Product Engineering and Design Thinking
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Module - 07
Product Complexity, Affordability, and Design Thinking
Lecture - 32
Complexity Mitigation in Multidisciplinary (Mechatronic) System: Concurrent Engineering Precepts

Welcome back to our course on Product Engineering and Design Thinking. Today we would be discussing the complexity of a product design and development and we are in the module 7 and the lecture number is 32, the Complexity Mitigation of Multidisciplinary System.

When we are saying multidisciplinary system, practically from the mechanical engineering perspective if we see then with mechanical engineering naturally for a complex product whatever we see nowadays starting from the cars to (Refer Time: 01:11) to a air conditioners.

Most of the products are becoming mechatronic in nature. That means, instead of pure mechanicals, the electronic involvement is coming in, control system involvement is coming in and moreover with the development of IT system they you know firmware and IT oriented or computer application oriented, computer software oriented solutions are also being embedded in this.

So, what we will discuss? Since we will be having so many different areas as I have just named quickly mechanical, electrical control, computer applications or computer software. So, it means that several different specialisms are working together simultaneously concurrently. Because it has to work concurrently otherwise sequentially if we do then it is a never ending process kind of a thing.

So, in concurrent engineering condition therefore, if we are working [FL] we have to understand that perspective also how different specialisms are working together. And how to therefore, manage to mitigate this complexity oriented situation when we are encountering during all design and development activities.

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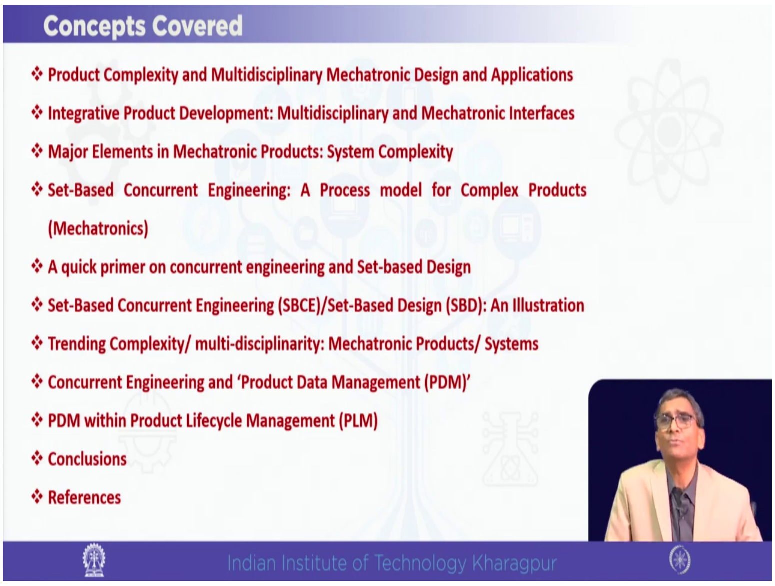

Alright, so, with this short preamble I will go into the a content slide ah which you can see I do not have to repeat, but then broadly it is as I have already mentioned it is about product complexity in multidisciplinary mechatronic designs. So, naturally it is integration of various specialisms so, integrative product development will be a discussed.

And naturally since we are discussing in terms of since we are particularly focusing on complexity and multidisciplinarity. Multidisciplinarity is bringing that complexity more into the thing. And therefore, we need to understand systems elements that is a mechatronic systems elements which we will also discuss.

Maybe it was part of your course, maybe you have studied it already, but then what we thought is that if you do not, you did not have it part of your course or for a quick understanding we will go through that once again maybe briefly, but then we will touch upon those. If did not you can of course, go in the for the depth of individual elements and those discussions.

So, here what we will do as we say in the concurrent engineering is one of the important pillars in this, but here we would introduce another concept called set based engineering. This set based concept we will discuss here we will see that in detail. And therefore, what we will do is we will set based means basically we are thinking of developing in multiple sets of solutions in individual or separate specialisms or disciplines. And then not immediately at a subsequent or later stage we would try and see how those things best fit in.

Because this that means, we are trying to keep this is a design flexible. So, that we can evolve a much better system when we are optimizing a little later and not to start with, that immediately we are fixing the all the parameters and we are trying to optimize.

No, we are trying even to see which set of solutions are the best set and then we will try and add up those (Refer Time: 05:19) designs. So, that is the thing and thereafter we will talk about how PDM that is the Product Data Management which is a very interesting electronic assistance through software etcetera.

The different packages and platforms are available through this we can get the facilitation for concurrent engineering. And we know that, perhaps we know that maybe many of you know that PDM that Product Data Management is a part of the overall system. That is it is not only design and development part, but then also its use how it would be manufactured and how it would be then disposed all these subsequent phases also will be part of it including its maintenance.

So, that will be the entire Product Life Cycle or PLM. So, this is the broad or in gamut of today's discussion. So, we will since we have in the introduction made and it a bit elaborate, we will not perhaps spend much time when the individual slides will be coming up. Then we would touch on those subjects and we can refer to this discussion that we have had just now in the beginning.

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So, we go to the aspect that we were just mentioning that now be it a consumer durable product like say air conditioner or refrigerator or even fans or it may be an industrial product. It is becoming more and more complex and is more and more mechatronic composed with mechatronic elements. Modern products such as mechatronic devices are multidisciplinary as we have said and this actually raises the complexity.

Now, examples are plenty and modern product systems such as you know conventional cars, we had seen that conventional cars are turning to hybrid electric vehicle or electric vehicle where a substantial portion of the components are not mechanical, but electronic and control system oriented.

So, and also with the you know computerized systems with where the embedded or firmwares are being implemented. So, starting from there we can talk of you know high end printers, medical equipment and instruments and already I have mentioned about many durable items consumer durable items also. So, these associates all these technologies that we have mentioned.

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So, now if you just see for example, in the consumer durable I have already given the example, but you can study it later I mean you can get more details starting from microwave camera to washing machine, toaster and then air conditioner I have said. In the medical diagnostic and test equipment, pace-maker, assisted surgery, in automotive I have already mentioned about this.

But then particularly if we go to the you know a control areas say cruise control, safety air bags, engine management which is called EMS, engine a Engine Management System, power transmission, antilock brake etcetera. So, these are examples of this mechatronic system in the automotive sector.

In defense, unmanned vehicle is very common you have seen in many situations maybe during a course and studies. This unmanned vehicles both for the ground, underwater, air and besides at the regular things say for example, aircraft engines and controls etcetera are there always.

In the manufacturing also we see the robotics, CNC machines, automated guided vehicles, in flexible manufacturing systems that which carries the you know pallets from the workstation to workstation etcetera that those are all the examples of the mechatronic system.

Now, you understand it is practically, practically everywhere. And therefore, we cannot escape the discussion on the complexity or design and development or product engineering in these areas. So, how to address this? That is why we have taken up this topic and that is why we will discuss the concurrent engineering most specifically set based concurrent engineering.

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Having said that let us understand that appreciation of multidisciplinary complex engineering system and its mechatronics. Here we would talking about that the I as I have already said that the increasing incursion of IT in mechanical engineering impart sufficient significant advantages.

Sufficient information is coming, knowledge is coming and that is creating significant advantages and benefits. And the discipline has evolved due to such need and termed as mechatronics which can be typecast between two major continuums. One is a spatial considerations, spatial consideration means piece while how it will be arranged within the system that a spatial integration of mechanics and electronics such as MID, Molded Interconnect Devices.

Let us say the communication antenna within the ah switches or say within a certain electronic devices those are the a molded interconnect devices that we can that we see. Similarly, there is another part in that continuum other extreme in that continuum is that that which is the control part. That control guided movement of multi body systems.

So, this control part and the spatial arrangement part these two actually are the two physical engineering challenges. The particular mix or combination of the these two in varying proportions of course, some where it is more that is less or etcetera otherwise vice versa, in a product system is considered depending on the application and the associated design factors.

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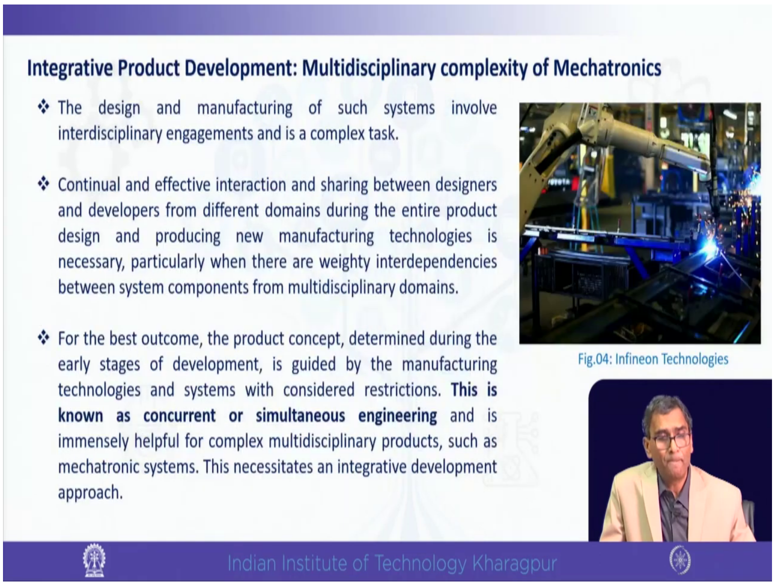

Now, as I said that since there are multiple disciplines involved so, automatically and naturally what comes in is the integrative product development consideration and that brings, multidisciplinary complexity. So, engagement of interdisciplinary specialisms and experts is a complex task itself.

Complex in many ways understanding the technology, understanding the nuances of technology and their interfaces, the communication technical communication issues and the you know preference of one technology over the other when the optimality comes in. So, all these makes the system makes this consideration very complex.

Continual and effective interaction and sharing between designers and developers therefore, from different domains during the entire product design and producing new manufacturing technologies is necessary because of this requirement. Particularly when there are weighty interdependencies. Obviously, now practically interdependencies are everywhere, when the interdependencies more strong or more weighty then it is required even more.

Alright, so, for the best outcome therefore, what we need to do? As we said the product concept determined during the early stage of the development is guided by the manufacturing technologies and systems. So, when we are designing, we are also considering how it will be manufactured. And so, all the processes are being considered together. So, design is not completely independent of the manufacturing system or manufacturing processes per say.

So, these two are to be taken together in an integrative way and therefore, these when we are doing these two things or multiple things in integrative way. Now, different specialism and different kind of a spatial arrangement and different kind of control requirement and that too when we are going for the fabrication of that, with keeping those constituents in mind, be it cost, be it weight, be it volume, it naturally needs a huge integration and collaboration where the concurrent engineering comes in.

So, that the smooth operation all these functions together happens. Like say if one is changing a specification on data or feature somewhere, in say the electronic specialism, the same thing how it is going to affect the mechanical system or vice versa. If a mechanical system is changing, how it is going to accommodate that part electronic part of circuit in that say package it its is of major consideration.

Now, naturally when these two or multiple things are to be taken together it needs smooth operational necessity. And therefore, concurrent engineering comes in a big way and obviously, that is very very important for multidisciplinary complex products.

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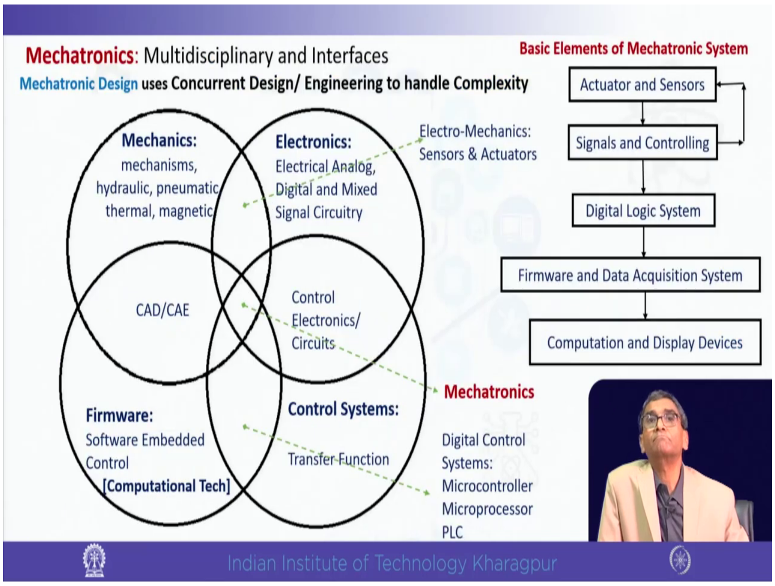

Here, we see the importance of concurrent engineering can be more understood from the complexity between individual and collective. Say between say this diagram presents four broad areas. Say mechanics, electronics, firmware and control system. You can see under each what are the general things, under mechanical comes mechanism, hydraulic, pneumatic, thermal, magnetic and all.

Similarly, under electronics you find the analog, digital and mixed signal circuitry. In the firmware embedded system or computer embedded control system is a computer tech, the you know codes are also written and the control system that we know is the for the through the transfer function that happens.

So, now all these are to be done simultaneously. And at this intersection of all four sometimes maybe other considerations also partly comes in sometimes majorly comes in that is also some material science based consideration, material based consideration.

Now, so, but at the core what you find this is mechatronics. So, when all these features are taken together, satisfying the specialisms, requirement of specialisms and bringing out that device of the product which performs, which actually fulfils or meets the need of a customer is the objective.

And so, here the understanding of complexity is a bit a clearer. And basic elements of mechatronic system as we know and see here also the actuator and sensors, signals and controlling, digital a logic system, firmware and data acquisition system and finally, the computation and display devices. So, we have to see I mean how it is showing, working etcetera. So, what is the outcome? So, that is being displayed, if temperature is going up how we are seeing digital is a when you see say when you use your vernier in the lab say for example, a micrometre in the lab.

Now when you see this digital micro vernier or digital micrometre, what do you see that, this connection between the mechanical movement and its conversion through the electronic system to the display, where we see that ok, this is the movement and that is getting reflected digitally. So, the analog signal is getting converted to digital. Now, sometime the analog is sometime the signal is the physical signal, sometime is the electrical signal. We will talk about that.

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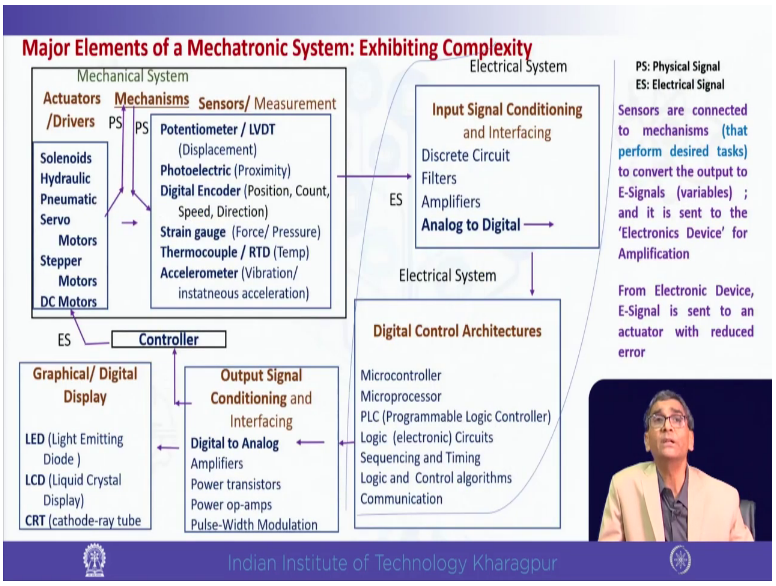

But then let us go to the next slide where we would find those that these different signals. But here one thing I would like to tell you how the mechatronic system works, what has been intended here in this discourse is, it has been done very comprehensively. That in fact, in through one diagram bringing the whole thing without missing any single aspect is a rather very uncommon or rare I would say.

So, we attempted to bring in one screen, the whole thing of a mechatronic system that you can see. That basically it has you know the mechanical system, the electrical system, the controller and the display basically if you see. So, here what we see is that that see on the in the mechanical system there are you can see that the actuators and drivers it may be solenoid, it may be hydraulic pneumatic system, it may be servo motors, stepper motors or even DC motors. And that actually feeds to the sensor, but feeding to the sensor actually comes through the mechanism which actually it operates through certain displacement that it makes.

So, that mechanism changes and that is sensed by the appropriate sensing system, if it is a displacement we are going to measure then we are taking say potentiometer, if we are taking say proximity then photoelectric sensor we are using, if we are taking force or pressure then we are taking strain gauge.

So, for say vibration or instantaneous acceleration we are taking accelerometers, opposition count so we take the digital encoder so and so forth. So, different types of sensors are available for different functional purposes.

So, we understand. So, there are actuators, mechanism, sensors. That sensor is producing the electrical signal that is going to the system and through the you know the system of discrete circuit filters amplifiers; this analog is getting a converted to digital. And then this digital control architecture all control architecture comes in the interplay, this microcontroller microprocessor PLCs that is Programmable Logic Controllers. So, all these are there to do the control part of the activity.

And that gives it to the as output signal this signal conditioning and interfacing that is now, we are getting digital to analog for the a controlling the actuator which originated. And where in this process what is happening that the error is getting but by the you know the cyclic operations as we have explained; the error is getting reduced from these corrections. And so, again so this process is repeated and so the correct value is set final by closer value is target value is set.

And on the leftmost side you can see that the display part comes in as I said that in the case of micrometre vernier or in case of your air conditioner, air conditioner where you can see with your remote which what temperature it is etcetera. So, similarly here you can see that what is the display, display may be LED or LCD. Earlier very commonly the CRT the Cathode Ray Tube were used, but nowadays mostly LED and LCD thing.

So, here as it is explained also, sensors are connected to mechanisms I have already explained that, to convert the output is signals that is the variables. And it is sent to the electronic device for application amplification. So, from electronic device E-signal is sent to an actuator with reduced error. That is the most important thing and that is how we are bringing the through the control system to the target values or specifications.

So, this is what is being done for the car, this is being done for the washing machine, this is done for the air conditioner, this is done for the vernier, this is done for many or most I mean even say watches. But earlier all the watches used to be that with the winding system and all, but only mechanical strings, but now it is all electronic mechanical and electronic combination.

So, the life of mechanical engineering today is this that it has to have the interfaces. So, that is why we are discussing particularly because when we are talking about design these are the products. And therefore, the product design angle is to be well understood from this perspective.

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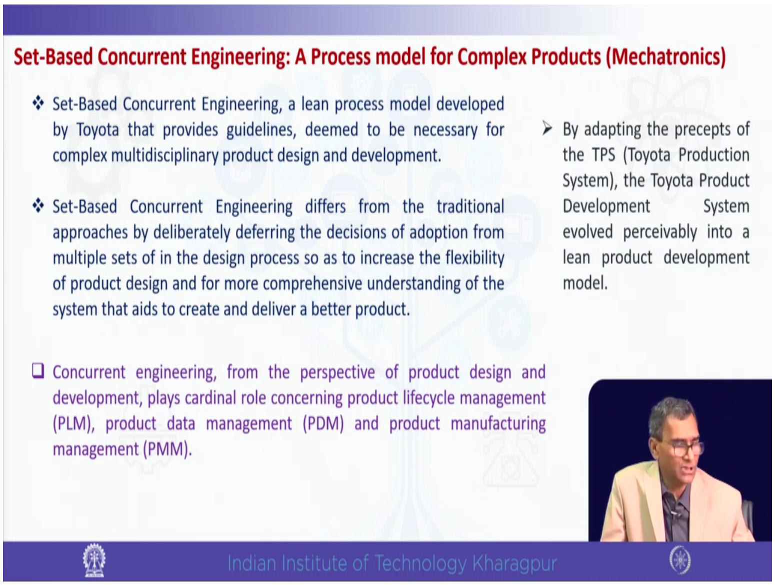

Now, once we are done with that part, we would go to as promised, we will go to the set based understanding set based designs. What is it? As I have already explained that set based are those that individual specialisms are creating different sets to be finally, you know assessed combining different possible sets for optimal performance.

So, this was actually done in the Toyota Company to start with. I mean this was a part of their lean processes, one of the lean processes, lean design process you may say. So, that is where so, that is where they set based design differs from the traditional approaches. I have already discussed about the PDM, Product Data Management, life cycle management and also product manufacturing management.

Where we see that you know a CAM thing comes in Computer Aided Manufacturing, but here our focus mostly will be on the design development part. So, yeah CAM also is important and their PMM comes in, when we are talking about the complete manufacturing of the product, yes.

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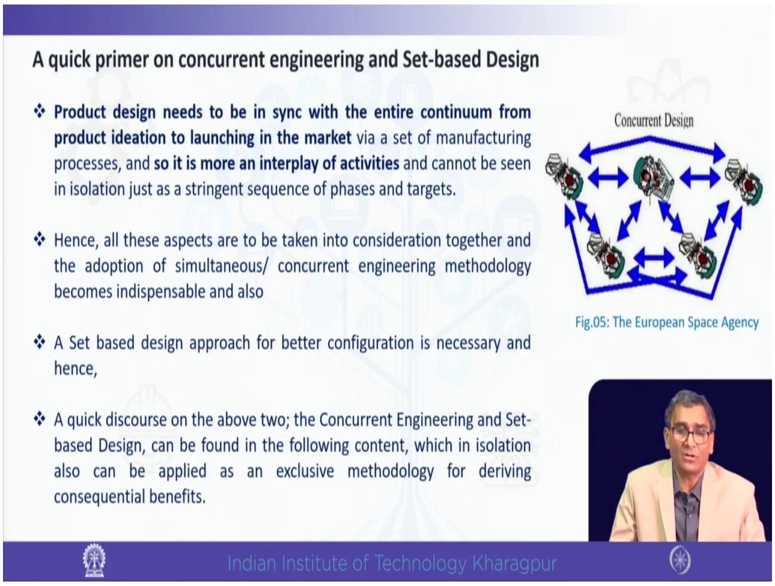

Now, a quick primer or on concurrent engineering and set based design very quickly, as I have already explained I will not have to spend much time on this slide. That means, it is not sequential, see it is being done concurrently each specialism is interacting with the other special specialism or groups subgroups, rather special subgroups directly. That is the pictorial representation and what is written here is only that.

It has to be in sync the product design has to be in sync with the entire continuum of the product ideation to launching in the market. So, end to end that is what I mean. So, everywhere the all these functionalities starting from the ideation, conceptualization, prototyping you know and finally, manufacturing (Refer Time: 27:28) to connected.

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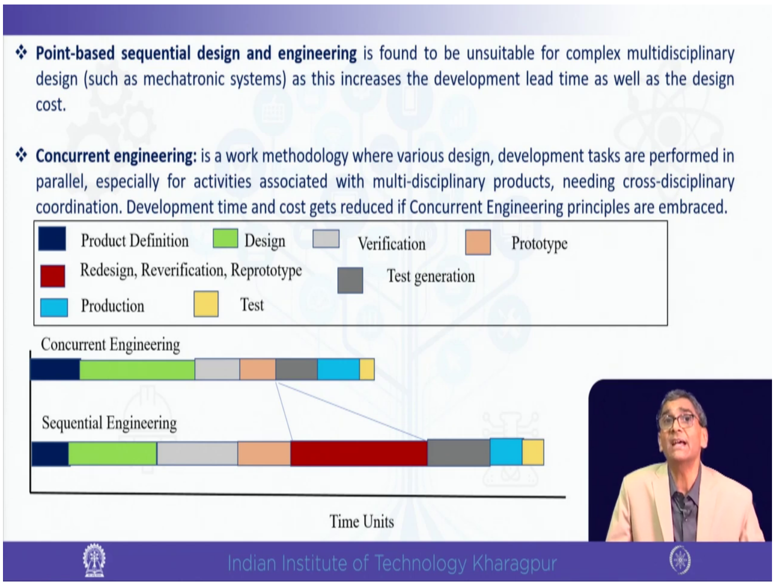

So, I would like to first go to the concurrent engineering what it affects, you can see very quickly I would go through these two bars at the bottom. One is that the lower bar I will discuss that first is the sequential engineering. What you see? That the this the you know legends are put on the up that the deep blue is the production product definition, green is design, grey is verification, orange is prototype, red is redesign re-verification prototype etcetera.

Then deep greys test generation and blue is production and yellow is test. So, what you will find the total time required in the sequential engineering is this I mean pictorially you can understand that. Now, what we are saying if we practice concurrent engineering that concurrent if we do many things that we have to do it a revise it, that is say redesign, reverification, reprototyping will practically can be done away with.

Now, I ask you to see the diagram once again carefully. What you see that this red part red portion which is the re-part, re-design, all the re that means, it should pass and go in one go properly because we are already interacting throughout. It is not that electronic circuit is given that mechanical specialism saying it cannot be accommodate.

Or mechanical part is given the electronic engineers are saying no, this circuit cannot be accommodated or the PCB cannot be accommodated in this. So, we are going concurrently. So, the correction set structure becoming being done in the during the process itself and the beginning itself.

So, it is saving all the re part of the thing redesign, re-verification and re-prototyping the entire time saving is happening. Interestingly you see while it is happening with the concurrent engineering says that give more emphasis and if necessary, give more time for the design part of it and the defining part of it.

So, initially if you give more time to the front end as we had discussed earlier the rest part will becoming less this is the beauty of concurrent engineering. We will see that the in concurrent engineering they are in a point based and sequential based designs.

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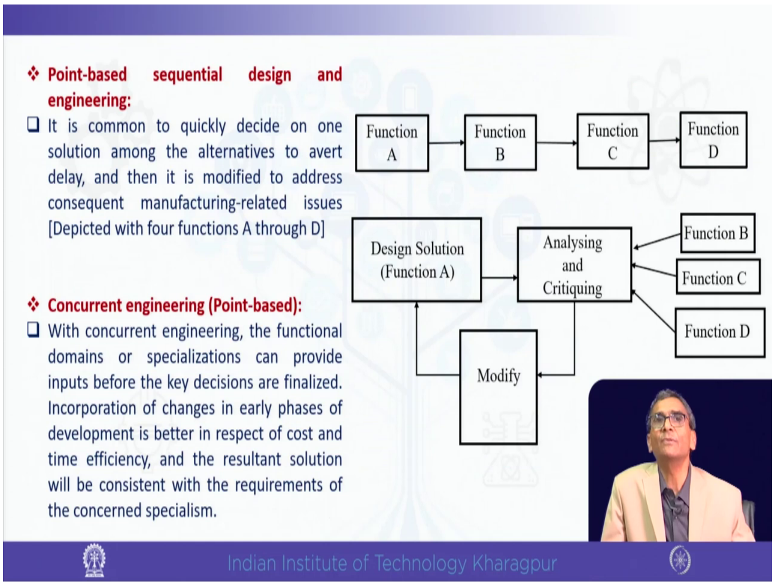

We will talk about that point based means say function A, B, C, D it is going sequential engineering, it is not concurrent ABCD sequentially. Concurrent engineering if it is point based say what happens, design function of a the lower one. The design function solution of function A which is being analyzed and critiquing.

Critiquing means you know commented on the it is failure possibilities mainly and or disadvantage or short shortcoming so pitfalls mainly. And then it is modified and accordingly and to suit say function B, C, D and whatever subsequent. So, it is point based. Point based means A is being corrected and accordingly B, C, D is getting satisfied.

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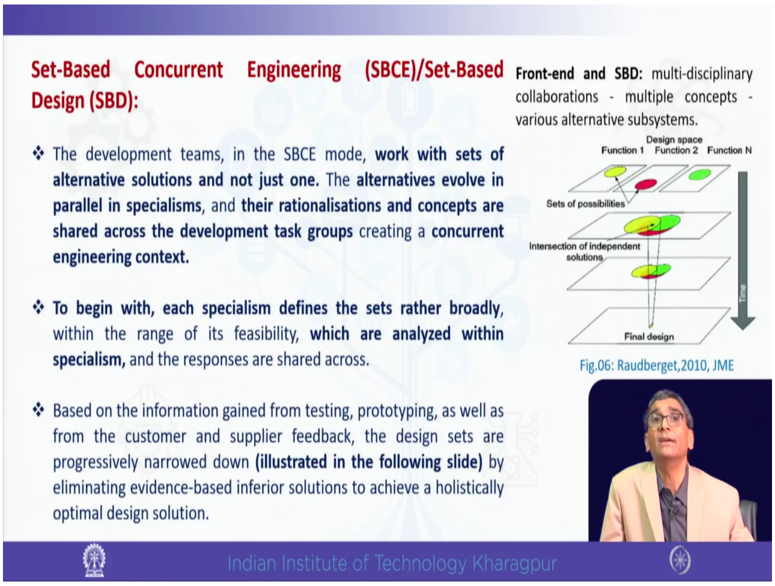

But in set based as you can see this figure you say Raudbergets figure which shows that the individual specialisms of different colors, they are having different sets. And through various layers they are being brought in closer together to see how the individual specialisms, the sets in individual specialism are matching and their intersection is giving us the design set.

Final design set which is called set based concurrent engineering or SBCE or is also called set based design engineering on design and. So, this initially it is defined brief broadly and subsequently it is narrowed down. That is what the set based concept is.

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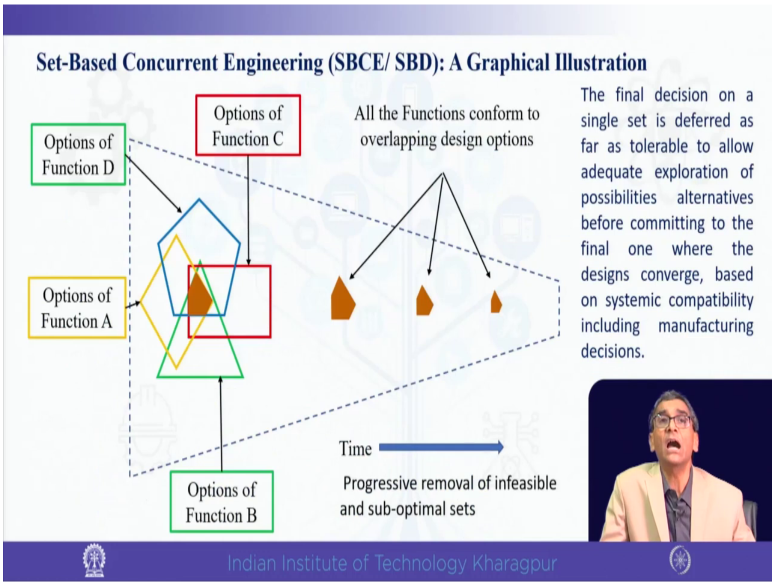

And of a we go to the next slide we will see how the difference a function A, B, C, D etcetera there. Now, you see of different I mean this shapes have been you know a imagined to be so that we can understand their interaction in intersection sorry, they intersection. The intersection you can see that initially there was an intersection of certain areas, but when we are considering other constraints all constraints from individual specialism, the area is becoming narrowed down.

The narrowed down you can see the size of the intersection configuration which is getting narrowed down where x axis is the time. So, as I said the final decision a single set is deferred as far as tolerable to allow as far as tolerable and it cannot be endless obviously, within given time and resources it is to be completed, but the purpose is that it gives a better design.

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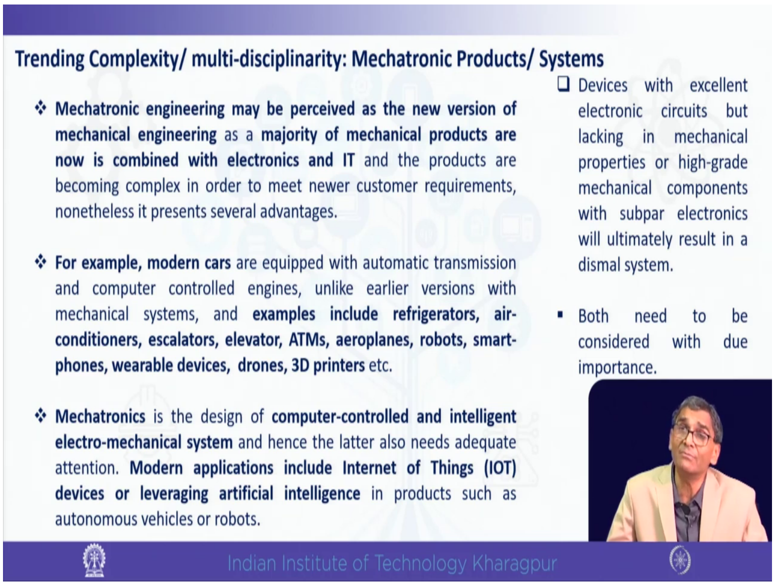

Though so, we have already discussed this we will not repeat this we it is the examples are given here that the ATMs elevators are the examples the. In fact, one thing more would like to say here the advanced systems I say computer controlled and intelligent electro mechanical systems any in such any electro mechanical system when it is joined with the computer control system becomes mechatronics.

So, modern applications like IOT or artificial intelligence can also be merged with this for a in the mechatronic system. If it is good in electric electronic, but not mechanical or vice versa it will not work.

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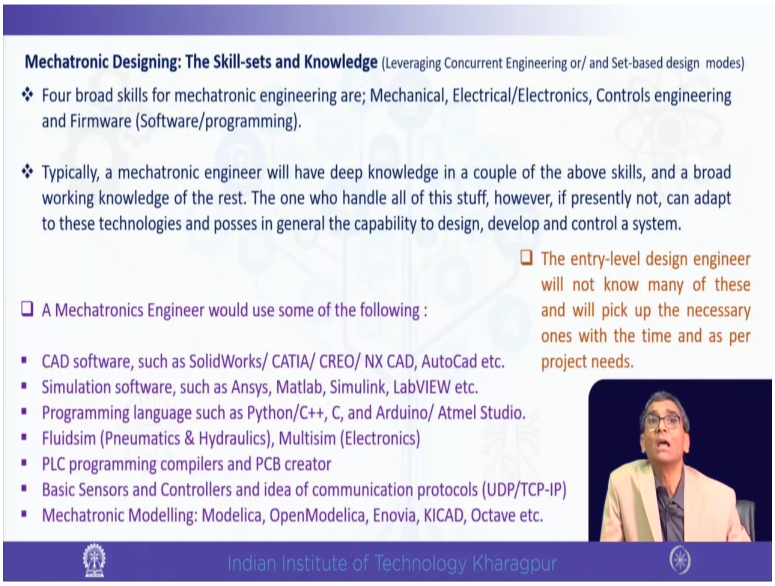

Now, we would talk about some because after all it is a question of career if you want to build your career in mechatronics. And so, what kind of skill set you would require. So, here are certain a list of software that you can see that the you know in different domains, if one thing I will tell you say in CAD software you have say solid works CATIA and all simulation software Ansys, Matlab and various others. In program language C, C plus, Python and Arduino, Atmel Studio and those are there.

In Fluidism a Multisim and Fluidism both will satisfy the requirement of a pneumatic hydraulic and electronic a basic sensor and controllers. And for mechanical modelling Mechatronic Modelling you have say Modelica or there is an open source OpenModelica or something like KICAD etcetera Octave etcetera and also in Enovia is there.

One thing do not get scared with this big list so called big list many of you already know thing is that the entry level mechatronic engineer is not expected to know everything. Therefore, I have written it in this orange color, if you see the entry level design engineer will not know many of these and will pick up the necessary ones with the time as per project needs. But then some basic things will be definitely be known to him he should learn.

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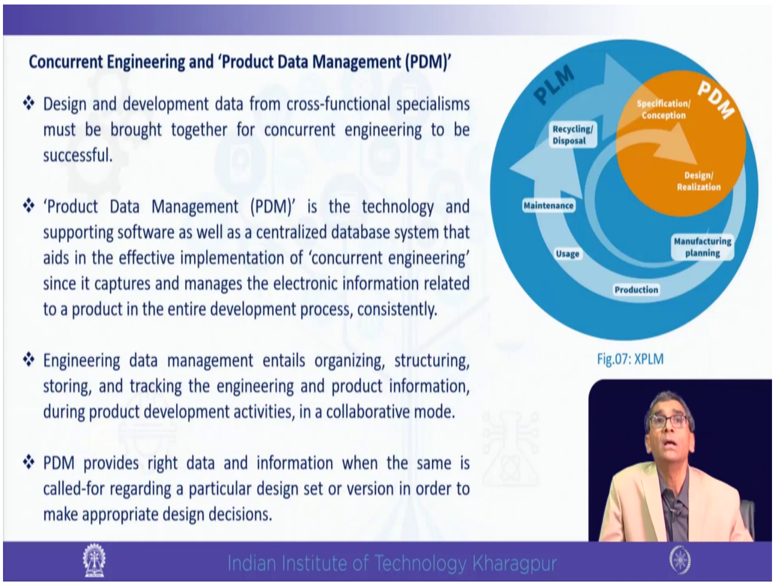

And so, we will come back to the last part of the thing that is PDM. We have already discussed that the PDM is actually a platform etcetera. We will talk about again that that is a electronic data management system. We will give certain reference of the software or platform available for this. Product data management is the technology and supporting software as well as centralized database system that aids the effective implementation of concurrent engineering. That is the in nutshell whatever it has to say. And PDM is within PLM.

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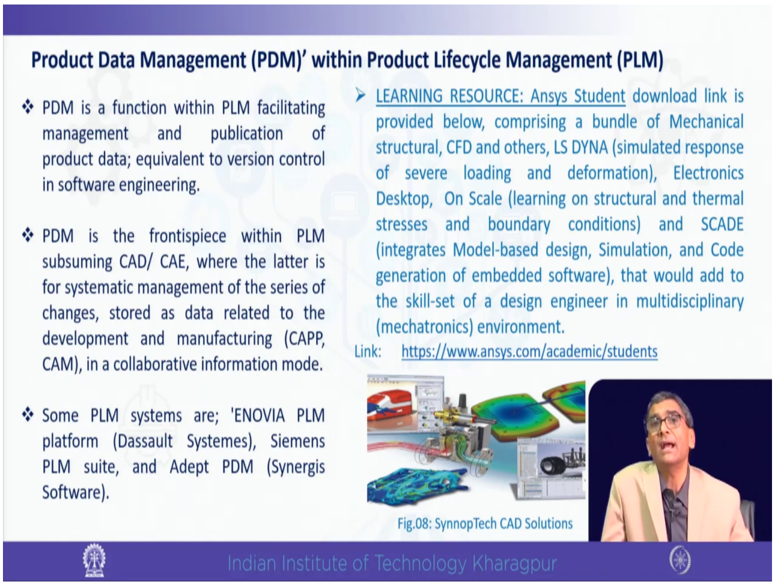

Now, here as we see that that there is particular this slide is as I have already discussed on the left side, but then on right side I just would like to tell you a good news that there is a learning resource, free learning resource Ansys student download link which has been provided here.

That gives a huge inputs the mechanical structural to CFD, LS, DYNA, SCADE which integrates model based design, simulation, code generation etcetera. So, this is if you see will be immensely helpful. So, I suggest you go to that site download some of the software's try it and what you already know that is I believe well and with that you can keep on adding things.

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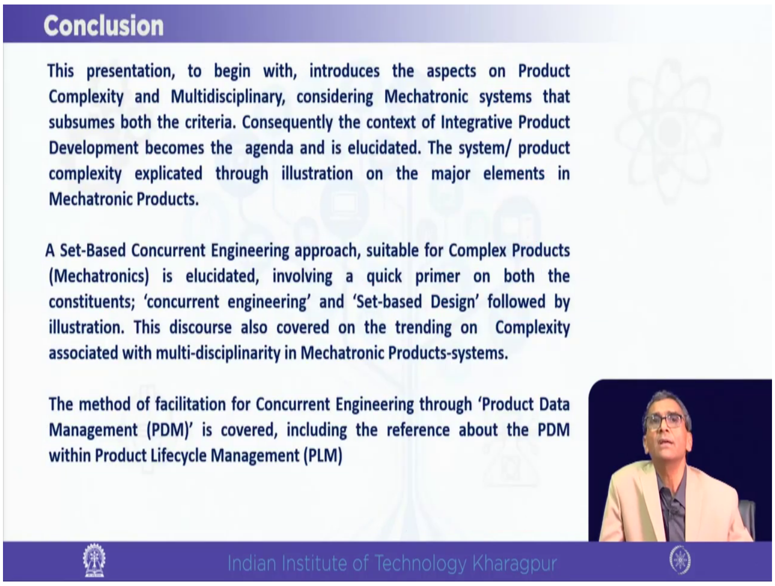

Now, because those are the things in any case you will be running on the way I actually have touched upon these things, name the software at least you should know where to get and for what. So, we have covered this mechatronic issues, the complexity issues, we have covered the set based concurrent engineering for reasons and finally, how the concurrent engineering will happen effectively for that we have talked about the PDM system.

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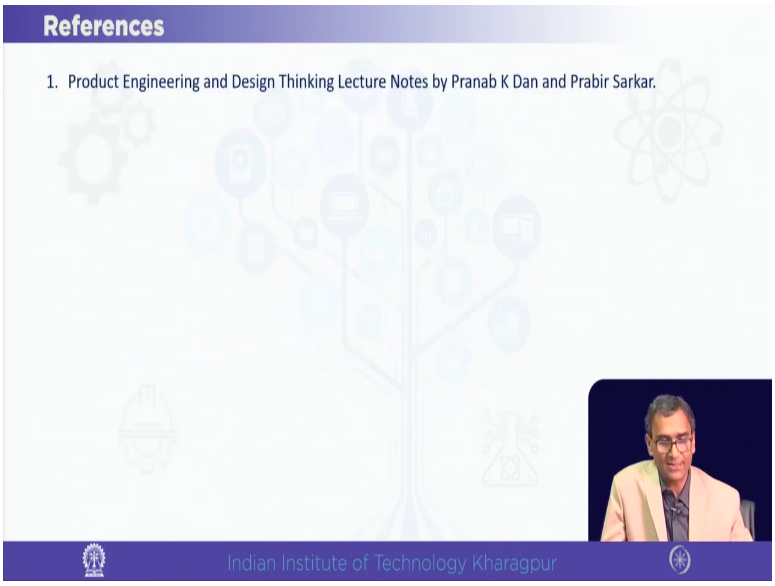

And this PDM system that some a name I have already mentioned that this ENOVIA PLM platform, Siemens PLM suit and adept PDM software these are certain available things. And so, you can always refer to them.

So, in the reference you can see it is the reference is given. And I am sure that this gives you an idea as to for multidisciplinary complex system, how to approach and how to find the skills required to do this and how to learn it because certain differences are also provided. Hope it will make you a great designer.

Thank you very much.