Reason - A Technical Magazine
Vol. – IX, 2009 & 2010

A BRIEF OVERVIEW ON THE HISTORY OF DEVELOPMENT OF MACHINE TOOLS

Dr. Santanu Das
Professor and Head, Department of Mechanical Engineering,
Kalyani Government Engineering College, Kalyani- 741235, West Bengal, India
email: sdas_me@rediffmail.com

Abstract : At present, wide variety of machine tools are employed in manufacturing. If one tries to find out the chronological development of the machine tools, the practice of ancient man in Paleolithic or Neolithic age to protect himself or to kill animals is to be looked at; the use of stones and the technic of sharpening the same may be considered to be the beginning of cutting tools- essential component of the machining process. Over the ages, metals and alloys are discovered and newer materials developed; use of different kind of energy is facilitated. Availability of electrical energy causes a revolution in the human civilization, and different machine tools with various cutting tools are developed for processing materials with high productivity to manufacture wide range of components. Application of electronics and computers make the machine tools with high precision and easy to control, maintaining high degree of repeatability. In the present paper, a brief overview is made on the history of development of mainly machining machine tools by dividing into four different periods of civilization of human beings, namely stone age, pre-steam engine period, post-steam engine period and age of electricity.

Keywords : History of Machine Tools, periods of development, machining, cutting tool, automation.

1. Introduction

Since ancient times, machining process is being used to make a job of desired shape and finish. Primitive men in stone ages made sharp stone pieces by chipping off excess stone portions from a big piece to use it to defend themselves, and also to cut different objects [1][2]. This can be considered as the preliminary form of machining which is an important manufacturing process. The basic process of machining is shown schematically in Fig. 1 where excess material is removed using a wedge-shaped cutting tool from a workpiece material.

With the increase in demand for high productivity, in place of manually operated machining processes, gradually, implementation of mechanized systems in the process was started; machining was carried out on power driven machines, called machine tools [2][3][4]. A machining machine tool, or simply a machine tool, consists of several mechanisms to facilitate machining process. After Ben C. Brosheer, Associate Editor of American Machinist in 1960s, machine tools are non-portable, power-operated units valued at $350 or more per unit used to shape parts progressively removing metals in the form of chips [3].

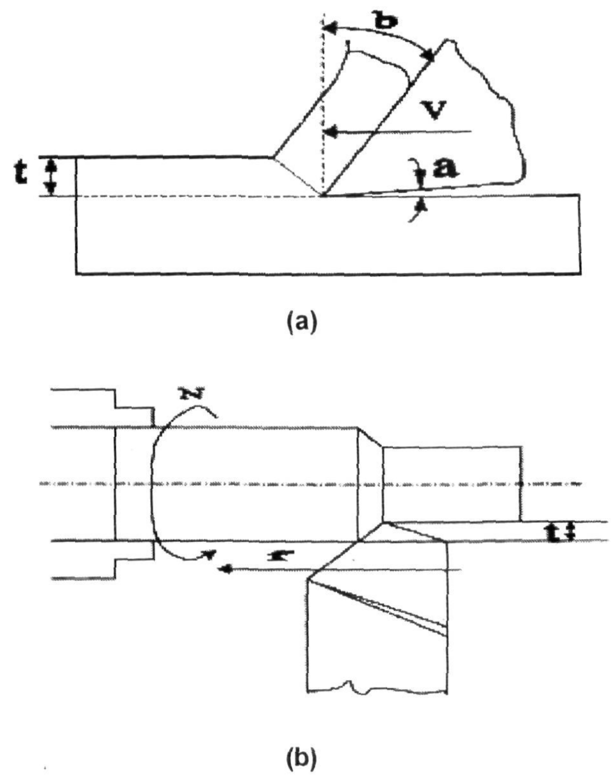


Fig. 1. Basic machining processes
a) basic process schematic, b) turning process

A machine tool is a part of machining system (Fig.2) consisting of a cutting tool to work up on the job hold properly in a fixture on a machine tool. For making a specified job in a machining set up, the first step is to determine appropriate machining process(es), cutting tool(s) and process parameters such that it is done with minimum time, minimum power consumption and minimum cost using the available machine tools and cutting tools maintaining safety conditions. Therefore, advancement of machine tools is very much linked with the advent of new cutting tools (types, geometry and materials).

Depending on various type of needs, different machine tools have been built up [3][5][6]. The lathe, named as the 'Father of All Machine Tools' can produce a wide variety of jobs, and hence, a universal type machine tool. Special purpose machines are used for making specific type of jobs only, such as cam grinder for making cams, gear hobbing machine and gear shaper for gear cutting, etc. The other kind of machine tool is mass production type, where large quantity of a job is made with high productivity; examples are automatic lathe, screw cutting machine, etc.

Chronological development of different machine tools is briefly presented in this paper by dividing the advancement in four periods.

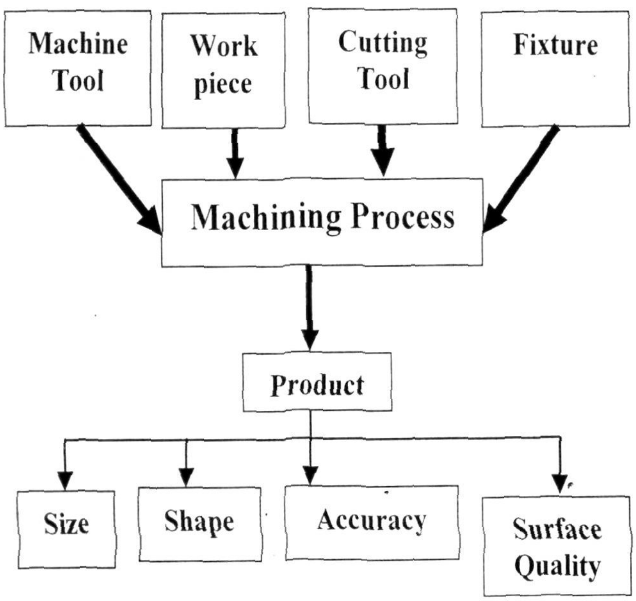


Fig. 2. Schematic diagram of the machining system

2. Development of Machine Tools

The ages of development of machine tools are divided into four periods. In the following sections, chronological developments of machining machine tools are briefly discussed starting from the stone age, in the pre- and post period of the discovery of steam engine and after the discovery of electricity.

2.1 Stone Age

Stone age is divided into two periods, namely Paleolithic age (old stone age) and Neolithic age (new stone age). While men in Paleolithic age used the stone pieces for various purposes, Neolithic people learned a lot about advanced uses of stone, tree branches, bone, etc. [2][7][8][9][10].

Primitive people preferably used sharp stones having more penetrating ability for protecting themselves from wild animals, and also for procuring food. Sharp edged stone pieces being not found abundantly, sharpening of stones was essential. Different stone-sharpening methods were resorted to, such as formation of flakes, cores and acheules as detailed in Fig.3.

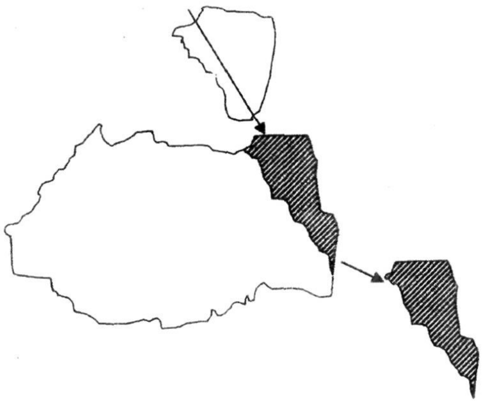
Flakes are the struck-off stone pieces. Remaining portion of the original stone after flaking becomes the sharp-edged stone. This was done either by hammering- known as percussion method, or, by block on block method, in which one big stone is struck against a huge block of stone. Cores made out of flaking are rubbed several times for finishing operation to make choppers, etc. Acheulian technic came later when a chopper was used to strike at an angle to the stone block to make a sharp edge.

Afterwards, composite tools were built up. Here, stone pieces are mounted on the broken branches of a tree or animal bones.

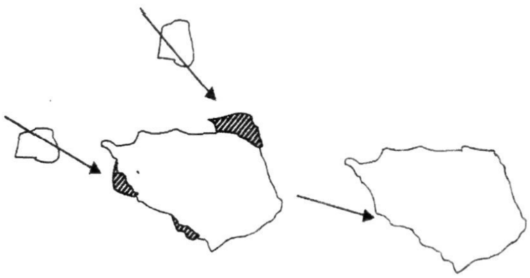
In the Neolithic age, sharpened stone axis, flint sickle, chopper, bow string drill, spinning spindle, hand grinding mill, plough were used mostly manually, and all these played a vital role in developing the machining process and machine tools at the later stages of human civilization. Developments of different types of stone tools are indicated in Table 1 [3].

2.2 Pre-Steam Engine Period

Till the second half of the 4th century A.D. when scarcity of man power poised a severe problem, machining operations were performed by labours, many a times the slaves, although around



(a)



(b)

Fig. 3. Methods of making sharp stone pieces a) making a small flake from a bulk piece of stone, b) making a big piece of stone sharp by removing extra materials from two sides.

Table 1: Developments of the stone tools

Approximate age in years (B.C.)	Cultural stages	Types of stone tools
1000000	Pre-palaeolithic	Crude usage of stone
800000	Lower-palaeolithic	Stone choppers used
100000	Middle-palaeolithic	Composite stone tools
40000	Upper-palaeolithic	Fine stone flakes, blades, files
8000	Mesolithic	
5500	Neolithic	Agricultural tools

1500 B.C., a primitive lathe, La-theme (meaning a paddle operated machine) was used in Italy; the concept of potter's wheel was also known to the Egyptians as early as 3400 B.C. to 3200 B.C. This concept helped evolve turning operation in a lathe.

Due to epidemic and other reasons when slaves died en masse, a short fall of the man power was felt acute, and this led to making of a crude lathe in 700 B.C. Some types of this lathe are also used by the carpenters nowadays. Bow string drills were also used by the Greeks, Egyptians and Romans in those days.

In the fourth century, animal power, water-power and explosives were used as the power source for running different machines in Rome [7][9][12].

Chinese people used horses which gave faster operation of a machine in the 12^{th} century. In the *13^{th} and 14^{th} century, industrial centres with water-*powered systems grew up mainly beside the rivers, and a number of saw mills were set up in England.

Windmills were widely used in North-West Europe in mechanization of machines in 15^{th} century. During this period, various cutting tools used were chisels, files, abrasive stones, engraver's burins, etc. Simple type of horse driven lathe with hand-held cutting tool was used during this time [10][11][12].

Various improvements in lathe were also incorporated in 16^{th} century [12][13]. Jacques Bessen built up paddle operated screw cutting lathe using rope-pulley drives. In 1568, concept of a mandrel for holding a job in a lathe was utilized by Hartman Schopper. Danner brothers and Leonardo da Vinci contributed much in continuous motion lathe and thread cutting operations during this time. At the same time, around Tula in Russia, small to big factories were set up and number of machineries were made.

In 17^{th} century, windlass powered broaching machine for making rifle barrels was used. A man driven wood planer made by Mathurin Jousse came into existence in the middle of this century. During this time, grinding and polishing wheels, file cutter, thread making knowledge were available. Bessen's oval turning were developed by Felibien and Plumier [7][11][13].

As the source of power, wind mills came first followed by hydraulic systems. Otto von Guericke in 1654 and G. W. Leibnitz in 1679 planned and developed air-lift pump and wind-operated pump respectively as the means to supply power to different mills. By this time, considerable progress was made in mining and metal extraction of copper, silver, lead, etc., especially, in Germany. All these caused improved machine tool structure design.

In the early 18th century, George Sorocold of Britain built up a great water wheel for silk mills; Stiernsund of Sweden established shearing mills, slitting mills, etc; Christopher Polhen also planned different water-powered machines. Mechanically operated slide rest applied to a turning lathe was invented by A.K. Nartov in Russia in 1712; he also made screw-cutting lathe, copying lathe, gear cutting machine, etc. Improvements on the horse-driven horizontal centre drills were introduced by a Swiss, Maritz, while simple ones had been in use in Spain, France, Sweden and England. In 1714, Sidorov of Tula Armoury, Russia developed water-powered machines to develop drilling gun barrels; Y. Batishev implemented in 1715 a rubbing machine for finishing and multi-spindle drilling machines to give high productivity. By 1750, a French, Antoine Thiout made a lathe with tool holding carriage which can move longitudinally along a lead screw, thereby reducing the dependency of a skilled operator [3][6][7][10][11].

The need of high quality products and hence, machining accuracy was also felt that time. French clock-and watch-makers were experts in developing precision instruments. La Lievre, Gideon Duvul and Ferdinand Berthoud invented Fusee Engine- a high precision machine tool- in 1763. Some other accurate machine tools were developed in Russia, such as grinding machine, spherical turning lathe, facing lathe developed by Lomonosov, special cylindrical boring machine and special purpose lathe for making parts of engines made by I. I. Polzunov. Between 1768 and 1780, a French textile machine expert, Jacques de Vaucanson devised lead screw driven lathe and drilling machine, and the lathe bed rigidity was improved by putting prismatic metal bench; a satisfactory screw-cutting lathe was made by Jesse Ramsden [3][6][11][14].

2.3 Post-Steam Engine Period

As a result of the endeavour of Savery and Newcomen since 1699, by 1740s, Newcomen's steam engine spread out rapidly. I.I. Polzunov in Russia also worked a lot on steam engines. Finally, Mathew Boulton and James Watt made commercially successful steam engine in 1770s and thereby outdating water-powered machines gradually.

The invention of steam engine was a major breakthrough in the history of science and technology. Steam engines were commissioned in most of the major industries and machining systems at that time. J. Rennie, an Englishman, contributed to diversifying the applications of steam engines [6][7][9][11].

In line with this, improvements in drilling machines were done by Focq (1770) and Crillon (1809); from 1775 onwards, a number of steam engine-run machine tools were popular- John Wilkinson in England invented [3][14] precision power-driven boring machine, I.P. Kulbin and Sabakin, both Russian, developed a special clock gear making machine, and screw cutting and cylinder drilling machine respectively.

Henry Maudsley, in 1794, developed a slide tool rest fitted to an engine lathe, and by 1800, lead screw and change gears were successfully incorporated in lathe. The first planer and horizontal milling machine were developed in 1817 by Richard Roberts and by Eli Whitney in 1818 in Britain. For wood working, Brunel and Bentham made a number of machine tools including sawing, boring, rough mortising, etc. However, many of these machines were still using manually driven big wheels using a chord. [4][11][14].

Parallel works were performed in the Tula Armoury in Russia during 1815 to 1825 when 135 units of special purpose machine equipment were built up. Principles of the interchangeable manufacture of rifles were also introduced by Pavel Zakhava; Zakhava also made an automated copying lathe in 1824 [6].

Interchangeable manufacturing technics were also utilized by Eli Whitney and Simeon North to produce pistols of large quantities.

Realizing the increasing demand of producing accurate components, use of precision measurement devices were promoted by Joseph Whitworth in 1930s. Henry Gambey made dividing engine for making accurate parts in 1840.

This followed development of a number of precision and high production machine tools, such as drill press with automatic feed by John Nasmyth in England in 1840 [14], Flitch's turret lathe facilitating mass production using indexable multiple cutting tool turret in 1850, power shaper in 1851, vertical boring machine developed in Boulton and Watt's foundry at Soho, etc. [4][7][11]. Within 1849-1854, Samuel Colt manufactured his famous revolver by precisely controlling production process on a complete interchangeable basis.

By 1855 in USA, Robbin's and Lawrences' gun were manufactured in a turret lathe with eight tools mounted on an octagonal indexable turret. Later in 1861, Ratchet and Paul mechanism was used to rotate the turret and for bar feeding mechanism. Meanwhile, hobbing machine was introduced in the year of 1856 for making gears. Multi-spindle drilling machine was designed in Britain in 1860 to achieve high productivity. Universal milling machine was built up in American firm Brown and Sharpe in 1862.

By 1880, different grinding machines were built up [14] for finishing the components. However, discovery of silicon carbide and alumina as grinding wheel material made in 1890s revolutionarised modernization of grinding machines.

Improvement in hobbing machine used for gear cutting was made further to make its successful use in America in 1887 onwards, whereas in Bretain its use started effectively since 1896 including making worm gears promoted by F.W. Lanchester. Introduction of gear box in 1892 in USA also played a key factor to provide easy speed and feed change facility in a machine tool [7][9][10][11]. This era was completed with the invention of the bandsaw by Leighton Wilkie in 1933.

It can be said that widespread use of machine tools was a 19th century development when the first industrial revolution had taken place. Further improvements on the machine tools developed, selection of optimal process parameters and on the process were only be possible till the discovery of electricity and its easy availability to the industry [3][14].

2.4 Age of Electricity

The discovery of electricity was a major event in the human civilization with respect to the advancement in science and technology. Although Benjamin Franklin noticed electricity in mid-eighteenth century, followed by the works of Luigi Galvani (1786), Alexsandro Volta (around 1800), G.S. Ohm (1826) to study on the behaviour of electricity, till the development of different types of turbines in the second half of the 19th century, electricity could not be used in the industry to run machines [7][9][10][11].

In Viena Exhibition (1873), application of electricity on to machine tools was demonstrated, and by the end of this century, electricity almost replaced the steam engine, etc. as a prime power source. Ormesby Iron Works was lit by the Parson's turbo-generator in 1888; by 1900, first Parson's 1MW turbo-alternator was installed [4][11][15]. This was a major land mark in accelerating the progress of human civilization; not only upgradation of existing machine tools was taken up, but also newer modern machine tools and machining systems were developed.

2.4.1 Stages of Automation

Easy availability of electricity facilitated mechanization and automation of machine tools [3][14][16]. Different kinds of automation are listed in Table 2.

It can be found out from previous sections of this paper that A(0) and A(1) levels of automation (Table-1) was achieved at the early ages of human civilization; later on self feeding (A(2)) through lead screw and feed screw had been invented. Repeat cycle operations, that is, A(3) level of automation, was also in use in the pre-electricity period when automatic screw cutting lathe and some other

Table 2 : Details of the stages of automation

Level of automation	Items automated	Examples
A(0)	Nothing automated	Hand tools, manual machines
A(1)	Power source	Powered machines and tools, Whitney's milling machine
A(2)	Dexterity, self feeding	Single cycle automatics
A(3)	Diligence, repeat cycle	Open loop NC machine, automatic screw cutting lathe, transfer machine
A(4)	Judgement, feedback control	Closed loop NC machine
A(5)	Evaluation, adaptive control system	Model of process control for analysis and optimization in adaptive control system
A(6)	Learning by experience	Application of Artificial Intelligence

machine tools were invented.

However, with the discovery of electricity- the most convenient form of energy, improvements in A(1) through A(3) levels of automated machines were found, and further progress was observed leading to A(4) and higher levels of automation within a short period.

Specially, numerical control (NC) and computer numerical control (CNC) machine tools were developed, and electrical gadgets were utilized to upgrade the existing machine tools to increase its effectiveness. These machines are stand-alone machine tools. Although a number of machining operations are possible in these machine tools, these poise some problems of time consuming setting of the workpiece when several machine tools are needed for the completion of the finished product [3][14][17].

Next came the concept of integrated computer aided manufacturing systems, such as DNC (direct, or, distributed numerical control) system, FMS (flexible manufacturing system), etc. In direct DNC system, a central computer controls many NC or CNC machines and the conveying process directly, whereas distributed DNC system uses satellite computers, each of which controls few machines, and a central computer oversees the satellite computers facilitating better manufacturing flexibility. In FMS, integration was thought of to such a level that once a raw material is given input to the system, all the processes, settings, conveying, testing and inspection, assembly of different components, etc. are done automatically to deliver the final product. However, small variation of job design within a narrow part family can only be incorporated in this system. Due to the complexity of this integration, small group of machines are integrated following modular or cellular concept, thus making flexible manufacturing module (FMM) or flexible manufacturing cell (FMC). Machining centres, both horizontal and vertical type, were also constructed that facilitate almost complete machining operations of a workpiece in a single set up utilizing CNC technology [3][14][17][18].

Feedback control systems, adaptive control systems and intelligent machine tools were also implemented in modern times [17][18][19].

2.4.2 High Speed Machining

The need of high productivity was felt increasingly with the progress of human civilization. In-line with this requirement, a number of technologies was implemented, since the early days of modern civilization. Semiautomatic and automatic lathes, multi-spindle machine tools, special purpose high production machines, were invented. Production rate in machining is directly related to cutting speed, feed and depth of cut. Hence, high production machining needs high speed, feed and depth of cut. However, when one tries to go in for high speed and feed operations, primary requirements are suitable machine tools and fixtures, and appropriate cutting tools [3][20][21][22]. Cutting tools should have suitable tool geometry and material.

Introduction of high speed tool materials results in suitable design of machine tools leading to high productivity. Till the end of 19^{th} century, high carbon steel was the main cutting tool material that was giving very low cutting speed (about 5m/min) for machining soft steels. Within 1870 and 1910, high speed steel (HSS) tools were introduced and further developed by Robert Mushet, and F.W. Taylor and M. White respectively. This HSS tools containing tungsten, chromium, manganese and carbon could give a machining speed of 10-20 m/min [3]. By 1923, addition of molybdenum, vanadium and cobalt in HSS resulted in machining up to a cutting speed of about 60 m/min.

However, with the introduction of single carbide (tungsten carbide with cobalt binder), and later on, mixed carbide (mixture of tungsten, titanium, and tantalum carbides (WC+TiC+TaC) with cobalt binder) cutting tools, cutting speed rose to about 150 m/min. Coating of alumina, titanium nitride, titanium carbide or titanium carbo-nitride on these tools caused more than two fold increase in cutting speeds. Toughened alumina or silicon carbide further increased the productivity raising the maximum cutting speed achievable up to about 450 m/min. Special ceramics, like stellite, cermet, ucon, etc. were also developed to promote high production rate machining. Diamond and cubic boron nitride (cBN), although costly tool materials, are being used in making high precision mass and batch production machine tools raising the cutting velocity to several thousand metres per minute [2][3][20][21][22].

To accommodate high speed cutting tools, proper temperature control, machine tool damping against possible vibration, design for suitable machine tool drives and components including fixtures are essential [20][21][22]. For temperature control, appropriate cutting fluid is to be applied; liquid nitrogen- a cryogenic fluid with boiling temperature of -196°C, can also be applied for this purpose which can give the best temperature control, however, need standardization of the process equipment [2][20][21][22]. For both high speed machining and grinding, this technic can be applied.

3. Conclusions

Following conclusions may be drawn from the above discussion;

- The history of the development of machining machine tools dates back to the ancient period of Paleolithic age.
- Entire history of development has been divided in to four periods of time and discussed accordingly.
- Development of cutting tools, salient features of automation and progress in high speed manufacturing have also been briefed in connection with machine tools that were essentially needed to keep pace with the requirement of high productivity which was natural with the progress of human civilization.

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Education is the best provision for old age.

– Henri-Frédéric Amiel