Sustainability Through Green Manufacturing System: An Applied Approach
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Lecture - 21
Green Manufacturing Techniques Continued

Good morning. Welcome back to Sustainable Manufacturing course.

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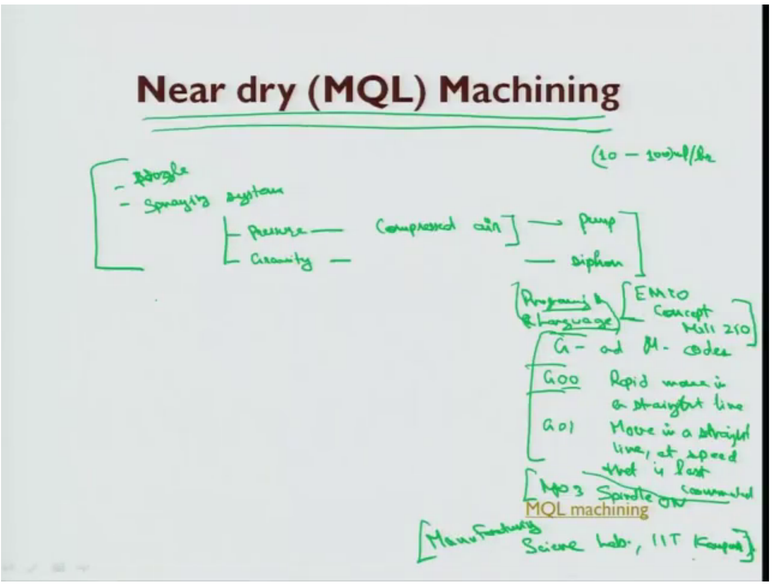

Now, next is near dry or minimum quantity machining. In this case, we already mentioned that 10 to 100 ml per hour of cutting fluid is sprayed. So, how do we do that? We need a nozzle here and we need a spraying system here. This spraying system maybe pressure spraying system or it may be using gravity only.

So, to spray this fluid, we need compressed air or some or a method to have air pressure. With compressed air in pressure kind of spraying system, we need to have a pump that pressurizes the fluids along with it and in case of gravity we only need a siphon. So, this is a system. This setup for the MQL will show you in a video and along with the MQL setup will also show you the various instruments those were being used to record certain outputs those are the performance and green outputs.

So, I will show you my MQL machining here

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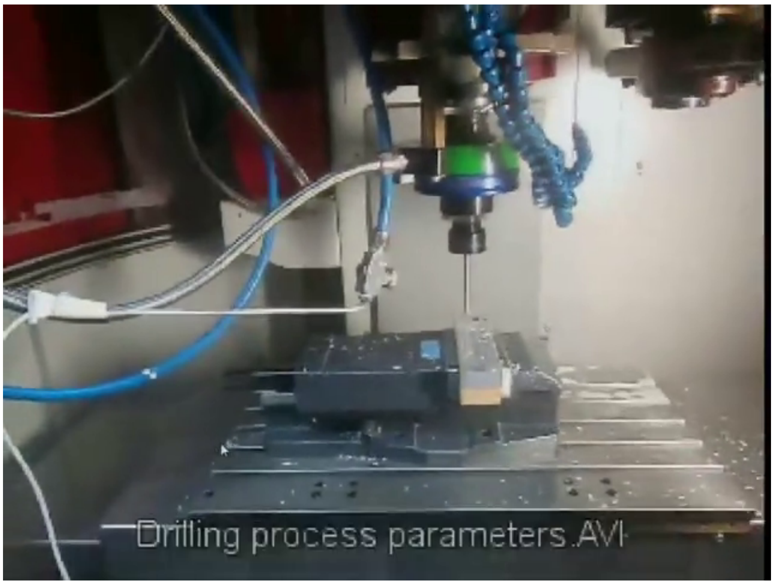

So, this is MQL-Minimum Quantity Lubrication drilling. So, you can see noise is coming here that is the kind of a peak noise. I have a nozzle here that is spraying with the fluid here. This nozzle from the white pipe the cutting fluid is coming and from the blue pipe on the top of the nozzle we have our air pressure. The pressurized air is coming up.

So, we have the air spray here or my mist spray here that is. So, this distance is also optimized. We can even keep multiple nozzles; this is only one nozzle. We can even keep 2 or 3 nozzles. This all depends upon the kind of machining we are doing. So, it is the drill is going in, it is performing the hole, it is making this through hole and it is coming out. So, repetitively go to the other position and make the hole.

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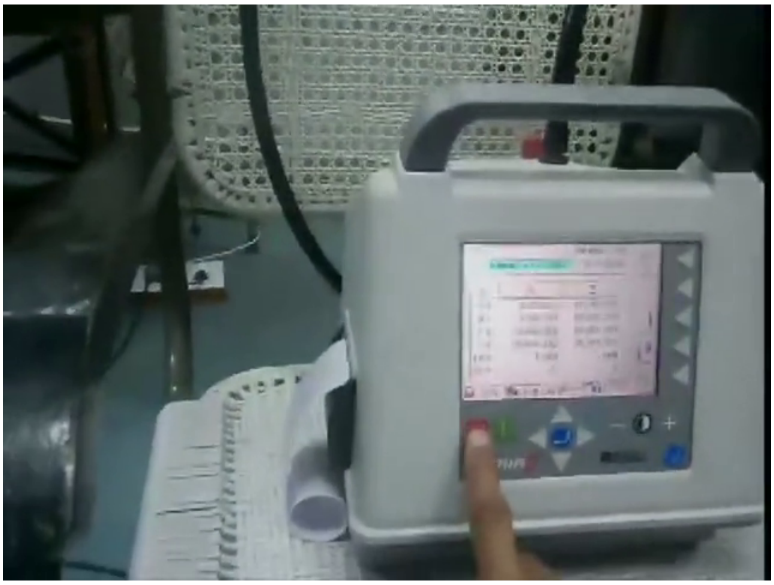

So, this is my air particle counter. That is collecting the mist particles or the aerosol those are generated; details about this we will discuss. This is one of the instrument that is been used here. Thus switch it off.

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This is my sound meter that is recording the noise at each one second; that is, the second rate, the pulse rate; it is kept as one second. It is recording the noise and even the peak noise that you might have heard here, was also recorded here. So, this average noise during this machining and the peak noise these were be recorded.

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This is my output of the machining here; this is actually the force, in the green color you can see thrust force; in the red and white colors glow we can see the torque during torque here. So, 4 holes were made and 4 peaks you can see, these are the machining force or the in the other words it is a energy that is being used here to make this force.

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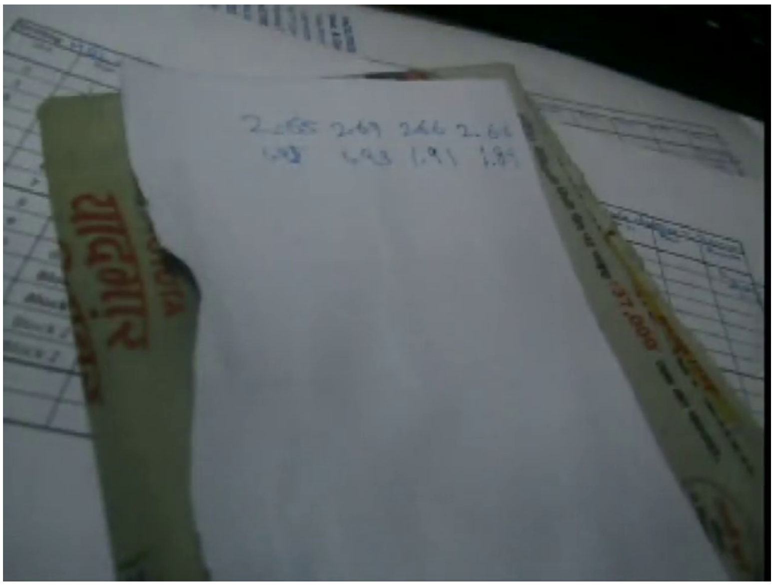

So, this would all be noted down here. The operator is just noting it down manually. This can also be synchronized; the sound meter, aero solid particle collector and the dynamometer output that is using lab view software this can all be synchronized that is for this machining time only all the outputs come altogether. So, this was my MQL machining. So, I would have to put some information here also about the language; the language of the programming language that CNC machine understand or I would say programming language.

So, this mechanical people know that we have G and M codes. So, in this case you might have noted that there was a rapid movement. This rapid movement is put here using this G00 code, that is the rapid move in straight line then G01 is the move in a straight line at speed that is last commanded. So, what happens, why I am telling this is; longer the machine would run the more bit of energy used here because when spindle is running we use this code M03 to switch on this spindle; this is spindle on.

So, I come up with the full code of this simple machining in the forth coming class. So, this is spindle on. When the spindle is on, some energy is being consumed. The energy, the level of energy related being consumed rises. So, at this state the moment of the tool has to be minimum that is for that this rapid move G00 code is used. As the move my machine, machining was being carried out, the milling machine was being carried out and the tool moves up and rapidly goes to the other position from where machining is to be started and together drilling also is rapid movement was there.

So, this was my programming language that is being used my EMCO concept mill 250 that is in our Manufacturing Science Lab., IIT Kanpur so the whole credit goes to our manufacturing science lab here.

So, we are talking about the near dry MQL machining here. How is it better than our dry machining and this comparable to our flood machining as well.

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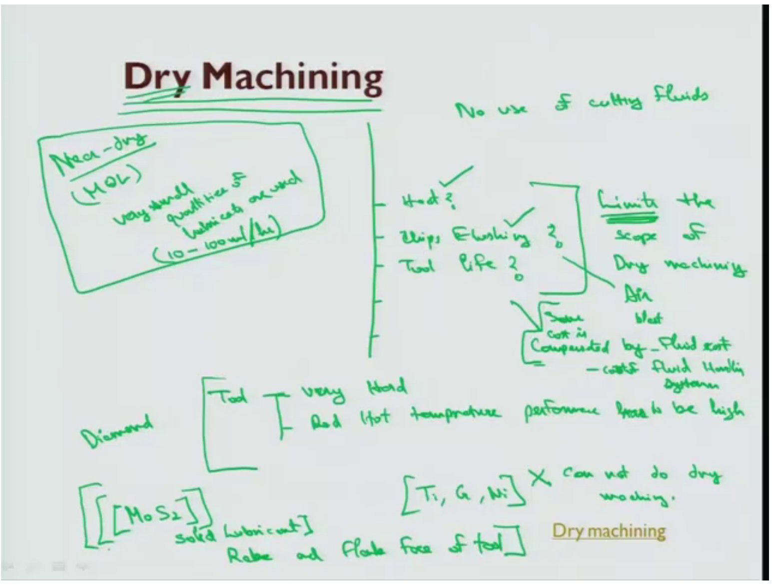

So, in dry machining what happens, the cutting fluid is totally eliminated. So, we had problems of heat generation and also in dry machining we can even use a solid lubricant like molybdenum disulfide, can be used, can be filled with micro holes in the rake or flank face of the tool. For example; in the drill, if this is my drill I can have some hole in the drill here and some micro holes could be put in here, from which with solid lubricant could be injected here and this solid lubricant would keep lubricating my work piece that would help to keep the quality in place. So, these kinds of techniques can also be used; that is, MoS2 solid lubricant. We have not used flood, we have not used MQL here, but this solid lubricant is put in the rake and flank face of tool. So, this becomes a kind of a self lubricating tool.

So, during dry cutting of hardened steel or maybe titanium the tool wear and friction coefficient at tooltip interface is such that tools could deteriorate very fast. Significant deterioration happens in that case. So, in that case this could be helpful if dry machining is chosen to be done. For both technologically and economically optimal results are produced by near dry machining that is Minimum Quantity Lubrication and high performance oils have excellent lubricity, biodegradability properties and they are environment friendly as well.

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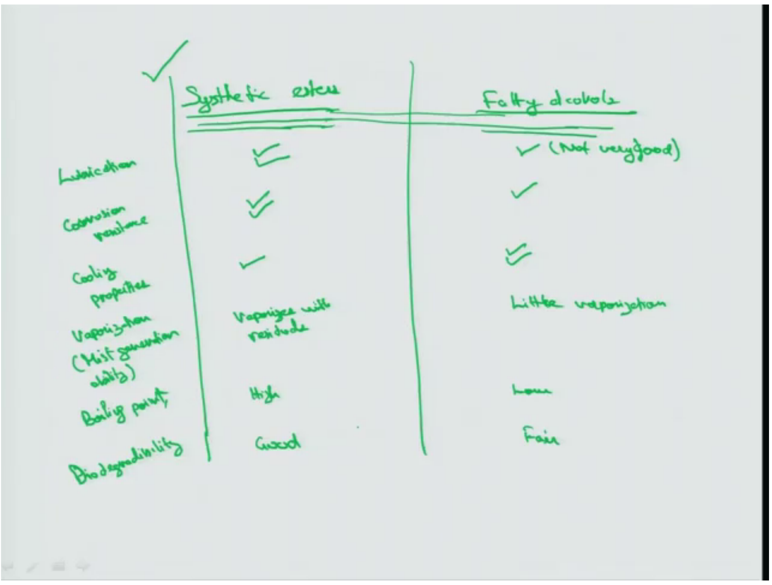

So, I can even compare synthetic esters a few lubricants of coolants those are used in MQL here. If I compare synthetic esters and fatty alcohols those are widely used in MQL process. So, these are chemically; synthetic esters are chemically modified vegetable oils and fatty alcohols are made from natural raw materials or from mineral oil. So, in this case, if I say the properties, the lubrication, corrosion resistance, then cooling properties, then vaporization that is mist generation ability. Then maybe it is for disposal I would say boiling point, at what point does are fluid becomes totally bad to be used. So, in that case boiling point plays a key role.

So, in this case synthetic esters are very good lubricants, but these are not very good. I would say these are also lubricants, but not very good. So, what I am telling here is the kind of the examples. The corrosion resistance of this one is also better in comparison to this one, fatty alcohols and the cooling properties are not very good in this case; however, the cooling in case of alcohols is a little better. Then in case of vaporization this synthetic esters vaporizes with residuals. So, this vaporizes and the boiling point is also high, in this case the boiling point is low. So, here it vaporizes air; vaporizes I would say with residuals here, it is a little vaporization.

Now, what would we choose as our cutting fluid here, it all depends upon what kind of application we are working on. If I say environmental performance, synthetic ester is one of the good options, because, if I say biodegradability that is also good here, this is fair.

So, this can be one of the good options as a cutting fluid. There are certain applications areas where dry machining and Minimum Quantity Lubrication can be used. It may also a wide range of material processes and combination of these may be drilling, reaming turning gear cutting and there is material on which these kinds of machine can be applied, for example: aluminum alloys, steels, titanium can also be for this one, near dry machining, titanium can be used, but dry machining cannot be done on titanium alloys, because titanium does not have very good heat dissipation properties.

Now cutting fluid avoidance is an important thing because of the ill effects of cutting fluid. The primary functions of lubricants are performed by the MQL itself. So, MQL is one of the options that can be used to do machining. So, we will use this option only in our lab demonstration session as well we will perform Minimum Quantity Lubrication machining of drew aluminum work piece.

We will conduct grinding experiments and also we will use the data that was from the previously conducted experiments that is drilling, milling and we will use this data to optimize it with respect to green, then we will carry it further to our factory to develop a green factory. We will make a process chain there of these machines chain of then first we will example which we might choose first doing milling, then drilling, then grinding, then maybe do some inspection, then maybe some assembly. Then we will just make our product to go out of our this production room and this kind of simulation will carry we will see how the simulation outputs, what is the throughput that is coming in.

So, this kind of machining we will choose.

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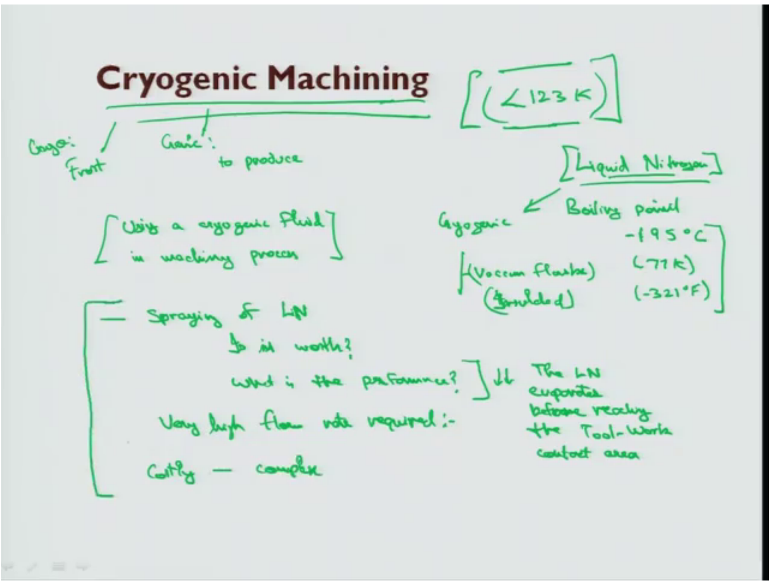

So, one other kind of the option or the green option there is cryogenic machining. What is cryogenic? Cryo means frost; this is cryo and genic means to produce. So, then cryogenic becomes the science that is associative generation of low temperatures then these temperatures are below 123 Kelvin that is the cryogenic. So, cryogenic machining is performing our machining process at this temperature that is cryogenic machining.

Now, in the past cryogenic machining was very difficult and costly. The method that was being used to spray is the material to obtain this temperature was not very well established and what is the material here? It is actually liquid nitrogen. This liquid nitrogen has it is boiling point very low that is 195 degree centigrade, if I say it in Kelvin it is about 77 Kelvin or maybe 321 degree Fahrenheit, oh sorry this is minus 195. So, this is very cool here. The temperature is minus 195 degree centigrade.

So, about 225 degrees difference of temperature is there from the room temperature. At this temperature the machining is carried out. So, liquid nitrogen is a cryogenic fluid that is why it is used here. This can cause rapid freezing on contact with the living tissue and it is actually we have to be kept insulated from ambient heat liquid nitrogen needs to be stored and transferred in a vacuum flasks, those are insulated. So, this fluid handling system is also very critical thing here, we will come to that.

So, we are talking about cryogenic machining here. What is cryogenic machining? It is using a cryogenic fluid in machining process; this is the definition. Now, what were the methods those were there to supply this cryogenic fluid liquid nitrogen. Earlier, what was happening, it was being sprayed; spraying of liquid nitrogen. Is it good to spray liquid nitrogen? Is it worth I would say. So, what is the performance now the issue here was the liquid nitrogen evaporates very quickly, so during spraying the flow rate that is required was very high. But, even with high flow rates the nitrogen mostly evaporated before even reaching the cutting. So, the performance was not good. The liquid nitrogen evaporates before reaching the tool work contact area.

So, very small amount of nitrogen would reach there. Ultimately, reducing it is cooling capacity. So, these kinds of drawbacks made cryogenic machines both costly and it was very complex. These things I am talking about the initial phase when it is started; when the cryogenic machining started.

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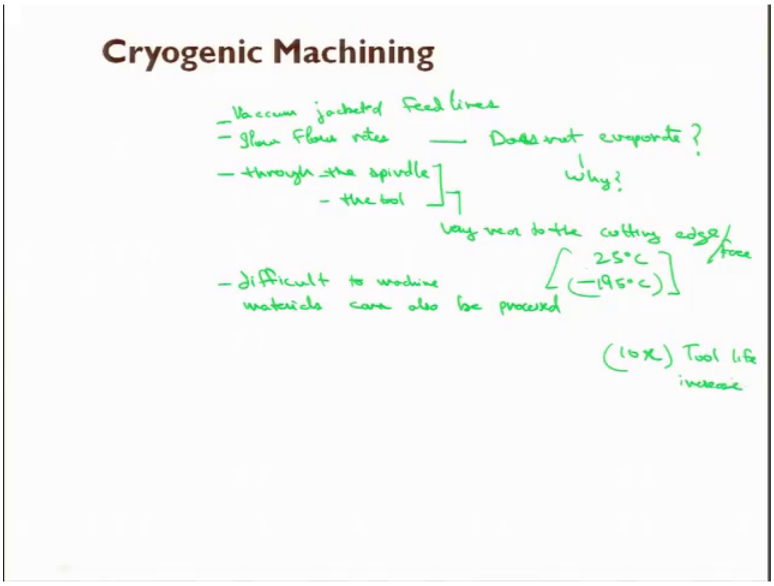

So, what is the new technology to overcome this drawback? So, new cryogenic machining technology utilizes vacuum jacketed feed lines that deliver the cryogenic fluid at slow flow rates. So how this slow flow rates could be effective, what happens? The fluid does not evaporate. Why? Now, what is there, this fluid is flown through the spindle only, through the spindle and through the tool and this is done very near to the cutting edge or maybe face.

So, at this point liquid nitrogen is allowed to evaporate and it cools the cutting edge to its temperature. The liquid nitrogen temperature is 195 degree centigrade. So, the refrigerator state allows the tool to be pushed beyond it is additional limits at very low temperature the tool performance becomes very good and it increases its wear resistance and difficult to machine materials can also be processed, now traditional coolants worked only at 25 degree temperature. This was the temperature.

Now, this difference is about 220 degrees. So, this advantage is obtained in my cryogenic machining. So, this significant difference allows increase processing speed and potentially increased tool life and this tool life increase maybe 10x like 10 times tool life increase.

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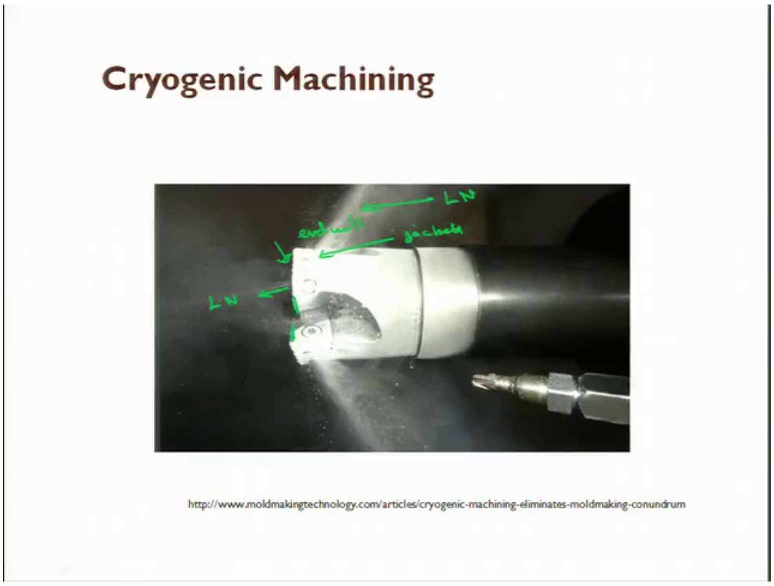

So, this is one of the figure here. This is my end mill and we have this jacket here from which liquid nitrogen is coming out. This is taken from a reference. And see it is also coming from this side. So, these are my cutting edges, this is the cutting edge here, this is the edge.

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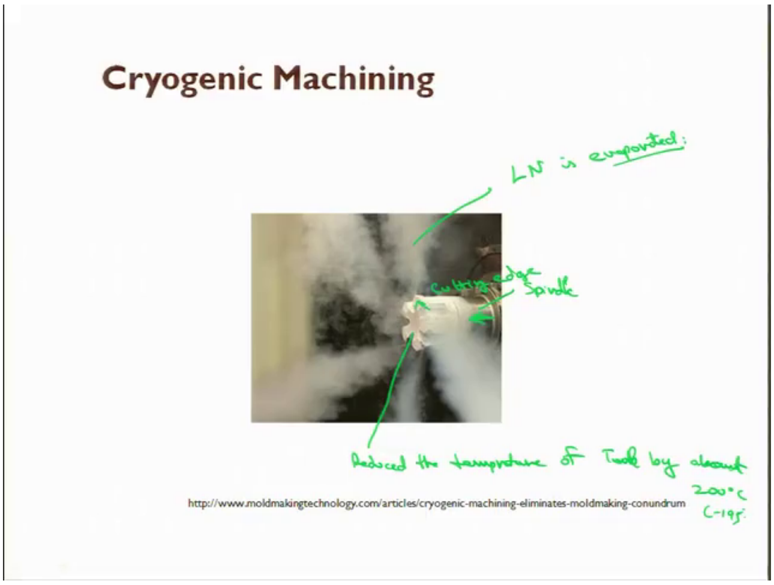

Also you can see here. See the liquid nitrogen directly is coming from the tool and it is coming from the spindle. This is my spindle here and small jackets are there small flow lines are there, very close to the cutting edge. This is my cutting edge and this is liquid nitrogen is evaporated, but before being evaporated it has reduced the temperature of tool by about 200 degree centigrade, if I will be very specific 195 degree centigrade, take it this much low.

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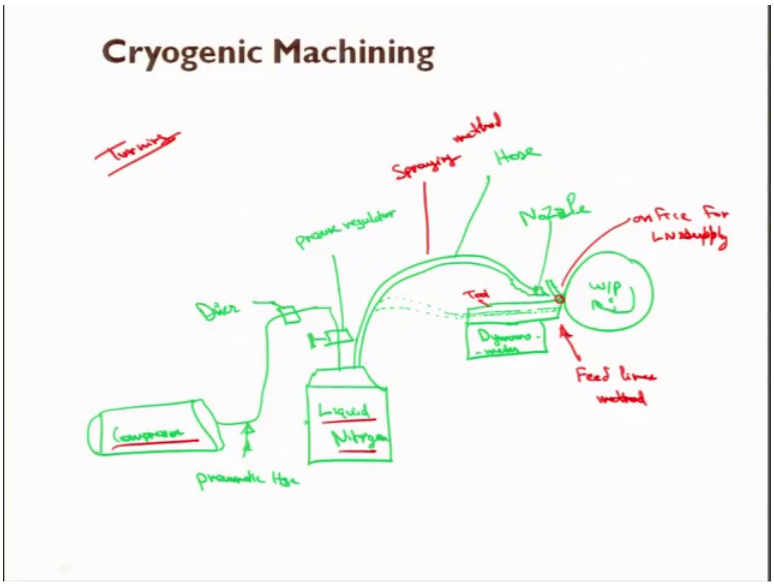

So, in the set up of cryogenic machining we need to have a system to produce liquid nitrogen and to supply it to the tool work interface as well. So, I could say there is some compressor here. This compressor is being connected to my cylinder, the vacuum cylinder that has liquid nitrogen in it. Now, this compressor is being connected with a hose, which I could call a pneumatic hose, now this I have my work piece, my tool, that is doing cutting here and this is my chip is being produced here. This is my tool; this is my work piece that is rotating, this tool if I say I have need to also by at the forces I can fix it on a dynamometer.

Now, this liquid nitrogen, this pneumatic hose also we can even have a dryer here that; also filters and pressure regulator can also be here. Now this is connected to our liquid nitrogen, actually, this pipe is not here, this hose, it is if you see the cylinder physically;

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This is my cylinder that carries liquid nitrogen. So this is my pressure relief valves here and this is my stainless steel hose that is very insulated SS that is stainless steel hose that is supplying liquid nitrogen to the machining point here. So, this is going to the machining point. So, and here even you can have flow meter to control the flow, here flow meter could be at there and this also is connected with my compressor that is producing liquid nitrogen. So, this pneumatic hose is connected here. In between I have a dryer and a pressure regulator. Now, here I have my steel insulated stainless steel hose that is supplying the liquid nitrogen to my tool work interface. This is my hose and I have a nozzle here, so, this is a kind of a spraying method.

In case of the other methods, this hose, we can have a small slot here in the tool and this hose could even be connected here and also then we need to have a small orifice at this point, I would like to change the color here a small orifice here; orifice for LN - liquid nitrogen supply. Now, in this case, this is my spraying method. So, this is my feed lines method. This is actually cylindrical cutting this process is turning process; a simple turning process. So, this is the set up of liquid nitrogen.

So, in which we have a compressor, liquid nitrogen carrying cylinder and we have tool this is my tool here which usually cutting of this work piece and it is connected to dynamometer which records the forces those are generated and this nozzle is there, that is supplying the liquid nitrogen here or second method maybe using this feed lines.

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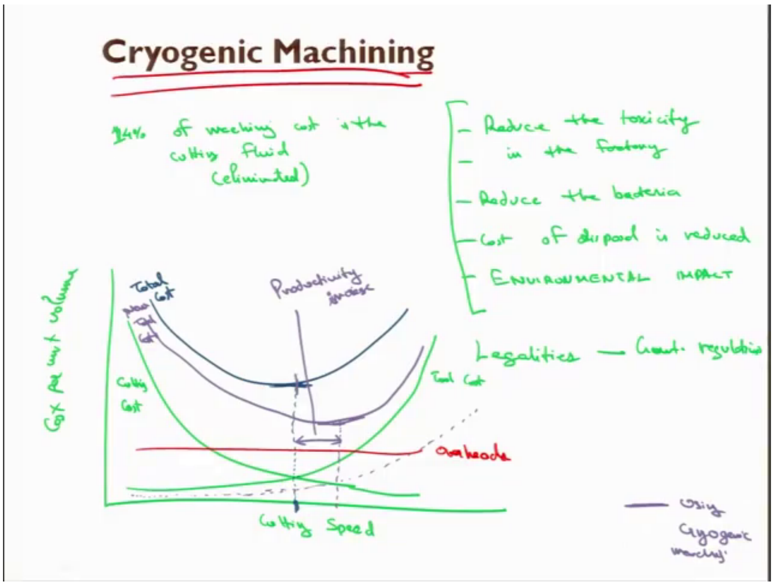

So, what was the motivation behind using cryogenic machining? We need to reduce the toxicity in the factory or maybe in the work environment, then similarly reduce the bacteria that are produced from the oily work environment or maybe from the cutting fluid, then cost of disposal that is reduced, then environmental impact the major thing this is also reduced.

Also certain legalities might be there; that is legality means government regulations for using less toxic materials. Now, besides MQL, cryogenic is also shooting up in the market. As I have already discussed 14 percent of machining cost is the cutting fluid. So, this is totally eliminated; however, cryogenic machining has very large initial investment. The equipment cost is higher. So, presently the status of cryogenic machining or its use in mass production is not very good, but if we see the total cost in machining, the cryogenic machining has a better performance.

So, if I say this is my cutting cost, what I am plotting with this, my cutting speed; with more speed the cost per unit volume is decreasing; this is cost per unit volume here. So, this is my cutting cost, now, if I say my tool cost with higher speed, my tool cost would rise, because at higher speed temperatures would be high and my tool will deteriorate and this tool cost would increase. So, then what I have, if I say I have some overheads here, then what I have here is my total cost would be like, this is my total cost. At this point, it would be minimum.

So, this cutting speed is selected to work on, it is nearly minimum distance. So, what happens in cryogenic machining? This tool cost curve has a lower slope. What happens, the total cost; this was my minimum cost here, this cost is now reduced. The new total cost would be like this. This is new total cost. This one is, this color is using cryogenic machining. So, this total cost is reduced and this becomes minimum at this stage. This becomes my increase in productivity. If this is my minimum cost here, total cost, this becomes productivity increase.

So, though the initial cost, investment cost in cryogenic machining is high, but if you see in long run because of the savings in tool cost, the investment cost can be compensated. So, in the long run the overall cost might be lower, so this is one of the benefit here of cryogenic machining.

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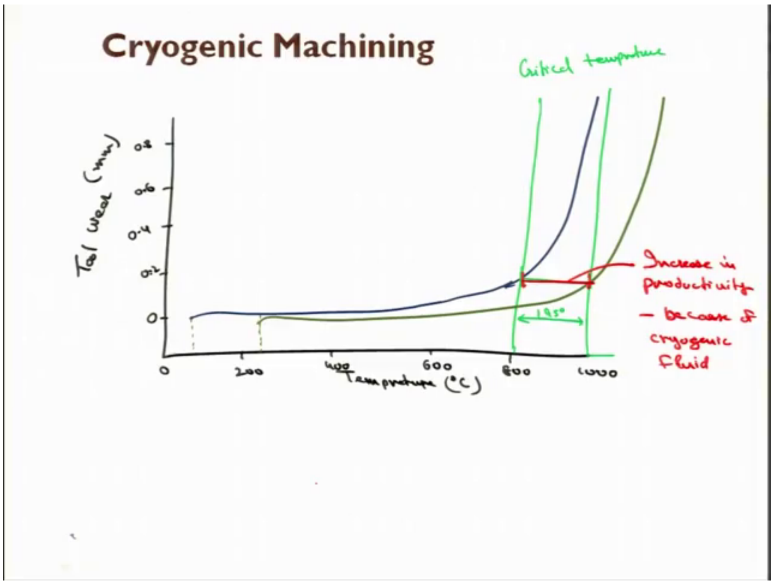

So, how does this tool cost low curve gets down, this I will try to elaborate here. So, when I plot my tool wear with temperature and if I say my machining is being coming out from 0 to 1000 degrees centigrade temperature and this is an absolute unit tool wear that is in mm and this is from 0 to 200, 400, 600, 800 and 1000 degree centigrade temperature is there and this varies from 0, 0.2, 0.4, 0.6 so on 0.8 mm.

What is the general trend of tool wear with respect to the temperature? So, at 0 degree or at maybe at room temperature the tool wear is nearly 0. It starts from here 0, starts from here and till about 600 degree centigrade the wear is very less. So it starts taking the highest log after this and becomes like this and at higher temperatures the tool wear is like this. So, after about 800 degree centigrade I am just taking something from for instance. This temperature might be different for example; this shoot up might come in some carbide tool. It all depends upon the tool work combination. What type of tool is being used? What type of work piece is there? If I say chromium tool is being used on mild steel, this temperature might be even different.

So, in this case this is like this. So, what does cryogenic engineering do? This for example, this is the critical temperature, if I say 800 degree is my critical temperature at which my tool starts with deteriorating. This is the critical temperature here, after which my slope is increasing very rapidly.

So, what does cryogenic engineering do; it takes this slope to a better level. What does it do; for example, this is 800 degree, if we do cryogenic engineering it will reduce the temperature by 200 degree centigrades approximate; if I say 195 degree centigrades, so, this slope would be at later stage, this slope would come here. In that case, the tool performance if since it has started here, here also a 200 degree difference temperature would be there about 105 degree.

So, this slope would start from here and it will go like this. In this case, that critical temperature has changed its place, so, this is 195 degree. So, what is this difference from this point to this point? This difference is my productivity increase. Now, this is increase in productivity which is due to or because of cryogenic fluid. So, this makes our tool cost even lower. That is why overall productivity increases there, overall tool cost is also decreased.

So, what does cryogenic engineering do? It eliminate the connection coolant, toxicity reduced, bacteria is also reduced, oily environment is not there, cost of disposal is also not very high because nitrogen is a gas that is very much volatile. So, the cost of disposal is negligible, better to put word negligible here that is it is closed to 0. So, I would like to put other benefits as well in this list here; for example, tool life increase that is 10 times, then processing speed is increased, regarding environmental we have clean environment because liquid nitrogen is a clean gas and nitrogen is does not come in greenhouse gases.

Also there are machining that is happening through carbon dioxide gas. Carbon dioxide also has a good performance in comparison to cutting fluids, but carbon dioxide is a GHG gas - Green House Gases. So, in environment we have 75 percent of the gas that is the nitrogen only. Nitrogen is not having any bad effect to human health. So, it does not even effective work environment in the factory. So, the environmental factor; here the clean factory we have, the clean surroundings of the even factory and the sterile work piece; work pieces are also clean, I would say environmental clean work pieces, then environmental friendly byproduct is also produced here.

So, in cryogenic machining status is, in the present state that feed line method is being used. So, methods have also being developed to have portable cryogenic systems, that could supply the cryogenic fluid exclusively for the specific machine, which may be called as self contained generating system; that is, liquid nitrogen would be produced or generated at the machine itself. The researches who are working in this area are trying to develop these systems in future.

This kind of system can be used where only single machine is there in factory, where cryogenic machining is required. In a big production system like in aircraft manufacturing, mass storage system would be feasible with a pipeline supply system.

So, this was all about the green machining methods or some of the green manufacturing techniques; dry machining, near dry machining and cryogenic machining. There are other machines, other methods which are being developed for green manufacturing which we cannot cover in this single course so as of now.

Thank you.