Programme Advisory Committee for Machine Tool R&D

Technology Roadmap for Machine Tools

September 2010

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Office of the Principal Scientific Adviser
Government of India
Vigyan Bhavan Annexe
New Delhi

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Contents

Foreword

The machine tool industry in India stands at the cross roads. It has the opportunity to deliver the latest machine tools and manufacturing technology to the rapidly developing industries in the country. To be able to do this, the industry has to bridge technology gaps which have arisen over years of operating in an economic environment which did not make much demand of its technology and machine tools.

The constitution of the Programme Advisory Committee for R&D in Machine Tools (PAC) by Dr.R.Chidambaram, Principal Scientific Adviser to the Government of India and the recognition of machine tools as a strategic industry vital to national security have given the industry the much needed shot in the arm to aspire for higher levels of technological abilities. The PAC has provided great support and impetus to the R&D efforts of the industry, besides enabling the participation of academic and R&D institutions in technology development.

The PAC had asked to make a study and bring out a document that identifies the technology gaps and a broad roadmap for machine tool technology development in the country. This document presents the results of such a study.

This document is only a roadmap in the true sense. It points the distance to be travelled and the direction. It cannot lay down the means and speed of travel. This has to be decided by the industry, which has competent companies working in various product segments. The technology issues discussed here have also been enumerated briefly in the "Vision Document & Perspective Plan 2010-2020" for the Indian machine tool industry placed before the Department of Heavy Industries in August 2010.

It is a matter of satisfaction that even as this document is being presented to the PAC, around five major R&D projects in the areas identified have been submitted to the PAC for approval. If this momentum can be sustained for a few years and projects implemented, there is no doubt that the country will see the latest machine tools being developed and offered to user industries. This is the most effective answer to counter instances of technology denial and ensure manufacturing competitiveness and national security.

We are ever grateful to Dr. R.Chidambaram for his unstinted support to the machine tool industry and for constituting the PAC which serves as a platform for developing machine tool technology in the country. We also thank Prof.P.Radhakrishnan, chairman of the PAC who has guided the preparation of this document through his inputs from time to time. Our thanks are also to members of the PAC and industry professionals who have contributed their views and suggestions during its preparation.

We are pleased to place this Technology Roadmap before the PAC. I would like to thank Mr.Anbu and Mr.P.J.Mohanram of IMTMA for piloting this effort and the IMTMA secretariat for bringing out this document.

M.Lokeswara Rao
President,
Indian Machine Tool Manufacturers' Association
28th September 2010

Roadmap for Machine Tool Technology Development in India

1. Introduction:

The Indian machine tool industry has come a long way during its 60 years of organized development. It now ranks 19th in world production and has the capability to manufacture the whole range of machine tools, especially CNC machines. The industry has good design strength and all its current products are the result of the industry's own design and development efforts over the last two decades.

Nevertheless, the industry suffers from the lack of a strong R&D which is required to propel it to the development of machine tools of the latest technology to compete with the best from abroad. The absence of this R&D has resulted in the industry losing nearly 70% of the domestic market for machine tools to foreign companies.

The PAC for R&D in machine tool industry constituted by Dr.R.Chidambaram, PSA to Government of India has been entrusted with the responsibility to identify suitable R&D projects to upgrade machine tool technology to meet the needs of the industry. The PAC has requested that a broad roadmap for machine tools in India may be put up highlighting the important areas of R&D for consideration by the PAC. This paper presents such a roadmap.

2. Main requirements from machine tools:

The main requirements from modern machine tools can be summed up as follows:

a) Productivity
b) Precision
c) Reliability
d) New materials to be machined/formed

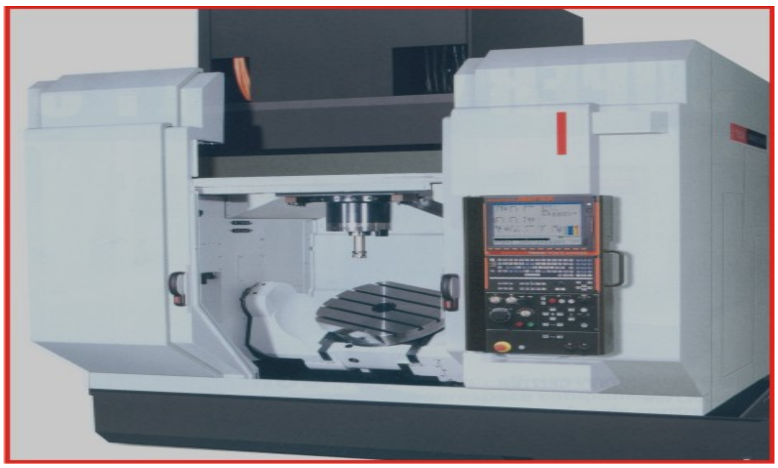
All R&D efforts by the most reputed machine tool builders are targeted at achieving substantial improvement in these aspects of machine tools. Several new machine design concepts and functional improvements have been evolved as a result, by international companies specializing in one or the other machine tool types. The bulk of such developments have come from Germany and Japan, which have a very strong history of machine tool development and an equally strong R&D mechanism. The developments of machine tools in India must likewise be oriented towards achieving major gains in the above three areas. The technology gaps that are necessary to be bridged are briefly outlined below.

3. Machine tool technology gaps in India :

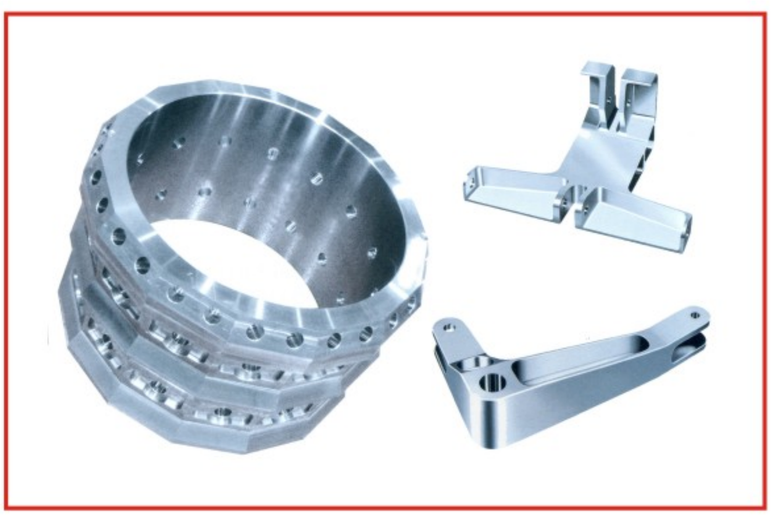
Productivity

a) **<u>Multi-axes machining centres</u>**:
Machining centres are used to machine cubic components. Mostly machines with three/four axes are used, with simultaneous interpolation in 3 axes being sufficient to produce the machining features. However, more advanced machining centres are equipped with 5 axes of movement including rotary movements. These are required to meet the manufacture of components for the aerospace and to some extent the auto and rotating machinery sectors. Typically, the machines will have the ability to machine in 5 axes with simultaneous interpolation, high speed spindles, and high precision. Such machines are mostly imported. Except for limited development carried out by some Indian manufacturers, there is no regular commercial production of these machines.

These machines also come under technology denial regimes. So there is paramount urgency in developing the technology of these machines on top priority, to reduce our dependence on imports and the associated risks.



Five-axes Machining Centre

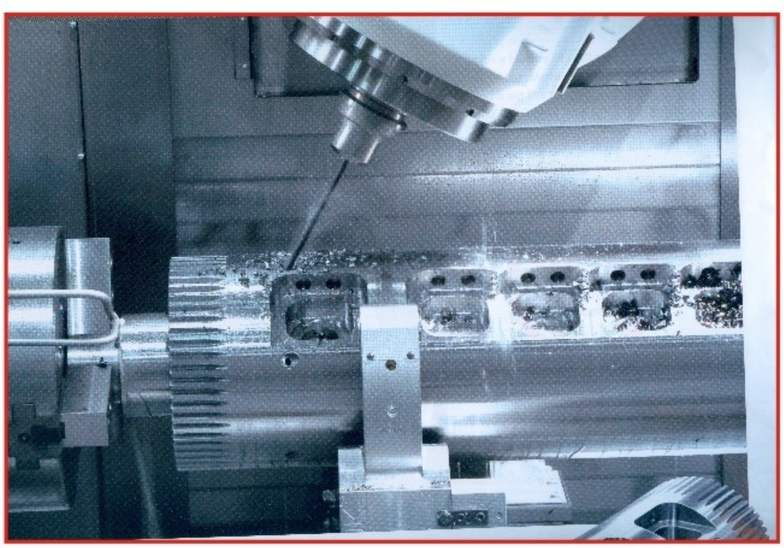


Components requiring 5-axes machining

Impellers machined on 5-axes machining centre

b) **<u>Multi Tasking Machines</u>**: In order to reduce set-ups and component handling, machine tools have more functions built into them so that they can handle different machining tasks on one machine. Such machines are highly productive, but require several spindles, tool turrets/tools and work holding features built into one machine. Typical examples are turn-mill machines, which can even carry out grinding, gear cutting, hardening operations on some models. The objective is to complete a complex component with several machining features, not all of the same type, in one setting.

The trend towards multi-tasking machines has shown strong development abroad, especially in those industries manufacturing components of high complexity, large size and high accuracy in small-batch production. Typically, such applications are in the power equipment, aerospace, valves, process industry components etc. Typical multi-tasking machines are Turning machines with Mill-grind-gear cut, Machining centres with turning capability, Vertical Turning Machines with machining, milling, grinding capability etc. Such machine tools do not have high demand but for certain applications are eminently suitable in maintaining accuracies, improving productivity, reducing fixturing and handling. Such machines reduce lead-time for special components to the minimum.



Typical multi-tasking machine

c) **High precision machines**:

The average tolerance band for components which was 5 microns a decade ago has shrunk to 1-2 microns today in normal operations like turning and milling. On finishing processes like grinding, the best machines deliver accuracies of 100 nm in regular production environment, repeatably and consistently. High precision machines are required to be developed in turning, machining centre and grinding primarily, but the technology is applicable to practically every machine tool type including special purpose machines.

Typical precision production grinder with 100 nm accuracy

Development of high precision machines calls for new materials, high static and dynamic design properties, effective thermal balance and precision in component manufacture and assembly. It requires concerted R&D efforts of individual companies along with institutions like CMTI, IITs etc.

d) **Large machine tools**:

The rapid growth of the energy, power, process and atomic energy industries, Railways and Defence and the nascent wind-mill industry has spurred the demand for large machines such as floor boring machines, large gantry machining centres, vertical turning machines etc. A limited capacity for the manufacture of such machines exists in Indian companies but the machines lack the latest features and technologies like hydrostatic bearings and slideways, error compensation etc. which makes the machines accurate and productive.

Large floor borer for machining energy sector components

e) **Gear cutting and grinding machines**:

Indian machine tool technology is lagging by around 10 years in these two critical areas, which are the mainstay of the automobile component industry. Only two companies produce gear cutting machines, and similarly only two companies produce grinding machines in any quantity in India. There is a large import of these machines, both new and used machines.

Gear cutting technology has become highly productive, with high cutting rates and dry cutting being the dominant features. Grinding machines offer high accuracy and grinding with CBN and super-abrasives. Both gear cutting and grinding have developed very high productivity through the application of latest technologies. Indian manufacturers lack the ability to compete and usually meet the less demanding applications from users. Development of the latest technology in these areas will require intense R&D.

Dry gear hobbing machine

Multiple diameter gear shaping machine

f) **Electrical and micro-machining**:

Electrical machining technologies such as electro-discharge machines (edm), wire-edm, electrochemical machines play a vital role in high precision and fine engineering in industries such as die and mould, defence, instrumentation, medical, optical, electronics, toys industries besides others. These are the backbone to the tool making industries and are critical to many component manufacture in the sub-millimetre dimension, often going down to micron level (hence the name "micro-machining"). In India one company alone specializes in edm technology, and has met user requirements fairly well. However the higher levels of technology are met through imports from Europe and Japan. Advances include higher metal removal rates, ability to control surface finish and texture, micron level dimensional accuracy, complicated profile generation etc. R&D efforts are needed to address these areas.

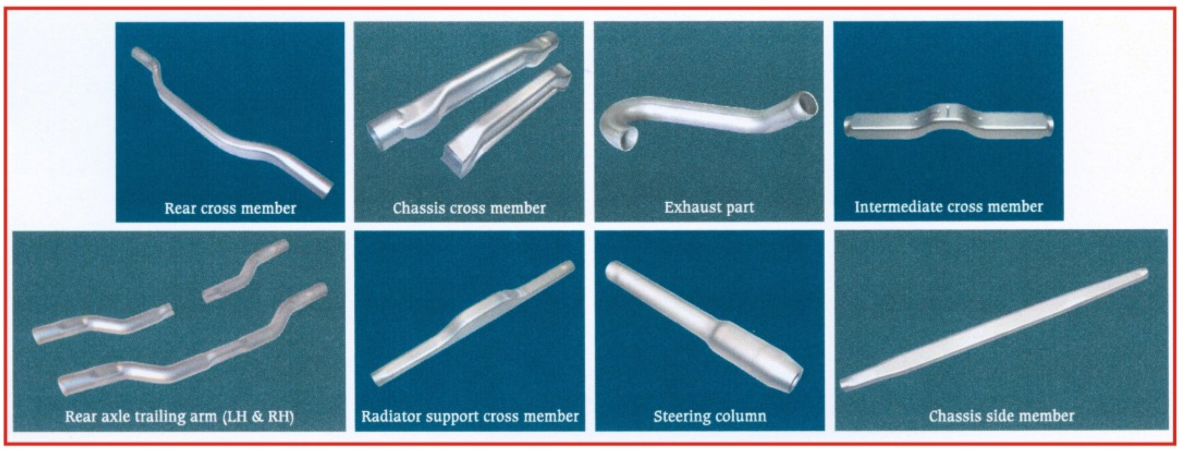
Micromachined components

g) **Metal forming machines and technologies**:

Indian manufacture of metal forming machines is limited to presses and sheet bending machines, largely. There is very little manufacture of modern sheet working machines such as punch/turret punch presses, transfer presses, fine blanking, cold/hot headers, forging machines, form rolling machines etc. Die casting machines, an important component of metal forming machines, is produced in limited quantities in India. Imports dominate in this as well, thanks to advanced technologies in process control. It must be mentioned that Indian industry has developed the latest servo press technology and hydroforming technology. However, these have yet to take strong market roots among users in India. Overall, as compared to metal cutting machine tools, Indian metal forming machines are relatively less advanced.

A study commissioned by IMTMA has estimated the demand for metal forming machines to reach Rs.8900 cr by 2014-15, growing at an annual rate of 21% in the next five years. Metal forming machines are expected to constitute nearly 50% of total machine tool demand by that time.

Flow-forming machine and components



Typical hydroformed components in automotive industry

It is clear from the foregoing that the industry needs to give special attention to R&D and product development in the future if it is to hold its position as a supplier of consequence in India. The focus will have to be developing the following metal forming technologies.

- Higher press automation and transfer systems,
- Servo presses,
- Sheet working machines (including laser, waterjet heads)
- Hydroforming,
- Hot forming technology
- Fine blanking
- Precision forging
- Flow forming

Hot forming press line

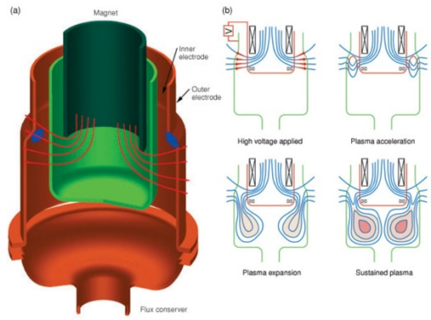
Hydraulic forging press

Forged aluminium wheels

Specialized technologies such as those below are required for specialized applications:

- Explosive forming,
- Magnetic pulse forming etc.

These are particularly important for the strategic sector for the production of armament, missiles, rockets and the like. These technologies also have application in auto component and other industries.



Magnetic Pulse Forming

h) **Supporting technologies for machine tools and manufacturing**:
The modern developments that have been described above have come about as a result of the progress in several supporting technologies:

- Cutting tool technologies
- Metrology and measurement technology
- Alternative materials (epoxy granite etc.)
- Thermally stable welded structures
- Hydrostatic spindles, guideways
- Motorised and high frequency spindles
- Smart machines with embedded sensors
- A range of accessories and attachments to improve productivity

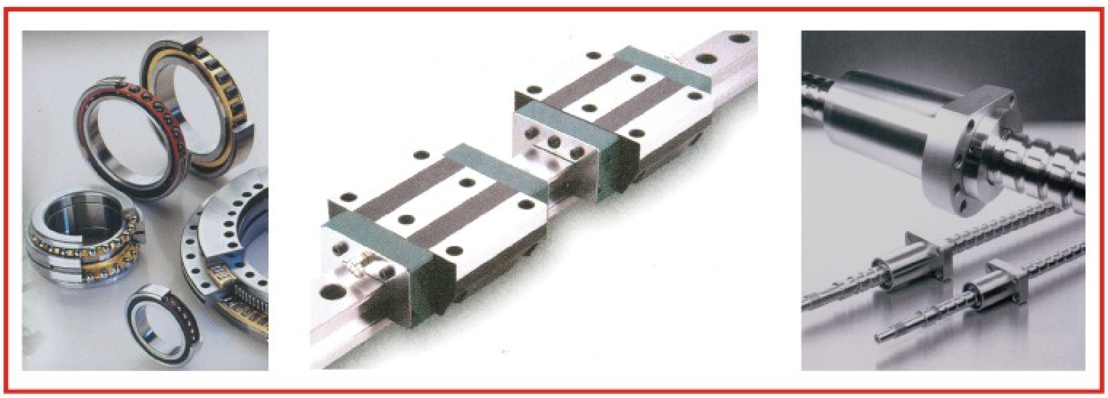
Each of these is a highly developed discipline contributing enhanced capabilities to the machine tool/manufacturing system. For example, measurement devices such as encoders and linear scales deliver measuring resolutions of 1-10 nm in the most accurate devices used on machine tools. There are only a few specialized companies which develop and manufacture such systems in the world.

i) **Critical components for CNC machine tools**:
The Indian machine tool industry suffers from a serious limitation which could prove a major weakness in future. The industry depends entirely on imports for all the critical components it needs to build CNC machines. These are:

- Anti-friction linear guideways
- Ball screws
- Precision spindle and ball screw support bearings
- CNC controls
- Spindle and axes servo motors with drive controllers
- Feedback measurement systems

These form the "heart" or "core" of all CNC machine tools and may be compared with the microprocessor and memory chips in a computer. This import dependence is because these items are of high technology and require heavy investment to develop their technology and manufacture. In the case of CNC, motors and drive controllers, these are essentially electronic systems of high sophistication and are the virtual monopoly of two companies in the world which have developed them over decades of R&D. India imports all these critical items largely from sources in Japan and Germany, just as other machine tool manufacturers do all over the world.

The danger in this dependence is that these items may be subject to export control as "dual use" technologies. There have been several instances where these items have been denied to Indian machine tool manufacturers when the machines are destined for the strategic sectors. So it is in India's ***manufacturing competitiveness and national security*** interest to invest the time, resources and effort to develop these critical components to make the machine tool industry relatively immune to denial regimes.



Critical mechanical items for CNC machines

j) **High speeds**: The application of high spindle speeds (10000-50000 rpm) and traverse/feed rates (50-150 mpm) are very common to achieve high productivity by reducing idle times. While Indian machine tools have recorded some improvement (12000 rpm, 48 mpm) they are yet to reach levels of foreign models. The realization of these capabilities requires R&D into machine static and dynamic behaviour, vibration and thermal control.

k) **Cutting tools and tooling**: Modern cutting tools play a major part in achieving high productivity. There is no R&D in this field in India. Almost all tools are supplied from Indian subsidiaries of MNCs. However, the industry is strong in the design and manufacture of HSS and carbide cutting tools both standard and special especially form cutters. The production of CNC tool and cutter grinding machines has also been taken up but suffers from the denial of multi-axes CNC systems required for these machines. While coated tools are made in the country, this is entirely based on technology and equipment from foreign manufacturers.

l) **Machine tool electronics**: An important constituent of machine tool productivity is modern drives and CNC. High performance axes drives, motors, drive controllers, feedback measuring systems and CNC form the HEART of machine tools. Unfortunately these are not made in India and the industry is entirely dependent on imports for its requirements. There is a case for a large R&D program only to develop this technology as a national effort of high priority.

CNC system for machine tools

Motors and drives for CNC machines

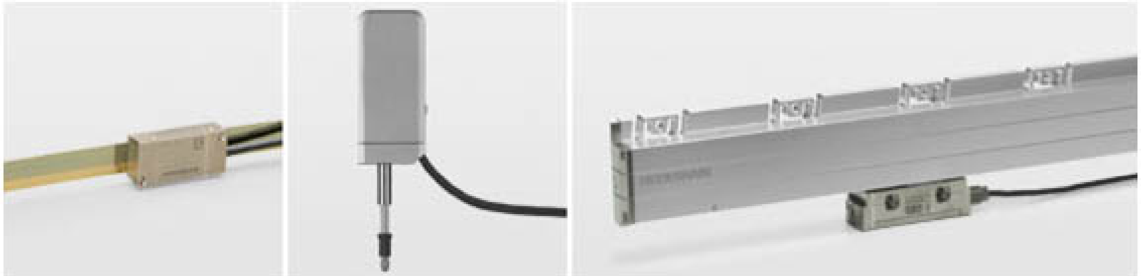
Integral motor spindle for CNC machines

Linear motors for feed drives

m) **Measuring systems**: All modern machine tools use very accurate rotary and linear measuring devices for position feedback. These are usually based on optical transducer technology such as encoders and linear scales. World-wide, just two or three companies have monopolized this technology. All control manufacturers also buy from these sources. These measuring systems are also required in the production of 3-Coordinate Measuring Machines, digital metrology and measuring equipment for the shop floor, precision gauging systems for on-line and off-line measurement in mass production, and in the manufacture of precision instruments, optics etc. for the strategic sector. Along with the development of machine tool electronics, the development of such measuring systems should also form part of the R&D program. Machine tool feedback systems are typically accurate to +/-3 microns and 2 seconds of arc. The measurement resolution is 10nm at speeds of 180 m/min.

   Measurement technology encompasses very advanced sciences in optics and diffraction, lasers, signal processing and electronics. The latest linear measuring systems measure at more than 200 m/min at resolution of 1 nm. Such systems are important also in other fields including strategic applications. This requires an inter-disciplinary approach to the development of sensors, transducers, digital electronics and controls.

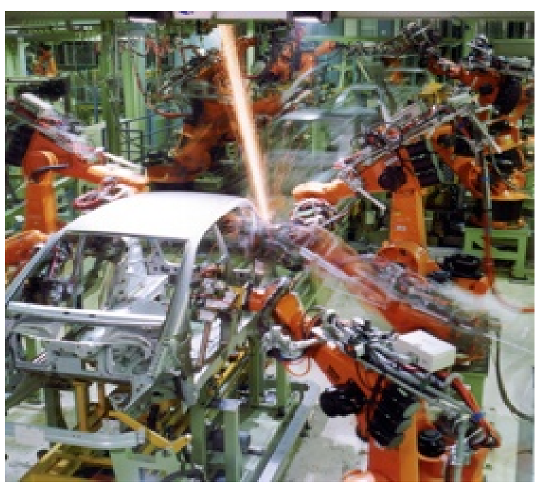
Linear optical gratings and encoder discs



Open and closed linear measuring systems

Encoders and angle measuring transducers

n) **Automation**: An important component of modern manufacturing, there is some competence in this field built up in India, but more needs to be done. Only one company in India specializes in providing automation solutions to industry. The bulk of the requirement is imported. Automation encompasses technologies from pneumatic, hydraulic and electric servo based systems. Advanced robotic automation is used in the automotive industry in the form of articulated robots for welding, assembly, press feeding, parts transfer etc. The number of such applications is increasing rapidly, and represents a major gap in the Indian machine tool range.



Auto body welding by articulated robots

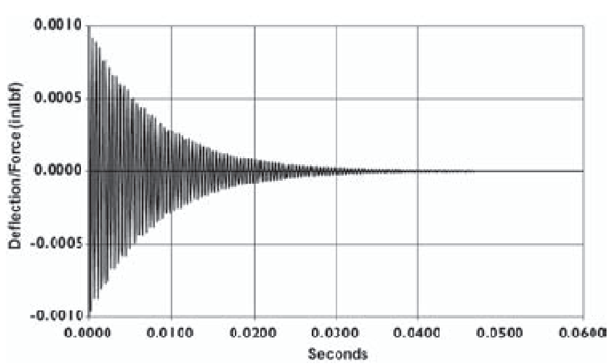
Precision:

a) **Thermal control**:
The primary factor that determines long-term accuracy is the thermal behaviour of machine tools. A lot of R&D is being done in this field, both to understand thermal behaviour and to find alternative ways of reducing thermal effects. Some R&D has been started with PAC support. Some other R&D requirements are;
   a) New materials: High accuracy machines abroad use epoxy-granite structural material to provide high thermal resistance and thereby improve machine accuracy.

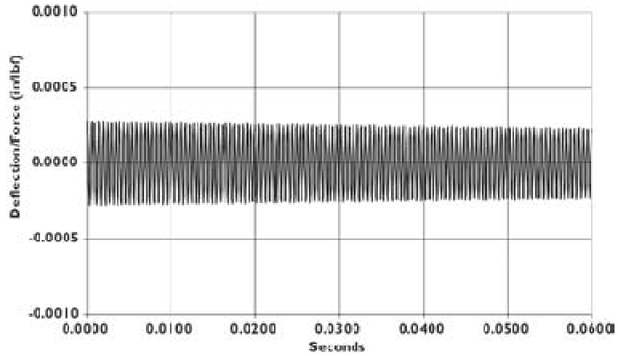
Epoxy-granite casting

   b) Embedded sensors: Thermal and other sensors sensors embedded at critical points enables information to be used by the CNC to optimize the performance (see "Smart machines" below)
   c) Cooling circuits: Multiple cooling circuits are provided to carry away heat generated in bearings, ballscrews etc.

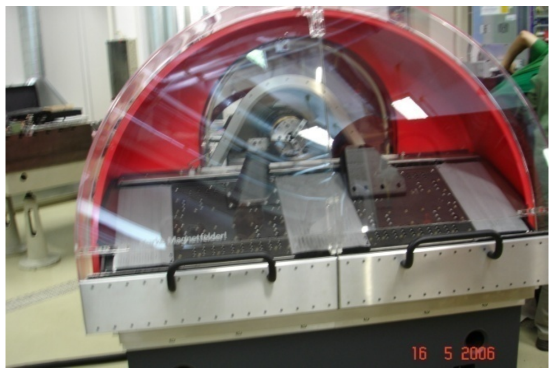
b) **Static and dynamic properties**:
Obtaining high precision also requires machines to be designed with high static and dynamic properties. Some approaches which need to be researched are:
   a) New materials: Again, epoxy-granite is used to realize high damping of structures (epoxy has a damping ratio 10 times that of cast iron, the normal machine tool structural material). Some machines have also introduced sandwich structures with metal foam to damp vibrations. Use of fibre reinforced composites is also being tried. A comprehensive R&D program is required to investigate these approaches and determine the best for any application, which may be different in each case.



Epoxy granite: damping



Steel: damping



Machine tool slides from FRP composites

b) Active vibration cancel: Modern machines are beginning to incorporate vibration sensing/measurement and active canceling systems to push metal removal rates higher, improve accuracy and finish on the component. No R&D is done in these concepts in India; this is a fresh field for investigation.

c) Light weight structures: Again, epoxy-granite is used to make structures lighter and so get higher acceleration and faster traverse rates, without losing dynamic rigidity and static stiffness.

c) Design methodology:

Indian companies do not yet apply the latest design tools available to them. Design tends to be empirical, based on past experience and optimization is followed as a design discipline by only a few companies. Modern CAD tools are used but mostly as a means to speed up the design process. CAE tools such as FEA are not applied scientifically to predict performance and optimize the designs at the design stage itself. In other words, "desk top prototyping" is not used as it should be; this results in longer testing and redesign cycles as well as penalties in weight, raw material, machining and the like.

One reason for this is the absence of experts with the necessary knowledge and experience to apply CAE tools, interpret the results and use corrective design in an iterative way until the required performance is obtained at the design stage itself. A programme of training Indian machine tool designers in these areas is required if Indian designs have to match foreign designs.

d) **Reliability:**

a) Reliability Modeling: Modern machine tools cannot be built using old, rule-of-thumb design methods. The latest CAD/CAE tools have to be used to accomplish “desk-top-prototyping” which assures final product performance near 90%. Among these is reliability. Machine tools are expected to deliver 98% uptime, 5000 hrs MTBF and minimum MTTR. This requires reliability to be engineered in at the design stage itself. So R&D into the subject is of importance. It should generate a model of the machine and be able to predict failure modes, probabilities, cost etc. using data on the individual elements going into the design. A project on “Reliability Modeling” of machine tools can be a pioneering effort needed for machine tools.

b) Testing: It is also necessary to establish an advanced machine tool testing facility to support product testing and upgradation. As a first step, the project for the setting up of an Advanced Machine Tool Testing Facility approved by the PAC is under establishment at CMTI.

c) Smart machines: Incorporate sensors for machine tool condition monitoring which triggers suitable response during operation and also when repair/replacement of items is required. Such sensors also permit self-diagnosis and correction and extend autonomous working of machines. Smart machines and controls which “know”, “learn” and “improve” are the machine tools of the future. Being a nascent field, India can enter this R&D field with some advantage.

Modern machines have begun to have sensors for temperature profiling and error correction, acoustic/vibration sensors to monitor cutting conditions, active vibration cancellation, adaptive controls, power failure recovery, tool condition monitoring, in-process gauging and probing to maintain accuracy etc. The objective is not only to improve part quality and productivity but also reduce down time, anticipate failures and extend autonomous operation without the need for constant operator presence.

e) New materials to be machined/formed:

Until the 1980s manufacturing industries largely worked with conventional materials like ferrous and non-ferrous metals. So machine tools were developed to work these materials optimally.

Modern machines are required to work on a far wider range of materials. These include hardened metal (for dies and moulds), aerospace alloys, heat resistant and high strength alloys, stainless steel, ceramics, FRP and composites, powder metal, granite, exotic materials like titanium, stellite, carbides, diamond and the like. This requirement has come about through component design to meet demanding applications. Machine tools have been developed to meet these requirements both on standard and special machines. Hard machining is a common application by which components especially in die and mould industry are machined and finished after the workpiece is hardened.

Technologies like tool monitoring, adaptive control, vibration sensing etc. have been developed to give machine tools the ability to meet tough manufacturing situations. Entirely new technologies like laser cutting, waterjet cutting have been developed. Such machines and manufacturing technologies are now fairly widely applied in India; however the Indian machine tool industry has not responded with its own technology and machines to suit. Most of such machines and technologies are imported. The defence, aerospace and nuclear industries use these technologies extensively.

f) **<u>Eco-friendly machining:</u>**

In line with all other technology fields, machine tool technology is also evolving towards eco-friendly machining and machine tools. Dry machining or machining with minimum quantity lubricant (so called MQL) avoids the use of cutting oils and the consequent need to dispose off the effluents. Similarly the use of lubricants is also being minimized and efforts are on to use dry lubricants-for-life to further minimize effluents and the need to dispose them safely. The use of minimum packing is also an important technology objective to meet stringent standards in the use of packing materials and their disposal.

The Indian machine tool industry has also to move in this direction.

g) **<u>Other sub-systems for machine tools</u>**:

The machine tool industry requires a strong industry of ancillaries producing various sub-systems and components which are used on machine tools and machining systems. It is not possible to catalog every such requirement in a broad technology document. Some of the more important of these are listed in the Machine Tool Technology Tree on page 22. Technology gaps in these areas are not recognized seriously enough by the industry. Most of these are imported where advanced technology is required by users. A programme to systematically develop these "peripheral" systems to international standards and productionize them is very much needed. The large number of SMEs engaged in the production of these systems may be encouraged to take up such R&D to close technology gaps.

The list given in this document is not exhaustive. There are a number of other sub-systems that may be included. Individual companies may take up the development of such technologies/products based on need and demand.

4. Pre-competitive R&D Opportunities:

Machine tool technology affords ample opportunities for pre-competitive R&D projects. Essentially these will have to push the performance of Indian machine tools in the areas of productivity, precision and reliability, while meeting the demands for machining new types of work materials which are finding application in the manufacturing world. These technologies are "under the skin", not very obvious on the outside, and difficult, if not impossible to copy by others. These technology elements give the performance edge to foreign machines over Indian machines, and there is no alternative to expending time, resources and manpower on R&D to close these technology gaps.

Some of the avenues for pre-competitive R&D are enumerated below. Again, this list is not exhaustive. Individual companies/academia/R&D institutions may come up with their many more, specific requirements which can form subjects for pre-competitive R&D:

a) CAE techniques: CAE relating to static, dynamic and thermal modeling of machine tool structures and assemblies to predict and optimize performance.
b) Alternative structural materials: Develop and test materials like epoxy-granite, granite, filled welded structures, metal-foam-sandwich, composites etc. for obtaining lighter weights, higher damping, and thermal isolation properties.
c) Active vibration damping: Sense vibration characteristics and embedded actuators to cancel vibrations and thereby push performance envelope of machine tools.
d) Sensors in machine tools: Thermal, acoustic, vibration, load and other sensors to be developed to monitor machine performance and initiate suitable action through the controller to optimize functioning.
e) Reliability modeling: Machine tools are complex systems of mechanical, electrical/electronic, hydraulic, pneumatic systems and components. A generic reliability prediction model can be developed to enable "designing to reliability".
f) Machining new materials: This is an extensive area for R&D.
g) Eco-friendly machines: Machine tools with lower power consumption, zero effluents can be the subject of R&D.
h) Lubrication: New lubrication technology avoiding the use of oils to make machines green, less expensive to operate and relatively maintenance free.
i) Laser sources for machining, welding and heat treatment
j) Waterjet cutting: high pressure pumps, intensifiers and cutting nozzles as a total system
k) High pressure coolant pumps, filtration systems
l) Machine tool electronics: to be developed as an R&D-cum-commercial venture through multi-disciplinary approach
m) Critical mechanical components for machine tools: to be developed as an R&D-cum-commercial venture
n) Measurement technology: For machine axes, in-process and post process measurement, gauging and inspection
o) Hydrostatic bearings, slideways
p) Ultrasonic machining for glass, ceramics and similar materials
q) Edm, ecm, ultrasonic machining systems both singly and in combination
r) Casting, forging and precision forming technologies
s) Metal forming analysis and simulation: press forming, flow forming, hot forming and other processes
t) Process development and stabilization in various metal forming processes
u) Micro-machining processes and technologies.
v) Cutting tools, coating materials, tooling.

5. Development of Machine Tool Technology:

The development of machine tool technology in India must be seen in the following perspective:

a. The industry has a good design capability, and produces a wide variety of machine tools and related equipment. For example, 5-axes machines, measuring machines, edm and wire edm, robotics and automation systems, large presses, hydroforming, sub-systems like rotary tables, tool changers, tool turrets, coolant systems etc. are manufactured by Indian companies through their own design and development efforts. However, these products do not match the performance standards of the latest machines from international companies. (An exception is tool turrets, which meet the most exacting standards and are also being exported in large numbers to be used as original fittings on highly reputed foreign machines).

b. The production volume of many machines is very small, and cannot be compared to the commercial scale of foreign companies. In other words, Indian capabilities are not "world standard" and mostly meet only Indian market requirements. Some exports are present, but these are not significant.

c. In terms of technology, Indian machines lack the more advanced features and "under the skin" technology details which are the result of intense R&D by foreign companies. The Indian machines are good imitations of foreign machines, but lack the technology edge to compete head-on with foreign machines.

d. This document has not gone into details of specifications of machines/components/sub-systems where technology gaps have been identified. This has to be done by individual companies/R&D groups formed for taking up specific development projects. The list in this document is also not exhaustive. Machines and technologies not specifically mentioned here may also be brought before the PAC/other funding agencies for approval for development.

The roadmap for development must be along the following lines :

I. Machine development must be taken up by machine tool companies to match the specifications, features and performance capabilities of modern machines from international companies.

II. To support this, academic institutions and R&D establishments should take up R&D on the component technologies, sub-systems and analytical inputs required by the machine tool manufacturers. This is best done by identifying specialist organizations in each field to participate in this R&D/Technology development effort.

III. Ultimately the R&D programs for machine tools are expected to deliver machine tools of various types, ready for commercial applications. The sub-systems and component technologies above will be integrated into these machines. So the development of machine tools, some of which have been enumerated in Sec. 3 of this document, must receive strong support through the PAC for machine tool R&D. Ideally, the ***R&D projects for both sub-systems and machines must proceed in parallel*** so that the technology gaps can be closed in the shortest possible time. If this approach is not adopted the ultimate machine tool development may be so delayed as to render them obsolete even before they are ready for commercialization. This aspect may be kept in view while structuring the exclusive R&D funding scheme that has been recommended.

Machines to be developed:

The machines that need to be developed have been identified in the sections above. Initial R&D studies have been made on some of the machines and development project proposals are under preparation. A comprehensive list of the various branches of the "Machine Tool Technology Tree" contributing to overall machine tool excellence is given below in the next section.

This is by no means exhaustive. There are several streams of machine tools and manufacturing technology that need to be developed and brought to international standards. It is also not possible to assign priorities, since machine tools and manufacturing technologies are simultaneously required by various sectors of industry in India. A practical approach will be for various companies to come forward to develop machine tool technologies in their areas of specialization. This way development can proceed along many fronts at the same time.

Strengthening R&D institutions to international standards:

The development of machine tools will require strong machine tool R&D institutions. At present India has only one such institution, the Central Manufacturing Technology Institute (CMTI) in Bangalore. CMTI needs to be strengthened with the latest facilities to design, test and evaluate modern machine tools. The Advanced Machine Tool Testing Facility being set up is the first step in this direction, but more needs to be done to make CMTI an institute of international standards. It is also necessary to consider the establishment of similar R&D institutions in the west and north of India, to support the machine tool industry which has strong manufacturing presence. Eventually, the machine tool/manufacturing technology R&D environment must be developed similar to the Fraunhofer Institutes, which have seven centres dedicated to R&D in Production Engineering at Aachen and other universities in Germany.

Funding of machine tool R&D:

The development of machine tool technology as outlined here will require substantial resources. A very approximate estimate is around Rs.2000 cr. The industry will not be able to able to raise this through its own internal resources. It is necessary to create an exclusive funding mechanism by government to meet R&D costs. This may be set up and administered by an empowered committee. R&D funding could be recovered through royalty on commercial sale.

Machine tools as focus stream in academic institutions:

Simultaneously with the strengthening of CMTI, select academic institutions such as IITs at Madras, Bombay, Roorkee and Kharagpur may introduce specialized course of studies and research in machine tools and manufacturing technology. This is required to provide the academic research inputs in many areas which have been identified for development. In addition, local engineering colleges and NITs may also introduce similar courses and research streams.

Some additional initiatives that may be taken to strengthen academia-industry R&D collaboration are:

a) Identification of academic centres of excellence that can take up R&D in fields in which they are strong;
b) Formation of multi-institutional R&D teams to tackle larger projects that cannot be taken up by any one institution;
c) Setting up centres like TIFAC-CORE in specializations that will contribute to the large R&D mosaic.
d) Training academic staff, students and R&D scholars in machine tool technology by attaching them with machine tool companies
e) Giving opportunities to these to visit international machine tool shows, research centres, universities and machine tool companies.
f) Explore joint R&D with international organizations such as the Fraunhofer Institutes in Germany and similar ones in other countries.

6. Technology Tree for Machine Tools:

Machine Tool Technology

Advanced Machine Tools

- Multi-axes machines
- Multi-function machines
- High precision machines
- Large machine tools
- Grinding machines
- Gear cutting machines
- Metal forming machines
- Micromachining technology
- Special technologies in forming
- Automation, incl. robots
- Laser, Waterjet cutting
- Ultrasonic machining
- New technologies in forming

(List not exhaustive)

Structures

- Precision castings

Alternative materials:

- Epoxy granite
- Granite
- Metal foam sandwich
- Filled welded structures
- FRP & composites

Mechanical Elements

- Spindle & ballscrew bearings
- Ballscrews
- Linear guides
- Hydrostatic & Aerostatic bearings
- Hydrostatic guideways

Major Sub-systems

- Coolant& Swarf management incl. MQL
- High pressure pumps
- Fine filteration systems
- ATC, Tool turrets
- APC & transfer systems
- Chucking systems
- Universal & Modular Fixturing
- Tools and tooling
- Tool assembly and setting
- Measuring, probing
- Index and rotary tables
- Bar feeding systems
- In-process and post-process gauging
- AC & chillers
- Hydraulic systems
- Pneumatic systems
- Lubrication systems
- Electrical gear meeting EMI standards
- Guarding & Safety
- Forming tools & tooling
- Dies & die changing
- Press Feeding systems
- Transfer systems
- Welding & Cutting heads
- Laser and waterjet systems
- Manipulators, grippers etc.

(List not exhaustive)

Electronics & CNC

- CNC systems
- Spindle & axes motors
- Linear motors
- Drive controllers
- PLC & positioning cards
- Integral spindle motors
- Direct torque motors
- Feedback encoders & Linear scales
- Sensors incl. embedded sensors
- Thermal error compensation
- Vibration sensor, cancellation
- Adaptive control
- Smart machine interface and controls

Development strategy for various technologies					
	Tree branch	**Component**	**Present capability**	**Desired capability**	**Development strategy**
1	Advanced Machine Tools	Machine tools of various types, including metal forming machines.	Indian companies produce mid-level machine tools; do not match contemporary international standards.	Reach international standards in machine tools made in the country. Most cases involve higher specifications and features to be designed in. Training in CAD/CAE tools required.	Individual companies may propose R&D projects citing technology and market needs, and these could be funded. An exclusive funding mechanism by government to meet R&D costs may be set up and administered by an empowered committee. R&D funding could be recovered through royalty on commercial sale.
2	Structures	Precision castings	Normal grey iron castings	Controlled dimensions, uniform property, good finish	Introduce latest foundry technology and metallurgy through international sourcing
		Alternative materials	Very preliminary experiments done with epoxy granite; no work on others	Full technology of alternative materials, design rules, manufacture	To be taken up by academic & R&D institutions through focused R&D projects. Static, dynamic and thermal requirements to guide R&D
3	Mechanical Elements	Spindle and ballscrew bearings	Critical elements for CNC machines not manufactured in India	Establish manufacture in India	Requires intensive R&D and expensive manufacturing facilities both for prototype and for eventual production. Stand-alone development not of use. A p-p-p commercial project with
		Ballscrews	Manufactured by HMT to collaborated designs of 1980s for internal consumption	To develop high speed, high lead ballscrews of contemporary design	

		Linear guides (antifriction)	Not manufactured in India; no technology available	To develop and manufacture	R&D costs funded by government, to be repaid through royalty on sale is suggested.
		Hydrostatic and aerostatic bearings/slideways	Limited technology developed at CMTI;	Needs R&D to bring commercially usable products	Can be included under the same project above
4	Major Sub-systems	All	Partially manufactured in India.	Major need is to improve quality and reliability of Indian manufactured systems. Next, to develop systems to international specifications and capabilities. Subsequently new sub-systems not manufactured in India may be taken up. (Note: It is not considered feasible or desirable to develop indigenous capability for *all* systems. Market needs must guide which ones should be taken up for development)	Specific R&D projects with participation by machine tool OEMs, sub-system suppliers and academic/R&D institutions need to be launched. Modern testing facilities need to be established at appropriate institutions such as CMTI. Funding through any of the schemes of PAC/TIFAC, DST, DSIR etc. considered adequate. Academic involvement required in analysis, simulation and desktop prototyping. Different institutions may be involved on different projects.

5	Electronics and CNC	All components listed; work in unison as compatible, tuned system on machine tools.	Very limited capability; PLC, servo drives and motors manufactured for industrial applications by a few companies in India. Do not match machine tool requirements.	Need to develop complete technology and production capacity. Technology very advanced;	Requires intensive R&D and expensive manufacturing facilities both for prototype and for eventual production. Stand-alone development not of use. A p-p-p commercial project with R&D costs funded by government, to be repaid through royalty on sale is suggested. R&D involves electronics, optics, physics and precision mechatronics. A multi-disciplinary team is required from several institutions. Involvement of electronic manufacturing unit essential from the R&D stage onwards.
		Smart machine interface and controls	Not available on Indian machines	Incorporate sensors and controls for error correction, condition monitoring, vibration sensing/cancellation, power failure recovery, greater autonomous functioning.	R&D in using and interfacing sensors commercially available needed. Sensors could be embedded or external; interface to CNC/PLC to be developed. Needs iterative development. Excellent scope for deep academic contribution from various institutions.

7. Development Contract as a route to Technology Development

The development of machine tools in India has largely been based on individual companies' initiatives. These have been in response to market needs and technology demands form user industries. HMT initially and other companies subsequently have developed and manufactured CNC machines, special purpose machines and a host of other products through their own R&D. In some cases they have drawn on the financial support from NCST, DSIR and other agencies set up to fund industrial R&D.

These efforts have paid dividends in so far as standard products are concerned, but the development of specialized machines required by users like auto components, DGOF, BHEL, Railways, DAE etc. has not kept pace with their requirements basically because of the small number and infrequent demand. As a result, these industries have imported their requirements from foreign companies which have the technology and the capacity to produce these machines. Examples: large VTLs, floor boring machines, multi-axes machines, high precision grinding, gear cutting, and similar technologies. As already pointed out, these are technology gap areas which need to be filled.

The R&D required for these technologies is expensive and also time-consuming. Risks are also high. Still, a way has to be found to develop these technologies in India as a strategy to secure the latest manufacturing technology and machine tool capability for the country.

One way to resolve this is to adopt the "Development Contract" route used by many countries. This route has been traditionally used abroad for the development of new, high technology machines. In the US, companies like GM, GE, Boeing, Lockheed, DoD, DoE etc. routinely award development contracts to manufacturers for the development of advanced machines and manufacturing technologies. In many cases, government agencies also directly fund companies to develop new machine tools. For example, the NSF has funded the development of the Hexapod Machine Tool to Ingersoll; the NIST has an ongoing project with the University of Michigan for Reconfigurable Machine Tools.

In the 60s and 70s, the Japanese Govt. in consortium with certain Japanese Heavy Industries like Steel, Shipping etc. which were well developed and profit making, actively promoted industry groups – such as Watch Industry, Electronics and Entertainment Industry, Automobile Industry etc., not just for domestic, but also for International markets. Concessions were given to these industries to invest in product R&D, product promotion for International (US & European) markets. Established industries such as Steel, Shipping etc. were asked to support the fledgling industries mentioned above in whatever manner possible to stabilize them and allow them to grow. Each such industry group that benefited from this initiative supported the next developing one. Thus they promoted their entrepreneurs to become global players.

The PAC, along with the government ministries/departments may approach the issue on similar lines in respect of the machine tool industry. Industries in power, infrastructure, Railways, Defence, DAE, including private sector industries may engage the machine tool industry to develop products for their requirements through ***risk sharing contracts***. This way, the machine tool industry could rapidly come of age and be a lead player within the country as well as develop a high export potential.

Development contracts are generally finalized on the following basis:

- The requirements are conveyed to the machine tool industry
- Companies are invited to bid for these contracts
- Bids are evaluated on the basis of the companies' capabilities and other factors
- Contract values are negotiated based on content and risk
- Development contract is awarded to the best-fit company

The risks of development are shared by the user and the machine tool company, and the government in some cases. Successful development phase is followed by a commercial production. If the development fails there is no penalty on the company, provided failure is due to valid technical reasons.

It is strongly recommended that this concept be adopted by large users in India such as automobiles, auto-components, government buyers to develop their future requirement of machines by Indian companies on a risk-sharing basis. Examples would be machine tools for the power sector, special machines for Railways, DGOF, DRDO, HAL, ISRO, DAE etc. At least 30% of their future requirements could be awarded as development contracts to Indian machine tool companies after a suitable evaluation of the companies.

This practice is not entirely new to Indian industry. ISRO, BARC, ADA have adopted this route successfully to develop their specialized requirements (especially where there is no recourse to imports due to denials). What needs to be done is to formalize and extend this to more products and technologies in machine tools to encourage indigenous development. This is a strategic need as much as a commercial need.

8. Technology denial:

An important factor that should spur machine tool development in India is the instances of technology denial to Indian industries from advanced countries. It is well known that certain advanced manufacturing technologies are disallowed for export to India on the basis that these are “dual use” technologies. The refusal is based on the IAEA Guidelines on the levels of precision and control capability of the machines. The relevant guidelines are reproduced in Annexure 2. The denials were usually applied to certain “entities” in India engaged in the defence, aerospace and nuclear manufacturing activities, and also applied to other manufacturers supplying to these establishments.

What is not so well known is that these guidelines have been applied against Indian machine tool companies. CNC controls with more than 3 axes simultaneous interpolation are denied to machine tool companies, even if they are not intended for use on strategic sector supplies. Several cases of precision machine tools being denied to Indian machine tool companies are on record, which have affected the production of components such as structural elements, spindles etc for building machine tools.

These instances bring out the vital importance of developing these competencies within the country and reduce dependence on foreign machines. This can be done only through a sustained R&D effort which is broadly enumerated in this document.

Annexure 1 : Programme Advisory Committee for R&D in Machine Tools: Office Memo by PSA's Office

F.No.: Prn.SA/MT/2005
GOVERNMENT OF INDIA
OFFICE OF THE PRINCIPAL SCIENTIFIC ADVISER
TO THE GOVERNMENT OF INDIA

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: 011-2302 2115
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Dated: 30th June, 2009

OFFICE MEMORANDUM

Sub: Re-constitution of the Programme Advisory Committee for Research & Development in the Machine Tools Sector – regarding.

In continuation of this Office's Office Memoranda of even number dated the 20th of April, 2006 and the 31st of October, 2007, the undersigned has been directed to convey the decision of the Government of India to re-constitute the Programme Advisory Committee (PAC) for Research and Development in the Machine Tools Sector w.e.f. the date of issue of this Office Memorandum.

2. The following will be the Composition and the Terms of Reference of the re-constituted PAC.

2.1 ***Composition:***

S. No.	Name, Designation & Organization	Status
(i)	**Dr. P. Radhakrishnan**, Former Vice Chancellor, Vellore Institute of Technology, Vellore and, currently, Director, PSG Institute of Advance Studies, P.O. number 1609, Avinashi Road, Coimbatore – 641 004.	Chairman
(ii)	**Shri N.K. Dhand**, Chairman and Managing Director, Micromatic Grinding Technologies Limited, C-27 and 28, Meerut Road, Industrial Area, Ghaziabad – 201 003.	Co-Chairman
(iii)	**Managing Director**, HMT Machine Tools Limited, "HMT Bhavan", 59 Bellary Road, Bangalore – 560 032.	Member
(iv)	**Dr. S. Mohan**, Professor, Department of Instrumentation, Indian Institute of Science, Bangalore – 560 012.	Member
(v)	**Shri P.J. Mohanram**, Senior Adviser-Technology, Indian Machine Tool Manufacturers' Association, 10th Mile, Tumkur Road, Madavara Post, Bangalore – 562 123.	Member
(vi)	**Shri B.R. Satyan**, Director, Central Manufacturing Technology Institute, Turmkur Road, Bangalore – 560 022.	Member
(vii)	**Dr. N. K. Mehta**, Professor, Department of Mechanical Engineering, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand – 247 667.	Member
(viii)	**Dr. P. Venkateswara Rao**, Professor, Department of Mechanical Engineering, Indian Institute of Technology Delhi, Hauz Khas, New Delhi – 110 016.	Member
(ix)	**Dr. A. K. Chattopadhyay**, Professor and Head, Department of Mechanical Engineering, Indian Institute of Technology Kharagpur, Kharagpur – 721 302.	Member

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(x)	**Shri Sushil Lakra**, Industrial Adviser, Department of Heavy Industry, Ministry of Heavy Industries & Public Enterprises, Room number 474-A, Udyog Bhawan, Maulana Azad Road, New Delhi - 110 011.	**Member**
(xi)	**Shri C.K. Viswanathan**, Director (Mechanical), Ministry of Micro, Small and Medium Enterprises, Room number 714, 7th Floor, Udyog Bhawan, Maulana Azad Road, New Delhi – 110 011.	**Member**
(xii)	**Shri A.P. Arya**, Managing Director, TAL Manufacturing Solutions Ltd., TATA Motors Campus, Chinchwad, Pune – 411 033.	**Member**
(xiii)	**Shri P.V.N. Sanjay**, Chief Executive Officer, Machine Tool Division, Batliboi Ltd., Ground Floor, Great Western Building, 130/132, Shaheed Bhagat Singh Marg, Fort, Mumbai – 400 023.	**Member**
(xiv)	**Shri Shrinivas G. Shirgurkar**, Managing Director, Ace Designers Limited, Plot No. 7 & 8, Phase-II, Peenya Industrial Area, Bangalore – 560 058.	**Member**
(xv)	**Shri Parakram G. Jadeja**, Chairman and Managing Director, Jyoti CNC Automation Private Limited, G-506, Lodhika, G.I.D.C., Village Metoda, District Rajkot – 360 021.	**Member**
(xvi)	**Shri Deepak S. Shrivastava**, Chief Executive Officer, Electronic Machine Tools Ltd., Elektra House, 691/1A, Pune Satara Road, Pune – 411 037.	**Member**
(xvii)	**Shri C.P. Rangachar**, Managing Director, Yuken India Limited, P.O. Box number 16, Parallel – II, Brigade Park, Whitefield Road, Whitefield, Bangalore – 560 066.	**Member**
(xviii)	**Shri Rakesh Kumar Singh**, Managing Director, SRB Machines Pvt. Ltd., 59/2/1, Site-IV, Industrial Area, Sahibabad, Ghaziabad – 201 001.	**Member**
(xix)	**Shri Shailesh D. Kawa**, President, Rajkot Machine Tool Manufacturers' Association, 44, Shivanda Complex, Dhebar Road, Rajkot – 360 002.	**Member**
(xx)	**Shri Neeraj Sinha**, Scientist 'E', Office of the Principal Scientific Adviser to the Government of India, 326, Vigyan Bhawan Annexe, Maulana Azad Road, New Delhi 110 011.	**Member-Secretary**

2.2 ***Terms of Reference:***

(i) The Committee shall develop, within the next 5 months, a Technology Road Map for the country's Machine Tools sector, identifying the thrust areas for Research and Development in that sector.

(ii) The Committee will critically examine the technology gaps in the Machine Tools sector in the said Road Map.

(iii) The Committee will generate project proposals and recommend specific intervention programmes in the short and long term.

(iv) The Committee will identify individuals / groups and institutions, with core competence, who can be invited to take up project proposals as per the prioritized needs.

(v) The Committee will recommend inter-institutional collaboration, if necessary, to ensure that all possible expertise available in the country is optimally utilized.

(vi) The Committee will facilitate involvement of industry / industries concerned for each project and encourage collaborative participation of industry and research organizations / institutions, in a consortium mode, right from the initiation of the project.

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(vii) The Committee will evaluate each project proposal and, based on the merit of the proposal, recommend the same for financial support. In doing so, the Committee will review the status of work already done by research institutions so that results of such developments could be incorporated in the projects recommended.

(viii) The Committee will evolve a system of evaluation of the projects which should be easy to operate and not prolonged / time consuming.

(ix) The Committee may invite, as special invitees, experts from the academia or the industry for discussion and special inputs during any of its meetings.

(x) The Committee will help in the setting-up of Project Review and Monitoring Committees (PRMCs) to closely monitor and evaluate the progress of each project / group of projects that gets sanctioned.

(xi) The Committee will recommend small research projects, to be taken-up as subsets of the main projects, which may be necessary for providing important inputs for the successful completion of the main projects.

(xii) The Committee will recommend market surveys, study visits and participation in international workshops for enrichment of the research and development programme.

(xiii) The Chairman of the Committee shall have the authority to co-opt members as and when required, and shall also have the authority to call for emergency meetings of the Committee, even when they are not due.

(xiv) The traveling and daily allowances will be payable, as per the existing rules of the Government of India, to the non-official constituents, if any, of the Committee.

(xv) The Chairman and the members of the Committee shall be eligible for the payment of an honorarium of Rs. 1000/- per head for each day of meeting attended.

(xvi) The Committee will have a term of 3 years from the date of issue of the Office Memorandum notifying its constitution. It will be expected to meet once in every quarter.

3. This issues with the approval of the Principal Scientific Adviser to the Government of India.

Neeraj Sinha

(NEERAJ SINHA)
SCIENTIST 'E'
and Member-Secretary to the PAC

30.6.09

<u>To:</u>

1. **Dr. P. Radhakrishnan**, Former Vice Chancellor, Vellore Institute of Technology, Vellore and, currently, Director, PSG Institute of Advance Studies, P.O. number 1609, Avinashi Road, Coimbatore – 641 004.

2. **Shri N.K. Dhand**, Chairman and Managing Director, Micromatic Grinding Technologies Limited, C-27 and 28, Meerut Road, Industrial Area, Ghaziabad – 201 003.

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11. **Shri C.K. Viswanathan**, Director (Mechanical), Ministry of Micro, Small and Medium Enterprises, Room number 714, 7th Floor, Nirman Bhawan, Maulana Azad Road, New Delhi – 110 108.

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19. **Shri Shailesh D. Kawa**, President, Rajkot Machine Tool Manufacturers' Association, 44, Shivanda Complex, Dhebar Road, Rajkot – 360 002.

Copy to:-

1. **Dr. R. Chidambaram**, Principal Scientific Adviser to the Government of India, 318, Vigyan Bhawan Annexe, Maulana Azad Road, New Delhi – 110 011.

2. **Dr. S.N. Dash**, Secretary, Department of Heavy Industry, Ministry of Heavy Industries & Public Enterprises, Room number 178, Udyog Bhawan, Maulana Azad Road, New Delhi - 110 011.

3. **Shri Dinesh Rai,** Secretary, Ministry of Micro, Small and Medium Enterprises, Room number 169, Udyog Bhawan, Maulana Azad Road, New Delhi – 110 011.

(NEERAJ SINHA)

Annexure 2 : Extracts from IAEA guide lines of "dual-use" equipment

IAEA
International Atomic Energy Agency

Information Circular

INFCIRC/254/Rev.7/Part 2[a]
Date: 20 March 2006

General Distribution
Original: English

Communications Received from Certain Member States Regarding Guidelines for Transfers of Nuclear-related Dual-use Equipment, Materials, Software and Related Technology

GUIDELINES FOR TRANSFERS OF NUCLEAR-RELATED DUAL-USE EQUIPMENT, MATERIALS, SOFTWARE, AND RELATED TECHNOLOGY

OBJECTIVE

1. With the objective of averting the proliferation of nuclear weapons and preventing acts of nuclear terrorism, suppliers have had under consideration procedures in relation to the transfer of certain equipment, materials, software, and related technology that could make a major contribution to a "nuclear explosive activity," an "unsafeguarded nuclear fuel-cycle activity" or acts of nuclear terrorism. In this connection, suppliers have agreed on the following principles, common definitions, and an export control list of equipment, materials, software, and related technology. The Guidelines are not designed to impede international co-operation as long as such co-operation will not contribute to a nuclear explosive activity, an unsafeguarded nuclear fuel-cycle activity or acts of nuclear terrorism. Suppliers intend to implement the Guidelines in accordance with national legislation and relevant international commitments.

BASIC PRINCIPLE

2. Suppliers should not authorize transfers of equipment, materials, software, or related technology identified in the Annex:

   - for use in a non-nuclear-weapon state in a nuclear explosive activity or an unsafeguarded nuclear fuel-cycle activity, or

   - in general, when there is an unacceptable risk of diversion to such an activity, or when the transfers are contrary to the objective of averting the proliferation of nuclear weapons, or

   - when there is an unacceptable risk of diversion to acts of nuclear terrorism.

CONDITIONS FOR TRANSFERS

6. In the process of determining that the transfer will not pose any unacceptable risk of diversion, in accordance with the Basic Principle and to meet the objectives of the Guidelines, the supplier should obtain, before authorizing the transfer and in a manner consistent with its national law and practices, the following:

   (a) a statement from the end-user specifying the uses and end-use locations of the proposed transfers; and

   (b) an assurance explicitly stating that the proposed transfer or any replica thereof will not be used in any nuclear explosive activity or unsafeguarded nuclear fuel-cycle activity.

ANNEX CONTENTS

1. INDUSTRIAL EQUIPMENT

1.B. TEST AND PRODUCTION EQUIPMENT

1.B.1. Flow-forming machines, spin-forming machines capable of flow-forming functions, and mandrels, as follows:

a. Machines having both of the following characteristics:

1. Three or more rollers (active or guiding); and

2. Which, according to the manufacturer´s technical specification, can be equipped with "numerical control" units or a computer control;

b. Rotor-forming mandrels designed to form cylindrical rotors of inside diameter between 75 and 400 mm.

Note: Item 1.B.1.a. includes machines which have only a single roller designed to deform metal plus two auxiliary rollers which support the mandrel, but do not participate directly in the deformation process.

1.B.2. Machine tools, as follows, and any combination thereof, for removing or cutting metals, ceramics, or composites, which, according to the manufacturer's technical specifications, can be equipped with electronic devices for simultaneous "contouring control" in two or more axes:

N.B.: For "numerical control" units controlled by their associated "software", see Item 1.D.3.

a. Machine tools for turning, that have "positioning accuracies" with all compensations available better (less) than 6 μm according to ISO 230/2 (1988) along any linear axis (overall positioning) for machines capable of machining diameters greater than 35 mm;

Note: Item 1.B.2.a. does not control bar machines (Swissturn), limited to machining only bar feed thru, if maximum bar diameter is equal to or less than 42 mm and there is no capability of mounting chucks. Machines may have drilling and/or milling capabilities for machining parts with diameters less than 42 mm.

b. Machine tools for milling, having any of the following characteristics:

1. "Positioning accuracies" with all compensations available better (less) than 6 μm according to ISO 230/2 (1988) along any linear axis (overall positioning);

2. Two or more contouring rotary axes; or

3. Five or more axes, which can be coordinated simultaneously for "contouring control".

Note: Item 1.B.2.b. does not control milling machines having both of the following characteristics:

1. X-axis travel greater than 2 m; and

2. Overall "positioning accuracy" on the x-axis worse (more) than 30 μm according to ISO 230/2 (1988).

c. Machine tools for grinding, having any of the following characteristics:

1. "Positioning accuracies" with all compensations available better (less) than 4 μm according to ISO 230/2 (1988) along any linear axis (overall positioning);

2. Two or more contouring rotary axes; or

3. Five or more axes, which can be coordinated simultaneously for "contouring control."

Note: Item 1.B.2.c. does not control grinding machines as follows:

1. Cylindrical external, internal, and external-internal grinding machines having all the following characteristics:

a. Limited to a maximum workpiece capacity of 150 mm outside diameter or length; and

b. Axes limited to x, z and c.

2. Jig grinders that do not have a z-axis or a w-axis with an overall positioning accuracy less (better) than 4 microns. Positioning accuracy is according to ISO 230/2 (1988).

d. Non-wire type Electrical Discharge Machines (EDM) that have two or more contouring rotary axes and that can be coordinated simultaneously for "contouring control".

Notes: 1. Stated "positioning accuracy" levels derived under the following procedures from measurements made according to ISO 230/2 (1988) or national equivalents may be used for each machine tool model if provided to, and accepted by, national authorities instead of individual machine tests.

Stated "positioning accuracy" are to be derived as follows:

a. Select five machines of a model to be evaluated;

b. Measure the linear axis accuracies according to ISO 230/2 (1988);

c. Determine the accuracy values (A) for each axis of each machine. The method of calculating the accuracy value is described in the ISO 230/2 (1988) standard;

d. Determine the average accuracy value of each axis. This average value becomes the stated "positioning accuracy" of each axis for the model ($\hat{A}_x$, $\hat{A}_y$...),

e. Since Item 1.B.2. refers to each linear axis, there will be as many stated "positioning accuracy" values as there are linear axes;

f. If any axis of a machine tool not controlled by Items 1.B.2.a., 1.B.2.b., or 1.B.2.c. has a stated "positioning accuracy" of 6 μm or better (less) for grinding machines, and 8 μm or better (less) for milling and turning machines, both according to ISO 230/2 (1988), then the builder should be required to reaffirm the accuracy level once every eighteen months.

2. Item 1.B.2. does not control special purpose machine tools limited to the manufacture of any of the following parts:

a. Gears

b. Crankshafts or camshafts

c. Tools or cutters

d. Extruder worms

Technical Notes: *1. Axis nomenclature shall be in accordance with International Standard ISO 841, "Numerical Control Machines - Axis and Motion Nomenclature".*

2. *Not counted in the total number of contouring axes are secondary parallel contouring axes (e.g., the w-axis on horizontal boring mills or a secondary rotary axis the centerline of which is parallel to the primary rotary axis).*

3. *Rotary axes do not necessarily have to rotate over 360 degrees. A rotary axis can be driven by a linear device, e.g., a screw or a rack-and-pinion.*

4. *For the purposes of 1.B.2. the number of axes which can be coordinated simultaneously for "contouring control" is the number of axes along or around which, during processing of the workpiece, simultaneous and interrelated motions are performed between the workpiece and a tool. This does not include any additional axes along or around which other relative motions within the machine are performed, such as:*

   a. *Wheel-dressing systems in grinding machines;*

   b *Parallel rotary axes designed for mounting of separate workpieces;*

   c. *Co-linear rotary axes designed for manipulating the same workpiece by holding it in a chuck from different ends.*

5. *A machine tool having at least 2 of the 3 turning, milling or grinding capabilities (e.g., a turning machine with milling capability) must be evaluated against each applicable entry, 1.B.2.a., 1.B.2.b. and 1.B.2.c.*

6. *Items 1.B.2.b.3 and 1.B.2.c.3 include machines based on a parallel linear kinematic design (e.g., hexapods) that have 5 or more axes none of which are rotary axes.*

1.B.3. Dimensional inspection machines, instruments, or systems, as follows:

a. Computer controlled or numerically controlled dimensional inspection machines having both of the following characteristics:

   1. Two or more axes; <u>and</u>

   2. A one-dimensional length "measurement uncertainty" equal to or better (less) than (1.25 + L/1000) µm tested with a probe of an "accuracy" of better (less) than 0.2 µm (L is the measured length in millimeters) (Ref: VDI/VDE 2617 parts 1 and 2);

b. Linear displacement measuring instruments, as follows:

   1. Non-contact type measuring systems with a "resolution" equal to or better (less) than 0.2 µm within a measuring range up to 0.2 mm;

   2. Linear variable differential transformer (LVDT) systems having both of the following characteristics:

      a. "Linearity" equal to or better (less) than 0.1% within a measuring range up to 5 mm; <u>and</u>

      b. Drift equal to or better (less) than 0.1% per day at a standard ambient test room temperature ± 1 K;

3. Measuring systems having both of the following characteristics:

a. Contain a laser; and

b. Maintain for at least 12 hours, over a temperature range of ± 1 K around a standard temperature and a standard pressure:

1. A "resolution" over their full scale of 0.1 µm or better; and

2. With a "measurement uncertainty" equal to or better (less) than (0.2 + L/2000) µm (L is the measured length in millimeters);

Note: Item 1.B.3.b.3. does not control measuring interferometer systems, without closed or open loop feedback, containing a laser to measure slide movement errors of machine tools, dimensional inspection machines, or similar equipment.

Technical Note: *In Item 1.B.3.b. 'linear displacement' means the change of distance between the measuring probe and the measured object.*

c. Angular displacement measuring instruments having an "angular position deviation" equal to or better (less) than 0.00025°;

Note: Item 1.B.3.c. does not control optical instruments, such as autocollimators, using collimated light (e.g., laser light) to detect angular displacement of a mirror.

d. Systems for simultaneous linear-angular inspection of hemishells, having both of the following characteristics:

1. "Measurement uncertainty" along any linear axis equal to or better (less) than 3.5 µm per 5 mm; and

2. "Angular position deviation" equal to or less than 0.02°.

Notes: 1. Item 1.B.3. includes machine tools that can be used as measuring machines if they meet or exceed the criteria specified for the measuring machine function.

2. Machines described in Item 1.B.3. are controlled if they exceed the threshold specified anywhere within their operating range.

Technical Notes: *1. The probe used in determining the measurement uncertainty of a dimensional inspection system shall be as described in VDI/VDE 2617 parts 2, 3 and 4.*

2. All parameters of measurement values in this item represent plus/minus, i.e., not total band.