Linear Systems Theory
Prof. Ramkrishna Pasumarthy
Department of Electrical Engineering
Indian Institute of Technology, Madras

Module – 07
Lecture – 06
Stabilizability

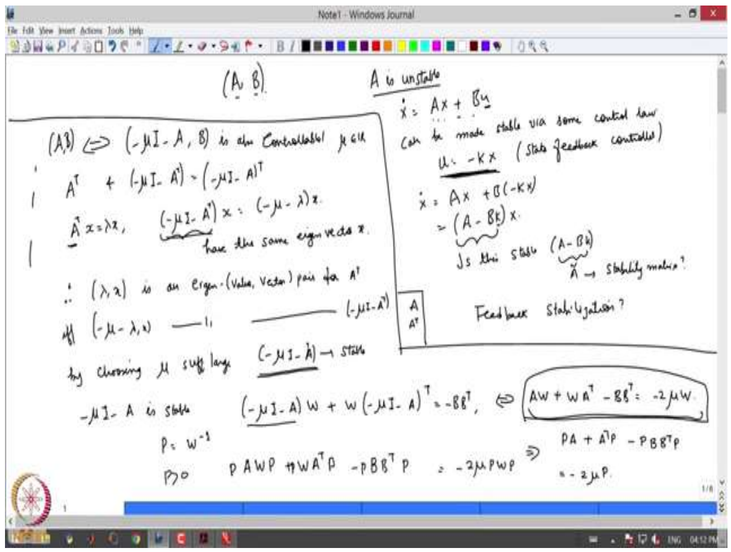
Hi everyone. So, welcome to this lecture number 6 of week 7 on the course on Linear Systems. In the previous lecture we saw about some details about what if the system is not completely controllable. And we had devised methods in a way where we could actually split up the controllable part and the uncontrollable part. And what we also saw how this changes the transfer function in that the transfer function is actually the transfer function of only the controllable part, and things related to the uncontrollable part do not actually show up in the transfer function.

And this actually shows up as some kind of a pole-zero cancellation which some of your undergrad control courses would have already taught you ok. So, today we will look more of what we can do with this uncontrollable systems. Is there some hope in with that with the systems or can I at least do some partial design and things like that.

(Refer Slide Time: 01:25)

So, before we define the general notion of Stabilizability we will start in general of what is a feedback stabilization for a general controllable system. So, we start with maybe asking some questions, right.

(Refer Slide Time: 01:37)



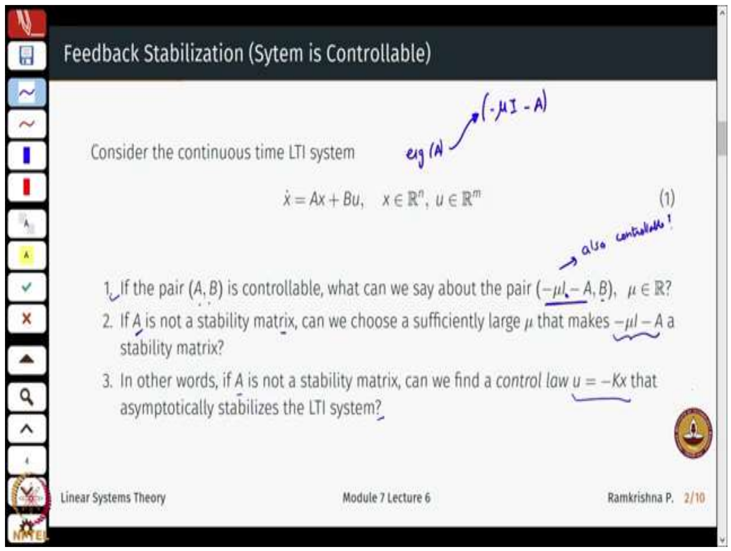
So, you know say I have the pair A, B which is completely controllable. And just recollect as, so whenever we do talk about pair A and B being controllable the we do not necessarily talk about the stability of the A matrix or not. So, those conditions were not and were neither were not necessary in deriving controllability properties. So, the controllability properties is independent of whether or not, the A matrix is a stability matrix or not ok.

So, the question that we can ask is the following. So, if A is unstable right; so unstable essentially means there is at least one eigenvector on the right of plane or at least there is one unstable pole or one unstable eigenvalue. So, is it possible that this system can be made stable via some control law ok?

Now, where is the control appear? The control appears here. So, assume my control is of the form u = -Kx which is also call a standard state feedback controller ok. So, you can the system be made stable via some control law, so A is unstable. So, what does is what happens when I use this control law? The system dynamics becomes Ax + B - Kx. So, this is (A - B)Kx.

Now I look at this matrix and ask myself the question: is this stable right. So, this matrix which is the closed loop A matrix or the system matrix is the stable. So, can I do a control K in such a way that the closed loop A matrix, let me call this $\tilde{A}$ is a stability matrix ok. So, this is the question we will ask about for ourselves about can we stabilize the system via feedback or also called as feedback stabilization, so right. And then how do we check for these conditions based on the techniques that we learned so far.

(Refer Slide Time: 04:39)



So, some questions that we will ask ourselves. So, if the pair A, B is controllable what can I say about the pair (-μI - A, B). You can check that whenever A, B is controllable this pair is also controllable. You can use any one of those test starting from the rank condition to the eigenvector test and so on, ok.

A little exercise you can do which I possibly the answer will be obvious later in the lecture. So, if I have some eigenvalues of A how are these eigenvalues related to the eigenvalues of -μI - A? So, this is this essentially is the identity matrix of appropriate dimension ok. So, what does this mean right? So, if A is not a stability matrix that A is unstable can we choose a μ sufficiently large that makes this a stability matrix ok.

Now, the next question is or the final question that we will ask or which we even motivated ourselves in this lecture is: if A is not a stability matrix can we find a control law that stabilizes the system and under what conditions can I actually find a control law that stabilizes the system ok. So, let us come back here.

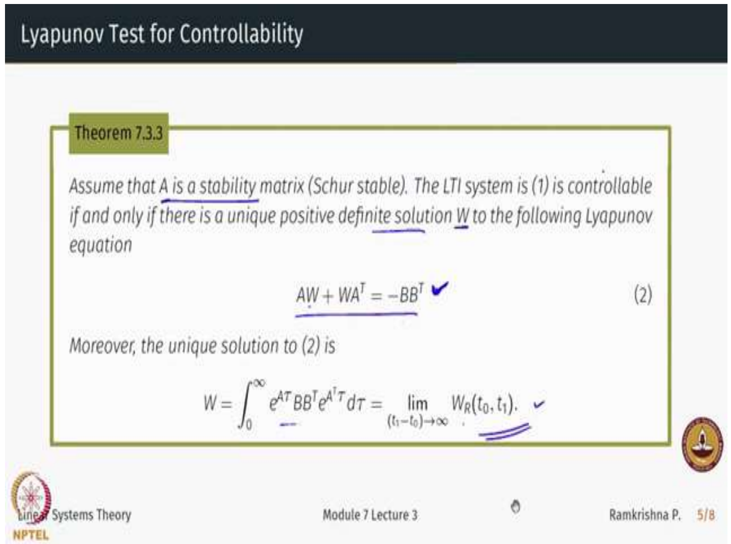
So, A, B being controllable also means (-μI – A, B) is also controllable ok. Now mu can be just any number nothing then that is true it must be positive or negative, it could be whatever in R ok. So, let us actually verify this. So, so what we know about the eigenvectors right. So, what is the relation between the eigenvector of $A^T$and the eigenvector of -μI - A^T; which is I am just taking the transpose of this entire thing minus -μI - A^T ok.

So, when x is an eigenvector of A^T associated to this eigenvalue λ, this is also same (-μI - A^T)x = (-μ -λ)x ok. Which means this A and this -μI - A^T have the same eigenvector x; sorry. And therefore, a certain pair λ, x is an eigenvalue and eigenvector pair for A^T if and only if -μI - λ x is an eigenvalue eigenvector pair for -μ with their identity $-A^T$ ok.

So, this kind of answers this first question right; if the pair A B is controllable what can we say about the pair minus (-μI – A, B) and then ok. So, once they have the same eigenvectors then the result follows from the eigenvector test for controllability. Therefore, by choosing mu sufficiently large I can make this matrix (-μI - A^T) to be stable. So, the transpose of this is also stable because A and A^T necessarily have the same eigenvalues why this is, so I think this was said earlier and we can also verify it for yourself.

Now, suppose that I choose a μ large enough such that -μI - A^T is stable or this also means that -μI - A is also stable ok. And then from the Lyapunov test what should happen? Well, -μI or equivalently I can say that AW + WA^T - BB^T = -2μW ok. Where do I get this from? I get this from this theorem which we had earlier right.

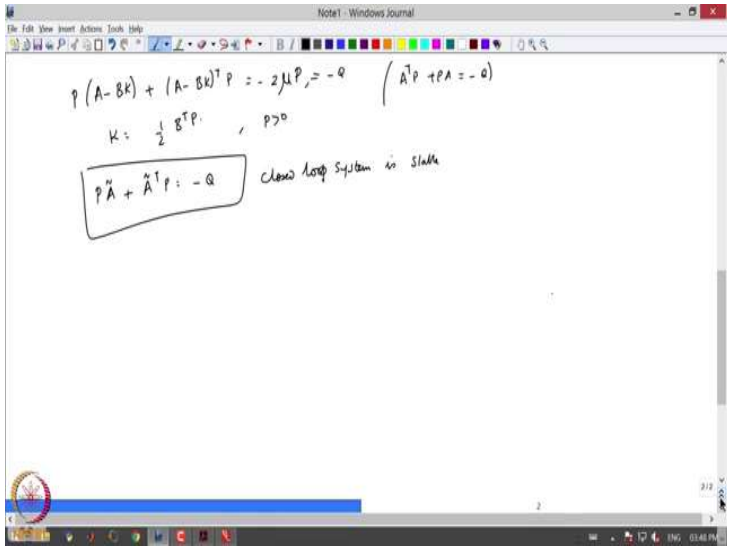
(Refer Slide Time: 10:52)



So, if A is a stability matrix; so in this case this A turns out to be this -μI - A. So, whenever this is a stability matrix the LTI system is controllable if and only if some relation like this holds ok. So, I am just writing that the exactly the same relation sorry, I am just a minus here, exactly the same relation with A replaced by this matrix. And therefore, equivalent condition now I have for mu to be sufficiently large such that (-μI - A^T) is stable looks something like this ok.

Now, what I can do is multiply on the right hand side of the equation by some P^{-1} ok. So, what will I have now let us say P = W^{-1} and I multiply both equations from the right hand side with this. So, what I have is AWP + WA^TP - BB^TP is, I will do this on both sides P here, P here, P and this is equal to -2μP here W and A P. So, this will result in an question which is like this PA + A^TP - P BA^TP = -2μP ok.

(Refer Slide Time: 13:02)

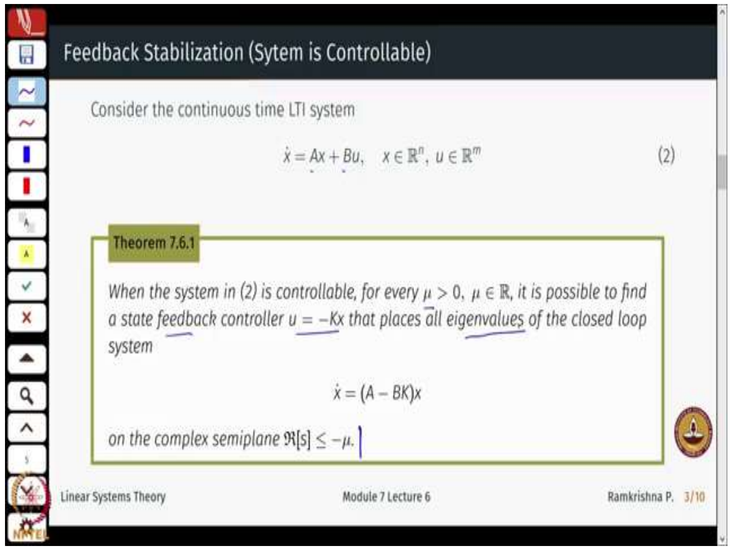


This can be further written as P(A – BK) + $(A-BK)^T$P = -2μP ok. This is when K is chosen as $\frac{1}{2}B^T$P ok. Now, what do we know that P > 0. So, this matrix which I multiply on both sides with P, because W is greater than 0 so this P will also be greater than 0 ok. So, this kind of resembles a Lyapunov equation right A^TP + PA = -Q ok.

So, what do we conclude from all this right. So, this P$\tilde{A}$ + $\tilde{A}^T$P is say I just call this as -Q right. So, where does this $\tilde{A}$ come from? This is the A matrix of the closed loop system. So, let us run through these steps again. So, I want to find out; so the question I asked to begin with was let us have a system Ax + Bu, A may not be necessarily stable.

Can I make this system stable via some feedback control law of the form u -Kx? And if such a K exists how should that K look like ok. So, I follow these steps all the way and what I get is this ok. Now this means that the closed loop system is stable ok.

(Refer Slide Time: 15:23)

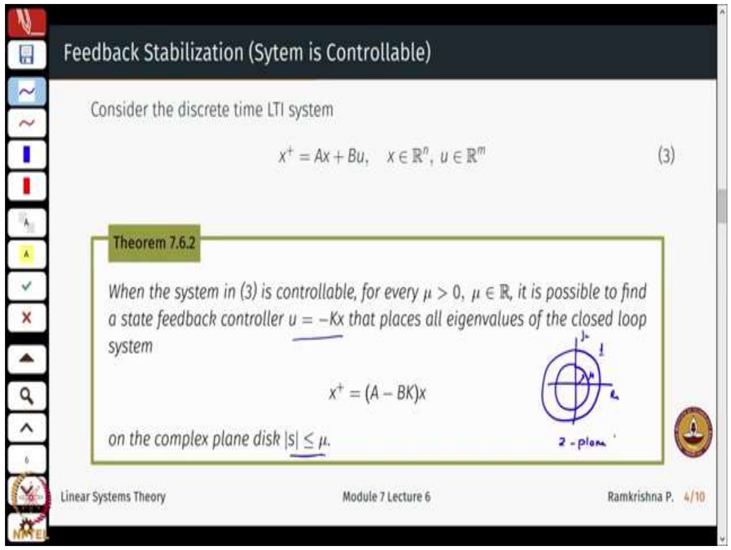


So, I can sum up all this into the following, that when this system is controllable that in that case for every μ it is possible to find a state feedback controller of the form u = -Kx. That places all the eigenvalues of the closed loop system to the left of -μ ok. So, that you can we can easily verify from here.

So, not only that this system stabilizes the this input law not only does it stabilize the closed loop system, but it also places all the eigenvalues to the left of -μ ok. So, this is a good indication of why if the system is a completely controllable I can place all the eigenvalues of the closed loop system in such a way that they are stable. And not only stable there also relatively stable in a way that all the eigenvalues are placed to the left of minus mu ok.

This also, similarly we did while we were doing the router bits criterion which not only gave us information of stability, but it also gave us information on the relative stability. And but by a little change of change of variable I could find out if all the poles or the closed loop system were say for example to the left of minus 1 and so on, right. So, this is a similar test right. And this you can easily verify by the properties of the A matrix here, its starting from here. Now, let us get back to where we began with right.

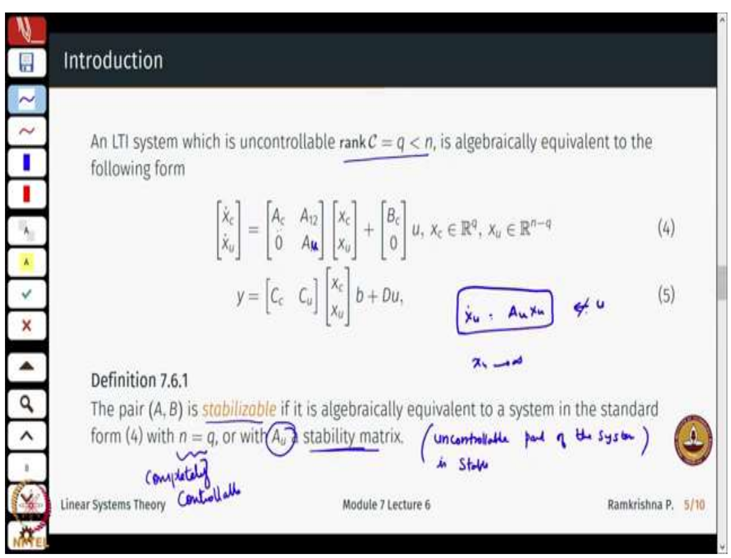
(Refer Slide Time: 00:03)



So, we begin with the controllable decomposition ok. Before that similar result also holds for the discrete time system where I can with the help of some feedback control law restrict all the system, all the complex sorry; all the poles in the complex plane to be within a disk of size less than or equal to μ. So, since for example: maybe this is my stability region this is my unit circle I can also place all the poles in such a way that they are less than some disk of radius μ.

And so, this is essentially what it what it means in the complex plane which is in necessarily the z plane in the in the in the case of discrete time systems.

(Refer Slide Time: 17:51)



Now, let us get back to stability tests when I do the controllable decomposition for cases, where rank of C is q which is less than n which means the system is not completely controllable ok. What is the notion of stabilizability in this case right, when I when the system is not completely controllable? Now system is completely controllable I know that any control of the form u = - Kx I just derived will place all the closed loop eigenvalues to wherever I want.

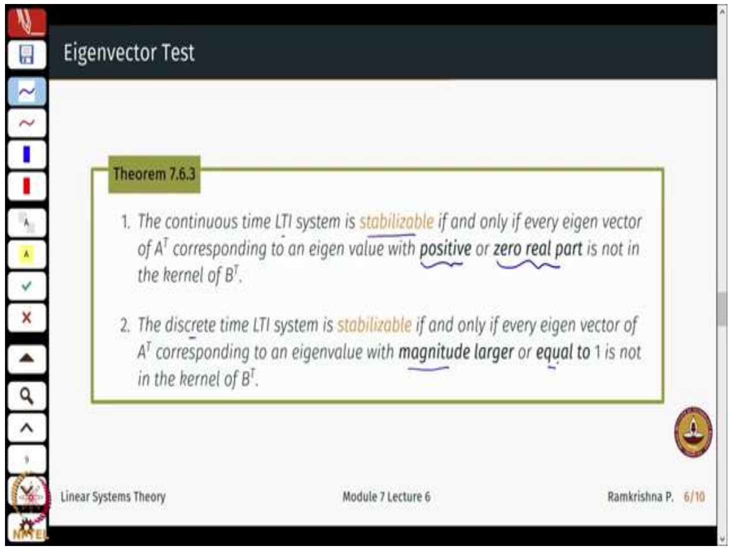
We will learn these methods of how to appropriately place them in the coming lectures So, that is not the objective of the of what is the appropriate design. But at least now I know that if the system is completely controllable I can place the poles accordingly, I can at least go from an open loop unstable system to a close loop stable system ok. What happens when the system is not completely controllable?

Well, in this case we say that the pair A, B is stabilizable, earlier we are talked about the pair being controllable but now we talk of a little weaker version. That the pair A B is stabilizable if it is algebraically equivalent to a system in the standard form with n being equal to q which means the system is completely controllable right. And if it is not completely controllable then what do I do?

Well, then at least should be A_u here, then at least I must ensure that A_u is a stability matrix, because the dynamics of x_u evolve according to $A_u x_u$ there is no influence of control input right, so there is no u here ok. And this evolved autonomously by themselves and if x_u is if A_u is unstable then Ax_u will go unbounded as time goes to infinity. And therefore, even if I can control the remaining parts so the system by itself is inherently unstable.

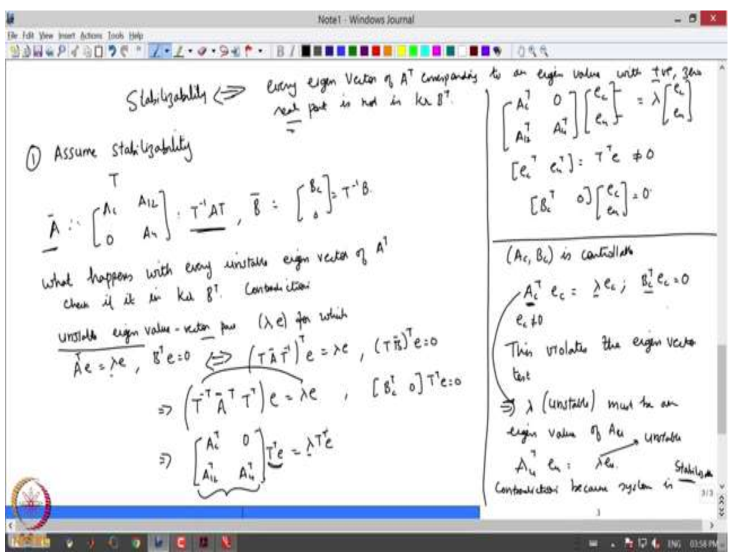
And therefore, for me to do anything with the system I must ensure or what is the necessary condition is that this A_u must be a stable stability matrix right. So, only then I can say that the system is stabilizable that if the uncontrollable part of the system should is stable, right. So, this is what it means right. A_u being stability matrix means the uncontrollable part of the system is stable ok.

(Refer Slide Time: 20:36)



So, how do we test this? In continuous time, the continuous time LTI system is stabilizable if and only if every eigenvector of A^T corresponding to an eigenvalue with a positive or 0 real part is not in the kernel of B^T; we will only do this proof. The proof will largely be based on the eigenvector test that we had for controllability ok. So, let us begin by doing this proof, right.

(Refer Slide Time: 21:20)



So, what do I need to show that stabilizability is equivalent to saying that every eigenvector of B^T corresponding to an eigenvalue with positive or; sorry zero real part is not in the kernel of B^T ok. So, again we will assume one and then prove the other and then second we will assume this and then prove this one ok. So, let us assume stabilizability right the first part, when as assume stabilizability.

And also that there is a similarity transform T which will take my system from A to this controllable decomposition form A_c, so 0 A_u via T^{-1}A T. Similarly B will be B_u 0 using T^{-1}B ok. Now, assume stabilizability and check what happens with every unstable eigenvector of A^T and check if it is in the kernel of B^T or not ok. We as usual prove by contradiction.

Which means, assume that there is an unstable eigenvalue vector pair λ comma when, we call this e just to avoid confusion in notation for which A^Te is λe and B^Te = 0; the e is an eigenvector corresponding to the eigenvalue lambda. So, what does this mean? So, this A I can write in terms of $\bar{A}$, that is.

So, from here $\bar{A}$ this A would be $(T\bar{A}T^{-1})^T$ e = λe. Similarly $(T\bar{B})^T$e = 0. So, this is just little modification of this way just plug. So, here I am writing A^T so $\bar{A}$ in terms of A and here I write A in terms of $\bar{A}$ ok. Now, this can also be written in the following way. So, I have T the inverse and transpose let me call it $(T^{-T}\bar{A}^T\ T)^T$e = λe.

And also here I can write this alternatively as $[B_c^T\ 0]\ T^T$e = 0; this I can ok. So, what does this simplify to this simplifies to how does A^T look like $\bar{A}^T$; $\bar{A}$ is something like this. So, I will have $\begin{bmatrix} A_c^T & 0 \\ A_{12}^T & A_u^T \end{bmatrix}$ ok. This is just be a T^T; T^T I just take this T to the other side and what I will have is λT^Te ok.

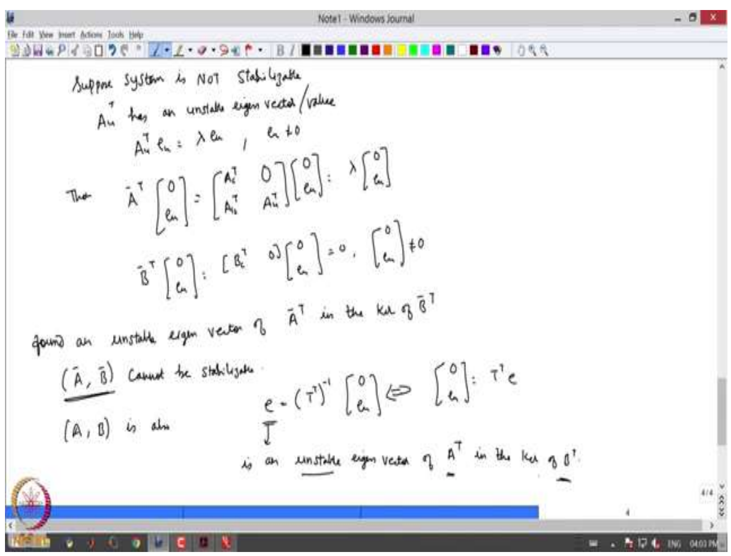
So, there is e here ok. So, let me write this in the following way $\begin{bmatrix} A_c^T & 0 \\ A_{12}^T & A_u^T \end{bmatrix}$. Now this T, let me write this a little properly T^Te is an eigenvector of $\bar{A}^T$ corresponding to the eigenvalue of λ. So, this is the eigenvector. Let me call this eigenvector $\begin{bmatrix} e_c \\ e_u \end{bmatrix}$, right where $[e_c^T\ e_u^T]$ is T^Te and this is not equal to 0.

I am just; I am just splitting this eigenvector into say some controllable and the uncontrollable part. So, this will be equal to on the right hand side λ$\begin{bmatrix} e_c \\ e_u \end{bmatrix}$ and similarly $[B_c^T\ 0]\begin{bmatrix} e_c \\ e_u \end{bmatrix}$ = 0 ok. Now, what do we know? We know that one that the pair A_c B_c is controllable. And then if I just write this down I have $A_c^T e_c = \lambda e_c$. And further, from the second thing I will have $B_c^T e_c = 0$ ok.

And what is also the assumption that $e_c \neq 0$. And therefore, so I have found a eigenvector λ of A_c^T which is the controllable part of the system in the kernel of B to B_c^T. So, this violates the eigenvector test. So, this means that if there is an unstable eigenvalue eigenvector pair then this λ which is unstable must be in or must be an eigenvalue of A_u the uncontrollable part. Because, again $A_u^T e_u = \lambda e_u$ ok.

Now this again contradicts, because my system is stabilizable, which means A_u must be a stability matrix and this λ which got kicked out of here is finding a place in A_u. Well, it cannot be in A_u this unstable λ cannot be in A_u necessarily because of the assumption of stabilizability. Stabilizability always meant that the uncontrollable part is stable. Therefore, every eigenvector of A^T corresponding to an eigenvalue with positive or 0 real part is not in the kernel of v^T. That is what we proved in this case ok.

(Refer Slide Time: 31:07)

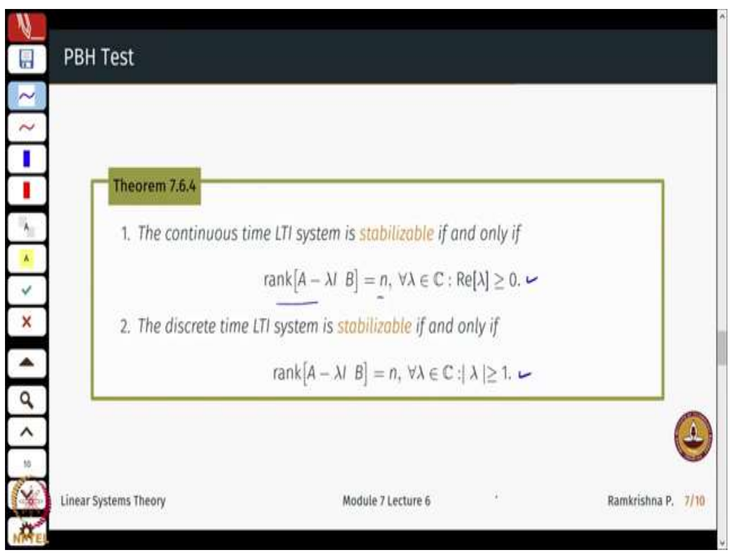


Now, conversely suppose the system is not stabilizable, ok. If the system is not stabilizable then A_u or A_u^T both of them has at least one unstable eigenvector or eigenvalue. So, which means $A_u^T\ e_u$ is λe_u, where $e_u \neq 0$. Then, the $\bar{A}^T e_u$ which reads like this. So, I have $\begin{bmatrix} A_c^T & 0 \\ A_{12}^T & A_u^T \end{bmatrix}\begin{bmatrix} 0 \\ e_u \end{bmatrix} = \lambda \begin{bmatrix} 0 \\ e_u \end{bmatrix}$ ok. And $\bar{B}^T \begin{bmatrix} 0 \\ e_u \end{bmatrix} = [B_c^T\ \ 0]\begin{bmatrix} 0 \\ e_u \end{bmatrix} = 0$. Again this eigenvector is not allowed to be 0 ok.

So, what does this mean that we have found an unstable eigenvector of $\bar{A}^T$ in the kernel of $\bar{B}^T$. And therefore, this pair $\bar{A}\,\bar{B}$ cannot be stabilizable ok. And so, if this $\bar{A}$, $\bar{B}$ is not stabilizable then it is easy to conclude that the original pair A B is also such that this eigenvector x is; let me call this e an eigenvector e which is $T^{T^{-1}}\begin{bmatrix} 0 \\ e_u \end{bmatrix}$ comes from $\begin{bmatrix} 0 \\ e_u \end{bmatrix}$ is T^Te this eigenvector is an unstable eigenvector of A^T n the kernel of B^T ok. Therefore, well this concludes are the proof.

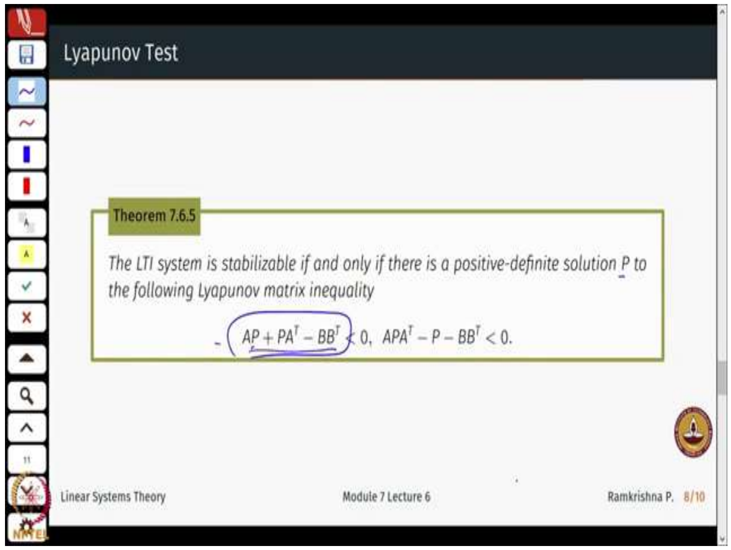
So, we started with the assumption of system not being stabilizable and found an eigenvector of A^T. And I unstable eigenvector of A^T which is in the kernel of B^T, ok. Similarly I can write down the result for the discrete time where we have looking at an eigenvalues with magnitude larger or equal to 1, ok.

(Refer Slide Time: 35:55)



I just read out the PBH test will not go into the details of that. So, the continuous time LTI system we stabilizable if and only if the rank of this matrix is n similarly for the discrete time systems, for eigenvalues which satisfy this relation. I will not really do go into the details of this, it is a straightforward proof coming from the controllable case ok.

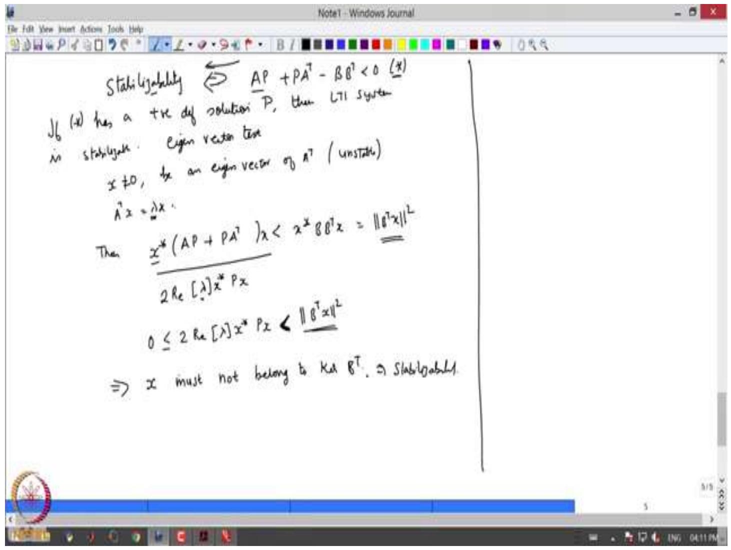
(Refer Slide Time: 36:23)



So, now coming back to this stabilizability of systems which are possibly not completely controllable, right. So, we say that the LTI system is stabilizable if and only if there is a positive definite solution P to the following Lyapunov matrix inequality, ok. A slight contrast to what we had over here right.

So, we assumed that A was a stability matrix then the LTI system was controllable if and only if there existed a unique positive definite solution W to this Lyapunov equation right and where W was given by this little expression here ok. So, here there is a nice equality, whereas here we also see that the sign of the BB^T is reversed and there is a strict less than strict inequality ok. We will slowly try to prove this and see also on the way why this conditions are looked a lot different to the conditions over here. So, let us try doing a proof for this.

(Refer Slide Time: 37:44)



So, stabilizability ok. So, I am just doing the Lyapunov for stabilizability is equivalent to solving A P + PA^T - BB^T < 0 ok. So, as usual I will do for the continuous time and the discrete time version will be a direct consequence of this ok. So, we start by showing that if this equation let me call this star has positive definite solution P then the LTI system is stabilizable, I show this way first ok.

So, I just again invoke the eigenvector test right. So, what was the eigenvector test? Just let us recall again. The continuous time system is stable if and only if every eigenvector of A^T corresponding to an unstable eigenvalue is not in the kernel of B^T, right. So, assume; that this is true that is what we will show that there well assume this to be true and show that the system is stabilizable .

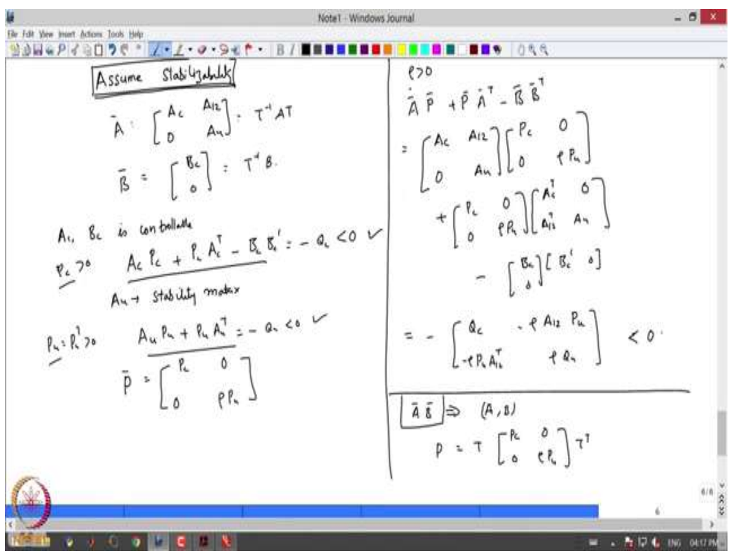
So, let x ≠ 0 be and eigenvector of v with unstable eigenvalue right; that is A^Tx = λx ok. Then what was what we must show? We must show check if this x is in the kernel of B or not ok. So, let us check with this a with the help of this inequality. So, this should be less than or equal to x^TBB^Tx and this also I can write as the norm of $||B^T x||^2$ ok. This is again the complex conjugate and so on.

So, I do all the steps as I do for in the earlier versions of the proof, so I get 2Re(λ) x^*P x on the left hand side and then of course I have a BB^T here. What do I know is that this eigenvalue is either positive or 0. Therefore, this will be something like this 2Re(λ) x^*P x and now this is strictly less than $||B^T x||^2$ ok.

Which means that if lambda is an unstable eigenvalue or because or we start with the assumption that λ is an un unstable eigenvalue this B^Tx is always greater than 0. And therefore, this eigenvector x must not belong to kernel of B^T that was what the statement was. That if and only if every eigenvector of A^T corresponding to an unstable eigenvalue or eigenvalue with the 0 real part, that is this guy.

This is should not be in the kernel of B^T. So, this unstable eigenvalue is not in the corner of B^T ok. Therefore, I can conclude stabilizability. And the strict less than here is because I also allow for 0 eigenvalues right, if there is instead of a strict equality I say I have a inequality like this then there is a chance that B^Tx can also be equal to 0 right. So, that is just to eliminate that condition, right. Now, we do the do the converse proof.

(Refer Slide Time: 42:59)



Converse proof would be that we assume stabilizability ok. Now assuming stabilizability I can do this $\bar{A} = \begin{bmatrix} A_c & 0 \\ A_{12} & A_u \end{bmatrix}$ which again comes as T^{-1}AT, $\bar{B} = \begin{bmatrix} B_c \\ 0 \end{bmatrix} = T^{-1}$B ok. Now if the pair A_c, B_c is controllable, if the pair A_c, B_c is controllable so the first result of today showed us something like this right. If the pair A_c, B_c was controllable I could write it you know something like this, right.

So, we make use of this result here and call this my Q matrix to equivalently write a condition here ok. I just take the controllable part A_cP_c + P_c $A_c{}^T$- $B_cB_c{}^T$ = -Q_c and this is always less than 0. And because of the controllability and then $P_c > 0$ it is symmetric and so on ok. Now second is, if I assume that the system is stabilizable which means A_u is the stability matrix right.

And whenever a is u is a stability matrix I can invoke the Lyapunov theorem; which says that there always exist the P_u which is symmetric and positive definite such that this holds is -Q_u which is less than 0 ok. Now what I have to show is that if this and this are satisfied which means where do these come from this come from the assumption of stability; whenever these two are satisfied can I show a condition like this which means ok.

Can I construct a new P based on this P here and this P here P_c and P_u. So, let me just define $\bar{P}$ as the new P which is $\begin{bmatrix} P_c & 0 \\ 0 & \rho P_u \end{bmatrix}$ ok. Now, for some scalar ρ > 0 let me just check what happens with this in equal. $\bar{A}\,\bar{P}$ + $\bar{P}$ $\bar{A}^T$ - $\bar{B}\bar{B}^T$. That is what the thing which I wanted to verify ok. So, let us see what happens to this.

So, A bar is $\begin{bmatrix} A_c & 0 \\ A_{12} & A_u \end{bmatrix}$. How does my $\bar{P}$ look like? $\bar{P}$ is $\begin{bmatrix} P_c & 0 \\ 0 & \rho P_u \end{bmatrix}$ plus the second term I again have a P which is $\begin{bmatrix} P_c & 0 \\ 0 & \rho P_u \end{bmatrix}$ ok. And then $\bar{A}^T$ this is $\begin{bmatrix} A_c^T & 0 \\ A_{12}^T & A_u \end{bmatrix}$ ok. -BB^T; how does the $\bar{B}$ or $\bar{B}^T$ that looks like? $\begin{bmatrix} B_c \\ 0 \end{bmatrix}$[$B_c^T$ 0] ok. Now I make use of this condition and I make use of this condition ok.

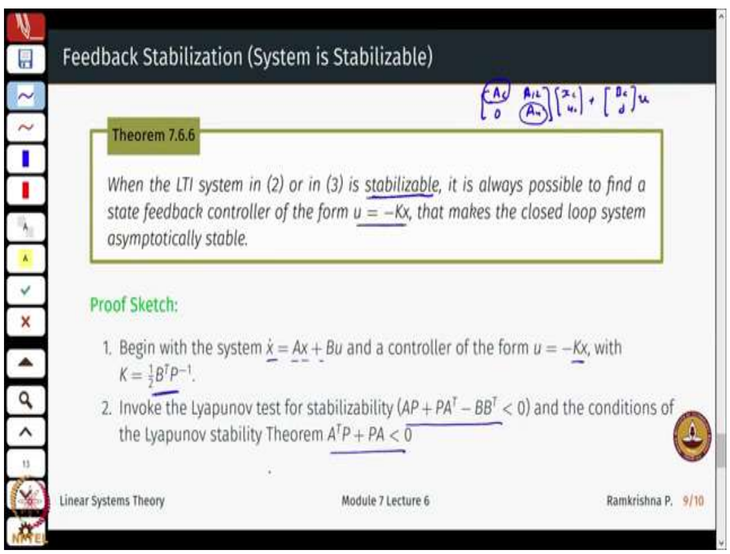
So, I this we will just simplify to Q_c - ρ$A_{12}P_u$, - ρ$P_u {A_{12}}^T$and ρQ_u ok. So, whenever rho is greater than 0 this is always less than 0; that is what we wanted to show. That whenever system is stabilizable then I can solve for a matrix inequality which looks like this condition. Now, we showed this for the transform system $\bar{A}$, $\bar{B}$ now this can be easily translated to A the pair A B just by choosing the P matrix to be something like this: T $\begin{bmatrix} P_c & 0 \\ 0 & \rho P_u \end{bmatrix} T^T$ ok.

So, I will leave this proof for you. So, it means to say that whatever property is holding for $\bar{A}$, $\bar{B}$ it also holds for this pair A, B ok. So, that kind of concludes the proof which is essentially the Lyapunov test for stabilizability ok.

(Refer Slide Time: 48:47)

So, the last result that we will do today is about feedback stabilization. Right, feedback stabilization in the sense of what if the system is not contribute completely controllable ok.

(Refer Slide Time: 49:01)

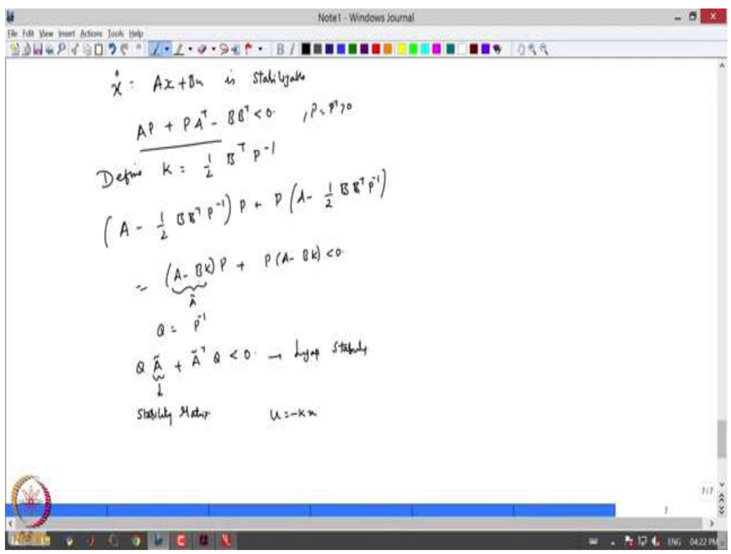


So, the result looks something like this. So, when the LTI system is stabilizable it is always possible to find a state feedback controller that makes a closed loop system asymptotically stable ok. So, this A_c can be unstable to begin with, A_u is a stable stability matrix because I assume that when that this is stabilizable means uncontrollable part is stable; plus $\begin{bmatrix} B_c \\ 0 \end{bmatrix}$ here and u ok.

So, when this system is stabilizable which means A_u is a stability matrix then with some control law of the form u = -Kx, I can make the system to be a asymptotically stable. Which means I can place all the poles of A_c or I will all or I can assign whatever values I want to this matrix A_c to the left of -μ or whatever we did in the previous case ok.

So, the proof is very similar. So, we begin with the; so we do a little (Refer Time: 50:09) so let us say I have a system x. So, it is Ax + Bu with a controller of the form u = - Kx with K being this one and then I just invoke the Lyapunov test for stabilizability and the Lyapunov condition for these stability ok. Let us actually do this and check what it means right.

(Refer Slide Time: 50:29)

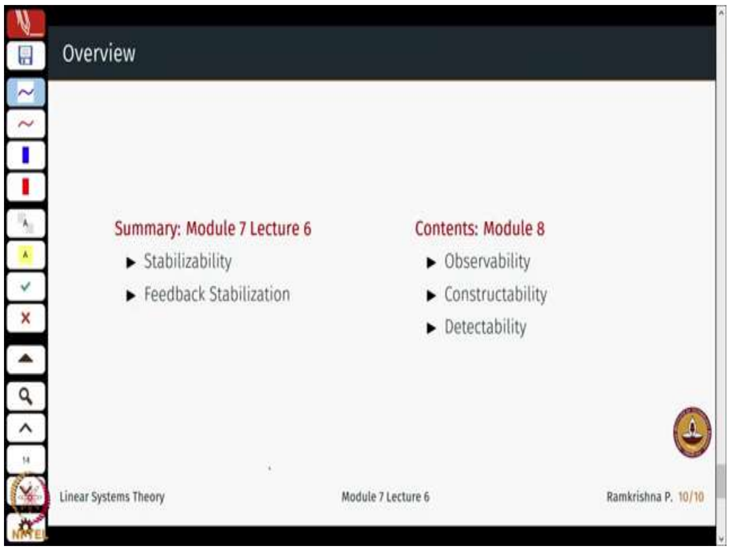


So, what do I know is $\dot{x}$ = Ax + Bu is stabilizable ok. Which means that, AP +PA^T - BB^T <0 ok. Now define so again that this P> 0 symmetric and so on ok. So, where does this come from? This stabilizability test comes from this the previous theorem that we had here ok.

Now, if it is stabilizable this condition holds and define K = $\frac{1}{2} B^T P^{-1}$ ok. And I can write this inequality in the following form A - $\frac{1}{2}$ BB^T P^{-1} P + PA - $\frac{1}{2}$ BB^T P^{-1} is again very similar to what we had before at (A - B K)P +P (A - B K) < 0. So, again multiplying this equality both from the left and right by Q is P^{-1} sorry Q is as P^{-1} I get Q $\tilde{A}$, if I call this $\tilde{A}$ plus A sorry $\tilde{A}^T$Q is less than 0 right.

Now, this is the Lyapunov condition for stability. Which means that this $\tilde{A}$ is now a stability matrix ok. Which essentially means that with the application of this control law u=- Kx I can get this A - BK to be a stability matrix ok. And this will it will eventually turn out and we will do a little proof of this while we do the control design that these are both necessary and sufficient conditions for stabilizability or even in the earlier case right when we had a completely controllable system those conditions were both necessary and sufficient, ok.

(Refer Slide Time: 53:14)



So, we talked today about stabilizability and then how can I stabilize or is there a possibility to stabilize the system via feedback ok. So, the next lecture we will start with the covering the basics of observability, constructability and its weaker form called detectability ok. So, that is coming up next week.

Thanks for listening.