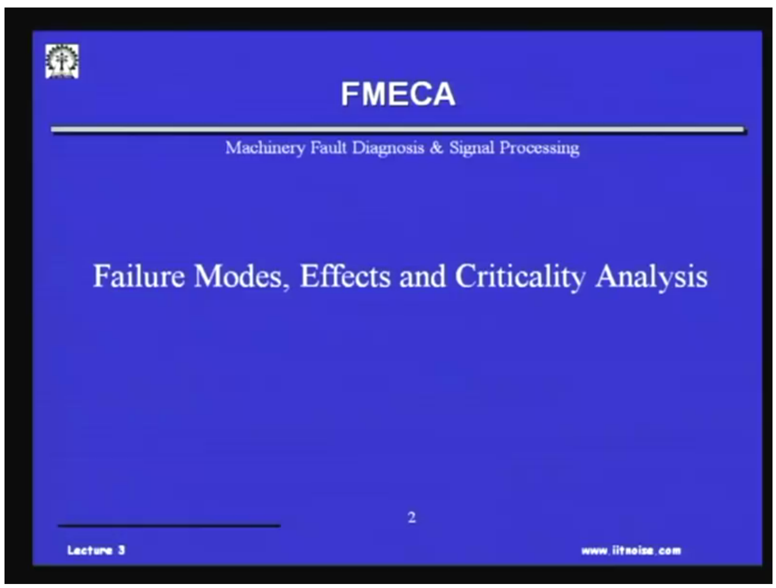
Machinery Fault Diagnosis and Signal Processing
Prof. A R Mohanty
Department of Mechanical Engineering
Indian Institute of Technology-Kharagpur

Lecture -03
Failure Modes Effects and Criticality Analysis

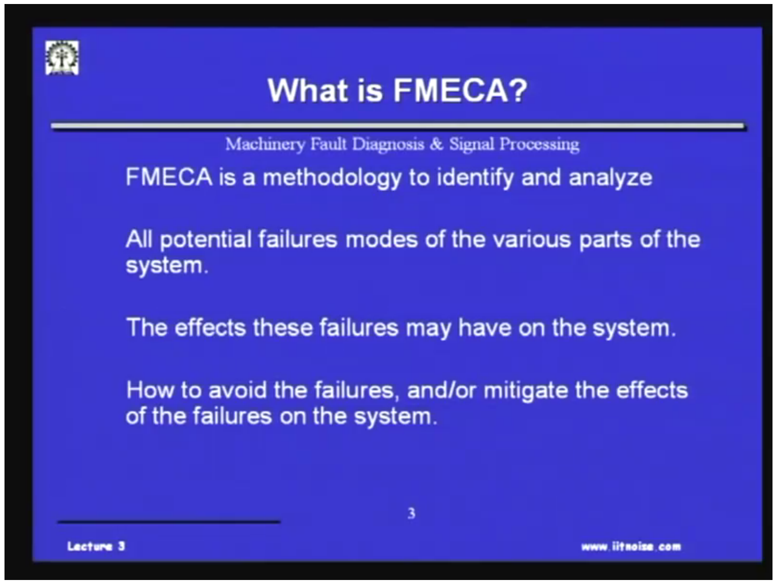
In the last class, we have talked about the different techniques of maintenance available to us namely the preventive maintenance, predictive maintenance and breakdown maintenance. But we must be always wondering now, well, in a large plant which maintenance is to be used, where. And to answer this question, we need to look into this lecture on failure modes effects and criticality analysis.

(Refer Slide Time: 00:41)



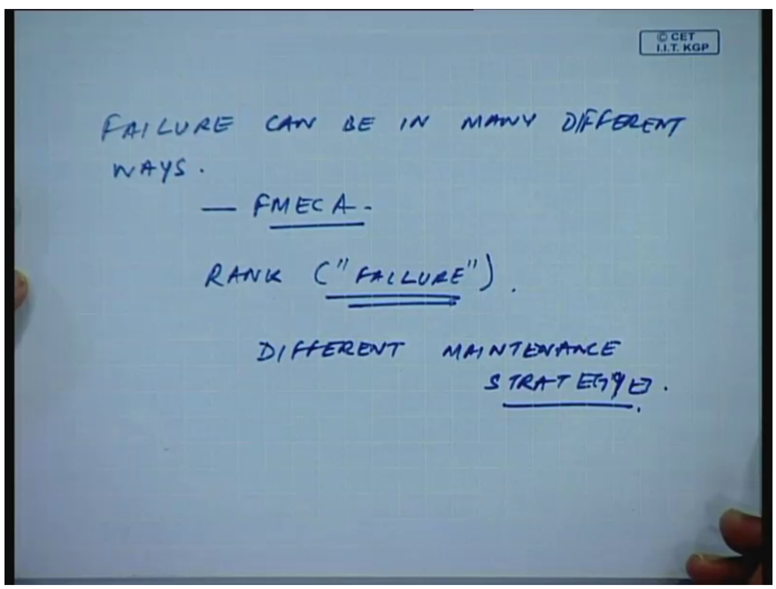
Well, Failure modes, effects and criticality analysis as you will see has many applications particularly, in engineering design, in the process design. But we will see how this FMECA are known as FMECA can be used to decide on which maintenance strategies to be used, in which kind of machine in the plant. Well to define FMECA?

(Refer Slide time: 01:13)



It is a methodology to identify and analyse all potential failure modes of the various parts of the systems. Systems, you know, could feel in different ways.

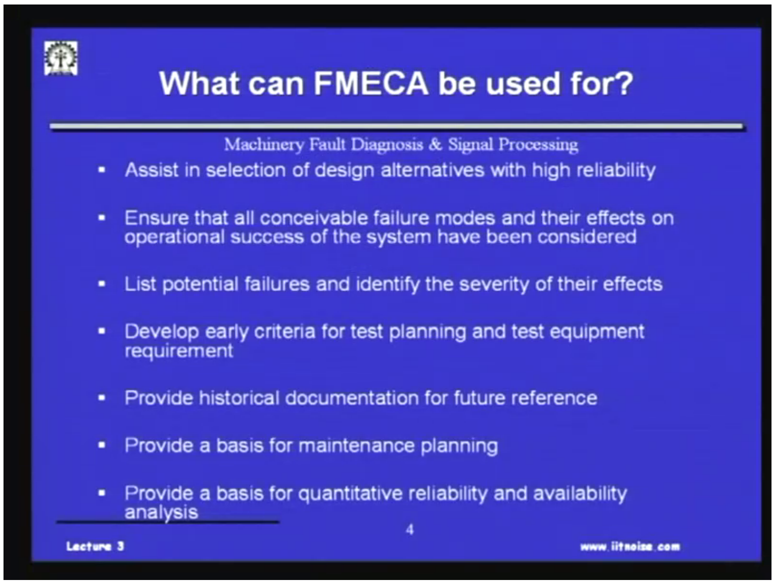
(Refer Slide time: 01:32)



Failure can be in many different ways. We will see how this FMECA is going to help us decide on which is a critical failure, which is a failure, which is not critical in the sense, it is not going to affect the downstream operations that much compared to critical failure. Deciding on that, we can turn off rank, I will say within quotes, the Failure. So, once we have ranked the failure, we can use different maintenance strategies, okay.

Well, we will see that how these failures have different effects on the system and how we can avoid the failures, to mitigate the effects of the failures on the system. So, in a nutshell, FMECA is going to answer, give answer to different questions we have, in terms of the severity of the failure, in terms of the frequency of occurrence of the failure, in terms of whether a failure can be detected at all or not.

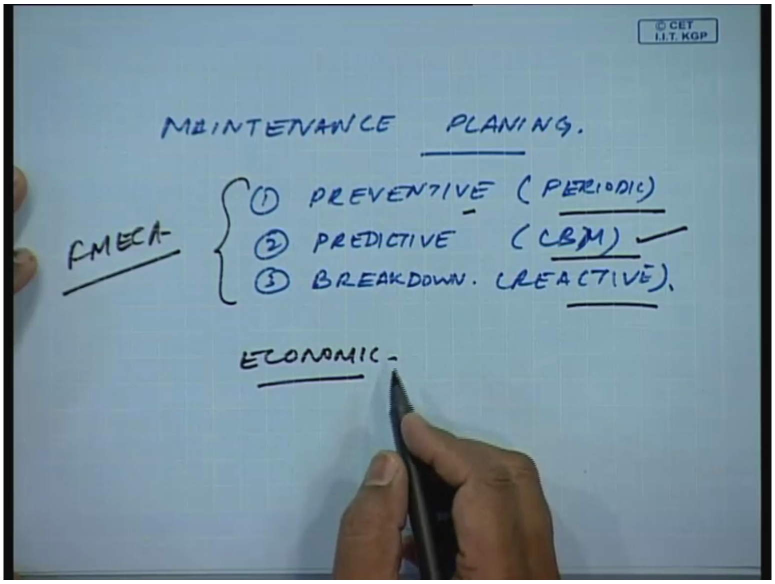
(Refer Slide time: 03:02)



Well, as I was telling you, FMECA is just not used for maintenance strategy but also to decide on an whether my design has an alternate, whether my design is robust, the design has a high reliability and whether the, all the fake effects of failure have been considered while designing the system; try to establish the different potential failure modes and their severity. Sometimes, we can also decide on planning schedule for the test equipment and the planning test procedure to detect these earlier failures.

And of course, now, we need to have documentation for future references, in the sense, if the plant system needs to be improved in terms of its operation, in terms of its maintenance, this FMECA worksheets, FMECA number will help us do that. Of course, you know, provide a basis for maintenance planning.

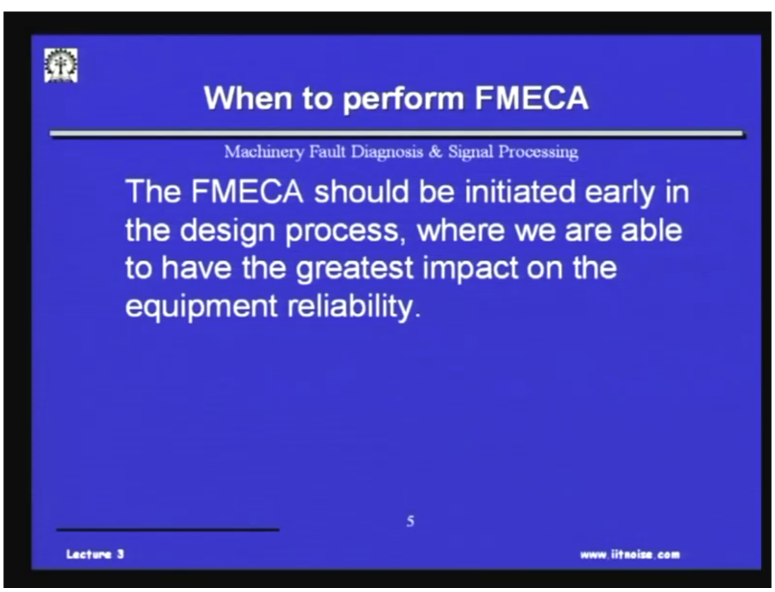
(Refer Slide time: 04:04)



The basis for maintenance planning, as you know, we have discussed that there are three types of maintenance: preventive, predictive and the breakdown. Another word for preventive was periodic, CBM and reactive. In the last class, I have told you that economic analysis that CBM is much economic in the long run than preventive. But because of the high capital investment involved in CBM we always cannot put high capital investments for all machines in CBM.

So, we have to decide by FMECA which kind of maintenance of machines need which kind of maintenance in this scheduling. So, this will give us quantitative estimate or, or ranking as to which machine needs to be done with what kind of maintenance.

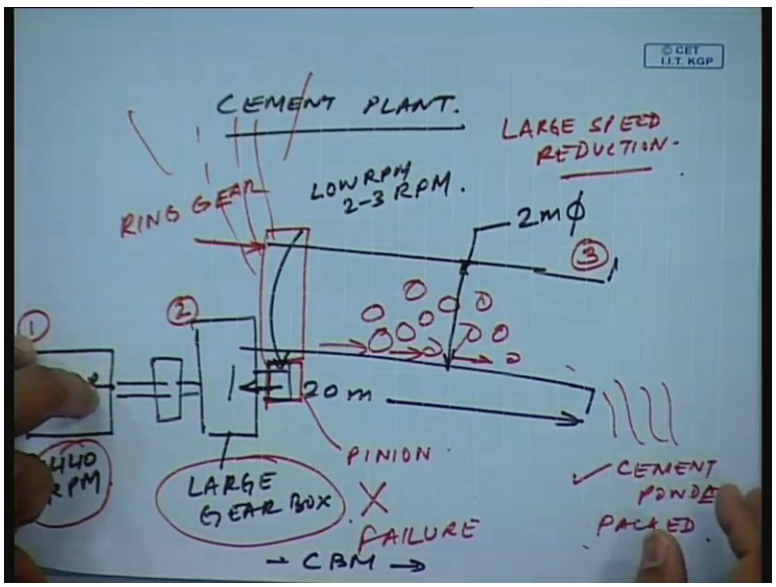
(Refer Slide time: 05:35)



Well, FMECA should be initiated only in the design process. We are able to have the greatest impact on the equipment reliability. I mean, in a certain amount of maintenance has already been initiated in a process on a plant or in the machines; we did not change its maintenance schedule. But had we done a FMECA analysis on such a plan would have known from before that such are the critical machines and we need to be careful about their maintenance.

For example, I will give this through, illustrate this through an example. For example, let us talk of a cement plant.

(Refer Slide time: 06:10)



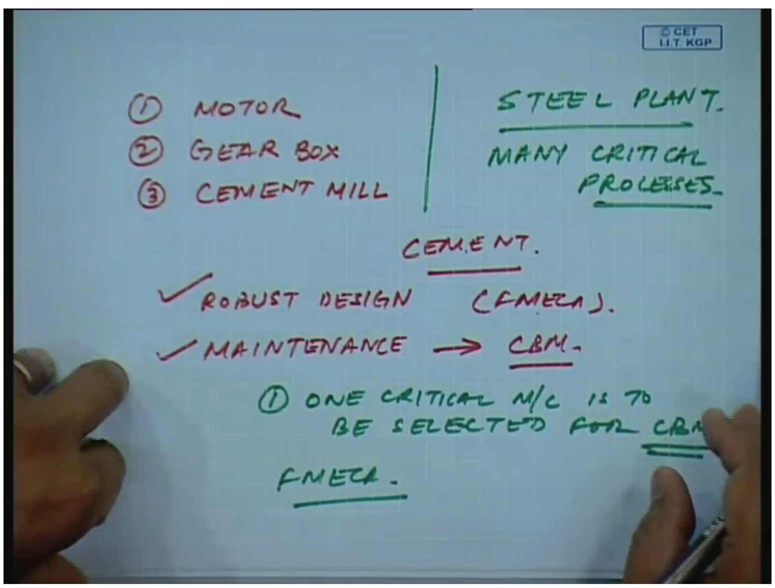
You know, in a Cement plant, there is a large rotary kill, this could be a diameter about 2m and this could be about 20 metres, long kill and this kill rotates at a very low RPM of the order of 2 to 3 rpm. And then, we have a motor which rotates at about 1440 RPM. So, to bring about a slow reduction of speed of the kill, this requests for a large gearbox.

And then, there is a pinion gear, with a ring here or a bull gear. Is the ring here and there is a pinion, pinion gear from the gear box. And then, what happens is feeding mechanism, the raw material which goes here and then they get ground here, they are very hard grinding media here; and then, finally we will have the cement powder which can be packed and sold off.

This is in nutshell a cement plant or the mill. So if you see the most important elements are of course, the motor, gearbox and the mill, ok; because as you know, standard motors on at 1440 RPM, the mechanical speed and then we have to bring about a large speed reduction from about 1440 RPM to 2 RPM. So, imagine in such a plant, if you are dependent on the daily production of cement powder, or cement from the raw material of limestone, gypsum extra.

Then, this gearbox fails for some reason and that is a failure in the gearbox. No matter what because is a critical component of the plant, if the gearbox fails, well and this mill is not going to rotate, then, we will not have any cement. So, this is going to critically affect the flow of the process of the output of the productivity of the plant. So, I have to be very careful in the gearboxes maintenance. So, we need to evaluate this gearbox around the clock and has to be done on this gearbox; CBM has to be evaluated around the clock.

(Refer Slide time: 09:34)



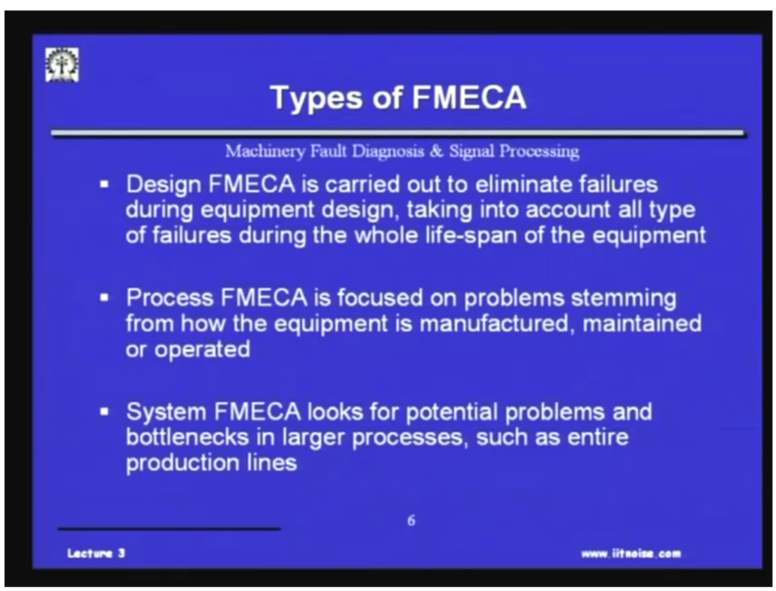
Now, the question is, for this plant, if I was to list down the critical factors, one is the motor other is the gearbox, third is cement mill. I cannot afford to have any failures in these, because they will affect the process, or the process by which I have my final product as the cement. So, I need to have obviously a robust design. I am sure the designers would have done of FMECA study to find out a robust design of the individual components.

But for the maintenance, question is, where should I put CBM in this motor gearbox or cement mill. Now, the question I will post you is, suppose; only one critical machine is to be selected for CBM, which one should be that? While many of you will come up with an answer of motor, many of you will come up with an answer of gearbox and many of you would be of cement mill. Well, you can have your own reasoning for that.

But you will cease to the study of FMECA that I can easily come up with the number and which rank these two or three items: motor, gearbox and the cement mill, in terms of their severity or in terms of their criticality and importance. So, had I done a FMECA study on the entire cement plant right from the beginning, I could have planned on which equipment needed to do, need to have a CBM.

And that is what we are going to look into in CBM and for a simple cement plant case; it is very important, easy for us in fact, when we had a motor gearbox cement mill. But, imagine if this was to be carried out in a large steel plant, there could be many critical processes; so, FMECA must have to be carried out in all these different processes.

(Refer Slide time: 12:23)

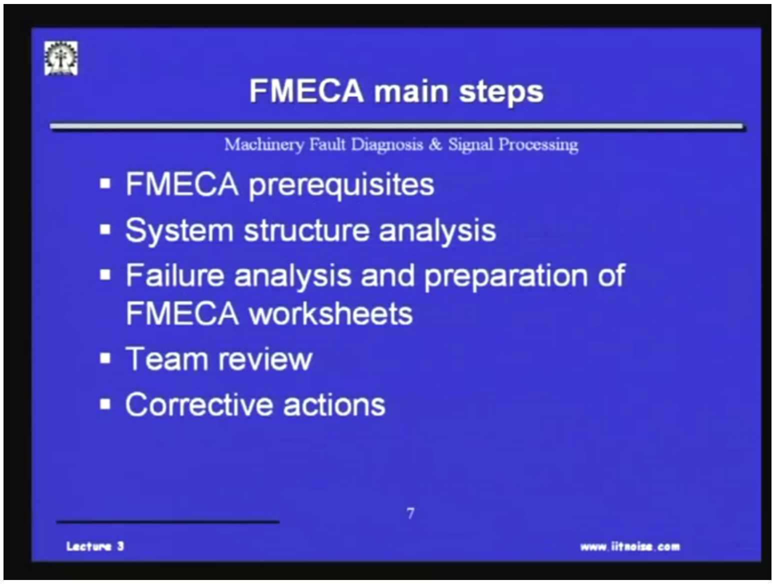


Well, what are the different types FMECA? Design FMECA, it is used to carry out to eliminate failures during equipment design, taking into account all type of failures, in the whole life span of the equipment. Well, we are not concerned with design FMECA right now because the designer should have already taken care of this FMECA, while doing the design of the equipment.

But the next is the process FMECA. For example, it is focused on how the problems are stemming, and how the equipment is manufactured, maintained and operated. So, once the equipment has been designed and put in place, we need to understand what are the problems for different equipments in terms of its manufacturing, in terms of its maintenance? And that is what sometimes, something we are going to focus in, through another example.

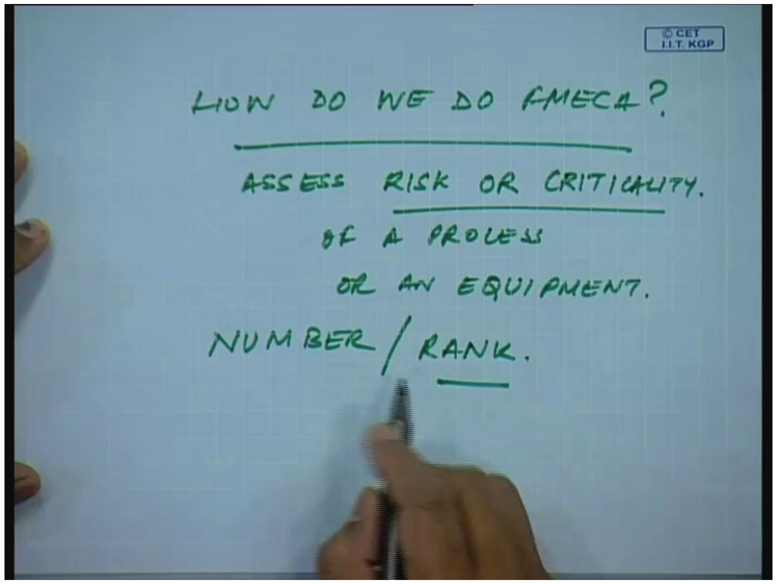
And of course, in a large system, whether in assembly lines, people needs to see the system FMECA, has to find out bottlenecks in the Assembly process and the entire production line. So there are different types of FMECA. People use according to their needs. sAnd to summa rise one is a design FMECA, another is the process FMECA and the system FMECA.

(Refer Slide time: 13:40)



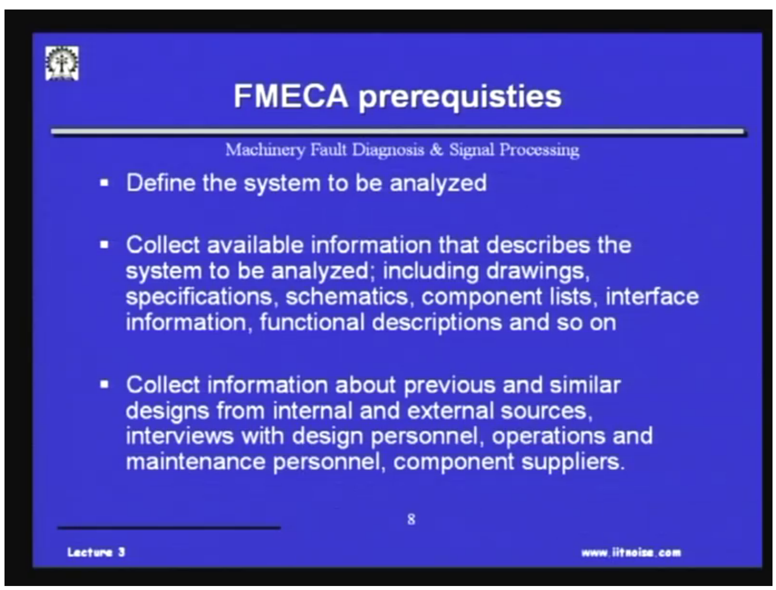
So, how do you do the FMECA? So, there are some system prerequisites and then, one need to know the entire structure of the system and then provide the failure analysis and prepare the FMECA worksheets and the team review for a way to corrective actions. Question is, how do we do FMECA?

(Refer Slide time: 14:03)



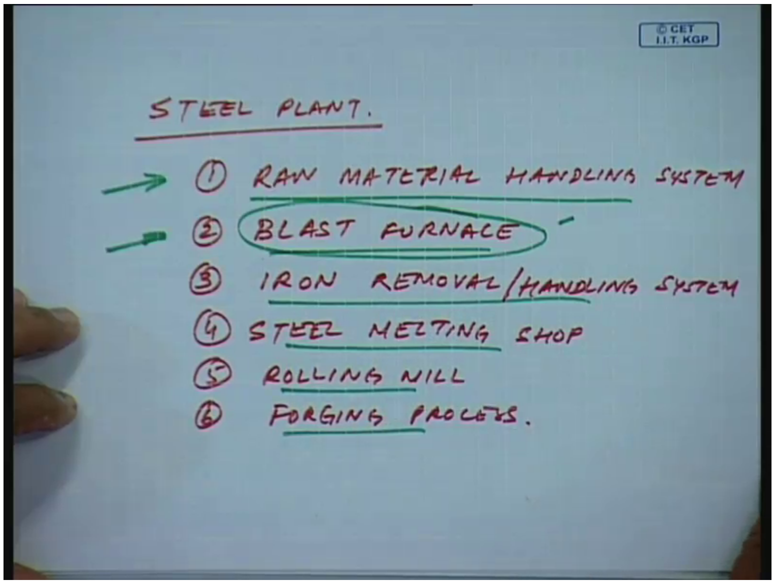
As I was telling you, we have to assess the risk, risk or criticality of process or an equipment and basically come up with a number. Otherwise, a rank for a particular process or an equipment so that we can decide on which machine needs, you know, be having what kind of maintenance.

(Refer Slide time: 14:59)



So, in the FMECA prerequisites, we need to define the system to be analysed; again we have to go back to the case of a steel plant; should I do some FMECA on the entire steel plant or should I do the criticality analysis on the different process of the Steel Plant. Again, let us to through, take you through an example, say of a steel plant.

(Refer Slide time: 15:14)



There are many critical processes: one could be the system in raw material handling systems. I will not go into the details of the raw material handling system. Basically, the raw material handling system for the iron ore, for the limestone, for the coking coal etcetera, ok. And then, the next would be the blast furnace. Blast furnace requisites could be cooling system, its air handling system is, again it material handling both; the raw material and the molten metal.

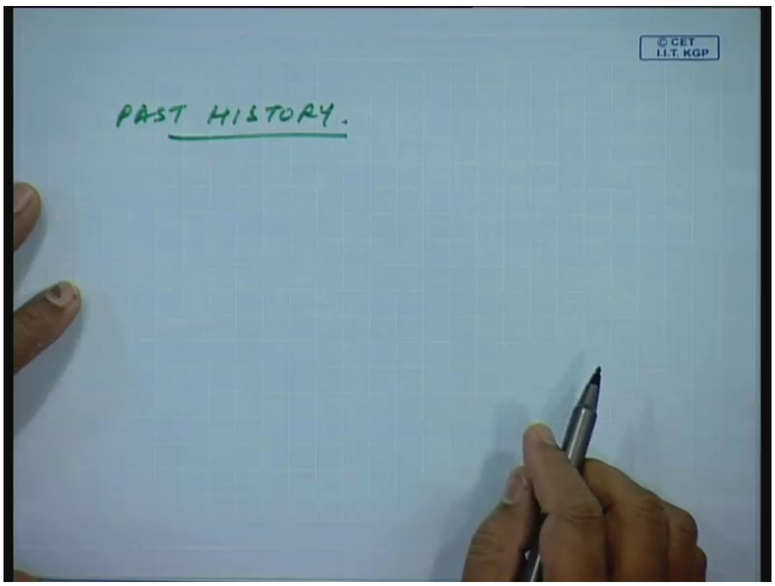
Then, we will have the iron removal and handling systems or once the iron has been made we have the steel melting shop, SMS; once you have the Steel, we will have the, depending on the products, we could have Rolling Mills or we could have forging processes and we will have to finished products for us to have the different critical areas of the Steel Plant; have just listed down.

These are about 6 different processes. They all could be important in steel plant. But in the individual processes, if I was to find out criticality of an individual process, I need to do FMECA on each one of them, ok. So, if I say, no, no, I will only focus my attension in the blast furnace, well that is good. And that is what I meant by defining the system to be analysed. We have decided that I need to do FMECA on the blast furnace only in a steel plant, well, good;

But then we no need to study all these system parameters of the individual blast furnace that could be, again the blast furnace could be, you know, the blast furnace material itself, the blast furnace control, the blast furnace operation, blast furnace maintenance; all these are the individual components of the blast furnace. Same is to for the Rolling Mill, the pressure, the motors, the material handling system etcetera.

So If I have to focus on any one critical operation or critical path, I could decide on any one of them. So, once I am clear about the system which is to be analysed, I will not go into the individual system, cannot find out its drawing specification, schematics, etcetera, and then, so that we know its functional description as well.

(Refer Slide time: 18:38)

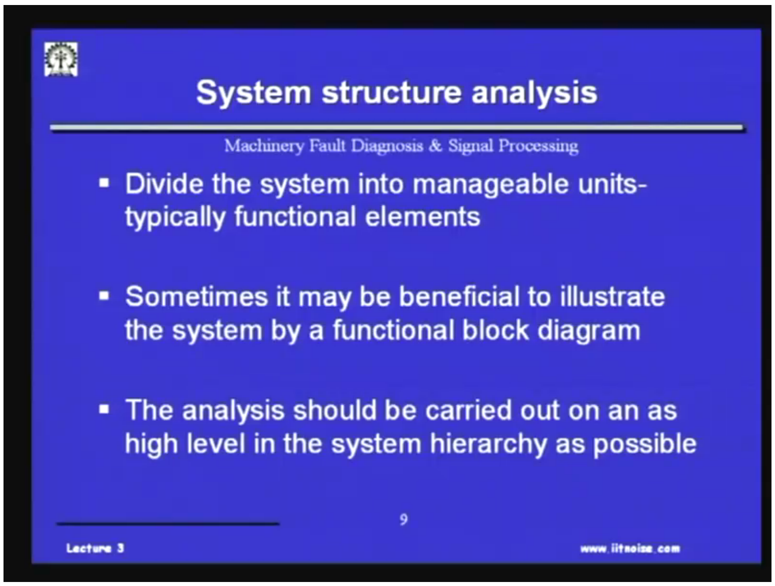


And another is, it is best, if you do maintenance on an equipment to know its past history in terms of the, in terms of the information from the operator, from the design personnel, from the component suppliers etcetera. So, once such an information in a nutshell, all I need to do is if I was going to implement FMECA on an individual critical components I need to know its entire specifications in centre operation from the right from the start to the end.

And know whether the functional description of each of the components and the also of the past history of its performance and maintenance, its feedback from the operator, from the management on the same system. One such a prerequisite is available to the person or persons who are doing FMECA on such a system, they will be well equipped or well informed to make a judgement about the criticality of that equipment and that is very essential.

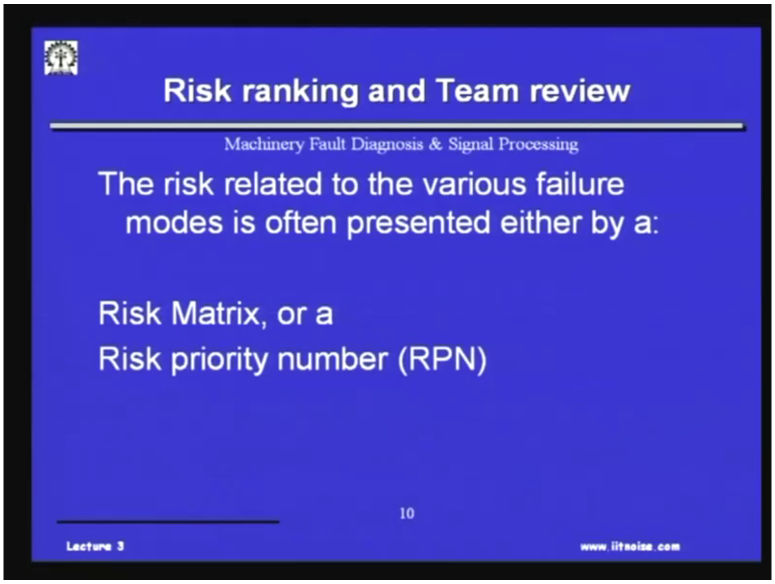
And when I talk about this person or persons I do not limit it to only the technical analyst, or the technicians or the professionals on that equipment, but it could be anybody who has some say, right from the bottom most part in the plant; right from the workers to even the executives in that plant authenticated in the, for that critical process. So, all of them can rank this process as for what they feel in terms of few numbers. And we will see how these numbers can be taken into account to evaluate the performance of such a plant or an operation.

(Refer Slide time: 20:24)



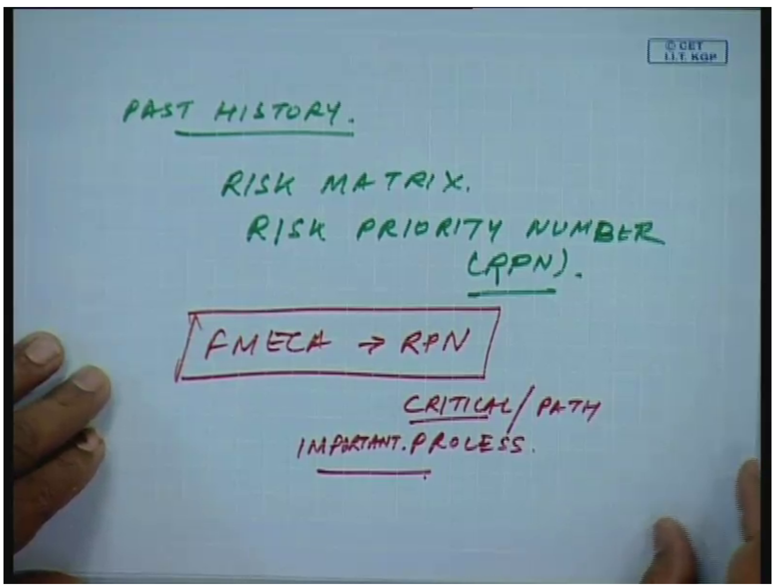
So, we will divide the system into manageable functional in elements. Just like, we saw the example of Steel Plant, where even we divided the Steel Plant about the say about, five or six different functional elements and so on. And sometimes to give a clear picture to the FMECA team, it is good to have a FMECA functional diagram. And the system analysis should be done on a very high level as possible because this gives us a view to look from the top down and so that we do not leave out any component by eminent in inadvertent error and so on.

(Refer Slide time: 21:06)



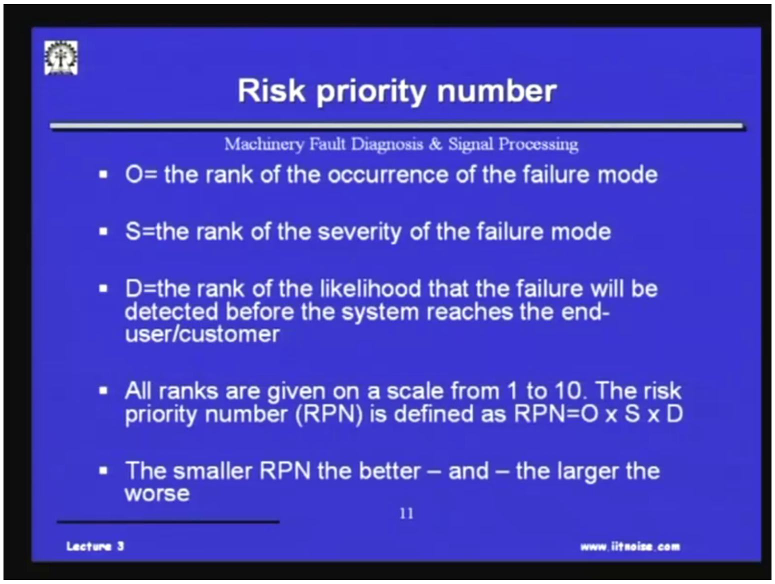
So, this team review and risk ranking is very, very important for doing FMECA.

(Refer Slide time: 21:18)



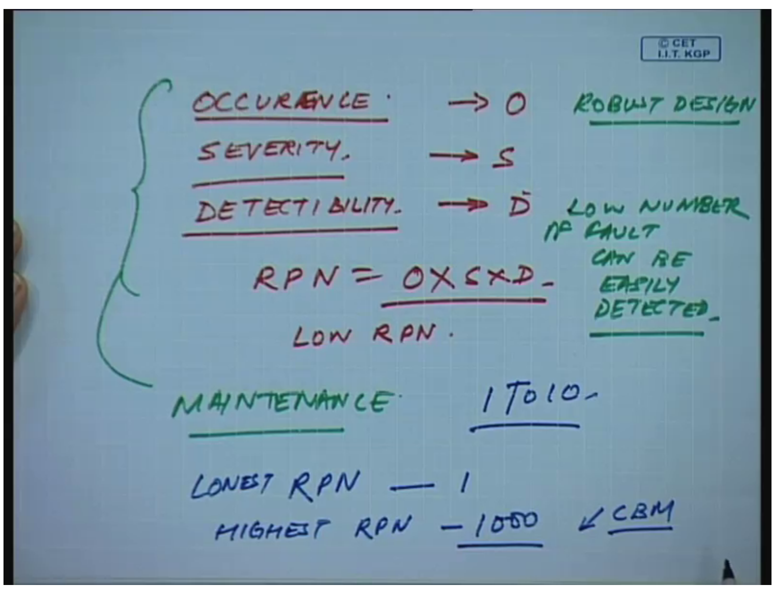
And they develop a Risk matrix or what is known as the risk priority number RPN. And this is the most important number out of FMECA is I have to find out a number which relates to the critical path or process value may not be critical to tell you find out its RPN number; I will tell you the important processes for which you have to find out the RPN number and question is how do we do or what do we do to find out this RPN numbers for different components.

(Refer Slide time: 22:26)



So, this is perhaps the most important slide in this lecture; that this RPN number actually depends on three parameters: one is the O, which is the rank of occurrence of the failure mode.

(Refer Slide time: 22:44)



That means of frequently this, the system is going to fail. It is that kind of a number O. In another is the severity of the failure. If there is a failure in this component how severe is it? Is it going to affect the other components in my process? So, that is how we given number of severity. And another is the detectibility. It is the rank that the likelihood that the failure will be detected before the system reaches the end user or customer, ok.

If I am not able to, because we always and multiply these 3 numbers R P N is equal to O times S times D. So, the lower the RPN number, the better it is, lower is the risk. So, if a fault is not being able to get detected, then, I will give it a number that it is very high. Say if a fault can be detected, because we are, we will focus this for maintenance only in our understanding right now. If a fault has occurred and if I cannot detect it, it is dangerous.

So, if I can detect it, I should give it a low number, if fault can be easily detected. Otherwise if fault cannot be detected and then if I give it a low number, it will have a Desire consequence in the sense, that fault has occurred in the system and cannot be detected. And that should not be my maintenance strategy. Well, the occurrence of a fault is I mean, I would not like that fault to occur.

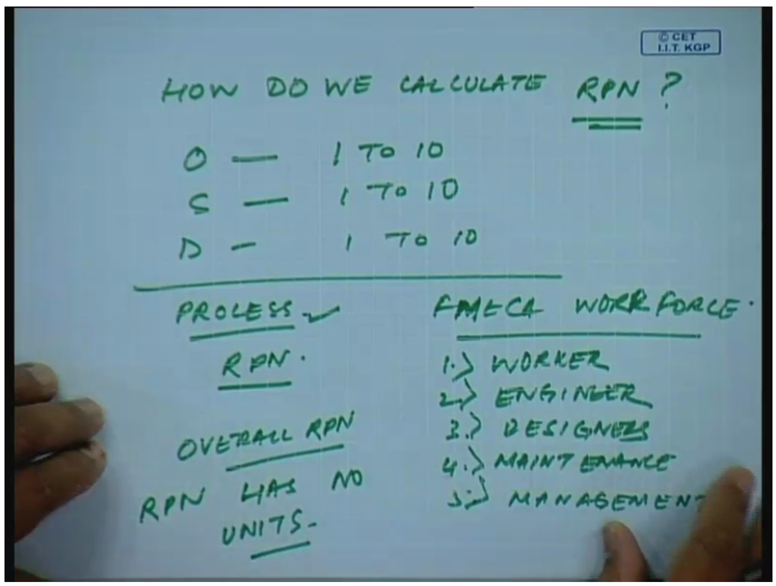
But if a fault is occurring how frequently it is occurring, if it is occurring at a very high rate, I need to give it a very higher number. But then, if I have done a robust design of the component, this occurrence could be brought down. If somebody says, you know, in a component I have repeated failures. Well, there could be many reasons for that. One could be a bad design, design is not robust; another is that I have to make a better design, so that the occurrence of failures is a minimum.

So, that is the most important parameter or rather one of the most important parameters is while doing FMECA on a system. The system is designed in such a manner that there are too many frequent failures; or that the design is bad or we are not doing something; we are the functionality is not proper or we are not operating it within the specs and so on. So, if occurrence of failure is high, it is the O, number this number for RPN will be high. And severity is another failure mode, where we rank this severity.

Suppose, if a failure has occurred, is that important that the this severity or this Failure is not going to affect my system, if it is not going to affect my other processes or the system I can give the low severity number, ok. And I have just explained to you about the detectibility, if they give it a low number, if the fault can be easily detected. So, the plant or a process if we can find out the critical, critical parameters and specify the OSD numbers we can give them the RPN or calculate the RPN numbers.

And another thing which is to be done is, if all the numbers are given or ranked 1 to 10, so the highest value of RPN could be 1 sorry, the lowest value could be 1. Highest RPN could be 1000. So, any number which has a high RPN number is more critical and the maintenance efforts for that system or processes have to be the best. And perhaps we can apply CBM for systems which have high RPN numbers.

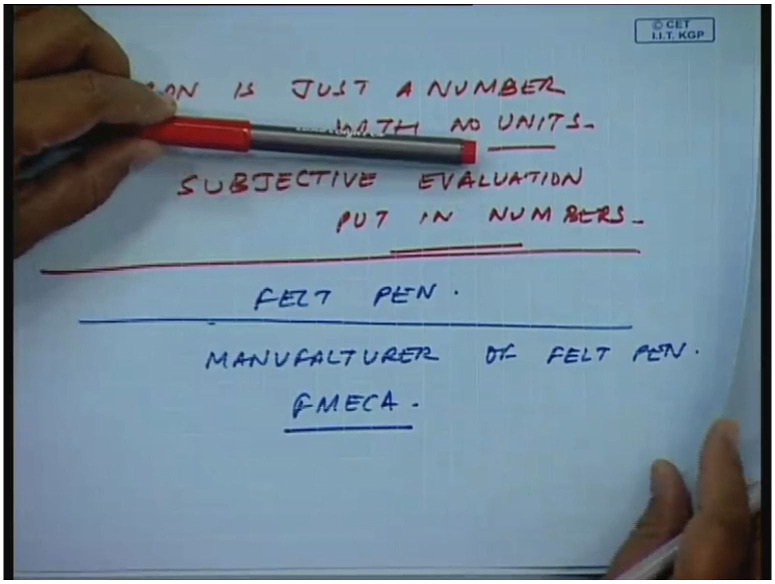
(Refer Slide time: 27:50)



So how do we calculate RPN numbers or Risk Priority Numbers? The question is, we can rank this O from 1 to 10, Severity from 1 to 10 and Detectibility from 1 to 10. Now, there are many different processes and you have your FMECA workforce which would consist of workers, engineers, designers, maintenance personnel and Management. So, you can, for a particular process, you can pull out members from such different functionality grouping up.

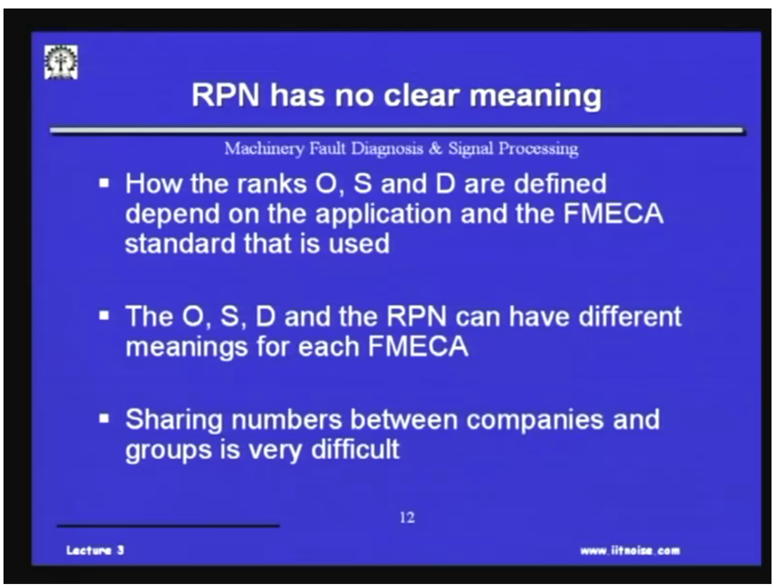
And ask them to evaluate the process or particular process where you have to establish the maintenance scheme; ask them to give an individual RPN number, estimate an RPN, number. Or you can come up with an overall RPN number and then rank them; rank their processes. The question is, RPN has no units. It is just a number.

(Refer Slide time: 29:43)



RPN is just a number with no units, ok. So, RPN has no clear meaning and how the ranks O,S and D are different depend on the application and FMECA standard that is used.

(Refer Slide time: 30:05)



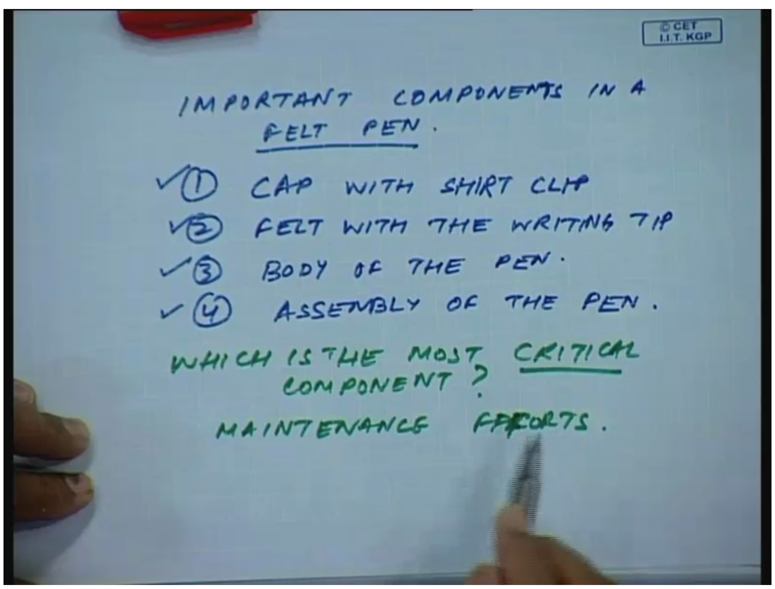
For example, the O, S, D in an RPN can have different meaning for different FMECAs. And it is since, it has no basis of any, it is very subjective It is a subjective revaluation reflected in numbers; another definition of another functionality. Subjective evaluation put in numbers, ok. I will give you in another example how people do FMECA. For example, because this is a subjective evaluation it is, it does not, you know, units like 10 kg or 10 units.

So this RPN, for a process for example, I have 2 steel plants and for 1 RPN for 1 Steel Plant blast furnace is 780, the Other Steel Plant blast furnace RPN is 500, I cannot say that. There are 500 RPN number means a better blast furnace. I cannot say that, because there is no clear meaning of this number from plant to plant because it is just to evaluate; just to rank a process or equipment in terms of its three parameters O, S and D.

So, there is no basis but in a plant or in a process where people have the familiarity with all the process and equipment, they can decide on the ranking. And then, we can evaluate or put our efforts are more efforts to the RPNs where the RPN number is high. And less maintenance refers to the process, process or equipment and where the RPN number is low. I will give you another example, you know, just you will understand.

Let us take the case of this pen by which I am writing, is a good example. In fact, if I can take the case of a felt pen here, felt pen, if I had a manufacturer who used to manufacture felt pen, he wants to do a FMECA, evaluate the most critical component in his manufacturing processes.

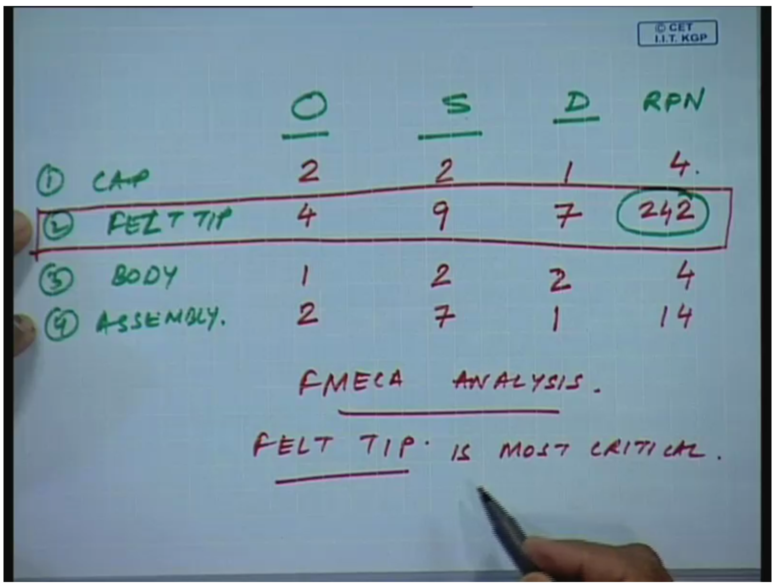
(Refer Slide time: 32:43)



To do that, let us assume the important components in a felt pen: And this could be for example, 1 could be the plastic cap with a short clip maybe, number 2 is the felt with the writing nib, writing tip; another is the body of the pen and of course, there is a process of assembly of the pen. So, a manufacturing company where we have to produce a felt pen say for example, if there 4 different manufacturing operations:

One is the cap with the short clip, other is the felt with the writing tip, third is the body of the pen and fourth is the assembly line where we have to put all these different components together and make this pen. The question is what, which is the most critical component so that my maintenance efforts, efforts could be put to the components which are the most critical?

(Refer Slide time: 35:04)



So I will list down these four components here, in terms of O S and D and calculate the RPM numbers. So, one is I will list them briefly: cap, other is the felt tip and third is the body, 4 is the assembly. Let us try to give the ranks of O, S, D and RPN to this cap. If a cap how from a rank of 1 to 10 f the failure of the caps are very robust, utmost the clip, clip may fail and it can occur, out of the felt tip, body and their assembly.

Perhaps, I will give it a rank of 2, Felt tip it can become dry that would be and it can happen periodically, if we left the Pen for lot of time or not use it, the pen, so this occurrence could be 3 or 4. Body of the pen may not fail, that could be an occasional crack and so I will give it a rank of 1 and then the Assembly of the entire pen assembly may become loose and this occurrence is also very low and could be given a rank 2.

The numbers I gave 2, 4, 1 and 2 these are very judgemental; these are very subjective; and I am sure if I ask each one of you to give your own rankings, you may come up with a similar ranking as well. And next is severity of these failures. Suppose this cap has failed, how severe is it or how important is it to affect the failure of the pen as a writing media.

Was this the cap fails, it will perhaps not influence or affect the performance of the pen that much. So I will give a low number. My felt tip yeah, the felt tip fails, it is very severe and it is going to affect the performance of the pen. So I should give it a very high number; and the body fails in a felt pen and the body fails, it is not that severe because the ink is not going to leak out.

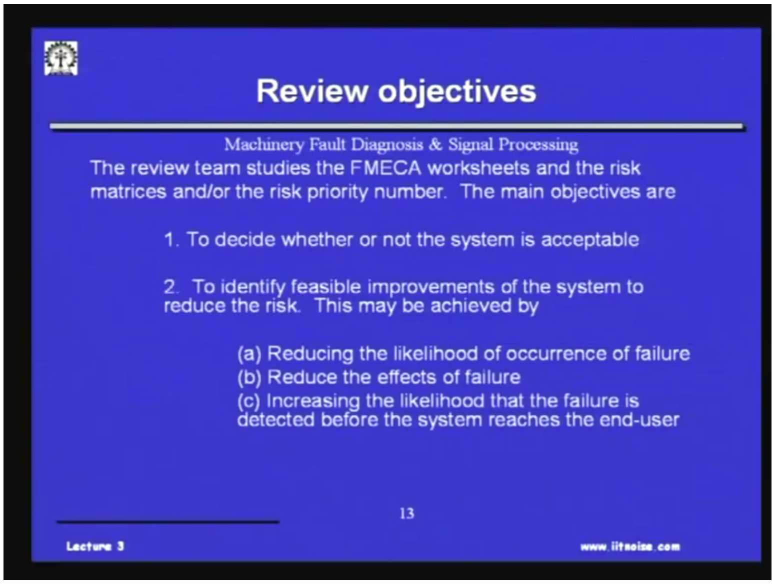
But, suppose, I had an old day, the fountain pen where we use to put ink inside the body, then the body was used as a container of ink and if that failed, it would see in the sense that it would stay in the body. But in a felt case of felt pen it is not that serious I will give it rank again of 2. Assembly of a felt pen is also very, sorry. The severity of the Assembly, yeah, if the Assembly was not proper the panel will not work.

So, I will give it a high number. Now, if you recall to my few slides, earlier I have told detectibility is given a low number if fault can be easily detected. Obviously it is a fault in the cap, we all can see from outside. So, I can give it a low number. Felt tip if there is a defect, I cannot see it, I cannot observe it unless I write it. So, I will give it a high number. Body, if there is a crack, I can see it while it can be easily detected.

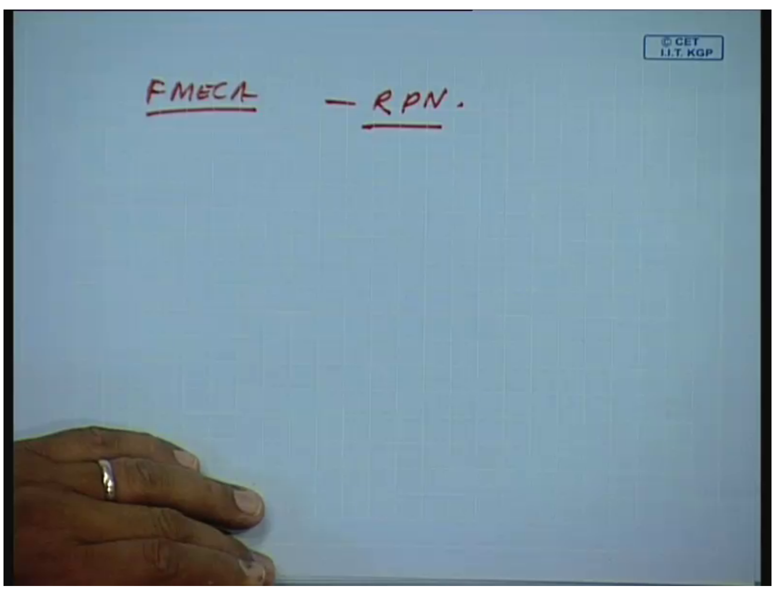
So I again give it a low number; Assembly, if it has failed, it can be easily detected, so I will again give it to low number. Now, now let us calculate the RPN numbers of this. This is 4, this is how much for4 into 9, 36 times 7, 21 + 242 and this is 4 and this is about 14; Now, if you just do this calculation here, you see the felt tip stands out amongst the cap, body and the assembly. So, in a pen manufacturing operation, the, according to the FMECA analysis, we just concluded that the felt tip is the most critical in its manufacturing.

So, we can say that the machines which are used to manufacture the felt tip have to have the best kind of all round maintenance. And you see through this simple example we could very easily find out that how FMECA is going to help us establish the maintenance schedule to be used on a different machine.

(Refer Slide time: 40:21)



(Refer Slide time: 40:26)



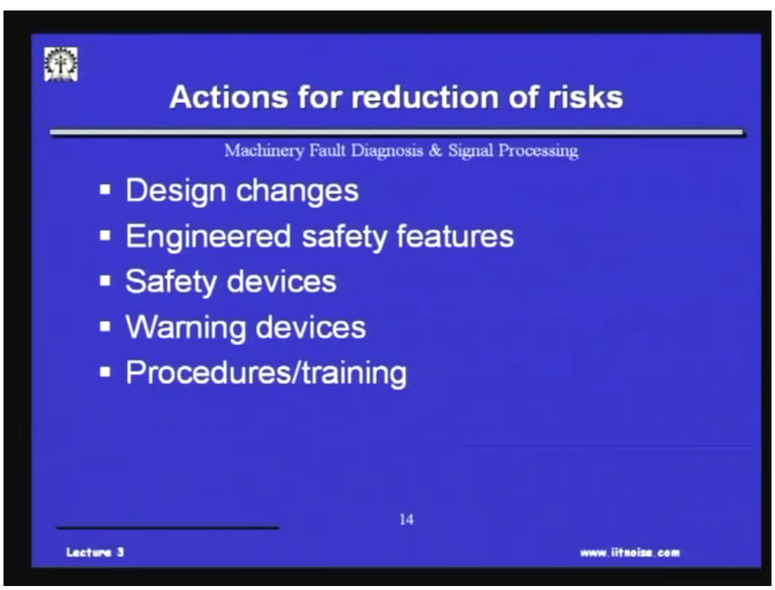
So once we know the RPN numbers, we can decide whether CBM or Condition based maintenance needs to be done to the most critical component. So, like in a steel plant now, we can decide on the different processes and then try to establish RPNs and then find out that in which process CBM to be done, in which process just break down maintenance has to be done, or in which process periodic maintenance is to be done.

Now, sometimes in the review of the FMECA worksheet once you have completed the FMECA worksheet, whether you have to see whether what are the systems drawbacks, whether it is acceptable not acceptable, whether it is feasible to reduce the risk, by reducing the likelihood of occurrence of the failure. So, we have to work on the parameters, which will reduce the occurrence of the failure so, that to bring down the number O.

Or reduce the effect of the failure that will have the number S and increase the likelihood that the field is detected before the system reaches the end user because as a manufacturer if I am not careful that I cannot see or detect the fault easily, then it is no good; Because in, it goes in the hands of the person who is the end user and the faults cannot be detected but the faults keeps on happening and that is not good design.

So, we have to ensure that the, we have to make the number, the deductibility low, so that the low number given in a RPN analysis, the faults can be easily detected. One such an analysis can be done; we can then can establish FMECA as a tool to identify the different processes, equipments so that more care or more efforts in maintenance can be taken in such equipment or plant.

(Refer Slide time: 42:38)

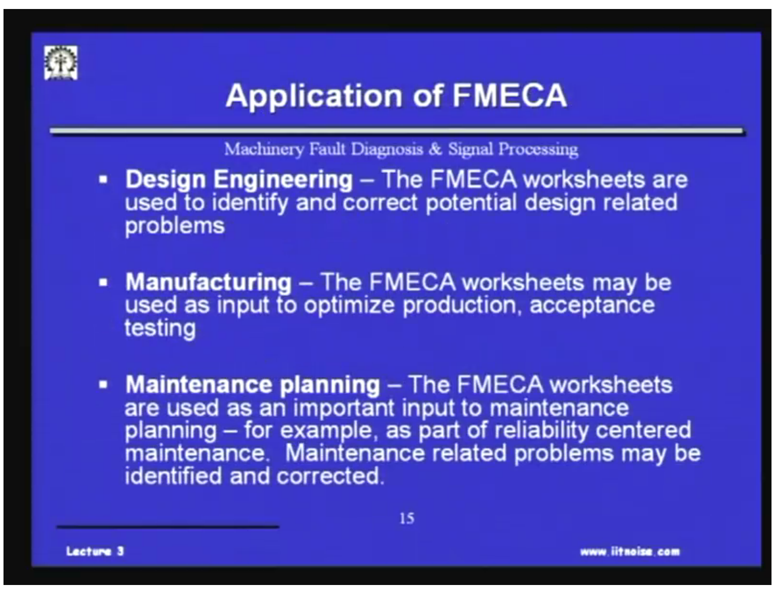


Well, how do we reduce the risk? We can make design changes, we can engineer certain safety features, we can put safety devices, warning devices, of course, are the right procedures and training in place such that your RPN numbers criticalities can be reduced. But as a maintenance engineer, we sometimes are called to maintain equipment which has been already designed.

But like we did FMECA for maintaining a plant or an equipment, FMECA could very well be done in the design stage as I was telling right from the beginning, by the designer itself to find out the different processes, different factors, by which the criticality of the equipment could be reduced, so that there is enough robustness in the design and the occurrences of failure is reduced.

The process is lead out so that the severity of the failure is reduced and there are features in the system, for example, putting warranty devices, safety devices etcetera, in the system so that the fault can be easily detected. And that would constitute in a holistic manner that the design is very optimum, a design which is maintenance friendly, a design which brings down the number of failures and bring down the eventually the laws of production.

(Refer Slide time: 44:03)



So, to conclude in this design engineering, the FMECA worksheets are used to identify and correct, potential design related problems in manufacturing; this, FMECA worksheets may be used as an input to optimise production, the processes, the acceptance testing and so on. But what we look today was in the maintenance planning. In the maintenance planning, these FMECA worksheets are used as important input to maintenance planning.

For example, as part of Reliability centred maintenance, maintenance related problems may be identified and corrected. So, once we know that the maintenance is critical, we will do CBM in such maintenance. Once we know that it is less critical, we may decide on whether to have a preventive sorry ah periodic maintenance or breakdown maintenance. So, we will talk about FMECA in the future classes when we apply it to different systems.

And then we will see how FMECA can be used, how the RPN numbers can be estimated and how as a designer also we should have an insight, how the RPN numbers could be reduced. Thank you.