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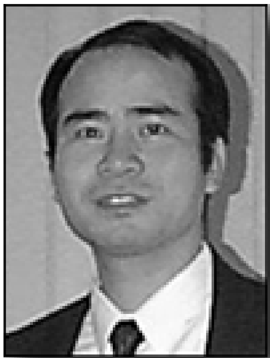

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Introduction

Unlike some other fields, Industrial Technology, especially Manufacturing Technology, is very practice-intensive in its curriculum. Abundant experience in the laboratory, workshop, and in actual industry (through tours, internships, etc.) is integral to a successful and meaningful education. In most of these activities, students learn from simple observation, practice, and repetition, but, limited by time and restricted access to necessary equipment, few principles behind specific functions are meaningfully interpreted by the students. Although tools are designed for specific purposes based on certain principles, these principles rarely appear in industrial technology curricula. The selection of cutting tools for various machines is an example that could be expanded to enhance the capabilities of industrial technology in manufacturing settings for future careers.

A good understanding of principles is central to solid performance achieved through education. By understanding the principles behind laboratory or workshop activities, students develop freedom and creativity in applying and developing their knowledge. Clear interpretation of principles, therefore, is of great help to students, and can be achieved through any combination of lecture, experimental demonstration, and laboratory exercise. The latter two provide students with "real" experience that demonstrates and reinforces the abstract theories and principles related to industrial technology in students' minds.

Tooling is a central concept in manufacturing. Cutting tool design is a tooling principle employed every day on the average shop floor; however, many of the machinists utilizing these principles to fulfill their quotas do so somewhat blindly, with only a superficial understanding of the cutting tool with which they feel familiar. Most of today's cutting knives are designed with a groove situated adjacent to the blade. While workers may recognize that this groove exists, they are oftentimes unaware of its purpose. A tool with this groove is called a controlled contact tool. The explanation of this design can deliver students not only the reason why a groove sits there, but also some knowledge of basic cutting theory. This information is crucial if industrial fields are to continue forward with their present rate of growth and productivity.
A good experiment can help students understand how this design functions in cutting. The objective of this paper is to design a laboratory experiment to demonstrate the functions of a controlled contact tool. In completing this experiment, students should be able to understand why the contact length should be controlled, how cutting parameters are affected by the controlled contact length, and how to design an experiment to demonstrate the functions of a controlled contact length. Before this experimental setup is discussed, the nature of metal cutting process must first be addressed.

Metal Cutting process

Cutting is a complicated process wherein performance depends upon a number of cutting and tooling conditions. To conduct a successful cutting, generally speaking, not only must the tool material be harder than the work material, but it must also be able to maintain that hardness at elevated temperatures. In another words, not only does the tool material have "cold hardness", but also "hot hardness". Nevertheless, the hot hardness is always limited to a certain temperature-extreme, beyond which tool hardness will be lost. Thus, it is important to keep the tool below a certain temperature.

The simplest cutting example is the orthogonal cutting, which is shown in Figure 1. While the tool is forced to cut into the workpiece, a chip is produced from the shearing zone and moves on along the rake face of the tool till it curves off or breaks up. The cutting force and the normal force act together to perform the cutting. Since there is no movement in the normal direction, cutting force supplies the whole power. This power is consumed in two ways: by breaking down metal bonds and by overcoming frictions. Both result in the release of heat. Three heat sources in the cutting process have been identified (DeGarmo, Black, and Kohser, 1997). Plastic deformation is one in which, under the shearing force from the tool, the chemical and physiochemical bonds along the shearing region are broken, thus producing chips. Heat is generated from this deformation of material. The contact area of the tool and chip is the second area where heat is generated. The chip, immediately after being formed, is forced to slide along the rake face of the tool undergoing secondary sheared deformation. Both the friction and the deformation generate heat. When the tool cuts, it rubs the newly formed surface of the work material. The friction created between the frank face of the tool and the new surface of the work material is the third source of heat. Heat from these three sources is converted from the cutting energy. About 97% of this energy ends up as heat (Ostwald and Muñoz, 1997). This heat causes an elevation in temperature in the tool, chip, and work material.

Although most heat (60%) is generated in the shear region in the workpiece (Ostwald and Muñoz, 1997) and 80% of the total heat goes to the chips (Sandvik Coromant, 1996), temperature increases in the tool because it remains constant in the workpiece. Heat from the workpiece is dissipated as the tool moves across it and sloughs off chips; the entire tool, however, remains in constant contact with the workpiece and consequently accumulates the most heat. There are two sources of heat to the tool. One is the heat the chip carries from the shearing region and the other is the sliding friction in the tool/chip interface. As shown in Figure 1, after being produced, the chip slides up the tool face for a certain distance and curves away. When the chip slides on the tool face under the pressure caused by the cutting force, it overcomes the friction force and thus generates heat.

The chip contacts the tool from the tip to where it leaves the tool. This distance is called the tool/chip contact length, or, simply, contact length. A longer contact length leads to a greater accumulation of heat in the tool. If the contact length can be shortened, however, the friction force and heat can be reduced. The contact length varies from case to case in normal tools, but by making a groove across the tool, the contact length can be limited to the distance from the tool tip to the groove. How the contact length affects the cutting force and the elevation of temperature in the tool will be examined in this experiment.

The Experimental Setup

The experiment was performed on an orthogonal lathe. A force measuring system and a temperature measuring system were set up on it, as shown in figure 2. The force measuring system consisted of a crystal dynamometer and a three-channel amplifier. The dynamometer was secured to the cutter post of the lathe to detect the cutting force in three dimensions. The detected signals were amplified by an amplifier and then collected by a computer with an A/D transfer.

The temperature was detected by a tool/work thermocouple with one end at the tool and the other at the workpiece, which was a copper tube. The thermocouple was calibrated through a furnace with an argon

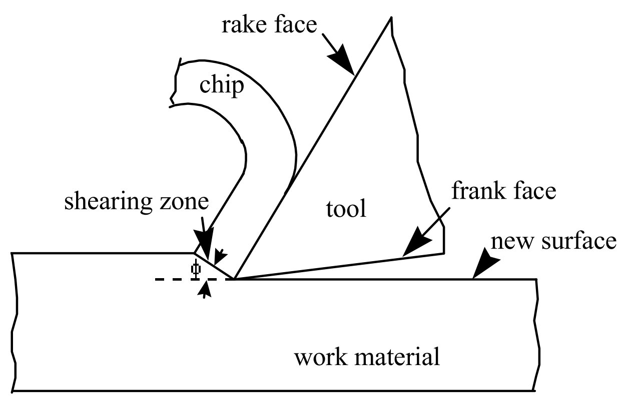

Figure 1. Diagram of tool action.

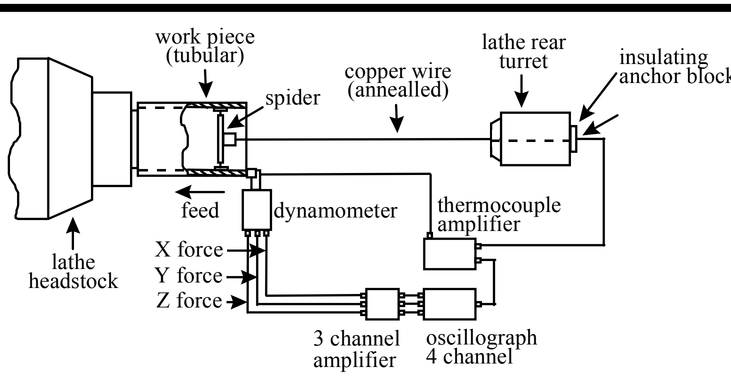

Figure 2. The experimental setup on a lathe.

atmosphere. Table 1 lists the look-up table for this experiment. A spider device was tied inside the tube. One end of an annealed copper wire was attached to the spider and the other end was connected to the thermocouple amplifier that was connected to the cutter to close the tool/work thermocouple detecting circuit. The temperature results a voltage and shown in an oscilloscope. The calibration data provides a look-up table while the machining process is taking place; the voltage response obtained from the oscilloscope is used to derive the temperature on this table.

The tool used was a high-speed steel cutter with a groove made 0.015 inches away from the tool tip. As an orthogonal cutting, the cutting edge is perpendicular to the direction of the cut. The cutter cut the copper pipe edge at one end towards the chuck of the lathe. The chip thickness was measured with vernier calipers.

mV	°F	mV	°F	mV	°F	mV	°F	mV	°F	mV	°F
0.0	73	0.7	262	1.4	376	2.1	549	2.8	662	3.5	799
0.1	118	0.8	279	1.5	392	2.2	567	2.9	680	3.6	835
0.2	149	0.9	291	1.6	406	2.3	585	3.0	698	3.7	871
0.3	176	1.0	313	1.7	428	2.4	601	3.1	718	3.8	909
0.4	199	1.1	333	1.8	446	2.5	617	3.2	738	3.9	963
0.5	223	1.2	347	1.9	500	2.6	631	3.3	757		
0.6	248	1.3	361	2.0	529	2.7	648	3.4	775		

Table 1. Look-up Table for Voltage to Temperature Conversions (mV to °F)

t_o*	t_c*	t_o/t_c	l_{cc}*	t_o/l_{cc}	F_c	F_t	T (°F)	ϕ	β	μ	HP_s
3	5.5	0.55	8	0.4	63	39	446	30.7	48	1.1	0.47
5	8	0.63	15	0.3	96	52	549	34.6	52	1.3	0.43
7	11	0.62	15	0.5	117	60	549	34.5	53	1.3	0.37
9	15	0.60	15	0.6	145	82	593	33.4	51	1.2	0.36
11	17	0.65	15	0.7	160	87	593	35.7	51	1.3	0.32
13	17	0.76	15	0.9	190	95	585	41.0	53	1.3	0.32
15	18	0.83	15	1.0	205	92	575	43.8	56	1.5	0.30
17	20	0.85	15	1.1	212	92	593	44.5	57	1.5	0.28
19	22	0.86	15	1.3	220	100	609	45.0	56	1.5	0.26

Table 2. Measured and Calculated Results

Results

The depth of cut (t_o, same as feed rate), thickness of chip (t_c), actual contact length of chip and tool (l_{cc}), force (F_c), and tangent force (F_t) of each experiment could be obtained through direct measurement, and the result was recorded in Table 1 from columns 1, 2, 3, 6, and 7, respectively. As mentioned above, the voltage (mV) was recorded through an oscilloscope and the true temperature (listed in column 8 in Table 2) was extrapolated from the look-up table. The other parameters of the machining process are based on the following calculations:

f: Shear Angle:
$\tan f = r_S \cos a/(1-r_c \sin a)$

b: Angle between F and R:
$b = \tan^{-1}(F_t / F_c) + a$

t_S: Flow Stress (PSI)
$t_S = (F_c \cos F - F_t \sin f) \sin f / w / t_0$

HP_S: Specific Horsepower (hp/in^3/min)
V = N*p*D/12
HP_S = HP/MRR (MRR = 12Vtw)

According to the experimental setup, the depth of cut is the same as

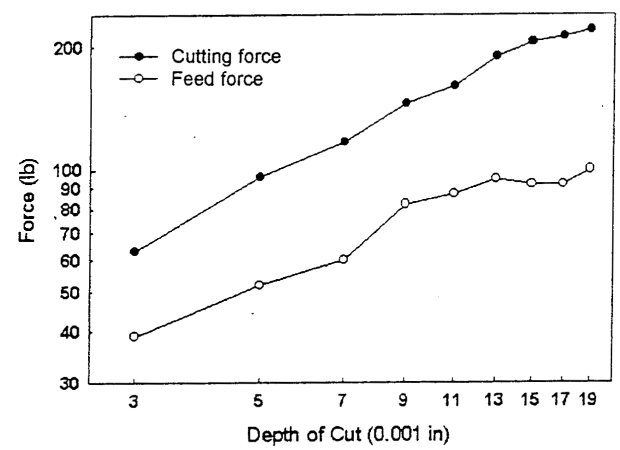

Figure 3. The resulted forces for various depth of cut.

the feed rate, which is denoted as t_0. Nine different depths of cut were tested. Results shows that, as the depth of cut increases, all other items also undergo either increase or decrease, except for the contact length of chip and tool, which stays at the controlled length after the feed rate increases to 0.005 inches.

The ratio of the thickness of formed chips to the thickness of unformed chips (r_c) increases as the thickness of the unformed chip increases. This shows that the thickness of the chip is not proportional to its original thickness. The deformation of the chip becomes less as the cutting deepens.

Both the cutting force and the tangent force increase in different ratios. The cutting force increases about twice as much as the tangent force, which is similar to that presented in *Materials and Processes in Manufacturing,* (DeGarmo, Black, and Kohser, 1997, pg. 607). However, as plotted in Figure 3, the increase of the forces against the depth of cut in a double logarithmic coordinate system is not absolutely linear, as shown in the same textbook (608). Instead, it increases linearly only in the range of the smaller depth of cut. When the depth of cut reaches about 11 thousandths of an inch, the increase becomes gradually less.

The same result occurs to the changes in temperature (T) and shear angle (f) (Figure 4). Both increase at smaller depths of cut and change to flat afterwards. The specific horsepower acts in a reverse way, decreasing as the depth of cut increases.

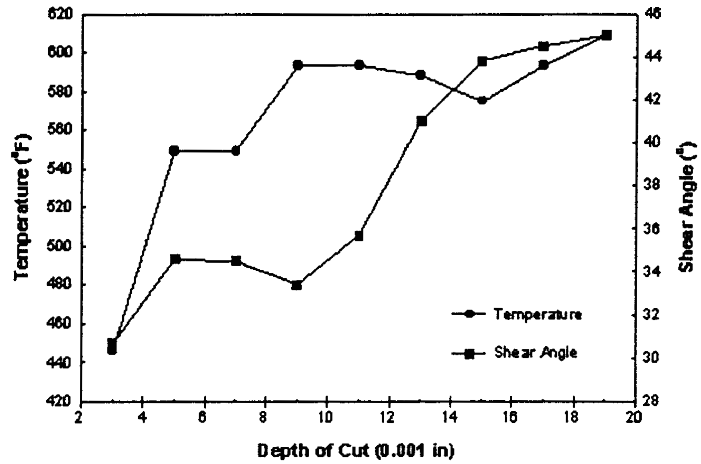

Figure 4. The temperature and shear angle corresponding to various depth of cut.

Discussion

The contact length of the tool/chip interface on a natural tool grows as the depth of cut increases, as shown in previous work (Juneja, and Seknon, 1987). Limited by an artificial groove, the contact length on a controlled contact tool cannot exceed the limitation. The shortage of meeting the natural contact is reflected in the ratio of the depth of cut to the controlled contact length (t_0/l_{cc}). When the ratio is small, the natural contact length is within the range of the limited contact length and the tool acts like a natural tool. This is how it shows in the range of smaller depths of cut in Figures 3 and 4. As the ratio becomes greater, the gap of the natural contact and the controlled contact widens. The shortage of contact reduces the friction force along the rake face of the tool, leading to the reduction of both cutting force and tangent force, as shown in Figure 3.

The shear angle (f) also changes to match the change of the resultant force. When the ratio t_0/l_{cc} increases to larger values, the shear angle increases more quickly. The larger the shear angle, the shorter the shear length, and the less the shear force, since the shear stress is constant. This results in less of the required resultant force being exercised. As the shear angle becomes smaller, the deformation of the chip becomes less. In turn, the ratio of r_c becomes larger. Because less force is required to remove a certain amount of material, the specific horsepower (HP_s), which specifies the energy required to remove a certain amount of material in a certain period of time, is also decreased.

The friction force and the shear force are the main sources of heat generation. It is obvious that the reductions of them lead to the reduction of temperature accumulation, as shown in Figure 4.

Conclusion

The cutting process can be affected by controlling the contact length of the tool/chip interface. When the contact is controlled to a certain length, so that the real contact is shorter than the natural contact, the cutting force is reduced. Consequently, the specific horsepower of the workpiece as well as the tool temperature is reduced.

References

DeGarmo, E. P., Black, J. T. and Kohser, R. A., (1997). *Materials and processes in manufacturing.* (8th Ed.) Upper Saddle River, NJ. Prentice-Hall, Inc.

Juneja, B. L., and Seknon, G. S. (1987). *Fundamentals of metal cutting and machine Tools*. New York, NY. John Wiley & Sons, Inc.

Kalpakjian, S. (1995). *Manufacturing engineering and technology.* (3rd Ed.) New York, NY. Addison-Wesley Publishing Company, Inc.

Ostwald, P. F. , and Muñoz, J. (1997). *Manufacturing processes and systems.* (9th Ed.). New York, NY. John Wiley & Sons.

Sandvik Coromant. (1996). *Modernmetal cutting – A practical handbook.* Fair Lawn, NJ. Sandvik Coromant.