TASK 2
AE224: MACHINING AND PRECISION MANUFACTURING

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I. FIRST QUESTION

Discuss the relative advantages and limitations of minimum quantity lubrication in metal cutting. Consider the relevant technical and economic aspects. If you would like to perform it in the lathe available in our lab, what are the modifications/additional setups required in the machine tool? Design it for the machine available in the lab.

Answer Cooling lubricants and coolant systems have various tasks in metal cutting. Primarily they conduct heat and reduce friction. They ensure a uniform temperature of the work piece and tool and help to maintain tolerances. Supply, preparation, and disposal of cooling lubricants can cause considerable costs. Additionally, these substances pollute the environment. A possible solution in searching for the optimum lubrication system is minimum quantity lubrication (MQL), which is becoming increasingly important. This is an alternative between wet and dry machining. In the case of minimum quantity lubrication, the quantity of the applied lubricant is reduced to a minimum. The maximum volume flow rate with MQL is less than 50 ml/hour. Compared to conventional wet machining, where up to 12,000 liters of coolant is used per hour and must be reconditioned again, the user of the MQL system does not need a higher quantity than a few millimetres.[10]

FIG. 1. Minimum Quantity Lubrication

Firstly, the disadvantages of the flood coolant are numerous, such as:

1. The high running cost of coolant pumps
2. High level of maintenance of coolant systems
3. Cleaning the work area of the machine tool
4. Particularly in summer or warm conditions, the unpleasant odour sometimes emitted by poorly maintained coolant systems.
5. Clearing up the spills from the leaks, which is often an issue
6. Health hazards due to emissions of cutting fluids on the skin and in the breathed-in air of employees at their workplaces including toxicity, dermatitis, respiratory disorders and cancer.

There are a lot of issues related to the usage of cutting fluid in machining operations. Therefore, it would be ideal to implement dry machining, but the adverse effect on tool life, higher temperatures induced and lower performance makes it unsuitable in most cases. Where dry machining is successfully employed, the process performance can be inhibited by the need to balance productivity against surface finish, tool life and maintenance costs. Therefore, even where users have a defined dry cutting process, MQL(Minimum Quantity Lubrication) can potentially assist with extending tool life and increase machining performance in terms of surface finish, cutting forces and process capability.

How does heat management is done on MQL?
In metal machining, the metal is removed by the cutting edge of a tool, which shears off a chip from the work piece. The energy used in deforming the metal is released, mostly in the form of heat, in the primary and secondary shear zones.

The energy released in the primary shear zone cannot be avoided. It is a result of the molecular bonds being broken on the work piece. Some of the heat goes into the work piece and the rest into the chip. The friction - and resulting heat - between the tool and the work piece in the secondary shear zone causes both the tool and the chip to warm. The heat in this zone is one of the largest contributors to premature tool wear. MQL, properly done, greatly reduces this heat by lubricating the chip-tool interface.

MQL focuses on heat management and the elimination of frictional heat. Some heat is removed by the vaporization of the fluid in the cut. More is removed through convective transfer as air is blown across the cut in the delivery of the fluid. While these are of measurable benefit when compared to dry cutting, the actual heat removal is generally about half of that removed by a flood coolant. However, an MQL fluid is specifically designed to be highly lubricious and work in the temperature ranges used in cutting. Minimum quantity lubrica-

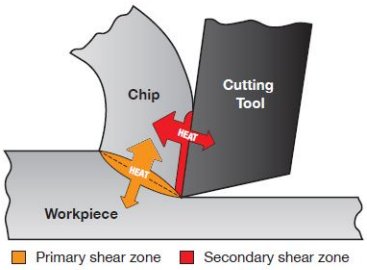

FIG. 2. Heat Generation in metal cutting1

tion today uses such precise metering that the lubricant is nearly completely used up. Typical dosage quantities range from 5 ml to 50 ml per process hour if lubricant is supplied by means of a minimum quantity lubrication system (MQL system). Application of a targeted supply of lubricant directly at the point of use lubricates the contact surfaces between tool, work piece and chip. The lubricant is either applied from outside as an aerosol using compressed air or it is shot at the tool in the form of droplets. Another possibility is internal lubricant feed through the rotating machine tool spindle and the inner channels of the tool. The extreme reduction in lubricant quantities results in nearly dry work pieces and chips. Losses due to evaporation and wastage, which may be considerable with emulsion lubrication (depending on the work piece being processed), are inconsequential with MQL.

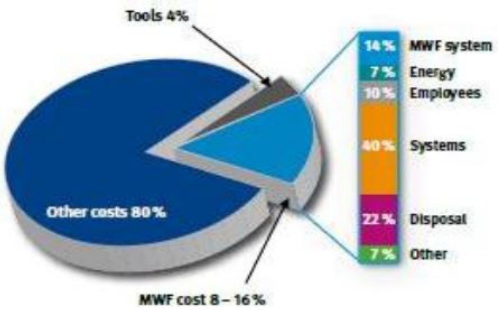

FIG. 3. Metal working fluid costs in metal machining

Today, the enormous cost-saving potential resulting from doing almost entirely without metalworking fluids in machining production is recognized and implemented by many companies, primarily in the automotive industry. While in the early 1990s small applications (sawing, drilling) were done dry, today it is possible to produce cylinder heads, crankcases, camshafts and numerous other components made of common materials such as steel, cast iron and aluminium using MQL in the framework of highly automated large volume production.[**?**]

Minimum quantity lubrication is a **total-loss lubrication method** rather than the circulated lubrication method used with emulsions. This means using new, clean lubricants that are fatty-alcohol or ester based. Additives against pollution, e.g. biocides and fungicides, are not necessary at all, since microbial growth is possible only in an aqueous phase. Metalworking fluids do not spread throughout the area around the machine, thus making for a cleaner workplace. Costs generated by conventional flood lubrication (e.g. maintenance, inspection, preparation and disposal of metalworking fluids) are no longer an issue with minimum quantity lubrication. The average percentages of these costs in the overall cost of wet processing are shown in Figure . The exact amount

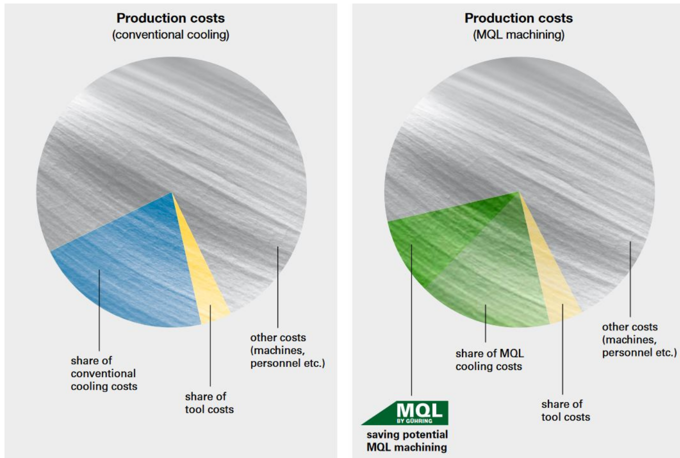

FIG. 4. Change in metal working fluid costs in metal machining due to MQL

of savings will vary by plant, but industry estimates are that from 8 to 16% of total operation costs are related to metalworking fluids (MWFs)2 and MQL will substantially cut these costs. When cost analyses are carried out for new assemblies and systems, investments in metalworking fluid systems (containers, pipelines, pumps, and filtration devices) play a major role. Furthermore, when minimum quantity lubrication is used, there are no costs for cleaning and drying the chips before their disposal or, as the case may be, cleaning the work pieces prior to subsequent processing. The exact percentage of metalworking fluid-specific costs is greatly dependent on the processing method, on the machinery, and on the specific building conditions.

The aims of the MQL is to achieve the following:

1. Reduction of thermal stresses at the tool point
2. Less tool wear
3. Effective chip evacuation from deep holes
4. Reduction of cooling lubricant requirement
5. High cooling and lubrication effect especially in deep holes
6. Reduction in component cleaning costs

7. Reduction in cooling lubricant disposal costs
8. Reduction in cost of disposal of scrap contaminated with cooling lubricant
9. Protection of environment and health through lower Emissions

The cutting fluid used for the Minimum Quantity Lubrication for a fault free and low emission metal machining must have very good lubricity and high thermal rating. In industrial manufacturing, synthetic ester oils and fatty alcohols with favorable vaporization behavior and a high flash point are used.

1. Synthetic esters are preferable for all machining processes in which the lubricating effect between tool, the work piece and separation from the chips is of prime importance. Examples of this are threading, drilling, reaming and turning.
2. Fatty alcohols are preferred for machining processes in which the separation effect rather than the lubricating effect is important. An example of this is the machining of non-ferrous metals.

FIG. 5. MQL virtuous cycle

In the MQL machining operation, there are some limitations also that must be accounted as well:

1. **Smell** - The smell of the lubricant is not inconsequential. Spraying the lubricant can cause the smell to be intensified.
2. **Sprayability** - The lubricant should spray easily and, especially with 1-channel systems , be able to produce a stable aerosol (oil-air mixture).
3. **Additives** - The additives should be adjusted to the processing requirements, particularly when processing non-ferrous metals and difficult-to-cut steels.
4. **Residues** on machine parts - Despite minimum spray amounts and the use of extraction devices, lubricants may leave residues on work pieces and machine parts. The lubricant should not resinate and should be easy to clean off if necessary.
5. **Viscosity range** - Practical experience shows that the best results with lubricants (ester or fatty alcohol) are achieved at a viscosity range of 15 to 50 mm2/s and in some cases up to 100mm2/s at 40 C. Upper viscosity limits should be discussed with the MQL system manufacturer (check device suitability for spray ability). In general the MQL system and lubricant should be compatible with each other.
6. **Lubricant change** - Before a new lubricant is used, the system should be completely drained and flushed. The flushing process should be performed with the new lubricant.
7. **Corrosion protection** - A check should be made as to whether the thin MQL residual film on the workpiece after machining offers corrosion protection that meets the requirements or whether additional corrosion protection is necessary.

Before, suggesting the MQL arrangement for the engineering lab, first look at the different systems available for the coolant systems. The classification is done primarily into two types: External feed system and Internal feed system.

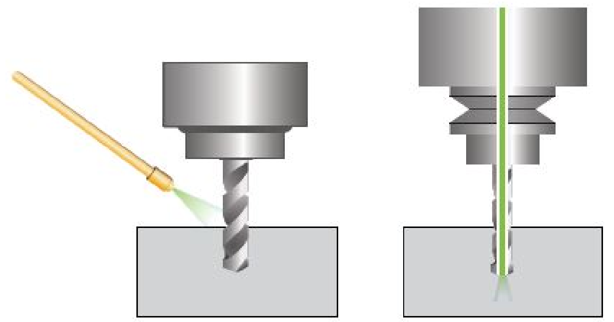

FIG. 6. Internal and External feed systems

In **External Feed System**, the lubricant is applied by means of spray nozzles around the circumference of the tool. This system is especially suitable for entrance-level implementation for standard processes (turning, milling, drilling). Low cost, simple retrofitting and the option of deploying conventional tools are the key advantages of these systems. The important two technologies that are widely used in external feed system are devices with metering pumps, devices with pressure tank & Targeted bombardment with oil droplets.
In the internal feed systems, the key advantages are:

1. Simple adaptation
2. Low investment costs
3. Little work to retrofit conventional machine tools
4. No special tools required

5. Rapid response characteristics

There are some disadvantages as well associated with the internal feed systems:

1. Limited adjustment options for the nozzles due to different tool lengths and diameters
2. Possible shadowing effects of the spray jet when machining

Internal feed devices enable direct supply of the lubricant to the cutting zone. The lubricant must be transported through the spindle, tool revolver and through the inner cooling channels of the tool. In contrast to devices for external feed, no adjustment of the feed nozzles is necessary and there is very little loss due to dispersion. The settings for oil and air amounts can be performed with the machine control system. Depending on where the vapour is generated, there are two common types of internal feed systems namely, 1-Channel devices and 2-Channel devices.
Advantages of internal feed system are:

1. Optimal lubrication at the cutting point (for each tool, even for inaccessible points)
2. No scattering or spray losses
3. Optimised lubricant quantity for each tool

Disadvantages associated with this process are listed as follows:

1. Special tools required
2. High investment costs
3. Suitability of machine is required

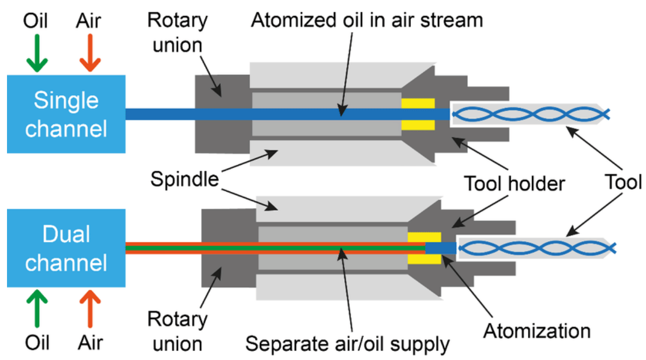

FIG. 7. 1 channel Vs 2 channel systems

Now, upon clearly going through the types of coolant systems, external feed systems are found to be suitable for performing turning operation as its easy to adapt, low cost is involved and no special tools are required.

Design of MQL system for lathe

We require following apparatus for performing MQL in the lab [?]:

1. Manual slide valve
2. Pressure control valve
3. Pressure gauge
4. Reservoir
5. Oil adjustment screw
6. 2/2 way valve
7. Restrictor
8. Spray nozzle
9. Magnetventil

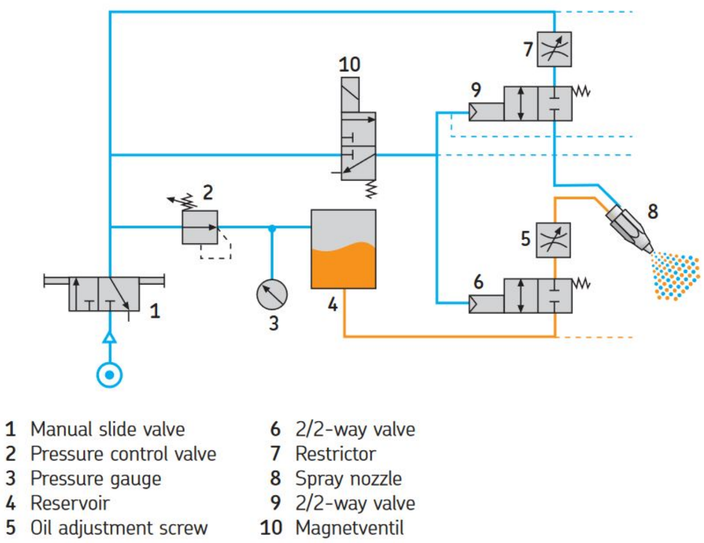

FIG. 8. Basic MQL external flow schematic

Since, the cutting fluid needs to be mixed with the air to make aerosol before its application, proper control over proportions of the two mus be there. Manual slide valve is used for manual switching the air circuit, pressure gauge is used to maintain a required level of pressure in the system, Reservoir is used to store the fluid to be sprayed as an aerosol, oil adjustment screw is used to control the amount of the fluid to be present in the aerosol, restrictor is used to control the flow of input air from the pneumatic port, magnetventil (electric current controlled device) is used to regulate the flow of fluid and finally, spray nozzle is required to spray the aerosol.

The components required to build up needs an pneumatic input from the outside as well and the specifications are shown in the Table.A clamp is required to hold the spray nozzle and keep the nozzle at a correct position, near the interface of the tool and the workpiece. The design the clamp is made using CATIA V5 [9] model as shown is Figure 26. The net design can be used to set-up an MQL for the lathe. The clamping device will be kept on the ground and the arm holding the spray gun will be placed near to the interface of the chip and the workpiece.

TABLE I. MQL supply conditions

S.No.	Parameter	Value
1	Air pressure	Approx. 3 bar
2	Flow rate	Nearly 100ml/hr
3	Lubricant	Micro-emulsion cutting fluid(eg. Yushiro MIC250)

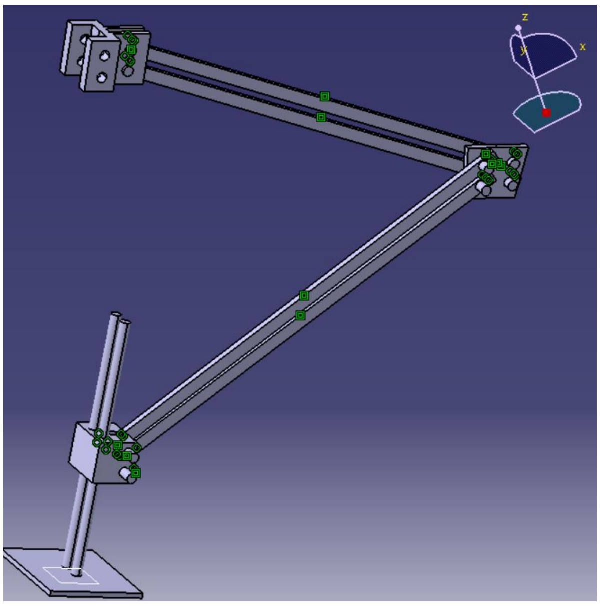

FIG. 9. Clamping device for holding spray gun

The air pressure and the flow rate of the coolant is dependent on the Work specimen material, cutting speed, feed rate, depth of cut and tool used for the cutting. The primary equipments for the fluid flow control can placed inside a metal casing to prevent damage for a long term use.

The proposed idea utilizes the low cost equipment and proves to be having much build-up cost as well as lower maintenance cost. Hence, MQL can be used in our Manufacturing lab as a permanent replacement for the flood coolant type to improve the machining quality and various advantages involved with this process.

II. SECOND QUESTION

What are the difficulties involved in drilling a hole with an aspect ratio 300:1? How can you overcome these difficulties? Does the force or torque in drilling changes as the hole depth increases? Describe methodologies of abrasive finishing in such high aspect ratio holes.

Answer: Drilling is a standard process for producing holes in metallic materials. Spiral drilling is a common and well-known method to generate holes[**?**]. A spiral drill consists of two main cutting edges and a small chisel edge. The forces developed during a drilling operation are the cutting forces, a pair of tangential forces, acting at the cutting edges. These forces are the acting radial forces which are of identical magnitude and counter-balance each other. The location of the drill tip and how the cutting edges are distributed on a drill head characterize whether a drill is balanced or unbalanced.

When the drill tip is located in the center of the drill head an even distribution of the cutting edges is achieved. Symmetry is obtained, resulting in the generated forces balancing each other. Thus no radial or transverse force is developed during an ideal drilling process.

Deep hole drilling is a complex process which is characterized by a high metal removal rate and hole. The process is used when machining holes with a relatively large depth to diameter ratio. When the hole depth increases, the demands on both tools and machining techniques increase. A hole deeper than ten times the diameter can be considered a deep hole which requires a specialized drilling technique. Deep-hole drilling is becoming increasingly more prominent in a variety of applications, such as weaponry, automo-

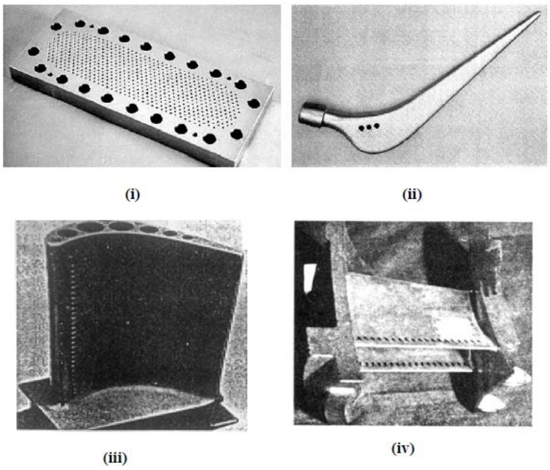

FIG. 10. Applications of deep drilling (i) Small holes in hardened steel, (ii) Hip joint holes in cobalt based superalloy, (iii) Cooling holes in turbine blade of nickel based super alloy, (iv) Cooling holes in gas turbine nozzles segment

bile industries, textile industries, electronic industries, aerospace industries, medical applications etc. When the ratio of depth to diameter (aspect ratio) increases it becomes extremely difficult to manufacture such holes.

Some difficulties regarding deep hole drilling are to overview the various forces acting on the drill during a deep hole drilling operation. A simplified picture of a deep hole drilling tool and the direction of the forces acting on the cutting edges is illustrated by Figure

As in any drilling operation, several things can go wrong like diameter can be incorrect, roughness too big, straightness is lacking, hole is in the 'wrong' location or has incorrect attitude. There are many challenges in the deep drilling process, which include:

1. **Bell mouth:** When the drill enters the workpiece instability can occur which causes the hole at that place to have a 'bell mouth' shape. When the drill enters the material a bit more the instability may stop and the rest of the hole will be drilled properly.

   There's a correlation between early gundrill failure (fatigue crack) and bell mouth formation; both can have a common cause in too much clearance between gundrill and starting bushing. If bell mouth formation is observed and isn't necessarily a problem for the workpiece, measures still have to be taken to prevent early failure of the gundrill.

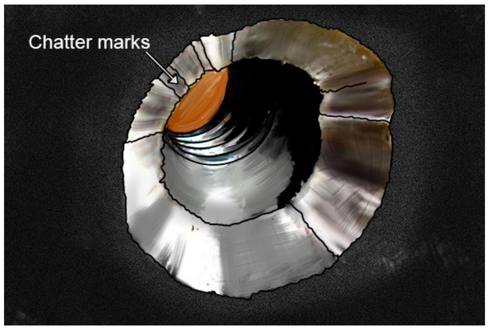

FIG. 11. Chatter in drilling

2. **Chatter:** Chatter vibration of long drills has been investigated using several drills with different overhang lengths and special drills with different pieces of additional as the experimental results showed that the vibration is a regenerative chatter and its frequency is equal to the bending natural frequency of the drill when the drill point is supported in a machined hole. Chatter when drilling can be caused by a variety of problems. Lack of rigidity in the spindle, dull or broken cutting edges, tools that are too sharp, excessive run-out in the drill, side loading, improper speeds and feeds plus on top of all that there may be chips in the bottom of the holes that the drill is skating on.

3. **Spiraling:** Spiraling is another form of dynamic instability which leads to a multi-lobe shaped deviation of the cross section of the hole from absolute roundness. It can be compared to the occurrence of tri-angular and quint-angular holes when spiral drilling plate, with the difference that this non-round section progresses in a spiral through the hole. In general multi-lobe shaped holes result from a circular movement of the center of the rotating tool around the ideal center of the hole where the number of points of contact of the rotating tool with the workpiece determines the number of lobes of the

cross section. The phenomenon is related to the various bending modes of the drill.

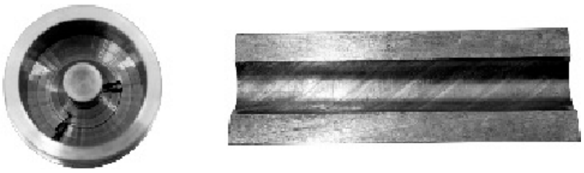

FIG. 12. Spiralling in drilling

4. **Runout Control:** One of the most significant challenges of deep hole drilling is maintaining control of runout, which increases with cutting tool length. Replacing a cutting tool that is 6×diameter in length with one that is 30× diameter, for instance, will result in substantially larger runout. Runout directly influences tool life. So when using small, longer drills, an accurate toolholder on an accurate piece of equipment is important. These effects are amplified further when using longer tools and are more prevalent with micro cutting tools.

5. **Walking:** A common issue when using longer deep hole drills (particularly those in excess 12× diameter) is the drill walking across the part. When attempting to enter the part, because the drill is rotating, it will want to move across the surface of the part rather than drilling downward into it.

6. **Chip control:** Most deep hole drills use internal coolant to assist with chip evacuation. Often, however, internal coolant is not available. The tools diameter may be too small to accommodate internal coolant, such as the case with micro deep hole drills.Application requirements may also prohibit the use of coolant because of material makeup. Also, the machine tool, particularly in the case of older equipment, may not have internal coolant capabilities.

7. **Hole straightness:** The most common cause is the starting bushing that isn't in line with the rotational axis. This causes deflection of the gundrill when entering. The amount of deflection may change during drilling depending upon the misalignment of intermediate support. The margin is the portion of the drill that is actually contacting the hole. A two-margin drill, commonly referred to as a single-margin drill (because it has one margin per flute) is preferred in long chipping materials.

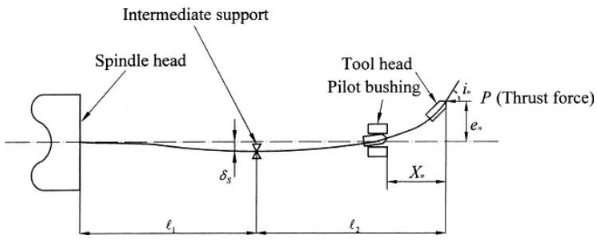

FIG. 13. Hole straightness error in drilling

8. The use of deep hole drills with the unused length accumulates runout and it decreases the level of rigidity of the overall setup. The drills selection is also a challenge in case of high pressure coolant flows. The slower feed rate and rpm reduces the risk of damaging the drills cutting edge.

The difficulties while drilling can be substantially reduced by using various measures, which include:

1. **To improve hole straightness:** The lower number of margins provides additional clearance in the longer chipping materials, allowing the tool to drill that hole in a situation that may not have been possible using a four-margin drill (commonly referred to as a double margin drill). The four margin drill provides excellent hole straightness compared to the two margin drill. The disadvantage is that it has a tendency to break in the longer chipping material. Although not as common, six-margin drills are also available. The additional contact point helps generate an even straighter hole while maintaining a more accurate diameter. So more margins add accuracy while maintaining a higher surface finish, but restrict the amount of clearance for chip evacuation. Another way to improve hole

straightness is to use a series of drills, beginning with a shorter, more rigid one and moving to progressively longer ones.

2. **To prevent walking:** A clean, perpendicular surface is important to help prevent this issue. A cast or rough surface may be manageable with shorter, stubbier (more rigid) drills, but a longer drill will have a higher tendency to walk, which quickly leads to tool breakage. A dull cutting edge also promotes the tendency to walk, so knowing when to resharpen or replace the drill is important. A center drill or pilot drilling improves the accuracy of the drill and provides more guidance to the deep hole drill. When drilling on an incline surface, the drill is likely to walk down the incline. Milling a flat on the surface, and even spot or pilot drilling into the flat can prevent walking. Probability of the breaking of drill's primary cutting edge or even chipping of the corner can be substantially reduced using these procedures.

3. A more accurate method of tool holding, or perhaps a more accurate machine tool, can help to compensate for the increasing runout from longer tools.

4. **To improve chip flow:** The advantage of using internal coolant is that it improves chip evacuation while cooling the cutting edge. Coolant is flushed down to the bottom of the hole, which, in turn, is pushing the chips back up toward the top. Pecking cycle can be used in the case of the external coolant flow and the tool coatings also play an important role in the chip control.

5. Correct amount and location of guiding pads on the drill (supporting continuum is not recommended) and enough whipguides to prevent the drill from bending.

Methods for drilling deep holes upto aspect ratio of 300 is extremely difficult due to the difficulties as seen above. The solutions of the problems may seem to be easy, but while implementing it appears to be far more difficult.

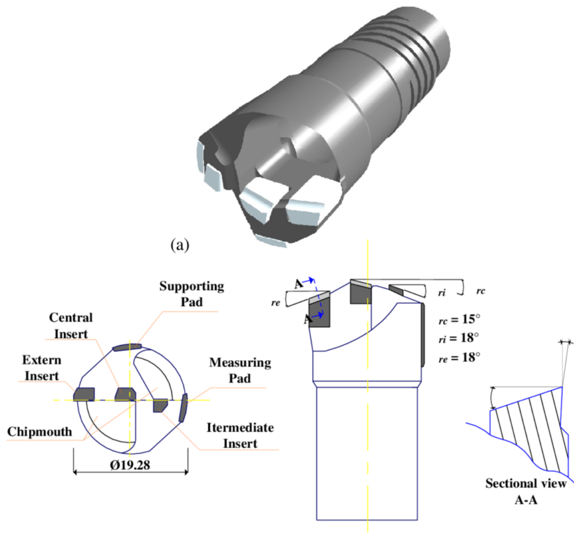

FIG. 14. Pads added in the drill to aid drilling

Only very few methods are capable of making holes of this much aspect ratio, still having some defects involved with them. Traditional method which is able to perform holes of such high aspect ratio is gundrilling.

Gundrilling is one of the oldest, over 150 years old in generally the same form. The gundrill system consists of several parts. Central is the gundrill tool itself[7]. Coolant is pumped through a hole in the inside of the drill to the drilltip where it exists and transports the chips via the outside of the drill (a V groove in the shank) to the chip box, where chips and fluid are separated. The chip box also contains support for the shank of the gundrill to prevent excessive bending and a start bushing that guides the drill during its entry stage. Also present is a seal which prevents leak of fluid to the outside (note that this fluid is under high pressure, up to 200 bar, depending on diameter). In this picture is shown a steady rest to provide support to the workpiece. In the situation above it's the workpiece that rotates, the gundrill itself is stationary; other methods exist, as we shall see later. The tool is held in a tool holder on the machine. This tool holder has a coolant channel inside and guides the fluid into the driver of the gundrill. The gindrill consists of several parts:

1. Tip(made of carbide, either entirely or

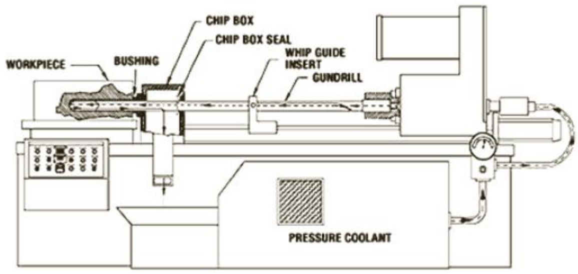

FIG. 15. Schematic diagram of gundrilling

partly)

2. Shank (steel of high yield strength)
3. Driver

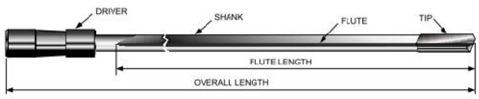

FIG. 16. Gundrill parts

It is not like the usual metal cutting tool, in the sense that it performs two different tasks at the same time: cutting(at the end of the tip) and burnishing (at support pads of the tip). It is because of the burnishing that occurs that the hole has such good surface roughness, which can even be better than may be accomplished with reaming and honing.

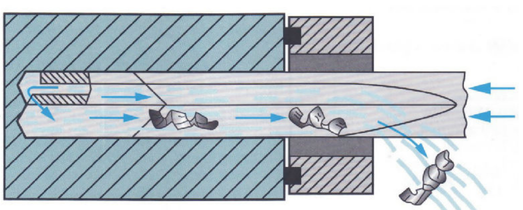

FIG. 17. Chip flow over V groove in gundrill

A nice thing about the gundrill is that it is capable of producing holes that are burr-free, so no subsequent operation is necessary to remove the burr. This also leads to less risk of machine operators cutting themselves accidentally and thus bleeding to death. Gundrilling can be used for drilling in a wide variety of materials, from plastics like Teflon and composites like fibreglass, to special high-strength die and mould materials like P20 and Inconel. Cast iron, aluminum, brass, molybdenum, steel, heat-treated stainless, polycarbonates, plastics, and many other materials too tough to spiral drill normally are easily gundrilled. Materials with a hardness of up to 46 HRC can be drilled. Even though, there are many advantages of gundrilling, many disadvantages include: relatively low productivity due to slow feeds, difficulties in re-sharpening of long gundrills of small diameters and it requires higher coolant pressure.

Advancement of this process has resulted into two new processes: STS system and ejector system.

STS is the abbreviation of 'Single Tube System', while BTA stands for 'Boring and Trepanning Association'. Both names are used to describe the same process.

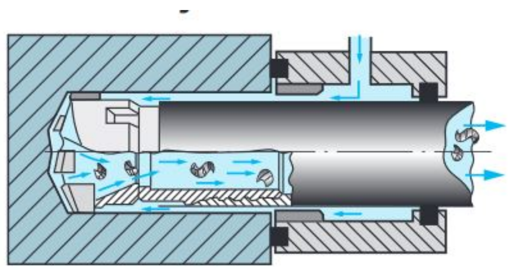

FIG. 18. STS/BTA system

The main difference between the various deep-hole drilling systems is fluid-flow and chip removal. Fluid enters the drill through the inlet in the pressure head, from where it is transported via the outside of the drill (with the wall of the bore acting as a pipe) to the cutting area. There it flows over the cutting edges, picks up the chips (while in the process cooling the area) after which the swarf is transported via the inside of the tube to the chip box. This is a difference with gundrilling where the chips were transported via the outside of the drill, the flute. Another difference is that seals are needed; one between the drill and fluid coupler and a seal between the workpiece and fluid coupler (this last seal has to withstand high pressure and high rotational speeds).

The advantage of this system is that this process can produce higher aspect ratio holes, but the major disadvantage of this system is that it can't be used for small diameters and coolant flow pressure required is even more that gun-drilling.

Another newer version is **Ejector system** looks a bit like the STS system, but differs in the way the fluid is supplied: the boring bar and the drill consist of two coaxial tubes. The drilling fluid to the drill head is supplied through the annular clearance between the boring bar and the inner tube; chips and fluid are removed through the inner tube, like in the STS system. The torque of the drill is mainly taken up by the outer tube.

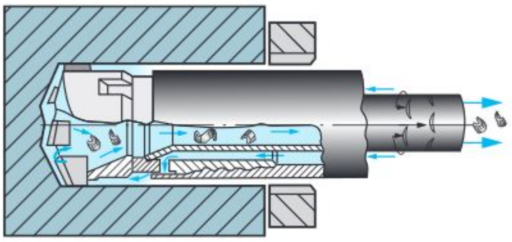

FIG. 19. Ejector system

The advantage of it is that it can more easily be retrofitted to machines than the STS/BTA system. This is because no seal is needed between workpiece and drill: the outer tube of the Ejector system negates the need for it, which makes this system more easy to retrofit. The STS system can only be used on special deep hole drilling machines, whereas the Ejector system can be used on deep hole drilling machines, NC machines, lathes, most conventional machines and machining centers.

Other that traditional drilling processes, non-traditional process used to make deep holes is **Shaped Electrolytic Machining (STEM)**. A highly specialized adaptation of electrochemical machining (ECM), known as Shaped Tub Electrolytic Machining(STEM) is used for drilling small, deep holes in electrically conductive materials. This process was primarily developed for generating high aspect ratio round and shaped holes in turbine engine airfoils.

Shaped-tube electrolytic machining is a non

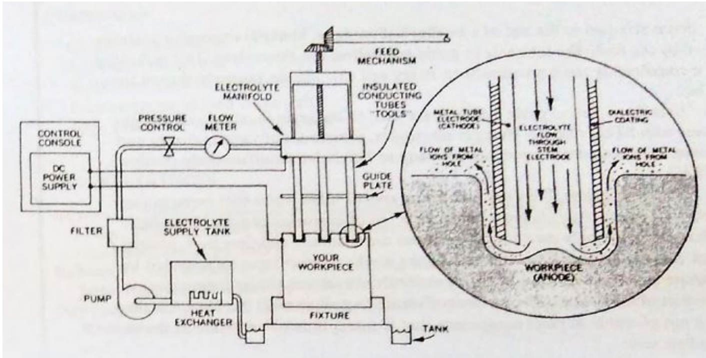

FIG. 20. Schematic diagram of STEM process

contact electrochemical-drilling process that distinguishes itself from all other drilling processes by its ability to produce holes with aspect ratios up to 300:1. Being an electrochemical process, STEM is unaffected by either material hardness or toughness. It uses an acid-based electrolyte instead of the salt electrolytes normally incorporated in ECM. The use of acid electrolytes ensures that the metal sludge by products from the electrolytic deplating are dissolved and carried away as metal ions. This eliminates clogging of the electrolyte flow path around the electrode, an important feature when drilling deep holes. A STEM electrode is a hollow, shaped tube that is covered with a thin organic coating on all surfaces except at the tip. The insulating coating protects the electrode from the corrosive effects of the acid and isolates the electrolytic action to the front surface of the electrode. Through the combination of acid electrolytes and coated electrodes, STEM drilling is uniquely able to produce high aspect ratio holes in electrically conductive materials. Major advantage of this method include: aspect ratio upto 300:1, no burrs, long tool life, not affected by material hardness and no induced stresses. However, some of the disadvantages are also associated with this process like corrosive electrolyte, expensive electrode, workpiece must be conductive and high preventive maintenance cost.

Turbine blades and nozzle guide vanes usually have several small diameter cooling channel holes, with diameters as small as 0.8 mm and aspect ratios as large as 300[6]. Because of

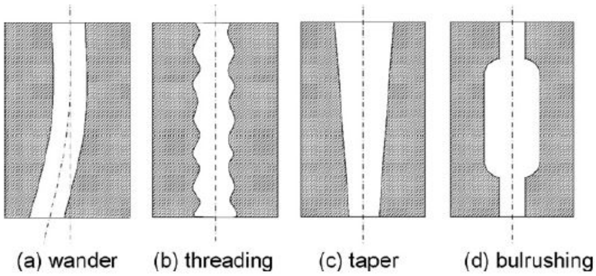

FIG. 21. Defects in shaped tube electrolytic machining

these large aspect ratios, processes such as laser beam machining, electron beam machining and conventional drilling are unsuitable for producing these holes. The most suitable process is shaped tube electrolytic machining (STEM) as there are no residual stresses in the work-piece and no cutting forces acting on the slender tool. The prominent defects that appears while doing deep drilling are given as follows:

1. **Drill wander:** Occasionally the drill deviates from the desired path and in extreme circumstances even breaks out into the blade surface or adjacent hole. The drill derives its stiffness from the electrolyte pressure and hence, at low pressures, it is prone to wander.

2. **Threading:** Sometimes the hole may exhibit a repetitive pattern of diameter variation which is reminiscent of a threaded hole. It is seen to occur at high electrolyte pressures.

3. **Hole inaccuracy:** The two main types of inaccuracies are hole taper and deviations from the required hole size. Another type of defect is longitudinal striations which are associated with hydrodynamic flow patterns.

4. **Drill bending:** There are two possible causes for its occurrence. In the first case, due to a combination of high feedrates and low voltages, short circuits can occur, leading to drill bending which can be corrected by replacing or straightening the drill. In the second case, the use of reverse voltage causes the drill to wear. If this wear is excessive, the overcut is progressively reduced leading to drill clamping and bending of the drill.

5. **Bulrushing:** This defect appears as a sudden local increase in the hole diameter . The reason for its occurrence is not fully known but it is believed to be linked with high pressures and low feedrates.

Cutting forces and torque

Geometric design varies between different types of drills. When the drill tip is located in the center, symmetry is obtained and the cutting forces balance each other out. The cutting speed decreases from the periphery in towards the center, where the drill tip is virtually stationary and is pushed into the material. This problem can be avoided by inward inclination of the center part. The clearance on the insert increases and the axial pressure on the drill tip is considerably reduced. The asymmetric geometry which is obtained means that the cutting forces do not balance each other out.

An unbalanced drill is characterized by an unsymmetrical distribution of the cutting edges on the drill head. The asymmetrical distribution of cutting edges gives arise to a resultant radial force which pushes the drill in a radial direction during a drilling operation. To counterbalance the resultant radial force and stabilize the tool, the tool is supplied with a number of pads. The main role of the pads is to absorb the resultant radial force generated by the cutting edges and stabilizing the tool.[8] The tangential

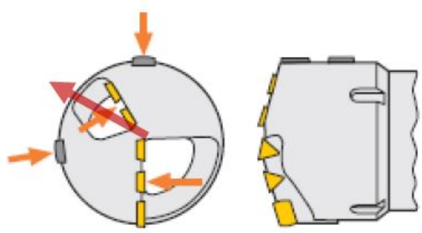

FIG. 22. Forces acting on a deep hole drill. The orange arrows illustrate the acting forces on inserts and pads and the red arrow illustrates the acting resultant radial force.

cutting force F_c causes the torque M_c and F_d is the radial force that acts on the guide pad. The cutting forces can be determined experimentally.

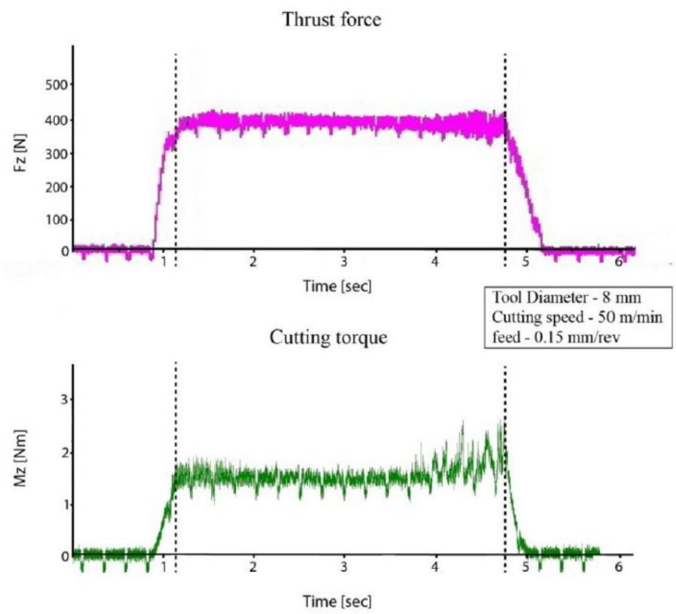

FIG. 23. Variation of forces and torque with hole depth

The variation of the torque and the forces is seen to slightly increasing with the increase in the hole depth [4]. As the hole depth increases, the variation in the torque value is appearing to be greater, suggesting that the radial forces increases with the hole depth. This can be accounted as when the drillbit goes more deeper, there can be a wobbling action coming into picture, due to which, the radial forces increases. A prominent increase in torque in experimental values with the depth is considered to be major contributor to the tool failure for deep hole drilling. However, the thrust force is nearly constant throughout, but, slight increase is seen here also. This slight increase is also accounted by the component of the force generated during wobbling in the radial direction.

Abrasive finishing of the holes

The abrasive finishing of the holes can be made with the help of methods like: Abrasive Flow Finishing (AFF), Magnetic Abrasive Finishing (MAF) and Magnetorheological Abrasive Flow Finishing (MRAFF). These process can be used for the deep holes as well with certain modifications in the parameters of the process.

In the Abrasive flow finishing machining, a semi-solid, abrasive laden putty is used which is passed through or across the workpiece removing smal quantity of material[3]. A hydraulic ram forces the abrasive medium through the workpiece. As abrasive medium flows through the part, its velocity will change with the change with the different cross sectional areas. Due to its low MRR, it is not suited for mass material removal. I is used for finishing in metals, ceramics, and many plastics in uniform and economical manner. It can be further classified into one way, two way and orbital AFM. AFM is able to

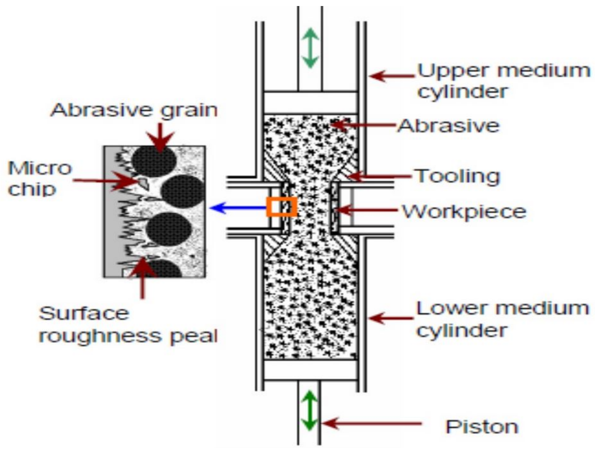

FIG. 24. Abrasive Flow finishing process

increase the surface smoothness upto 10 times. The limit for best surface finish is 0.05 microns. Holes must be of diameter 0.2mm for effective processing. Although, it has good finish in one operation and it is a fast and can finish inaccessible areas, but, it is capital intensive and cannot process blind holes.

In Magnetic Abrasive Finishing, the process is capable of doing precision finishing of the material [2]. Since, this process does not require direct contact with the tool, the particles can be introduced into areas which are hard to reach by conventional techniques. It can be used to do finishing of the holes having high aspect ratio with the help of alternating magnetic and non-magnetic regions. The use of the multipole tip system with tool and alternating magnetic region for MAF process. MAF can be performed in different ways, depending on the type of magnetic field like permanent magnet, direct current and alternating current.

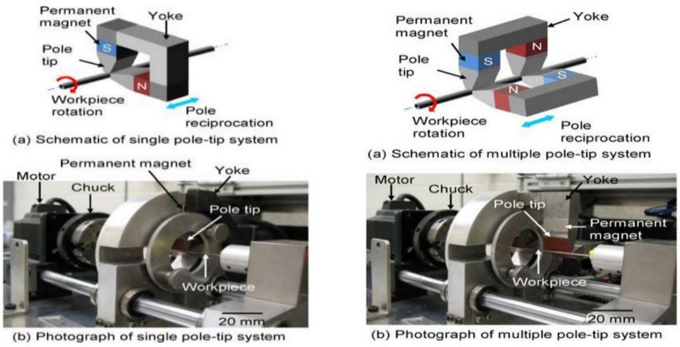

FIG. 25. MAF system for holes

Now, the process named as Megnetorheological abrasive flow finishing (MRAFF) process provides better control over rheological properties of abrasive magnetorheological finishing medium[1]. Magnetorheological (MR) polishing fluid comprises of carbonyl iron powder and silicon carbide abrasives dispersed in the viscoplastic base of grease and mineral oil; it exhibits change in rheological behaviour in presence of external magnetic field. This smart behaviour of the MR-polishing fluid is utilized to precisely control the finishing forces, hence final surface finish. In MRAFF process, MRPF is extruded

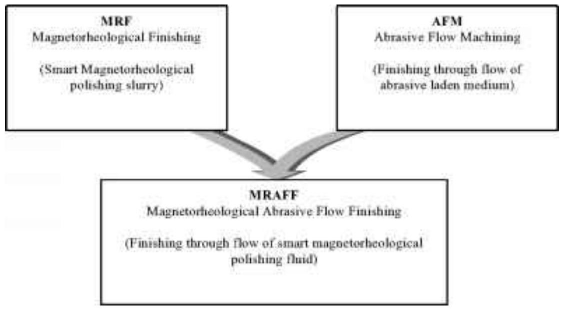

FIG. 26. Magnetorheological Abrasive Flow Finishing

through the workpiece passage to be finished utilising two opposed cast iron cylinders under the presence of external magnetic field[1]. The viscosity of smart magnetorheological polishing fluid (MRPF) is a function of applied magnetic field strength, and it is varied according to the desire finishing characteristics. In MRAFF process, a magnetically stiffened slug of MRP fluid is extruded back and forth through or across the passage formed by workpiece and fixture. Abrasion occurs selectively only where the magnetic field is applied across the workpiece surface, keeping the other areas unaffected.

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