www.ijemr.net ISSN (ONLINE): 2250-0758, ISSN (PRINT): 2394-6962

Vandana Publications
IJEMR

Volume-5, Issue-3, June-2015
International Journal of Engineering and Management Research
Page Number: 631-636

Force System Due to the Presence of Elasto - Viscous Flow Zone during High Speed Machining

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ABSTRACT

During high speed machining a thin non crystalline layer is found to appear between the tool and chip (secondary shear zone) which is known as flow zone, due to melting of chip surface adjacent to the tool face because of high pressure and temperature at the tool chip interface. The nature of flow zone is believed to be elasto -viscous at moderately high cutting speed. In the course of literature survey it was found that the force system during high speed machining has been the subject of many investigations. But none of the present metal cutting theory is capable of predicting accurately what happens to the cutting mechanism/ force system, mainly because of the presence of the flow zone at the tool chip interface. It indicates that very little work has been performed during high speed machining and no definite trend has emerged out so far.

The main objective of this paper is to present the theory of cutting forces on the assumption that the secondary shear zone consists of solid material area and the molten area, considering hydrodynamic and momentum effects. This theory explain that the work piece properties and cutting conditions influence the formation of flow zone, which effects the formation of secondary shear flow and hence force system behavior. A new force system which is applicable to high speed machining is developed including momentum and hydrodynamic forces.

***Keywords*----** Chip interface, Flow, Shear zone, Elasto

I. INTRODUCTION

In recent decades tremendous expansion in metal working has occurred. For global competitiveness there is a need of increased production rate to meet the increased demands. As a consequence, companies have to optimize their production processes including cutting processes. In order to achieve this aim, industry adopts very high cutting level (high cutting speed and feed rate). Under severe conditions caused by a high cutting level, the mechanical stress and temperature at tool chip interface and around the cutting edge can be critically high, resulting in an excessive tool wear or then a premature tool failure. Due to the complexity of the tool chip contact, the full understanding of contact conditions has not been developed enough. In addition, there is no model able to predict correctly the friction law along the tool rake face. The temperature at interface is directly influenced by the friction velocity. It has been find out that the friction coefficient is very much dependant on the sliding velocity. The range of temperature is very large. The pressure along the interface is also very much different as reported by Trent [7]. Both have a great influence on friction behavior. The microscopic parameters are inadequate to provide local information about the friction.

The tribological conditions at the sticking sliding contact (rubbing zone and secondary shear zone) is shown in fig 1, depend on coupled thermo mechanical phenomena and on the evolution of the local conditions of stress, velocity, temperature and the thermo mechanical behavior of the work piece material [12]. In the sticking region, the pressure is large and a layer of chip in contact with the tool is stationary, consequently, a relative motion takes place in adjacent layers with the flow velocity which gradually increases until the bulk chip speed is obtained [13,14]. But the question that still remains is how the sticking sliding zones vary in terms of machining process. Some researchers have assumed pure sliding/ Pure sticking contact [15]. This approach analyzes the tribological parameters governing the tool chip interface [11] and sticking-sliding contact.

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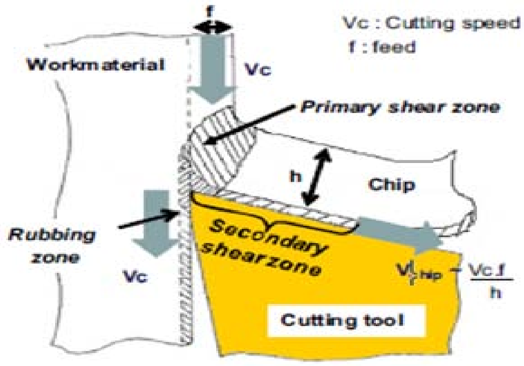

Figure 1

During high-speed machining there will be a disappearance of the builtup edge and formation of molten flow zone. The Side of the chip adjoining to the tool face is strained so heavily that it tends to loose its crystallinity. This crystalline layer is usually known as flow zone. According to Schaller such a layer may be approximated as a Newtonian liquid. He further concluded that the liquid in the flow zone would behave as a couette flow with a constant value of flow zone thickness and therefore a hydrodynamic pressure would not be developed [15. Later on be Desalevo and Saw have shown that flow zone thickness is not constant but increase in the direction of flow and it will generate positive pressure between chip and the tool [10]. They presented the analysis on the assumption that this layer behave as a Newtonian fluid. However they have mentioned that non Newtonian treatment of the layer may complicate the situation and immediate effects will not be known easily. It is believed that at moderately high cutting speed the flow zone may be approximated as the elasto- viscous fluid and as speed increases the flow zone changes to viscous one, because of high temperature and pressure at the interface.

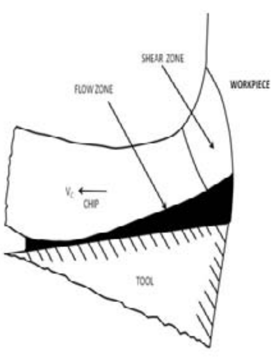

Fig 2

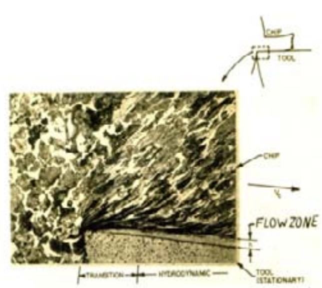

Fig 3

In this paper the theory of cutting forces on the assumption that the secondary shear zone consists of solid material area and the molten area, considering hydrodynamic and momentum effects are developed and discussed.

II. FORCE SYSTEM

In fact conflicting views exist regarding the force behavior at very high cutting speeds. It appears that in some cases the cutting forces increases with increasing speed whereas in others it decreases. Below is presented a theory of cutting forces which will be applicable in the presence of flow zone.

(a). AT THE SHEAR PLANE

It has been found that the shear zone during machining, which is quite thick and of irregular shape at slow speed, progressively approaches a planar, thin zone shape with increasing speed and for such a case cutting model is shown in fig.4 and shear stress is given by

$$\tau = y\frac{dp}{dx} + C_1 \qquad (1)$$

The shear zone of total volume V, which was consists of solid material at low speed will consist of a solid material volume, V_S and of molten volume V_F, at high speed machining so that

$$V=V_S+V_F \qquad (2)$$

It means with increasing speed, the hydrodynamic flow zone reaches within the shear zone thereby reducing the volume of the solid material. In other words, the shear plane of constant area, A, consists of a solid material area, A_S and of molten area, A_F. Therefore, equation (2) may be written as

$$A=A_S+A_F \qquad (3)$$

Where A_F=b h_t (h_t is the value of h at tool tip.)

At low cutting speed, no flow zone exists and therefore, A_F=0 in eq. (3). With increase in speed the flow zone will grow in size in analogy with such processes as recrystalization , self defusing of atoms and grain growth with changes in flow zone thickness with reasonable limits. At high speed momentum effects gain importance and become very considerable, during the analysis of force system in this secondary flow zone, momentum force must be considered along with other components of force system. The momentum force caused by the change in flow direction from uncut workpiece to the chip and acting parallel to shear velocity vector is given by F_m

(b). AT THE TOOL CHIP INTERFACES

When chip moves along the rake face of the tool a resultant force R', which is the resultant of the normal force and the friction force acts the tool rake face. The reaction of R' on the material is R and it is this reaction which deforms the material. From the geometry of the figure .4

$$R = R' = \sqrt{F_n^2 + F_f^2} \qquad (4)$$

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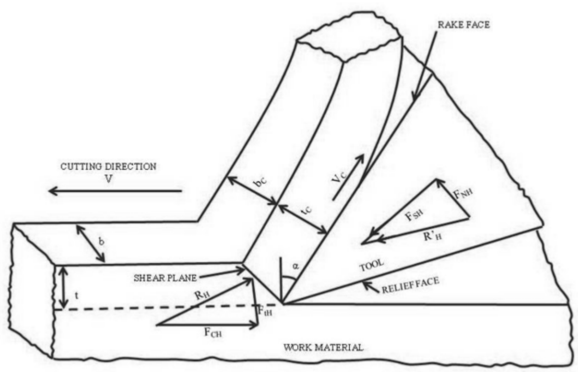

Cutting forces Fig. 4

(c). DUE TO CHANGE OF DIRECTION

Momentum force in machining is caused by the change in flow direction from uncut work piece to chip and is given by

$$F_m = \frac{btV^2\rho}{\cos\theta}\left[\frac{1}{1+\tan\theta\tan\alpha}\right] \quad (5)$$

FORCE GEOMETRY DURING HIGH SPEED MACHINING

A momentum force circle and merchant's cutting force circle along with resultant force circle is given in fig.5. The ratio of momentum to cutting force circle diameter will increases with the velocity. The resultant, modified forces may be expressed as.

a. Cutting and thrust forces:

$$F_{cH} = F_c + F_{cm} \quad (6)$$

$$F_{tH} = F_t + F_{tm} \quad (7)$$

b. At the shear plane :

$$F_{SH} = F_m + F_c\cos\theta - F_t\sin\theta \quad (8)$$

$$F_{NH} = F_N = F_c\sin\theta + F_t\cos\theta \quad (9)$$

c. At the Tool -chip interface :

$$F_{fH} = F_m\cos(90-\theta+\alpha) \pm (F_c\sin\alpha + F_t\cos\alpha) \quad (10)$$

$$F_{nH} = F_m\sin(90-\theta+\alpha) + (F_c\cos\alpha - F_t\sin\alpha) \quad (11)$$

F_{fH} and F_{nH} are normal &shear forces due to the presence of elasto–viscous flow zone at the tool chip interface (appendix-A)

F_c and F_t are conventional cutting and thrust forces at low speed and is given by

$$F_c = \frac{tb\tau\cos(\beta-\alpha)}{\sin\theta\cos(\theta+\beta-\alpha)}$$

$$F_t = \frac{tb\tau\sin(\beta-\alpha)}{\sin\theta\cos(\theta+\beta-\alpha)}$$

Where b-chip width, t-thickness, v-cutting velocity, ρ-density of material, θ -shear angle, α- rake angle, β- friction angle.

Momentum effects become more and more important as cutting speed increases. Therefore the modified merchant's circle has been developed as shown in fig . 5.

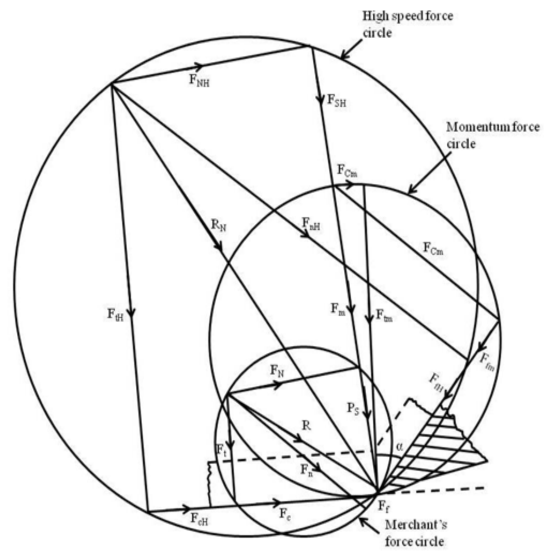

Figure 5: Force geometry during high speed machining

III. PARAMATRIC ANALYSYS

Various parameters associated with a typical case are:

Dept of cut	=2.5mm
Feed	=0.25mm
Cutting speed	=200m/min.
Chip thickness ratio	=.46
Tool chip contact width	=3mm
Length of fully developed	
Elasto- viscous layer	=.5mm
Film thickness, h_0	=0.0125mm

Rake angle α=100, μ=.5, shear stress τ=400 N/mm2

Following quantities have been assumed, based on the cutting conditions and properties of elsto- viscous layer

Latent heat	H =31.4 cals/g
Absolute viscosity	μ=12500 poise
Modulus of rigidity	G=0.84x10-2 dynes/cm2
Density	ρ=7.8 gms/cm3

The variation of various forces involved in cutting operation at high speed ranging from 200 to 800 m/min has been examined. Fig. 6 shows the effect of momentum force at different face width 2.5, 3.5, 4.5 and 5.5mm and it was found that variation increases as cutting speed increases. Fig. 7 shows the effect of variation of cutting speed on cutting and thrust forces, whereas the variation of shear force and normal force are shown in fig. 8. It was found that the normal component of shear force does not change with the cutting velocity. Fig. 9 shows the variation of friction force and normal force at the rake face during high speed machining, without formation of flow zone.

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The forces represented in fig.9 are replaced by the hydrodynamic pressure and shear stress which are created due to the presence of elasto- viscous flow zone (Refer Appendix-A) .In this new force system the forces at tool chip interface due to the presence of flow zone has been reduced considerably as compare to the forces in the absence of flow zone.

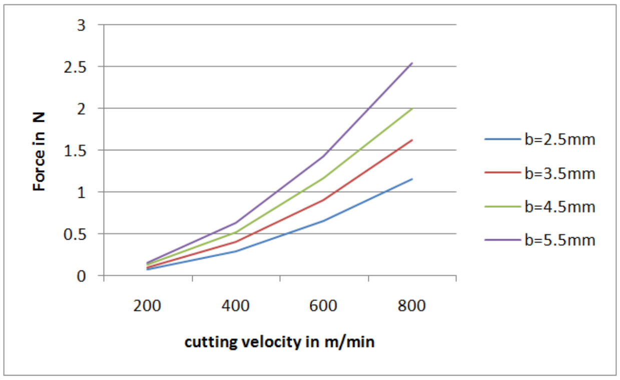

Figure 6: Effect of momentum force at different face width

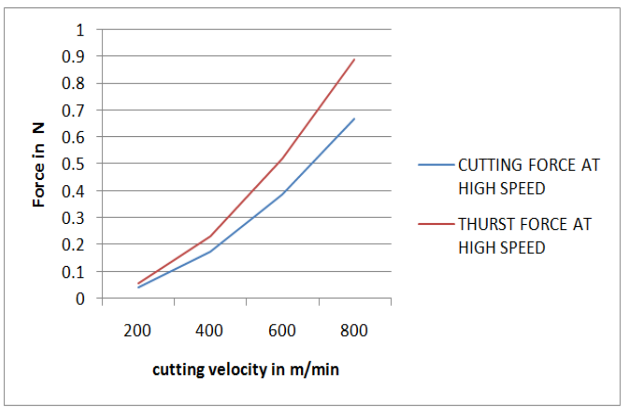

Figure 7: Variation of Cutting and thrust forces

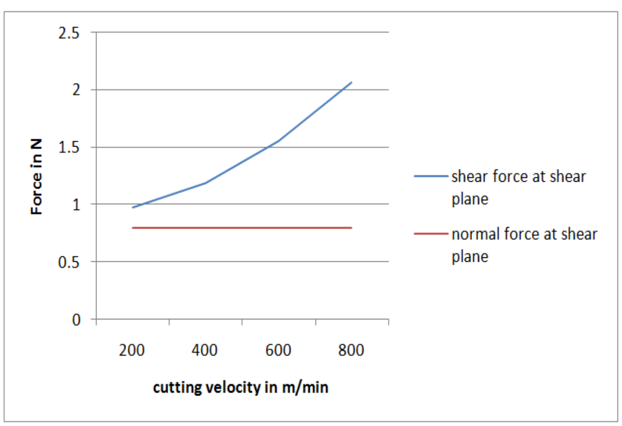

Figure 8: Variation of forces at shear plane

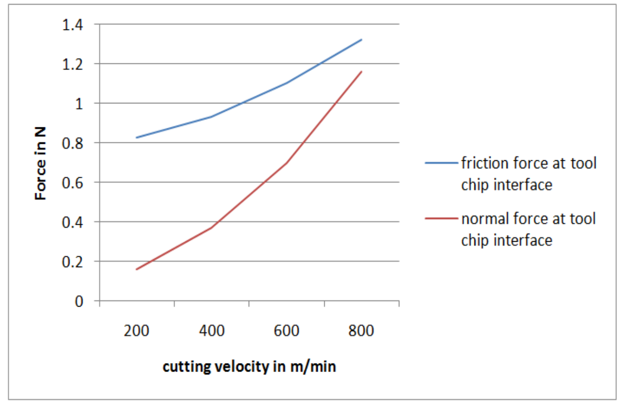

Figure 9: variation of forces at tool chip interface

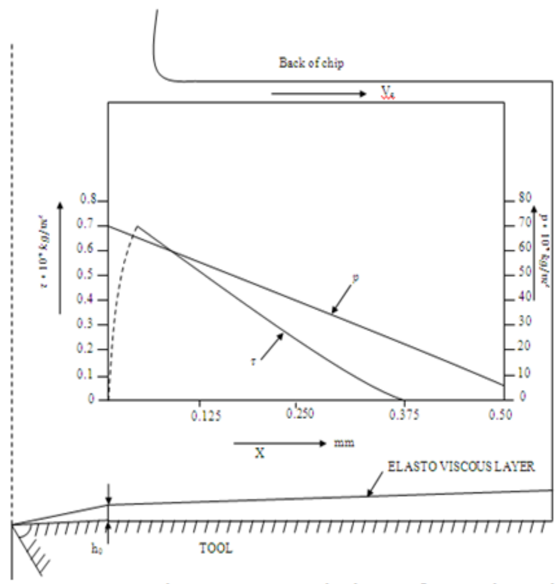

Figure 10: Variation of p and τ with X

IV. CONCLUSION

The viscous flow zone that forms at tool chip interface during high speed machining represents the actual behavior which can be used to make realistic estimates of the force system. While estimating the thickness of flow zone, additional assumptions have been made to make the problem mathematically tractable. These assumptions places some doubt on the relevance of force system but they could be modified at the expense of mathematical complications. For example, thermal treatment of the flow zone could be added which gives actual variation of the flow zone over the rake face of the tool.

Force system at high speed machining was analyzed considering the force system at the shear plane ,at tool chip interface and due to change in direction. A new

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force circle is obtained by combining the merchant's force circle at conventional speed and momentum force circle. Thus a new force theory is developed which will be applicable in the presence of flow zone at tool chip interface and will explain the cutting mechanism.

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Appendix- A: **ELASTO-VISCOUS ACTION AT TOOL – CHIP INTERFACE**

It is clear that film thickness increases in the direction of flow. just like in hydrodynamic bearing we are having two surfaces, one of which is tool surfaces and it is determined by the geometry of the tool. Second surface is due to melting of the chip adjacent to the tool surface.

At moderately high cutting speed flow zone may conveniently be considered as elasto viscous one, for which the shear stress is given as

$$\tau = y\frac{dp}{dx} + C_1 \tag{1}$$

Where C_1 is a constant of integration and is a function of x.

$$p = \frac{6G}{a^2}\left[\left\{(b^2+x)(1-\beta x) + \frac{\beta}{2}(x^2-b^4)\right\} log(b^2+x) - x(1-\beta x) + \frac{\beta x}{2}\left(b^2 - \frac{x}{2}\right)\right]$$
$$+\frac{48\,QG}{V_c a^3}\left[(b^2+x)^{\frac{1}{2}}\left(1-\frac{2}{3}b^2\beta - \frac{2}{3}\beta x\right)\right] + \frac{B}{\beta} + D(1-\beta x) \tag{2}$$

And

$$C_1 = \frac{6GQ}{V_c a^2}[(1-\beta x-\beta b^2)log(b^2+x)+\beta x]$$
$$-\frac{4G}{3a}\left[3(1-\beta x-\beta b^2)(b^2+x)^{\frac{1}{2}} + \beta(b^2+x)^{\frac{3}{2}}\right] + A(1-\beta x) \tag{3}$$

Where A, B and D are constants of intergrations and

$$\beta = \frac{G}{\mu V_c}$$

$$A = \frac{4G}{3a}[3b - 2b^3\beta] - \frac{6GQ}{V_c a^2}[(1-\beta b^2)\log\, b^2] \tag{4}$$

$$D = \frac{6G}{a^2\beta}[(1-\beta b^2)log\, b^2] + \frac{48\,QG}{V_c a^3\beta}\left[\frac{1}{2b} - \beta b\right] \tag{5}$$

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$$B = -\frac{6G}{a^2}\left[\beta(b^2 + L)\log\frac{b^2+L}{b^2} - \beta L + \log b^2\right]$$
$$-\frac{48\,QG}{V_c a^3}\left[\beta\left\{(b^2 + L)^{\frac{1}{2}} - b - \frac{L}{2b}\right\} + \frac{1}{2b}\right] \quad (6)$$

$$Q = \frac{\frac{4}{3}\left[3b\left(L-\frac{\beta L^2}{2}\right)-2b^3\beta L-(b^2+L)^{\frac{3}{2}}\left\{2-\frac{4}{5}\beta\,(b^2+L)\right\}\right]}{\frac{6}{V_c a}\left[\left(\frac{\beta L^2}{2}-b^2-L+\frac{\beta b^4}{2}+\beta b^{2L}\right)\log\,(b^2+L)+L\left(1-\beta b^2-\frac{\beta L}{2}\right)\log\,b^2+L\left(1-\frac{\beta b^2}{2}-\frac{3}{4}L\beta\right)\right]} \quad (7)$$

By using the above values of A, D, B, and Q in equations (1) and (2) the pressure distribution (p) and shear stress (ι) at tool chip interface can be obtained.

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