

A STRATEGIC APPROACH OF ENVIRONMENTALLY CLEAN MACHINING

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Abstract A growing world population aspiring to better standards of living is putting severe strain on the Earth's resources. Manufacturing Industries are expected to respond by producing more products with less resource and less waste and pollution. Environmental issues impact on every aspect of life and business activity. The life concept is essential to achieving sustainable development in the long term. Both products and manufacturing processes have to evolve to new level of efficiency. This paper examined the implications of this development for machining processes.

Keywords: Environment, Clean, Machining.

INTRODUCTION

Sustainability has become the cornerstone of environmental policy development for governments, international agencies and industrial firms. The starting point for the transition to sustainable development has been the design of environmentally friendly products. This approach is now being extended to the processes and facilities used in the manufacture of such goods. Initially attention focused on chemical processes, especially those with toxic by-products, but interest has expanded to include virtually all production processes including those of material removal.

METHODOLOGY FOR CLEAN PROCESS DESIGN

The source of the hazard must first be identified and the risk potential must be assessed. This will frequently involve inputs from various disciplines such as engineering, production, health and safety personnel. Hazards may arise due to the use of a particular process/machine, raw material, auxiliary material or their inter-action. Alternative solutions for hazard elimination can then be considered. One approach is to isolate any part or parts of the process identified as being hazardous. In practice this would involve enclosure of the process or machine. This would eliminate any direct hazards arising, but auxiliary systems would be required to render harmless any residues or emissions generated. The most radical approach is to avoid the process step completely, or to replace it with an alternative process. This generated involves modification of the upstream and downstream processes as well. The final assessment of the proposed

solutions must consider not only the ecological benefits but also their technical feasibility and cost effectiveness.

MACHINE TOOL SYSTEMS

Comprehensive assessment of the environmental compatibility of a machine tool requires the overall consideration of all aspects from design, through manufacture, operation to retirement from service. In the use phase the materials and energy conversion processes need to be critically assessed. The supplied electrical energy is almost entirely converted into heat that must be dissipated. In absolute terms the energy levels are not economically significant at an average of less than 5% of the hourly machine costs [Pfeifer et al. 1994]. No significant improvements can be expected by increasing the mechanical and electrical efficiencies of the machine elements. Fig. 1 shows the Material and Energy Conversion in a Machine Tool [Pfeifer et al. 1994].

The incoming raw materials or workpieces should be pre-formed so that only the minimum amount of material is to be removed in order to produce the final shape. Any hazards associated with the raw material must be carefully evaluated. Lubricated oils and hydraulic oils are only used in small quantities and can be recycled at the end of their useful lives; however leakage of these oils will lead to contamination of the cutting fluid. Decommissioning and recycling of machine tools do not generally pose any problems [Pfeifer et al. 1994]. The major environmental hazard associated with machine tool operations due to the use of cutting fluids. Contaminated soil and ground water, as a result of coolant leakage or dumping, is an issue that may need to be addressed when decommissioning or refurbishing a machining installation or when.

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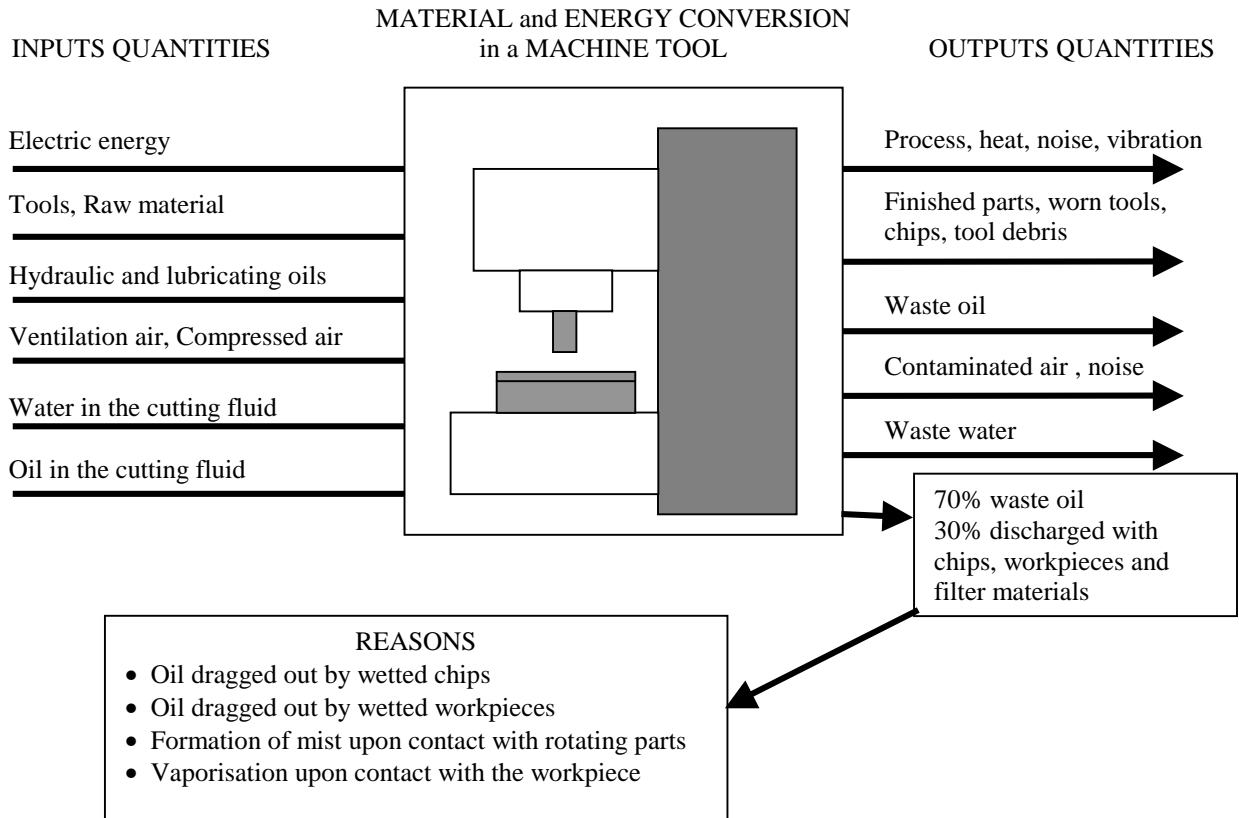


Fig. 1 Material and Energy Conversion in a Machine Tool [Pfeifer et al. 1994]

purchasing a facility that was engaged in these activities

High material removal rates still require the use of large volumes of cutting fluid to reduce friction between the tool and workpiece/chip, to cool the cutting zone and machine frame and to remove chips from the machining position. The use and function of cutting fluids is one of the least well-understood aspects of machining operations from a scientific viewpoint. In traditional material removal processes cutting fluids are the main source of environmental and health hazards [König and Rummenholler, 1994].

A strategy for cleaner machining operations is presented in fig. 2 . Process isolation is the least preferred option. Modification of the process to reduce the toxicity and/or volumes of the emissions and wastes generated is an intermediate step. The most innovative and preferred solution is to avoid the use of cutting fluids by changing to dry machining or by using alternative processes such as turning instead of grinding.

LIFE CYCLE ENGINEERING

Life cycle Engineering (LCE) is the art of designing the product life cycle through choices concerning product concept, structure, materials and production processes. Life Cycle Analysis (LCA) evaluates the environmental and resource implications of these

decisions. At present few techniques exist for conducting LCAs of machine tools and their associated processes. Additionally the unbiased data required to quantify many environmental effects are not readily available.

DESIGN FOR ENVIRONMENT

The Design For Environment (DFE) approach to the design of machine tools provides the designer with the data necessary to evaluate the environmental impacts of alternative design concepts and features. The performance variation of machine tools over time and the reconditioning or recycling of a machine tool at the end of it's useful life are other area that need to be addressed.

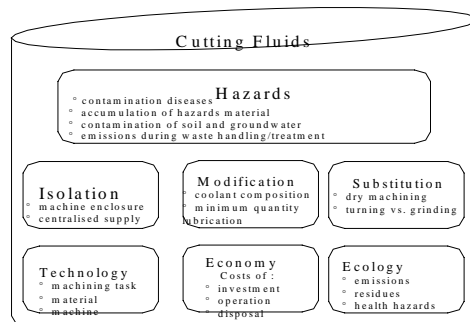


Fig. 2 Strategy to Alleviate Cutting Fluid Hazards

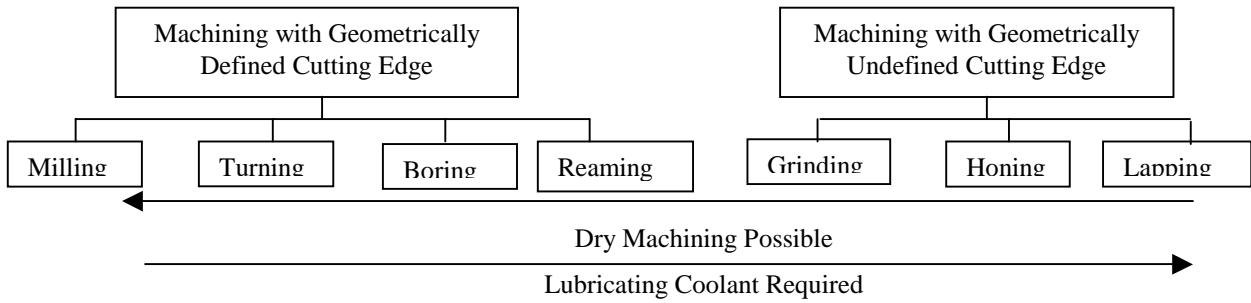


Fig. 3 Necessity for Cutting Fluids

DRY MACHINING

The conversion to dry cutting obviously eliminates all problems associated with cutting fluids but can present new problems of dust generation and chip evacuation and disposal. The extent to which dry cutting is technically feasible for geometrically defined edge and geometrically undefined edge machining processes is summarised in fig.3. Cast Iron have traditionally been machined dry, the wider feasibility of dry cutting has been possible by the development of new cutting tool materials and coatings. At low cutting speeds the lubricating properties of the cutting fluid reduce abrasion and adhesion and prolong tool life. Coated HSS or carbide tools now offer the possibility of carrying out these operations dry. Broaching of soft tempered steels is normally carried out at cutting speeds of 1 to 25 m/mm. The use of TiN coated HSS broaches, under conditions of dry cutting, achieved tool lives 5 to 10 times greater than uncoated HSS broaches with oil lubrication [Pfeifer et al. 1994].

Cast iron, cast aluminum alloys and non-ferrous metals can be dry turned and milled. In wet cutting of these materials, the casting dust mixes with the emulsion to form a sludge, which is both highly abrasive and, when it settles, the deposits can cause corrosion. For dry operation the machine must be encapsulated and dust extraction provided. In one application a high speed milling operation was used to replace abrasive belt sanders in the finishing of aluminum castings for automatic transmission housings. The face mills were 500 mm dia with 26 PCD inserts operating at a speed of 15000rpm. Feed rate is 12.5

m/min and the surface speed is up to 4500m/min. Productivity and quality increased dramatically by converting to dry milling with tool lives in excess of 200000 parts being made possible by a high precision presetting procedure for the tool inserts. A vacuuming system captures the chips produced and because they are clean and dry they have a high resale value [Aronson, 1995].

Drilling, tapping and reaming operations are more difficult to perform dry. In drilling heat is generated not only at the cutting point but also a result of friction between the heel of the drill and the bore wall; additional heat is generated in the flutes due to the rubbing action of the evacuating chips. In tapping the tools are subjected to very high mechanical and thermal stresses due to crushing, friction and adhesion [Pfeifer et al. 1994].

The extent to which dry machining is presently possible for geometrically defined edge machining operations is shown in Table 1.

Table 1: Current Feasibility of Dry Machining

Work Material	Geometrically Defined Edge Machining Processes					
	Turning	Milling	Boring	Tapping	Reaming	Deep Drilling
Heat Treated Steel	∇	∇	◆	◆	◆	◆
Cast Al Alloy	∇	∇	◆	◆	◆	◆
Constructional Steel	∇	∇	◆	◆	◆	◆
Non Ferrous Alloys	∇	∇	∇	∇	∇	*
Cast Iron/ Ductile Iron	∇	∇	∇	∇	◆	◆

∇ Possible ◆ Under Development * Not Yet Possible

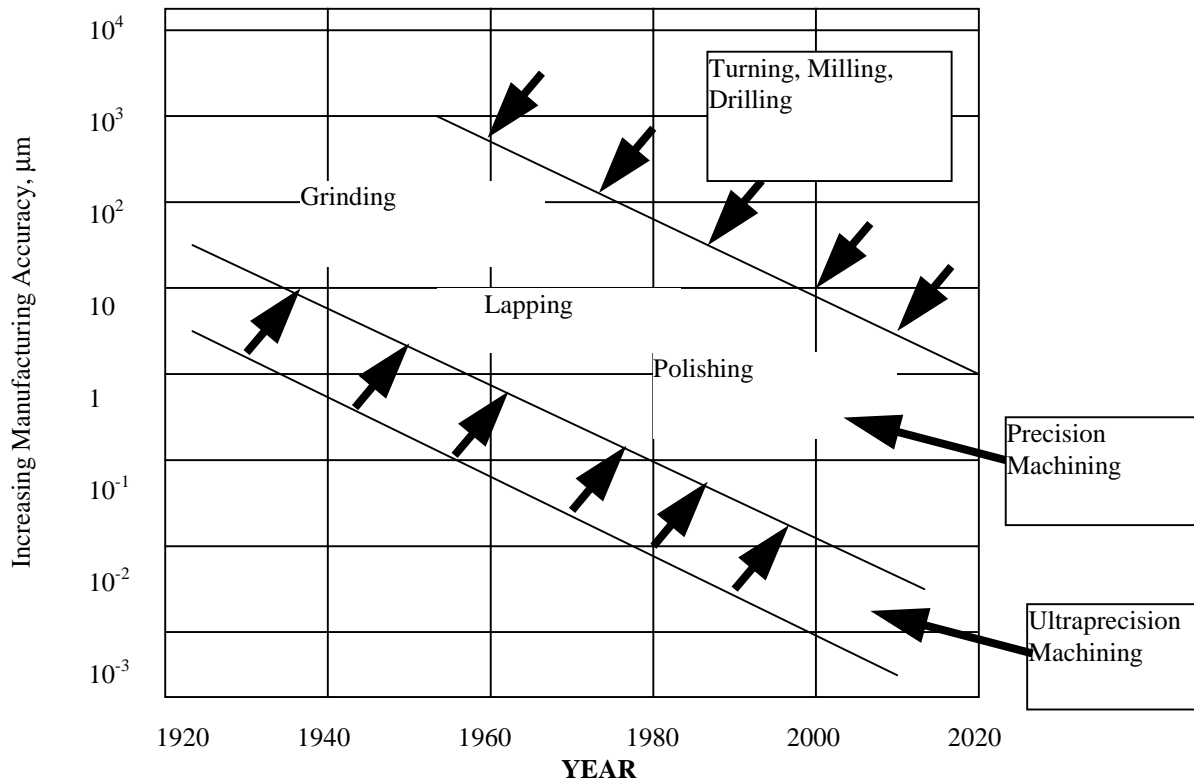


Fig. 4 Accuracy in Machining

HARD TURNING VS. GRINDING

In parallel to the trend of increasing cutting speeds accuracies attainable in machining processes have been increasing continuously as indicated in fig. 4 . The arrows indicated the situation in which the fine finishing processes are finding increased competition at one level from conventional processes such as turning, milling and drilling and at another level from ultraprecision machining processes. Conventional machining and ultraprecision machining take place with defined cutting edge conditions whereas fine finishing processes such as grinding, lapping and polishing operate with geometrically undefined edge conditions. The fine finishing processes have some significant disadvantages. From a production viewpoint they are much less flexible and the specific energy required for chip formation is greater due to the highly negative rake angle. From an environmental standing the disposal of waste fluid and sludge from fine finishing processes is both difficult and costly. One example of the use of alternative processes, which in many instances brings both economic and ecological benefits, is the replacement of grinding processes by conventional processes in the machining of hardened ferrous components. Previously rough machining was carried out on the material in the annealed state and, following Hardening, the final shape would be produced by grinding. Developments in cutting tool materials, such as CBN and ceramics, now mean that machining can produce a finished component in a single operation [Chou and Barash 1995], [Liu and Mittal 1995].

Turning is the most common application of hard machining but milling, drilling and broaching are also feasible [Konig et al. 1990]. The Problems in using a single-step machining process to produce hardened precision components can be classified as follows [Konig et al. 1993], [Liu and Mittal 1995], [Matsumoto, 1991].

Surface Integrity: Provide a level of surface integrity comparable to that of ground and /or superfinished surfaces.

Machine Tool Accuracy: Improve machine tool accuracy to that of grinding machines or better.

Cutting Tool Life: Improve tool life so that it is sufficient for production processes. poor but the volume of material removal is also normally low. The environmental and health effects associated with the various non-conventional removal processes are summarised in Table 2.

Manufactures of non-conventional machining systems and the end users of this equipment must install and maintain auxiliary systems to protect workers against harmful emissions e.g. fumes, dust, noise, electromagnetic radiation etc. and to render harmless any process residues generated. In some processes, such as EDM and ECM, specialist waste disposal and treatment services are required due to the toxic nature of the waste involved [Tönshoff, 1996]

Table 2: Environmental /Health Hazards associated with Non-Conventional Machining Processes

Process	Dust/ Mist Generation	Gas/ Fume Emissions	Corrosive/ Irritant Chemicals	Ionising Radiation	Non-Ionising Radiation	Noise	Sludge Disposal	Fire/ Explosion
USM							o	
WJM	o					◆	o	
AWJ	o					◆	o	
AJM	◆					◆		
CHM		◆	◆				◆	
ECM		◆	◆				◆	o
EDM		o	o		o		o	o
LBM		◆			◆	o		◆
EBM		o		◆	o			
PBM	◆	◆			◆	◆		◆

o Potential Hazard ◆ Significant Hazard

NON-CONVENTIONAL MACHINING PROCESSES

These processes offer unique advantages and overcome the limitations of traditional processes. Traditional machining relies on direct mechanical contact between the tool and workpiece and this fundamental physical requirement inherently limits the process. Non-conventional processes are often characterized by a high energy density in the cutting zone. This frequently necessitates investment in capital-intensive equipment and the use of special process media. The energy performance of non-conventional processes is generally

Fig. 5 shows many of the inputs to the machining process are directly controlled in order to achieve particular outcomes. Other outputs have been neglected but are receiving greater attention because of their environmental impacts.

CONCLUSIONS

Manufacturing industry is now beginning to take a more proactive role in the development of cleaner manufacturing processes and in the design of more eco-efficient products. The ultimate goal is sustainable development where the waste or residue from one

process or product becomes the raw material for another, as part of a large cycle, this imitating naturally occurring eco-systems. In the case of material removal operations much research is needed to better understand the mechanisms of material removal and the interactions between the various system components. Finally attention must focus on how the use of machine tools affects the environment. Traditionally many of the issues here have been under emphasized because they rarely had an effect on produce value. As illustrated in fig.5 shows inputs and outputs in a machining process. A large number of engineering based models are required to describe the input-output relationships involved. These models must be integrated together so that the consequences of any process change can be fully evaluated both in terms of production performance and environmental effects.

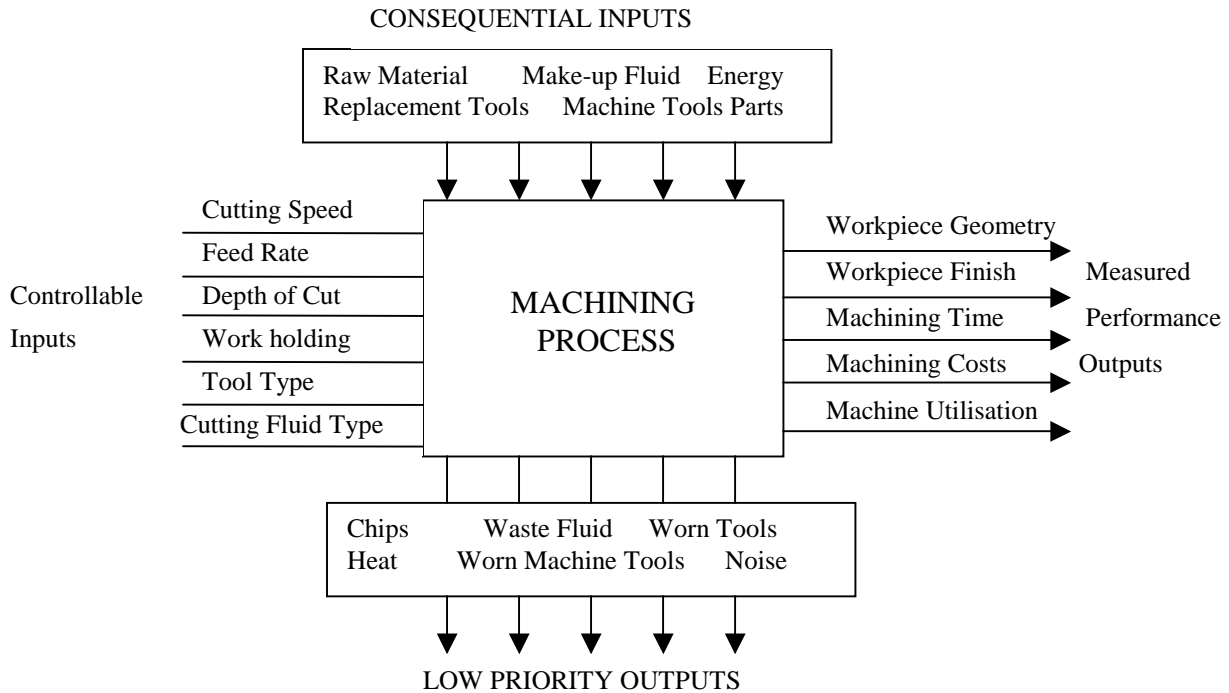


Fig. 5 Inputs and Outputs in a Machining Process.

REFERENCES

Aronson, R. B., “ Why Dry Machining?”, Manufacturing Engineering Soc. Of Manufacturing Engineers (USA), vol. 114(1), pp. 33-38, Jan. 1995.

Chou, Y. S., and Barash, M., “ Review on Hard Turning and CBN Cutting Tools” 1st Int. Machining and Grinding Conf., Soc. of Manufacturing Engineers (USA), Michigan, USA, pp. 949-962, Sep. 1995.

König, W., and Rummenholler, S., “Ecological Manufacturing” Annual of the German Acad. Soc. For Production Engg., vol. 1(2), pp. 1-4, 1994.

König, W., Berktold, A., and Koch, K. F., “Turning versus Grinding – A Comparison of Surface Integrity Aspects and Attainable Accuracies”, Annals of the CIRP, vol. 42(1), pp. 39-43, 1993.

König, W., Klinger, M., and Link, R., “ Machining Hard Materials with Geometrically Defined Cutting Edges– Field of Applications and Limitations” Annals of the CIPR, vol. 39(1), pp. 61-64, 1990.

Liu, C. R. and Mittal, S., “ Single Step Superfinishing using Hard Machining Resulting in Superior Surface Integrity”, Journal of Manufacturing Systems, Soc. of Manufacturing Engineers (USA), vol. 14(2), pp.129-133, 1995.

Matsumoto, Y., “ Hard Turning Vs Grinding” MTA/SME Point – Counter point Series, Soc. of Manufacturing Engineers (USA), 1991.

Pfeifer, T., Eversheim, W., König, W., and Weck, W., Manufacturing Excellence: The Competitive Edge, Chapman and Hall, 1st edition, 1994.

Tönshoff, H. K., “ Environmental and Safety Aspects of Electrophysical and Electrochemical Processes” Annals of the CIRP, vol. 45(2), pp. 553-568, 1996

Weck, W., “ Problems on the Way to Achieving an Oil-Free Machine Tool” VDI Report 1240, pp. 209-232, 1996.

Abbreviations

- AJM Abrasive Jet Machining
- AWJ Abrasive Water Jet Machining
- CBN Cubic Boron Nitride
- CHM Chemical Machining
- EBM Electro Beam Machining
- ECM Electrochemical Machining
- EDM Electro Discharge Machining
- HSS High Speed Steel
- LBM Laser Beam Machining
- PBM Plasma Beam Machining
- PCD Polycrystalline Diamond
- USM Ultrasonic Machining
- WJM Water Jet Machining