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Full Length Article

Study on the influence of fluid application parameters on tool vibration and cutting performance during turning of hardened steel

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ABSTRACT

Recently the concept of hard turning has gained much attention in the metal cutting industry. In hard turning, multiple operations can be performed in single step, thereby it replaces the traditional process cycle. But it involves very large quantities of cutting fluid. Procurement, storage and disposal of cutting fluid involve expenses and environmental problem. Pure dry turning is a solution to this problem as it does not require any cutting fluid at all. But pure dry turning requires ultra hard cutting tools and extremely rigid machine tools, and also it is difficult to implement in the existing shop floor as the machine tool may not be rigid enough to support hard turning. In this context, turning with minimal fluid application is a viable alternative wherein, extremely small quantities of cutting fluid are introduced at critical contact zones as high velocity pulsing slugs, so that for all practical purposes it resembles pure dry turning and at the same time free from all the problems related to large scale use of cutting fluid as in conventional wet turning. In this study, fluid application parameters that characterize the minimal fluid application scheme were optimized and its effect on cutting performance and tool vibration was studied. From the results, it was observed that minimal fluid application in the optimized mode brought forth low vibration levels and better cutting performance.

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1. Introduction

Conventionally when parts requiring high hardness as functional requirement are to be machined, the work piece is turned to the near net shape, hardened to the required hardness and ground to the final dimension. This lengthy process cycle can be avoided if the hardened work piece is directly turned to the final dimension. This is possible by hard turning. In hard machining, multiple operations can be done in one step, complex part contours are adapted easily and has high metal removal rate [1]. Also the nature of chip formation in hard machining is quite different from that of conventional machining. But hard turning involves very large quantities of cutting fluid, requires rigid cutting systems and superior cutting tools like CBN or ceramic tools. Procurement, storage and disposal of cutting fluid involve expenses and it has to comply with environmental legislation such as OSHA as well.

Uzi Landman [2] reported that the frictional forces between two sliding surfaces can be reduced by rapidly fluctuating the width of the lubricant filled gap separating them. This principle was used in developing the minimal cutting fluid application system by Varadarajan et al. [3]. They found that when a high velocity narrow pulsing slug of cutting fluid is used, the width of the lubricant filled gap between the tool rake face and chip varied and will reduce cutting temperature effectively. Vikram Kumar and Ramamoorthy [4] continued investigations on turning of AISI 4340 steel of hardness 35 HRC using the same technique. In their investigation, they compared the performance of different types of TiCN and ZrN coated carbide tools during turning of hardened steel with conventional wet turning and turning with minimal fluid application by varying the speed and feed. From the results it was found that the overall performance of the cutting tools during minimal cutting fluid application was superior to that during dry turning and conventional wet turning on the basis of parameters such as cutting force and surface finish. Similar results were obtained during an investigative study on the comparative performance of TiCN and TiAlN coated tools during turning of AISI 4340 hardened steel under the same conditions. Also from literature it was observed that the machining performance during minimal fluid application was very much influenced by nozzle exit pressure and the quantity of cutting fluid [5].

Thepsonthi et al. [6] explored the performance of minimal cutting fluid application in pulsed-jet form during high speed end milling of hardened steel using coated carbide ball end mill. The results

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indicated that the use of such a system can bring forth better machining performance in terms of cutting force, tool life and surface finish when compared to flooding and dry machining. Controlling the amount of cutting fluid delivered can enhance specific machining performance with decreasing costs and environmental impacts [7]. Also it was observed that metal working fluids account for 3% of the cost of most machining processes.

In hard turning, the presence of tool vibration is a major factor which leads to poor surface finish, cutting tool damage, increase in tool wear and unacceptable noise. In metal cutting, dampers were employed to suppress tool vibration and to improve cutting performance [8–13]. Even though the usage of dampers is effective, its design and fabrication takes more time and investment. In literature, researchers have successfully used coatings like Balinit Hardlube and Balinit Tri-ton DLC to improve cutting performance and to eliminate the need of cutting fluids during dry drilling of aluminium alloys [14]. Also Rivero et al. [15] developed an on-line sensorless tool wear monitoring system during high-speed milling of aluminium alloys and they confirmed the relevance of cutting force signals for tool wear monitoring. Abuthakeer et al. [16] studied the effect of spindle vibration on surface roughness of workpiece in dry turning using ANN. Instead of using damper and coated material, a scheme which resembles dry turning, free from pollution problem and produces tortuous damping effect in metal cutting was thought of to improve its effectiveness. Hence in this investigation, an attempt was made to develop a special fluid delivery system which can supply minimal cutting fluid at a high velocity in pulsed mode and also to study the effect of fluid application parameters on tool vibration and cutting performance during turning of hardened AISI4340 steel. Rate of fluid application, frequency of pulsing and the pressure at the fluid injector are considered as the fluid application parameters. A set of fluid application parameters are to be identified that will reduce tool vibration and bring forth better cutting performance in terms of tool wear, surface finish, cutting temperature and cutting force during turning of hardened steel. Also an attempt was made to compare the cutting performance obtained during hard turning using minimal fluid application with dry and conventional wet turning.

2. Development of a minimal fluid applicator

The minimal fluid applicator system consists of a fuel pump (Bosch type) with four cylinder compression ignition engine which is coupled to an infinitely variable electric drive. The fuel pump has a plunger with helical groove which can rotate about its axis and the degree of rotation of plunger determines the quantity of fluid delivered per stroke. There is a provision for rotating the plunger so that the quantity of fluid delivered per stroke can be controlled accurately. A specially formulated cutting fluid can be applied at critical locations such as tool–work interface and the tool–chip interface in the form of a high velocity, narrow pulsed jet through a fluid injector nozzle with a specification DN0SD151 and a spray angle of 0°. When a high velocity narrow pulsing jet is used instead of a continuous jet, better cutting performance could be achieved. This is due to the fact that when a pulsing jet is used, the width of the lubricant filled gap between the tool rake face and the chip fluctuates with a frequency equal to the frequency of pulsing of the fluid jet [17]. This technique involves cutting fluid particles of very high velocity (about 70 m/s) that tend to penetrate the critical zones rather than float in the air as in most of MQL applications [18]. The plunger reciprocates as the motor rotates and delivers one pulse of cutting fluid for each revolution through the fluid injector. The fluid coming out of the injector consists of myriads of tiny droplets (Fig. 1), the velocity of which depends upon the pressure set at the fluid injector nozzle. The higher the pressure, the higher will be the velocity of the individual particles. Size of the particle delivered through fluid injection is calculated using equation (1). It was found that for the parameters selected in this study, the average size of fluid particles was 83.9 µm and the thickness of the formed covering was 0.9 mm.

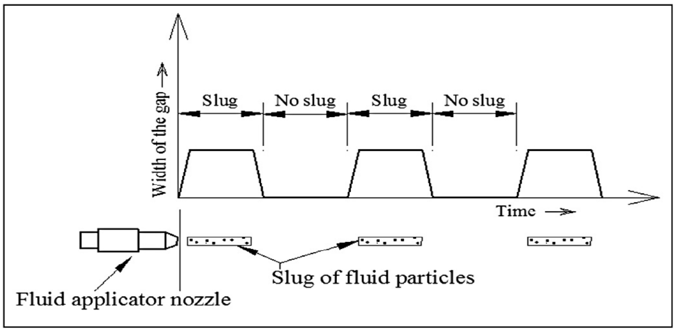

Fig. 1. Schematic view of pulsing slug of cutting fluid.

$$D = 1.44 d_o (W_e M)^{-0.266} (L_P)^{-0.0733} \quad (1)$$

In the fluid application system developed it is possible to vary the pressure, frequency of pulsing and rate of delivery independently. For any pressure at the fluid injector, a required rate of fluid application can be maintained at any desired frequency of pulsing. The system can supply a pulsing slug of cutting fluid at four locations in the same machine tool or to four separate machine tools simultaneously. In this investigation, a specially formulated mineral oil based cutting fluid which acted as an oil in water emulsion was applied as a narrow pulsed slug at tool work interface. The photograph of the fabricated minimal fluid applicator is shown in Fig. 2. The fluid application system developed in this study has the facility to increase the injection pressure up to 100 bar, frequency of pulsing and rate of delivery of cutting fluid can be varied up to 750 pulses/min and 8 ml/min respectively.

2.1. Formulation of cutting fluid

Since the quantity of cutting fluid used is extremely small, a specially formulated cutting fluid which can fulfill the task of cooling and lubrication was employed in this investigation. Accordingly commercially available mineral oil (considered as base) along with other ingredients such as friction modifiers, emulsifying agents, coupling agents and anti-corrosion agents are identified. Table 1 shows

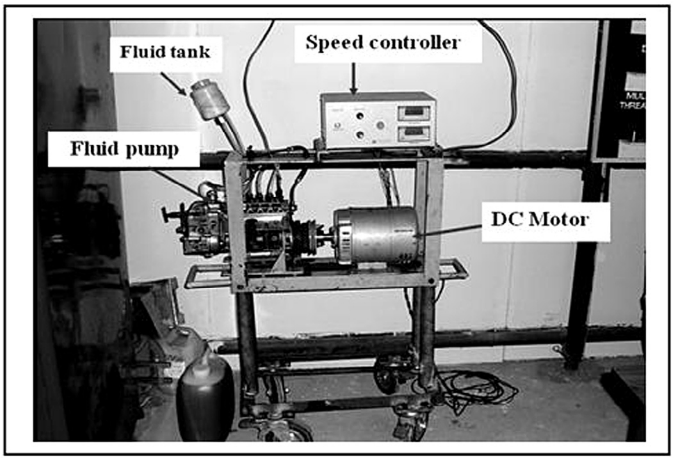

Fig. 2. Photograph of fabricated minimal fluid applicator.

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