Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology – Part- 2

Module- 15
Ultrasonic Machining Unit

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Hello and welcome to this manufacturing process technology part – 2, Module 15.

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We would we were just trying to discuss the process modeling related to the ultrasonic machining process and we also found out how the various you know working parameters like for example the hardness of the work piece the hardness of the tool the amplitude of motion of the tool the frequency at which it moves etc…

Plays a very critical role in determining what is the material removal rate, so let us look at a practical numerical example.

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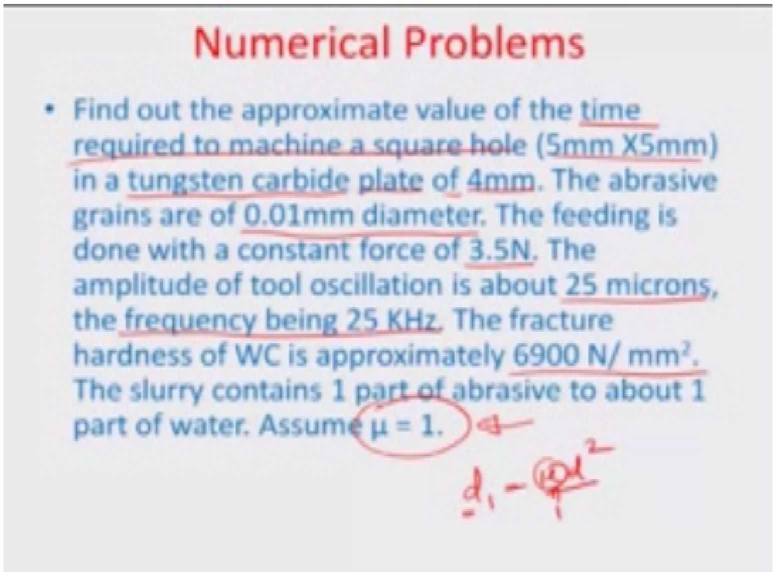

Where we can really find out what is the MRR trying to find out the machining time, so we want to find here the approximate value of the time that is required to machine a square hole which is 25 mm^2 and the work piece that we are using here is tungsten carbide, so it is basically made up of you know the work pieces tungsten carbide played about 4 mm thickness, so the total volume that is involved here is about 100 millimeter cube the abrasive grains are all of about 0.01millimeter diameter and the feeding force is done with the constant force o f3.5 Newton's.

The amplitude of the tool oscillation is about 25 microns, in the frequency at which the tool oscillates about 25000 Hertz the fracture of hardness of tungsten carbide is approximately 6900 Newton / mm^2 and it is also further shown that the slurry contains about one part of a abrasive to one part of water you assume the μ value to be equal to 1, so basically we already know by Shaws theory that the d1 the diameter of the projection on the surface of an abrasive grain is μ times of d^2 so in this case the μ value is taken as 1 so having said that now let us try to find out numerically what is going to be the time that is needed for the total machine.

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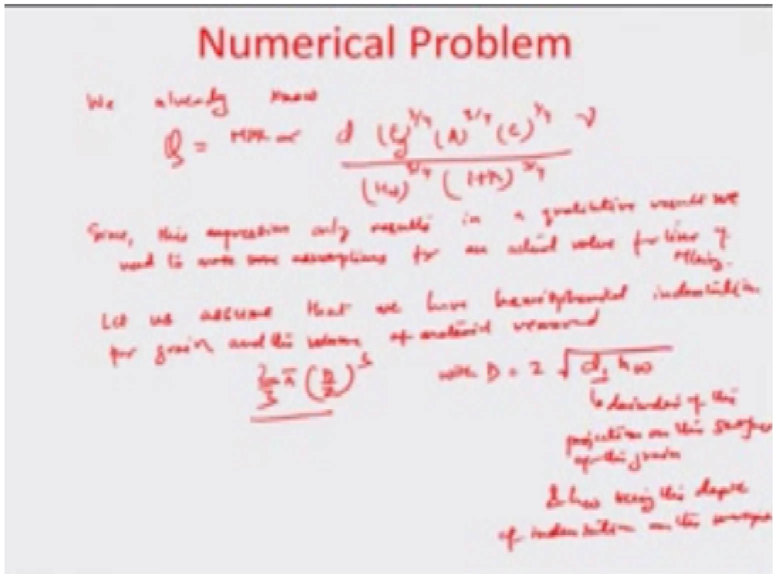

So we already know that the material removal rate Q is proportional to the diameter D the average force of the tool or that the tool exerts on the abrasive surface to the power ¾ amplitude of motion $8^{3/4}$ concentration of the abrasive slurry to the power of ¼ ν where ν is the frequency of oscillation of the tool head times of the hardness of the work piece to the power ¾ 1+ λ to the power of ¾ so since this expression only results in a qualitative result we need to make some assumptions for an actual value for time of machining.

So let us assume that we have Hemispherical indentation grain and the volume of material removed is given by $2/3\ \Pi\ (D/2)^3$ so this is with the presumption that D can be represented as twice $\sqrt{d_1 H_w}$ d1 being the diameter of the projection on the surface of the grain and H_w being the depth of indentation on the work piece.

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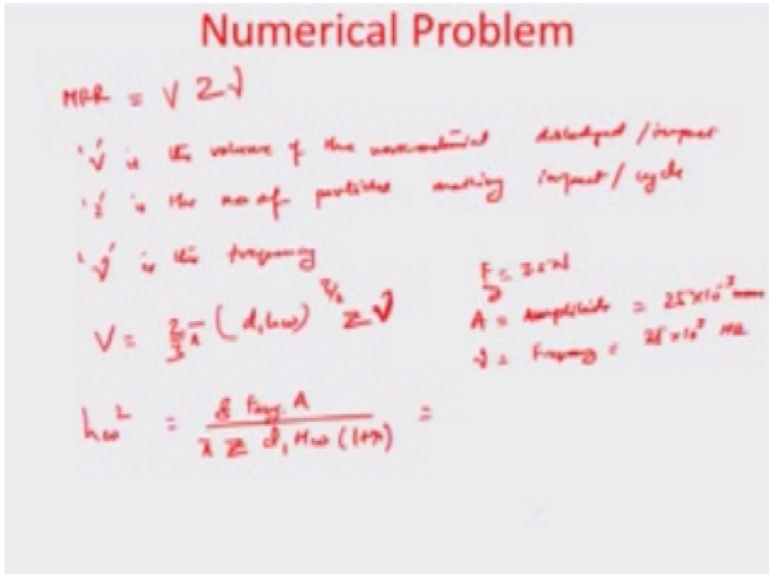

So having said that now the MRR material removal rate equals ν times of Z times of sorry V times of Z times of ν where V is the volume of the material removed and I am going to calculate this just in little bit so here v is the volume of the work material dislodged by the impact z is the number of particles making impact per cycle and ν is the frequency so V therefore becomes equal to 2 / 3 Π $(d_1Hw)^{3/2}$ z times of ν and f as already been mentioned as 3.5 need an average force A is the amplitude of motion has been mentioned to be 25 10^{-3} millimeters ν is the frequency which is mentioned as 25 10^{-3} hertz so H_w^2 can be approximated by the expression eight times of F average times of amplitude A/ Π zd_1 H_w 1+ λ.

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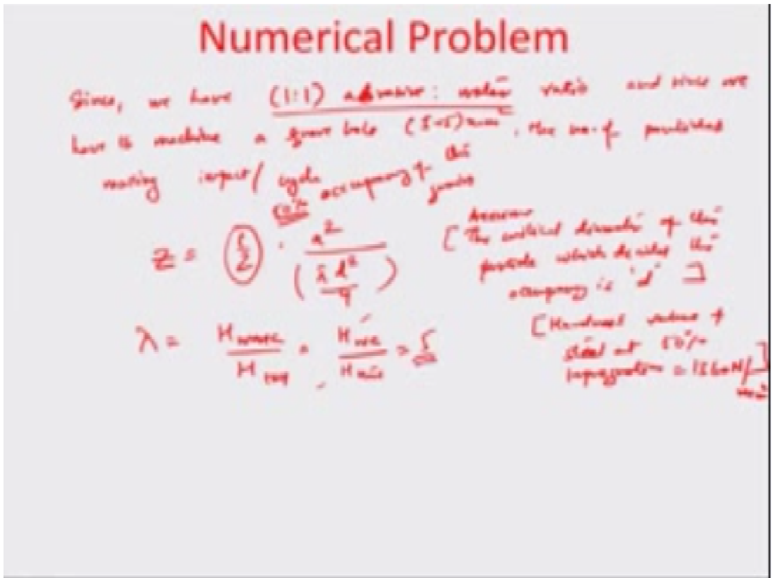

And since we have 1:1 abrasive to water ratio and since we have to machine square hole dimensions 5 x 5mm^2 the number of particles making impact per cycle Z can be represented as exactly ½ this comes because there is exactly a 50% occupancy of the grains already told about the 1:1 abrasive to water ratio so therefore exactly 50% of the area has been occupied by the oppressive grain, so half times of area of the vibrating tool head which is phasing the grains which is A^2 times of the total amount of a grained area assuming that the critical diameter of the particle which decides the occupancy is small d okay.

So let us also assume let us also sort of find out the value of λ here which is actually the H work by H tool, so we already know that the work is out of tungsten carbide and the tool is that of steel so that steel and we take the hardness values of Steel at 50% impregnation as1360 Newton/ mm^2 and we already know that this hardness ratio is close to about 5 so tungsten carbide is about 5 times harder than the tool which is steel in this particular case.

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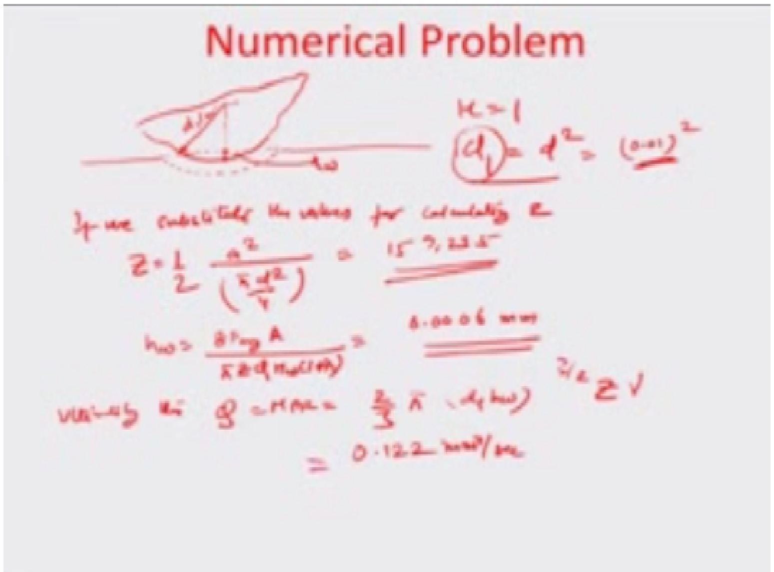

So now let us look at how the grain interacts with the surface let us say we are interacting with the grain which is something like this with respect to a surface where there is a dislodgement because of the effect of the grain and here we further assume that if we look at the center to the grain projection boundary the diameter there is d_1 and we further assume that the total amount of impregnation that happens in the vertical direction is H_w okay, so this is the impregnation of the work piece of the indentation of the work piece we already know μ is given to be 1.

So the d_1 value comes as roughly d^2 in this particular case if we substitute the values for calculating Z we already know that Z was calculated to be ½ times of A^2 / Π small d^2 / 4 and this comes out to be equal to about 159 235 approximately and the H_w value again from the equation drawn earlier about the H_w which is 8 times of average force times amplitude divided by Π Z d1/ H_w 1 + λ this d_1 is calculated from you know the d^2 so 0.01^2 so that is how much millimeters the value becomes so the H_w would then become equal to 0.0006mm.

I am not going into the details of this calculations you can just simply plug in the values and obtain the value of the indentation depth, so ultimately if we wanted to calculate the material removal rate Q this can be written down as 2 / 3 Π d_1 H_w $^{3/2}$ Z times of the tool vibration frequency ν okay and so if we can plug these values together the total material removal rate in this scheme in this case comes out to be equal to 0.1 22 mm^3/ s.

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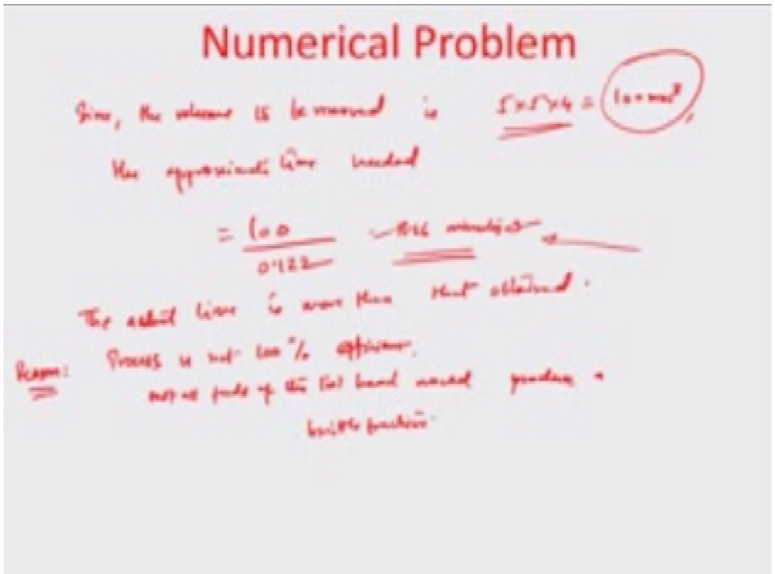

And we now can really find out the total time that is needed for removal of the material since the volume to be removed is 5 x 5 x 4 100mm ^{3} the approximate time needed to remove this volume of the material would be determined by 100 /0.12 to that is close to about 13 . 66 minutes so you can think of it that the rate is so very small in comparison to any conventional machining that a very small amount of volume which is almost about 100mm^3 in a4 mm thick plate you know takes as high a time as about 30 minutes in order to remove okay.

So the actual time required obviously if we look at pretty much more, so in this particular case for example the actual time is more than that obtained and one of the reasons is that that the process is not 100% efficient okay so not all moments of the tool at any instance of time would result in a impact that would cause a material removal this is really a very idealized case, so actual time should be probably an order of magnitude more in comparison to what is important here.

So we can say that that not all feeds of the tool ^ would produce a brittle fracture, so that is how you basically try to formulate or estimate time that is needed for us some processes let us look into now details about how the use a machine tool is really designed what are the different factors associated with the tool and with the cutting material like the abrasive slurry etcetera or even the tool head that is being utilized in the case of this kind of machining.

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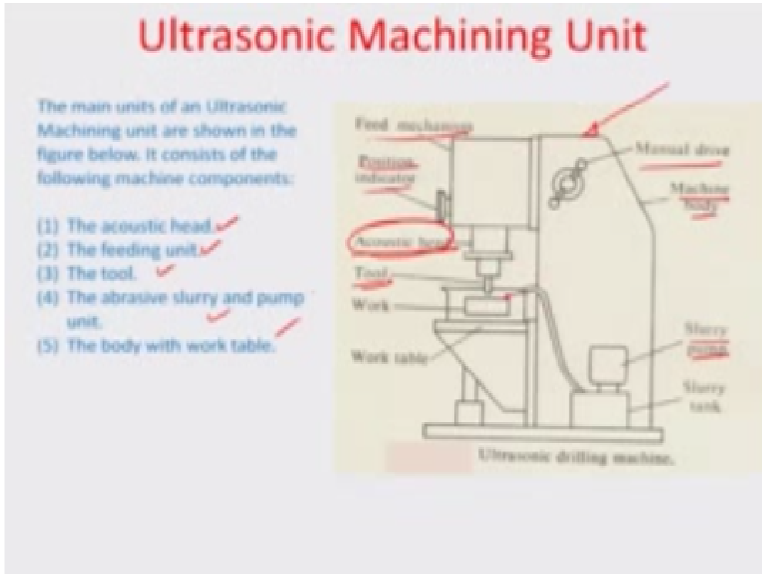

So this is pretty much how I USM system looks like you have a tool here if an acoustic head which is again magnet statically controlled you have a position indicator again feed mechanism you also have a manual drive machine body there is a pump which is used for feeding the abrasive slurry to the machining zone and this is really the jet which moves out the slurry or throws out the slurry into the to the machine zone and then you know you always have a collection of this particular slurry.

And it is not a very good idea to use this slurry unless you manually are able to separate out the metal or the material that is being brittle fractured okay or material that is being removed and mix us with the slurry, so the best idea would be to not to be used because again there is a question of the abrasive grains losing sharpness etcetera and same parameters as had been early I talked about in the AJM would come into existence when we talk about this kind of this form of machining.

So the main units of ultrasonic machining again are this acoustic head we will try to have some details about how this head is designed what is you know then with this a feeding unit which would actually lead to the gradual feed you see the tool is vibrating in this particular case but the amplitude of motion is very small around the mean positions there is a increasing need of shifting or changing the mean position every time there is a drilling taking place or there is a metal removal which is taking place and you have to keep on feeding the tool.

So that the new mean position is closer and closer to the corrupted profile that is coming out of the material that has been removed okay, so you have the tool the abrasive slurry and pump and body with the work table

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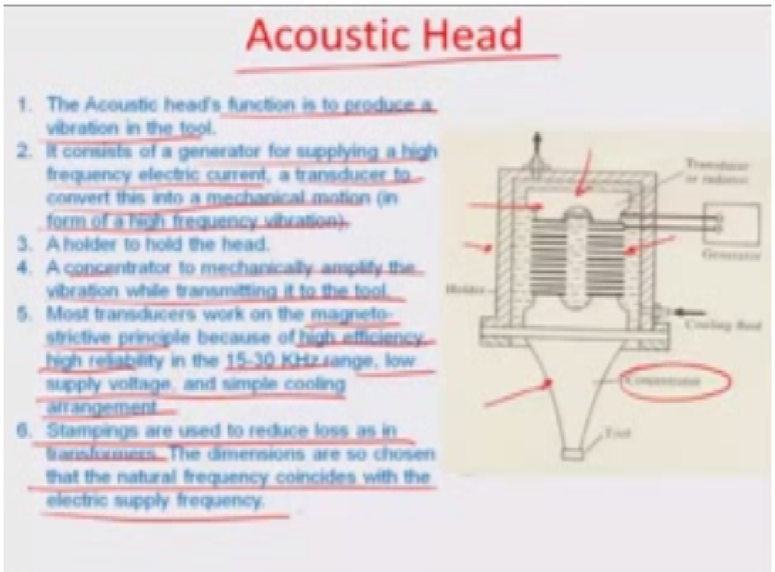

And if you look at individual mechanisms you the first thing that comes into mind is this acoustic head, so typically what is the function really of this acoustic head its function is to produce a vibration and that too at a ultrasonic frequency about 20 kilohertz or so it consists of a generator for supplying a high-frequency electric current transducer to convert this into mechanical motion in form of high frequency vibrations a folder to hold the head so this is really the tool head and you are requiring a holder to make this stable and then later on in induced vibrations onto this tool and with reference to the holder itself okay.

So there is a concentrator which is used to mechanically amplify the vibration while transmitting it into the to this peculiar shape of the concentrator actually determines how much mechanical transfer is there of you know the vibration signal and typically all the transducers they work in the magnetostrictive principle which is really about orientation of the dipoles in an external magnetic field which is created through a coil as you can see right here and so because of the change of the dipoles there is a change in the overall volume a bulk volume of the crystals which would let the material you know convert mechanic I mean such magnetic energy into mechanical energy okay.

So this typically magnetostrictive principles are deployed mostly into the high efficiency and higher liability they are vibrations in the range of 15 to 30 kilo Hertz done with a low supply voltage and a simple cooling arrangement and the best idea to prevent losses because of again eddy current based heating is just as in a transformer you use a laminated core you can use a laminated core in this particular case.

So there are stampings which are used to reduce losses just as you design the cover of a transformer you can design the core of this magnetostrictive material dimensions are so chosen that the natural frequency coincides with the electric supply frequency, so that you can have maximum energy conversion from you know add the resonating mode of the structure from the x10 supply to the from the supply signal to the to the mechanical signal which you get at the end of the tool.

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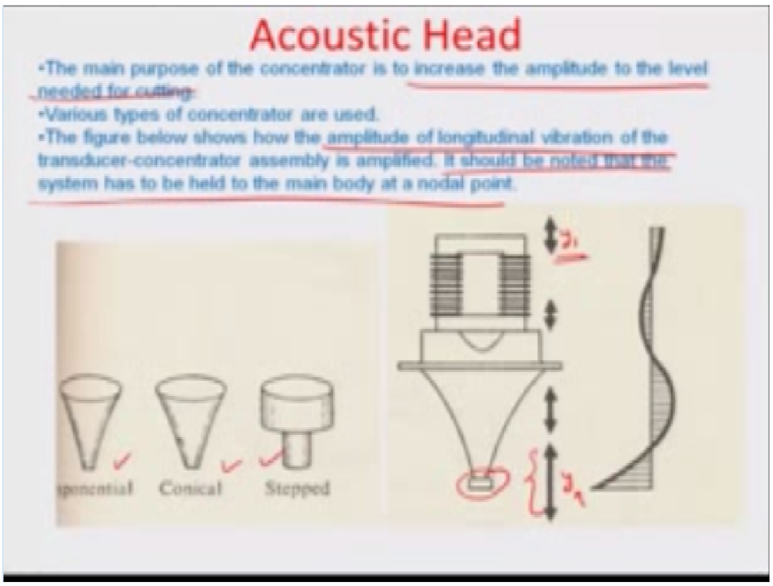

So that is how acoustic head would typically be designed there are many concentrators that can be used there can be exponential conical or stepped concentrators the main purpose of the concentrator is really to increase the amplitude to the level needed for cutting for example you can see here that the Y directional amplitude slowly increases from y_1 all the way to y_n here at the tip which is actually the highest okay.

So the purpose of a concentrated is really to a sort of magnify your amplify the magnetostatic effect which is really small displacement into micron sized amplitude of motion of the final tool head of various types of concentrators that are used as shown figure below kind of show amplitude of longitudinal vibrations of the transducer concentrator assembly is amplified it should be noted that the system has to be held to the main body at the nodal point very firmly because obviously the concentrated would also be moving relatively with respect to this tool holder in order to call it a reasonable motion okay. A cutting motion of that can be impacted by the tool head okay.

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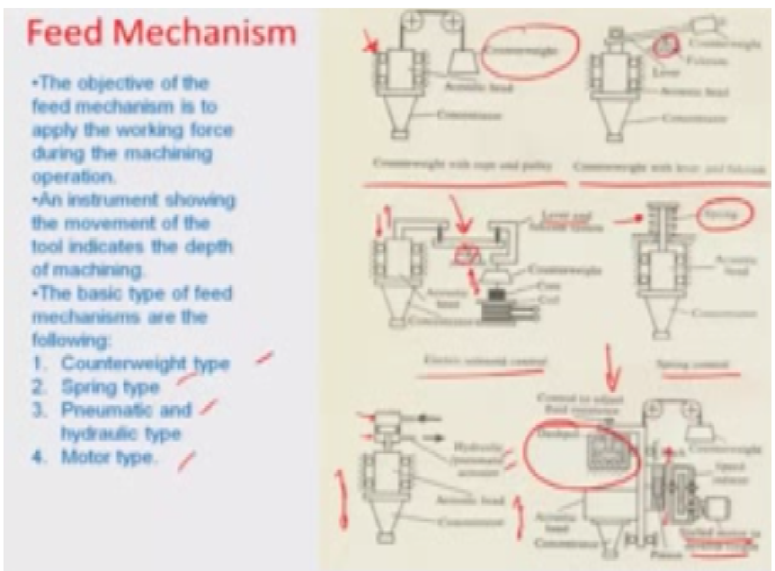

So there are many feed mechanisms which are deployed for feeding, so that the mean position shifts as I had mentioned earlier towards the work piece you are trying to machine the work piece so you have to ensure that the mean position about which the tool is vibrating should actually a shift towards the work piece as the Machine action or machining action is continuing so you have a mechanism which is based on counterweight with rope and pulley as you can see here the counterweight and this is the guiderails over which the tool holder slides with the concentrator and they are all connected to a rope tension.

There can be counter weight with Lieber and fulcrum about this point and there is a Liberty introduced by the counter weight which can we can let the relative feed motion happen or get executed there is electronics all annoyed control which is used in a similar way by using a again a fulcrum point and some kind of a balance, so you have a Liebern fulcrum system as you can see here in this area and then you are supposing there is a change in the characteristics of the solenoid here it may need to either upward or downward motion of the coil which may further this balance.

And create a turning talk around this fulcrum point so that you can move again the tool head within the guide rails there is a spring control again which is done by this spring mechanism which kind of limits or checks the farthest point up to which the concentrator can move there is also hydraulic pneumatic actuator where is a cylinder which is deployed with pneumatic or hydraulic fluids running on both sides.

So that it could have a promotion of this concentrator of the tool holder you can also have a an electrical motor based system here for example here you can see this motor creates spark which results in some kind of you know pinion movement which can further enable the rack to move in bi-directional manner and there is also a damper arrangement which is used to adjust the speed with which motion should take place in this particular case.

And so therefore you can actually shift the rack between in both ends so that you can get a bi-directional motion of the acoustic head with the concentrate so all these basic feed mechanisms namely the counterweight type the spring type pneumatic hydraulic type motor type etc you know even linked with Lieber fulcrum a rope pulley arrangement they are used are deployed and as the process of machining evolved there were different generations of these feed mechanisms which were deployed in place earlier.

Now the most important and easy to control one now is this motor based control which is actually there on most of the machines as on date.

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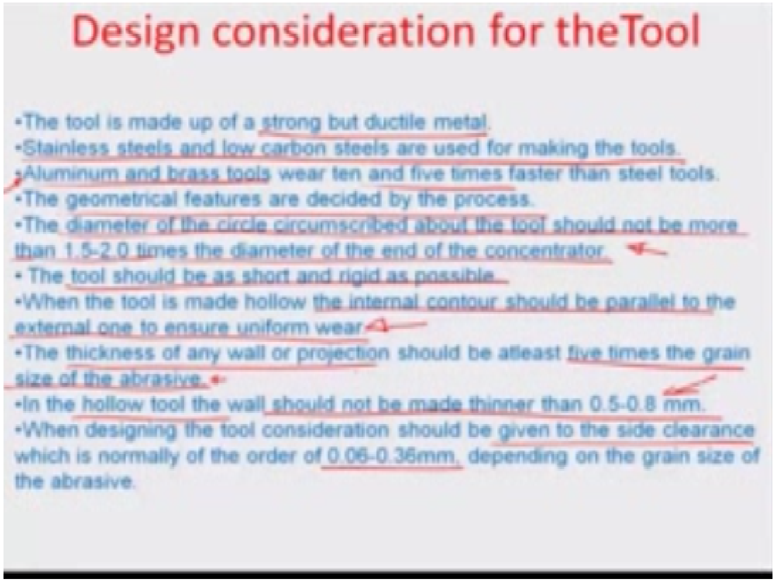

So we can also look at the some of the design considerations for the tool so there are certain thumb rules which are used for by the people who actually are responsible for designing the USM tool the tool is made up of a strong but ductile material typically a metal stainless steels and low-carbon steels they are used for making these tools in generally but there can be softer materials like aluminum and brass tools although they were faster probably 5 to 10 times faster than what steel tools may perform but then for certain applications they have I mean there are designed well designed aluminum and brass tools as well.

Geometrical features are decided by the USM process itself but there are certain thumb rules within which the tool geometry should be limited one of them is that the diameter of the circle circum scribed about the tool should not be more than about 1.5 to 2.5 or 1.5 to 2 times the diameter of the end of the concentrator okay, so this much amount of you can say wobbling motion can be given to the tool without failure the tool should be as short and rigid as possible when the tool is made hollow the internal contour should be parallel to the external one to ensure the uniform wear otherwise there would be stress concentration and the thickness of any wall or projection be at least 5 times the grain size of the abrasive.

So this will ensure that the drain does not impinge on the tool to create a hole on the tool surface in the hollow tool the wall should not be made thinner than about 0.5 to 0.8mm so that is how small you can go and designing holler tools hollow tools obviously are an advantage because there are very low masses that need to be taken care and so there can be very effective and a high speed or high frequency movement established at the tool is hollow rather than if it were solid.

So when designing the tool consideration should be given to site clearances as well as normally of the order of about 0.06 to 0.36mm and depending on the grain size of the abrasive again it can change so normally close to 60 to 360 microns as the side clearance which should be given while we talk about doing machining on certain surfaces, so the tool should be always lower in size then the Machine profile that that is created.

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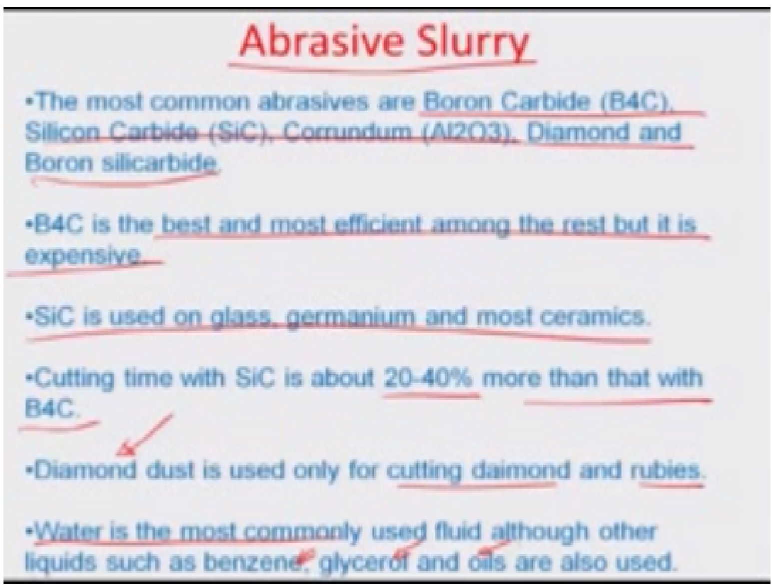

So let us now look at some details regarding the abrasive or the compressive slurry that is being used for the cutting actions the most common use depressives here are boron carbide silicon carbide corundum aluminum oxide diamond and boron silicabride boron carbide B4C is considered to be the best and most efficient among the rest but it is very expensive obviously diamond is the hardest, so if you are trying to cut something which is very hard diamond would be the way to go.

Silicon carbide is used on glass germanium and most ceramics cutting time with silicon carbides about 20 to 40% more than that with boron carbide and wherever you are doing or cutting diamonds or rubies you will have to obviously use diamond because it is having equal hardness to the one which is being machined also if you talk about fluids mostly the slurries are made on water samples so all the fluids are water-based and there can be some classification of benzene glycol sorry glycerol some other oils from time to time.

But generally you know water being have you know low viscosity is an ideal fluid to sort of carry the abrasive to the zone of machining and also carry back the brittle fractured material which comes off from the machined surface so that is about abrasive slurry.

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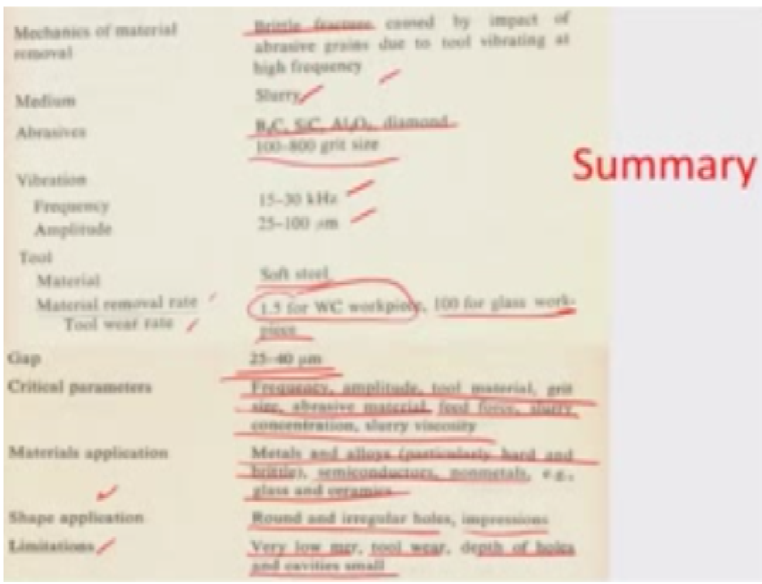

So in summary if we look at the whole process in totality we understood the mechanics of material removal of the USM process it is brittle fracture driven caused by impact of the abrasive grain due to tool vibrating at a high frequency the medium that is used for machining is mostly slurry made up of abrasives which contains boron carbide silicon carbide Lumina diamond soon so forth.

Typically about 100 to 800 grit size of oppressors are used there is frequency range in which vibrations happen on the tool head about 15 to 30kilo hertz amplitude about 25 to 100 micrometers materials that are used as soft steel otherwise other soft materials like aluminum and brass can be used from a case-to-case and if we look at the material removal rate to the tool were rate it is typically about 1 and ½ a tungsten carbide work piece and about 100 for glass work piece.

So depends on what is the material and hardness obviously has an impact part of the material the difficult the more difficult it is to remove through this process the tool work is we the tool work piece gap is typically in the range of about 25 to 40 microns and some critical process parameters for controlling you know this material process are the frequency amplitude tool material grid size abrasive material feed for slurry concentration viscosity of the slurry soon so forth and some materials which this process is normally applied for you know purposes of material removal are typically glass and ceramics from where it started maybe you know most brittle in nature.

So the semiconductor materials are non metals and then some metals and alloys particularly the hard and brittle ones which can be directly applied with machining process you know to convert a machine so regarding the different shapes which can be applied for this machining processes is preferred that you have round in regular holes mostly it can be used as a drilling process you can create impressions from time to time using this process but then you know there are other processes like EDM etc…

Which are more appropriate as far as impressions or making of impressions goes on surfaces and the limitations are that it has a very low material removal rate the tool where depth wholes and cavities are very small so in summary that is what the US and process is about so I am going to look at a different process ECM electrochemical machining after this particular module probably in the next module and in that we will discuss various aspects basics about the ECM process and how we can model the process.

So that we can get a good topology you know of the work piece given a certain diet topology which is being made this is a die sinking process in a similar manner as the abrasive water jet machining are on this USM are hard sonic machining so we will talk about this more in the next module up till then goodbye thank you.

<u>Acknowledgement</u>

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