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INTELLIGENT COOLING SYSTEM FOR MACHINING

A H M Fazle Elahi[1,*] , Zinat Ara Nisha[2] and Imam-Ul-Ferdous[3]

[1, 3]Department of Mechanical Engineering,
Khulna University of Engineering & Technology, Khulna-9203, Bangladesh
[2]Department of Electrical & Electronics Engineering,
University of Dhaka, Dhaka-1000, Bangladesh
[1,*]fazle.elahi.ashek@gmail.com, [2]zinat.ara.nisha@gmail.com, [3]imam.ul.ferdous@gmail.com

Abstract*- Machining operation involves the removal of material and in friction cutting high temperature is developed. Such high temperature often lead to several problems like high tool wear, change in hardness and microstructure of the work-piece, burning and its consequence to micro cracks. Cutting fluid related costs and health concerns associated with exposure to cutting fluid mist and a growing desire to achieve environmental sustainability in manufacturing have caused industry and academia to re-examine the role of these fluids and quantify their benefits. Application of cutting fluid by conventional process reduces the above problems to some extent through cooling and lubrication of the cutting zone, though the wastage of cutting fluid is profuse. So a new efficient process has been introduced to improve the cutting zone and be economical in coolant use. The Intelligent Cooling System (ICS) has been used to corroborate the machining environment by reducing the cutting zone temperature as to less use of coolant. This system includes temperature sensors to detect cutting zone temperature and the integrated Arduino micro-controller then open the solenoid valve to supply the fluid as a continuous spray. In this work related parameters has been experimented along with the amount of coolant use in order to reach a conclusion about the performance of newly executed technique compared to similar purpose methods.*

Keywords: Intelligent Cooling, Machining, Pulsed jet cooling, Minimal Quantity Lubrication (MQL), Comparison of cooling methods, Cutting fluid.

1. INTRODUCTION

Recently, the concept of hard turning has gained considerable attention in metal cutting as it can apparently replace the traditional process cycle of turning, heat treating, and finish grinding for assembly of hardened wear-resistant steel parts. Hard turning can possibly facilitate low process cost, low process time, better surface quality, and lower waste. (1) Cutting fluids are employed in machining to reduce friction, cool the work piece and wash away the chips. With the application of cutting fluid, the tool wear reduces and machined surface quality improves. Often the cutting fluids also protect the machined surface from corrosion. They also minimize the cutting forces thus saving the energy. There are mainly two types of cutting fluids used in machining (I) neat oils or straight cutting oils (II) water-mix fluids. (2) Neat oils are based on mineral oils and used for the metal cutting without further dilution. They are generally blends of mineral oils and other additives. The most commonly used additives are fatty materials, chlorinated paraffin, sulfurized oils, and free sulfur. Sometimes organic phosphorous compounds are also used as additives. Extreme pressure additives containing Chlorine, sulfur, or phosphorous react in the tool–chip interface producing metallic chlorides, phosphates, and sulfides, thus protecting the cutting edge (3). Neat oils provide very good lubrication but poor cooling. Water-mix fluids are of three types (a) emulsified oils (b) pure synthetic fluids (c) semisynthetic fluids. Emulsified oils form an emulsion when mixed with water. They are used in a diluted form with concentration of 3–10%. (4) Increasing of productivity is impossible without utilization of modern tools and machines, modern types of cooling and lubrication fluids (CLF), CLF dosing techniques, and modern equipment. From the structure of the cost of machined part, it can be concluded that the cost of CLF participate 15 %, costs of tools 10 % and costs of energy consumption 4 % of total costs. (4)The structure of the machining related cost is depicted in Fig 1.

So the productivity can be increased by reducing the cost of coolant and the tool. In order to get the goal pulsed jet cooling has been invented by researchers where a mist of coolant is supplied intermittently. However, the pulsed jet cooling is somewhat not efficient for hard metals as the coolant flow occurs after certain intervals. Time gap between two spray increase the cutting zone temperature which render almost same consequences as dry machining. Whereas in intelligent cooling sensors detect the temperature and switch the valve to supply fluid, hence any material can be machined without having any difficulty of coolant system.

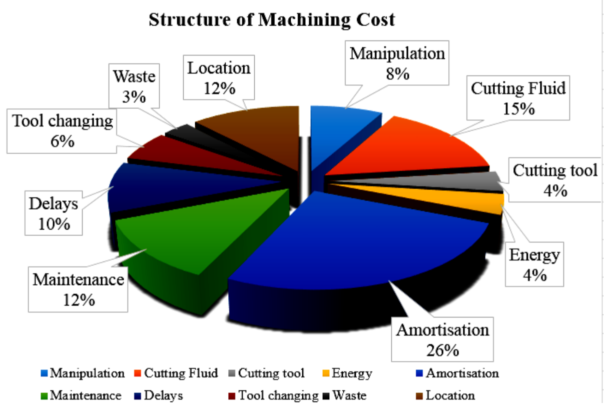

Fig 1: Structure of machining cost by percentage

When a cutting fluid provides lubrication to a machining process, it serves to reduce friction levels and thus moderate increases in temperature (5). For many machining operations, however, the principal role of the cutting fluid is to remove heat during the process, especially from the zones indicated in Fig 2.

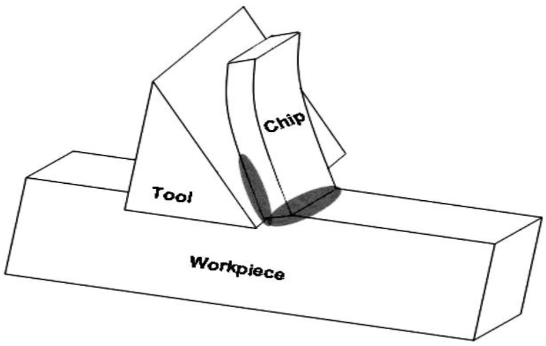

Fig 2: Area of heat generation due to friction in the cutting zone

Previous research has examined the perceived benefits of cutting fluids across a wide variety of cases. It has also cast some doubts on the necessity of cutting fluid use in some machining processes and under certain conditions. Fluid-related costs are large because high production manufacturing plants frequently utilize several cutting fluid reservoirs each containing thousands of gallons of cutting fluid, and often an entire reservoir is flushed to clean the system when quality issues arise (6) – certainly, reducing the amount of fluid employed can produce significant cost and waste savings. Extensive use of cutting fluids in machining operations leads to a sizeable waste stream. Responsible handling of used/waste fluid is needed to avoid the contamination of lakes, rivers, and groundwater. In addition to the environmental challenges of managing a used cutting fluid waste stream, cutting fluids also introduce several health/safety concerns. The National Institute for Occupational Safety and Health (NIOSH) estimates that 1.2 million workers involved in machining, forming, and other metalworking operations are exposed to metalworking fluids annually (7). Dermal exposure to these fluids represents a health concern, as does the inhalation of airborne fluid particulate. (8) The application of cutting fluids within a machining operation often produces an airborne mist, and medical evidence has linked worker exposure to cutting fluid mist with respiratory ailments and several types of cancer (9). This makes the use of cutting fluids a health issue with the potential of both long and short-term consequences.

2. METHODOLOGY

A dual chamber fluid reservoir has been used to store and supply the cutting fluid through a piping. Before staring the operation some cubes of ice has been put on the fluid chamber to increase the cooling capacity of the lubricant. As the liquid is a water based coolant the melted water does not damage any property of the cutting fluid. The force of the fluid flow is generated by compressed air. A regulating valve is integrated in the long lining of fluid flow thus the proportion of fluid and air mixture can be controlled. An air compressor has been used to get the compressed air for this purpose and also for creating mist at the mixing nozzle. The Nozzle consists of two inputs and one output. Cutting fluid and compressed air got in by the inputs and a spray of mist spray out by the output. The whole system has been controlled by the Arduino micro-controller system. A solenoid valve, thermal infrared sensors and logic control circuit has been connected to the reservoir system. Thermal sensors detect the temperature of the cutting zone without contact and switch on or off the solenoid valve to deliver the coolant. The triggering temperature can be defined by the logic control program, so any kind of material hard or ductile is executable by the same system. Fig 3 illustrates the flow diagram of the total coolant flow organization.

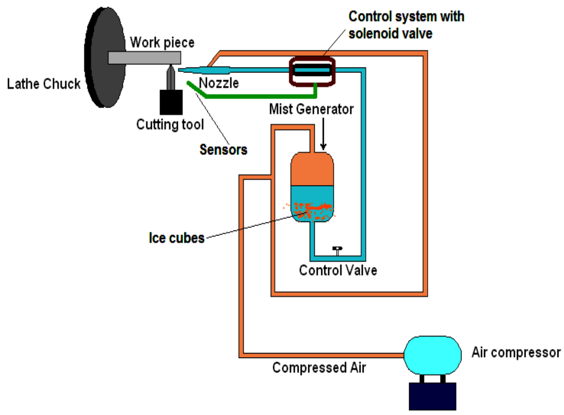

Fig 3: Flow diagram of the coolant supply

3. DESIGN AND CONSTRUCTION

3.1 MECHANICAL SYSTEM

Experiments were conducted in a horizontal lathe machine with 25mm diameter and 200mm long work-piece. The cutting tools selected were PVD coated carbide inserts (ACZ310, Sumitomo Electric Hard metal, Japan). The work-piece chosen was AISI 01 compliant hardened tool steel (ASSAB DF3) having a chemical composition of 0.95% C, 0.11% Mn, 0.6% Cr, 0.6% W and 0.1% V. (10) Cutting Conditions: (i) Spindle speed 175rpm, 225rpm, 280rpm, 350rpm. (ii) Cutting velocity 15m/min to 45m/min. (iii) Depth of cut 0.4mm, 0.6mm, 0.8mm, 1.0mm, 1.2mm. Applied cutting fluid has been stored with ice cubes in the reservoir and is conventionally known as Diode-sol- M. It was mixed with water by the ratio of 1:8 for use. Table 1 illustrates the characteristics of the coolant. (11)

Table 1: characteristics of the coolant used for experiment

Name	Diode-sol-M
Appearance	Clear
Volumetric mass at 15ºC	972
Color	3.0
Viscosity at 40ºC	39
Flash point	188
5% emulsion in 200ppm HW:-pH	9.1
Solution water type	Emulsion
Appearance	Milky white
Filter/ Chip Corrosion Test	Stain (5%)
Initial Foam (0 min)	10
Collapse Time	15 sec-nil

The following figure Fig 4 is of final system setup.

Fig 4: Final construction image

3.2 CONTROL SYSTEM DESIGN

Control system includes a solenoid valve and the Arduino control circuit. IR thermal sensor has been used to detect the cutting zone temperature without having any contact. (12) IR temperature sensor with laser marking for metal, ceramic and lustrous targets having a range of 0 – 2000 ^{0}C, optics 150:1, and spectral range 1 / 1, 6 µm has been calibrated for this purpose. When the prescribed temperature 120ºC get passed by the machining zone temperature the solenoid valve switched on and the fluid starts to flow. The program of the micro-controller has been designed in such a way that when the input temperature goes up to 120ºC the valve will be open continuously and if the temperature stand still at 120ºC, the valve will act as a pulsed jet device so it will open and close after 2 sec interval. This supply of coolant continues until the cutting zone temperature goes down to the safe temperature. A LED is placed on the circuit to indicate whether the temperature is in safe zone. The following flow chart Fig 5 shows the logical interpretation of the control circuit.

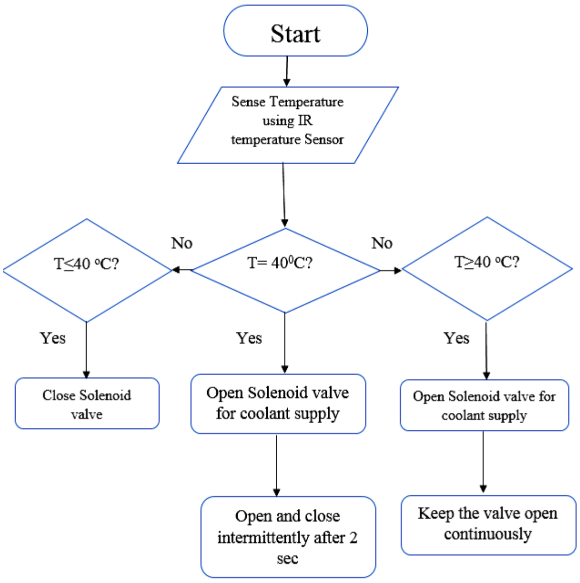

Fig. 5: Flow chart of the control logic

4. RESULT ANALYSIS

I. Tool wear:

It is the amount of metal shrank from the tool point to a degree which eventually causes distorted operation on the work-piece. When cutting velocity is high as 120 m/min, the chip makes fully plastic or bulk contact with the tool rake surface and prevents any fluid from entering into the hot chip- tool interface. This will results in high cutting force. When cutting velocity is less, feed and depth of cut is more the cutting force will be more. Lubricant or cutting fluid mitigates the effects of friction as to heat generation on the cutting zone. Fig. 6 depicts the average tool wear for the experimental conditions respective to different cutting conditions. It is evident that in the Flood cooling condition (A) the tool wear is maximum and intelligent coolant supply minimizes that tearing down of tool. Hence improve tool life as to machining performance.

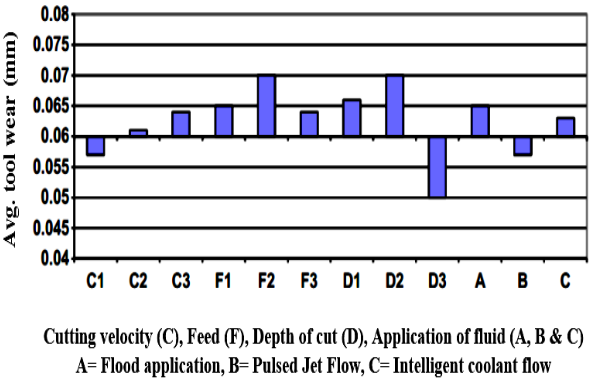

Fig.6: Pictorial view of tool wear in various machining condition (12)

II. Temperature variation with the change in depth of cut:

Temperature is the key parameter of the cutting zone as all operations performed in the machine engender heat and increase temperature. This heat or temperature is involved in the development of high friction, residual stress, deformation of both tool and work piece and high surface roughness. In Fig. 7 it is apparent that intelligent cooling of cutting zone render most consistent temperature control over flood or pulsed jet system. When the IR sensor detect a temperature of 40°C or higher it opens the valve to deliver fluid. This fluid is mixed up with ice at the reservoir so it is much cooler than the cutting zone temperature. Thus the coolant takes away a lot of heat and reduces the machining temperature. In case of flood cooling a large amount of coolant wasted away but carry less heat because of the specific heat of water. In the occasion of pulsed jet and intelligent cooling the lubricant is supplied in the form of mist so it can carry a lot of heat with it. Furthermore the intermittent cooling of pulsed jet provides same amount of mist after certain interval which cannot handle capricious temperature changes due to high depth of cut or other machining conditions.

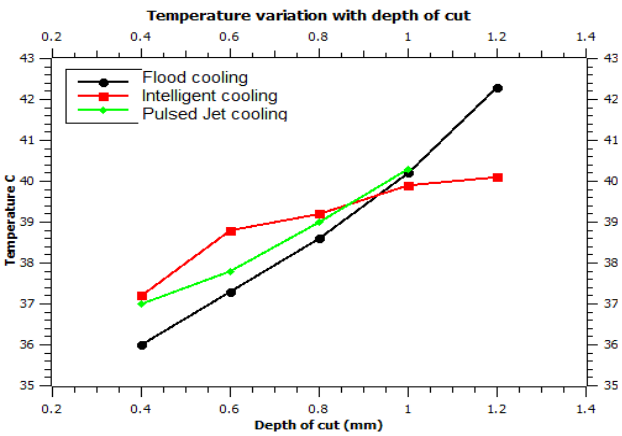

Fig. 7: Variation of temperature for different depth of cut

III. Surface roughness

Surface roughness is directly related to the cutting edge of the tool and the chip removal along with the machinability index of the cutting forces. Fig. 8 substantiate the effectiveness of the intelligent cooling system. The flood cooling and pulsed jet cooling reduce the surface roughness though not as appositely as the intelligent system. In the advanced intelligent coolant supply method maximum surface roughness found is 18 µm. whereas the value is 23 µm & 19 µm for flood and pulsed jet cooling respectively.

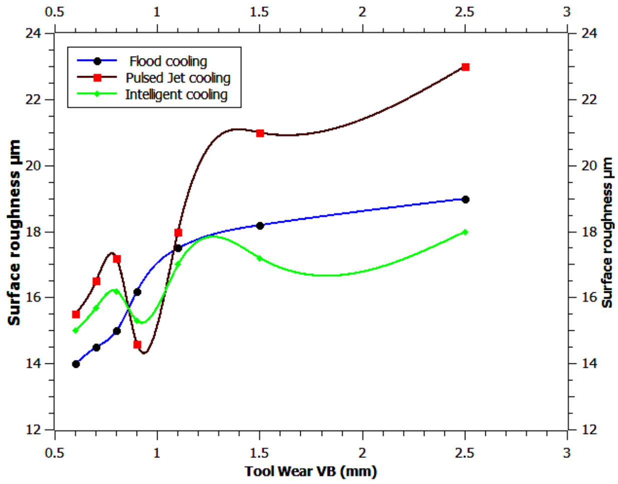

Fig. 8: Surface roughness trend due to tool wear

IV. Tool life

It is also dependent on the temperature of the cutting zone and the feed rate and depth of cut. Tool life can be increased by reducing the cutting zone temperature which has been done here by using cold cutting fluid in the form of mist according to the system requirement. Fig. 9 illustrates the flood coolant flow provides maximum tool life than other two, however the wastage of fluid is high in the conventional flood cooling. Compared to the pulsed jet cooling, intelligent coolant flow offers more tool life.

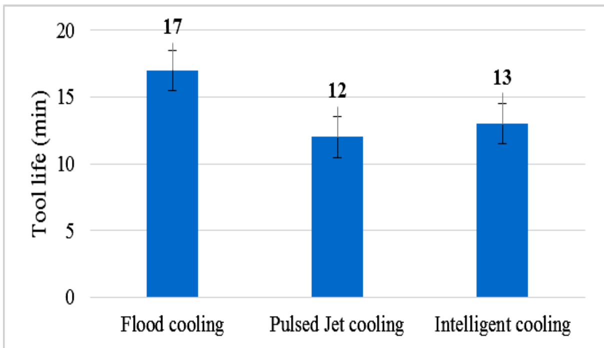

Fig. 9: Different tool life measured in three cooling method

V. Amount of coolant used

The key and desired parameter of the experiment is to find the coolant needed for some analogous coolant supply method. Because in conventional flood cooling large amount of liquid get away without taking any heat which eventually cost higher machining cost. Fig. 10

depicts the amount needed for the three types of cooling and it is apparent that the flood cooling takes a lot more amount than other two method. Only 21 ml/min coolant flow is needed on average of 1 hour time for delivering coolant to the machining zone. Though the amount is a bit higher than pulsed jet coolant, the overall performance of the proposed method facilitates us to demonstrate the better phenomena.

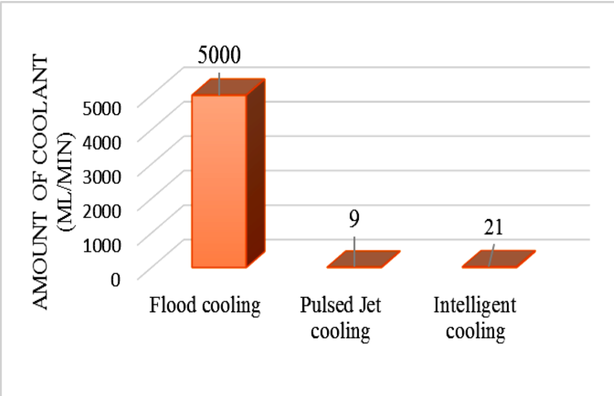

Fig. 10: amount of coolant applied for various coolant supply method

5. CONCLUSION

Industrial operation depends upon machinability on a large scale. An extensive examination of the functions of cutting fluids and interactions with other machining system components has led to a general understanding of the roles that cutting fluids play in a metal cutting process. It is manifest on comparing those conventional cooling models with the novel method that proposed coolant supply practice would be more economical and convenient for manufacturing industry. Based on experimental conclusions the process original cost effective lubrication could be asserted as the optimum. Though future research will be performed on low cost hybrid machining. Environmental and health hazards due to the over usage of the cutting liquids will be a key concern for the further study.

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