Product Engineering and Design Thinking
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Module - 06
DFM, Rapid Prototyping and Affordability Engineering
Lecture - 30
A Primer on Design for Quality: Robust and Reliability Engineering

Welcome back to the course on Product Engineering and Design Thinking of NPTEL module 6 lecture number 30 is A Primer on Design for Quality focusing mainly on Robust design and Reliability Engineering.

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So, we go to the slide concepts covered where we would be talking about the robustness and reliability because often in essence though these are two different aspects and two different treatments are done, but then for product these two practically are inseparable for its good performance and quality.

So, in literature, they often come together and that is why we would discuss it in here together and jointly. So, we know what is robust design, how it is different from you know the rugged design etcetera, what is the special purpose of it. Then we would discuss that robust design, robust design has two pathways. One is the FMEA pathway, the failure mode and effect analysis and which is having two sub components one is design FMEA and another is the process FMEA.

So, once the process FMEA is done then once the design FMEA is done, then process FMEA also is undertaken that one is the design aspect and other goes in the manufacturing aspect. So, product engineering since it is both are important however, if we understand one FMEA the other FMEA is exactly similar only in the context is design and their context is manufacturing.

Then we quickly or move on to Taguchi's robust design methodology which is the most popular one in this domain and widely used and you will find many resource materials on this and we will discuss that and in we will present certain definitions which are concerned with this. But, remember we are doing here this quality aspect of the design.

So, while design remains the main focus, we are also saying these are the aids, which is required by the designer. So, that is to be learned and that is to be practiced. So, the Taguchi's contribution we will discuss then we would talk about the Taguchi's two parts mainly because it is actually three part aspect the system design from there it comes to parameter design and then the tolerance design.

Taguchi's main contribution is considered to be in the parameter and tolerance design that we will discuss. What a downside let me tell you why we will do is the parameter design I will touch upon the main areas, but which has not been dealt well or dealt much rather is the tolerance design on which we will have to have a separate session.

Though we will touch that topic today, but an elaborate session is required and we will take in the next session. Then, we will talk about the reliability what is the concept and what the designer considers as system level reliability assessment through the reliability block diagrams. So, these are the things that we would be dealing with today.

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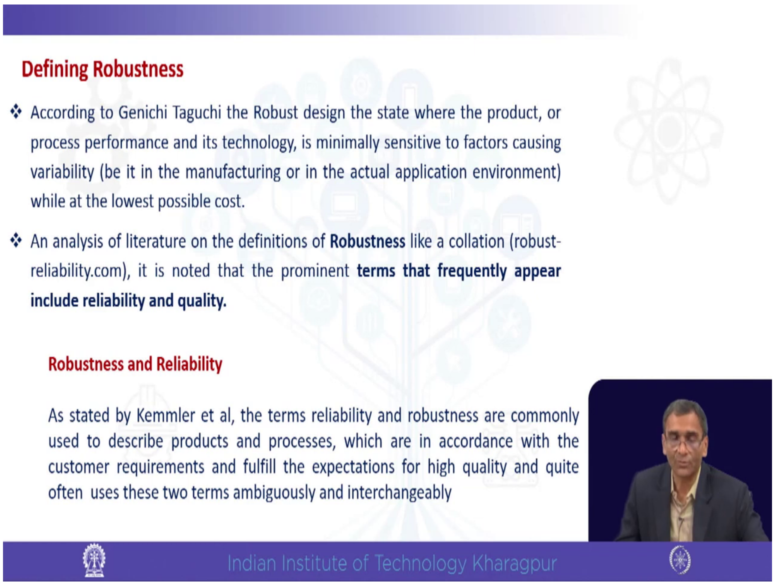

So, obviously, as we are starting, we will have to define certain features and this in short the essence of Genichi Taguchi's. Genichi Taguchi's robust design is that it despite the presence of certain conditions which are not which cannot be controlled always, the system should be able to perform well. That means, the system should be insensitive or rather more technically speaking should be minimally sensitive to the performance of the product.

We will discuss what those variations are and they are called noises as Taguchi had defined them. So, here an analysis of literature on definition robustness like a collision you can see that collision that robust reliability dot com is noted that the prominent terms that frequently appear include reliability and quality, which is very normal and we will deal exactly like this.

Also, Kemmler has observed that the terms reliability and robustness are commonly used to describe products and processes which are in accordance with the customer requirements and fulfill the expectations of high quality that is good quality and quite often uses these two terms ambiguously and interchangeably.

So, they make no distinction though technically there is a distinction, but that is why irrespective of those concerns we will deal both so that we understand that the entire gamut is covered. So, there is no further complication in the discussion.

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Now, slightly modifying another approach by the Mechanical Engineering Department of University of Denmark. I have put it because I have liked it because it is very to the point robust design is systematic process in designing products, devices and production equipment so as to make its performance and function minimally sensitive to the multifarious sources of variations.

What are those variations? One is from the ambient condition which is which could be external noise extra or source of variation. Maybe change in temperature, maybe change in humidity, there are many products which are affected by this.

Then there are there is a thing production and assembly tolerance or degradation. So, the product itself gets degraded over the use, say bearing will wear out and there will be you know wear and tear happening to the parts and that would call cause vibration and all. So, there is called internal noise, but that noise is being created.

And, also there is a possibility of unit to unit variation from this thing and all this removal or rather making it minimally sensitive to this variation. The point is that despite these variations, despite wear and tear, despite the change in ambient conditions. Like say if there is a cloudy day, if there is a humid day, the TV should not perform badly.

That is external or temperature variation. The mobile phone should not be affected or some other equipment should not be affected due to salty weather. The corrosion easily will not be you know corrupting the system.

So, these are some of the things that external thing and internal I have already explained. But all these are to be accomplished at the lowest possible cost. Again, you remember, we have talked about affordability aspect earlier and now we will straight away go to that consideration for this when we particularly deal with that in the subsequent discussions.

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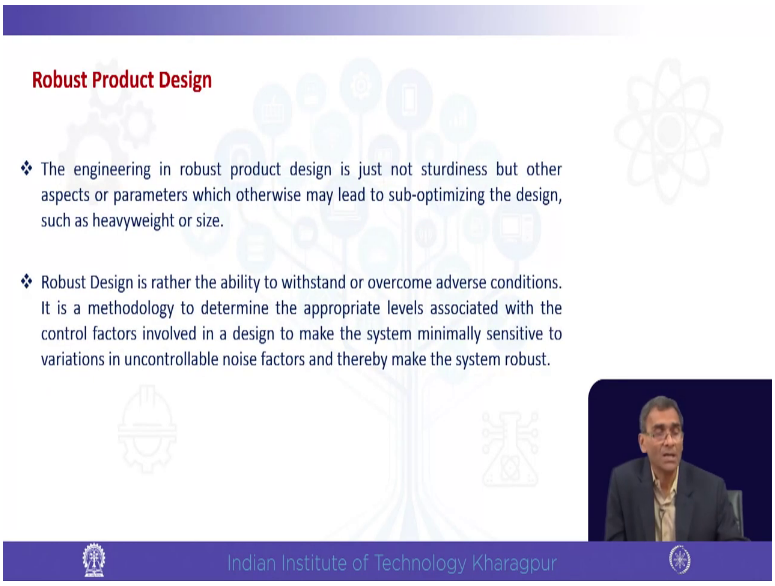

Robust product design, the engineering in robust product design is just not sturdiness or ruggedness, but other aspects or parameters which otherwise may be may lead to sub optimizing the design such as heavy weight or size. It is rather the ability to withstand and overcome adverse conditions.

Adverse condition I have already explained what is the adverse conditions like say vibration like the noises and the humidity, temperature change, conditional change etcetera. Yet it has to be minimally sensitive to variations in uncontrollable noise factors.

I said one is controllable that is the design control parameters and those are uncontrollable parameters. We cannot remove those uncontrollable parameters, please remember this. But our job is to find out the solution despite the presence of the uncontrollable parameters and that is called robust design. We will discuss how subsequently.

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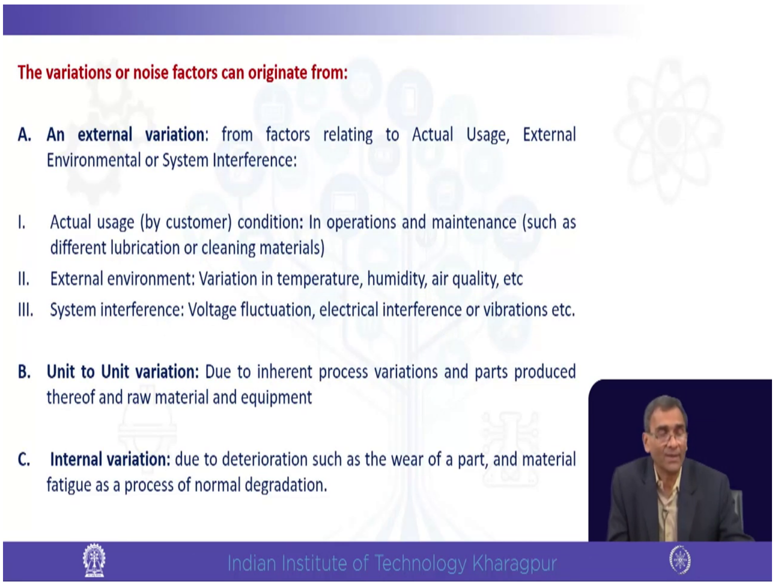

So, here I have already I would not spend time on this because I have already explained what is the external variations are, what the unit to unit variation is and what the internal variation is. So, we have already mentioned that in the course of discussion. When you will study the document, you will find whatever I have discussed. They are all pointed out. So that when you appear for your assignment of test, it will be handy and easy for you to go through. These points are there these three things that I have discussed already.

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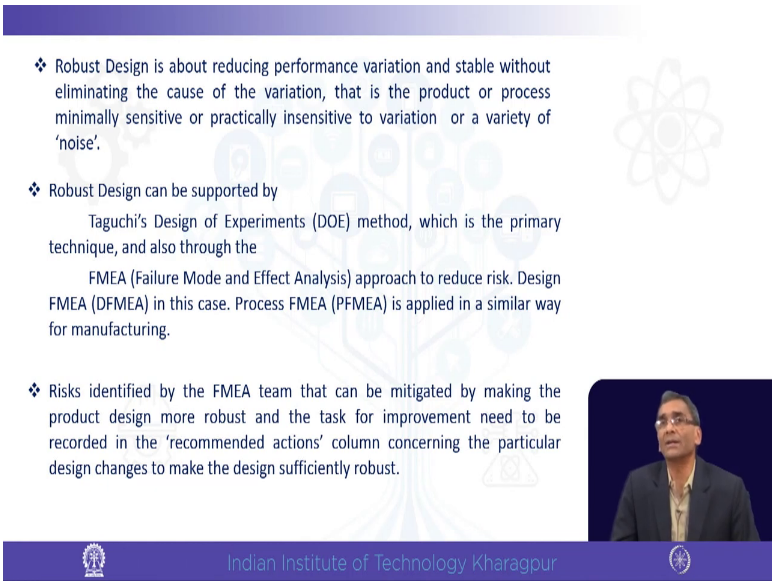

Now, therefore, the objective of robust design is to reduce the performance variation and how it is to be done that is the as I said there are two methods primarily one is the Taguchi's design of experiment method and the other is failure mode and effect analysis. I said in the beginning when I was discussing the concepts and we have discussed both that they are the DFMEA and FMEA we will discuss that.

Risk is also taken into consideration through this FMEA as the team FMEA team which normally comprises of various involved stakeholders like design representative represent from manufacturing, from quality, from the costing etcetera. They can mitigate the risk by making the product design more robust and the task for improvement need to be recorded.

But what are the things to be done for improvement or risk minimization is a thing called there is a format in FMEA that you can always find from the website etcetera where there is a recommended action what to do. So, there one will note down ok this is the action to be taken to mitigate that risk. So, if something is getting corroded, then what is necessary the material should either be plated or the painted then one will have to examine which one is more long lasting or cost effective etcetera the design aspect of it.

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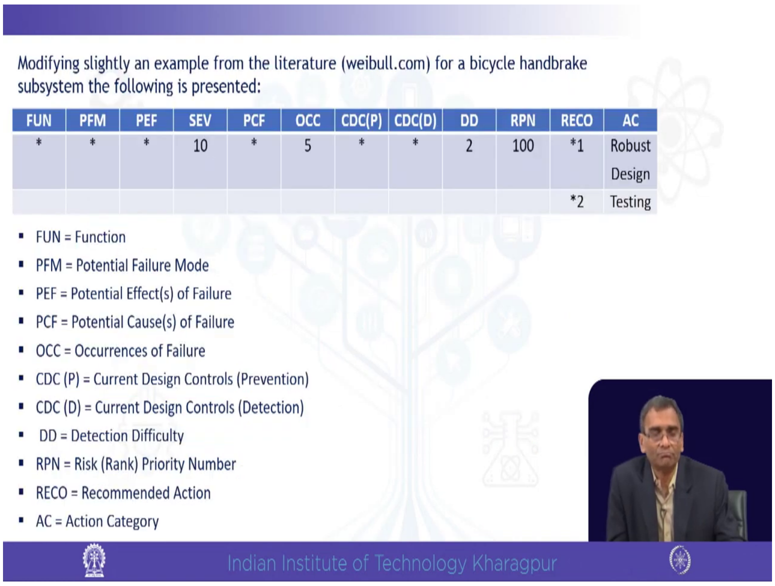

Here I will give you the glimpse I just said that that the format is available the slice of the format is presented here is that the first column is function, then is function that is function of the part what exactly it does that is the function of the part.

Potential failure mode, potential effects of failure, PCF – Potential Cause of Failure, OCC – Occurrence of Failure, CDC – Current Design Control, CDCD is a Current Design Control Detection, DD – Detection Difficulty, RPN Risk or Rank Priority Number, RECO

Recommended Action which I just now mentioned recommended action what to do and finally, to understand which action category it comes to. So, all these have been defined here.

Now, you would find there are certain aspects which means this explanation we will discuss that. But then there are three columns where you would find certain digits what these digits are. Here the three digits is under safe or severity short form is safe it is written here also and then this OCC, OCC stands for this Occurrence of Failure and DD is Detection Difficulty. ACV I find it is missed out from this list, but just note that ACV means severity short form of severity.

Now, it is all put in a scale of 1 to 10. If the severity is very high, then severity means what will happen if severity is there, we will explain that soon. So, first let us note that. So, in a scale of 1 to 10 suppose severity is 10 occurrence in a scale of 1 to 10 is 5 and detection difficulty suppose is in a scale of 1 to 10 is 2 we will say how it is done and then the product of these 3 is 10 into 5 into 2 is equal to 100.

So, recommendation 1 is a details, but the action category is robust design something else also is recommended as test 2 that is in testing category which is the problem undertaking for a bicycle handbrake subsystem design.

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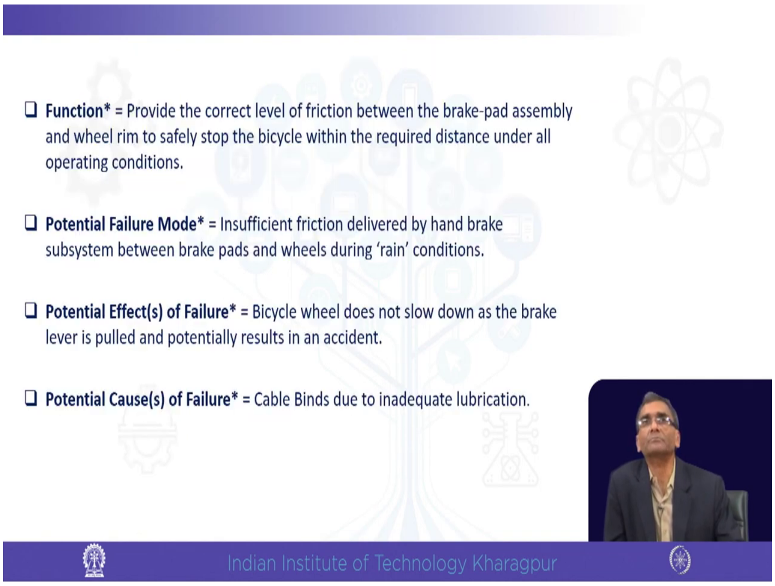

Now, the function as we said that we will discuss that provide the correct level of friction between the brake pad, assembly and wheel in this particular example case. So, I am explaining because in the literature in the books you will find the generic explanation, but I thought that I would explain that each and everything with an example so that it goes to your mind very well wheel rim to safety stop to safely stop the bicycle within the given range or within the distance under all operating conditions.

So, even it is raining even in the rain it should function and should stop. Potential failure mode how it can fail? The insufficient friction delivered by handbrake to the subsystem between the brake pads and wheels, wheel rims. Potential effects what will happen?

Bicycle will does not slow down as the brake lever is pulled and potential result in an accident. So, that is the effect. So, it is very severe. So, it is that is why you will find it is in category 10 top 10. Potential cause of failure a cable binds due to inadequate lubrication.

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Current design control prevention, handbrake design guidelines reference number from some reference number it is given. Current design control, detection, bicycle system, durability test reference number. So, those are the reference number from which this details that information will be put in.

Now, recommended action – what is the recommended action? Exactly we have talk about this. This is the heart and essence of FMEA, redesigned handbrake cable routing to reduce friction and make the system minimally sensitive to lubrication degradation.

And, so, it is the robust design category and recommendation 2 is the modified bicycle durability testing which is in the testing category. Now, what is the outcome of this multiplication of severity, occurrence and detection difficulty? That is the if the suppose it is 10, 5 and 2 something is say 8, 2 and 1. So, 8, 2 and 1 give a product of 8 into 2 into 1, 16.

So, that gives the rank which problem is more prominent or dominating problem. So, if the RPN number the product of this three would give us the priority. That is why it is called rank priority number. The RPN is equal to the multiplication of this three severity value, occurrence value and detection difficulty value.

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The FMEA team when dealing with the design related aspects of brake pad orientation, it procedurally would consider robust design techniques, such as DoE, Taguchi's DoE to beget the brake pad adjustment design more robust to the noise adjustments. Noise adjustment means say in the condition of rains where there is it becomes slippery yet it should have the (Refer Time: 19:21)

DFMEA is an analytical process for identifying, mitigating, and eliminating risks of failure associated with product design that reduces the number of defects and hence it is an effective product engineering methodology. It is pivotal for product quality management and leads to the following benefits which is here.

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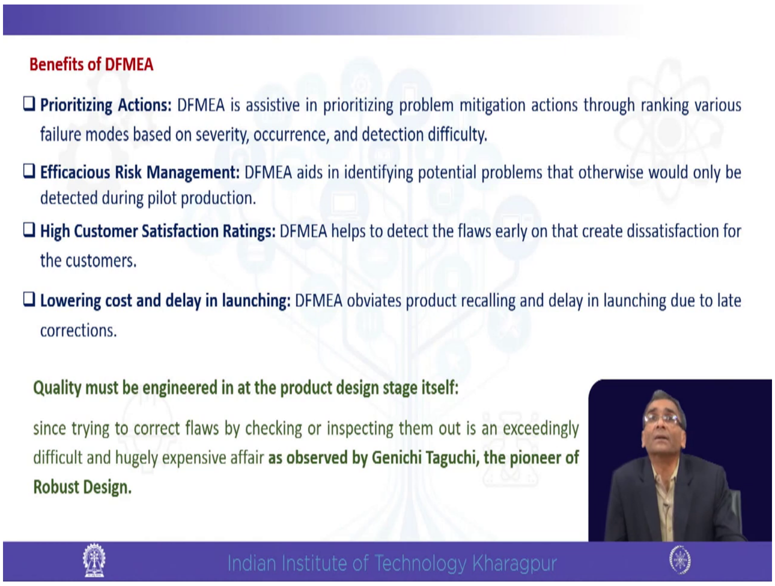

It prioritizing actions we have said that how it is prioritizing. Efficacious risk management, yes. High customer satisfaction, yes. Naturally if there are less defects reaching out to the customer because of this there is a reason the customer should be happy or satisfied. Lowering cost and delay in launching.

So, if we can detect or predict our failures earlier and make take corrective actions or preventive actions then obviously, the later on corrections are not required and the cost will go down and because of this extra unnecessary work it can be removed that building will be easier and quickly it can be delivered. So, product launching time also is reduced.

Because it is always believed that if product quality should be built in the product it should be engineered in the product it cannot be screened out by testing because by testing out later on, we might think find that some product is good and some product is bad, but then that does not help because a bad if it is a bad product already, we have to reject and that means, waste of energy money everything waste of resources. Instead, if we can address them earlier that is the best thing that FMEA is giving us that advantage too.

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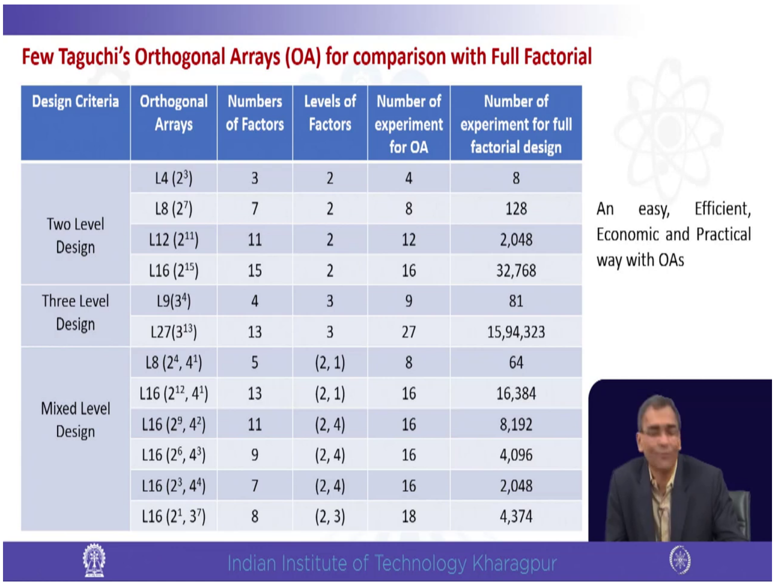

Now, from here this we have discussed FMEA from here we will go to the next approach which is Taguchi's approach. Now, what is Taguchi's approach Taguchi Taguchi's approach is the say if we are having multiple variables say the in any product development, multi criteria, product development multiple features.

So, different parameters what is to be set at what value, so that the best quality product comes out? Where a where should we set the parameters so that the variation is variation in performance is less least. So, suppose there are 10 parameters to be tackled. Now, so, we have to change one after another and see which creates what kind of impact this particular parameter or variable which leaves what kind of impact.

Suppose only with there are three factors only three factors and each factor can be having a maximum value and minimum value then you will find only for these eight experiments are to be carried out. Similarly, which is called level to the power factor this is the factorial formula which I will show you in the next slide.

Here you see one is that the full factorial we have presented it just for convenience you can see any of this it is only a partial presentation. Say two level design, some three level design and some mixed level design; mixed level means I will explain. So, here the first row you see which I have just explained L4; that means, that L4 which is 2 to the power 3 that normally, if we carry out experiment that would be 8 required only just right hand side column.

But Taguchi has proposed an array where with four treatment conditions the similar result will be available with enough confidence and satisfaction. Now, for such a small experiment, we understand this is the difference as we move on to higher levels any other levels because this why I am touching upon only this? Because on parameter design, I have given the websites, the links later on which you will have huge material to study if you are interested or if it is necessary.

But, for assignments whenever I said you will study whatever you will study that will not part that is for your own learn that you would know learn out of your interest out of your requirement and that will not be part of your assignment or examination. Whatever is presented here and discussed that will be only part of the assignment, but you can always out of interest go there and learn because there are plenty of material available.

Now, just see another thing say if there are three factors then with three levels maximum, medium, minimum. Say for example, then we have 8 we have to carry out 81 experiments where Taguchi is suggesting an array through which only through 9 it will be done. Fantastic results or other places in the you know say for L16 where 32,768 experiments are required, but with Taguchi only 16 will do.

So, you understand to how to what extent the Taguchi method is efficient to reduce the number of experiment because if you can reduce the number of experiment, we can quickly set the parameters those parameters and immediately start working on it so that the performance variation is minimal.

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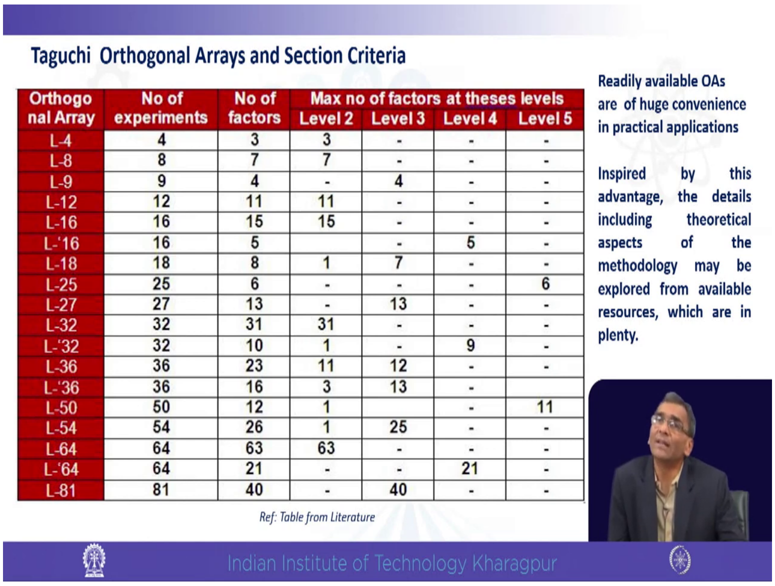

Here I will present this thing which is available anywhere you can Google and find out it is universally available I just have presented from one of the literature source. This is very common and everywhere we will find it. It is not any I would say secret thing anywhere, that on the left hand side these are the arrays. You do not have to do anything. Taguchi Genichi Taguchi has created all these tables for us.

When you go to that particular table you know how many experiments are to be carried out. You only have to know how many factors are there in your experiment and how many levels whether only minimum, maximum or minimum, maximum, medium or whatever it may be more. Whatever that level is that can be obtained from this level.

Say for example, if they say let look at the say second one it says that if there are maximum 7 factors at level 2, 8 experiments can manage. Normally, it would have been 2 to the power 7, so many experiments normally full factorial had to be carried out, but Taguchi has devised a chart where a table where only with 8 experiments we would get similar results, reliable results. These are these ways are readily available. This advantage is there.

So, any practitioner would love to use this because everything is ready, we will be just using it is a format or template or table and go ahead with the application usage. So, we will now, therefore, discuss in more details, but remember as I said our there are many resources on this parameter design etcetera.

And therefore, I will not spend much time on this and we will leave that to you giving the glimpse of what is done stepwise, but I will deal separately on the tolerance design where after parameter design the tolerance design part is not dealt in with very much scantily available. So, I will discuss with that.

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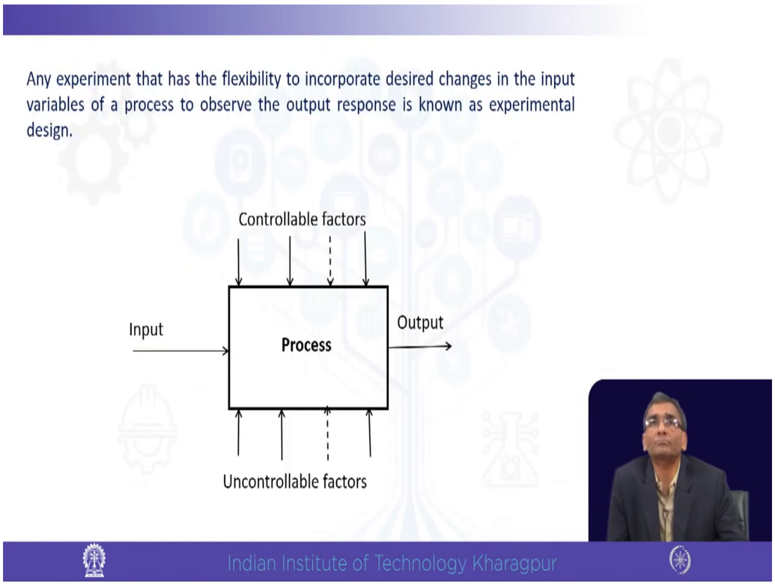

So, this is a general format you know that input, process, output, there are controllable factors or uncontrollable factors; uncontrollable factors of the noise that we have said.

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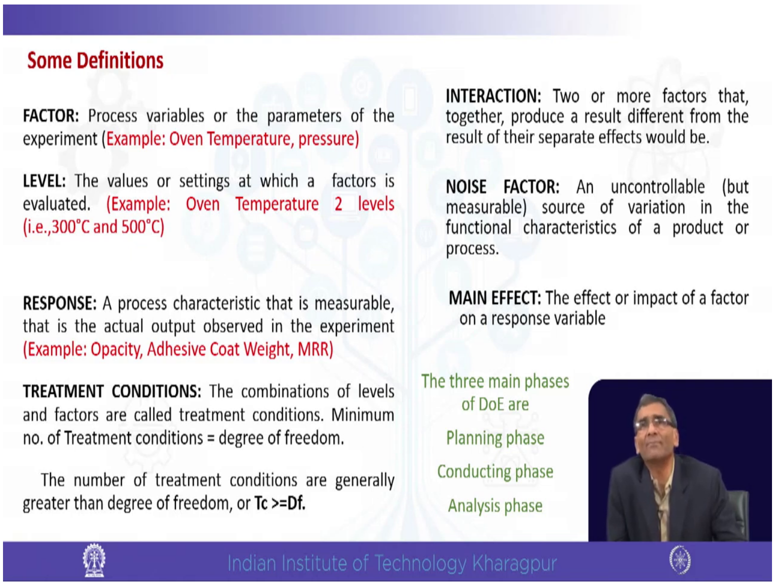

I have already given you the definitions that factors levels and those are there you can always check the data response what is the outcome, what is the result that is. Treatment conditions we have discussed treatment that eight; that means, experiment that those are called treatment condition experiments are treatment conditions.

Interaction is there if say multiple factors we are talking about if those factors have any interaction or one influences the other kind of a situation. Noise factor we have said and main effect is that effect of the individual parameters that we are discussing so far.

It has basically three phases DoE has three phases – one is a planning phase, then the conducting phase and the analysis phase. The planning phase is which orthogonal array etcetera we will take up; conducting phase is actually carrying out the experiment and analysis phase what the result comes and what it keeps.

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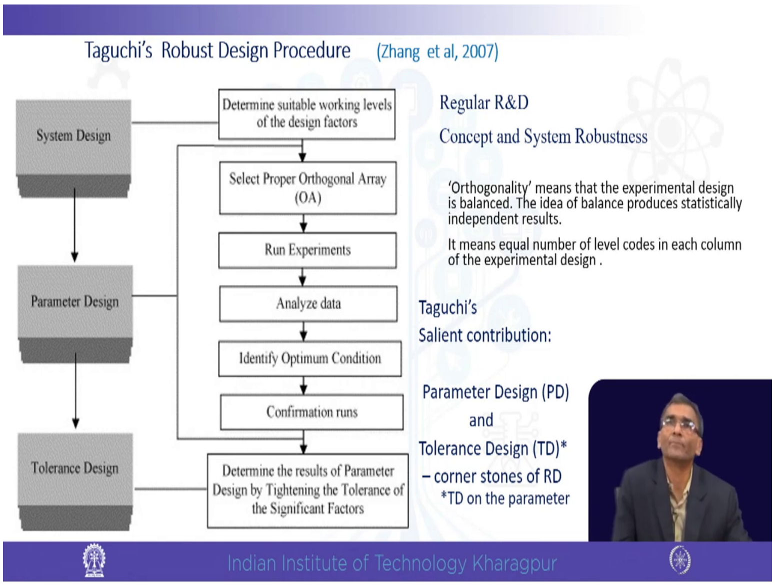

The definitions are everywhere I am not spending much time on the definitions you can see that and this is also the steps I have already explained that first is system level, then there is a parametric parameter design then tolerance design. And, here the orthogonality means that the experimental design is balanced.

Balanced means I will show you what is called balanced, but now you see under the parameter design as I said it is the selection of the orthogonal array table that is that L8 or L99 or L27 or whatever then actually carry out the experiment, run the experiment, analyze data, identify the optimal condition which combination of parameters – a at minimum, b at maximum, c at medium, d at minimum, e at maximum like that or that particular value. Why I am saying maximum may be it is 60 degree centigrade those kind of values and confirmation runs. So, this is what this.

And, then tolerance design. What is tolerance design? That is in short then when we are deciding a parameter to be of certain scale and set we are saying that this parameter design should also not fluctuate too much if we see that parameter is 60 to what extent that give the best result whether it is 60 plus minus 1 or plus minus 2 etcetera. So, within which range we have to come down to so that the performance is intact. So, how tight the tolerance are to be made is the direction given from the tolerance design.

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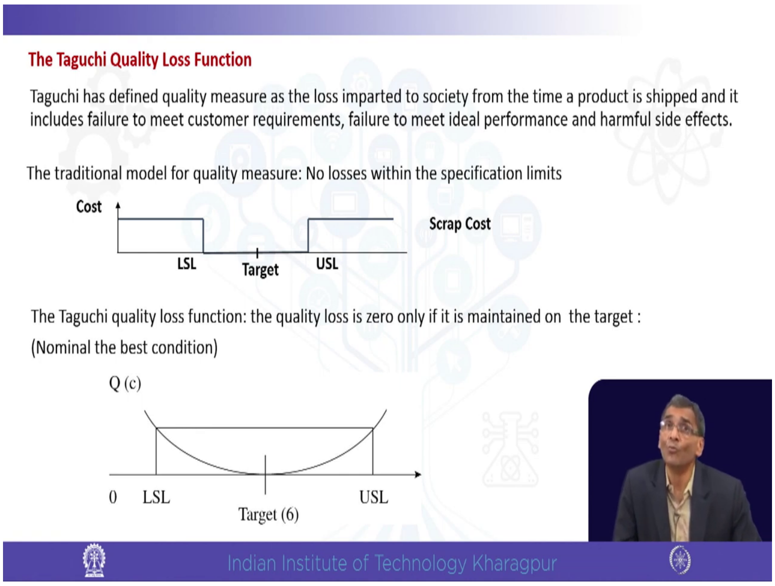

So, in Taguchi's loss function here you see the traditional model is there is a upper specification limit or lower specification limit. The target is in between because if it crosses the upper limit we reject if it crosses the lower limit you reject, that is very well you have learnt in your studies earlier.

But Taguchi has proposed that the loss function should be perceived as this that, if even if you within specification limit if you were moving away from your target your cost actually to the society is up. That means, if you are not meeting a target some leakage is happening, some waste is happening, if the road is not properly designed or the tire is not properly designed, then it will create a different level of friction and that would cause more fuel burning.

And, if there is more fuel burning it will create more obnoxious gases or greenhouse gases and that would create the environment pollution. So, you can understand the implication to the society how it goes. So, any deviation though permissible according to upper and lower control limit, but this loss function is very important which is a parabolic function proposed by Taguchi which you can see that if we are moving from the target value on the left or right side the USL or LSL side that is going up.

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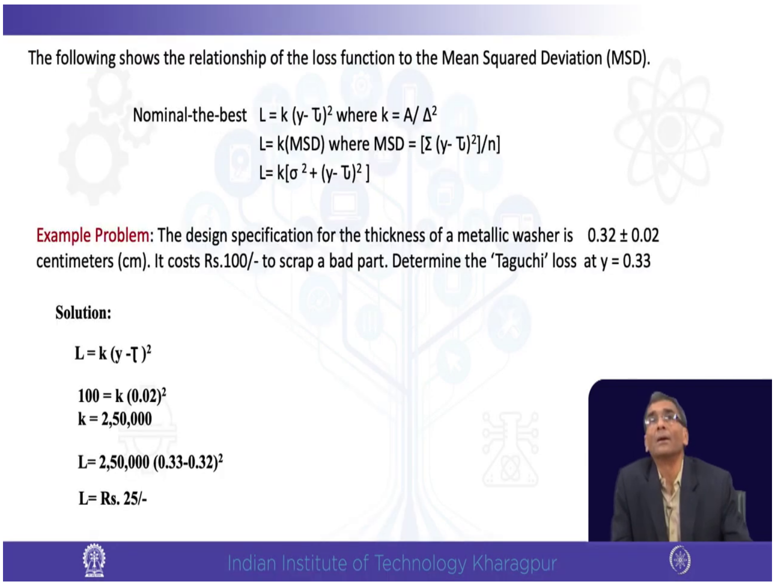

There is one short calculation that we will see. We will do the nominal the best kind of a thing that is a nominal dimension with the fluctuation. Similarly, there is a one thing called larger the better, smaller the better. I will not go into all these detailed discussion here because those are all available in plenty you can see if you want.

And, the calculation you can see say for example, without going into much of the theory metallic washer which is 0.32 plus minus 0.02 centimeter. Now, if this scrap cost is 100 rupees and then what would be the cost at when y is equal to 0.33. You will find the given the formula here that deviation means a cost. So, this is how we go ahead with this.

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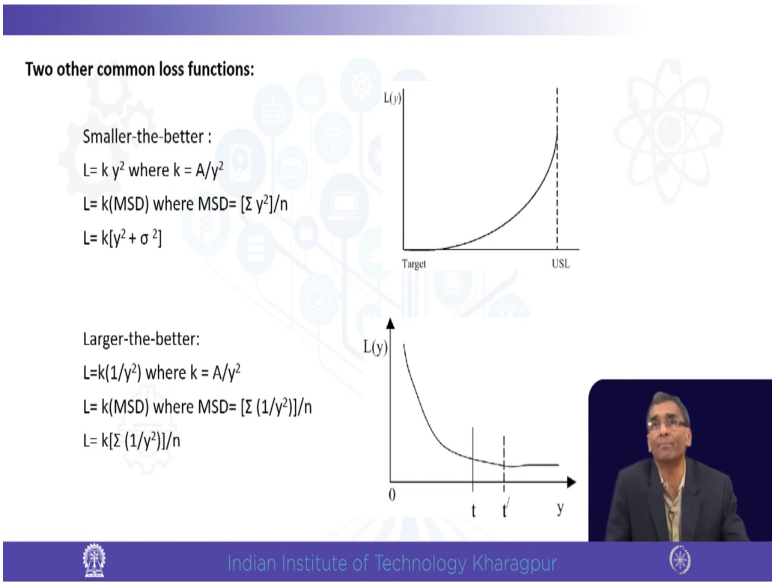

Now, here similarly the larger the better smaller the better and larger the better there, which are also considerations. But obviously, we are skipping it for detailed discussion now because those are all available, because this is not the main course. We are into product engineering or design course.

Our main course is not to Taguchi's design of experiment. So, I will touch upon this thing and if you feel that it is interesting and important for you then you go ahead. I am touching because if I do not touch you will not perhaps know in many cases what exactly is the solution? That is why I am presenting it.

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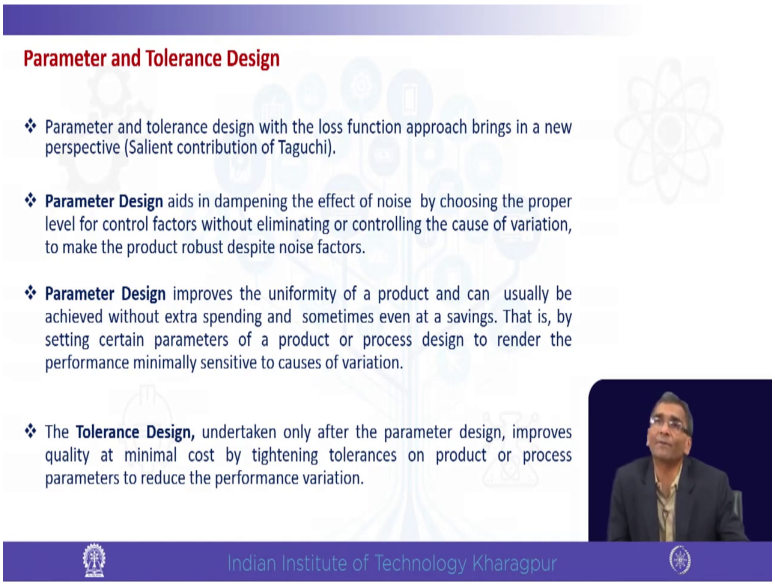

Now, parameter and tolerance design I have already discussed that. Parameter design aids in dampening the effect of noise by choosing the proper level for control factors without eliminating the control controlling of the cause of variation and we have said. And, it improves the uniformity of the product.

The tolerance design undertaken only after the parameter design improves quality at minimal cost by tackling the tolerances. It is done only after parameter design and it improves quality at minimal cost by tackling tolerances on product or process parameters to reduce the performance variation. So, this is the tolerance design.

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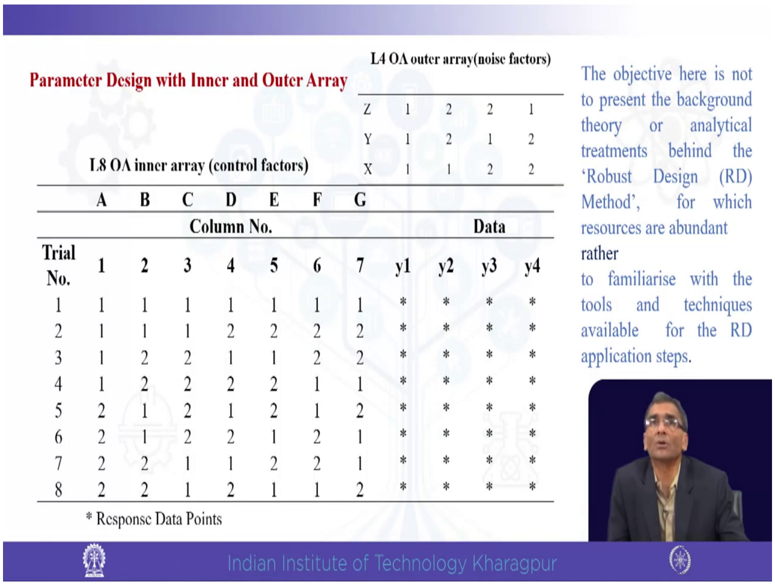

Now, here this is what you will see when you study anything in parameter design. I will soon after give the all the links where from. You can see this is this is this is combination of two arrays. One is L8 for the inner array or control arrays which Taguchi called inner array L8 or O8 and on top you find L4 or OA4 outer array which is the noise factors.

Suppose, there are three noise factors. So, three noise factors at two level each. So, it will be four treatment conditions and here in the control you have seven factors and two levels. So, there will be eight treatment conditions. So, when I combine these two, we get this parameter design outlay.

Now, what we do is y1, y2, y3, y4 these are the responses that is the result. If we conduct a conduct a study with this conditions when that noise level is 1111 and the say when all these are at level 1 these are the values. These are the responses. So, we take the average of it and do calculation or find the signal to noise ratio, we will discuss separately when we discuss in a separate discourse on this. But we would understand what the process is.

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Here are these sources links from where you can understand parameter design. I would give a glimpse of this. I said it is a primer. We will not go into the detail of this because details are plenty available. Only where the details are not as a hugely available or not practically available the tolerance is a I will take a special discourse.

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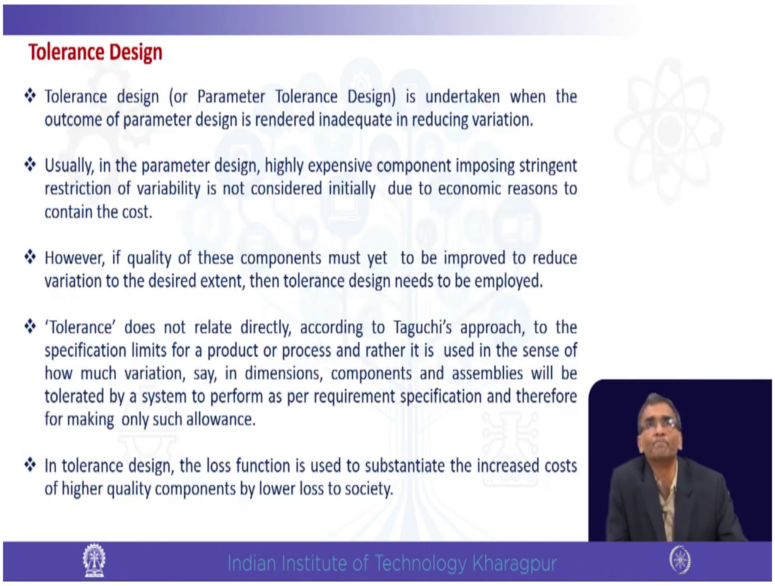

Now, we are into that tolerance design. I have already said the things about it. Only thing to be remembered a tolerance here is not directly according to according to Taguchi approach is not connected to the specification. But, it is connected to the variation of the you know ranges. Now, we have to find out which what will be the tolerance for a given parameter based on this operation. I have already discuss the other aspects of it. So, when you will study this slide later you will know that already these aspects have been discussed.

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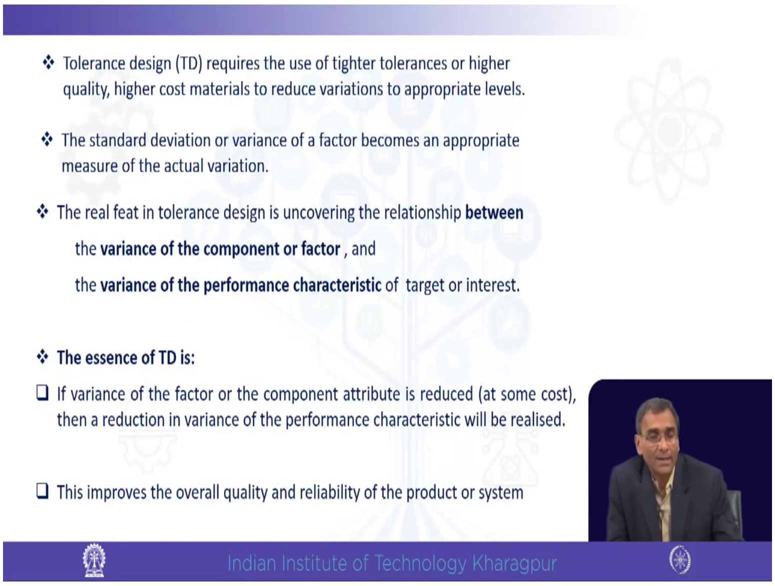

Now, the real feat in tolerance design is uncovering the relationship between the variance of the component factor and the performance characteristic of the product. So, if we can relate these two, then our job is done. So, essence is the variance of the factor or the component attribute is reduced obviously, maybe at some cost, then a reduction in variance of the performance characteristics will be realized.

So, this relationship how much if I reduce the particular tolerance range how much improvement we can bring in to the performance of product. This relationship is to be established and this improves the overall quality of the product.

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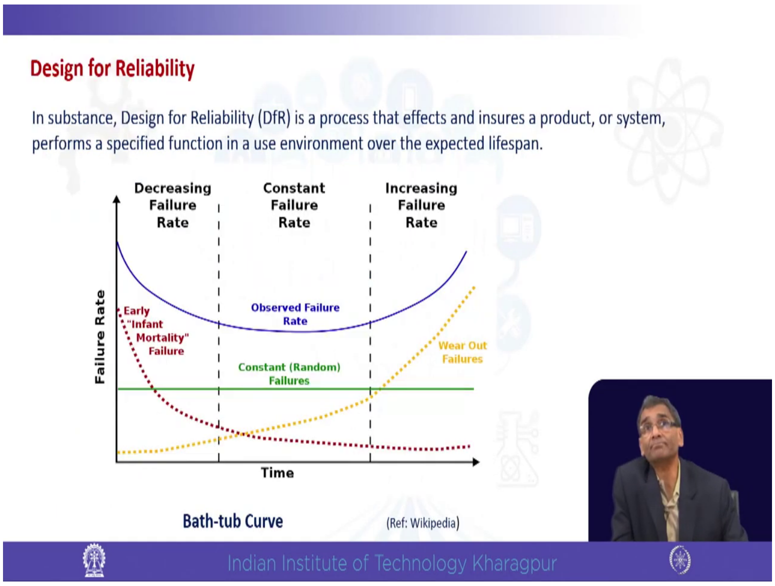

And, it leads us to the last leg of today's discussion is that design for reliability. So, what is design for reliability? It is just to see which perhaps you have read earlier also, but I will explain the bathtub curve which is called on y-axis you will find failure rate how it fails and why excess is this time. And, you can see that initially there would be multiple failure because it is called teething problem.

So, when you are launching some planning something new launching something new doing some new program there are many snacks, so, which will fail. So, initially in the red line will find that initially there will be some failure and it will become steady; whereas, the wear and tear will not happen in the beginning, but towards the end.

So, in the yellow line it is showing that and the green line is the random or called constant failures which is uniformly going on. So, combining these three, we get the blue line which looks like a bathtub and therefore, it is called a bathtub curve and that gives us indication that the useful life mostly is in the blue zone in the middle section that is the constant failure rate.

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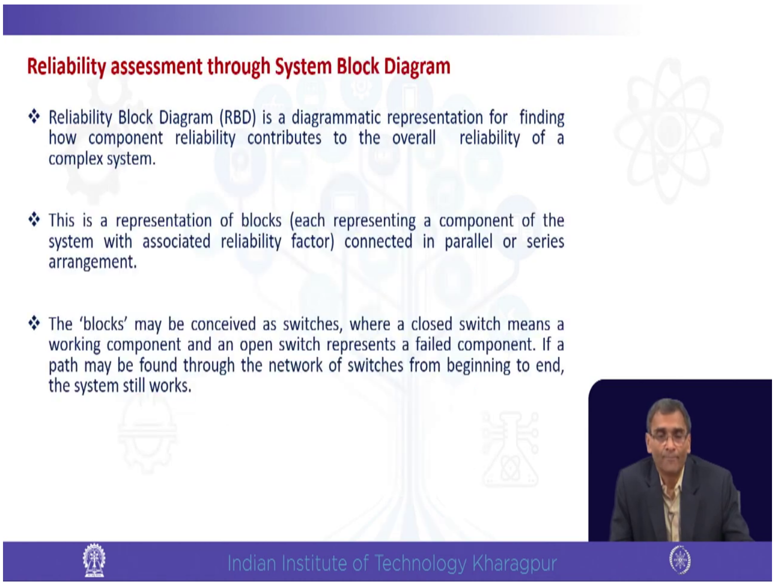

Reliability assessment through system block diagram, this is one interesting part that engineers or the designers mainly will have to assess the system reliability which actually is dependent on the component reliability involved in the system. So, we will see an example better than understanding or discussing theory.

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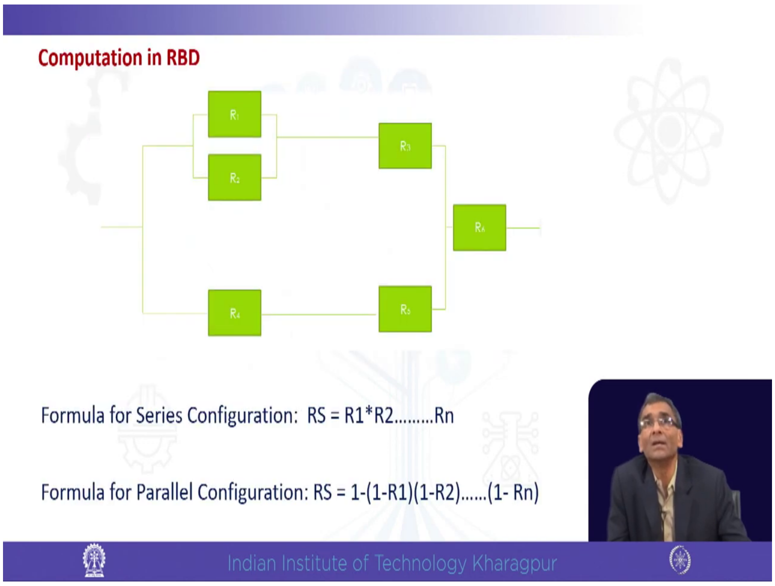

We will go to a computation of reliability block diagram. So, suppose this is the diagram. This is how things are connected say R1 and R2 are in parallel here. Similarly, the system somewhere it is in series somewhere it is in parallel. So, if we have to calculate the reliability then the reliability is if it is in series anything is in series. Say, here say for example, R4 and R5 has are in series.

So, for that part of reliability calculation it will be multiplication, but for R1 and R2 it is parallel. So, it will be 1 minus 1 minus R1 into 1 minus R2 that is what is given in the formula.

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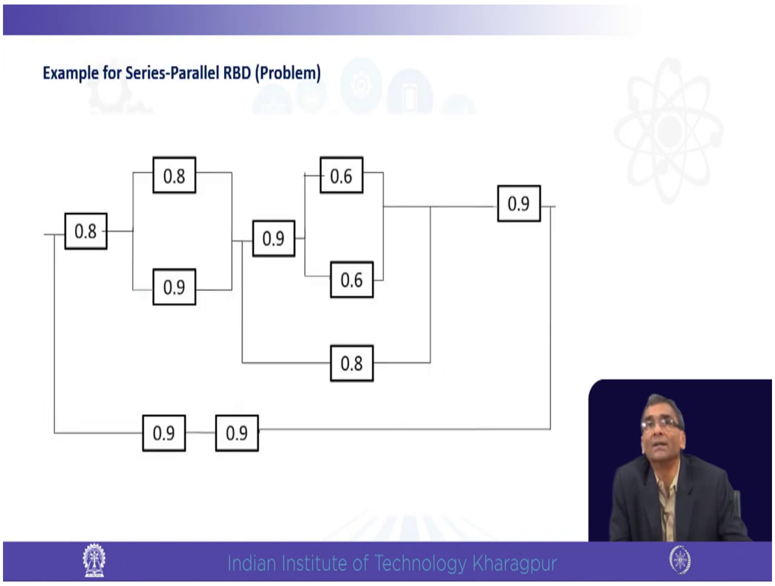

Now, I will be closing today's discussion mainly after showing this which is the example of a series parallel system where within the blocks you will find the reliability values put in. Now, if I ask you what is this system reliability, you would be using that formula just you have learnt the series and parallel.

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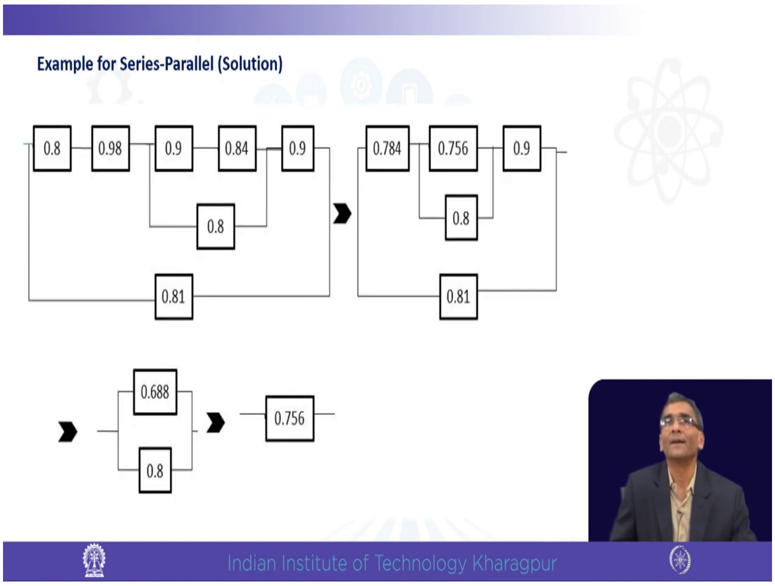

The solution is here I am giving the solution. So, you will find that these values wherever is there and step by step whatever you see and you can try it once the lecture is over and when you hear that, then you can do this calculation and final system reliability is 0.756 or in some people where it is called 75.6 percent or something.

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So, now here we close today's discussion on this part, but I would also point out that some discussions are necessary for tolerance design which is very important and we will take up a new discourse for this. And, reliability assurance particularly for mechatronics complex products these are very important. So, it will be dealt with the complex products context.

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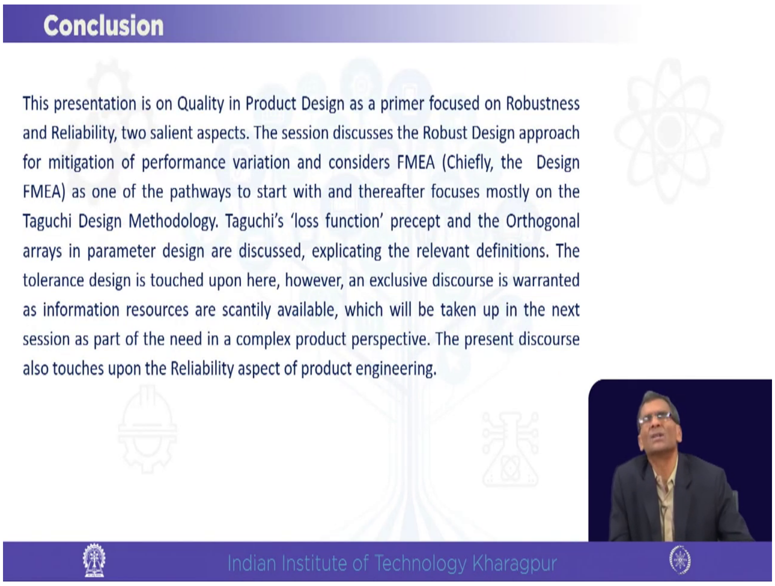

And, so, here we have discussed the various aspects of robust and robust design and reliability involving FMEA and Taguchi's loss function how it works and presents discourse in the product engineering.

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This is the reference and I am sure that you would love to do the you know certain calculations as has been shown here and you will go to the parametric design thing. And, I am sure you would be interested to do that and this is rather easily available the parameter design and that is simple. I hope it helps you.

Thank you very much for listening to this discourse. Thank you once again.