Introduction to Robotics

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Lecture 16: Overview of Electric Actuators and Operational Needs

I am Doctor Krishna Vasudevan from Electrical Department and we will be first looking at the subject of Electric Actuators for the purpose of robots. So, let me write that down.

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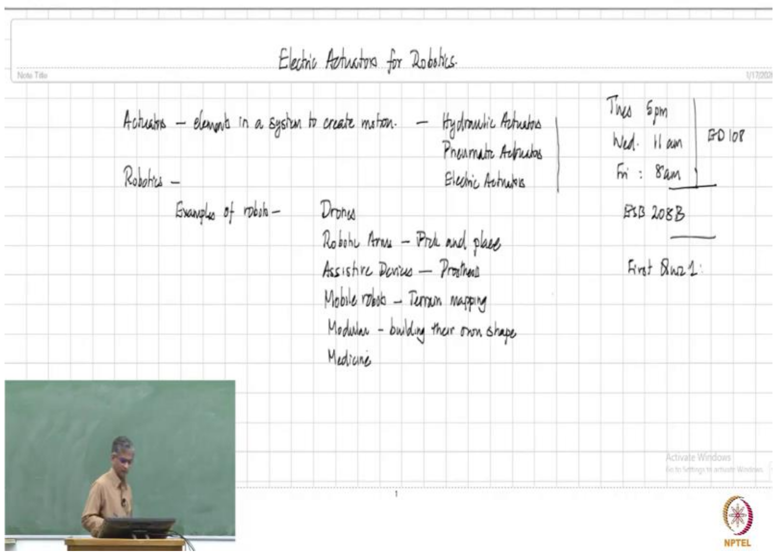

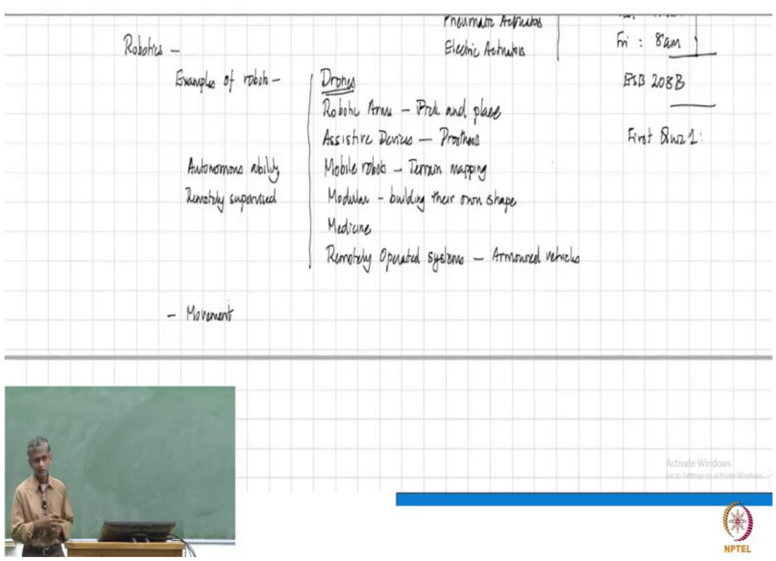

So, let us look at actuators and that is what we are going to talk about. Actuators are essentially elements in the system, elements in the system, to create motion. There are of course, various ways in which you can get actuation. There are hydraulic actuators, there are pneumatic actuator and there are electric actuator. apart from , i mean these are the main variety of actuation system that are used in industry and maybe you have studied about some of these earlier.

Now, of course, when you look at the area of robotics one needs to pay attention to the needs of the domain of the robotics, and choose actuators that are able to meet the application need. So, let us start with some examples, examples of robots. I am sure you would have seen or heard or whatever about various application of robot. Any suggestion, where have you seen use of these kind of system?

Student: Drones.

Professor: Drones, yes drones are one widely used currently, a remotely operated system now and we had a very famous examples of a drone attack few days ago. Anything else?

Student: Industrial robot.

Professor: Industrial robots, can you be more specific?

Student: Robotic arms.

Professor: Robotic arms, for what purpose?

Student: Pick and place.

Professor: Pick and place robots are one of the most frequently used in industries. Anything else?

Student: Assistive device.

Professor: What?

Student: Assistive device?

Professor: Assistive device. Assistive devices in the sense, can you be more specific?

Student: Prosthesis.

Professor: Prosthesis?

Student: Yes.

Professor: Yes, they are assistive devices, yes, so we would not really call them in, I mean fit them in the place of robots because when you say robots we are talking about more autonomous system. Any other examples of robots?

Student: Mobile.

Professor: Mobile robots used for what? Application.

Student: Terrain.

Professor: Terrain, mapping.

Student: Modular.

Professor: Modular? Can you be more specific what do you mean by modular applications?

Student: They are building their own shape.

Professor: Modular, that is you are saying building their own shape. We have robots in medicine that can perform surgery.

Student: Remotely operated.

Professor: Remotely operated?

Student: Yes.

Professor: Yes definitely remotely operated, not yet, we are not yet in a state where we can keep yourself a robot. We are not there basically. So, these are all many of the systems that are there, and certainly there are lot of needs for remotely operated systems. So remotely operated systems for example it could be army vehicles, armored vehicles where you want to send a remotely operated vehicle in to the enemy domain and do some sort of surveillance perhaps which is I mean, you have already listed the example of drones which do that but drones are for aerial survey.

Whereas you may have remotely operated armored vehicles on land which does the same thing, which enter into an enemy domain and do some kind information as they can get. So, in all these situations the goal is to have some sort of autonomous ability, probably remotely supervised approach. And if you look at the design of all these kind of system, one then look for, so look at all these applications, it is important that they are having movement which is the essence of having a robot, you wanted to achieve something.

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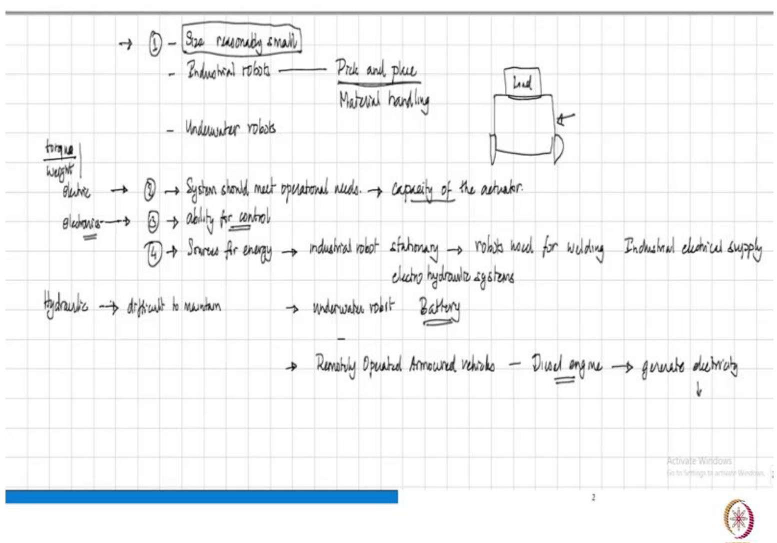

And since, you are looking at this kind of an application it is necessary that size of any system that is used on board, size must be reasonably small. Of course, ideally you would say that I wanted it to be as small as you can make it no size at all, zero size and achieve some actuation but that of course, is impossible, so you would do in the best feasible kind of system.

And if, if you have applications that are not going to be something that requires movement, physically from one place to another, if you take for example, industrial system, industrial robots we had one variety which we have mentioned that is equipment that are going to take some object and then put it somewhere else. So these are, these mechanisms do not move from location to location, they are stationery and their objective is to move an object from one place to another, so they have robotic arm that gets hold of one object and then shifts their location to some other, some other location, robot itself does not move.

But on the other hand you have another application for example, if you look at the aspect of material handling, material handling robots. So, here the idea is that you may want to shift some material from one place to another which is a long distance away, so you have a system, you may have and there are various ways of achieving it, one could be a sort of box type thing with wheel here and the object that is located here, and this box moves wherever it needs to go, I am sure you would have seen these kind of applications somewhere.

So, applications in industry are for variety things. Then you have also application for underwater, underwater robotics. So, you have systems that go underwater look at the environment there, maybe attempt to, attempt to locate something which has accidentally fallen off. So, in all these type of situation you need size to be reasonably small because if you are going to look at a system that is moving, obviously anything that is going to move has to shift itself first apart from whatever load is going to be there.

So if you do not want the actual system itself to be extremely heavy, you want it to be able to take the load with the system, on the other hand if you have these kind of systems you are not really concerned so much about how big it is because all the while it is going to stay in one place and therefore you may have a little bit of delay in sort of selecting the actuator and selecting the other system. So, one important thing as I mentioned is therefore how big the system is.

The second important thing is that your system should meet operational needs. There is no use in having a system that is small but it cannot meet your load requirement, but if you want to lift this phone and put it there, you need to lift a certain weight, for that you need to have a certain actuator or a certain step and that has to be moved so the actuator can be capable of accommodating the movement which makes the arm move from one place to another and then put it there.

So, range of movement is important, speed of movement is important all that is going to decide how, how much is the capacity of the actuator. And then, you do not want to have an uncontrolled system, you cannot have an actuator, fit it and say you do what you want. So you need to have an ability to determine how this system is going to actually move, instance to instance. So, you need to have an actuator that has very good ability for control.

So, all these three aspects one, two and three are major aspects in determining what sort of actuation system you want. The other important aspect in any actuation requires energy, without a source you cannot achieve any movement, therefore you also need to look at what kind of sources are available, sources for energy, what sort of sources are available at a particular location for a particular application that you can make use of.

So, if you look at examples for this, let us say you have an industrial robot which is stationary. One other use for an industrial robot which is at fixed location is robots used for, used for welding. Have you seen that? In assembly line especially if you go to automotive industry, assembly lines are filled with these things, robots that bend in all kinds of forms and then apply the requirement on the weld.

If you look at these kind of applications, they are always located at a fixed place in an assembly line, they do not need to move, they do not need to do anything else, other than bend their arms and things that are determined apriorly. You do not go every time and tell the robot to move like this. So somewhere it has been decided apriory that this robot will start with its arm in a particular position then move through few angle and rotations and all that, and they go and stay there for some particular time until the weld process is over, and then come back in a certain way.

So these are, since they are always fixed in a particular way and the industry is filled with electrical, electrical sources in the sense electricity in available everywhere, it is most appropriate to build this out of electrically actuated systems. Electrically actuated in the sense at least the first source of activation would be electricity, the end result would still be achieved using something else. So, there are actuating elements known as electro hydraulic system.

So they are essential hydraulic systems but the first level of actuation is by, is by electrical means. So, the electrical entity, the electrical actuated entity then releases the flow of oil and that oil is going to ultimately result in the movement of the arm. So, it maybe electro hydraulic but then the initial form at least may be electricity because its widely available. But on the other hand, if you look at an underwater robot, how do you actuate this?

Student: we can use a wired connection

Professor: That is very difficult. You do not know at what depth you are. If you are not going to get a fixed amount of this thing at all, initially there is no measure when you are on the surface, as you go down you get increasing amounts of thing, so that is very difficult. Anything else?

Student: Battery is there.

Professor: Battery is probably the best bet as of now. Otherwise you could have some kind of oil, fuel, diesel etcetera stored within that and then operate an engine which you then give to the actuation to whatever you want to move. And that is another option, but I do not think they are used in this underwater application, you do not want to take fuel all the way down. But in majority of the situation where the depth is not very high, they do not give the storage mechanism at all inside.

They are simply having a long reach of electrical supply which is going to be available on shore, onboard and you simply make a long electrical link to the underwater robots and it draws electricity from the shore. So this could be a way in which it could. If you want an autonomous operation then you need to definitely have some kind of storage mechanism onboard, so that is what we have.

Here you have as I mentioned, industrial electrical supply. Then I mentioned remotely operated armored vehicles. In this case it is remotely operated that means you are looking at an armored vehicle located somewhere and then you going to be sitting far far away inside your own area and this enemy, this remotely operated vehicle is going to go into the enemy domain and you need to operate from there which means that it is impossible for you to have a long electrical link for several long distances.

Therefore there must be a local energy storage and this is the armored vehicle. Therefore the best form of energy storage will be fuel itself. So in this case what you have onboard is basically diesel engine. But this engine has to first of all move the vehicle that is one thing. Apart from that the vehicle may have lot of other accessories for detecting many things. You may need to, you may need to detect whether you have any explosives located underground for which you need some sort of sensor.

And those will need to be actuated by some arm. So you have to lift the sensor and then maybe rotate it adjacent to the arm, move it a little bit maybe. Therefore there are further actuation means for moving other accessories that are located on the board. So, how does one move that? Ultimately the source of all that maybe from the diesel engine. So in these kind of applications usually the way it is, it happens is, this then is used to generate electricity and then that is used to operate whatever else we want to operate as an electrical accessory.

So, there are various forms in which energy storage or energy usage could be available and one needs to select the appropriate mechanism for that. Now, if you look at this aspect, ability to have good control you need to have systems where it can respond the way you ask it to. So if you look at the way systems are designed today, most of the systems that require some sort of a control depends upon electronics.

You want to write some software, you have some algorithm which you know, which you want to implement and which says that this arm should move from this to this location, to this part with certain velocity profiles etcetera. So this is an algorithm and the easiest way to implement the algorithm is to implement it in the electronics, some digital electronics. FPGS MCs so on. So this is exactly what you have, an electronics forms the basis of implementing very sophisticated algorithms.

And once you have that you may then use the end result of your algorithm which is available in electronics to actuate the non electronics system that is fine, but it is easier if there is an electric system in hand which we can control. And it so happens that when you look actuators that you want to control, as of today the actuating systems that give you the best ability of control are electric system.

So, from that viewpoint you have electrical actuators as the best means that is available. Then if you look at the system that meet the operational need, you need to select the capacity of the actuator that is apropriate for the particular use at hand, which means that if you want to lift this phone you need a certain capability from the actuator, if you want to lift this entire bench, obviously your actuator needs to be bigger.

So one needs to select the size and the capability accordingly, there also you find that electric systems are fairly good, it means that output or not really our, the mechanical torque that it is able to generate divided by the weight of the system, is what is going to determine when the efficacy of a particular actuator that you select. And electric actuators are not very bad in this case, they do fairly well and are able to meet most requirements.

However, if you look at this number and you want to select the best out of the lot, you will find that hydraulic systems offer the best options amongst all varieties. They, they are usually the smallest for its output load capability that you want. So, if you look at the earlier days when actuation systems were required, they were invariably hydraulic systems.

But the world is sort of moving away from hydraulic systems mainly due to the fact that hydraulic systems are difficult to maintain at a big new system, you have to have oil which is high pressure, and then that oil has to circulate through lot of orifaces and you have to maintain the oil to be highly consistent, no dust etcetera and you have to take care of leakages which will make the operation very difficult.

So, because of all these things you want to move towards electric actuators which are much much easier to maintain and operate. So, due to all these kind of situation, so if you look at the first one, hydraulic are the best, as far as size is concerned, but due to other things that we just now discussed we want to move toward electric actuator.

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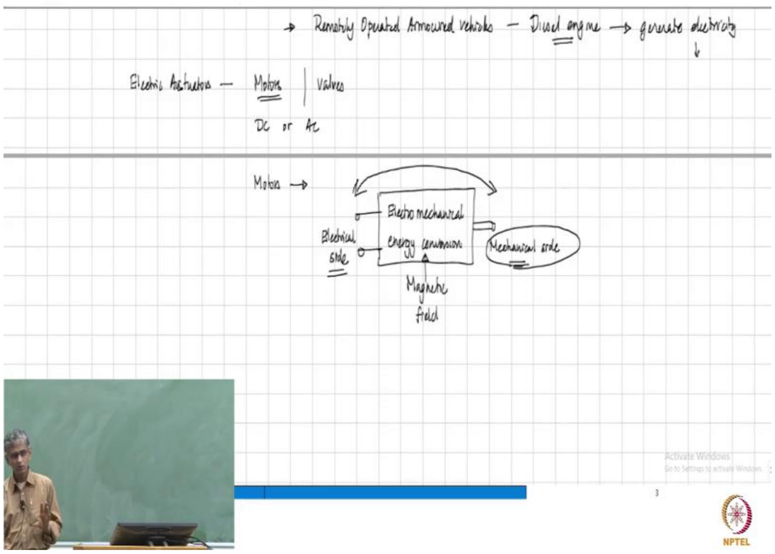

So, if you then look at electric actuators itself, electric actuators are today mainly electric motors. There are sometimes other valves that are used, electromagnetic valves, which can either release the fluid flow or stop the fluid flow. But unless that is the role of, of that is the operational need and mostly one looks at electric motors. And when you look at electric motors one needs to take recognition of the facts that what is the source of energy that is available, in what form?

Electricity, that is available, electricity is available in either in DC or AC and one may at the outset say that I would choose the motor that is appropriate for the form of the source. You have AC source, the AC motor, a DC source the DC motor, that approach works well if you want to look at very small application. So, if you look at electric motors, I am sure you would have all at least had some initial introduction to electric motors. So, electric motors are basically electro mechanical energy conversion devices which then accept an electrical input and deliver a mechanical output, or this is mechanical side of link and this is electrical side of link.

And en electric motor therefore enables an interaction between these two sides. You make the electric motor or electric machine in a more sort of generic sense is an appliance or a device that can change the electrical energy and convert it into mechanical or take mechanical and convert to electrical, both ways are feasible for any (electric) electric, electro mechanical device. And this interaction happens in the, that is, is enabled by the presence of magnetic fields inside the system.

So, unless you have magnetic field this entire thing does not happen. So first of all you need establish the field inside the system. So, if you have such a system then it is feasible to control the electrical side and get what you want on the mechanical side. Ultimately as far as robots are concerned, you are interested in the mechanical side of things and to achieve what you want, you need to have a good ability to control the electrical side of things. There are many different varieties of electric motors that are available.

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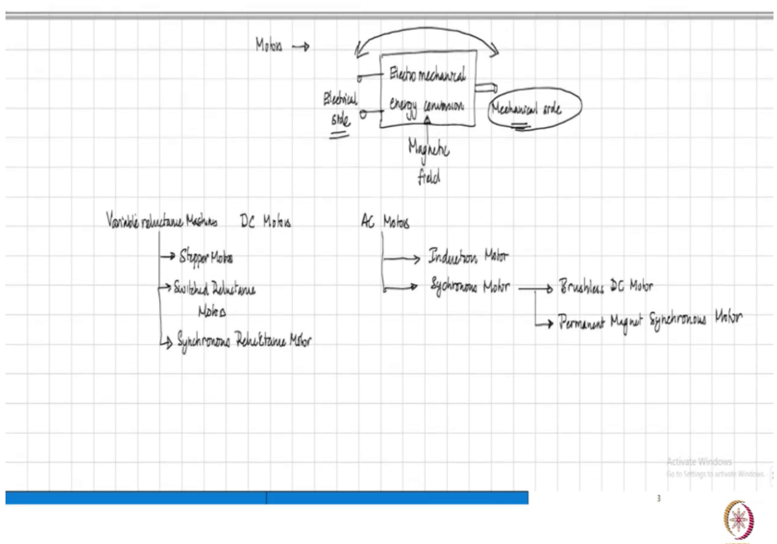

So, broadly these motors are called as, one is DC motors and the other is AC motors. In AC motors there are different varieties, one is called as the induction motor, another is the synchronous motor. The synchronous motor, there are other variety which are called as Brushless DC motor, Permanent Magnet Synchronous motor. There are yet another group of machines which are known as Variable Reluctance Machine. So under this group what you have are Stepper Motors and Switched Reluctance Motors.

And now there is another variety which is also making its appearance that is called Synchronous Reluctance Motors, reluctance motors. So these are broadly a large range of available electric motors for used in your actuation, used for actuation. Now, the question is, which one will you use? Now, if you look at the need for actuation I said earlier that any system that you are going to select must meet the operational needs.

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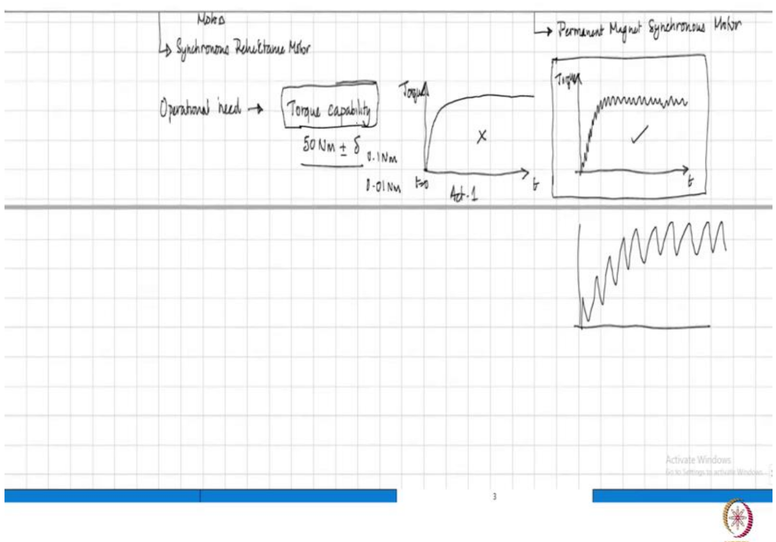

What do you think will be an operational need? From the actuator, what do you think will be an operational need?

Student: Torque requirement.

Professor: Torque requirement is the primary need. So torque capability is a primary need. Any sort of movement requires due to generating a force which in again a rotating system is the mechanical torque. Now, if this is what you need let me give you few examples, let us say that with respect to time, I am going to draw a graph of mechanical torque, actuator 1 gives you, I mean this is T equal to 0.

That is when you start, when you start the actuator and you find that the mechanical torque goes like that. Let us take the table to generate the mechanical torque that looks like this. In the next case, I have another actuator 2. This is torque again, the next actuator generates the mechanical torque that looks like this. Which one will you choose?

Student: The stable one.

Professor: Why did you use the word stable?

Student: the other one have oscillations.

Professor: So, there are oscillations, I do not know whether it is decent enough to call it as unstable. But so you think that the first one is better, why? How do you think that the oscillation, the second one will impact your operation?

Student: there will be vibrations.

Professor: There will be vibrations.

Student: Object may get damaged.

Professor: Object may get, may have some damage in a few cases, but what does it mean? You said that there may be vibration. What determines whether vibrations will be there? Definitely this mechanical torque is having oscillation. Fine. But is it going to imply that you will have vibrations? Is there any thing else between this and the vibrations that you will see?

Is there anything else that is going to determine how much vibration will be there? Damping is the important aspect, you are going to have an actuated that is generating this, but in all of that, this result in the vibration of a system, there are certain other elements in between. For example, if you take the case of a robotic arm, let us say I have a robotic arm that is going to pickup this and place it there.

And in my arm I have a actuator that in the first case moves like this, second case it is active. The first case is obvious, there is no difficulty there is a smooth mechanical torque, it goes and settles down there. Now in the next case, there is a slight oscillation that is there. So how do you think the system will move? Is it going to really move like this?

Student: There we have damping later.

Professor: whether you have?

Student: damping later.

Professor: damping later. So the actuator that is resting inside, at the place where which is going to have a rotational motion, that is the one that is having this kind of a mechanical torque, and the motion is not of the actuator but of your arm. And between the actuator and the motion of the arm, sits your mechanical system equation, which contains lot of mass and therefore there may be a moment of inertia which reflects on to the, on to the actuator. And that moment of inertia and the motion of the arm and your weight etcetera, will mean a substantial actuation of this ripple, even if there is no damping, substantial actuation of that ripple may be there in the actual motion that is felt.

Student: so it depends on the natural frequency.

Professor: It depends on the natural frequency.

Professor: It may. So, exactly. So there are these undesirable things the question is how much? There is likely to be losses in the system due to this, there maybe undesirable resonances that may happen, but the question is at what frequency? So, if this oscillation frequency is far far away from your mechanical system, resonance frequencies. As long as it does not cause an undesirable oscillation in rotor speed itself, definitely let us say you have another actuator, a third actuator which is generating something like this, how is this different from the second one?

Student: higher amplitude

Professor: higher amplitude lower frequently. So which one do you think is more, is little more difficult, is it the third one or the second one?

Student: Third one.

Professor: Third one. Why? Because amplitude are higher definitely, then we can match the mechanical frequency of the resonance. Usually mechanical resonance frequencies are low frequency. You do not look at the mechanical resonance happening at 100 kilohertz, it never does that. If you want 100 kilohertz resonance in a mechanical system you are looking at ano scale, a very very light system which is unsuitable for robotic applications. So, mechanical system when you look at it usually they are mass, weight and therefore resonance frequencies are fairly low.

Therefore the last system that I do is more likely to cause difficulties in operation as compared to the second one. So given the mechanical system you can always therefore determine what size of frequencies are allowable in that system such that it does not cause a difficulty. We must look at the fact that we are looking at an engineering application and not a physics application. I mean if you look at just analysis and say physics, if you want an output equal to x, you are looking at x dot 0 as the output.

But when you come to engineering, if you say you want an output of x, you are looking at x plus or minus something, which is acceptability. So acceptability is what is of intrest not the fact that it should be exactly equal to some number. For example, if you say that this mechanical torque I want to be equal to 50 Newton meter. As an engineer, you would immediately ask how much is the accuracy. You want to get 50 point 00000 or you can 50 with some allowance there, so you always say plus or minus some delta.

So, if this is the requirement that is physically achieved, you can always say depending on the application I want this value to be equal to 0 point 1 Newton meters, maybe the application require or maybe the application require 0 point 01 Newton meters, but it is never equal to 0. So you have always a certain allowance in your application which can then determine how much of ripple magnitude is allowable. And then comes the question of how much ripple frequency is allowable which then consideration based on your mechanical system design, so based on that one can allow.

Therefore we are now saying that it is not necessary to have this kind of system, if you get it, very good, nobody complains. But it is okay to have this kind of system, provided you are within your design limits, design requirement. So, this is, this therefore is a very important aspect in system design that such a behavior is acceptable, why we will see later as we go on. So, this is one important aspect, ability for generating torque.

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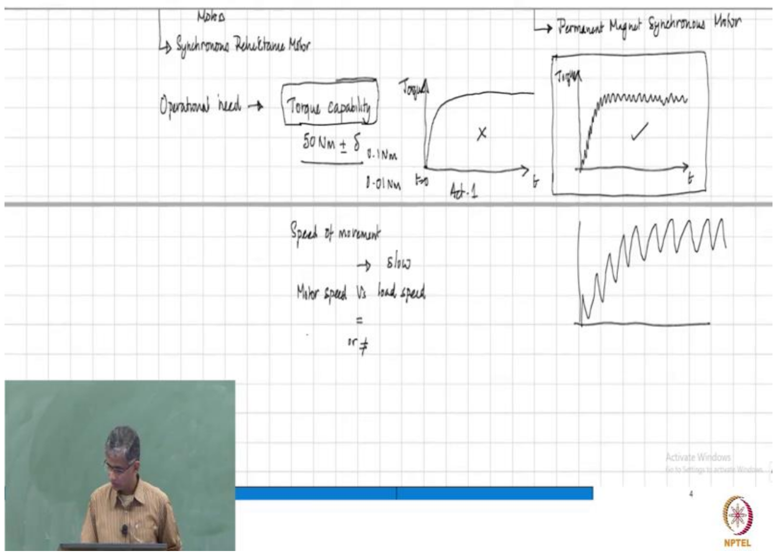

The next one is speed of movement. It should be capable of moving at whatever speed you want it to move. Having said that, now let us say that you want ultimately this robot arm to go from here to there, how much time would you like it to take to go from here to there? Do you want it to move in one second or do you want it to move in let us say fifteen seconds, how will you determine that?

Student: based on weight.

Professor: Weight of what we are moving definitely has to be considered, but how long it is going to take to move from here to there is usually an operational need. For example, if you are at an assembly line and you have objects that are moving along the belt and the robot has to pick this up and put it in a box. So this is one of the things in an assembly line, where you want this entity to assemble the output, the end output you want to lift it and put it in a box and close it and send it over for dispatch, so this is one application.

So you want this to take it out, put it in a bag. And this entire operation of taking this from here, locate it in the box and bringing the arm back must be finished by the time the next object comes, otherwise it is going to miss norms. So you need in a determined operating the rate of movement of the belt then you know how much time you have in order that this arm goes from here to there and then comes back. So, that when determining the speed with which you wanted to move.

Usually given a mechanical system you do not foresee that you require to move from this, from here to there, and bring it back in one second. That is too high a speed for a mechanical system, You can build a mechanical system but the actuation need to be very very large, you are looking at very fast movement, faster the movement move your actuation need. So usually speed, the end speed of, speed which you want to achieve in comparison to the motor speed that are available to you would be rather slow. If you look at an electric motor speed for example, you will be seeking in the levels of something like 1500 RPM.

You do not want the arm to move at 1000 RPM and keep it there. You will probably hit something, impossible to do. You would be looking at a much slower speed. So now, the question arises is do you make the motor itself rotate at a slow speed, or do you make the motor rotate at higher speed and do something else to make your arm move slower? Is it feasible to make the motor rotate at higher speed and get the arm to moving slower? How will you do it?

Student: Gears.

Professor: Gears is one. So you are really looking at motor speed versus load speed. Whether you wanted to be same or you wanted to be different. So, this is one important aspect in deciding what kind of motors you wanted to be used.