Advanced Machining Processes
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Lecture No 11
Introduction to Micro-machining

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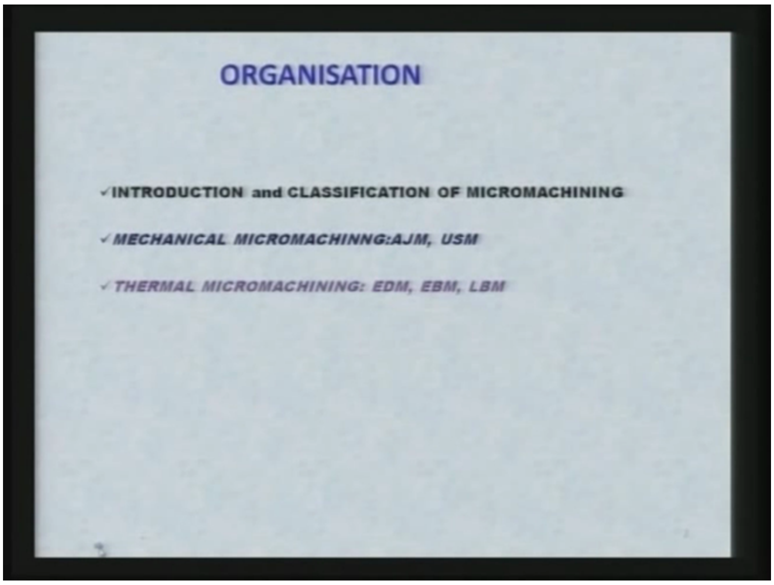

To the chapter on introduction to micro-machining the organization of this lecture is as follows, Introduction and classification of micro-machining processes, mechanical type of micro-machining processes such as abrasive jet machining, ultrasonic machining, thermal micro-machining processes such as electric discharge machining, electron beam machining, layer beam machining, electrochemical type of micro-machining processes.

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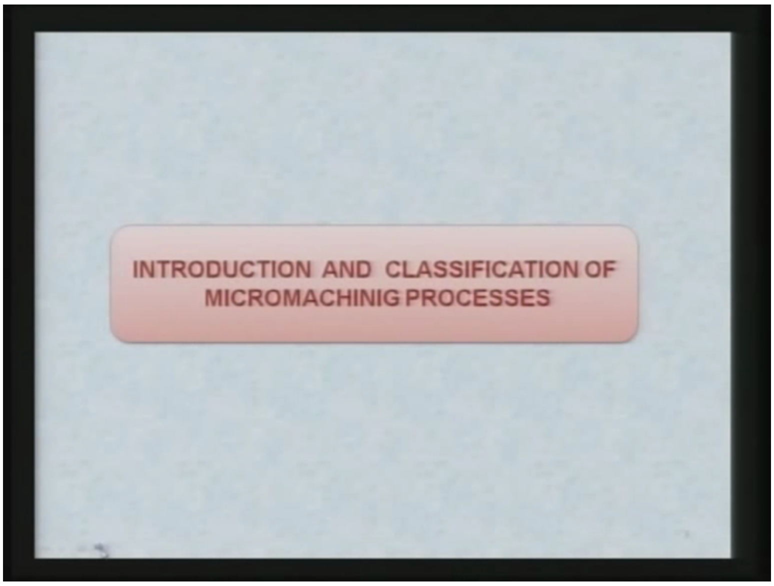

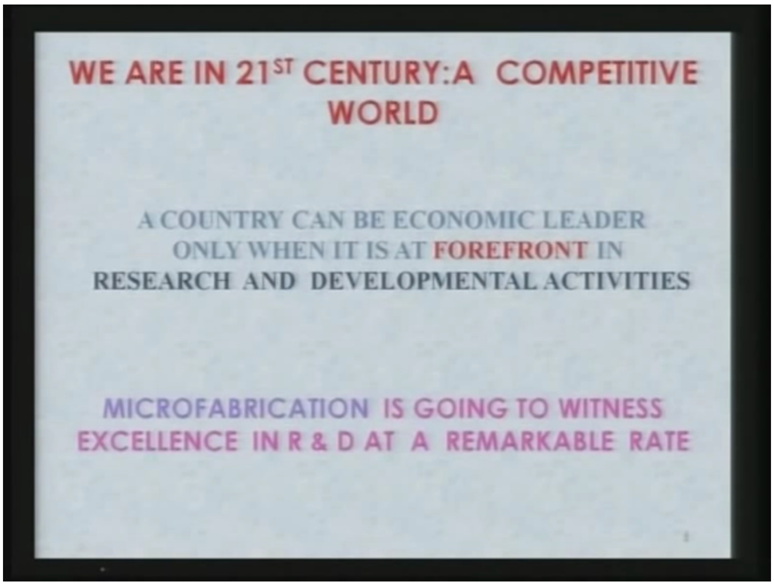

Introduction and classification of micro-machining processes, we are in the 21st century which is a competitive world, a country can be economic leader only when it is at forefront in research and developmental activities in the nation. From that point of view micro-fabrication is going to witness excellence in research and developmental activities at a remarkable rate as will be quite evident in this lecture, in the following 2 lectures.

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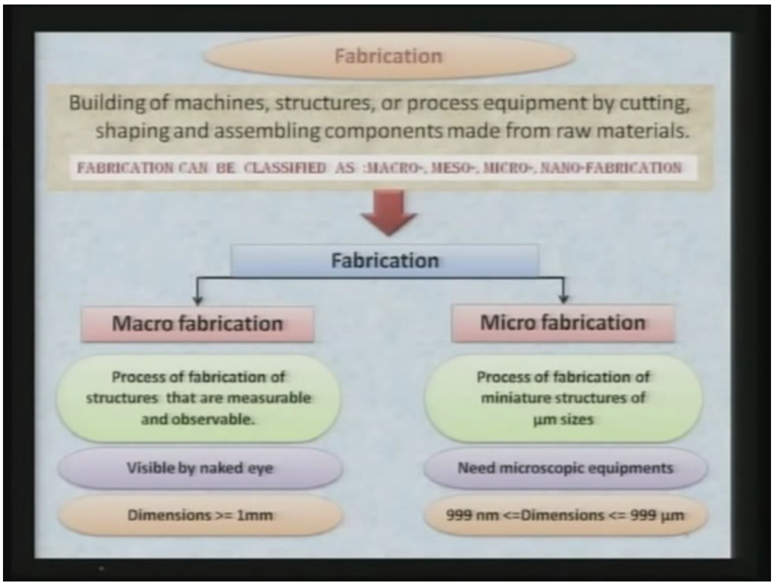

Now first let us understand what is fabrication or what is manufacturing or micro-manufacturing later on. Building of machines, structures or process equipment by cutting, shaping and assembling component made from raw materials. From this fabrication point of view you can classify this fabrication processes in macro-fabrication, meso fabrication, microfabrication and nano fabrication. This fabrication can be classified mainly in 2 classes macro fabrication and microfabrication.

In place of 4 types of fabrication I have just mentioned…I am going to concentrate basically on macro fabrication in general which also includes meso fabrication and microfabrication where I am going to take up some examples of nano manufacturing also. In macro fabrication means where the dimensions are large enough you can see by naked eyes, you can feel them by your hands also. Process of fabrication of structures that are measurable and observable by naked eyes, they are visible by naked eye. Normally their dimensions are bigger than 1 millimetre. In case of microfabrication, process of fabrication of miniatures structure whose dimensional is are comfortably mentioned in micro-meters. For viewing them properly or absorbing them properly you need microscopic equipments or microscopes for that particular purpose. Their dimensions are greater than 999 nanometre and smaller than or equal to 999 micro-meter.

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Now let us see what is micromanufacturing we have seen 4 types of manufacturing macro, meso, micro and nano? Now let us just see what is the definition of micromanufacturing? A set of processes used to fabricate features, components or systems with dimensions most conveniently described in micro-meters. We will keep this definition in mind while discussing the microfabrication or micromanufacturing.

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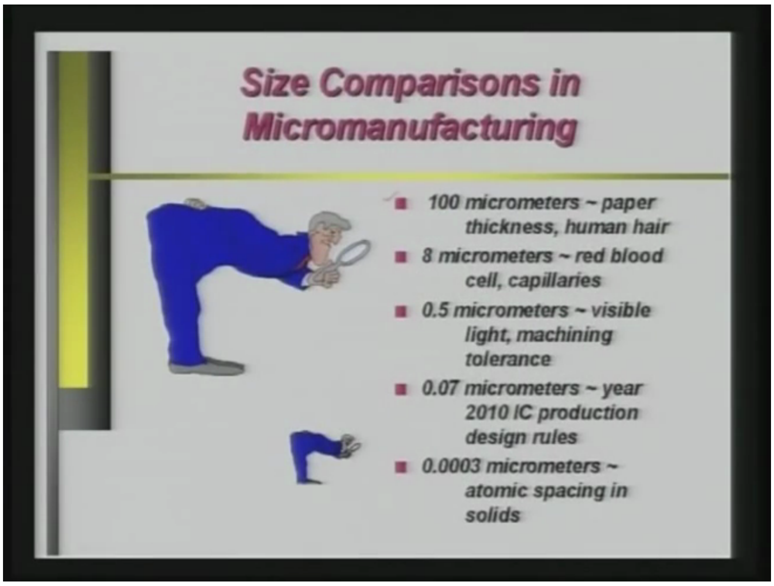

Now what the size of…size comparison in micromanufacturing is very important to understand. Now if we take the hundred micrometres that includes the paper thickness which we normally used for writing, human hair which is around hundred micron size. If we take 8 micro-meters then red blood cells come in that category, capillaries also come in that category. 0.5 micro-meters their visible light wavelength, machining tolerance is also been nowadays talked many times in terms of half micron at the machining tolerances. 0.07 micro-meters in the year 2010 or beyond IC production design rules will be following or using 0.07 micro-meters or 70 nanometre as their dimensions and 0.0003 micro-meters that comes out to be 0.3 nanometre as atomic spacing in solids that is 0.3 nanometre means 3 angstrom and which is the spacing between atoms in the solids.

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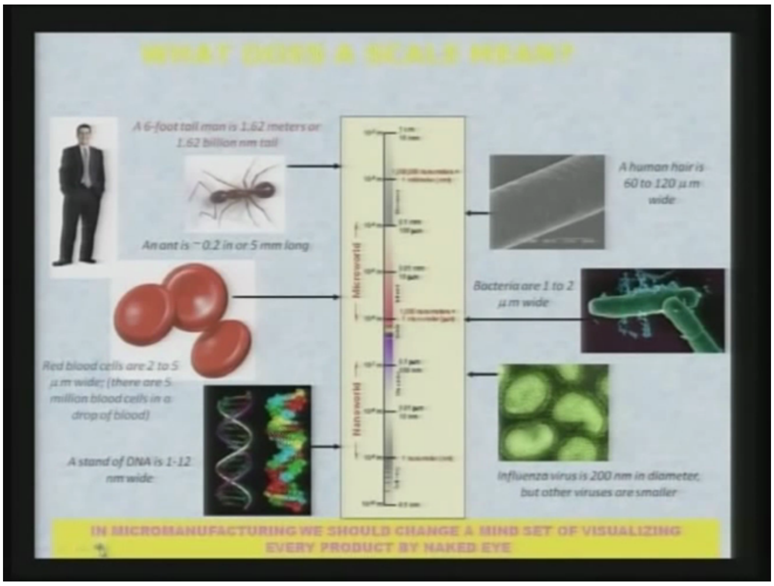

Now let us see here 6 foot 6 feet tall man is 1.62 meters or 1.62 billion nano meter tall, so you can convert this meter in terms of millimetre, micro-meter, nanometre and ant is 0.2 inch or 5 millimetre long, so inches can be converted and you can see the comparison between different you know species or human being or blood cells. Red blood cells are 2 to 5 micro-meter wide there are 5 million blood cells in a drop of blood. A standard DNA is of 1 to 12 nanometre wide, so now you can just try to imagine what are these are dimensions and how can you imagine them you know in your mind when we talk of all these dimensions. Now here you can see a human hair is 60 to 120 micro-meters depending upon the diameter of the thickness of the hair.

Bacteria are 1 to 2 micro-meters wide, so in micromanufacturing we should change a mind set of visualising every product by naked eye which is not possible, you have to take the help of high magnification microscopic equipments just like optical microscope, scanning electron microscope or atomic force microscope to view these products and see their structure configuration, dimensions, shapes, et cetera. Now you can see here I have shown a scale length which starts with 1 centimetre to 1 angstrom. Influence of virus is 200 nanometre in diameter but other viruses are smaller as you can see in the last figure.

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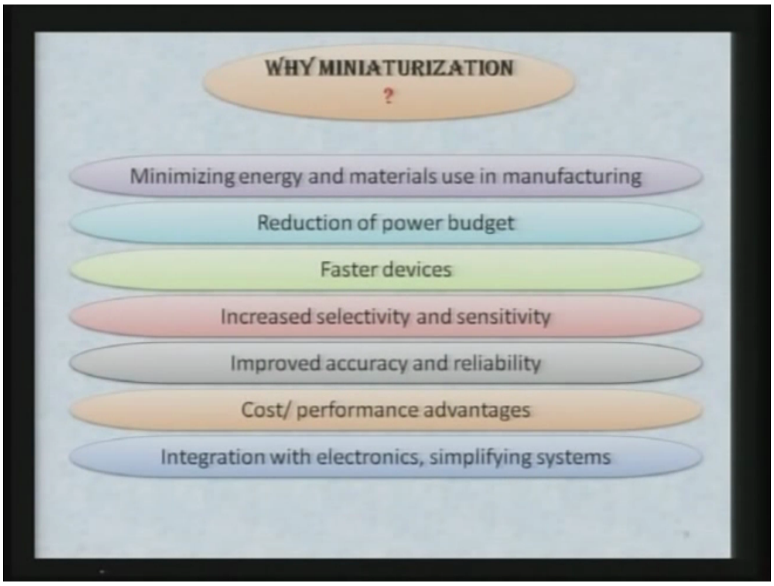

Now the question is every product that we see nowadays in our daily life their sizes are reducing continuously. If you go back to 20 years and see your telephone, how big the telephone was and today if you see the micro if you see the version of cellular phone such a small you now cellular phone now every much more feature much more better cell phones are available these days compared to what you have telephones, so miniaturisation or reduction in the size has taken place continuously or you can see the case earlier we used to have the hard disk or magnetic tapes or other kind of devices for storing the computer memory, nowadays if you see such a small chip is there or such a small pen drive is there which can store as many as 14 GB data.

So miniaturisation is conditional taking place in different area of everyday life and question arises why this miniaturisation is important? There are certain reasons for this minimising for example, minimising energy and materials used in manufacturing certainly the cell phone requires much smaller materials for manufacturing as compared to our old age telephone. Same way reduction of power budget, the total power consumption in these devices is much lower compared to the large size devices, devices are faster in response, increased selectivity and sensitivity of these devices compared to the older one, improved accuracy and they are more reliable compared to the large size, definitely cost advantages is there, performance advantage are there and integration with electronics and simplifying systems is there.

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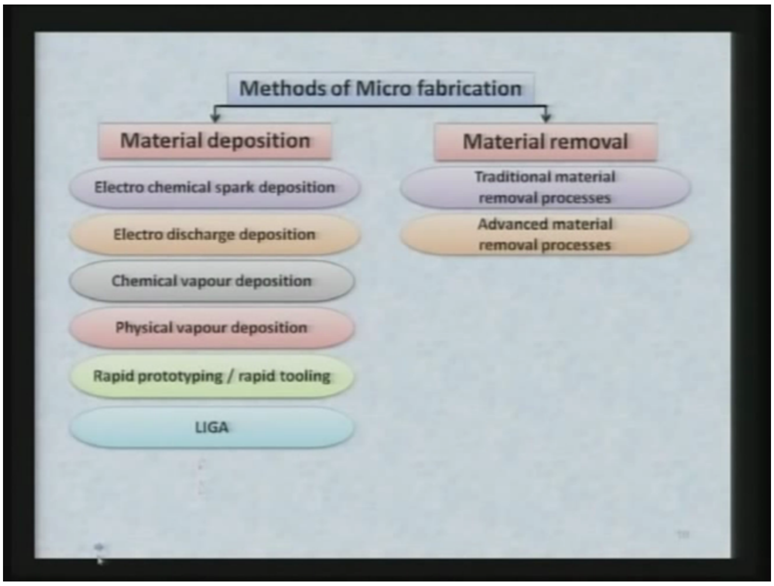

Now the question arises what are the methods of microfabrication? You have 2 categories of micro-fabrication one is by material deposition another is by removal of the material. Either of the 2 can be used depending upon your device requirement or product requirement. There are various methods of processes which are used for microfabrication using material deposition one of them is electrochemical spark disposition, electro discharge deposition, chemical vapour deposition, physical vapour deposition, rapid prototyping rapid tooling, Liga these are some of the material deposition processes this is not the end there are other processes also which has not been listed here. Then there are various material removal processes they can be classified in 2 categories one is the traditional material removal processes just like milling, turning, et cetera and another is the advanced material removal processes such as ultrasonic machining, abrasive jet machining, electric discharge machining, electrochemical machining, et cetera.

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Now micro-products nowadays focus is on miniaturisation through development of novel production concepts especially micro-and nano for the processing of non-ceramic materials. Microfabrication deals with all kind of manufacturing processes but at micro-and nano level that means their features or their dimensions can be expressed in terms of micro-meter or nanometre. The replication of micro-parts through moulding is one of the preferred routes for micro manufacturing because of its mass production capability and relatively low-cost.

Although I am not going to discuss micro parts production through moulding process but this process is the unique process or unique concept which already prevailing for micro part same has to be used for micro parts if mass production is to be done. Mass production you cannot do economically and at a faster rate by a material removal process or even material deposition processes. However, in this talk I will mainly concentrate on micro attritious processes that are micro-machining processes. These processes also have their own importance for making the die for moulding purposes, micro-moulding purposes or punches or other kind of the tools and tooling you have to go for attritious processes that is micro-machining processes that I am going to teach today and in the following lectures.

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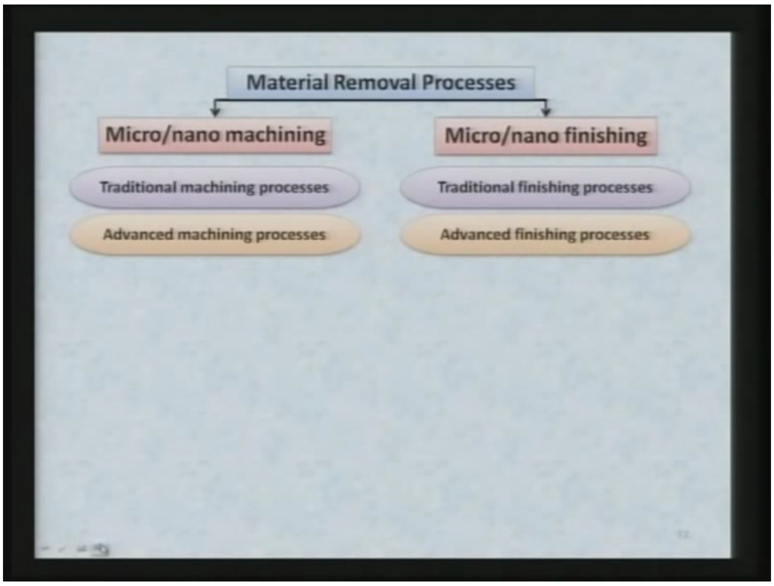

Material removal processes again there are 2 categories micro/nano machining processes, micro/nano finishing processes. Now there is a basic difference in micro/nano machining and micro/nano finishing processes, in machining processes we are making micro fissures or micro components giving proper shape and size while in case of finishing processes, we are improving the surface quality of a macro or microproducts but that surface finish or surface quality are at micro or nano level. Now micro/nano machining there are 2 types again traditional machining processes and advanced machining processes. In case of micro-nano finishing also you have traditional finishing processes and advanced finishing processes.

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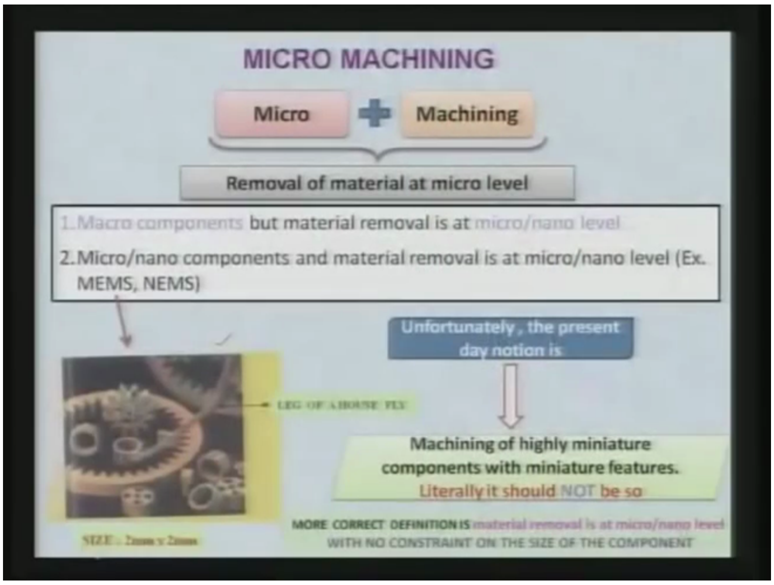

Now micro-machining is made of 2 words micro plus machining, we already know the definition of micro that is 10 raise to power minus 6 meter and machining we all know about what the machining is that is the removal of the material at micro level. Now macro components but material removal is at micro/nano level this is very important to understand when we talk of micro-machining it does not always mean that you are going to make micro component. The component may be of the macro size or meso size and you are creating the fissures of micro size or nano size.

So micro components but material removal is at micro/nano level that material removal is in the form of chip if it is being machined by applying the mechanical forces or you can get the debris of a very small size if you are using the thermal processes like micro electric discharge machining, laser beam micro-machining or you know you will get the reaction products in case of electrochemical micro-machining. 2^{nd} one micro-nano components and material removal is at micro/nano level this is very simple that you are when you are going to make MEMS, NEMS, et cetera the component itself or the elements of the device itself are having the dimensions of micro size. Then definitely the material remover from those devices or parts or elements is also going to be at micro or nano level.

You can see a very interesting example here, here is it 2 millimetre by 2 millimetre size frame which is having so many components you can see and you can measure now the dimensions of these components and here I have tried to show a leg of a house fly, now such a small leg a house fly has, now within that size you can see how many components are there, so that gives you an idea what size of components we are talking about when we talk of micro parts or micro components. Unfortunately the present-day notion is when we talk of micro-machining normally it comes in the mind of the people that machining of highly miniatures component with miniature features literally it should not be so it is not correct because we are talking of machining at micro level, not making the component at micro level. So more correct definition of micro-machining is material removal at micro/nano level with no constraint on the size of the component, component can be either macro component, meso component or micro component or nano component.

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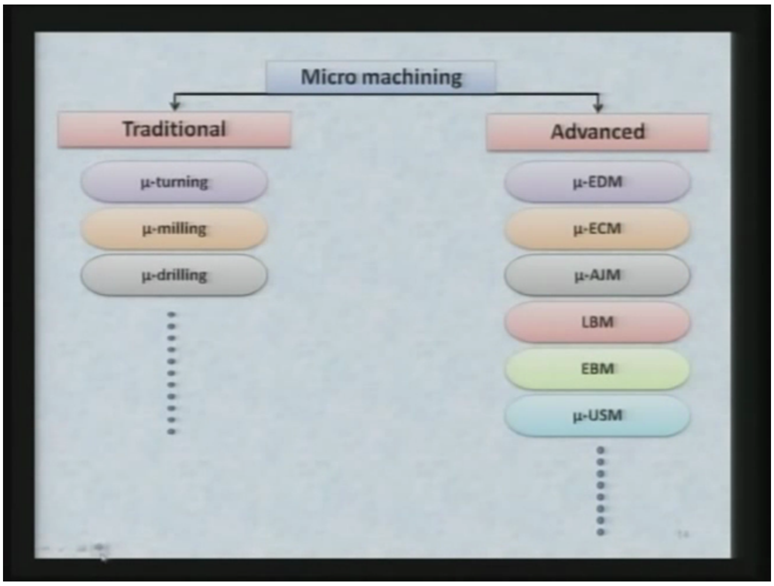

So micro-machining let us see what other various processes in traditional micro-machining processes micro turning, micro-milling, micro-drilling and so many other traditional micro-machining processes are there. Then there is a whole lot whole list of advanced micro-machining processes like micro EDM, micro-ECM, micro-AJM, laser beam machining, electron beam machining all of them come into category of micro-machining and including ultrasonic micro-machining.

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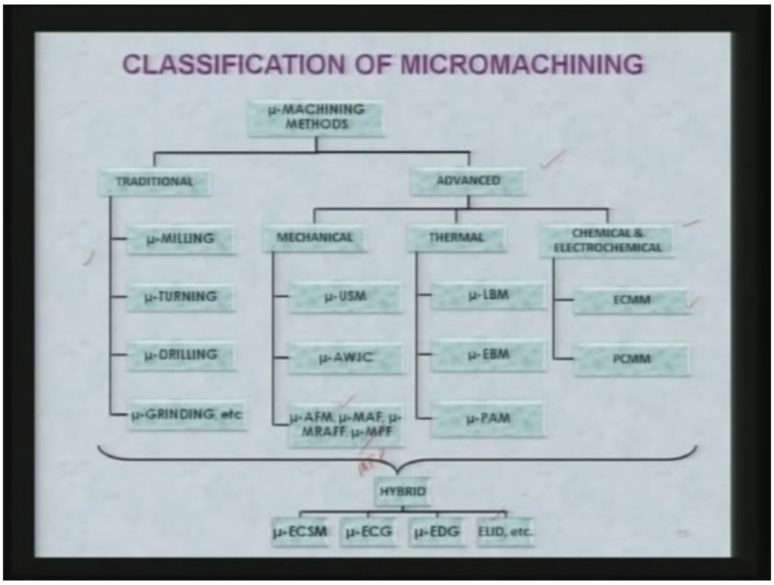

If you want to classify micro-machining processes I have shown here, you can see whatever I have shown mention earlier slide you can see there is a classification that a class of traditional micro-machining processes micro-milling, micro-turning, micro-drilling, micro-grinding, et cetera and there is a class of advanced micro-machining processes mechanical type advance micro-machining processes included ultrasonic micro-machining, abrasive water jet micro cutting, micro-abrasive flow finishing, micro magnetic abrasive finishing, micro magnetorheological abrasive flow finishing, micro magnetic float polishing and this is MFP not MPF.

Then on the thermal side you have laser beam a micro-machining, electron beam micro-machining, plasma arc micro-machining and other processes are also there which I have not listed here then in the 3rd category if we see chemical and electrochemical which includes electrochemical micro-machining and photochemical micro-machining. These are not the complete list you can add many more processes to this particular list. Now there is another category that is known as hybrid processes, now if you take one single process which has many merits and some demerits also but if you combine a particular process with another traditional or advanced machining processes, you may overcome some of the disadvantages of a particular process and if you combine 2 or more than 2 processes and try to make use of the merits of these processes then you call it as a hybrid process.

So you have certain categories here like electrochemical spark micro-machining here you have ECM process combine with EDM process and you are using it for machine material at micro/nano level, then you call it as electrochemical spark micro-machining. Same way electrochemical micro-grinding ECM processes we know it is applicable for electrically conducting material but surface finish obtain is not that very good and we also know grinding process. Here material removal rate is quite low but surface finish obtain is controllable and quite good compared to ECM. So if you combine these 2 processes and use it for micro level feature creation or machining of finishing then you call it as electrochemical micro-grinding. Same way electric discharge micro-grinding where EDM and grinding processes are combined together to take advantage of both the processes, then another process you have electrolytic in process dressing ELID and other processes are also there, they come under the category of hybrid processes some of them I will be discussing.

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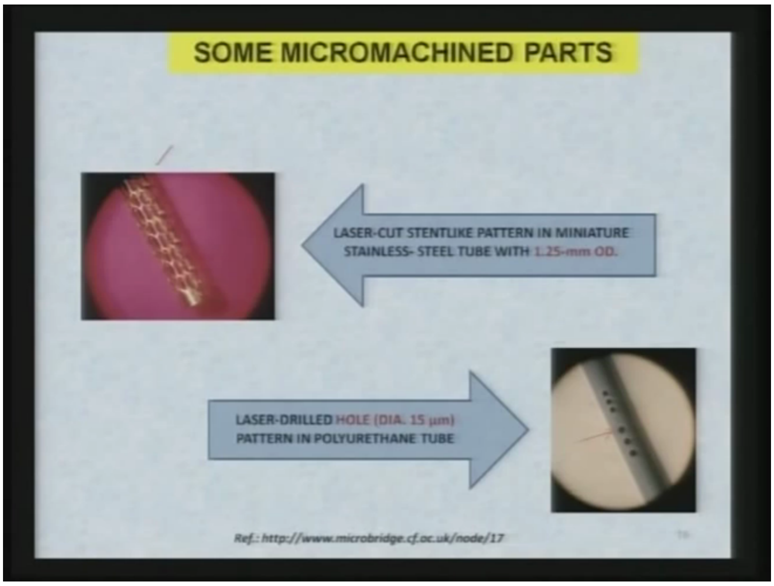

Now let us see very interesting some couple of examples of micro parts, now you can see some micro-machining part, here you see this particular interesting part if you see it carefully it is laser cut stent like pattern in miniature stainless steel tube with 1.25 outer diameter, you can see here the outer diameter is 1.25 but in this this is hollow from inside and different features are created which are of microns size and it is not that easy, it is very difficult to make this kind of component. Then here you can see another simple not that complicated but it is laser drilled hole of 15 micron size pattern in polyurethane tube, so this is the tube you can see here and these are the different types of the whole large size and small size that have been created using the laser beam.

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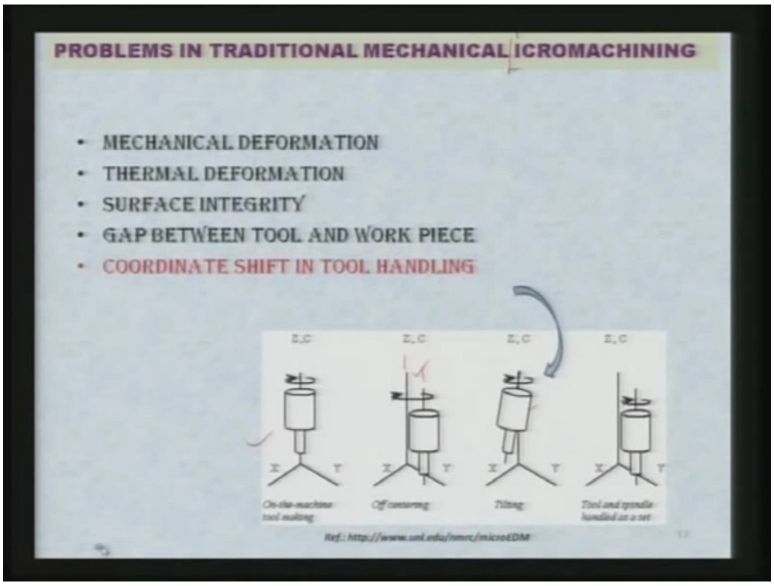

Now I have mentioned to you that we have traditional mechanical micro-machining processes, here m is missing mi micro-machining. Now there are certain problems associated with mechanical type of micro-machining processes are shown here. Mechanical deformation take place when we are talking of micro-features or micro/nano pattern then mechanical deformation becomes very important even slightly larger force will deform or damage the fissure. Thermal deformation because any mechanical machining processes you take, heat is always generated and because of that heat the deformation of the machine features or component may take place which will change the shape and size of the component.

Surface integrity is another problem then gap between tool and workpiece I will show you the figure for this in this slide itself and coordinate shift in tool handling. Now you see the example here if you are making the tool at a particular machine and using this particular tool on another machine, it really becomes a big problem you can see here if here in this particular case you are making the tool on a machine and on the same machine without disturbing the tool you are making the part then it works nicely because excess of the tool, excess of the workpiece, excess of the machine itself they remain intact does not change.

If you are shifting it then this kind of problem may arise like off centring one axis is here another axis is here and this will damage your component or you will not be able to get the right kind of components or there may be some tilting of the tool compared to the axis of the workpiece or the machine. Again you are not going to get a correct kind of the machine features or the component. Tool and spinning handle as a set, if you are handling both of them together but still that there may be a shift of the axis that also is going to create a problem, so one has to be very careful while doing mechanical type of mechanical traditional type of micro-machining operation.

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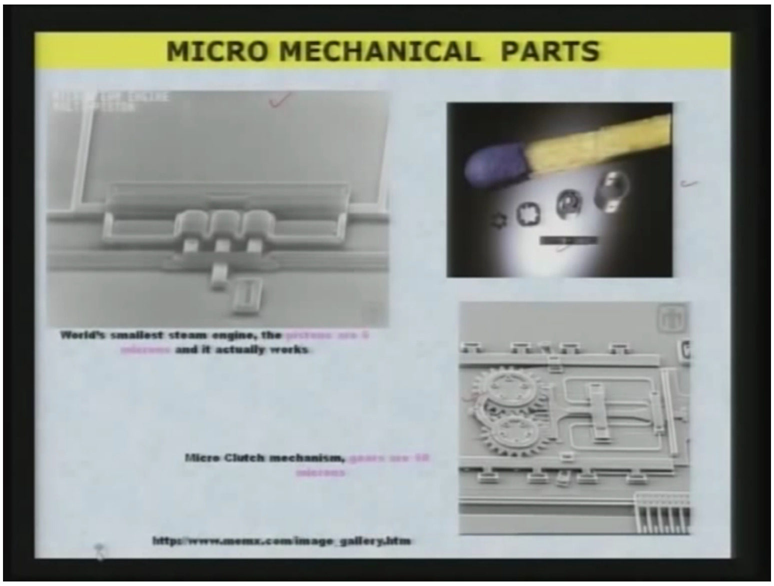

Now these are the very important components which I have taken from certain (())(26:23) and here now you see here in the left side this is a world smallest steam engine the pistons are 5 micron in size you can see here the pistons are inside this and they are 5 micron in size and it actually works this is not just a model, it really works they operate it. Now on that side you can see here micro-clutch mechanism (())(26:51) are 50 micron size you can see the different parts over here and they move with respect to each other and they work really, they deliver the work. Now here is another example you can see the matchstick head over there and compare the dimensions and sizes of these different components that are shown here. So this really gives you an idea that you should arrange your mind set as long as visualisation of micro-and nano features and components are concerned.

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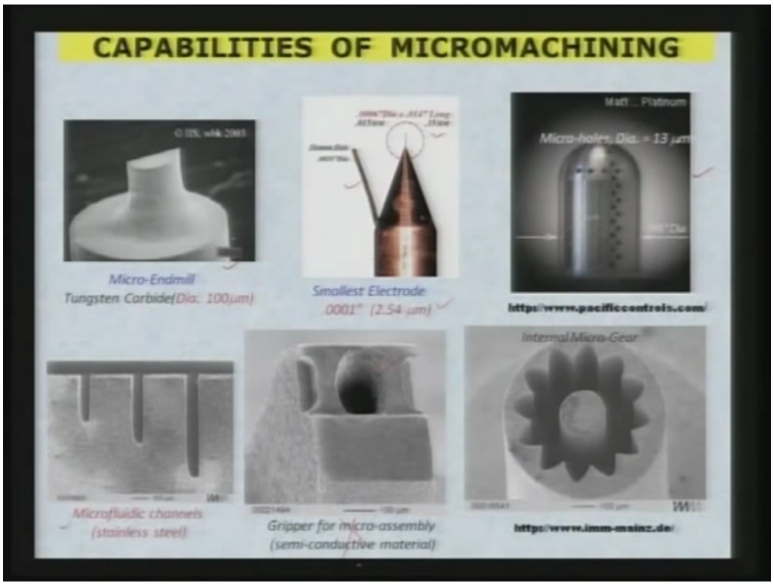

Now other some more capabilities of micro-machining you can see here example micro-end mill tungsten carbide 100 micron diameters in this particular case. Now you can see here 2.54 micron size smallest electrode that has been created over here that you can see on this side and this is the size of the hair. Here internal…here another example on this side micro-holes diameter 30 micron they are shown over here with the arrow you cannot see it clearly material is Platinum. Now microfluidic channels they are commonly used and they are made here on the stainless steel sheets here is the gripper for micro assembly semi conductive not really a gripper it is just a hole over here, so it is not gripper and you can see here internal micro gear, how beautifully and sharply it has been made and they have been taken from the site.

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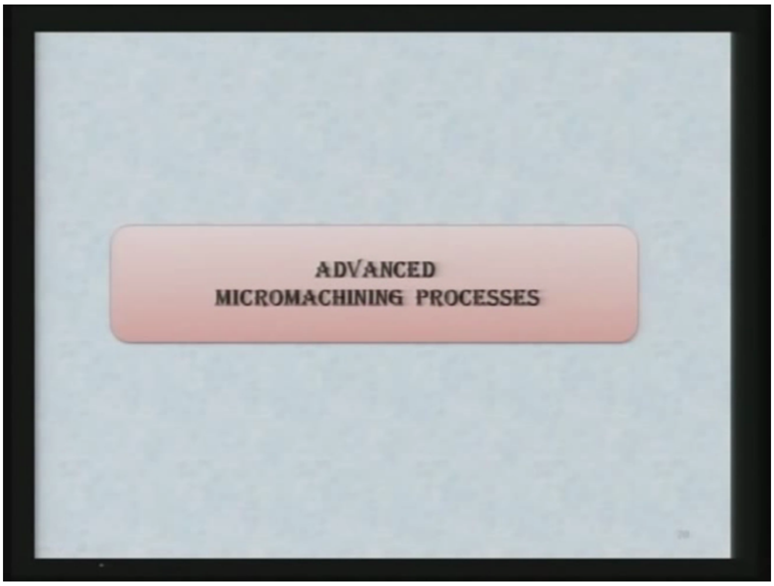

Now let us see advanced micro-machining processes, principles in general you have we have already discussed while discussing individual advanced machining processes still will show you in very brief and quickly I will explain the principles also.

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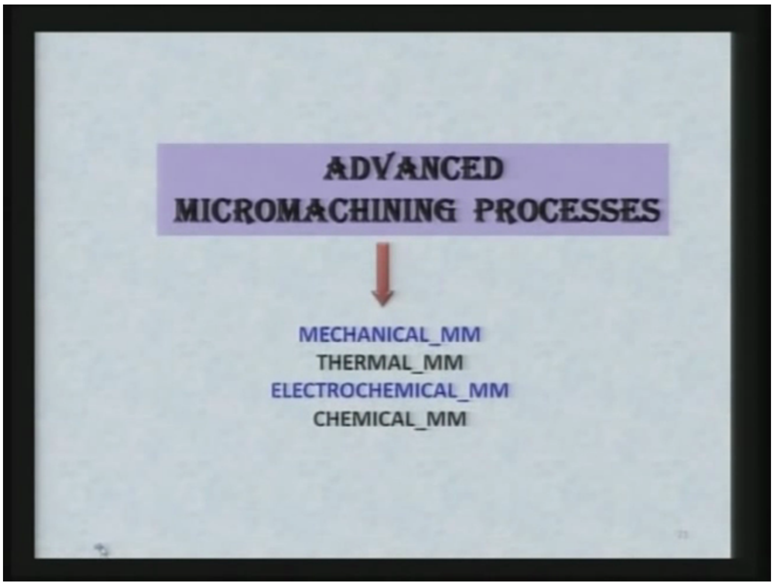

Let us see advanced micro-machining processes they can be classified as mechanical micro-machining, thermal micro-machining, electrochemical micro-machining processes and finally chemical micro-machining processes though these are the basic 4 categories of micro-machining using advanced machining processes.

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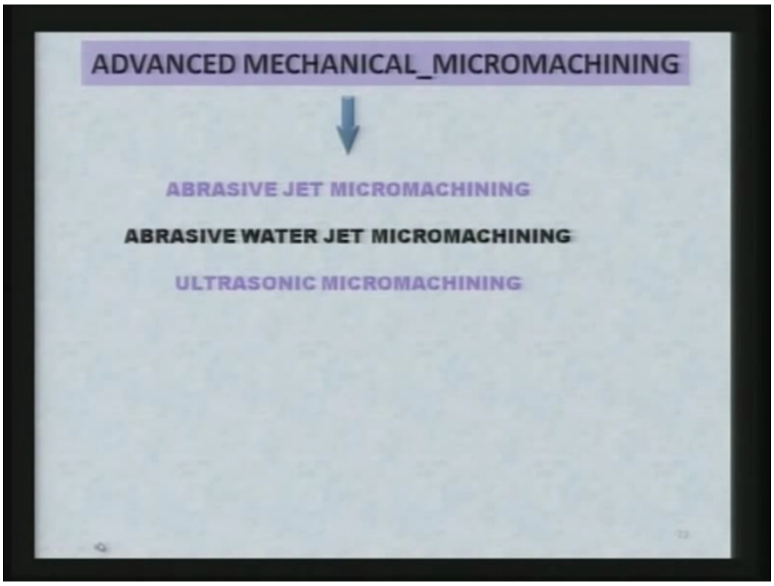

Let us see the examples of advanced mechanical type micro-machining processes which includes abrasive jet micro-machining, abrasive jet abrasive water jet micro-machining, ultrasonic micro-machining. Now since principles we have already discussed while discussing these individual processes, so I will just give you some differences between macro and micro machining and some peculiar examples of the applications of these micro-machining parts or micro-machining processes. Please note here very carefully that while discussing these various processes I am not going to discuss the working principle.

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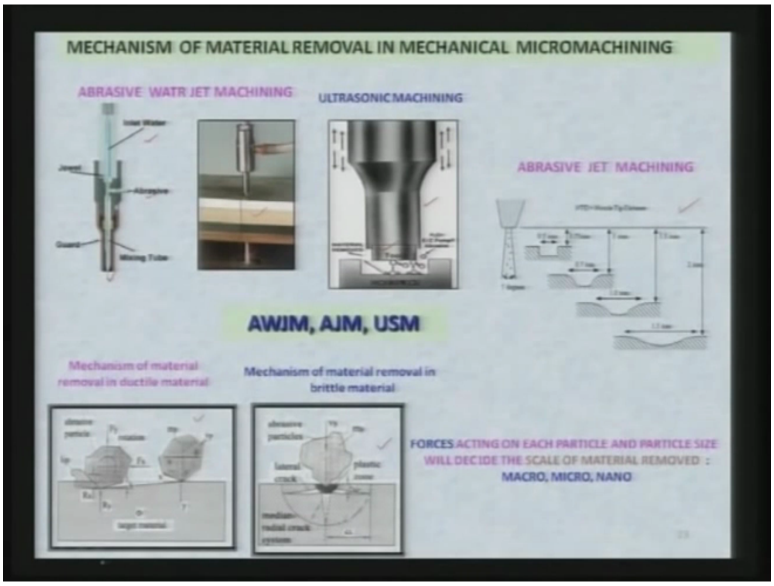

Now if you see here abrasive water jet machining principle is shown over here. Now it is simple you have the water inlet over here abrasive is been fed from the side and here is the mixing tube in which water and abrasive particle mix with each other and then abrasive water jet is coming out over here. Now the important point to note here is that you will get micro-machining or micro-machined part when the nozzle size is really very small otherwise rest of the things remain same.

Now while applying macro machining processes for micro you have to scale down the machining parameters just like in this particular case nozzle diameter has to be reduced, pressure has to be reduced and more importantly the size of the abrasive particle have to be significantly reduced because when we talk of micro-machining the size of the abrasive particle should be very low maybe few microns or sub-micron size of the abrasive particle then only you are going to get the clear-cut fissures as you can see over here that the width of the (())(31:46) is quite small here is the abrasive water jet cutting any here is the abrasive water jet coming out of the workpiece after cutting a slit in the workpiece. Working principle remains the same that the kinetic energy of the abrasive particle and water jet are utilised for removal of the material from the component.

In case of ultrasonic micro-machining again the abrasive particle size goes significantly low as well as the size of the tool also has to be in terms of micron size in only you will be able to drill the hole or create the fissure of micron size rest of the principle remains the same except that here the frequency of vibration is very high in terms of megahertz rather than kilohertz and you can see here the fissure created is just the cavity the help of the tool over here and this is the tool holder which is vibrating at megahertz frequency. In case of abrasive jet machining again you can create the fissures of micron size using the same principle that is the air is the carrier and abrasive particles of microns or sub microns of very low size that is few microns or few say less than hundred micron size and you will be able to create the cavity working principle remains the same which I have already discussed.

The principle remains same in case of all these 3 processes all these 3 processes if abrasive particles is hitting a hard material, brittle material then fracture is going to take place brittle fractures going to take place and a very tiny chips or fracture debris you are going to get out of it depending up on what is the size of the abrasive particle and what is the what are the properties of the workpiece material and what is the kinetic energy with which aggressive particle is hitting the workpiece. Now if it is rectangular material then in place of fracture you may get the deformation of the workpiece depending upon at what angle an abrasive particle is hitting the workpiece as you can see in this particular figure by shear deformation it is removing the material in the form of the microchip. So the force is acting on each particle and particle size will decide the scale of material removed whether it is macro, micro or nano size.

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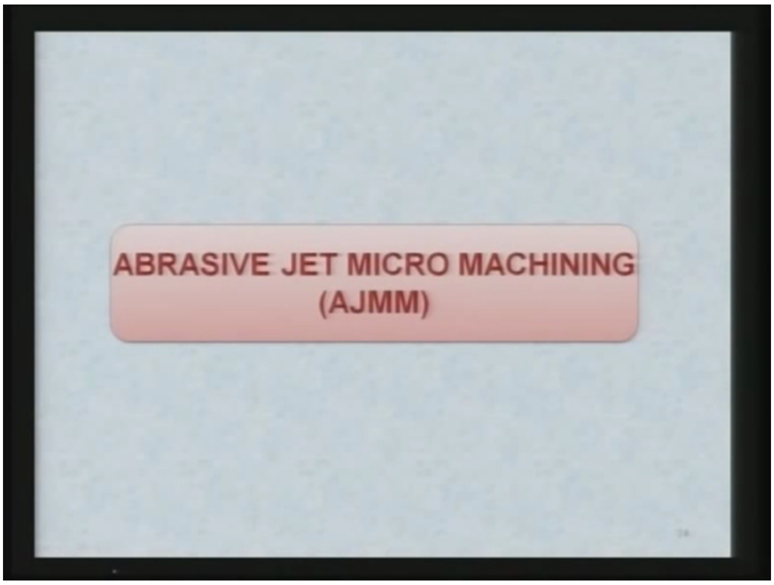

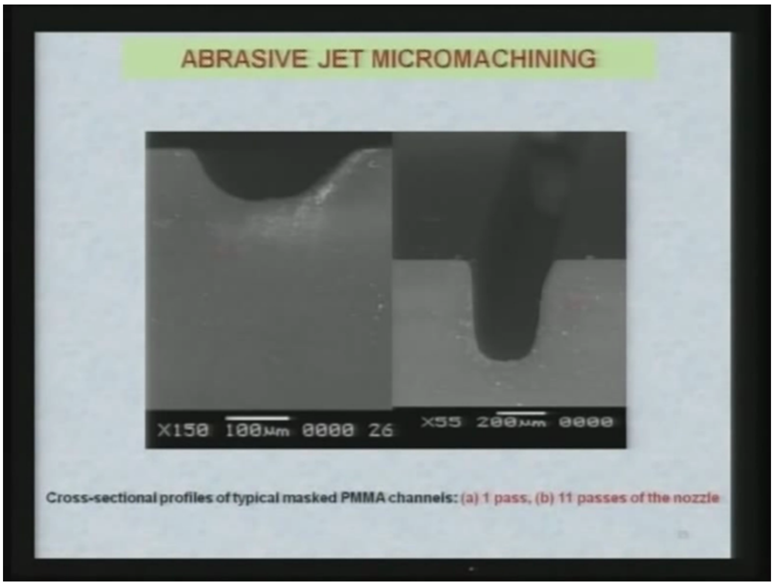

Now let us see some examples of abrasive jet micro-machine parts, you can see here cross-section and profiles of typical masked PMMA channels, it is in one pass you can see the size and shape of the micro-machine channel and in 11 passes you get the depth to the machine channel and can compare the dimensions because the scale of 200 micron is given here, so it clearly indicates the capability of abrasive jet micro-machining processes for creating the fissure of the micron size.

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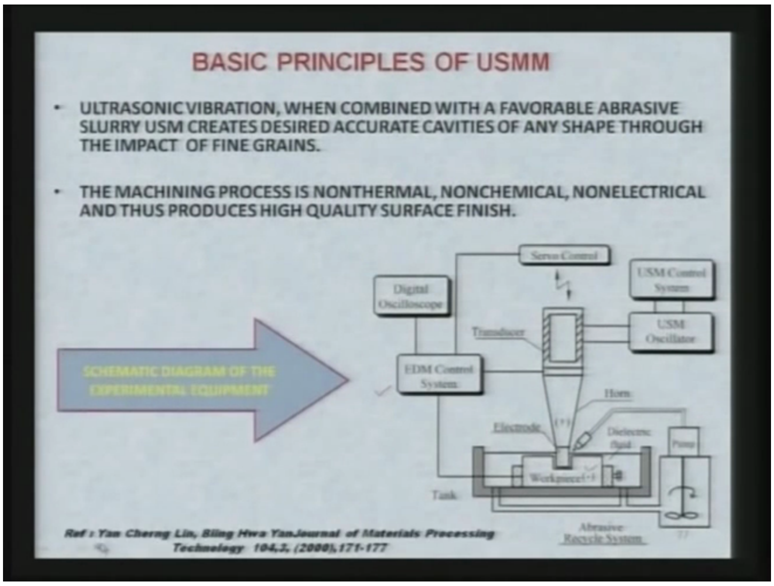

Working principle and set up for ultrasonic micro-machining remains the same which I have already discussed you can see over here shown over there that is the horn is there, tool is there, dielectric fluid is there, now here this particular setup indicates the ultrasonic assistant EDM process because EDM control systems there and workpiece is electrically conducting that is shown over there tool is shown over there. Ultrasonic vibration when combined with favorable abrasive slurry USM creates desired accurate cavities of any shape through the impact of fine grains. The machining process is non-thermal, nonchemical, non-electrical and thus produces high-quality surface finish.

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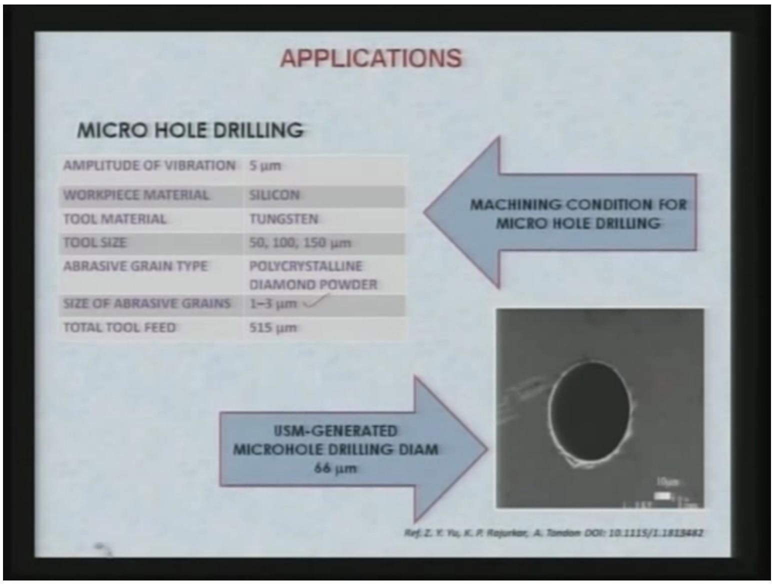

Application you can see here amplitude of vibration 5 micron, workpiece material is silicon, tool material tungsten, tool size 50, 100, 150 micron, abrasive grain size type is poly crystalline diamond powder, size of abrasive grain is 1 to 3 micron, so you can see the size of the abrasive particle that you require very small and total tool feed 515 micron. Now this is the cavity you can see how fine you have obtain a cavity and here is the skill shown over there and USM generated micro hole drilling diameter is 66 millimetre, so it is basically only while ultrasonic machining not ultrasonic assistant electric discharge machining which are issued to you in the earliest slide and here is a silicon which is normally you know very difficult to machine with such fine fissures.

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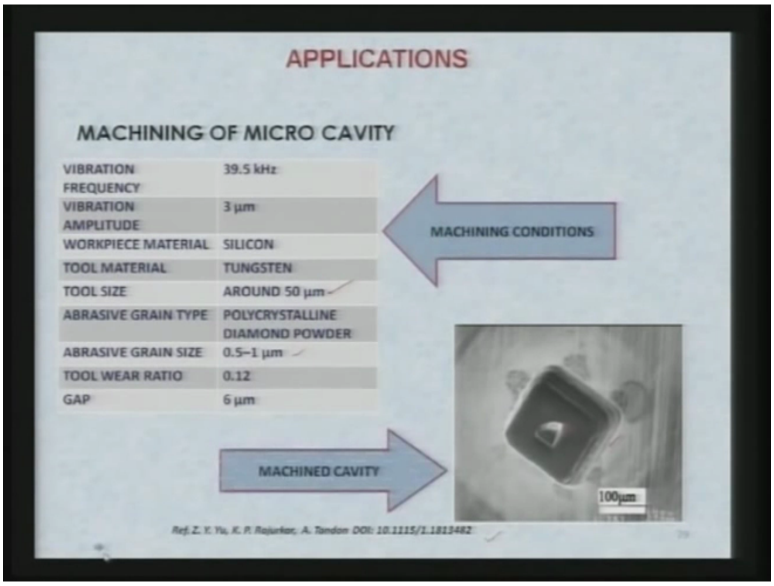

Now this is another important very good application you can see vibration is 39.5 kilohertz, vibration amplitude is 3 micron, against silicon workpiece, tool material is tungsten and tool size is 50 micron and abrasive grain type is poly crystalline PCD powder, abrasive size is still smaller that is 0.5 to 1 micron size and tool wear ratio is 0.12 and gap is about 6 micron. Now you can see here the projection that been created over here and the milling that has been done over here, so such kind of complex features can also be machined with the help of ultrasonic machining process here is the reference.

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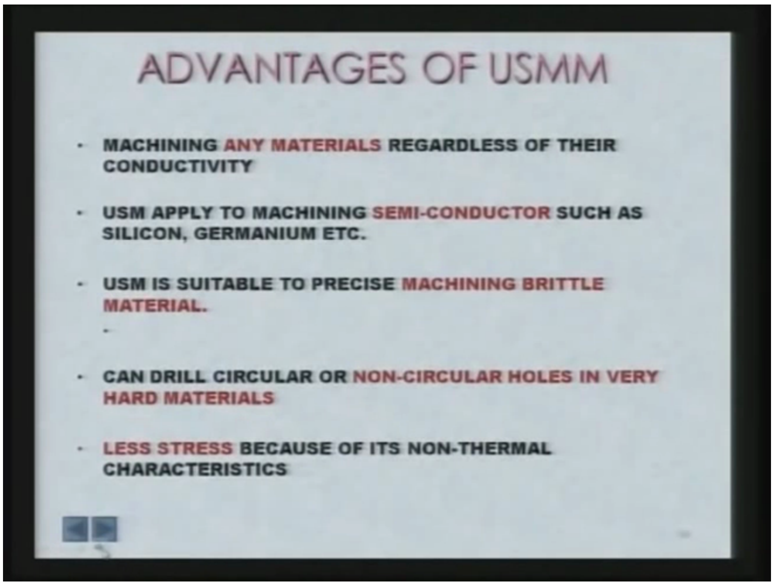

Now there are certain advantages of ultrasonic micro-machining over the other processes. Machining any materials regardless of their conductivity this is very important advantage because ultrasonic machining does not require electrical conductivity of the workpiece to be machined or it need not be magnetic material or high thermal conductivity or low thermal conductivity are also not the consideration for this particular process. Ultrasonic machining apply to machining semiconductor such as silicon, germanium, et cetera. Ultrasonic machining is suitable to precise machining of brittle material which is difficult by other processes because brittle fracture probabilities are always there. It can drill circular or noncircular holes or cavities in very hard materials as we have seen 2 examples in the last 2 slides. Less stress because of its non-thermal characteristics and secondly the amount of material removed by each abrasive particle is very small because the particle size itself is of 1 to 5 or 1 to 10 micron, so the total force acting is also very small.

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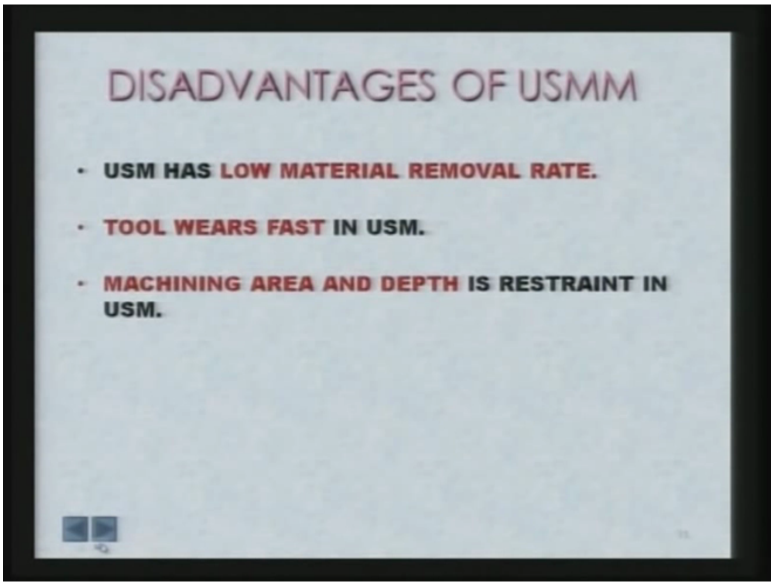

However there are certain disadvantages of ultrasonic micro-machining process, ultrasonic micro-machine has low material removal rate that is the process is very slow compared to other processes. Tool wears fast in ultrasonic micro-machining. Machining area and depth is restrained in ultrasonic machining because depending upon the size of tool you can remove the material from the workpiece.

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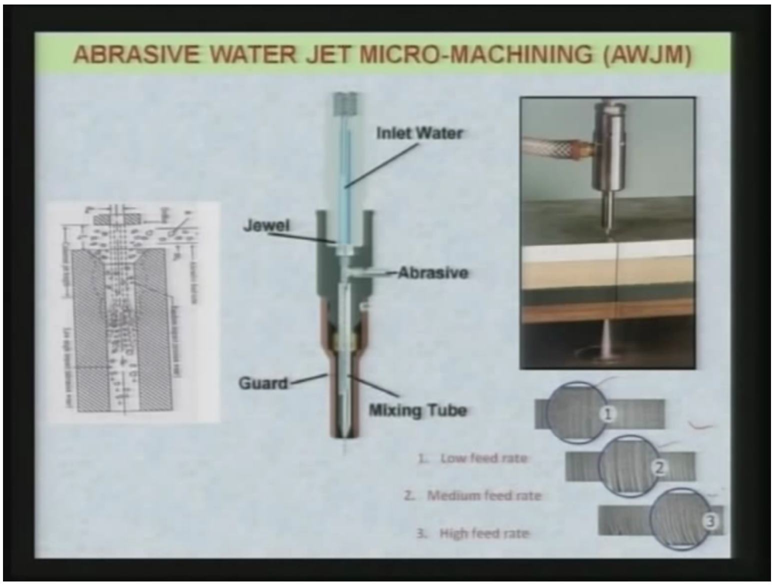

Now these figure I have already shown, I just want to show this particular part that when you are machining with the help of abrasive water jet machining and if it is a deep machining or deep cavity creation or deep cutting then surface is that you are going to get will have different characteristics at different depths, now you can see also at different feed rate. If feed rates are different the characteristics of the machine surface will be different, if depth is different then also the characteristics or the machine surface are going to be different, so you can see here at low feed rate the kind of surface you are getting at medium feed rate and at the high feed rate large number of striations are observed which are really not desirable.

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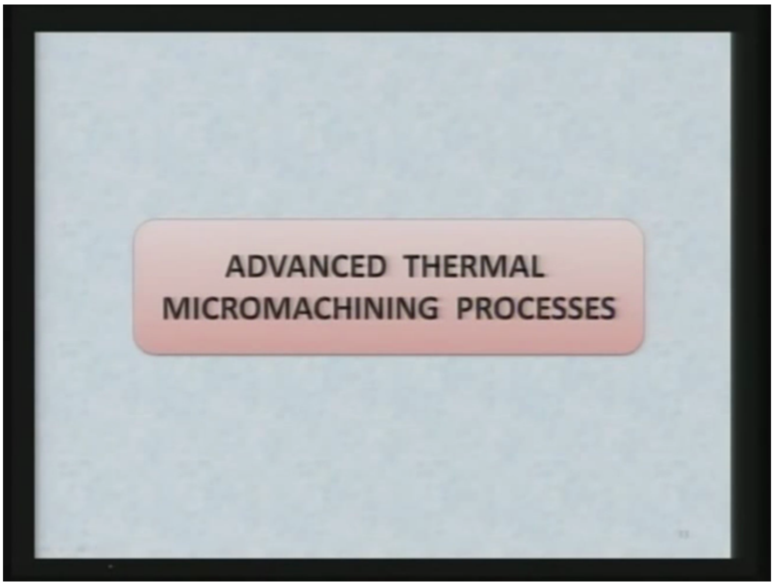

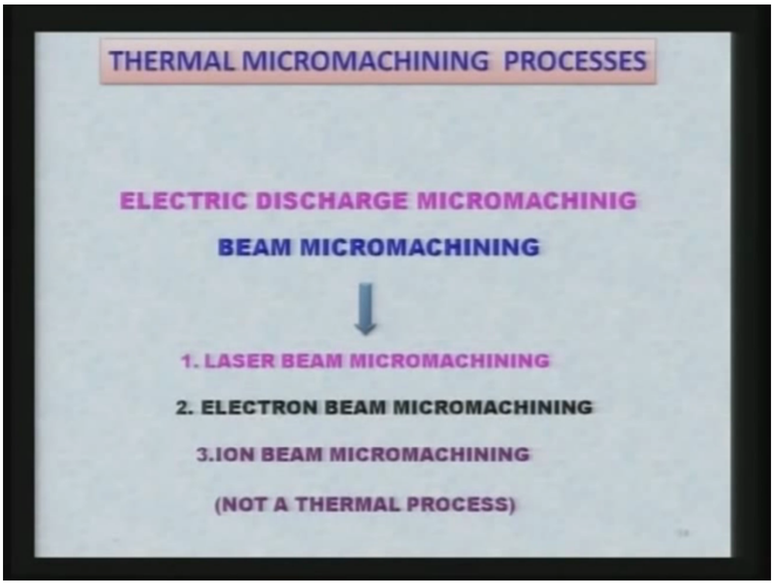

Now let us see some specific applications or examples of the advanced thermal micro-machining processes. We will see the electric discharge micro-machining processes examples of the component then there are a set of beam micro-machining processes like laser beam micro-machining processes, electron beam micro-machining processes and ion beam micro-machining processes. I will just give you examples of the parts fabricated using these processes. However, ion beam micro-machining processes really are not a thermal process, it is not a thermal process, it is non-thermal process. However, it has been placed in the category of thermal micro-machining processes as being done by various other authors and researchers also.

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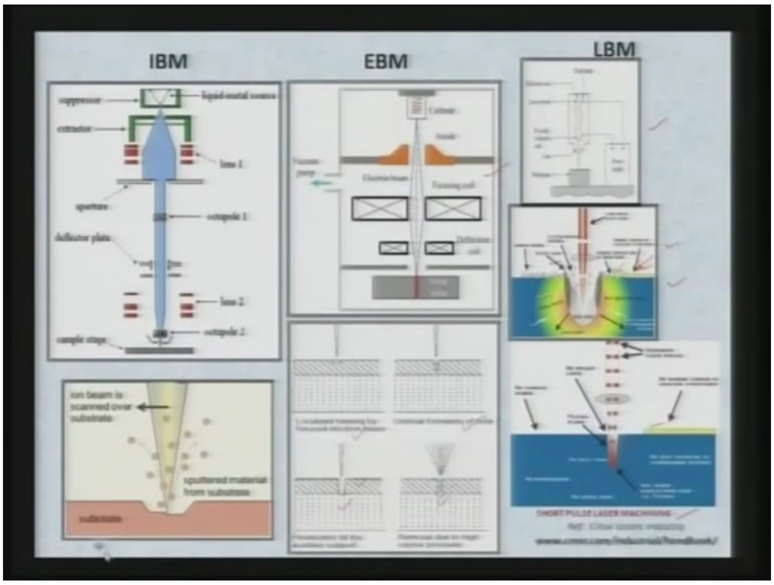

Now let us try to understand the working principle of ion beam machining process. As you can see here as the ion comes and hits the workpiece surface at the top, it has the energy, it has the single ion is supposed to remove the material from the top surface of the workpiece in the form of atoms. The energy of each ion should be just sufficient remove one atom but normally the energy of each ion is more than the required one for removal of the single atom that is why one single ion removes many atoms at a time and if the energy is high enough and what it will do? It will go…hit inside the surface that is in the subsurface and get planted and if it happens in really it is damaging the working surface which is not desirable.

So you can see here various features are there of the setup and here ion beam is scanned over the surface wherefrom it is removing the materials in the form of the atoms. Now here is the working principle of the electron beam machining which we have already discussed and again here localised heating by focused electron beam, gradual formation of the hole as you can see here compared to this one and here penetration till the auxiliary support, this is the auxiliary support, this is the (())(44:18) machine and then removal due to high vapour pressure because this auxiliary support creates the vapour and these due to these vapour I mean they try to come out of the hole they remove the molten material of the workpiece and that is how you are able to eject the remaining molten material from the cavity or the hole in case of electron beam machining.

Then layer beam machining is very interesting process and there are 2 types of lasers one is the continuous wave laser and 2nd is the pulse wave laser both have merits and demerit. Now I need not to explain this we have discussed it, now this is important figure you can see here there are various kind of problems if you have a long pulse laser. Now you can see various defects are shown over here, these are the recasts layer is here and then you can see here micro-cracks are generated over here, heat effect zone is there and then you can see damage to the surface, over subsurface damages are there. Now all these defects are there if you are using long pulse laser beam machining processes, if it is a short pulse laser machining process you can see here all those defects which are shown over here they are absent over there, there is no surface debris over here as you can see, no micro cracks are there, no shockwave is there, no melt zone is there.

This is the hole which has been created over here and no heat transfer to the surrounding materials is show over here and no damage caused to the adjacent structure that is the adjacent structure in this particular case, the adjacent structure has been damage as you can clearly see over here but in this particular case there is no damage to the adjacent structure. So it is always desirable at you use short pulse laser micro-machining setup if you want highly accurate and you know well designed component as such.

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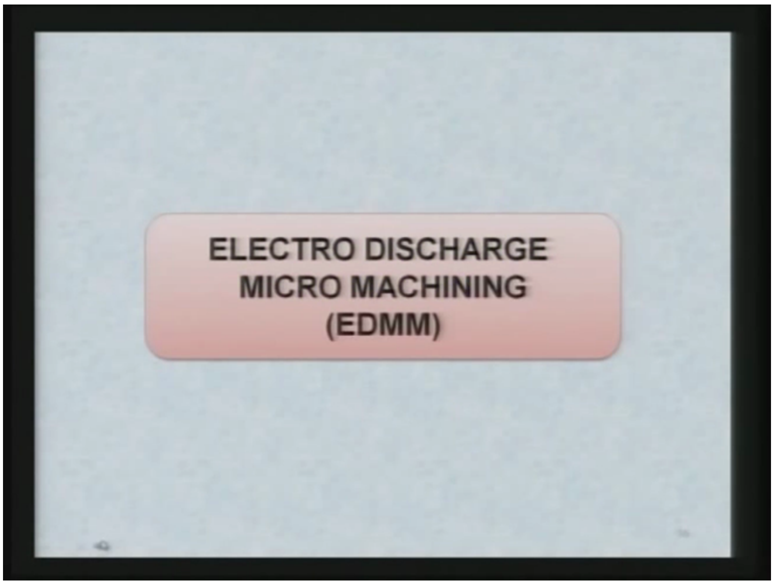

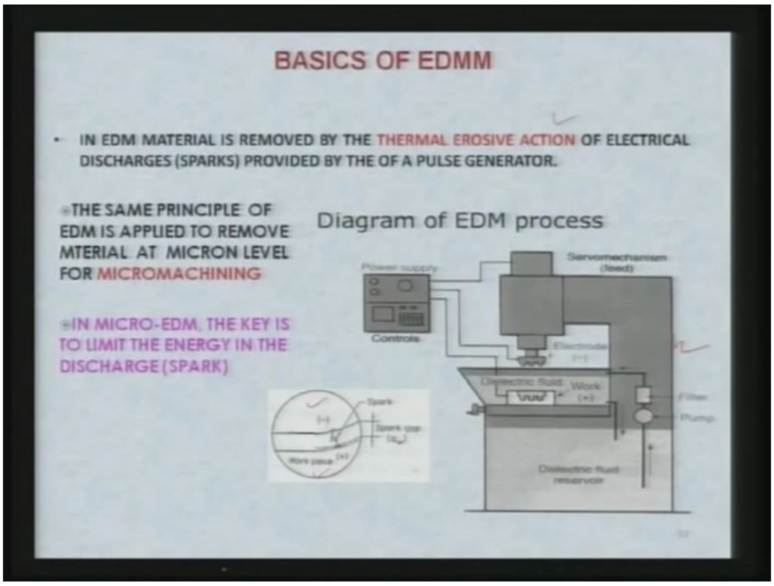

Now let us see the example of electron discharge micro-machining, now we all know the working principle of electron discharge micro-machining that there is a tool which is normally cathode and there is a workpiece which is normally anode, so the workpiece material should be electrically conducting in EDMM material is removed by the thermal erosive action of electrical discharges or sparks provided by the use of a pulse generator. Now the same principle of EDM is applied to remove material at micro level for micro-machining and you can see these the setup over here the same type of setup is there also in micro EDM, the key is to limit the energy in the discharge, this is very important because you are scaling down the macro EDM process to micro EDM process. So in each pulse the total energy contained should be very low compared to macro EDM otherwise the part itself is burnout and gets damaged.

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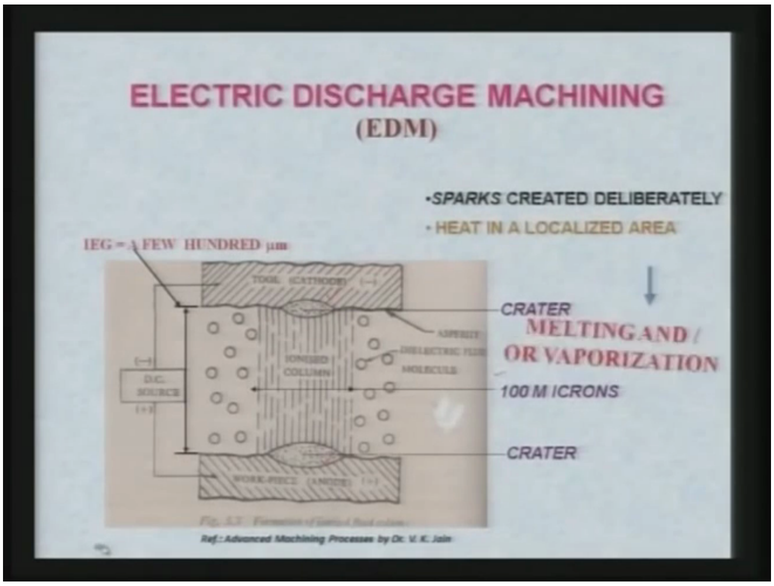

The working principle we have already seen when sparking takes place between the tool and the workpiece in electric discharge micro-machining also sparking takes place between the tool and the workpiece and you can clearly see the material is removed from the tool as well as from the workpiece. In case of macro these cavity form are much larger as compared to the micro EDMM and definitely the voltage that you using is very low compared to the voltage that you used in case of macro EDM. Now this is the figure related to the macro EDM where 100 micron size of the plasma column 100 micron size as width of the ionised column shown but in case of EDMM electric discharge micro-machining this column is very small maybe within 10s of micron or even less than that depending upon various micro-machining diameter.

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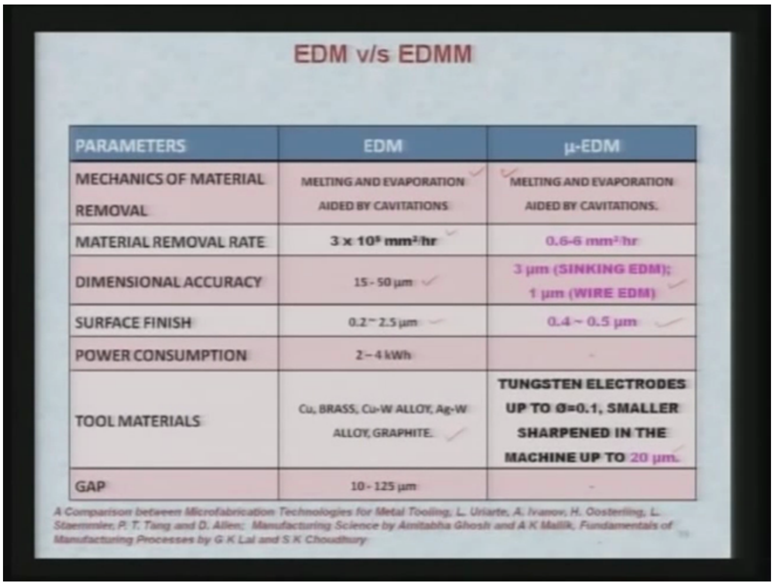

EDM v/s EDMM

PARAMETERS	EDM	μ-EDM
MECHANICS OF MATERIAL REMOVAL	MELTING AND EVAPORATION AIDED BY CAVITATIONS	MELTING AND EVAPORATION AIDED BY CAVITATIONS.
MATERIAL REMOVAL RATE	3×10^5 mm³/hr	0.6-6 mm³/hr
DIMENSIONAL ACCURACY	15 - 50 μm	3 μm (SINKING EDM); 1 μm (WIRE EDM)
SURFACE FINISH	0.2 ~ 2.5 μm	0.4 ~ 0.5 μm
POWER CONSUMPTION	2 – 4 kWh	-
TOOL MATERIALS	Cu, BRASS, Cu-W ALLOY, Ag-W ALLOY, GRAPHITE	TUNGSTEN ELECTRODES UP TO Ø=0.1, SMALLER SHARPENED IN THE MACHINE UP TO 20 μm.
GAP	10 - 125 μm	-

A Comparison between Microfabrication Technologies for Metal Tooling, L. Uriarte, A. Ivanov, H. Oosterling, L. Staemmler, P. T. Tang and D. Allen; Manufacturing Science by Amitabha Ghosh and A K Mallik, Fundamentals of Manufacturing Processes by G K Lal and S K Choudhury

So here it shows the comparison of the EDM that is macro EDM and micro EDM, you can see in mechanics of material removal in both the cases remains the same that is melting and evaporation aided by cavitation. Material removal rate are very different in case of EDM this is 3 into 10 raise to power 5 micro-meter cubes per hour while in case of ED micro EDM it is 0.6 to 6 cubic millimetre per hour, so there is a vast difference in the machining rate. Dimensional accuracy is 10 to 15 sorry 15 to 50 micro-meter in case of EDM while in case of sinking EDM but micro EDM you have as good as 3 micro-meter and 1 micro-meter in case of wire EDM that is wire electric discharge micro-machining.

Surface finish in case of macro EDM is 0.2 to 2.5 micro-meters while in case of micro EDM it is 0.4 to 0.5 micro-meters. Tool materials that can be machined are more or less the same in both cases copper, brass, copper tungsten alloy, silver tungsten alloy, graphite, et cetera while in case of micro EDM tungsten electrode of 2.1 millimetre diameter that is 100 micron, smaller sharpened in the machine up to 20 micron and they are used as the tool. Gap maintained between the tool and the workpiece in EDM is 10 to 125 micro-meters while in case of micro EDM it is much smaller than this particular value.

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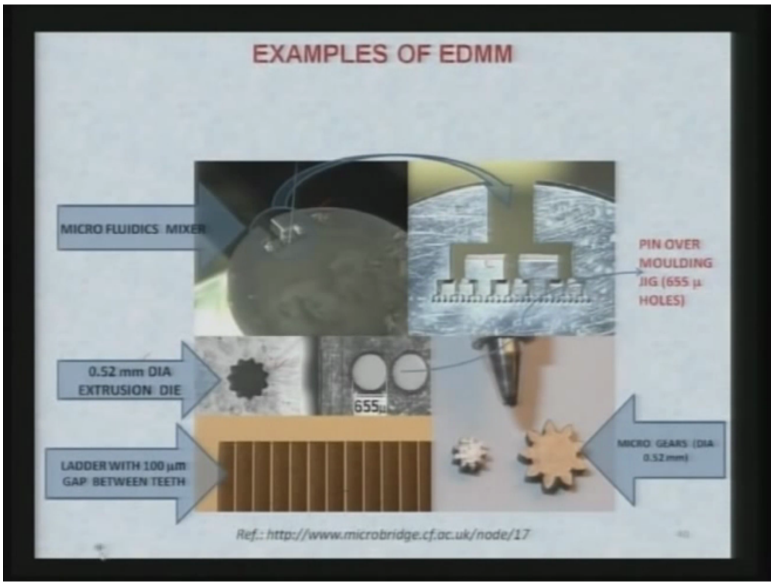

Now you can see the examples of electric discharge micro-machining process, now if you see here micro fluidic mixers this is shown over here in the enlarged view of the scene is shown here. Now you can see these are the different channels, et cetera obstructions given over here and this is the micro-fluidic mixture that has been created using micro EDM process. Now here is the 520 micro-meter diameter extrusion die that has been created using electric discharge micro-machining and here is the here is the ladder with 100 micro-meter gap between teeth you can see over here they have been made and you can see this is the hole of 65 micro-meter pin over moulding jig that has been made and these are the micro gears whose diameter is 520 micro-meter, so you can use this process EDM process for making micro-fissures as well as micro components this is very clear from this particular slide.

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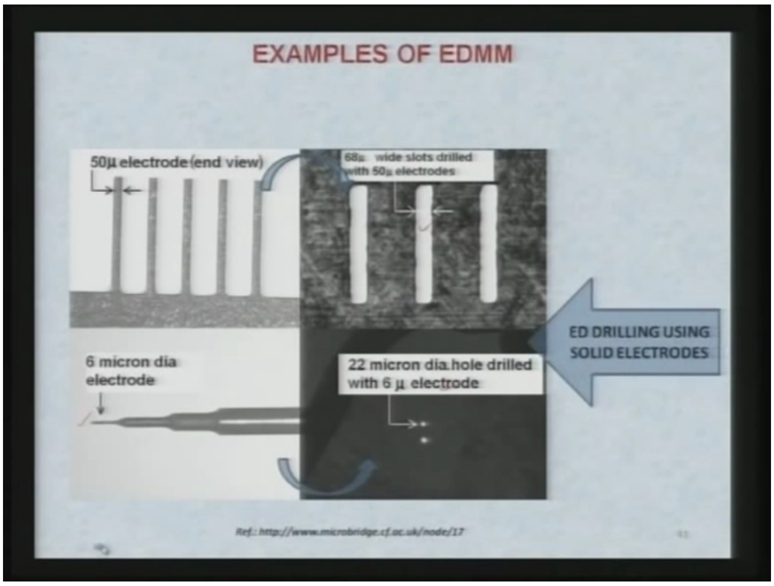

Other examples of electric discharge micro-machining you can see here that here is a kind of the tool they have made of 6 micron diameter size which can be used for electrochemical process or EDM micro EDM process or micro ECM process or ultrasonic micro machining process or any other kind of the processes you can use these kind of tools. Now you can see here 68 micron wide slots drilled with 50 micron electrodes and this is the 32 micron diameter hole drilled with 6 micron electrodes, so you can see there are differences in the size of the tool and the difference in the size of the machine feature.

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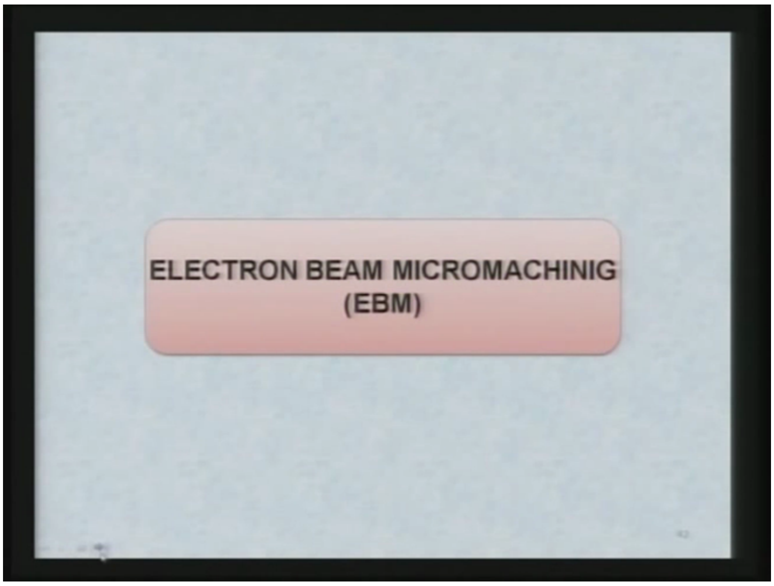

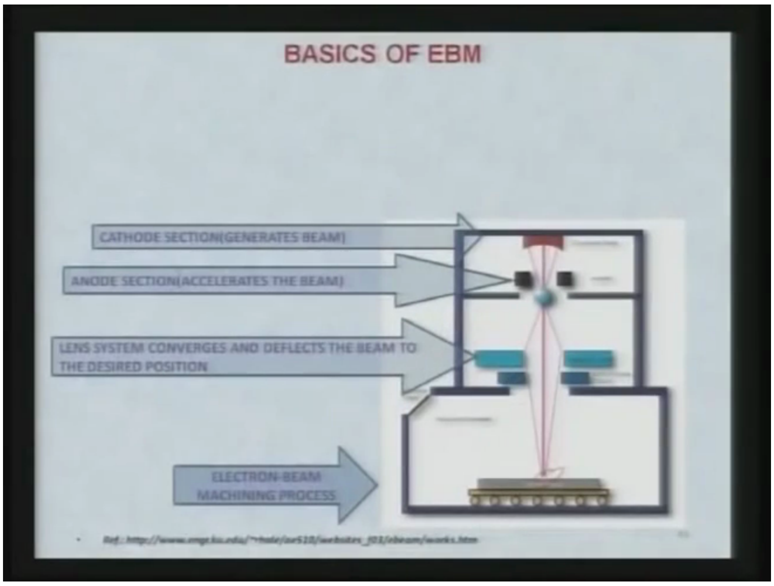

Now let us see some interesting examples of electron beams micro-machining. This I have already explained and not going to discuss it in detail except that you are getting beam of the electrons which is focused and controlled by certain devices and this beam of the electron hits the workpiece surface and these electrons are having very minimum mass but the velocity with which they are moving towards the workpiece is very close to the velocity of the light that is why the kinetic energy of these electrons so high that they are able to create very high temperature in the localised area and the temperature is so high that the material which is to be machined can melt and even vaporise it.