Advanced Machining Processes
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Lab session - Water Abrasive Jet Machining

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 2652 jet machining center, which is actually able to cut steel sheets as thick as about 40 to 50 mm using a water jet. And this jet is fired at a very high velocity at a reasonably high level of pressure, and there is a mixing, a pre-mixing between the jet and some sand particles or garnet particles, which would lead to some kind of an abrasive-based wearing and brittle fracture on the surface. I think in my lectures earlier I had illustrated, how an abrasive jet machining process works, let us 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 particles.

In this case, the air which otherwise is in a AJM system is replaced by a high-speed jet of water, and that is why it is called water abrasive jet machining process. So, let us describe the system in little more details from an engineering application to let you know about how the machining is carried out in this particular center. 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 abrasive hopper.

And you have these sort of you know brownish kind of material of a certain grit 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 6 to 5 to 6 on a Mohs scale, and it also has further sizes in the range of a few tens of microns. 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 first part of the machine. The second part, of course, is this stage that you can see here.

This actually is a XYZ 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 a computer-aided design file, and so this whole machine. So, the XYZ stage again is operated by means of motors and a controller, and the controller itself is connected to a PC, a personal computer unit here which you can see on this side. So, the controller is actually a part of this personal computer here, and you can see that there is a capability to handle CAD files in this particular PC. The motherboard of the PC is kept somewhere here, and there is a control panel which is at the backside of this particular PC which would be responsible for giving the XY 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, where all the machining operation takes place. I think I had illustrated earlier that this term 2652 means that a bed is about 26 inches in breadth and about 52 inches in length. So, that is about the size of the maximum workpiece that can be 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 26 inches and 52 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 700 microns in this particular case.

In fact, the nozzle if you look at, and I would like to illustrate to a drawing which I have for this particular nozzle. 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-pressured water and the abrasive. In fact, there is a track here which can be seen a very fine track in this particular size which shows how the abrasive is getting into this particular zone here where the mixing is happening. And the idea is that the water is shot at a very high velocity across this small region which is also like a dual orifice, and this orifice has a diameter of about close to 300 microns, and it has a capability of giving a high velocity because naturally the area has reduced, and if you want to maintain the continuity theory, the velocity which comes out of this nozzle is a very high about 770 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 Bernoulli's equation in this region is quite 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 velocity. So, this particular green tube which follows this blue region is actually the discharge tube, and the discharge tube further accelerates the water, but then because of the smaller diameter of the tube there is a 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 a emanation velocity at the rate of about 530 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 is close to about 40000 psi about 40 kPa and kilopascals, 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.

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, 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 reverse osmosis which is happening together, so that you have good filtration, and you have less iron content on 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 effects in terms of nozzles getting deteriorated rapidly or depletion and replacement of the nozzle more frequently needed so on 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 an ion exchange resin material. It is a tank filled of such a resin, and there is a basically pure form of water which is fed into 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 filtration systems which are there in this particular machine, and there is one pump which is actually to give 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. So, 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.

This is the deionized 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 into the next stage of the machine is about close to 50 micro siemens which is quite a high number of 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 into 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 deionized water number one for ensuring 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 pipeline which goes to the back of the workshop, and outside just opposite to the wall there is a chiller which would ensure that the water is at about close to 8 to 10 degrees which is actually the operating temperature for this machine, because you know it is a process where you are doing shear action on metal, and typically illustrating some of the shear stresses that would be needed are of the range of about 400 Newton per millimeter square. So, that is about what the ultimate shear stress of material like steel would be, and so if you are wanting to hit upon in that particular value of shear stress, you definitely need a self-cooling system, so that there are no other warpage issues as such of the workpiece because of the high temperature which would get in the process of the shear.

So, therefore there is a tendency of this water to carry the heat away, and therefore it has to be at a low temperature. From the chiller which is outside this wall, the water comes back into the system, and it goes all the way through a pipeline which is underground here, and you cannot see on the video, but it actually comes into this unit, and from here it is fed in a reciprocating pump which is 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 40000 psi 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 40000 psi is now taken into through this pipeline cut. So, this pipeline here, right here is the one which is feeding the compressed water onto the system, and this goes thereby 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 machine beam 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 OMAX layout, and another is called the OMAX make. The manufacturer for this machine is OMAX, and that is why these are customized software's which have actually come with the machine and is operable on a regular windows PC. You can actually go ahead and go to this OMAX layout. So, this window is actually the OMAX layout window.

So, you go to the file option here, there are different sub-options which are in this area open, reopen, insert, import. So, we want to import from another CAD file. So, I 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 dxf which we have actually imported. So, we will just sort out or we 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 the CAD.

And there is already a computer-aided design file which has been stored here, which has been 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 1 millimeters, and a maximum dimension of close to probably 5 or 6 millimeters. And there is an issue of where the nozzle has to be placed because the nozzle itself is about 700 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, OMAX make-out software. However, we just need to do some pre-processing 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 OMAX 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 options here, one is you know you this area is hollow, by the nature of the part it looks like that this is actually a hollow region, and then the part is actually made in metal with an outer boundary given by this outside you know this set of lines on the part.

So there is, there are two set of cuts which are important, otherwise there is a complete workpiece out of which you 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 should not 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 us 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 line, right now you know right now because you have given only 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 in this particular region, but also in this region as well. 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 demagnify. So, supposing you want to 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 sheet of metal which we want to finally machine through this process is pierced in this particular zone.

Similarly, we also want to do this piercing action in the other direction so that you have an idea of which to cut and which not to cut. So now we have made up these 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 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 finish 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, you have to right-click on this quality, go to the window and then there are these different 1, 2, 3, 4 and 5 different speeds at which the process can be initiated.

Let us say we want to just do it at some moderate speed of 3. So, we select this 3 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 therefore, 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 3 which means moderate speed for doing the machining operation. 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 am 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 here, start the piercing action and once this piercing has been started it goes follows this path, goes through all this boundary here, cuts all this thing in the piercing mode and then following this up to here the piercing actually happens and then you are defining the cutter path to go to this other end here and from here the piercing action has 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 this piercing stops and after that, you are resting it in a final position. So, this is the home position to begin with initial position and this is the final position and actually you have what you have done is you have defined the path which is important to cut this field feature out of a otherwise solid workpiece.

So, once it has been done you save this file and then you save it with certain name may be new file machining 992014 imported dot DXF in the desktop itself and then you emerge, or you open another option here which is called the path option. 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 intended 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 pick start which means that you know this is the point from which the machining would actually start. So, you 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 OMAX layout. So, the layout and the path both have been given by the software. You can just save this particular file and the save option would ensure that there is another subsequent file just at the same location where 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 992014 e which has come.

This was our CAD file which came out from the OMAX layout, and this is the file which has been the and this file is basically the file which has been saved with the path information of the machine. So, what we want to do is to go down here in this OMAX make software and open this particular file. So, there is an open file open option which is there where you can actually select. So, you go to the desktop it is already at the desktop and you can see where this new file machining 992014 e. or is. So, you selected this particular path and make it ok. So, it automatically imports this particular path in 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. So, now the question of defining the material properties come into picture to begin with. So, there is an option here called change path setup which actually leads you into this earlier obtained screen and on the left corner left lower corner here you see there is a tab especially which says enter your material setup here. So, this is actually about the material of the workpiece 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 drop-down library here which would actually be able to get generated where there are two different grades of metal aluminum as you can see 2024 and 6061. So, we actually do this 6061 because it is at a 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 3 mm. So, we can actually monitor or make it 3 mm tool offset. Now, this is a very interesting thing what tool offset really means cut. So, here you can see 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 grown old in the system.

So, the nozzle diameter is close to about 800 microns that we are using right in this case. So, basically offset is because is needed because the nozzle's center is actually the geometrical array which needs to be defined in the path. So, the path is actually the array of the how the center of the nozzle or center of the pressure of the nozzle the discharge 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 the nozzle and the 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 it is like you know cutter compensation. In a CNC 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 a similar manner, this is in the nozzle area. So, once we have done that and let us now go back to the software here. The tool offset that we are setting in this case is about 400 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 1 is to 1 read out. So, whatever is the dimensions on the CAD software is to be read out in terms of the machining path etcetera on the OMAX layout or OMAX 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 6061 grade, machinability is given, the thickness is given, the tool offset of 0.4 mm is given, tool rotation is given and there are certain estimates that the machine gives. For example, it says the estimated time to make this part is about close to 0.72 minutes or 42 seconds. Estimated cost to make this part is about you know probably 0.3 of or maybe about 30 cents which is about close to 15 rupees or so. So, estimated abrasive needed also is estimated by the machine to be about 140 grams. And then you can also define certain other aspects like the pressure etc. 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 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 happen. So, you can see it is about 2300 bars and the higher side of the pressure and the low pressure can vary all the way to about 1100 bars also. You have a joule diameter in this case which is after where is reading out about 350 microns, the abrasive flow rate is given to be 0.3 kgs per minute so on so forth. And so therefore, this mesh size that we are using, and abrasives generally are defined with the grid size, or a mesh size is about in this particular case 80.

So, we are using 80 mesh size it varies all the way to about 200 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 babysit triggered which means that now we 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 machining operation and then we will monitor how the machining continues cut. So, here there is a question of turning on a valve on the 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 pump's 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 the controlling of the water flow into the machine here and there is a small valve right here in the 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 so that you can feed the pneumatic valves and the machine can operate for the various machining aspects cut. So, as you can see on the 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 workpiece operating these particular arrows. So, 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 is actually a deposit of the sand that is why you are seeing this is brown and this sheet is actually almost 3 mm thick and it is mounted on a water bed. So, this is 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 all the cutting action etc. 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 these 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 as you can see here there is a lead screw which would actually be able to swivel the stage to and fro away from the workpiece or into the workpiece. I think I had 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 on to a surface. And so therefore, it is very important that you optimize that throw distance so that you have maximum 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 by the manufacturer to have a nozzle tip distance of correspondingly up to 1 to 3 mm.

So, we will keep it at the maximum distance. So, we will keep the distance to be the minimum which is about 1 mm, and we are doing this by means of the steel scale which is close to about 1 mm. So, we are going to sort of put this scale into this particular you know between the nozzle and the workpiece and then using this manual lead screw we want to just get the get to a point where this you know this the lead screw can be optimized for the nozzle tip distance to be about 1 mm. So, this is about touching the scale now you can see the pressure on the scale which means that the distance is about 1 mm 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 a reference zero or home position for the process to begin. So, on the right upper corner of the screen here you can see nozzle position has been indicated and so there is distance from user's 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. So, you want to reset the paths 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 OMAX path control.

So, here on the 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 says 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 or 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 workpiece surface cut or other focus cut.

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 wanted to cut in the aluminum and this gives you a sort of understanding that how the whole machine path would be designed for doing this cutting action. 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 or the path home position automatically and we are now set for basically working on the machine for that. Now, I would like to just add on here something very important is that this machine is operated at a very high pressure of close to about 40000 psi and naturally if with such a high pressure you are hitting upon a material there is going to be a lot of noise emission because of that and in order to prevent that from happening and also the fact that you should not have splashes 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 an option here on this particular machine. So, when you see this toggle here which says water level and so in if you really want to put this toggle in the up position the bellows would swell and the whole water would come in a manner it will come flow over the workpiece as well as the nozzle and the water would actually the level of the water would go up and similarly 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. So, now if you see, now if you see if I just 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 200 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 a safety-related issue. This machine has some splashes which come out and also the fact that the jet of water is so high speed that it may as well be able to if it cuts a piece of aluminum which is 3 millimeters it is as well as very serious for some kind of a limb or hand or something which gets caught up there. So, you have to be extremely careful while operating the system to be away from the system when you are 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 are 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 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. Thank you.