian vector q r times q q r tilde, then q 4 transpose and omega r has the usual definition that omega r will be equal to omega minus omega 0.

So, this since we have done for the magnetically actuated satellite, so using this you can do the control you can choose as I will be giving you the materials for uploading the materials. So, there we will see that how to choose the k p and the k v, k v and the k p value ok, but this kind of problem it will not form part of the exam. This is for your knowledge, this is for your information because it will become too large to tackle for all these problems. So, using this is a linear control, but your system is non-linear. This is the non-linear system.

So, q tilde you know that q tilde dot will be R q tilde times omega r tilde. So, use this and this along with this control to solve your problem ok. You can by trial and error also you can fix this k p and k v, but if you use the stability or Lyapunov stability analysis, it will give you a range. We have to choose k p and k v and then it will be easier, ok.

If already you have proof mathematically and then choosing this value it become c g rather than doing trial and error ok. So, this constitutes your non-linear system and for that you are using linear control. This is linear control, but proof will come from the Lyapunov system for this one Lyapunov stability analysis ok. So, what you are looking for you have to do it in that way only. So, here in this case q r will be equal to 0 0 0. This is the desired altitude and omega r tilde. If you are looking for the relative angular velocity with respect to the orbital frame, so we have to feed it this way.

So, this will be the controller here and q r measured will come from the other place. So, this is q r reference value q r r and this is omega r r q r tilde and omega r tilde will come from the satellite sensors. So, this is your plant ok.

So, this completes your control block. There can be so there are many practical issues, dead zones and other things in world. So, all those things can be taken care of through the control. For that you look into the book by Marcel J. Sidi and another book by Bong Wie on a Spacecraft Dynamics ok. So, you will get the related control design how to put you cannot do the simulation.

You can assume your satellite having certain moment of inertia and then check out whether your system is converging or not using this control you choose the values ok. So, at least you can do in the simulation the proof. Anyway what I am going to give you for the magnetic actuator, so the same will be applicable here in this case also with little bit of modification ok.

So, please refer to this book by on a Spacecraft Dynamics by Marcel J. Sidi ok. There we will get the related issues for if you are looking for the control design. So, we will find the corresponding control design. I have provided you the basic techniques in the thoroughly discuss the dynamics and also giving you the idea how to go about doing the controls, but the actual control implementation it can be done only on the computer. Please do some exercise, so that you get to know that ok.

The another part that k v and k p if you are doing by trial and error, you can choose also different values for them not necessarily the same values. That means, you can choose them we say the k v you can write as a identity matrix here and then k v 1 k v 2 and k v 3 along the three axis, the same way you can also keep for the k p. So, it depends how you are going to design and the design will depend on your requirement how much precisions you are looking for in pointing the satellite toward the earth or if is a inertial pointing. So, what is the degree of precision you are looking for?

If you are looking for the fine tuning the control means if you are looking for pointing the satellite inertially very precisely, so in that case you need the micro thrusters. Using the normal thrusters it will not work. So, you require very small amount of force or the impulse and the torque generated out of that then will be small and you will be able to manoeuvre your satellite by very small amount ok.

So, in that case the thruster is fired for a very small time and the thrust produced may be on as is called the micro thruster. So, it may be of the range from 10 to the power minus 5 to 10 to the power minus 6 Newton, for the micro thrusters for the larger thruster of course in the case of the rocket. So, for depending on the size of the rocket the thrust is enormously large because it has to lift thousands of tons of the weight of the rocket and the satellite, hundred thousands of tons in the depending on the case it maybe, ok.

So, this thrust control part is over. We can have only if the matlab code coding problem and if we said some design problem. So, again it will be only more mathematical proof in world if you are doing with the linear system. So, it is a there is not much to do in that case because only you need to place the pole according to your requirement and the in that case you have the LTI tool available in matlab linear time in variant system toolbox is there in the matlab. So, that toolbox you can use to place the poles of the system and you can get the desired result.

So, we end this lecture here and then we will continue in the next lecture and we will start with the aerodynamic torque and the solar radiation torque ok. So, these two topics will be our last topic and there after you can have also the this is fluid rings for the satellite altitude control itself, but we are not going into the fluid rings. You can look into the papers and the materials in the references ok. We will be confined to the aerodynamic drag and the solar radiation drag and the torque due to that ok. So, these are the topics that we are going to discuss in the next lecture.

Thank you very much.