**Micro System Fabrication with Advance Manufacturing Techniques**

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# Lab Session - I
# Abrasive Water Jet Cutting

Hello and welcome to this new center of machining, which is called the abrasive water jet cutting system on my left here is a machine which is also better known as 26 jet machining center which is actually able to cut the steel sheets as thick as about forty to fifty mm using a water jet, and this jet is the fired at a very high velocity at a reasonably high level of pressure, and there is a mixing pre mixing between the jet, and some sand particles or the garnet particles which would lead to some kind of a abrasive based varying, and brittle fracture on the surface I think in my lectures earlier I had illustrated how a abrasive jet machining process works lets recall that. So, what I told you is that there is going to be a high velocity high impact particle which can strike a surface make an impact, and create a brittle fracture, and this brittle fracture would be subsequently removed by a gush of the wind or air which carries these particle in this case the air which otherwise is in a j m system which is replaced by a high speed jet of water, and that is why it is called water abrasive jet machining process.

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So, let us describe this system in little more details from an engineering application to let you know about how the machining is carried out in this particular center cut. So, if you can see the various parts on this particular machine the first thing for me to share is this container here which is called a abrasive hoper, and you have these sort of you know brownish kind of material of a certain grid size, and this is called garnet.

So, it is actually silicate it is a sort of sand of aluminum, and other few other materials, and it has a very high hardness value about six to five to six on a more scale, and it also has further sizes in the range of a few tons of microns and. So, this is basically a feed unit for the loosely you know loosely otherwise held this garnet which would by gravity action be fed into the nozzle, and I will show that later how this feeding happens, and the mixing happens. So, this is the first part of the machine the second part of the course is the stage that you can see here this actually is a x y zee stage where there is a capability which is driven by a controller, and the controller again is having an input data from a cad file or computer rated design file and. So, this whole machine cut (FL). So, the the x y zee stage, again is operated by a means of motors, and a controller, and the controller itself is connected to a p c a personal computer unit here which you can see on this side, and cut.

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So, the controller is actually a part of this personal computer here, and you can see that there is capability to handle cad files in this particular p c the mother board of the p c is kept some where here, and there is a control panel which is at the back side of this particular p c which would be responsible for giving the x y, and z motions to the various motion controllers which are there on the stage based on the software which is operating in this particular computer. So, having said that let us now focus to the machine bed this right here is the bed of the machine.

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Where all machining operation takes place I think I had illustrated earlier that this term twenty six fifty two means that a breadth is about twenty six inches in breadth, and about fifty two inches in length. So that’s about the size of the maximum work piece that can be a accommodated in this particular machine, and also it indicates that this is the span over which the whole nozzle would be able to move. So, it can move in a region which has an area of twenty six inches, and fifty two inches. So, this right here as you can see in the bottom right here is the nozzle, and the nozzle is having a small fine orifice of the diameter of about seven hundred microns in this particular case. In fact, the nozzle if you look at, then I would like to illustrate to a drawing which I have for this particular nozzle.

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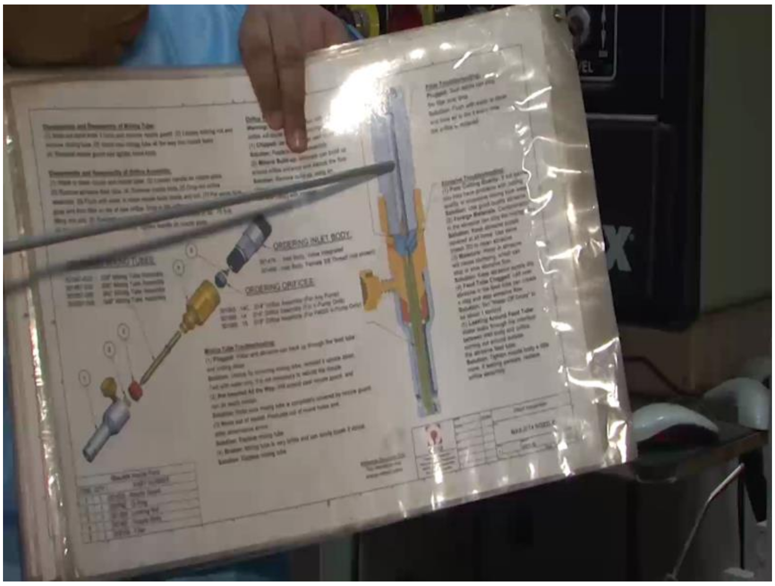

So, this is the sectional view of the nozzle, and you can see that there are two aspects of this nozzle there is a zone here which is in blue which is actually the mixing zone for the high pressure water, and the abrasive in fact there is a track here which can seen very fine track in this particular size which shows how the abrasive is getting in to this particular zone here where the mixing is happening, and the the idea is that the water is short at a very high velocity across this small region which is also like a jewel orifice, and this orifice has a diameter of about close to three hundred microns, and it has a capability of giving a high velocity, because naturally the area has reduced, and if we were to maintain the continuity theory the velocity which comes out of this nozzle is a very high about seven hundred seventy meters per second velocity. So, this is about the kind of velocities that the water hits upon. So, at this particular velocity naturally the pressure by equation in this region is quiet low, and therefore, there is a tendency of the abrasive to sort of get pumped, and well mixed into the stream jet which is at such a high ah velocity. So, this particular green tube which follows this blue region is actually the discharge tube, and the discharge tube.

Further accelerates the the water the, but then because of the smaller diameter of the tube that is the huge amount of wall friction which the jet faces, and at the end of the day there is a loss in energy, and there is ammunition velocity at the rate of about five hundred thirty meters per second which is actually this velocity of the spray or the jet which comes out now the pressure that was necessary to create such a velocity in this small orifice which is close to about forty thousand p s I about forty k k k p a, and kilo pascals, and this is done by a sort of accessory based system which is attached to this machine which I am going to do in the next part of the lecture cut. So, you can see now this is we are at the back of the machine or this is the back end or back side of the machine, and you can see that on my right here is the abrasive jet machining unit

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And on my left you can find a lot of water lines which are laid out in a particular manner, and this is basically the water handling system, it is very important to produce water you know which is of high quality there should not be many impurities in that, and therefore, it is typically advisable to do reverse osmosis on this water before feeding it to the system and. So, we have a deionizer, and a reverse osmosis which is happening together. So, that you have good filtration, and you have less iron content of the water you have to remember that at such a high speed there is going to be substantial increase in the temperature, and therefore, if there is some kind of impurity or ions which are there they are going to create adverse effect in terms of nozzles getting detonated rapidly or depletion, and replacement of the nozzle more frequently needed. So, on and. So, forth. So, we do not want to do that, and therefore, filtration of this water is very very important for which you need separate accessories, and customized filters for the same. So, looking at these systems this actually is a iron exchanged resin material it is a tank filled of such a resin, and there is a basically pure form of water which is fed in to this column, and there is first level filtration which happens across this setup the water goes further into this other unit which is closed parallelly, and there are second level filtrations systems which are there in this particular ah machine, and there is a one pump which is actually to give the ah the initial head or displacement to the water sample, and there is another high pressure pump which is actually in this region which would allow this water which has been purified at the first level to come into this membrane here there is a column at the back of this machine which houses a membrane. So, therefore, you have a high velocity water passing through this membrane once, and this membrane actually cut this is the deionize membrane, and this is the membrane actually which gives you high resistive water, and gets rid of all the ions across this water.

So, typically the resistivity here that we actually envision for the water sample to be fed in to the next stage of the machine is about close to fifty micro semens which is quite a high number of the the conductivity, and quite a reasonable number of the conductivity low number of the conductivity, and it is good to mention here that lesser is the conductivity of water sample even while there is a tendency of this water to flow small orifices there is always a charge, which gets acquired to the water, and the low resistive nature or the high resistive nature of the water actually suffices for any such charge to not flow into the system which may lead to some other potential problems in the machining etcetera.

So, therefore, it is very important to have a completely ionized de ionized water number one for insuring that there is no reactivity of the different systems to the ions at that high speed, and also to ensure that because of this high pressure jet rushing through the tubing etcetera there is a tendency of charge gathering of the water that should not happen, and these are the two reasons why resistivity of the water is needed in the sample. So, once the water has been actually purified in the system it is sent back into a chiller unit through this particular pipe line which goes to the back of the ah work shop, and outside just opposite to the wall there’s a chiller which would ensure that the water is at about temperature of close eight to ten degrees which is actually the operating temperature for this machine because you know it is a process where you are doing sheer action on metal, and typically illustrating some of the sheer stresses that would be needed are of the range of about four hundred newton per millimeter square. So, that is about what the ultimate sheer stress of material like steel would be and. So, if you are wanting to hit upon in that particular value of sheer stress you definitely need a self cooling system.

So, that there are no other warp age issues as such of the work piece because of the high temperature which would get in the process of this sheer. So, there for there is a tendency of this water to carry the heat away, and therefore, it has be at a low temperature from the chiller which is outside this wall the waters comes back into the system, and it goes all the way through a pipe line which is under ground here, and you cannot see on the video, but it actually comes into this unit, and from here it is fed, and a reciprocating pump which actually at the bottom of this particular system, and what ensures is that the reciprocating pump adds the pressure head, and takes it all the way to about forty thousand p s I as I was already illustrating. So, there is a separate cooling circuit for that pump there is also a separate circuit which would give you the water compression, and the compressed water at forty thousand p s I is now taken into through this pipeline cut.

So, this pipeline here right here is the the one which is feeding the compressed water on to the system, and this goes there by into the nozzle. So, this is the additional accessory which is needed for such a machine to be commissioned in a laboratory. So, we will now like to go to the front side of the machine again, and try to see how the machining can be done at a micro scale using this particular machining cut. So, here as you see in this computer screen the process starts really with there are two software's which are actually lying parallel here one is called the o max layout another is called the o max make the manufacture of that machine is o max, and that is why these are customized software which have actually come with the machine, and is operable on a regular windows p c you can actually go ahead, and go to this o max layout cut [FL].

So, this window is actually the o max layout window. So, you go to the file option here there are different some options which are in this area open reopen insert import. So, we want to import from another cad file. So, am just going to go import the data, and go to the desktop, and I have placed a cad file which is actually as a dot d x of which we have actually imported cut [FL]. So, we will just sort out or we will just select this particular file which we have just recently imported from a cad package you have to understand that this machine, and the way that the controller is designed the path that it takes is on the basis of data from cad, and there is already a computer rated design file which has been stored here which has been ah done by somebody some other user which we are wanting to use on this machine to cut the particular feature.

So, typically if you want to really give a job order the cad file has to be given during the time of the job order itself. So, that we can actually import this particular file without having to look at the geometry itself. So, this file is actually built on parts with a minimum dimension of about one millimeters, and a maximum dimension of close to probably five or six millimeters, and there is a issue of where the nozzle has be place because nozzle itself is about seven hundred microns in diameter, and therefore, there always has to be a question of offsetting the nozzle by a certain distance. So, that the path of the center of the nozzle is little bit away from the machining zone or the machining edge, and this option will come a little bit later when we talk about the actual machining operation which would be on the other make out on o max make out software; however, we just need to do some preprocessing to the cad data itself. So, that the machine is able to work in I have imported this file now, and this is the drawing that has been imported into the o max layout.

And there are certain things which we have to define one of them is we have to give the machine an indication of where it has to really go, and pierce the sample. So, there are two, and ah options here one is you know you this area is hollow by the nature of the path it looks like that this is actually a hollow region and, then the path is actually made in metal with an outer boundary given by this outside ah you know this these set of lines on the part. So, there are two set of cuts which are important otherwise there is a complete work piece out which we have to remove the zone as per this particular boundary outer boundary, and also remove the material of the zone as per this inner boundary of the material. So, for doing that you have to now somehow define where the machine should pierce, and where it not should pierce, and for that you need certain lines which defines the machine path from the start of the piercing action all the way to the end of the finishing of the machining.

So, for doing that let is actually pick up this option line go to near to somewhere in this surface which you really need to machine off, and draw a line in this manner. So, that it gives you an indication that as the machine travels or the nozzle travels in this region automatically it will be able to pierce of this region. So, this intelligently has been given as a data to the machine similarly you have on the other hand the ah the line now right now you know right now because you have given on the one direction the machine will pierce in this half zone, and the other half will remain as such incomplete. So, what we have to do is actually give also a secondary option where you draw a line from the end of this particular first line all the way to the other direction. So, that you have now defined that the piercing action should be not only in this particular region, but also in this region as well cut [FL].

So, one thing you have to remember is that wherever this cursor is being pressed it basically zooms that particular area right for example, in this case if it is pressed here it zooms this particular area you can actually go by just rolling the cursor on the other direction it can just de magnify. So, supposing you want place the cursor here. So, that you want to define this particular end here also there is a requirement that a line be drawn. So, that it gives you the information that the the sheet of metal which we want to finally, machine through this process is pierced in this particular zone similarly we also want to this piercing action in the other direction. So, that you have an idea of which to cut, and which not to cut now we have made up this piercing zones as this line this particular line this line, and this line, and this whole path is as such defined in continuity with all these lines. So, the piercing action would be the first to be initiated and, then the jet would move as per this particular track, and cut the whole periphery of the system.

So, once we have done that I think we are now ready to sort of select the speed at which the process would happen, and typically based on the finesse of the process there can be several different speeds which you can select, and in this particular case you know there is an option here at the bottom end called quality. So, we have to right click on this quality go to the window and, then there are these different one two three four, and five different speeds at which the process can be initiated let us say we want to just do it at some moderate speed of three. So, we select this three and, then because we have selected a window we can actually with this window cover this entire selection, and make it all go by that same speed. So, now, I have defined that for the cutting action of this whole feature as such starting with the piercing in this region, and a piercing in this zone.

The speed has been set to a grade of three which means moderate speed for doing the machining operation cut [FL] how to get rid of this [FL]. So, now, you know you have kind of defined the path for this particular line here, and you know it is very important for it to also give the start position of the cutter. So, what I ‘m going to do is to go to the end of this line here, and try to make another position which would be the home of the you know or the beginning of the cutter. So, now, what is happening here is the following you start the cutter from this home position go all the way through this line her start the piercing action, and once this piercing has been started the it goes follows this path goes through all this boundary here cuts all this thing in a piercing mode and, then following this up to here the piercing actually happens.

And then you are defining the cutter cutter path to go to this other end here, and from here the piercing action is again started to take place you cut all these things in this particular path the whole geometry is concluded like this and, then goes all the way to this place the piercing happens up to here up to which the piercing stops, and after that you are resting at the final position. So, this is the home position to begin with initial position, and this is the final position and, then actually you have what you have done is have defined the path which is important to cut this feature out of a otherwise solid work piece. So, once it has been done you have save this file and, then you save it with certain name may be you file machining nine nine two thousand fourteen imported dot d x f in the desktop itself and, then you emerge or you open another option here which is called the path option cut . So, now, finally, once this path is ready we have to realize or we have to give the information to the software that this particular is the internet path. So, there is a path option here on the left side as you see here right here.

So, you click on that path option, and come, and there is a small pointer which says quick start which means that you know this is the point from which the machining would have actually start. So, you would go to the end of this line, and just select this particular zone. So, that you now have the whole path defined, and this is really the end of the process for the o max layout. So, the layout in the path both have been given by the software you can just save this particular file, and the save option would insure that there is another subsequent file just at the same location were the earlier cad file was done, and there would be a saving of this file in that particular location now we want to close this software because this is no longer useful to us. So, we just save this whole whatever has been drawn and, then you see that just parallel to that process there is another new file machining nine nine two thousand fourteen e which has come this was our cad file which came out from the o max layout, and this is the file which has been the [FL], and this file is basically the file which has been saved with the path information of the machine.

So, what we want do is to go down here in this o max make software, and open this particular file. So, there is a open file open option which is there where you can actually select. So, you go to the desktop its already at the desktop, and you can see where this new file machining nine nine two thousand fourteen e dot for is. So, you select this particular path, and make it. So, it automatically imports this particular path, and this particular file, and here is where you have to do the machining using, and several different parameters now we need to define in the system in this particular software cut . So, now, the the question of defining the material properties come into picture to begin with. So, there is an option here called change path set up which actually leads you into this earlier obtained screen, and on the left corner left lower corner here you see there is tab specially which says enter your material setup here.

So, this is actually about the material of the work piece in this particular case as in the machine bed we have actually mounted a variety of aluminum we would like to change this option to aluminum. So, there is a dropped down library here which would actually be able to get generated were there are two different grades of metal aluminum as you can see twenty twenty four, and sixty sixty one. So, we actually do this sixty sixty one because it is that ah sort of you know higher machinability, and then you know you have the thickness to be set in in this case the sheet thickness that we are using is about three m m. So, we actually monitor or make it three m m two loft set now this is a very interesting thing what two loft set really means cut [FL]. So, here you can see that that this right here is basically representing the nozzle orifice.

And right now you know, because of the various you know abrasive actions which have happened the nozzle has given a hold in the system. So, the nozzle diameter is close to about eight hundred microns that we are using right in this case. So, basically off set is because is needed because the nozzles center is actually the geometrical array which needs to be defined in the path. So, the path is actually the array of how the center of the nozzle or center of the pressure of the nozzle that is charged how that follows the particular cut path, and naturally the center has to be off centered because there is going to be a finite radius of a nozzle, and this center of the nozzle is definitely away from the path otherwise it will be actually corresponding to a higher size of the cut, and that should not happen.

So, a setting up of the offset is very much needed at the beginning its like you know cutter compensation in a c n c tool for example, we talk about cutter compensation when we define a certain circular cutter size and, then we just simply add that radius on to the cut path length to define the new path in the similar manner this is in the nozzle area. So, once we have done that, and lets now go back to the software here the tool option that we are setting in this case is about four hundred microns which is the radius as I showed you in the previous illustration rotation of the tool we do not want that the tool should rotate at the beginning and, then the scale to which we want this to happen is only one is to one read out. So, whatever is the dimensions on the cad software is to be read out in terms of the machining path excetra on the o max layout o max make software. So, once we have defined the path now we are all set, and ready to go.

So, the library is actually estimated, and here on the right you can see the various properties which come up for example, you know here you have selected the metal aluminum sixty sixty one grade machinability is given the thickness is given the two loft set of point four m m is given tool rotation is given, and there are certain estimates that the machine gives for example, it says the estimate time to make this path is about close to point seven two minutes for forty two seconds estimated cost to make this part is about you know probably point three of maybe about thirty cents which is about close to fifteen rupees or. So, to estimated abrasive needed also is estimated by the machine to be about hundred, and forty grams and, then you can also define certain other aspects like the pressure etcetera. If you look at the whole data sheet on the right here in the screen you can find various options like there are two pierces, and that the piercing is done at a high pressure, and the cutting is also done at a high pressure width of the path is given the height of the path is given length of tool path length of cutting all these different values are given and. In fact, the pressure values are also estimated because aluminum you know the material properties are already fed in the software software can give you a value of what is the set pressure that is needed on the higher, and the lower side for this cutting action to successfully happens you can see it is about twenty three hundred bars in the higher side of the pressure, and the low pressure can vary all the way to eleven hundred bars or. So, you have a jeweled diameter in this case which is after where is reading about three hundred, and fifty microns as abrasive floor rate is given to be point three k g's per minute so on so forth. And so therefore, and this mesh hide that we are using, and abrasive generally are defined by the grid size or mesh size is about in this particular case eighty. So, you are using eighty mesh size it varies all the way to about two hundred mesh size of the abrasive.

So, having said that, and having all these reading all these values you know we are almost ready to do the next step of operation which is actually the machining, and now we have to enable the pressure setup because here you can see there is a option here sounding maybe say trigger which means that now you have to probably fire the cylinders to generate the high pressure of the system. So, that the cutting action can begin following which we will do the begin begin machining operation and, then we will monitor all the machining continues cut. So, here there is a question of turning on a valve on a machine which actually gives you the air pressure because naturally there are certain pneumatic valves which would operate where it would actually you know be able to give control of the water flow, and the way the flow would happen water flow the water pressure has already been started to generate because of the reciprocating pumps action which is. In fact, started only thing is how to control it in a good manner. So, the pneumatic valves are normally used for controlling decontrolling the water flow into the machine here, and there is a small valve right here in this system which you have to turn on for ensuring that there is a compressor outside this room which generates this air pressure, and this is the way that you set the pressure through this line on to the machine that you can feed the pneumatic valves, and the machine can operate for the various machining aspects cut.

So, as you can see on this screen here there are this green arrows which are actually for toggle, and basically what it means is that you can position the nozzle at a certain region of the work piece operating these particular arrow you have a left side arrow right side arrow indicating the direction similarly if you want to go into the bed or outside you have this up, and down arrow like cursors which are illustrated here. So, now, I would like to sort of operate on these by pressing, and then you know looking at the nozzle which is there, and how the nozzle moves you will see just as I press the cursor cut.

So, here you can see that this is the aluminum sheet that I was talking about this brownish material here this actually is the deposit of the sand that is why you are seeing this is brown, and this sheet is actually almost three m m thick, and it is mounted on a water bed. So, this actually filled with water because naturally the jet actually cuts in a submerged manner it is underneath the water that the jet actually does the cutting and. So, therefore, the water level would rise to a certain extent where it will do the all the cutting action etcetera the other important aspect which I would like to show is that you have to really support the plate by putting weights on the plate you can see several weights which are lying all around this plate, because you ensure that while cutting action there is no lateral movement of the aluminum plate as such for the machining operation.

So, what I am going to do now is to sort of operate this nozzle using this toggle keys. So, you can see the nozzle goes inside by using the toggle key and, then I just take it ahead to a zone where I want the machining to happen or begin. So, this is probably the zone that I would like my machining activity to actually happen, and this is kind of a home position for the tool cut.

So, here there as you can see here is a lead screw which would actually be able to swivel the stage to, and fro away from the work piece or into the work piece I think I have mentioned this earlier that there has to be a good nozzle tip distance for these kind of throw processes where either abrasive jet machining you say or whatever water jet machining you say it is about throwing certain abrasives onto a surface right and. So, therefore, it is very important that you optimize that throw distance. So, you’re your maximum material material removal rate, and minimum drag forces which otherwise come in if the nozzle tip distance is not optimized.

So, in this particular case it is advised why the manufacturer to have a nozzle tip distance of correspondingly of one to three m m. So, we will keep it up to maximum distance. So, we will keep the distance to be the minimum which is about one m m, and we are doing this by the means of steel scale which is close to about one m m.

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So, we are going to sort of put this scale into this particular you know between the nozzle, and the work piece and, then using this manual lead screw we want to just get the get to a point get to a point where this you know this the lead screw can be optimized for the nozzle tip distance to be about one m m. So, it is about touching the scale now you can see the pressure on the scale which means that the distance is about one m m it has already been set.

Once this has been done, then you lock the particular you know the lead screw. So, it ensures that it does not move back, and then you do something on the controller. So, that this is treated as the reference zero or home position for the process to begin cut [FL]. So, on the right upper corner of the screen here you can see nozzle position has been indicated and. So, there is a distance from users home which is actually a machine defined we do not want to mess with this, and the other one is the distance from the path start which actually has been now given a certain position, and we make this zero ok.

So, you want to reset the path, and do this as the reference for the machining to begin, and that is probably the last step of doing you know the control, and the calibration on the system before we actually start the machining operation there you can actually go into this process, and right click on this. So, that you get into another control menu which says o max path control. So, here on this start button if you were to right click there is always going to be an option for dry run, and you can actually simulate what is going on. So, there are different sub options which are opened in this menu which say dry run at full dry run at half rapid speed you know so on so forth, and one fourth rapid traverse speed. So, we can actually see how the machine machining is happening within the system by operating this dry run.

So, let us actually now focus on the system, and see that because of dry run what would be happening the machine path you can get visible by looking at the way that the nozzle goes into the work piece surface cut [FL]. So, here in the dry run mode you can actually see that how you know we will start dry run at half rapid traverse speed, and if we do the left click on there you can see that you know there is without the actual the jet being operated you can see the nozzle cut the particular dimension that small feature size that we want it to cut in in the aluminum, and this gives you a sort of understanding that how the whole machine path would be designed for for doing this cutting action I now now I just close this option here, and then try to make it go to the home position. So, there is a go home option here. So, it will actually go now to the path start position of the path home position automatically, and we are all now set basically working on the machine for that...

Now, I would just like to add on here something very important is that this machine is operated with a very high pressure of close to about forty thousand p s I, and naturally if with such a high pressure you are hitting upon a material there is going to be lot of noise emission because of that in order to prevent that from happening, and also the fact that you should not have flashes typically when this particular jet hits on the machine you basically try to increase the overall bed water level to a certain area. So, that you can submerge the nozzle as well as the plate on which the cutting action is happening

So, there are air bellows which are available within this bed, and there is a option here on this on this particular machine. So, when you just see this toggle here which says water level and. So, if you really want to put this toggle in the up position the bellows would swell, and the the whole water would come in a manner it will come flow over the work piece as well as the nozzle, and the water would actually the level of the water would go up, and similarly the level down means that the bellow would again contract, and the water would recede because of that. So, let us just look at the bed what happens when I do this toggle up. Now if you see now if you see if I do this toggle there is always this you know water level which is elevated because of this bellow, and now everything which is being cut is submerged within the water, and the cutting action would happen within the water itself.

So, this is where the machine readiness is now to a hundred percent, and we are now in a position where we can actually fire the begin machining command. So, that you can start the machining process, and you have to be very careful because this is ah safety related issue this machine has some flashes which come out, and also the fact that the jet of the water is. So, high speed that it may as well be able to if it cuts a a piece of aluminum which is three milli meters it is as well as very serious for some kind of a limb or hand or something, which gets caught up there that is why we have to be extremely careful while operating this system to be away from the system when you’re basically trying to operate the machining process. So, I am going to now fire the start machining option, and get the process in a ready shape. So, that you can get the component machine.

So, let me put a caution here as soon as we start the machining there would be a sound which will come which will be the noise of the machining operation and. So, what we are going to do in the video is to just expose you to the sound for a little bit, and then delete the sound. So, that you do not you’re not uncomfortable listening to this process. So, I am going to now do the start option here. So, I will just go ahead, and do start, and now you can see that the the cutting action has started to happen you can see the water rushing past the nozzle. So, that you can have the cutting action going on in the metal sheet this is the part.