New Paradigm in Machining

Manoj Nayak
Faculty of Engineering and Technology,
Manav Rachna International University,
Faridabad (Haryana)
manojnayak69@gmail.com

Rakesh Sehgal
Doctor
Mechanical Engineering Department,
National Institute of Technology,
Hamirpur, (Mimachal Pradesh)
rsehgal@nitham.ac.in

Abstract: *Manufacturing managers, engineers and researchers will have to be on toe to apply knowledge to their advantage to continuously improve the productivity and competitiveness of manufacturing. Manufacturing technology and management techniques, more so the machining concepts have undergone a sea change in last five to six decades. Manufacturing Industry is now under increasing pressure of global competition, stricter environmental legislation and supply chain demand for improved sustainability performance. Hence approach to productivity go hand in hand by being environmentally conscious, environmentally responsible and environmentally sensitive. This paper attempts to provide in documents, the latest innovations, the latest technologies and explicit knowledge of the practicing engineers, managers, and research scholars in engineering industry and institutions to assimilate the latest trends in machining and visualize a glimpse of the future of machining. A wide spectrum of topics is included in this paper and briefly discussed.*

Index Terms: *Machine tool, NC/CNC, Green machining, MQL, Dry machining, Cryogenic machining.*

I. INTRODUCTION

Machining constitutes, generally both cutting and abrasive processes that are mostly complimentary. Performance of the product to a large extent is dependent on the accuracy and consistency of the machining processes used to produce the parts. Machining processes have some basic limitations that are to be given due consideration at development stages and also is the subject matters of latest researches to improve the processes as it is a major manufacturing process in engineering industry. Major objectives for manufacturing engineering today are different. Major emphasis is on low-volume and large-variety, even in high volume production industry to face global competition. In last two decade, improvements and innovations in all the areas have been significant. The processing has become faster. The quality is better and there is a significant narrowing of tolerances over last five decades. Unit cost has been gradually reduced. Environmental legislation is instrumental in promoting innovative approaches for enhancing the cutting process, thereby promoting the development of more environmentally acceptable options.

The fundamental solutions is renewable lubricant technology, minimum quantity lubrication machining, dry machining, case study on elimination of machining wherever possible, cryogenic machining, concept of recycling of cutting tools, recycling of chips, alloy development etc.

II. EVOLUTION OF MACHINE TOOLS

The growth of the market of arms, bicycles and sewing machines led to a rapid expansion of machine tool industry since its inception a century back. Refer Table 1. But with radically improvement in new cutting material, all the existing machine tools were to become obsolete. The automakers made strong impact on new production machine tools refer Table 2. With cut in assembly time for Model T (FORD) from a day and a half to an hour and a half, it was realized no machine shop could supply components that fast. Then the need of designing new machines for multi-station manufacturing rose.

The history of manufacturing was marked by the development of mass production first in the automotive industry and was followed by the improvements in machine tools and cutting tools, and the introduction of new and better materials with which to manufacture the cars and other consumer goods. By early 1920s machine tool builders competed fiercely with one another in bringing out machines of higher production capacity, especially for the auto industry.

Table 1 : History of Machine Tools of Pre-Auto Era

Crucible steel	1746	Benjamin Huntsman,
Screw Cutting Lathe	1579	Besson
Vertical boring mill accurate enoughto bore gun barrels from a solid casting	1713	Maritz a Swiss
Horizontal boring mill	1758	Peter Verbruggen and a Swiss Jacob Ziegler.
Boring cylinders of James Watt Engine	1776	John Wilkenson
All-metal lathe with lead, screw, changewheels and compound slide rest	1800	Maudslay
Copying Lathe for turning stocks of rifles and pistols.	1818	Thomas Blanchard
World's first Turret Lathe.	1845	Stephen Fitch
First automatic turret lathe Spencer.		Christopher Miner
Universal milling machine for manufacturing twist drill		Joshep R. Brown
Gear-cutting machine using a formed milling cutter for producing involute teeth.	1855	Joshep R. Brown
Universal Grinding Machine Grinding machine and Abrasive wheel	1876.	Joseph Brown Charles H. Norton
A milling machine gear cutter	1867	William Sellers
Gear shaper working on the molding generating principle to make small bevel gears for the chainless bicycle.	1884	Huge Bilgram of Philadelphia
A machine that generated bevel gears by using a rotary cutter and a combination of motions rotary, swinging of the cutter carrier, and lateral.	1898	James E. Gleason
Gear shaper of advanced gear cutting machine.	1897	Edwin Fellow
Cutting gears by using a worm with teeth	1766	Ramsden in England
Produced a machine that would hob spiral gears.	1835	Josheph Whitworth
Obtained the patent for pull-broaching	1898	John N. Lapointe

World War II put a stop to car industry, as most of the plants were requisitioned to produce war machinery and equipment. After the War, many automakers were in bad shape. But the effort of rebuilding the industry started with a new zeal and many new technological strategies evolved for the manufacturing of 'The Machine that Changed the World'. It is evident from activities such as setting up of Automation. Department in Ford in 1946 that devoted to making equipment operate at its maximum rate (which usually can not be done without automatic loading and unloading) and to making work safer by eliminating hand loading of presses. By Oct.21, 1948, Automation Department had approved more than 500 devices, costing $3 million that were expected to increase production by 20% and to eliminate 1,000 jobs. Next automation project related to the machining line were engine block, where automation meant mechanical handling of blocks in, out, and between machines. Morris automobile plant in Coventry, England in 1924 used a new approach to automation. In 1929, Graham Paige installed in its cylinder department a system of operations that included automatic jigs and fixtures with transfer bars to move work from machine to machine; all the basic elements of the modern transfer machine were present in the system. With increased automation for higher production came the increasingly specialized machinery for manufacturing processes.

Table 2 : Production of New machine Tools

In 1903, A. B. Landis patented an automatic magazine feed release for short cylindrical parts
L.R. Heim obtained his patent for the Centreless grinding principle in 1915
In 1922, Cincinnati Milling Machine Co. acquired Heim's invention and introduced its first production centerless grinder.
In 1905, both Norton Co. and Landis Tool Co. offered specialized grinding machines for automobile crankshafts
In 1934 external or surface broaching was introduced.

Shortly after World War II, John T. Parsons envisioned the use of mathematical data to actuate a machine tool. An electronic control system for machine tools was developed with the US Air Force funded program. The first commercial production based NC unit was built by Bendix Corp. and was produced in 1954 for machine tools introduced in 1955.

The three machines were tied together by handling equipment, and the whole system was under tape control called a Digitape that was developed by Hughes Aircraft. The entire line was called the Milwaukee-Matic Model I. In December 1958, a NC horizontal spindle multifunction machine "Milwaukee-Matic II" was introduced. The machine was capable of automatically changing cutting tools in its spindle. The first numerically controlled machine or machining center was born to make the beginning of the second industrial revolution. In 1960, the first controller with transistor technology was introduced. Integrated circuits (ICs) came in 1967 that permitted a 90% reduction in the number of components, as well as an 80% reduction in writing of program. NC and then CNC have contributed immensely in changing the manufacturing practices in last decades.

Today, even in automobile industry, dedicated machine tools are no more the preference. Flexibility for quick engineering/model change without any stoppage is becoming the basic demand from the manufacturing system. Computerized manufacturing provides the answer.

Machine Tool a strategic industry forms the backbone of many if not most of the major sectors of industrial activity in a country in the traditional manufacturing context. Therefore, a country, which is on the threshold of becoming a major global industrial and economic power must have a strong, well-developed, robust and modern machine tool industry to support and assist its manufacturing sector.

New paradigm in the machine tool technologies are surveyed from the viewpoints of high speed and high performance machine tools combined multifunctional machine tools, ultraprecision machine tools, advanced and intelligent control technologies and green machining and machining technologies and advanced machining accessories.

III. MACHINING AND FLEXIBILITY

Cutting parameters: machining-speed, feed and depth of cut (DOC) are to be the maximum to reduce the cycle time. Cutting parameters are dependent on machine tools, work-holding devices, cutting tool materials and their capability to withstand the heat generation and shock loading during the cutting, tool rigidity, and coolant. Tool size and tool holding methods determine the tool rigidity. Cutting fluid provides cooling of the interface of work-piece and cutting edge and facilitates flushing chips away from the work-piece. Tool life is another important consideration in machining that demands careful attention. Trend is to achieve a tool life that provides the minimum cost per part machined by the tool. Machined parts are defined by four quality characteristics: size, geometric, surface texture, and surface integrity. Basic work-piece changed in different manners demanding flexibility in its manufacturing.

Time cycle over the years have reduced and have made the equipment free to do some extra work to justify the return on investment. Once the equipment is expected to be flexible to handle more types of components, two other factors becomes more significant: firstly, the increase in investment due to flexibility and then the effectiveness of flexibility. While the increase in investment to ensure flexibility must be the minimum, the effectiveness of flexibility must be real. Production loss for changeover must be minimal. Changeover process should not influence the expected life of the equipment and the quality of output after every change. It has been observed that sometimes the flexible equipment turn out to be the most inflexible one when it is put in actual use, if not properly planned.

IV. EMERGING WORK MATERIAL

Automotive, aerospace, and defence industries are the leaders in development of the new found materials and processes to provide manufacturing assistance to industry's goals of quality, cost and delivery e.g automobile manufacturers with a quest to make the vehicle lighter and fuel efficient are searching for materials (10% mass reduction yields a 6-8% increase in fuel economy). Nodular iron casting (e.g. crankshaft, connecting rods, camshafts, knuckles, etc.), and powder compacting/sintering (e.g. oil pump gears, crankshaft/ camshaft sprockets) are replacing steel forging. Although iron and steel are stronger and stiffer than aluminum and magnesium, they are not attractive, if they result in a weight and energy usage penalty to the final product Aluminum provides about 50% weight reduction over cast iron. Aluminum Metal Matrix composites (MMC) another new materials being developed for automotive application because of weight advantage. For instance, a strong but easily oxidized fiber such as graphite can be encased in a corrosion resistant matrix such as aluminum. Magnesium will be the next to capture a larger number of applications in automotive manufacturing because of weight and strength considerations. The only limitation of magnesium: being severely corrosive with salt in the atmosphere near seacoasts, or applied to de-ice roadways. Magnesium is making a comeback, and a number of research initiatives exist in the United States and Europe to improve there processing, especially casting. Industry will be increasingly switching over to exotic, composite, engineered, honeycomb, and sandwich materials to reduce weight, cost and manufacturing requirements. However, the new materials may also present new challenges for machining. Machining must move to fast track to meet the challenge.

Concern was expressed about recycling of highly engineered tailored materials without losing the structure about graded powder metallurgy tool steels where the composition varies over small areas.

Other recent areas of materials technology emphasis, such as nano-materials, present similar problems: because the alloying elements are so finely dispersed in the alloy, it is not currently possible to recover these alloying elements during recycling.

A. Alloy Development and Strengthening

Suggestion for alloy development is thick to limit the systems investigating to those containing elements that can be easily recycled. It remains to be seen whether such systems will have economic value. Although composites are expensive to fabricate and inspect, it remains an attractive avenue because they often permit a lightweight structure to have high stiffness and tailored properties for specific applications, thus saving weight and reducing energy needs. Composites, however pose serious problems in recycling, as it may be impossible to separate the reinforcing material from the matrix. The other performance limitation: the moduli of the matrix and the reinforcing phases are usually different, leading to the possibility of fatigue failures at the interfaces between them unless they are carefully designed. A further problem, shared by all newly developed materials, is that extensive mechanical and environmental testing, under static and dynamic conditions, is required before designers will use the material. This trend is a barrier to the introduction of new and useful material systems. It was also important that evaluation of the recyclability of a new material be included in the material database.

Acceptance of intermetallic systems by designers of new materials systems based on lightweight has lagged except for TiAlN. Intermetallics are hard to fabricate, and frequently have properties that are little better than existing alloys. It is significant, however, that current advanced military and commercial airframes are making use of a number of resin-matrix composites for control surfaces and structural members.

V. EVOLUTION IN MACHINING SYSTEM

The effect of technological and economic forces on both product and production system creating a paradox in which increased performance is expected from the machine tools under more difficult conditions with less human supervision. The proliferation of NC/CNC, FMS, and CIM concept are evidence of the above. The machine tool may be viewed as being the sub system within the large manufacturing system. Improvement in the performance of the machine tool system, and thus the manufacturing system, may therefore be obtained through the integration and improvement of the elements within the machine tool system notably such as the cutting process, the machine tool structure, the workpiece and its fixturing, cutting tool, sensors and the controllers.

A. Machine Tool Design

Machine tool may be viewed as being the key elements within a manufacturing system, which may consists of robotic devices, automated guided vehicles, cell controller, automatic storage and retrieval systems etc. NC/CNC in machine tools has made the revolutionary transformation in manufacturing. CNC can be configured for a wide variety of machine types and performance levels from simple two-axis turning centers to five-axis high speed machining centers to multi-station transfer. Parts requiring machining are generally rotationally symmetrical, disc type or shaft type, prismatic ones, or combination of the two mentioned earlier. Parts are getting more and more complex as designers try to combine components that were formerly an assembly into a single piece for better built-in quality. Some part configurations tend to combine rotationally symmetrical and prismatic surfaces. The most daunting challenge is how to make a machine with both low inertia in its moving members and the structural stiffness to resist falling prey to the increased propensity for vibration that comes along with ever increasing high speed, feed, depth of cut along with new cutting technology and new tool materials. Machine tool design involves use of technology like composite filled bases and hydrostatic way systems, non-contact bearings using air, hydraulic fluid, or electromagnetism to support the spindle shaft etc. Manufacturer's challenges are to improve all the mechanical and electrical components and make a-state-of-the-art machine tools. A new concept of intelligent machine tool is already under development with the following specific features as goal: intelligence, autonomy, flexibility and cooperation.

B. Tool Wear/ Breakage Monitoring Systems

Poor future prospects were forecast for the cutting processes because of the higher energy waste and related economical inefficiency. However, recent developments in machine tools, computerized control, automatization, combined with the related unforeseen improvements in the cutting materials and their protective coatings with special geometrical shapes of the tools, make such a prognosis completely invalid. Moreover, the degree of use of the machining operations has even significantly increased. New cutting materials increase the tool efficiency costs of performing machining operations, and also highly increase the reliability of the cutting and the quality of the products [2].

Processing tool condition is very influential on reducing rejects and standstills in manufacturing, which can directly be seen through geometric, surface and structural properties and characteristics of a processed part.

Failure of monitoring causes the slow down of the process. Increasing tool wear may cause serious damage not only to the tools, but also to the work-piece and sometimes, even to the machine tools. Effort is being made to substitute the dependence on skilled operator's eyes and ears to signal the need to replace the tools once they are worn. Commercial systems are available "one sensor/one tool per process". Intelligent neural networks and neural fuzzy techniques are methods for merging monitoring properties [3].

C. Accuracy of Machine Tool

Qualities of performance capabilities of machine tools are defined by accuracy and repeatability. Precision of a machine tool is one major factor deciding part accuracy. Trend is toward tighter part specification for all machining processes. For a consistent production of quality parts over the effective life of the machine tool, emphasis today is on a regular monitoring and maintenance of the accuracy of machine tool.

D. Trends in Coolant Application and Management

Metalworking fluids cool the tool/machine tool, flush the chips from the cutting area, lubricate the work-tool interface and reduce friction, and help fracture chips into manageable sizes. It also provides cleaning and anti-corrosive benefit. An intelligent coolant management is critical. Flood cooling (at pressure less than 5.5 MPa) and high-pressure and high-volume cooling are major trends for machining. Both the trends aim at assuring to get the coolant effectively onto tool-part interface to avoid intermittent cooling and heating of cutting point/s during cutting.

E. Modular Work-Holding System

Trend is to use modular and quick-change work holding. The objective is to provide productivity improvements and to enhance flexibility without the costs inherent in dedicated, custom-built fixtures. Modular fixture uses off-the-shelf standard clamping and locating components that are mounted on a standard sub-plate to accommodate the configuration of the work-piece.

F. Work Holding Chuck

Chuck tends to open at higher rpm was the reason for slow speed turning. It necessitated redesigning of work-holding equipment, as with higher rpm the centrifugal force that pulls the chuck's jaws outward becomes critical. Higher spindle speeds demand some way of counteracting centrifugal force without applying clamping pressures that will distort the work

G. Intelligent Fixturing System

As the trend towards smaller lot sizes and higher accuracy parts continues, many manufacturers are finding that dedicated workholding systems just don't provide the versatility they need. Modular systems, on the other hand, are best suited to small quantities or infrequent production runs. These and other flexible fixturing systems not only clamp accurately and consistently, but allow multiple machining operations to be performed in one setup, often slashing both production time and cost. IFS are the future of work-holding system that is being developed initially for the high volume production. An IFS consists of a vision system, a flexible clamping system, a part location system, and a micropositioner that positions the fixture so that the workpiece is precisely aligned on the machine tool table. Flexible fixturing systems have a strong potential to reduce capital-investment costs by as much as 25% per machining system.

H. Cutting Tool

Tool materials, top form geometry, hole making tools, thread making tools and techniques, tool holding system, tool clamping systems, modular/quick change toolings. There has been a continuous development of tool materials over this century starting with high-speed steels to diamond. However, the need to machine increasingly more and more difficult-to-machine materials and at increasingly higher and higher cutting speeds is continuous imposing pressure for the development of new tool materials. The manufacturers of tool materials are accepting this challenge, as the rewards can be considerable. It appears that the time for monolithic tool materials seem to have come to an end being replaced by more and more of engineered coated tools. Whisker reinforced ceramics have bright future for selective workmaterials depending on the combination of whisker and matrix materials used. New whisker reinforced composite materials of different combinations of whisker and matrix materials may pave the way for new tool materials custom designed for a given application.

All these material and coating developments have addressed some of the problems one would phase without the use of a lubricant to a certain extent. Such approach has potential for dry machining

I. Micro-Geometry of the Edge

Micro-geometry of a cutting edge plays a pivotal role on the workpiece surface properties and the performance of the cutting tool. In order to improve the overall quality of the finished component, tool edge geometry should be carefully designed. Design of cutting edge may affect the chip formation mechanism and therefore help reducing cutting forces and increasing tool life [4]. It is known that sharp tools are not durable enough for most of the machining operations; therefore, tool manufacturers introduced different types of tool edge preparations such as chamfered, double chamfered, chamfer + hone, honed, and waterfall (also referred to as oval or parabolic) edge designs.

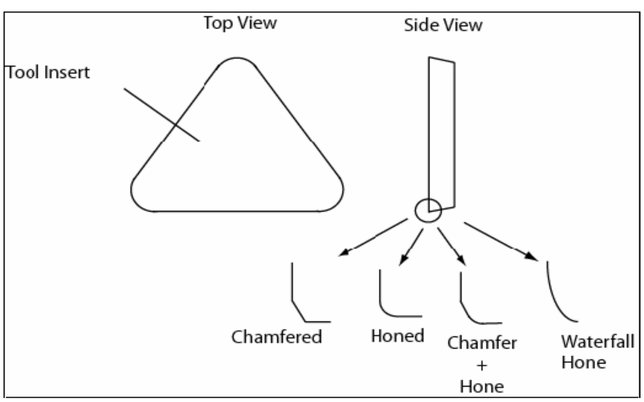

Fig 1. Various Types of edge designs

Micro-geometry along the cutting edges is controlled to strengthen the edge and extend tool life.

J. Wiper Insert

In turning, the development of new wiper insert is a strategy for achieving double productivity with the same surface finish. Manufacturers claim to improve surface finish two times over standard inserts. Alternatively, the feed rate can be increased at least by 20% without sacrificing surface finish requirement.

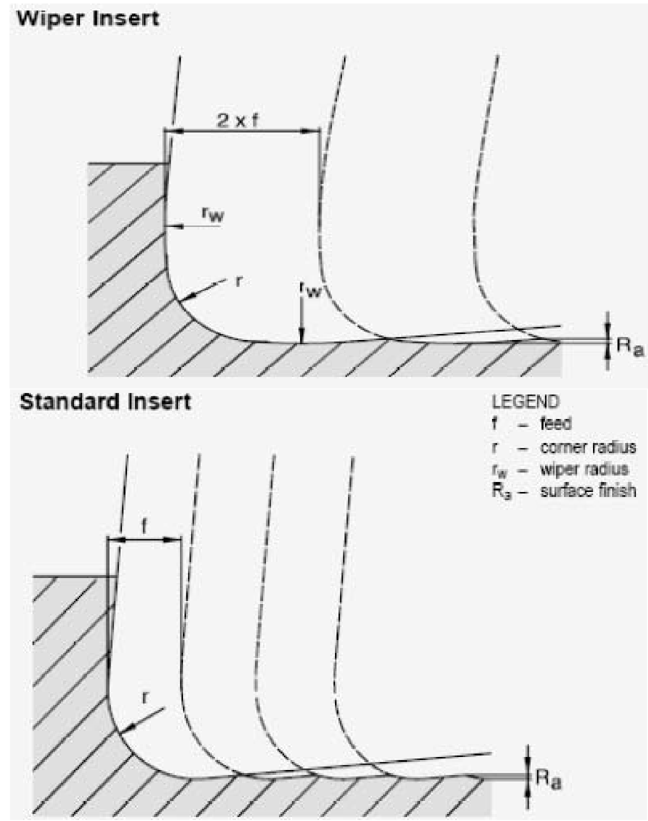

Fig. 2 : Wiper Vs Standard inserts [15]

K. New Shapes

New shapes of inserts are emerging that have more cutting edges on an insert. Hexagonal insert with 12 cutting edges and double-sided octagonal edges with sixteen cutting edges have come for face milling cast iron. Inserts shape is selected relative to the entering angle and accessibility requirements of the tool. The largest possible point angle should be applied to give insert strength and reliability. But this has to be weighed against the variation of cuts needed to be taken. Here, the versatility of the tool, through the degree of tool access, is determined by the size of the point angle

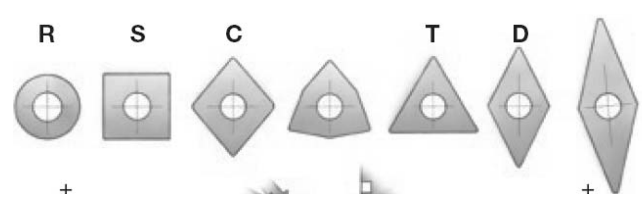

Fig. 3. Various Shapes of Inserts [15]

L. *Intelligent Insert*

Very soon 'smart' cutting tools will be in use. The effort is to find a production method to install electronic sensors right on the cutting edge of an indexable insert. These smart tools will be able to talk to the machine and the total system to adjust speeds, compensate for heat and generally make the metal cutting process more efficient. A high speed steel, carbide or ceramic cutting insert or tool carrying an integrally mounted sensor to permit the sensor to sense and monitor machining phenomena on the cutting insert on a continuous basis to determine whether the cutting insert is operating efficiently and effectively [5] is already patented.

M. *Non-Traditional Machining Processes*

Stringent design requirements and difficult-to-machine materials such as tough super alloys, ceramics, and composites, have made traditional machining processes costly and obsolete. As a result, manufacturers and machine design engineers are turning to advance machining processes. These machining processes utilize electrical, chemical, and optimal sources of energy to bind, form and cut materials. These techniques apply lower mechanical loads, leading to lower capital equipment costs due to reduced machine stiffness requirements. They enable cost effective machining of high-performance materials that prove difficult or impossible to machine conventionally. Environmental stewardship adds a burden to these new technologies, requiring process developments.

N. *Tool Coating for Better Tool Performances*

Coatings are one of the "most revolutionary and productivity enhancing technologies ever developed". Coating primarily increases wear resistance, reduces cutting forces and temperatures at the cutting edge and thereby indirectly affects the deformation and fracture behavior of the tool. Hard coatings thus compliment the properties of the base tool materials and the optimized tool geometry with improved performance: better life, or higher cutting parameters, or the both. TiN, TiCN, TiAlN, TiAlN-X, CrN, Super-R, Dialub, ZiN.

O. *New Machining Concept*

High speed machining, Hard machining, Dry machining, Near-dry machining, Near-net-shape machining, Machining difficult-to-machine materials, Bulk machining.

P. *Abrasive Machining/Grinding*

The process- external cylindrical grinding, high speed grinding, creep feed grinding, high efficiency deep grinding, internal grinding; New grinding machines; Grinding wheels:-Development of aluminum oxide grinding wheel, CBN grinding wheels; Single point OD grinding. The challenge of grinding with small chip thickness, undefined cutting edge geometry, and high specific grinding energy will be a significant hurdle to overcome, unless the environmental case dominates in the future [1].

Q. Machine Controls

Higher machining speed up to 50,000 rpm as standard with feed rates of about 60m/ min will be effectively used in high-production lines. Linear motors may even increase the feed rates to 100m/min. Machining will have to cater to many models. Flexible automation will be integrated in the medium-to-low production lines. Controls will be open and PC based as standard. Performance improvements of microprocessors and gradual reduction in cost will make the machine more accurate. Based on the knowledge of the machine tool dynamics and the required machining accuracy, enhanced software will be able to adjust the cutting parameters such as speeds and feeds to optimize the machining performance. Intelligent integration of sensors and adaptive control of the cutting forces on real time basis will further assist the overall improvements.

R. Virtual Machine Tool Library

Remote diagnostics for machine repair and support using PCs and Internet will eliminate delays, and reduce anxiety of production managers. Basically, a technical person of the machine manufacturer gets in reality as close to a machine operator in need as quickly as possible with technology allowing simultaneous audio, data, and video interactive communication.

VI. RECENT MACHINE TOOL TECHNOLOGIES

A. High-Speed, High-Efficiency Machine Tools

It is well known that demands are mounting for greater maximum main spindle speeds and feed speeds i.e. machine tools of higher speed and higher efficiency is much needed to avoid chatter vibration [15].

Avoidance of chatter vibration has been posing a new challenge in the machining of aluminum materials for aviation purposes. Generally, chatter vibration is avoided by reducing the depths of cuts and cutting speeds (low-speed stability), but it is possible to avoid chatter vibration by increasing spindle speed.

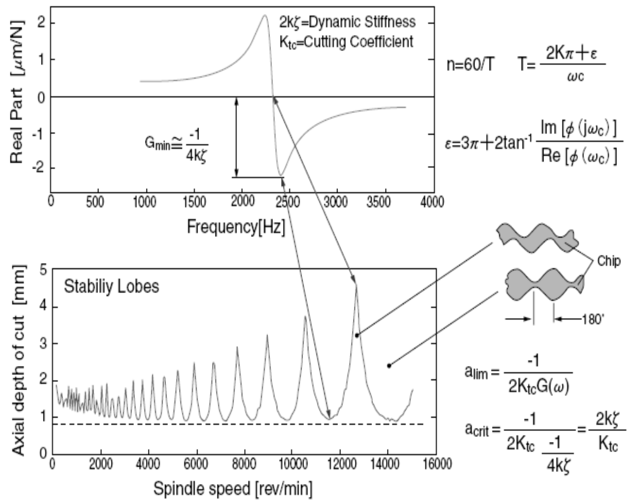

Fig. 4. Stability chart of regenerative chatter vibration [16]

Results [16] obtained for stability graphs such as the one shown in Fig This graph shows that chatter vibration does not occur in the region of depths cut below the stability lobes relative to spindle speeds on the horizontal axis. Variations in chip thickness are caused by differences between the roughness of the finished surface generated by the immediately previous revolution of the main spindle or by an immediately previous cutting edge and the roughness of the finished surface currently generated by the current cutting edge. This variation in chip thickness contributes to variation in the cutting force and contributes to continuing vibration. If we can run the main spindle at a higher speed that is equivalent to the vibration frequency, then the difference between the phase of vibration resulting from the immediately previous revolution and the phase of vibration deriving from the current revolution can be effectively controlled, thereby eliminating variations caused by chip thickness. If such a condition is realized, chatter vibration will not occur even with greater cut depths.

Utilizing this principle, high-speed, high-efficiency cutting has been implemented for aircraft components made of aluminum and other materials.

There has been mounting interest in the dynamic characteristics of a main spindle system that includes a main spindle, chuck and tools. As a result, the interrelation of bearings and other design factors with the dynamic characteristics of the main spindle and main spindle system has been clarified both theoretically and experimentally, and this achievement has been applied to the design of main spindles.

B. Combined Multifunctional Machine Tools

In addition to high-speed, high-efficiency, cutting capable machine tools, research on machine tools is currently focused on combined multifunctional machine tools, including 5-axis machining centers and combined multifunctional turning centers. In addition to machining of bores, outer circumferences and end faces, certain applications are executed for slope machining and hobbing. Many different 5-axis machining centers have been developed. In particular, in addition to orthogonal 3- axis vertical and horizontal machining centers, many simultaneous 5-axis control machining center products that have work tables with two additional axes for rotation and oscillation are used widely.

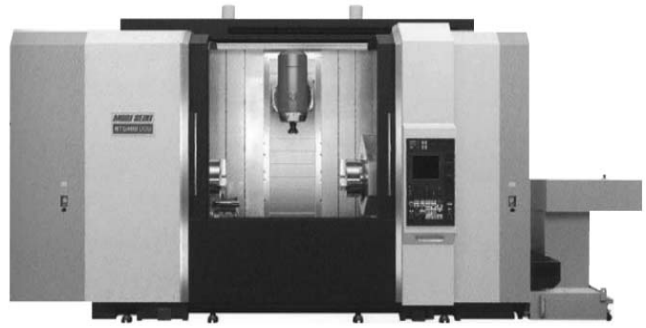

Fig. 5. Combined multi-axis machine tool (Mori Seiki Co. NT5400DCG)

Most recently, some machining centers have a worktable driven by a DD motor and a high-speed, high-power rotary table capable of high-speed indexing, and they feature the functions of vertical turning centers. Combined multifunctional machine tools have advantages that include the following. They are capable of machining complex forms that require simultaneous control of five axes. Loss in machining accuracy from dismounting and remounting the workpiece is prevented because once a workpiece has been mounted to the chuck, all machining processes are executed without need for rechecking the workpiece.

C. Ultra-Precision Machine Tool

Previously, the industrial fields that required ultraprecision machine tools were limited and the market scale for ultraprecision machine tools was relatively small. In contrast, needs have been increasingly mounting for ultraprecision and micro-machined parts and components, such as dies for optical parts and components. Progress in the component technologies for ultraprecision machinery, such as air hydrostatic bearings and guides, is remarkable. Process for preparing optical lenses has changed from injection molding with plastic materials to a hot-pressing process with glass. To cope with this trend, an increasingly larger number of dies are being made of materials that are extremely difficult to machine, such as tungsten carbide and ceramics, and these dies must undergo many machining processes including grinding and polishing. These techniques in die machining processes and glass press-forming processes are contributing positively to the manufacture of the lenses on camera cell phones and digital cameras, which are both increasingly common.

VII GREEN MACHINING

The new cutting fluids have to meet the requirements of the environment protection set either by in-house regulations, or regulations imposed by the state or international ISO 14000 environmental management standards [5]. The trend towards renewable lubricant technology is now irreversible, driven by global warming, dwindling oil reserves, ethical corporate policies and government strategies to encourage biomaterials. Hence going green, recycling, salvaging are the buzzwords when it comes to new technologies or developments in the manufacturing world. The fundamental solutions discussed is renewable lubricant technology, minimum quantity lubrication machining, dry machining, case study on elimination of machining wherever possible, cryogenic machining, concept of recycling of cutting tools, recycling of chips.

A. Renewable Lubricant Technology

One of the primary obstacles limiting the use of synthetics for aqueous metalworking fluids has been their cost compared to petroleum. Today, that cost gap is rapidly closing. In fact, vegetable oils may even have seasonal cost advantages. Furthermore, as the cost of petroleum base stocks rises, vegetable based fluids are becoming more attractive. Use of environmentally responsible metalworking fluids is definitely gaining momentum globally. Improvements in technology have significantly enhanced the performance vegetable-based fluids, while the cost differential compared to petroleum-based fluids has become less of an issue, opening the door to greater use of environmentally responsible fluids. The results in the study [6] indicated that in general, coconut oil performed better than the soluble oil and straight cutting oil in reducing the tool wear and improving the surface finish. The uses of vegetable cutting oils was investigated [7] in reducing thrust force and improve surface finish at different spindle speeds and feed rates during drilling. Here three different vegetable-based cutting fluids developed from raw and refined sunflower oil and two commercial types (vegetable and mineral based cutting oils), where used.

B. Minimum Quantity Lubrication

Ford, which started using MQL in Germany in 1998, said for typical mass production modules the introduction of MQL helps to reduce annual coolant consumption by about 30,000 gal, water use by 250,000 gal, filter media usage by several thousand yards and compressed air usage by millions of cubic feet [8]. Furthermore the permissible exposure level (PEL) for metalworking fluid aerosol concentration is 5 mg/m3, per the U.S. Occupational Safety and Health Administration (OSHA) [9], and is 0.5 mg/m3 according to the U.S. National Institute for Occupational Safety and Health (NIOSH) [10]. The oil mist level in U.S. automotive parts manufacturing facilities has been estimated to be generally on the order of 20-90 mg/m3 with the use of traditional flood cooling and lubrication [11].

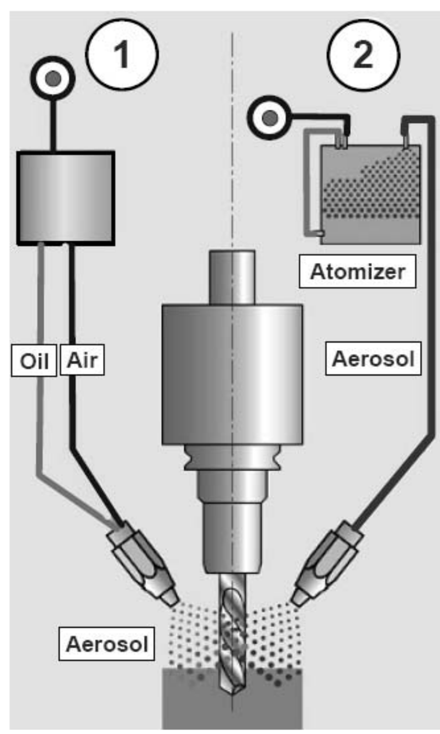

Fig. 6. Minimum Quantity Lubrication [14]

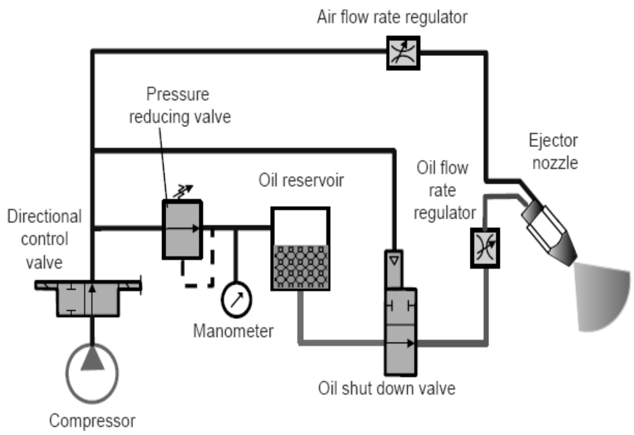

Fig. 7. Aersol Control Unit [14]

What is this MQL Concept? This concept is referred to as "near dry lubrication" or "microlubrication" and has been suggested as a means of addressing the issues of environmental intrusiveness and occupational hazards associated with the airborne cutting fluid particles on factory shop floors. Minimum quantity lubrication refers to the use of cutting fluids of only a minute amount, with a flow rate of 50 to 500 ml/hour, which is much lower than used in flood cooling condition, where, for 10 liters of fluid can be dispensed per minute. This requires extremely high pressure-absorbing high performance oils and very precise spraying head technology, which allows the smallest amounts of lubrication medium to be applied.

C. Dry Machining

Dry machining is making inroads onto many shop floors, as it eliminates or greatly reduces coolant use, often cutting costs and providing a healthier working environment. Where many shops run into trouble, however, is in integrating dry machining into their existing operations. Current standard tool geometries are not economical for dry machining, so shops should select optimized tool geometries to reduce friction between the tool and the chip. Turning or milling operations are the easiest to convert to dry machining. In these operations, cutting edges are exposed and chips leave the cutting zone quickly, having little contact with the workpiece and tool. The chips, therefore, serve as a medium to dissipate heat. On the other hand, chips are not so easily flushed out in a drilling operation, allowing heat to build up quickly in the confined depths of the hole. This also applies to operations involving taps, fluteless taps, and reamers. One approach towards dry machining is to improve the properties of the tool material by making them more refractory, or generates less heat during machining (reduce both shear and friction energies), and/or takes away the heat generated rapidly in dry machining by some other means. Dry machining places considerable physical and thermal stress on tool cutting edges. Edge honing is vital in increasing cutting edge strength, as non-honed edges have a tendency to crack, gall, and crumble under the stress of dry machining. However, honing does reduce edge sharpness, which can increase heat generation during machining. The larger the hone, the duller the edge and greater the heat generated. By permitting both a sharper edge and a smaller hone, ultra-fine grain carbide and diamond substrates deliver the edge strength and reduced heat generation required for optimum tool life and performance. Dry machining requires the use of a tool with a thermally protective hard surface coating. Even with the sharpest tools, high temperatures build up quickly and must be diverted away from the tool. Among conventional coatings, TiAlN (titanium aluminum nitride) has been the top choice for improved thermal insulation during dry machining. But the adhesion characteristics of conventionally applied, single-layer TiAlN coating have not supported optimum performance. Under the dynamic stress of dry machining, single-layer TiAlN has a tendency to fissure, crack, and flake off the tool. Multilayer TiAlN coating, whose structure inhibits surface fractures from reaching the tool substrate, offers significantly improved performance. New coatings such as Guhring's Firex multi-layer hard coating, which is comprised of distinct, alternating ultra-thin layers of TiN (titanium nitride) and TiAlN coating, offer even better results. Firex's structure combines the good adhesion characteristics of TiN, high heat resistance of TiAlN, and the ability to absorb cracking of TiCN (titanium carbonitride).

D. Cryogenic Machining

Sustainable cryogenic machining technology has a high potential to cut production costs and improve competitiveness by reducing resource consumption and creating less waste. In cryogenic machining a cryogenic CLF (non-oil-based i.e. liquid nitrogen LIN) is delivered rake face of the cutting tool inserts, which is exposed to the highest temperature during the machining process, or to the part in order to change the material characteristics and improve machining performance. The LIN in cryogenic machining systems quickly evaporates and returns to the atmosphere, leaving no residue to contaminate the part, chips, machine tool, or operator, thus eliminating disposal costs. Additionally, cryogenic machining could help to machine parts faster, with higher quality, increased machining performance, and a reduced overall cost [12]. Some experimental results finding discussed showed potential benefits of cryogenic machining are: (a) reduced friction coefficient on the tool-chip interface (b) LIN applied is superior to emulsion in lowering the cutting temperature (c) increased tool-life due to lower abrasion and chemical wear (d) increased material removal rate with no increase in tool-wear and with reduced cutting tool changeover cost, resulting in higher productivity (e) improved machined part surface quality with the absence of mechanical and chemical degradation of the machined surface.

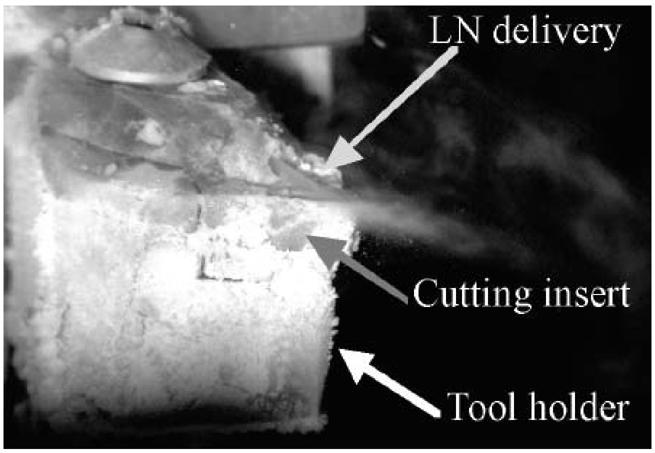

Fig. 8. Cryogenic Liquid Nitrogen Delivery [12]

E. Concept of Recycling of Cutting Tool

Recycling cutting tools is an easy way to reduce costs throughout the supply chain while benefiting the manufacturing industry and the environment. Cutting tool recycling has various immediate and long-term benefits. Eliminating waste, by definition, reduces consumption of resources and helps companies cut costs. Recycling expands material supply. Also, recycling processes typically require less energy and produce less pollution than those used to create virgin materials, whether through mining or other means of production. The effect of rising prices of alloying elements due to economic and political reasons are causing concern across the tooling sector, and like recycling of carbide tips etc. is attracting considerable attention from cutting tool producers. If the price chart of cobalt and tungsten are to be referred, they remain volatile for longer period. Such uncertainty can be addressed by recycling; moreover it not only reduces the carbon footprints and consumption of natural resources, but also can generate extra cash and reduce production costs. Sandvik Coromant's Coromant Recycling Concept (CRC), launched in 1996. The group sets regional goals and price levels for recycled materials in each geographic market, ensures adherence to applicable laws in countries where the program operates, manages promotional campaigns and organizes the vast reverse logistics network required to effectively recycle cutting tools [8,13].

F. Precision Micro machining

21st century advanced manufacturing today is faced with a recent new paradigm that is rapidly changing the scope of machining processes. This paradigm can be best characterized by the phrase "smaller is better". As we move into the 21st century, this paradigm is increasingly impacting other technologies, which, in turn, is driving manufacturing to new miniaturized processes. Machining technologies are included in this drive toward the production of miniature components. Machined micro/meso scale components with micro scaled features (ranging between10 microns and 100 microns) are increasingly required for products in many industries including aerospace, defense, electronics, bio-medical, power generation and propulsion. These miniature components are currently very difficult to manufacture often requiring new and innovative machining processes along with new tools. There is increasing interest in the development of machining technologies based micro scale machine tools commonly known as Micro Machines.

CONCLUSION

While there has been impressive fundamental work in some of the above areas to develop new technologies, they have not been widely implemented. In some cases this is because of high initial investment. In other cases, new design practices to take advantage of new materials have not been established. The recommendation is the key areas in R&D needed to overcome the challenges thrown by metal cutting business. The prescription as how to view the machining can be well understood is as follow: A review of the balance sheet of a typical machining center indicates that approximately 10% of income results from the sale of machining chips and scrap metal. As this amount represents the typical net income of such a center, the chips and scrap must be viewed as a product rather than waste.

REFERENCE

(1) www.unists.com New Machining Concept: Aerospace and Automotive Collaboration.

(2) G. Byrne, D. Dornfeld, B. Dekena, Advancing Cutting Technology Annals of the CIRP 52 (2003) 483-507.

(3) M. Balazinski, E. Czogala, K. Jemielniak, J. Leski: Tool condition monitoring using artificial intelligence methods, Engineering Applications of Artificial Intelligence 15, (2002), 73-80.

(4) Toenshoff, H., H-G., Wobeker, and D., Brandt, "Hard turning-influences on the workpiece properties," Transactions of North American Manufacturing Research Institute, Vol. XXIII, 1995, pp. 215-220.

(5) S. Ramalingam, D.A. Frohib., Intelligent inserts with integral sensors, 2010, Patent No: 4927300

(6) M. Anthony Xavior, M. Adithan, "Determining the influence of cutting fluids on tool wear and surface roughness during turning of AISI 304 austenitic stainless steel." Journal of Materials Processing Technology, 2009,Volume 209, Issue 2, pg 900-909

(7) E. Kuram, B. Ozcelik, E. Demirbas, and E. ??k., "Effects of the Cutting Fluid Types and Cutting Parameters on Surface Roughness and Thrust Force." Proceedings of the World Congress on Engineering, 2010, Vol II, London, U.K.

(8) www.ctemeg.com

(9) Aronson, R. B. "Why Dry Machining", Manufacturing Engineering, 1995, pp. 33-36.

(10) U.S. Department of Health and Human Services, Occupational Exposure to Metalworking Fluids, NIOSH Publication, 1998, Vol No. 98-102.

(11) Bennett, E.O. and Bennett, D.L., "Occupational Airway Diseases in the Metalworking Industry," Tribology International, 1985, 18/3, pp. 169-176.

(12) Yildiz, Y., Nalbant, M. "A review of cryogenic cooling in machining processes" International Journal of Machine Tools & Manufacture, 2008, vol. 48, no. 9, p. 947-964.

(13) www.sandwik.com

(14) Viktor P. Astakhov "Ecological Machining: Near-dry Machining" General Motors Business Unit of PSMI, 1255 Beach Ct., Saline MI 48176, USA.

(15) Y. Kakino: Latest Trend of Main Spindle for NC Machine Tool

(16) Y. Altintas, M. Weck: Chatter Stability of Metal Cutting and Grinding, Annals of the CIRP, 53/2 (2004) p619.

❐