**Design for Quality, Manufacturing and Assembly**
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**Lecture – 01**
**Introduction to DFX**

So, welcome all, my name is Palaniappan Ramu, I am going to talk about design for quality this is a part of DFX design for x course one of the excess that we talk about this quality. So, in this particular course which will span about 10 to 12 hours we are going to talk about the introduction about quality the concepts on quality, how to measure quality and how to include quality in a design frame that is what we are going to talk about. So, this is going to be the layout of this particular course per say.

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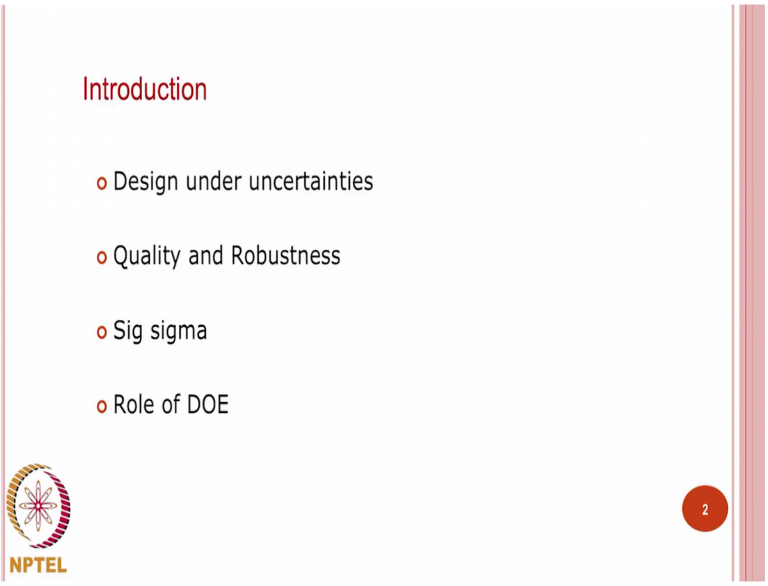


First I will introduce you to the need to design under uncertainties, the word uncertainties is a fashionable term, but you can the equivalent word that you might already been exposed to is variability randomness. So, you can take any design in this world and you can question whether it is deterministic take washer design for instance the washer usually has a thickness it has an inner diameter it as an outer diameter.

You usually go to a manufacturer to fabricated to manufactured. So, when the manufacture uses it in a press tool though he hopes he will get 5 mm as the outer diameter. It is not necessarily true that for every single washer that he is going to fabricate is going to manufacture he is going to get a 5 mm outer diameter. So, it might be anywhere between 4.8 to 5.2 that is what we usually term it as, what we term it as?

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Error, but what is it, it is usually called the other word correct error there is an error in the manufacturing true it is called the tolerance. If you are a manufacturer when an OEM original equipment manufacturer comes to you and says can you manufacturer this washer to me, the usual question that you ask is what is the tolerance it is allowed. So, this example was to drive the idea that the designs are the variables that are involved are random. So, any example you can take in this in this world you can take the size of your fingers they are random.

You can take the height of the people in this class room not all of your of the same height if I, there about 60 of you if I plot the heights of you in this class room it will follow a particular distribution which we will discuss later. This wholes could anywhere you know you go to a basketball field though all of them are at all of them are not of the equal height. So, was the case with your weight anything that you take as an example and more importantly what we will be discussing are interested in this course is more from a manufacturing perspective.

So, for instance if you consider an automotive example. So, car or a motorbike, all the motorbikes like 100, 1000 motor bikes or 10000 motorbikes or 1000 motorbikes or 1000 cars per day that is manufactured out of a particular plant. Let us say that an engine 1000 engines are manufactured on a particular day, you think engine number 1 and engine number 7 will be the same what might be the changes, what might be the differences, they go through the same process it is an automatic process they go through the same process what could be the difference.

It is predominantly a robotic controlled process right. So, the idea is to minimize the variability that is why human interference is not there then the machine does it the way you ask you to do. So, you fixed the machine keeps repeating it, but there could be variability due to other factors, operating conditions could. The environment within that particular shop floor might change because of that there could be the capability of the machine the precision of the machine the variability in the precision of the machine might influence the outcome ok. Though there could be there will be only minor changes they will look identical usually when you see they will look identical, but the engine number 1 and engine number 7 or not necessarily the same.

So, you get about 1000 cars you release in the month of March, there might be 1 engine that might fail in the 10th month, but the remaining 99 engines might work just fine until about 5 years or 6 years there was one particular error that was there in that particular engine which might fail it in the 10th month. So, there so, basically the idea or this couple of examples that I gave you is to drive the concept of uncertainty. And usually when there is human interference is there usually these uncertainty is large and there are also classification on these uncertainties there are in certain things you will be able to control these uncertainties are randomness.

In certain things you know that it is random, but you cannot do anything about it, for instance when you are trying to design a wind turbine or wind mill that is the word that you ways are use to. One of the important and interesting design factor is the wind speed is the wind speed constant on a particular day or between 2 days or over a period of 10 days it is going to differ. So, it is usually measured like meters per second, how many meters per second. So, basically there is a second wise variation is there, this is an average when we say usually what is the average wind speed is what the question is.

You would look at all those contour plots that are available in the meteorological data these are all the average wind speeds that are available for particular areas. For instance in the Adyar area where we are located it is roughly about 3.5 to 4 meters per second depending on which part of the year you are talking about. Now the deal is if you are talking about the design of a wind turbine more the wind speed the larger is the rpm, hence larger is my power generator it is a simple combination right But then as I told you just now the wind speed is not constant today it might be more, tomorrow it might be less, now it may be more, in the next minute it might be less. I know that it is variable, but do I have control on the wind speed I do not have control on the wind speed.

So, similarly take an example of motorbike or a car manufacturer, they say if you see in the advertisements they say like x kilometers per liter right I do not want to give a number, but I am just saying x kilometers per liter and then there is an asterisk on top of it what is that asterisk mean, you understand what I am saying.

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If you read that that asterisk at the bottom will be explained as under test conditions. So, the test conditions is better than your home it is a nice laid out the test condition with nice hump and things like that and under those conditions under the test conditions it is expected to give about x kilometers per liter. Often times you will get less than that, but the question is if 5 of you in this classroom by the same car, on the same day from the same dealer and then drive it for about one month more or less in the same type of roads same environmental conditions in come back what is your expectation on the mileage of each of these cars.

I mean I am not asking a number my question is we will all of you have the same mileage, it is likely that you will have variations someone might get 10 kilometers per liter, someone might have got 10.5, someone might have got 8 kilometers per liter and there are numerous reasons why this change could happen and there might be a case where two people had like exactly 10.2 kilometers per liter that is also possible, but if you look at the variability within a day between 2 days you can understand.

It could be the variability in the engine performance, it could be in the variability the way in which you drive the car, the particular person how they drive the car, where you pumped the petrol, in which petrol bunk did you pump the petrol and there are so many no add at what temperature conditions did you drive it, did you drive it early in the morning, did you drive it late in the night, did you drive during the day, when it was really hot. And was there are lot of weight time was there are lot of traffic in the route that you drove compared to another guy who actually drove it in a highway.

So, there are different reasons, but end of the day the point that you want to understand is there is going to be variability in the mileage that the cars gave, not all of them are going to give you the what the dealer promised as x kilometers per liter there is going to be a difference and the difference is driven by different reasons. But; however, car manufacturer still cannot say oh the car will give x kilometers per liter provided this guy rights, if you write it will give you only x minus 5 kilometers per liter I cannot say that.

So, as a customer when I buy a car I hope it is going to give me somewhere close to that x kilometers per liter and as a manufacturer it is my responsibility to keep up the promise as much as possible. So, this is the underlying idea about quality or robustness. So, we will look at that stuff. So, we will look at what quality is usually there is meaning when I say what quality is the definition or conceptually we will try to understand what quality is, what robustness is and we will also try to discuss what are reliability is and what is the difference between all these 3 of them because what I see amongst engineers forget about lay man.

Amongst the engineers you do not people do not appreciate the difference between these 3 terms, there is a reason why you have 3 different terms called quality robustness and reliability people just comfortably you sit in an inter changed fashion. So, one of all the one of the important outcomes of this course is also to have clarity on, what quality is, what reliability is and what robustness is as a matter of fact we will use concepts from robustness to drive quality. Then there is something called as 6 sigma which is well known concept which is usually used in the manufacturing industry, do any of you know about what 6 sigma stands for. It is a concept used in manufacturing industry do you know what sigma represents here sigma is a standard notation used for some quantity do you know what it is.

Student: (Refer Time: 12:03).

Sorry standard deviation ok, standard deviation is represented basically it is a deviation, but it is a standardized deviation. So, it is called a standard deviation it is call sigma it says 6 times of that standard deviation. So, to quickly say it says the concept of 6 sigma advocates about 3.4 parts per million which means if you are going to manufacture about a million components like let us go back to our washer example. If I am going to manufacture one million washers if I am a 6 sigma manufacturer about 3.4 parts in that can fail 3.4 does not make sense right. So, 3.4 is just a number you cannot fail 3.4 you can either fail 3 or 4. So, to make it more sensible if you are going to make tenth million parts then 34 parts can fail that is what it means. So, 1 million is 3.4 10 million is 34 parts can fail.

So, that is the quality. So, that is the equality for instance if you take a cricket player. Let us take our famous example of Sachin Tendulkar. So, did Sachin Tendulkar go and hit a century in every game that he went he did not, but then when you compared Sachin Tendulkar with his peer who was more or less at the same time, where is this guy Sachin Tendulkar hit more runs or was more consistent or was more successful in terms of the runs scored compared to this person during the same time that is what it needs. So, in that sense what it means is if you consider the Sachin Tendulkar scores to be an outcome of a manufacturing process the number of times he got out under 10 was relatively less compared to this person.

The number of times he hit 0 runs what much lesser compared to this person. So, the standard deviation in Sachin Tendulkars performance was much lesser compare to any of his peer who was not as successful as him. So, it is a simple way of looking error. So, and then in order to carry out these matrix you need took understand and demonstrate and carry out some experiments, how do you do these experiments are they going to be in a periodic manner or they are going to be in a periodic manner, the way in which you design those experiments is called Design Of Experiment that is what DOE stands for.

So, we will also discuss I will try to give you an overall view about design of experiments, but specifically we will discuss about the design of experiments call orthogonal array ok. So, the idea behind orthogonal array is instead of doing a periodic and design of experiment in full factorial experiment you can just do a fraction of it and still get the more or less the same amount of information. There is no guarantee that you will get the entire information, but you will get more or less the same amount of information and using which you can do multiple things. So, the point if you look at it design of experiment is not only for that if you take any product design and general.

Starting from conceptual design, detail design, fabrication, you go into a proof of concept then you make changes then you come back then again you go into manufacturing meaning you do a design change you go into manufacturing then you go for a prototype. In all this process you have to make decisions and it is a cyclic process and every time you go through the process you are going to make new decisions.

These new decisions can come out of expert opinion like you know experts in the area come and tell you that this is what it is it has to be this way, if it is creating this problem likely this is a solution and if you are working for a company there could be legacy information ok, there are companies car companies which have existed from more than 100 years and they have a legacy. So, we have built things like this over the years and there is a reason why it is like this.

So, you can use at legacy to do that, but every time you have to make a decision and these decisions are governed by some knowledge that comes out of experiments you have to conduct this experiment. So, often times in design it is called a forward design or a backward design ok. So, what you need to do is this when you design in the forward sense you hope not to fail. So, you say that I design my motorcycles and cars such that it does not feel under these conditions and then you design it, but then when you manufacture and when you give it to work client who buys it and uses it actually it might fail on field.

There are different reasons on why it might fail, may be that particular condition you did not simulate, you did not expect that they might use it in that condition and it was not suppose to have been used in that condition, then what happens is this is usually done the reengineering way. So, you try to simulate that situation and understand why that failure happened and then go and adjust your design in such a manner so, that it will not fail in the future. So, what happens is in this condition for you to understand why a particular failure happened you have to conduct a series of experiments.

That is where this design of experiment comes into picture, when I say experiment it is not physical experiments necessarily it could also be computational experiment. So, today the computational world has gone to a state where they call it as a digital twin ok, today you have a car or physical prototype you have a car on the computer equivalent car ok. You say like now accelerate the car, go at 60 miles per hour it will go at 60 miles per hour on your computer and then you can simulate you can put dummys inside the I mean of course, in the physical car also I you can put dummies and crash them and see what happens to the dummy.

The same thing you can also do on a computer model ok, you can put a person representing a human being inside the car and you can let the car crash against barrier and then you can see what happens to the car ok, at what portions it will deform because in a car crash situation for instance the occupant should not be affected. The most important thing in a car what you think is the most important thing in your car you [laugher] nothing else in the car.

The more irrespective of what the car is the most important thing and the most valuable thing in the car as you, because if I get you outside unscratched you can always buy another car, even might be even expensive than there. So, the most important thing within a car is the human being. So, usually all the matrix are based on the human being to begin with. The remaining things are derived out of the human safety the first metric that comes in terms of crash ratings is what is the neck injury criteria, what is the head injury criteria, what is the knee injury criteria.

So, that is what and car when it is used for this all this end cap crash ratings and all that, they will look at what happened to the dummies head how much is the head injury, how much was the neck injury, because if you see you can go Google and YouTube you can see any car crash, you can see what happens to the dummy the first thing it will do, it will go and hit the top roof, it will go forward. So, there is a head injury criteria, there is a neck injury criteria, and then it will come back and lee.

So, there is a knee injury criteria because you will go and ram against you are the frontal part because of the inertia because you are going at a high speed right. So, you go and hit a barrier you will go forward that is the reason you are asked to where your seatbelt otherwise you will not come back if not for the seatbelt you will crash and you will go across if it is very fast then of course, your air bag will come out. So, that the first criteria important criteria is your the human being, the remaining stuff you know like if this has to happen for the if I have to keep the neck injury criteria or lesser than some value for the human being what should be the corresponding variations in my car in my car geometry. So, there is something called a sill.

How much can the sill go down what can what are the allowable deformations in my chasse, what are the allowable deformation in my frontal portion of the car, those are all derived from this matrix ok. So, in order to understand all this things because your crash can happen from any direction you cannot say always a crash should happen only in this direction, crash can happen from anywhere and in order to understand all these things I need to do a experiment. So, it need not be a physical experiment it can also be a computer experiment, but these computer experiments are whatever experiment is it lets you understand, it let us you understand the mechanics of failure from which you can learn and go ahead and design.

So, for what variable combination do I do these experiments, there are numerous combinations, if you take a car and the variables that will influence the car safety in terms of a crash I do not know there are some thousands of variables ok. So, if you are do going to do a combination of those thousands of variables we are talking about few thousands of designs that is not going to be possible.

So, what you will do is, this you will filter you will filter and then finally, you will get few variables let us say that it is even 10 variables, imagine 10 variables one variable varying with 10 other variables, second variable varying with 10 other variables, you have more than 100 combinations. It is not easy imagine crashing 100 cars, no car company can do that even on computer it becomes very difficult because of full car crash is a very expensive simulation it takes anywhere between 1 day to 4 day depending on the non-linearity of the model that you have.

Yes computer digital twin is a good replacement to the physical experiment, but still it is expensive. So, that design of experiment the whole reason for this example was to drive the need for a design of experiments. So, now, what happens is you cannot do as many experiments on computer or physical experiments to understand the mechanics of failure. So, what you try to do is, you do that some selected combinations and the selected combinations are governed by your design of experiments which predominantly come from statistics or the other simple way to look at it is a grid uniform grid, but uniform grid has it is own limitation.

So, hence people do a design of experiments which is a governed or which has it is basic from statistics. So, these are the 3 major conceptual learning's that you will have in terms of this particular part of the course, the first one is you will understand the concept of quality, all these days we might have use a word quality very loosely. So, we will give some scientific value to the word quality as an engineer how you should look at quality that something that we will look at.

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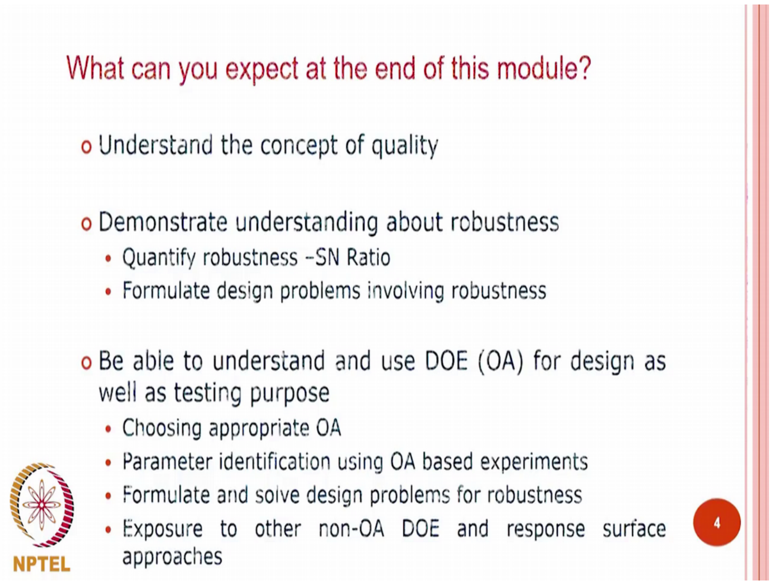


The second important outcome would be you will be able to understand about robustness and quantify. Whether you want or not you are an engineer and being an engineer you always want a quantify things there is always numbers you know you cannot just talk English it is always you are interested in quantifying things only numbers speaks to us. So, you need to be able to quantify robustness so, if you have 2 components or 2 products you need to answer which one is more robust. So, in order to do that I need a metric. So, if there are 2 people I ask is a taller or b taller. So, you can find out, how you use a tape and then you measure someone right. So, what is the metric here what is the metric used sorry to trivial question what is the metric used sorry.

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Some unit of length which represents the height so you say this guy is 170 centimeters height tall and this guy is about 180 centimeters tall so, this guy is taller. So, the metric that is used is some unit of length, in a similar fashion we need a metric for robustness or otherwise you cannot compare if someone asked me whether he was a good student or she was a good student I cannot say anything just like that I will conduct exams and then I will say oh this person got a 80 points and this person got 85 points.

So, probably this person, this student is better than that student based on the exam now by no other and the not in subjective term. So, I need to be able to quantify to compare I need to be able to quantity things. So, you need to be able to quantify robustness, we will see how to quantify robustness and eventually you want to bring these robustness into your design problem. So, when you begin see in the early days only functionality was the requirement, if you take a car design for example, people wanted to go from point a to point b, I do not want to walk I want to go from point a to point b someone z there is some something there structure with 4 wheels ok. So, you go and stand on that it will take you from point a to b.

That is all was required some point and time ok, then what happened is when the concept of mobility increased and then people said that you can automatically you can go from point a to point b you do not need to walk. Then many people started buying, the movements people started buying there are expectations I am paying you and out of the 10 times I am going 4 times it is not taking me to b, conceptually it still takes you to a to b because that is that is why I went and watered, but out of the 10 times I am boarding at a it is not necessarily taking me to b, only 6 times it is taking me to b the remaining 4 time something happens in between. So, then who our manufactured the cars had to make this kind of had to bring this reliability into the loop they say like.

If you are going 10 times, all the 10 times it will take you from point a to point b. So, from the functional part of it people had to look at the reliability part of it. So, the moment you talk about reliability then it also includes maintainability, serviceability and from a manufacturing perspective, why it will not it did not go from point a to b because some problem with particular component which related to it is manufacturing. So, you need to make sure that the manufacturing was very clear all parts that came more or less had the same dimensions. So, that there will perform to the same level so, these are the things. So, what happens is now or actually we are beyond that right now.

Robustness is a very well understood quality is a very well understood and implemented that is the important part implemented concept. So, I should be able to now define and be use robustness in my design. So, that my design conditioner my design objective to begin with this I will design a product that will have enough robustness that is what my statement itself then you can always put an optimization statement on top of it saying that I will build a product such that it will have minimal cost.

Today it is not only cost it is other environmental conditions come into picture ok, I need to have a minimal cost, I need to have a minimal emissions, I need to maximize my sustainability, all these are related in one sense, because the moment you use better material or try to minimize your emission the cost is going to go up. So, you want to keep your cost also down. So, you have to have interventions from a design perspective as well. So, that is what the second bullet here talks about, this bullet here talks about the formulating the design problems in involving robustness.

The third important outcome is what we discussed already is the design of experiment. So, you will be able to understand what a design of experiment is, from where the idea emerged and be able to. So, let me clarify you might not be able to come up with a design of experiment that is not the scope of this course. That is a very interesting subject how do you come up with the design of experiment for instance and orthogonal array how do I design and orthogonal array is a very interesting subject. It is the slightly mathematical in nature, but that is not the scope for this course what we will do here is, we will say for a your particular experiment how many variables are required.

If these are the number of variables then what is the orthogonal array that you need to select the orthogonal array the type of orthogonal array will be governed by the number of experiment so, all these are connected. So, your number of experiments will be connected to the your budget. So, when you say this is my budget I will tell you that these are the number of experiment that you can conduct, then you can only taken appropriate orthogonal array that will influence the number of variables. So, these are all the chicken and egg problem. So, yeah to clarify you might not be able to build a design of experiment, but the scope limits us to understand and use the orthogonal design of experiment for design as well as testing.

This is the example that I told you right, the forward design process is what the design that I am talking about. So, in case some failure happened and you want to understand why the failure happened then I am calling it is a testing purpose. So, you want to understand why this particular failure happened you try to simulate different combinations of the design variables right. So, understand you will be able to choose the appropriate orthogonal array for your problem and parameter identification as I told you, in a car crash there are infinite number of variables when you cannot run and experiment with infinite number of variables or thousands of variables to give number. Maybe you can run about 7 to 10 variable so, how do you identify that.

So, you can do some kind of a sensitivity study to understand which variables are important and then select that. And you can solve formulate and solve design problems then depending on the availability of time we will discuss a little bit to other non orthogonal array design of experiments like Latin hypercube sampling and hammersley sequence there are whole lot of design of experiment ideas. So, we will touch up a little bit on that and we will also see something called response surface approach is what do you do with these station of expand, our exposure in this particular course we will limited to finding an optimal combination of the design variables that we will give you a particular response.

But you can do much more with other and design of experiments you know which is called the design space exploration, maybe I will I will consider showing you some other slide at some other point that we will point in time that will cover those discussions. So, this is all you expect at the end of this module this is just to make sure our expectations match you are not in this course for some other stuff.

So, this is the reference that I will closely follow I take cannot be said as a text book, but majority of the content we will come out of this book and there other information from my other learning's also might come. So, there might be newer editions of this I am not sure and at some point there was a cheap edition that was available I am not sure whether it is available now.