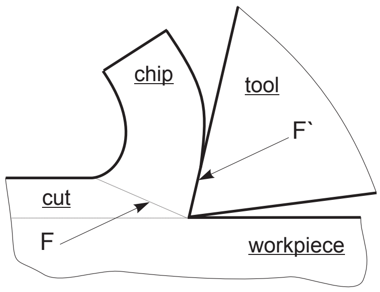
5.3 CUTTING FORCES

Introduction

Cutting is a process of extensive stresses and plastic deformations. The high compressive and frictional contact stresses on the tool face result in a substantial cutting force F.



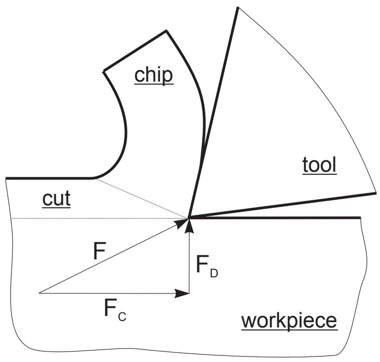
Total cutting force F and reaction force F` in orthogonal cutting

Knowledge of the cutting forces is essential for the following reasons:

- proper design of the cutting tools
- proper design of the fixtures used to hold the workpiece and cutting tool
- calculation of the machine tool power
- selection of the cutting conditions to avoid an excessive distortion of the workpiece

Cutting force components

In orthogonal cutting, the total cutting force F is conveniently resolved into two components in the horizontal and vertical direction, which can be directly measured using a force measuring device called a dynamometer. If the force and force components are plotted at the tool point instead of at their actual points of application along the shear plane and tool face, we obtain a convenient and compact diagram.



Total cutting force F is conveniently resolved into horizontal component F_C and vertical component F_D

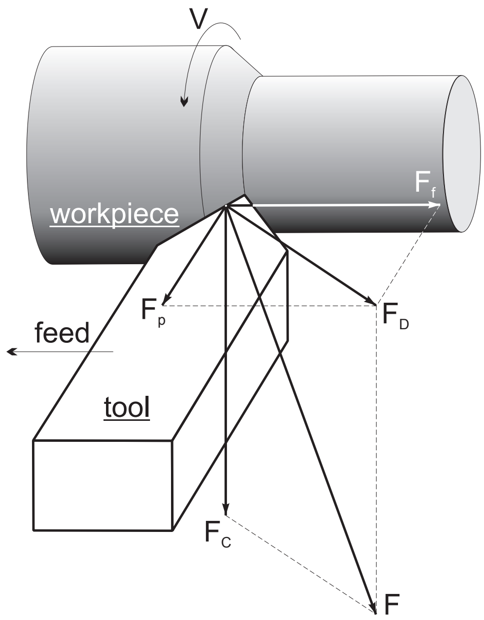
The two force components act against the tool:

1. *Cutting force* F_C : this force is in the direction of primary motion. The cutting force constitutes about 70~80 % of the total force F and is used to calculate the power P required to perform the machining operation,

$$P = VF_C$$

2. *Thrust force* F_D: this force is in direction of feed motion in orthogonal cutting. The thrust force is used to calculate the power of feed motion.

In three-dimensional oblique cutting, one more force component appears along the third axis. The thrust force F_D is further resolved into two more components, one in the direction of feed motion called *feed force* F_f, and the other perpendicular to it and to the cutting force F_C called *back force* F_p, which is in the direction of the cutting tool axis.



Force components in three-dimensional oblique cutting

Force determination

Cutting forces are either

- ❖ *measured* in the real machining process, or
- ❖ *predicted* in the machining process design.

Cutting forces are *measured* by means of special device called tool force *dynamometer* mounted on the machine tool.

For cutting force *prediction*, several possibilities are available,

➊ for approximate calculations of sufficient accuracy for all practical purposes, the so-called *specific cutting force* (*cutting force per unit area of cut*) k_C is used:

$$F_C = k_C h_D b_D$$

This parameter is well tabulated and could be found in the most handbooks.
For small cut thickness and dull cutting tools k_C must be increased. The value of thrust force F_D is taken usually as a percentage of F_C.

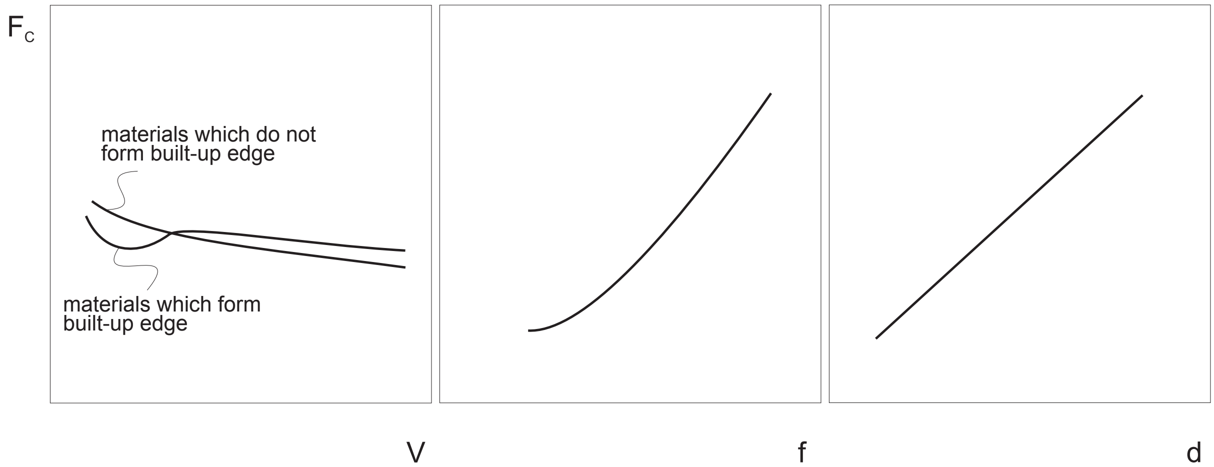
➋ more advanced options for cutting force prediction are based on *analytical* or *numerical modelling* of metal cutting. Due to the complex nature of the cutting process, the modelling is typically restricted to orthogonal cutting conditions, although solutions for the three-dimensional cutting are also available in the literature.

Cutting force control

The cutting force value is primarily affected by:

- ❖ *cutting conditions* (cutting speed V, feed f, depth of cut d)
- ❖ *cutting tool geometry* (tool orthogonal rake angle)
- ❖ *properties of work material*

The simplest way to control cutting forces is to change the cutting conditions. The next diagrams show the dependencies between F_C and cutting conditions:



Cutting force as a function of cutting conditions

The *cutting speed* V does not change significantly the cutting force F_C. Increasing the cutting speed slightly reduces the cutting force. The dependence is more complex in the low speed range for materials, which tend to form a built-up edge. When the built-up edge disappears at high cutting speeds, the dependence is essentially the same as this for materials, which do not form a built-up edge at all.

Feed changes significantly the cutting force. The dependence is non-linear because of the so-called *size effect* at low feeds.

Depth of cut also changes significantly the cutting force but the dependence now is linear.

From the above it can be concluded that the most effective method of force control is to change the depth of cut and feed. If for some reasons change of the cutting conditions is not justified, machining with positive tool orthogonal rake angles will decrease significantly the cutting force but at the same time will increase the possiblity of tool breakage.