TRENDS IN ENGINE COMPONENTS' MACHINING

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In older engine plants, a large number of engine components were manufactured in-house. The present trend is to manufacture only 5Cs - Cylinder block, Cylinder head, Crankshaft, Camshaft, and Connecting rod in-house and procure all other components from vendors. Some prefer to reduce these numbers depending on the availability of reliable vendors nearby. In a newer approach, even for these 5Cs, the roughing operations are being farmed out. The in-house facilities of manufacturing concentrate only on highly value-added, critical, high-technology operations that require high capital investment and can not be expected from vendors with limited resources.

1C: CYLINDER BLOCK

Material of cylinder block is generally cast iron. Weight of a typical cast iron 4-cylinder block for passenger car varies in range of 30-40 kg. A drive to improve engine quality, with respect to weight, power, noise, fuel economy and reduced emissions demanded improvement in casting process as well as a switch over to stronger, light weight materials. Conventional casting switched to high pressure moulding to attain thinner wall thickness and consistency in dimension. Lost foam process is also being used by high tech companies because of its superb as-cast finish, that eliminates a large number of hole making/rough machining operations, besides the significant reduction in the weight of the component. There is also a trend to use aluminum with cast-in liner to save on weight of engine.
Generally, the sequence of operations on a typical machining line for cylinder block is as follows:

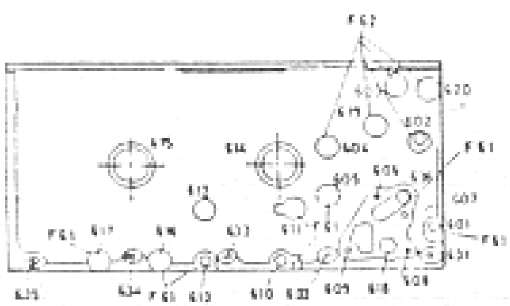
1. Qualifying
2. Rough Mill Pan and Head faces
3. Rough machining cylinder bores
4. Milling bearing cap width and slots
5. Finish mill pan and bearing cap width
6. Drilling oil holes (compound angles)
7. Drilling, reaming, tapping (Left & right, pan and head faces)
8. Assembly of bearing caps
9. Finish front and rear end
10. Drilling, reaming, tapping (end faces)
11. Line boring crankbore in parent material
12. Finish tappet bores
13. Assembly cam liners, finish line boring
14. Finish cylinder bores
15. Finish mill /grind head face
16. Hone and grade

Besides, some plug assembly, washing, and leak testing operations are carried out at appropriate locations.

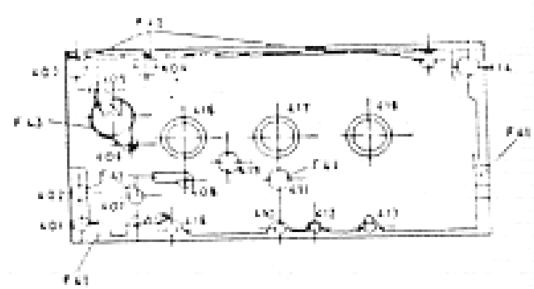
Qualifying from cylinder bore for stock equalising for subsequent boring operation is usually the most important operation. That is carried out on the first station of cylinder block machining line. It assures uniform wall thickness of cylinder bores after machining, that results in thermal stability during operation of engine. The block is set on three cast (foundry) spots. Sideways location is taken on two cast spots. Endwise location is obtained through especially developed equalising mechanism. In one such method, the block and fixture are designed to move slightly in a plane parallel to the direction of transfer, as the equalising probes are forced into position through welch plug bores. With equalising ensured, the block is clamped and an end locating pad and two sides locating pads are machined for subsequent operations.

In typical cast iron 4 - cylinder blocks, total numbers of holes are about 140-180 and total number of processes used may be about 70-80. Holes are mainly normal to the surfaces, but oil holes are angular. Most of the straight holes are of low depth and require multiple operations such as drilling, reaming, counter-boring, tapping, precision boring, etc. Fig 3.1 shows the hole diagrams of a typical cast iron gasoline engine cylinder block.

- Considering the increase in scale of production, the reliability of the machining processes, and the other commercial and operational requirements, the manufacturing concepts have changed over years. Chronologically, the different methods that became popular in manufacturing of the prismatic components, such as cylinder block, are as stated below:
- General purpose machines such as milling machines, radial drilling machines, etc. with special fixtures with crude material transportation between the machines.
- Special purpose machines with multi-spindle, multi-slide, linear or rotary indexing with built-in special fixtures and jigs and roller conveyor in between for part transfer.
- Transfer machines with a large number of machining heads built around the different workstations where the component is transferred after completion of operation on one station to the next station through varied types of transfer mechanisms.
- Flexible manufacturing systems with conventional CNC machining centres with pallets, large size ATC and transportation system with a centralised control. Fixtures are mostly manual and modular.
- Flexible transfer machine with CNC machining centres/modules, CNC head changers and automatic transfer of component as in conventional transfer line.
- Agile manufacturing with special NC 3-axis machining units - different for heavy duty operations such as milling and for light duty operations such as drilling, tapping, etc. doing parallel processing and has better re-configurability to meet increasing or decreasing volume of production, if so required.



RIGHT FACE



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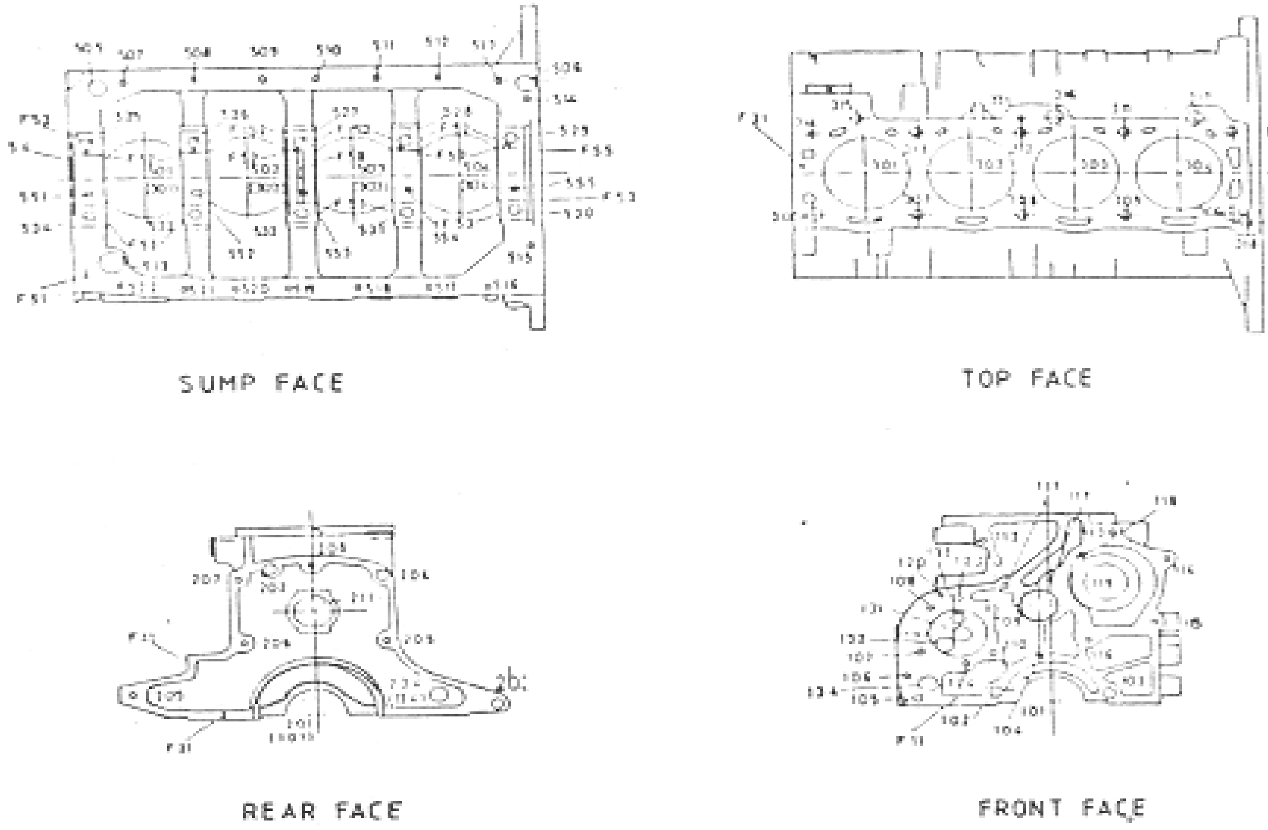


Fig. **3.1 Hole Diagrams of a Cylinder Block.**

Cost distribution in traditional manufacturing of cylinder blocks and cylinder heads with special purpose transfer machines is as follows:

• Transfer and fixtures	19%
• Milling Heavy and Rough Cutting	24%
• Workpiece Dedicated Machining	20%
• Drilling, Tapping and Slight Milling	37%
Total Machine Tool Cost	100%

In ***traditional transfer machine***, most of the machining stations for milling, drilling, tapping, and other light operations (requiring over 50% of cost) are totally dedicated with most productive multi-way, multi-spindle machining units. Split-ups of operations are carried out to attain the desired cycle time that is generally in seconds. Turnover, swiveling, and diagonal turning devices permit the processing on all the surfaces of the workpiece. Workpiece and the machining method decide the use of stationary clamping fixtures or of transportable fixture platens. Transfer of the workpieces or the platens from station to station is through walking beams or sliding transfer. Though all the machining

operations of a cylinder block can be integrated in one single transfer machine, normally the installation is split into a number of manageable size machines. Very limited engineering changes can be executed and that also after a considerable time loss required for setup change. For a new model, a new transfer is required or investment amounting to about 60~80% of that for a new facility, is to be incurred for retooling taking about 12 to 24 months. However, for a very high annual volume of production with considerable product life, transfer machine is the most economical solution.

Flexible transfer machine incorporates some 3-axis NC machining centre modules and a number of multi-spindle head changers (one of the many variants developed by different machine tool builders, Fig. 3.2) with traditional transfer system and provide the best of flexibility at reasonable cost. Transfer of parts from station to station may be through free flow transport system. For achieving a time cycle of 3 - 4 minutes for a typical 4 - cylinder cast iron cylinder block,

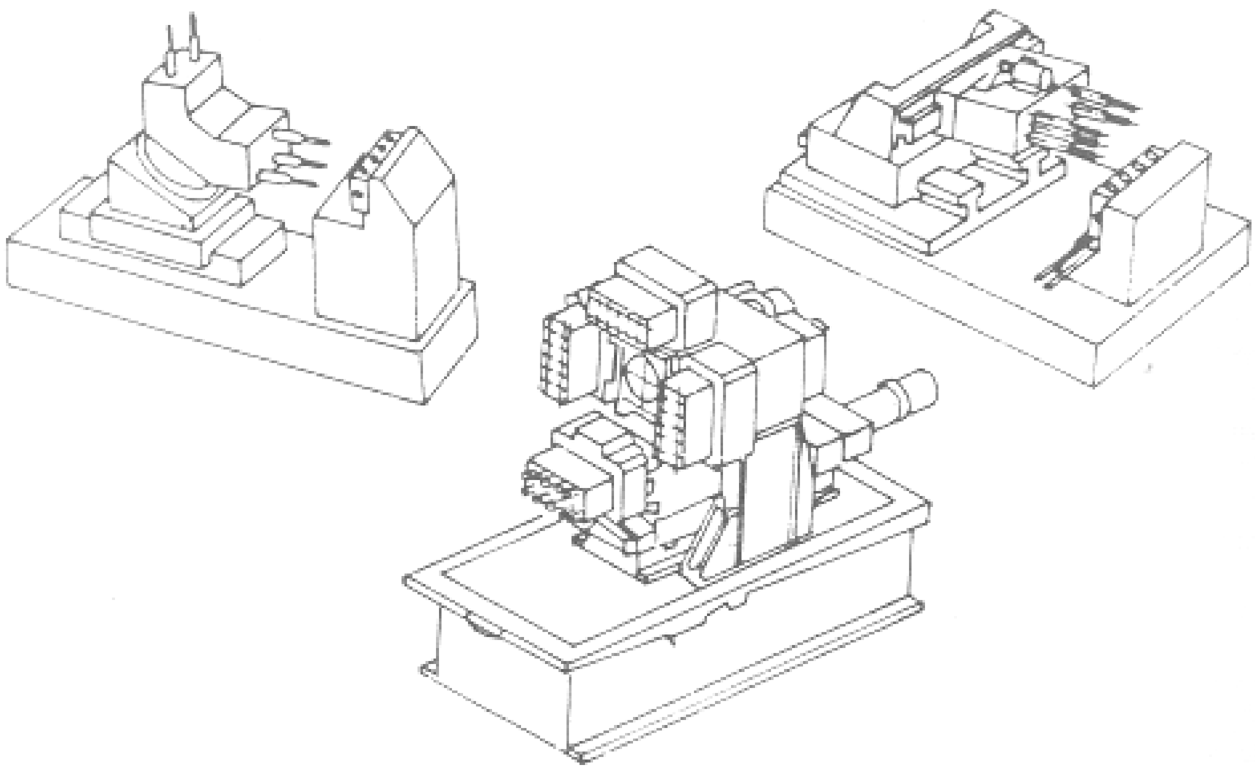


Fig. **3.2 Some Variants of Head Changers.**

the machine requirements may be something like 35-43 that will constitute: 20-25 NC single spindle machining centre modules, 8-10 Special Purpose machines, and 6-8 assembly machines. With multi spindle NC head changers/indexers, the number of NC single spindle machines may be reduced, if volume of production makes that justifiable but will require extra investment for every new head if engineering change requires the same.

The single spindle machining centre modules were ideally the best answer to overcome the subject limitation of flexibility of head changers. However, the productivity of the single spindle machining centre required major improvement. Using a conventional machining centre meant compromises such as very heavy unit doing a very light job or a light unit machining heavier cuts in operation such as milling in many passes - a waste both in terms of production efficiency and economy. For improving the productivity, separate machining centre modules based on application have been developed and used. The milling operation and heavy roughing operations are carried out with heavier 3-axes units. For lighter operations, such as drilling, reaming, tapping, counter boring, etc., lighter, fast and accurate 3-axes machining units - so called high speed machining centres, are applied . Presently a high volume manufacturing system incorporates - high speed machining centres/modules, and the high performance tooling systems developed for the purpose.

High speed machining centres: High speed machining centres/modules have been developed to cut down the machining time of the operations. It has been made possible through integration of many improvements in different areas: high speed spindles (speed 1200), high rapid traverse speed (say, 40 m/min. or more) and minimum acceleration and deceleration time required for starting and stopping of the spindle as well as for all linear axes, powerful CNCs with high processing speed, lower tool change time. High speed spindle unit is generally an integration of motor and spindle. Basically, the spindle is the armature of the motor, with the rotor mounted directly on the spindle shaft, and the stator mounted within the head housing. For keeping the spindle thermally stable throughout the speed range, an effective spindle core cooling is provided. Fig. 3.3 shows one such cooling system. Simultaneously, the motor spindles (Fig. 3.4) are designed with hybrid bearings, (ceramic balls as used by one manufacturer).

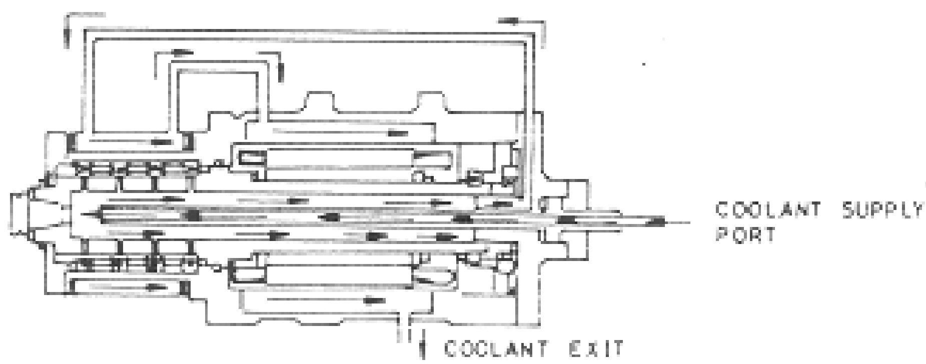


Fig. **3.3 Cooling System for High Speed Spindle.**

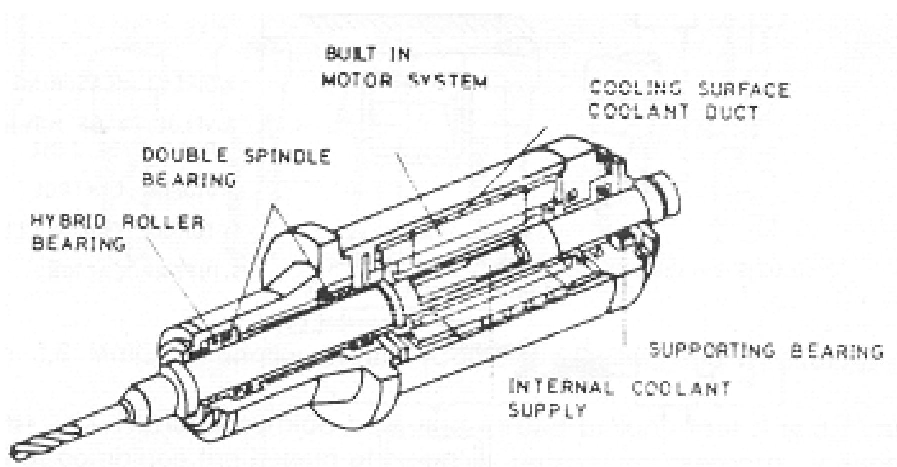


Fig. **3.4 Motorised Spindle with Hybrid Bearings.**

The responsiveness to starting and stopping of motor is also required to be excellent. In one case, the acceleration to 12,000 rpm takes 1.7 sec. and the deceleration time is 1.3 sec. The spindle is also equipped with an interface for hollow steep taper (HSK) and a balanced clamping system developed for high speed operation in range of 16,000 rpm to 24,000 rpm that is safe with centrifugal forces at the high speed. The HSK standard (DIN 69893) was jointly developed by German machine-tool builders, cutting-tool manufacturers and end users for a rigid tool holding at high speed machining. Compared to the conventional taper-shank design, the HSK system is nearly twice as stiff and three times more accurate, with an axial repeatability of +/- μ1 and a maximum runout of 3μ. The geometry holds tools against the spindle face, ensuring higher retention force, higher torque transmission, and less deflection.

For high rapid traverse speed, the linear guides with an anti- or reduced friction rolling ball elements, are used to provide very precise control of the load carrying capacity as well as to allow highly accurate preloading of the units. In another case, linear motors have been used to significantly reduce the effects of mechanical transmission characteristic like friction, backlash, and wear (Fig. 3.5). Linear motor applies translational thrust directly to the slide for near instantaneous movement. (Along with the maximum speed, the acceleration rate to attain the maximum speed is more important.) One such machine attains the maximum speed of 40 m/min. within 45 mm. Acceleration and deceleration time also depend on mass to be moved. By innovative design, machine tool builders developed extremely rigid and low-mass structure to position a light tool for drilling operation and similar light operations. One such machining unit consists of a stationary top column with vertical cross slide mounted in sliding block construction (X - and Y- axis). A horizontal slide with integrated motor spindle (Z-axis) is guided out of the Y- slide frame. Top column and axis slide are made of tubular steel. Only approximately 250 kg mass is to be moved for drilling operation in place of 2000 kg. for the conventional machining centre.

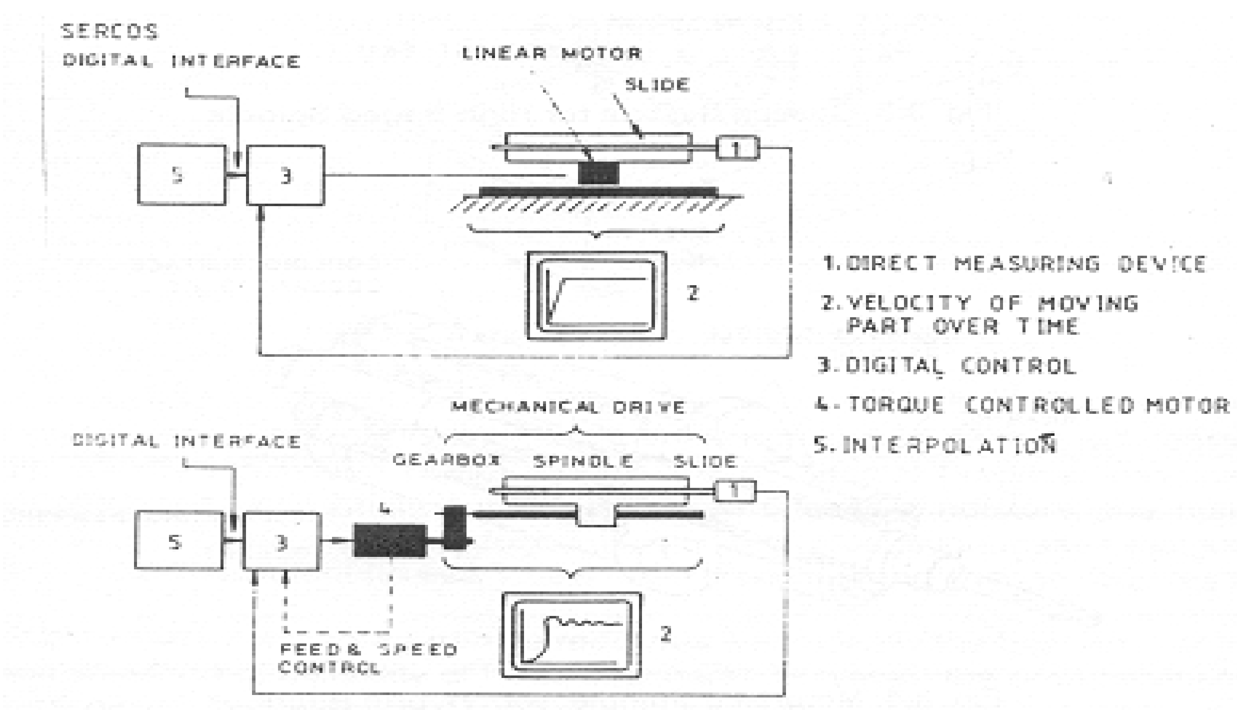


Fig. **3.5 Liner Motor Drive Vs. Mechanical Drive.**

The combination of intelligent servo drives, fast numerical control and some dedicated software, translates the desired machine tool movement immediately. Look ahead function and block preparation ensures high precision and reduces non-cutting time. Tool changes are made directly into the machine spindle, eliminating the need for tool-holding devices. The disc type magazine makes a short axial movement to remove a tool from the spindle shaft and replace it with another, that has further reduced the tool change time. These high speed machining centres/modules are generally provided with small number of tools in magazine and a chip to chip time of less than 4.5 sec.

Difference of performance between a high speed and a standard machining centre is as follows:

HIGH SPEED VS STANDARD MACHINING CENTRES

	FEATURES	*HIGH SPEED*	*STANDARD*
1.	*Spindle speed, rpm*	*12 ~ 24.000*	*6,000*
2.	*Chip-to-chip time, sec.*	*3.0~4.5*	*10*
3.	*Rapid traverse rate, m/min.*	*40~60*	*15~20*
4.	*Acceleration & deceleration*	*less than 3*	*4~6*
5.	*time, sec*	*35~70%*	*100%*
	Cycle time		

High Performance Cutting Tools for machining centres: Development in cutting tools have covered various aspects: Multiple operations can be carried out by the same tool with no time loss in tool change. The accuracy attainable by three operations - centering, hollow milling, and reaming - can be achieved in a single operation by the latest high performance drills. Kennametal's G-7 model drill with two reaming cutting edges is claimed to eliminate the need for the subsequent reaming.

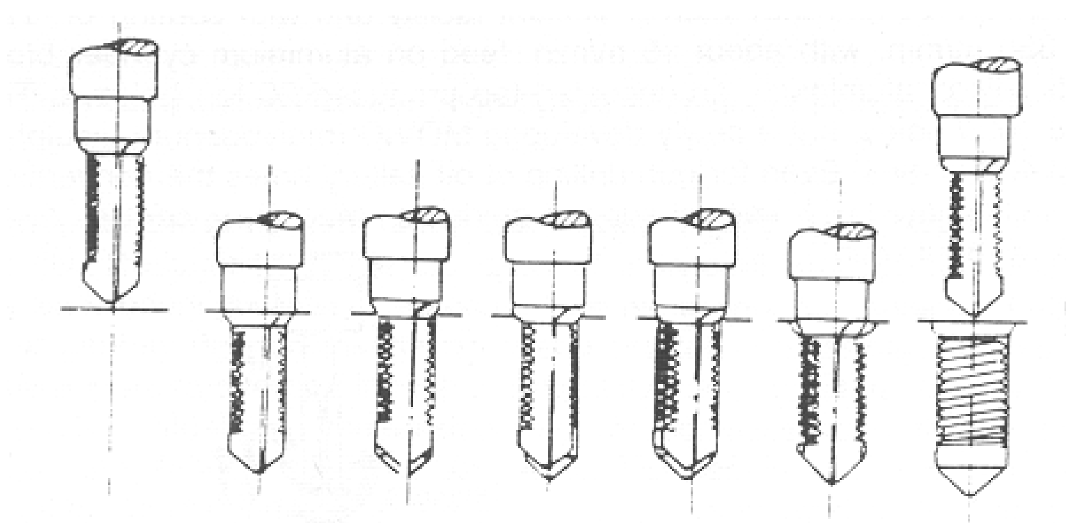


Fig. 3.6 Multiple Function Thriller (Combined Drilling and Threading)

Thriller (Fig.3.6) and Tornado carbide hole and thread making tool (Fig.3.7) are another development that combines the cutting of chamfer, recess, counterbore, and threads (with helical interpolation) on machining centres eliminating a lot of non-cutting time, and

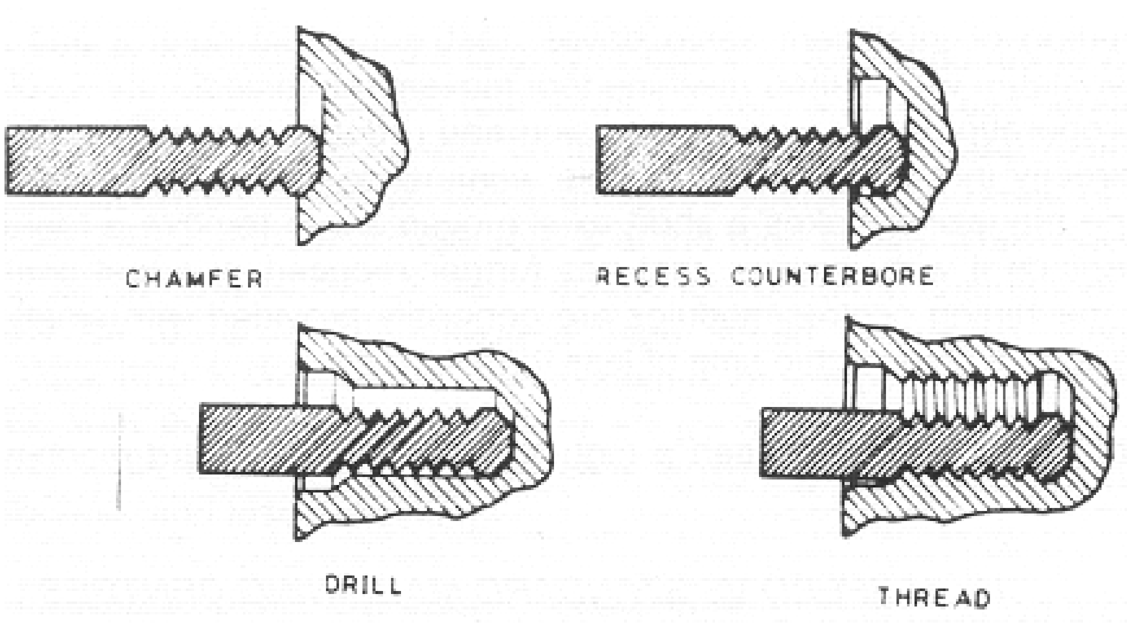


Fig. **3.7 Tornado Hole End Thread Making Tool.**

produce a better quality. Tapping was another process that was not very compatible to high speed machining centre. Efficiency of tapping process has considerably improved. Tension-compression tap drivers with limitation of thread depth control as well as synchronous tapping developed for close depth control, required machine spindle reversal. However, with self-reversing tapping heads or thread milling, and also high performance taps, the tapping time has been considerably reduced. Self-reversing tapping attachments are replacing synchronous-feed tapping with cycle time reduction by half and tap life increase by 5 times. CNC capability has also helped in improving the process efficiency. One such example is that of the bus-coupling concept, that allows rapid communication between the drive units and CNC (Fig. 3.8). The intelligent control system can synchronise the spindle and Z-axis allowing a tapping at 4000 rpm. A floating tap that slows cutting is thus not required. Internal coolant hole carbide tools and various coatings have further increased the cutting parameters that can be used for these operations. For an example, a carbide drill with internal coolant facility and with coating of TiAlN can be operated at 350 m/min. with about 15 m/min. feed on aluminium cylinder block/head. In tapping a 9% silicon aluminium, an uncoated tap produced 20 tap holes, a TiAlN coated tap produced 1000 holes, but a newly developed MOVIC (molybdenum disulphide) coated tap produced 4000 holes. Even for gun drilling of oil gallery holes the conventional special machines are eliminated with special support guides on machining centres that allow high rpm operation without whip.

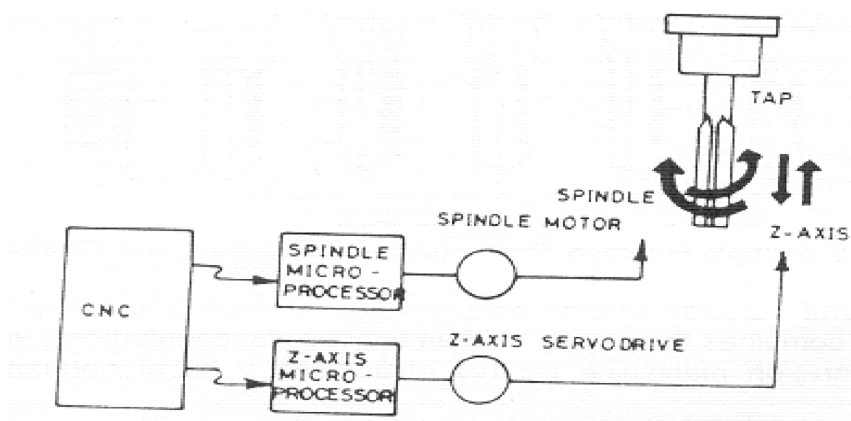


Fig. **3.8 Rapid Feedback Through Bus Coupling for High Speed Tapping.**

All these improvements make the high speed machining centre unit/module achieve extremely high performance such as, for instance 10 holes (5 mm diameter, 15 mm depth) in something like 6 seconds. that is, machining some 100 holes in a minute. Hard tapping is carried out with upto 4,000 rpm or drilling with 15,000 mm/min. feed and that also with capability of achieving grade IT 6 on precision holes.
Fig. 3.9 shows a cost comparison for the drilling operations (approx. 35 to 40% of the system cost, if transfer machines are used) with single spindle 3-axes high speed units and with multi-spindle units as on transfer machines.

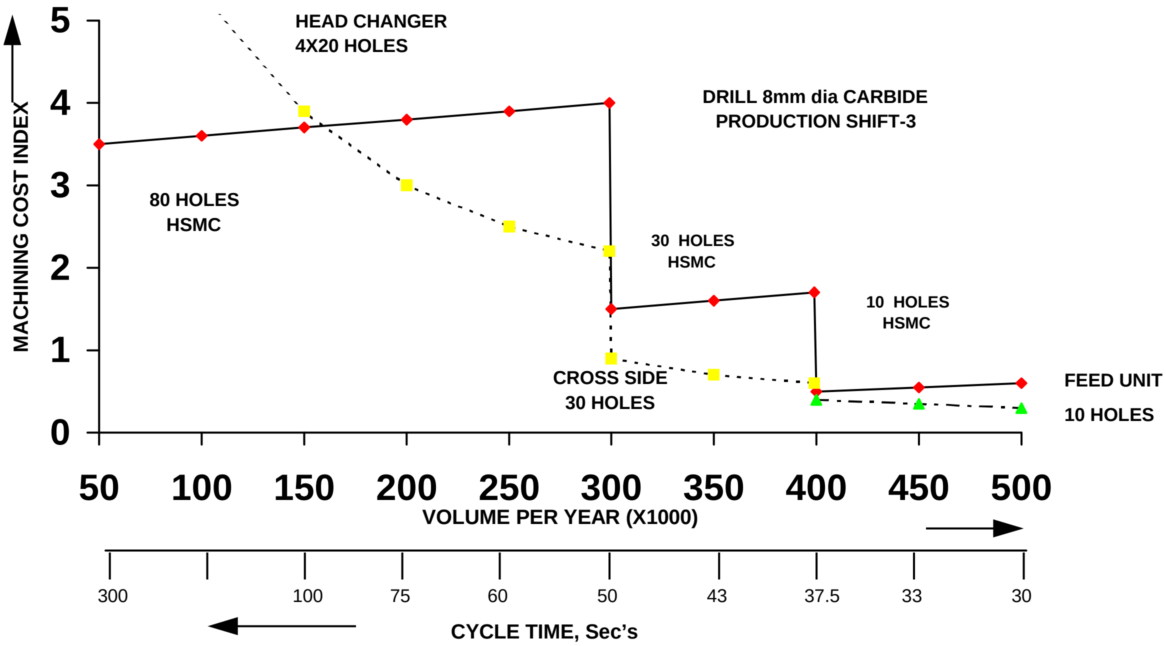


Fig. 3.9 Cost Comparison Between High-Speed Machining Centres and Multi Spindle Drilling.

Agile manufacturing system is the latest trend. Agility covers both- adaptability as well as flexibility. Reductions in the life span of individual products have necessitated this flexibility and reconfigurability. Planning time necessary for dedicated transfer lines that require accurately defined machining operations for all possible variants of the product, cannot be any more afforded in highly competitive environments. It does not meet the real time production situations. Immediately after the commissioning, the transfer line is ready to produce the desired capacity, say, 4000,000 per year. If it is not being run at the capacity, it is not economical. In a real situation it takes months sometimes even years to reach the capacity. A product change is required much before it has paid for its cost. At the time of change over, the transfer line demands that the manufacturer builds up an unpredictable volume in inventory before the line is shut for rebuild. In agile manufacturing, the flexible cells can be built up slowly as the project gets underway. Besides, delivery and installation of even a new agile manufacturing system with machining centre-based cells take much less time than that it would take to design and get the design approved by the customer for a transfer machine. In agile manufacturing production is increased gradually as required by actual situation in steps 25000, 50000, 100000 and even to 4000000 or more, if so required by adding machining units to the cells. Unnecessary upfront capital investment is avoided. During change over to the new part, old parts may be gradually phased out and the new parts can be phased in, one machine at a time depending on production requirement and availability of add-on tooling such as new fixtures or tools. Unlike, traditional transfer line, flexible cells allow the room

for simultaneous engineering and/or continuous improvement that is today the order of the day. Agile manufacturing system is thus aimed to combine the speed and reliability of the transfer line with the flexibility of the machining centres. The main features of an agile manufacturing system are as follows:

- Multi-step machining system: For each operation (machining step) one dedicated CNC machine is used for the pertaining process.
- Parallel process: Several parallel operating machines for each machining step is provided to meet the required volume. During breakdown of a machine in this machining step, the other unit takes over.
- Process optimised CNC machines: Heavier 3-4 axes units for rough milling/ boring and lighter high speed 3-4 axes units for lighter operations.
- Single spindle machining: with fewer tools on changer or with turret providing the best flexibility to produce a range of different parts, within the same work envelope, by changing the tool, the workholding equipment, if necessary, and the part programme - but with a minimum of change or no change to the machine units
- Reconfigurable flexibility: Adding of another station and moving the others to different locations in the system required by change of sequence in machining of the new part is quickly carried out. The key aspect of the facility design is modularity of each unit that builds the system. Even hardwiring and piping are replaced by plug-in electrical cables and adaptable hydraulic and pneumatic lines.

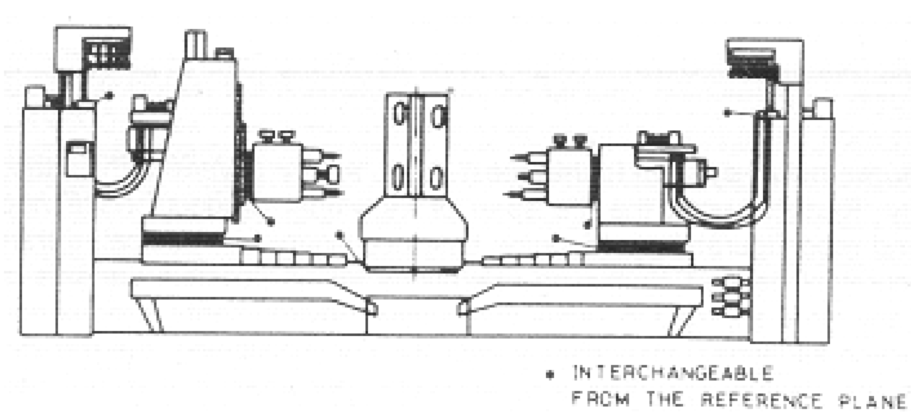


Fig. **3.10 Heller's FST System.**

Heller's FST system (Fig.3.10) permits swapping or exchanging of all the three basic elements of a machining station on a transfer line: machine columns, machine heads, and component carriers. A Y- column with drive unit may be replaced with an X-Y column with drive unit, a milling head replaced with a facing head or drilling head, or a stationary fixture carrier replaced with a carrier with a 90 or 360 degree rotary table.

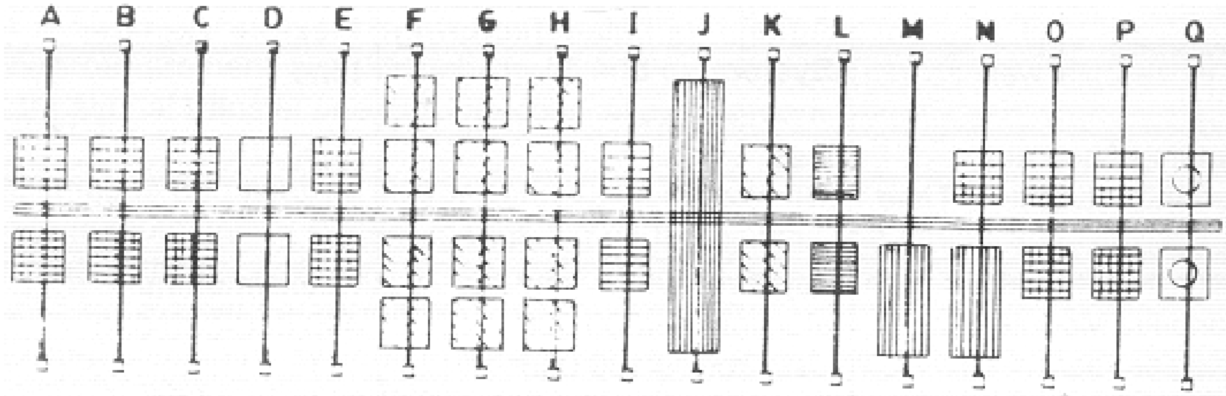
A quality comparison of agile manufacturing with traditional transfer based mass production will be somewhat as given in Table below

	Agile Manufacturing System	**Flexible Transfer Line**
Planning Accuracy	Less	high
System Lead Time, months	16 ~ 24	24 ~ 30
Feature Changes	days/week	weeks/months
Economic Module Size, parts per year	aluminium <300,000 cast iron <160,000	400,000-600,000
Part Flexibility	High	less
Volume Flexibility	High	medium
Redeployable	90 %	less than 5%
Batch Size	Small	high
Service and Maintenance	simple, all units identical	complex special unit design
Change-over Flexibility	simple, part dedicated approx.10 % of investment cost	complex units, fixtures & tools involved , > 30%
Manufacturing Lead Time	High	medium
Investment Cost	120 - 130 %	100%
Floor Space	100 - 135 %	100%
Training Level of Operator	High	less
Part Tracking	part tracking high investment	simple dedicated transfer

Ref. Huller-Hille's presentation at 'Made in Germany' Symposium.

As claimed by one machine builder, the agile manufacturing system with single spindle high speed machining centres built for serial production as a transfer machine line, can handle volumes of 250,000 to 1 million parts per year and can still remain cost effective in comparison with traditional transfer lines. With change in material to aluminium, cylinder blocks can be machined at higher speeds and feeds with high performance tools that have further made the single spindle machining centres practical solution in an agile manufacturing system. However, aluminium has put some different demands, on chip disposal, coolant, and clamping forces quite different from those for cast iron, that must be carefully taken into consideration for the manufacturing system in use. Even the slides with lift and carry pallets require replacement because of the silicon content (that is a grinding agent) in aluminium used for cylinder block. For part transfer, free flow conveyor or gantry loaders with double grippers may be used. Flexibility of work holding may be achieved through part specific methods - such as pallets, add-on adapter etc. Another trend is to switch over to dry machining to eliminate environment problems caused by wet machining and sludge generated out of the different operations. Vacuum exhaust system is being

used for effective chip disposal in dry machining. Fig. 3.11 shows a schematic layout of an agile manufacturing system for a cylinder block.



	Cell A - Qualifying (Front & Rear Face)
3-4 Axis Machining Centre	Cell B - Rough Mill Pan & Deck Faces
	Cell C - Rough Machining Cylinder Bores
3-4 Axis Machining Centre	Cell D - Milling Bulkhead Width & Undercut
(High Speed)	CellE - Drilling Oil holes(Compound Angles)
	Cell F - H Drilling, Reaming, Tapping
	Cell I - Finish Mill Pan & Bearing Gap Width
Line Boring Machining Centre	Cell J- Assembly of Bearing Caps
	Cell K- Drilling, Reaming, Tapping (End Face)
	Cell L- Line Boring, Crank Bore in Iron
Head Indexer Machining Centre	Cell M - Finish Line Boring, Crank Bore
	Cell N- Finish Front & Rear End, Gauging
	Cell O- Finish Cylinder Bores
Honing Machine	Cell P- Finish Mill/Grind Deck Face
	Cell Q - Plateau Honing, Gauging

Fig. **3.11 An Agile Manufacturing Layout.**

Four important areas that require special attention in cylinder block machining are :

- In line crank boring
- Deck face grinding / milling to take care of double material near cylinder bores, when the cylinder block is aluminum casting.
- High speed cylinder boring with CBN tooling

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In-line crankboring is still done on a dedicated SPMs. However, by proven spindle units with counter bearings for the boring bars a risk for the finish operation is eliminated. The table is designed to move with part and the fixture into the machining area (NC controlled) with flexible positioning of the part. A wedge-type slide unit may be incorporated to allow a NC controlled height positioning of the part. With cambore moving in cylinder head, the line boring has been made easier. Sometimes, the crankbores are finish honed to maintain the size and alignment. Some even use diamond sizing tool, that is a diamond plated, tapered bar that removes upto 0.20 to 0.25 mm. on diameter in a single through pass to finish the crankbores.

Deck milling*:* Head face of cylinder block requires good surface finish, flatness, and dimensional control with respect to crank bore. Face milling with close pitch cutter and a finishing wiper blade or surface grinding is the usual practice for cast iron cylinder block.

Present trend is to use high speed milling with ceramic inserts as milling cutter blades. Some have used rotary milling cutter with round ceramic inserts, and one square CBN wiper insert and obtained a very good tool life and very high consistency in surface integrity while providing a considerable saving in setup time and increased production. However, aluminium cylinder block with cast in liner presents a difficult situation of machining of two materials in the same pass. In normal machining it causes poorer surface finish and flatness. A new system of high speed grinding with elliptical movement of the grinding quill on machining centre has been tried with very significant success.

***Cylinder boring**:* Cylinder bores of cast iron cylinder block were machined earlier with multi-blade cutters-firstly with grind type and then with insert type. Heat and distortion of the cylinder bores were minimised through positive cutting geometry of the blades that reduce the cutting force imparted to bore. Presently, single point ceramic tools with various means of size compensation are used for finishing the cylinder bores. Sometimes, the single spindle high speed boring takes a semi-finish cut in forward downfeed and then, switches over to finish cut in upward feed. The machine may be with double spindle with adjustable centre distance, if production rate is high enough. Bore pitches are adjustable through numerically controlled worktable slide. With the advent of aluminium cylinder block, tooling techniques have further improved productivity. In one case, a tool head (Fig.3.12) featuring three MAPAL finishing cutting edges, three diamond guide pads and a taper hollow shank with face contact (HSK- DIN 69893) has been used for precision boring of cylinder bores that enables at least triple feed at the same cutting speed. Compared with single point machining, the number of parts per tool change increased from 10,000 to 25,000 cylinder bores. The surface finish improved from R_a 1.0 micron to 0.2 micron, the straightness changed from 8 microns to 4 microns and the roundness improved from 13 microns to 3 microns. Further, liners could be pressed without cooling (earlier nitrogen cooled to -150 degree centigrade) in aluminium block. The contact area of liners gets increased from 60% to over 90% that resulted into substantially better thermal conditions. A very exact face of the counter bores at the top of the bore to locate the cast iron liner is machined through two slides - one working slide and one balancing slide because of the high rpm used. Some semi flexible special machines have been used to machine the joint face and the cylinder bores in one setup, that results in an especially high accuracy of the cylinder block.

Honing of the cylinder bore is done to produce a good load-bearing surface finish as well as excellent dimensional and geometrical accuracies. A conventional honing tool with a series of externally mounted abrasive pads is simultaneously reciprocated along a longitudinal axis and rotated around it as the tool feeds into the bore. During the process, the pads expand radially to vary the depth of cut and increase the bore to the desired size. A parallel cross hatch pattern is produced on the finished surfaces.

Plateau honing is considered advantageous providing better wear resistance of piston tracks, better oil retention in the lattice structure of the surface eliminating the necessity to use costlier material for piston rings, and dramatically reduced oil consumption (Oil consumption has dropped by over 40% on modern engines). Practically no ‘running-in’

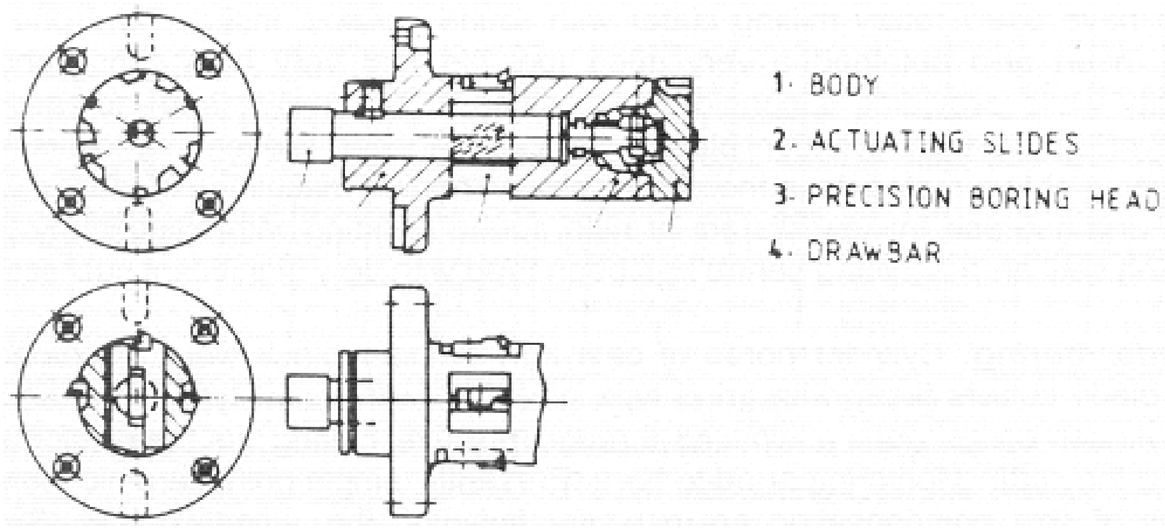


Fig. **3.12 A Mapal Multi Cut Precision Boring Tool.**

period on new engines and higher engine efficiency through reduced friction are other benefits of improved machined surface.

Plateau honing results in a certain structure which is characterised by a deep cross hatch with interspersed fine support area called plateau. The valleys retain the oil reservoir and the plateaus form a bearing surface. As a result, the reservoir keeps on lubricating the piston ring/cylinder wall interaction which reduces the contact friction and hence eliminates glazing and scuffing. The plateaus result in a large contact area between the piston ring and cylinder bore which enables higher compression rates through improved sealing.

Plateau honed surface in the cylinder bore is achieved through a two-stage process. Half of the 6~ or 8~ sticks mounted on a double expansion honing tool is used for rough honing and the other half for finish honing. A combination of abrasive and super abrasive sticks brings better productivity. Changing of direction of rotation of the honing spindle may be programmed to improve the structure of the bore surface. New methods of in-process auto-sizing ensure dimensional accuracies. Cylinder bore geometry in term of straightness, roundness, and cylindricity also play an important part in performance of engines. Automation control of stroke position (such as Cylindromatic) guarantees low degrees of cylindrical error independent of the skill of the operator, the material, the pre-machining, and the quality of the honing tool. A dimensional tolerance of less than 2μm, the cylindrical form and roundness lower than 0.3μm and surface finish between 0.3 and 0.8 R_t are achievable through good honing practices. However, too smooth a surface is equally bad, as it provides for insufficient lubrication that results in the piston ring polishing the cylinder bore.

However, developing the final plateau surface with a conventional tool may bend over torn peaks of material, instead of shaving them off. A brush honing as a secondary operation is very often recommended to produce a good load bearing surface in an engine bore

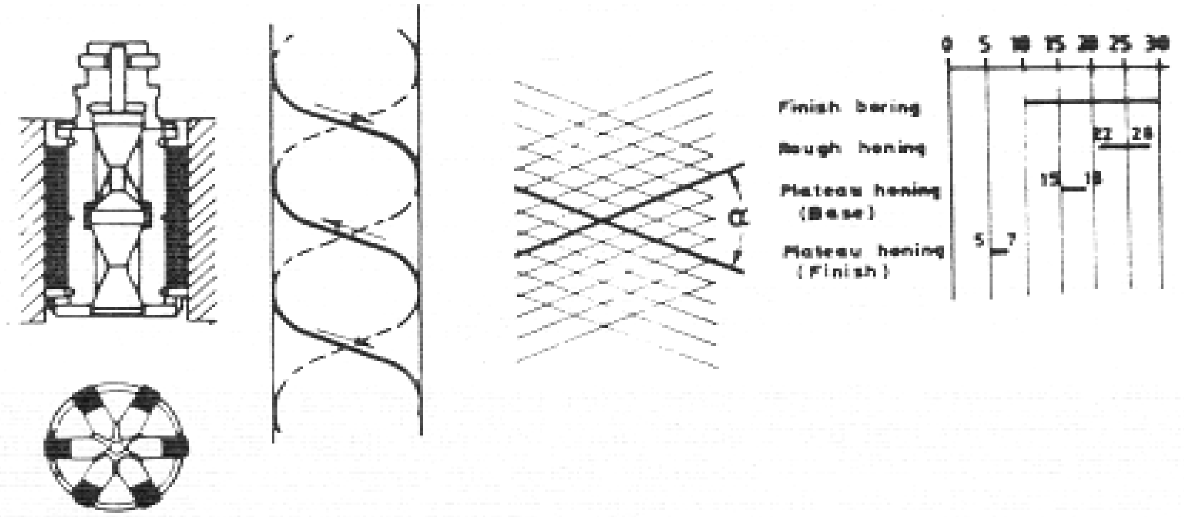


Fig. **3.13 Diagram of a Honing Tool with Honing Movement.**

without leaving the torn and folded material common with plateau type honing processes and will result in the consistency of engine performance. The need for a specific cross-hatch angle is being questioned. A number of studies are being conducted with current or unconventional surface preparation techniques such as plating of various types, burnishing, brushing, and etching. The performance and wear characteristics with these processes do not indicate a need for a specific cross-hatch angle. Diamonds and more recently, CBN is replacing silicon carbide in both rough and finish honing with improved stone life, reduced cycle time, and consistency in bore finish over extended periods. Vitreous bond is replacing metal bond, as it is claimed that vitreous bond materials have stronger abrasive crystal's retention characteristics and are more free cutting. Brush honing is replacing SiC finish and/ or plateau honing steps, or augmenting them as final step. Brushes containing SiC or aluminum oxide- impregnate nylon filaments are replacing MB (metal bond) or VB (vitrified bond) abrasive stones and improving the residual surface of the finished bore.

A change from conventional tooling to super abrasives has tremendously improved the productivity, and quality. Super abrasives have generally been used in boring, milling and honing processes. For crankboring where the length of the boring bar is large and the tolerance requirement is in range of 0.018 mm, the relative machining speed is kept low. For this application, the use of PCD (poly crystalline diamond) tools can achieve some times 50 times the tool life of a tungsten carbide. At the slower speed the diamond does not react chemically with the cast iron. For cylinder bore machining, when tungsten carbide can with less than 245 m/ min., alumina-based ceramic at 550 m/min., with silicon nitride and PCBN (polycrystalline cubic boron nitride), a speed of 1220 m/min. and higher can be used. PCBN provides advantages over silicon nitride both in productivity as well in improved cylindricity. PCBN in milling is also proving advantageous over silicon nitride for thin walled section faces using smaller cutter diameter and interpolation to complete the face. Particularly in milling the deck face having dissimilar material such as in cast in liners in aluminum block, PCD is very effective. Tool material for spot facing, reaming, etc. in aluminium machining operations is now PCD. Tool life difference is usually 100:1 at tool cost of 10:1 over carbide. A carbide reamer, for example, would last 2000 parts, and with

PCD, 150,000. With two relappings of the tool, 450,000 parts may be machined. Instead of changing tools twice a day, it is once every three month. Next to come is diamond coated carbide tools with obvious advantages of multiple edges, chip geometries, and potentially lower cost over a brazed-in PCD. CBN will replace all the tools presently used for cast iron. Surfaces traditionally broached or finish milled such as main bearing cap seat, are ground with super abrasive (CBN) grinding wheels and high pressure through spindle coolants on high speed machining centres. The process provides the tight tolerances without the excessive thrust and stroke normally required for broaching. Scope of super abrasives in deck grinding and other areas are forthcoming as a necessity.

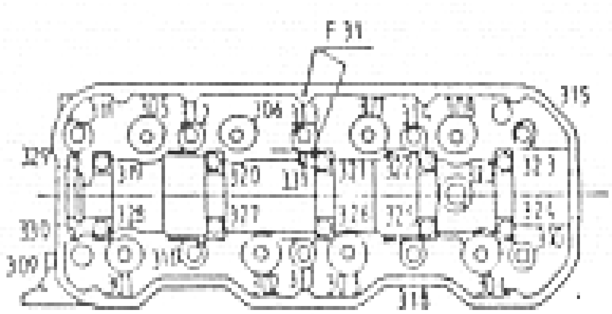
Quality assurance : Cylinder bores, crank bores, joint face heights from crank bore are critical dimensions that are checked using precision gauges and grading is marked on individual block for selective assembly. Bores are checked for roundness, straightness, and parallelism. Besides, the inter-relations such as alignment of crankbores and oil seal bore, squareness of crankbore axis and cylinderbore axis, and surface finish of cylinder bores, crankbores and top face, are also important and carefully monitored. Precision measurement of surface features of cylinder bores such as crosshatch angles, dimensions of plateau including groove width and depth, stroke reversal radius, and area of blow holes can be carried out directly with some versatile production floor type equipment that are marketed by various manufacturers.

2C. CYLINDER HEAD:

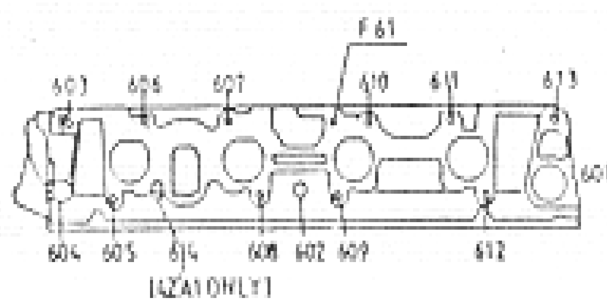
Material of cylinder head is generally aluminum, but for diesel engine, cast iron is in use.

Generally the sequence of machining of cylinder head will be as follows:

1. Qualifying
2. Rough mill all faces
3. Drilling , tapping and reaming on various faces
4. Finish valves in parent metal
5. Washing leak test, and assemble seats and guides
6. Finish valve seats and guides (Intake)
7. Finish valve seat and guides (Exhaust)
8. Finish mill cover and joint face
9. Assemble cam bearings cap
10. Finish cam bore
11. Deburring, washing, leak test and gauge



TOP FACE



INLET FACE

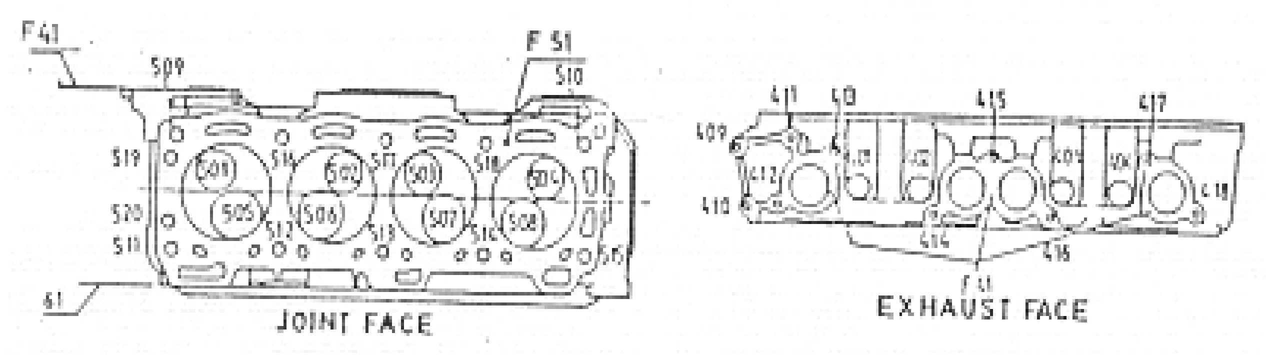


Fig. **3.14 Hole Diagram of a Typical Cylinder Head.**

For a typical 4-cylinder aluminum cylinder head, numbers of holes vary between 50-100, and almost 50-60 processes are used. Fig. 3.14 shows a high diagram for a typical gasoline cylinder head. Machining of cylinder head follows the similar systems as the cylinder block. As aluminum is more amenable to high speed machining, single spindle machining centres are laid out in sequence for most of the operations. A flexible system even for a very high production is very much cost effective. In a conventional flexible transfer line, the number of machines required for a cycle time of 3-4 minutes are: 13-15 NC single spindle machining centres, 5-6 Special Purpose machines and 6-7 assembly machines.

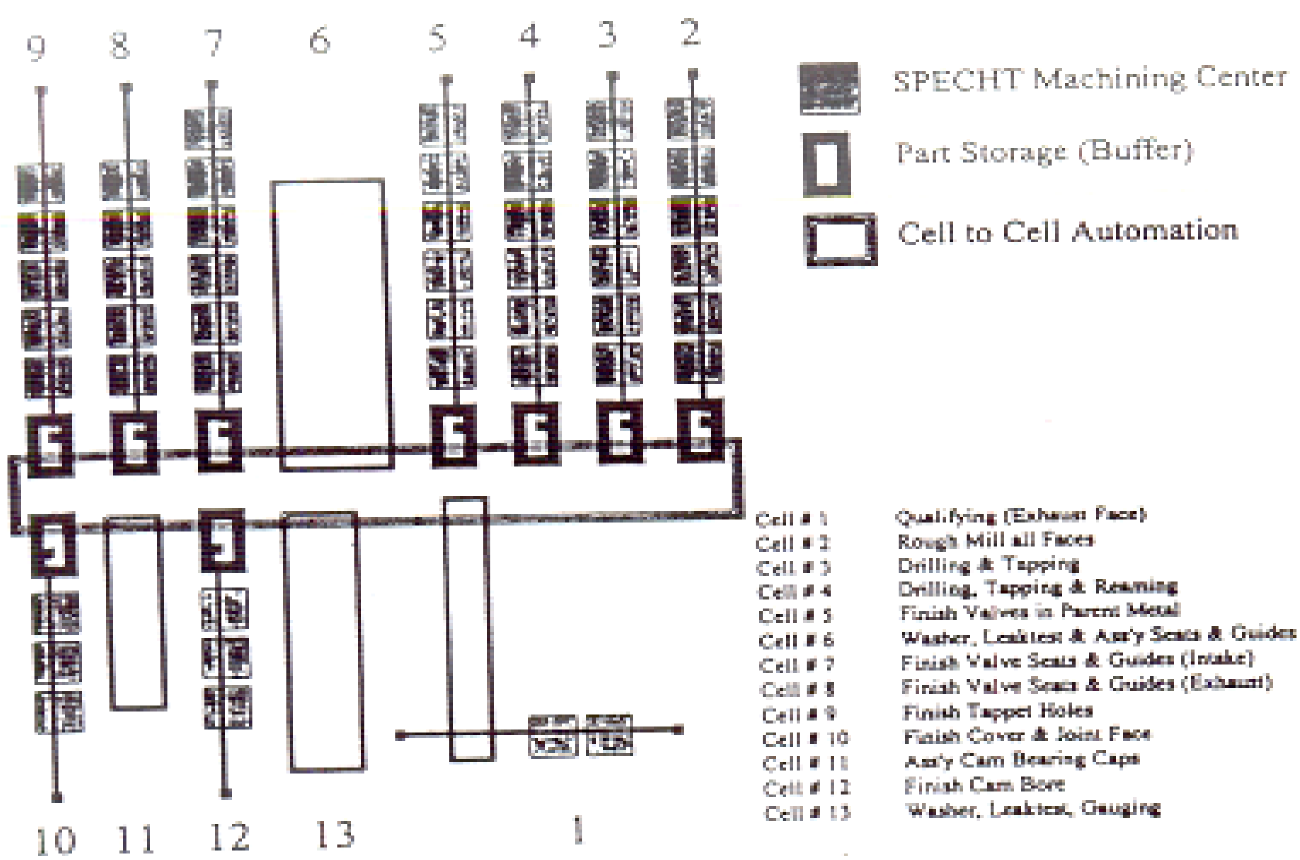


Fig. **3.15 An Agile Manufacturing System for Cylinder Head.**

With high speed machining centre/module, the number of machining centres may be reduced by 30~50%. Fig. 3.15 shows schematically an agile manufacturing system for machining of an aluminium cylinder head.

Finish milling of cylinder head is important. On aluminium cylinder head instead of using a large face cutter, some manufacturers now contour mill the surface with smaller end mill cutter. With established combination of higher cutting parameters through CNC, burrs generated are less and the flatness of the face is better producing a very reliable gasket face. With electronic control through suitable probes, the combustion chamber volume is controlled in close limit of about +/- 1~2 cc that is very important these days for the efficient burning of fuel and in turn, for emission control.

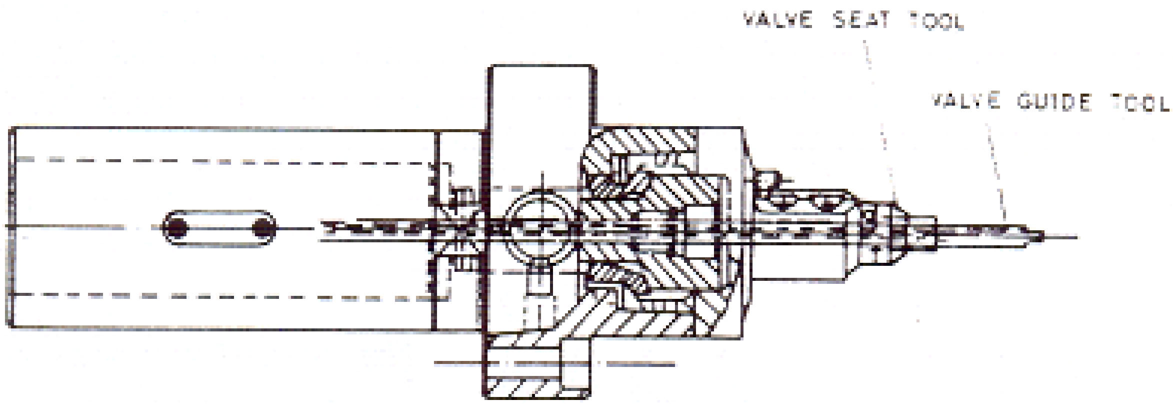


Fig. **3.16 Tooling to Finish Machine Valve Seat & Valve Guide by Reaming Out.**

For finishing of valve seat and valve guide bore, the valve seat machining that used to be plunged finished with form ground cutter was changed to generating process with single point tool for better seat quality. However, with improved tooling such as MAPAL cutter, it is now also finished by plunging the cutter. The tool used these days for plunging comes with CBN blades which provides excellent tool life. Valve guide is either gun reamed or machined with special microboring bar simultaneously where the valve guide reaming is completed before valve seat cutter come in cutting. In another system of MAPAL tooling (Fig.3.16) machining of valve seating ring and valve guide is carried out on a simple machining station. Concentricity required that is less than 0.02 mm, is achieved by means of so-called ‘feed-out spindles’ on which the reamer is guided in a revolving bush and the valve sear ring machined. The tool for machining the valve seating ring is a precisely clamped tool with 3 blades with cutting leads each corresponding to an angle on the valve seating. The contour is therefore produced by facing. The blades can be set very easily away from the machine in the longitudinal direction. At the centre of the tool is an accurately revolving bush for guiding the reamer for the valve guide. By means of a new highly - accurate connection system, the bush revolves with absolute accuracy.

Cambores are now mostly integrated overhead in cylinder head, and are of either same size for all or in some cases of gradually reducing sizes. It requires a long line boring bar

(Fig.3.17) along with sufficient support to maintain the size straightness and finish of the relatively small bores located separately. Sometimes, fixture with provision for raising and lowering of the work piece is necessary for feeding in the tools. It was almost impossible to carryout the machining on machining centres. On high speed machining centres, a special hydrostatic bearing for out-board support of the line boring bar is used for line boring of cambore. MAPAL fine boring tools are with long guide pads placed on the circumference of the tool body (Fig.3.18), that extend along the length of the body. Mapal tools have replaced the conventional ones with clear-cut advantages. The tool is located on the machine spindle, may be of a machining centre, and guided in a bush to start the bore. The tool is then guided further by the machined support journals. As a result of guiding by the pads in journals, the bores are produced in a perfect line, with an alignment better than 0.01 mm. For machining aluminum, a tool life of more than 50,000 cylinder heads may be achieved using PCD blades. On high speed machining centres, a special hydrostatic bearing for out board support of the line boring bar is used for line boring for cambore.

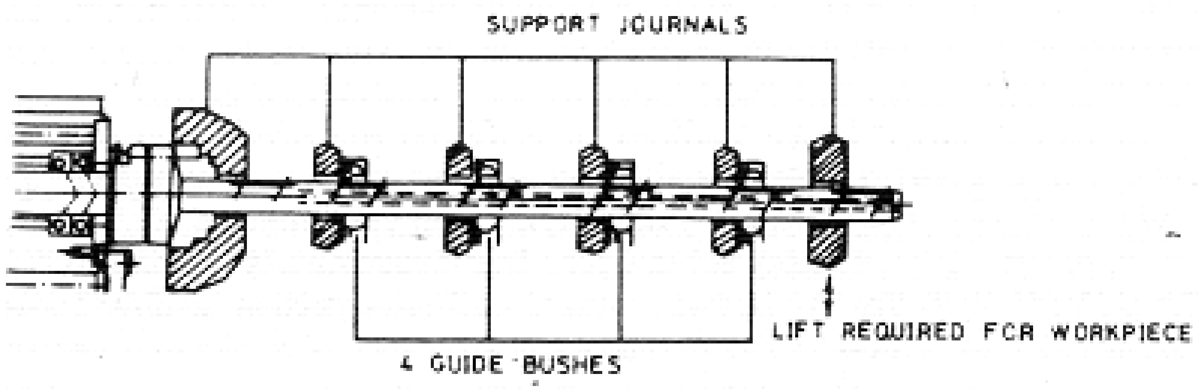


Fig. **3.17 Conventional Cam Boring Tooling System.**

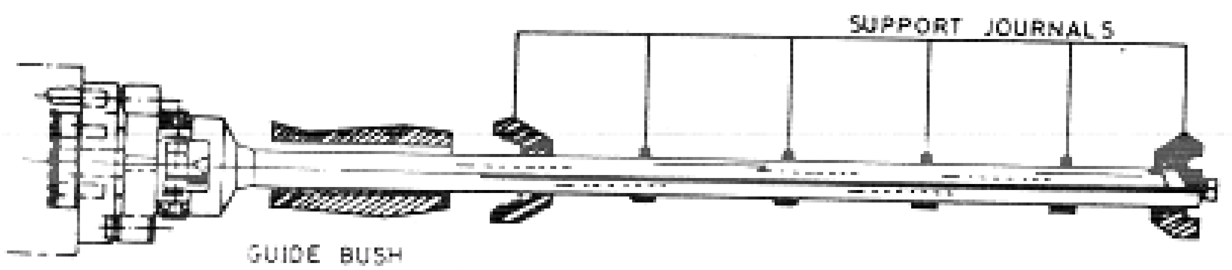


Fig. **3.18 Mapal Fine Cam Boring System with Guide Pads.**

For aluminium cylinder heads, **deburring** of all the surfaces such as intake and exhaust faces, combustion chamber profile faces, cambores, must be carefully carried out. Other wise fragments of the sharp edges could breakaway, either damaging the engine or impairing its performance. Tube type brushes are used for deburring bores, while disk type brushes are used for deburring various faces. Steel wire brushes as well as abrasive impregnated nylon brushes are used with manual hand tools or on special purpose machine built for the purpose.

For both cylinder blocks and heads, **leak testing** is essential to eliminate the problem of water leakage in oil line during running. Simplest system of leak checking is the air under water test, where the sealed component is pressurised with air and submerged in water. Rising air bubbles enable to visually trace the leak. Such methods are now unacceptable, as it necessitates the component being put in water. A dry air leak test is preferred. The system operates on the principle that flow out into the test cavity (leak) is equal to flow into the test cavity, once the cavity is pressurised. The system fills the cavity and maintains a constant pressure. If there is a leak in the cavity, air will pass through a flow detection element, which produces a signal proportional to the rate of flow. Time cycle is much less. The settling and checking periods required by pressure decay and subversion systems are nearly eliminated. However, underwater visual leak testing is carried out for the leakers after a dry air leak test for locating the leaks in the parts.

Quality assurance: The valve guides and the valve seats of the assembled engine must be perfectly aligned (Fig.3.18). Any offset between valve seat and valve guide causes progressively growing deposits of combustion residues and increased oil consumption in addition to disturbed heat transmission and excessive wear. With multiple valves per cylinder, the checking of valve seats becomes a major quality assurance task. Conventional form testers for roundness errors and radial runout errors are time consuming. Now measuring machine is available that checks 24 valve seats of a cylinder head with 6 cylinders in less than 30 seconds. Size and alignment of cam bore are another important feature that is generally checked and recorded using dedicated gauges. At the end of transfer line, the checking of the positions of certain holes such as valve seat, was done using dedicated ‘dog house’ gauges. The measurement is done in reference to the same location as in the machining process so that correction, if any, become easy. For every new cylinder heads, some 5~8 gauges were used. CMMs are now extensively used for keeping watch on any deviations. CMM is now rugged and fast to cater to specific requirement, and is also cost- effective to operate just near the machines.

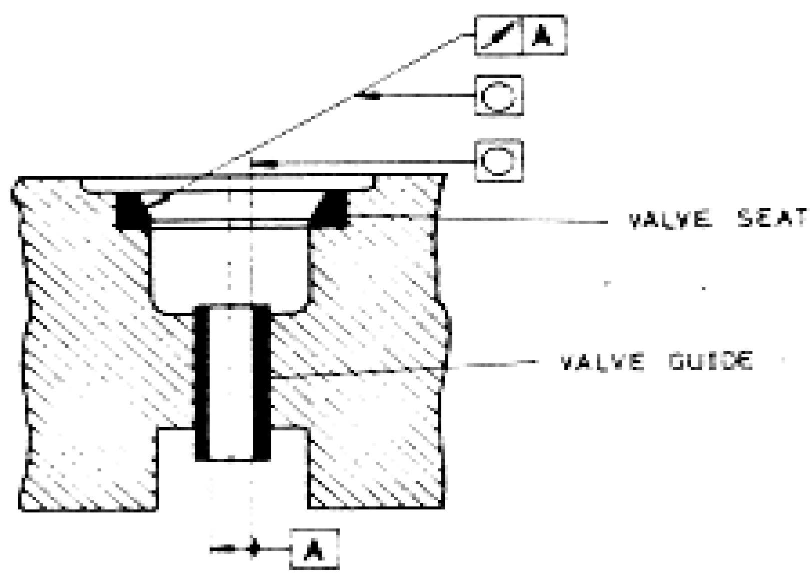


Fig. **3.18 Critical Quality Requirement in Cylinder Head.**

3C. CRANKSHAFT:

Material is generally forged steel, but the trend is towards a switch over to cast iron for gasoline and lighter diesel engine.

Generally, the sequence of machining for crankshaft is as follows:

1. Mass balance and centre both ends
2. Turning of both ends for clamping
3. Turning of main bearings, post end, flange, pins etc.
4. Drill oil holes
5. Deep roll pins and main bearings
6. Finish grind main bearing diameters
7. Finish grind pin bearing diameters
8. Finish grind post end diameter /flange
9. Drill, ream, tap, etc. at both ends
10. Finish balance
11. Superfinish main and pin bearings, oil seal diameter, thrust faces
12. Wash and inspect

Geometric centering with face milling is popularly used as first operation to create reference rotational axis for rest of machining. However, to reduce the initial unbalance to go beyond a correctable limit for the final balancing, **mass centering** is **also resorted to** by many manufacturers, whereby the rotational axis is brought to correspond with its main inertia axis. As in geometric centering, the axis of the crankshaft is decided by the rough and uneven surface of its main bearings, it results in significant unbalances. The machining operations to follow may further cause additional unbalance. Consequently, the final balancing will require a large number of drill holes and/or a not desirable drill depth to bring the amount of unbalance within specified limit. Mass centering eliminates the undesirable conditions and provides some advantages as follows:

- Reduction of the initial unbalance by 50~70% compared to geometric centering.
- Simpler, cheaper final balancing machine
- Shorter correction process, shorter cycle time, better life for drills.
- Not many undesirable balancing holes on the counter weights damaging the purpose of counterweights.
- Reduction in crankshaft weight right at design stage

If so desired, mass centering can provide a biasing centering - a defined shift of the inertia axis - to optimise the location of the scatter of unbalance that may be caused because of the following machining operations

Journal and pin turning on multi-tool (form), multi-slide lathe has become part of history now. CNC turning centres are also used for turning of journals and ends.

External milling, Internal milling or whirling (Fig.3.20) are at present universally used for machining of both journals as well as pins. The circular cutting path of the internal cutter surrounds the pin and provides favourable contact conditions as against the contact of the external cutter that extends over a much reduced path. At identical feed rate, the

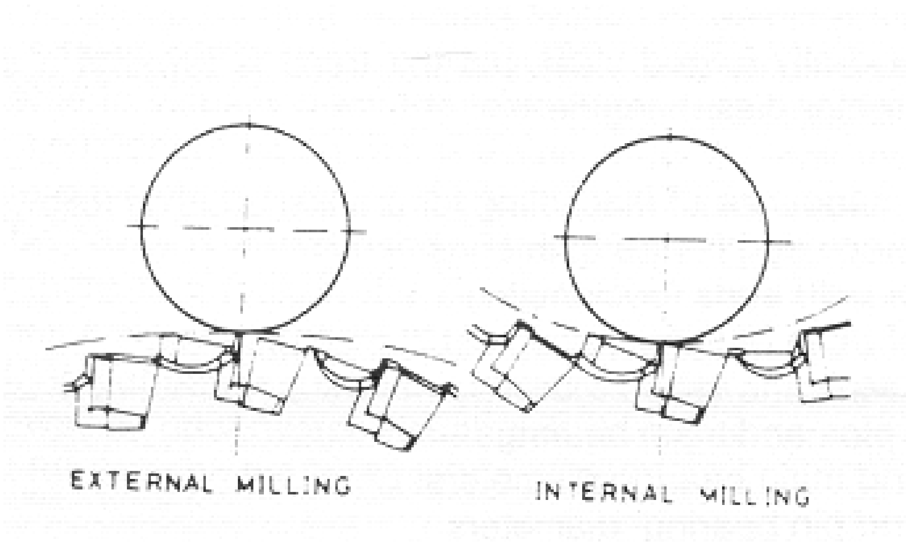


Fig. **3.20 Crankshaft Milling Methods.**

maximum cutting depth to be applied during internal milling is much smaller than that during external milling. The greater cutting arc length combined with the smaller maximum applicable cutting depth results in a smaller thickness of cut for each cutting edge (lesser strain for the cutting edge) at identical rotary feed rate. So higher feed rate almost twice of that used for external milling may be used. Furthermore, the peaks of the polygon profile produced at identical rotary feed rate per cutting edge for internal milling cutter are less pointed because of the better adaptation of the tool path to the workpiece surface as against the one produced by external milling. Different configurations of internal milling machines are used depending on production requirements and the part design. Internal crankshaft miller with two cutter heads- one for main journals and the other for pins, may be used for high production. Machining of crankpins and main bearings in one setting is preferred for better quality, as the errors getting in because of second setup are eliminated. Machine with a single cutter head may be used in plunge mode to complete machining of journals as well as pins if radius on mains and pins are the same. During operations, the crankshaft remains firmly clamped and stationary. The clampings are at the pre-machined ends. For improved rigidity of work holding for heavy milling load, an additional 'traveling' clamping fixture that clamps the main bearing (already machined) closest to the pin to be machined, is provided. Sometimes, a fixed clamping unit permanently fixed to the machine bed clamps additionally the central main bearing (already machined). The centre of cutter head rotates around the diameter to be milled (Fig. 3.21). Single rotation completes the desired bearing diameter size. The inner circle of the cutter inserts always cut the required circular shape of the diameter being machined. On some milling process the crankshaft rotates just one turn. In mechanical milling machines with internal tooth cutters, a master crank running synchronously with the chucks translates the movement of milling slide. CNC miller provides more flexibility for setup, better efficiency, and improved accuracy compared to crankshaft turning machine. However, milling has certain limitations: It can not produce axial recessed undercuts at all, and radial turned grooves only to a limited extent. The tool will have only one profile and it is not possible to divide up the cutting process into strict individual task. Milling is the best where the forging quality is suspect.

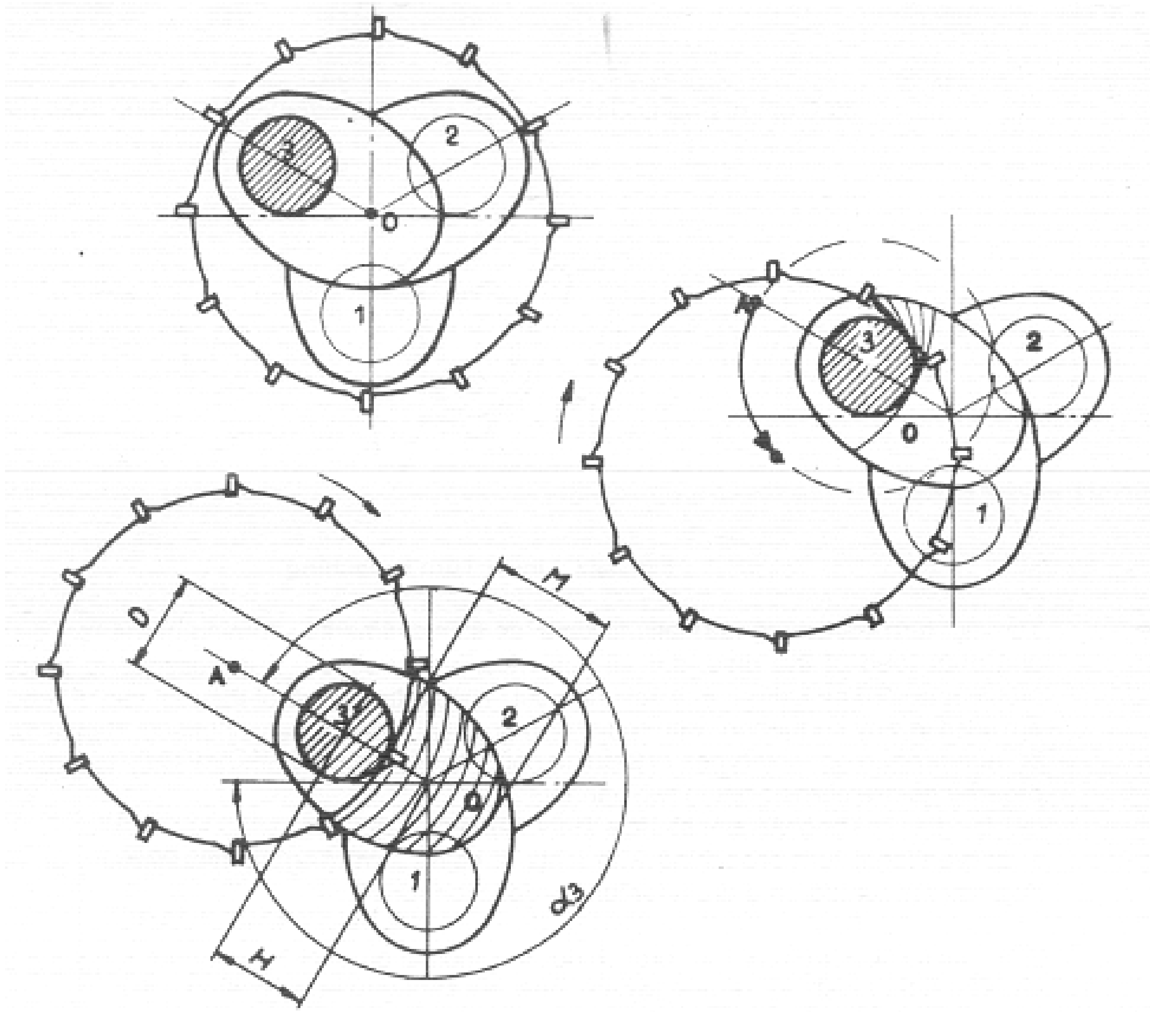


Fig. **3.21 Internal Crankshaft Milling for One Bearing Diameter.**

Turning/turn broaching is the latest method for machining crankshaft. It started with linear turn broaching (Fig. 3.22) that required a substantially long tool. Next to come was rotary turn-broaching with all the cutting edges arranged on the outer periphery of a rotating disc. Both the methods had a serious disadvantage: the feed must be designed as a cutting edge projection when the broaching tool is manufactured. This projection must not exceed about 0.5 mm. Hence depending on the radial path to be traversed, the broaching tool will have an extremely large number of cutting edges for corresponding length or diameter. Turning/turn broaching machine was developed to overcome this disadvantage faced in turn-broaching. Tool is circular - all the cutting edges located on the same radius. Feed per tooth depends on the feed movement and can be varied. For larger radial path required for machining of the cheeks, the process can be run in turning mode. A typical cutting arrangement followed in crankshaft machining is as follows:

- Rough-turning of cheeks and journals by plunge-turning, with the cutting divided over several cutting edges.
- Finishing of the bearing width, journals and recesses by turn-broaching (but finishing of undercuts by turning).

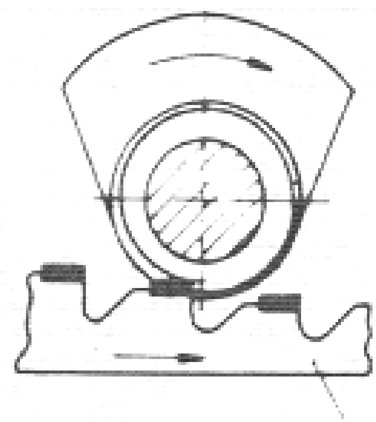


Fig. **3.22 Linear Turn Broaching.**

Turning/ turn broaching is totally flexible, as all movements - turning of the tool disc, radial and axial feed of the disc, are all numerically controlled. It is possible to produce any profile required including an axial undercut. The cutting edge of the tool can, if required, be provided in any sequence, with radial or tangential feed to the workpiece. Hence for turning or, turn-broaching, any types of adjustment of diameter or width are easy to achieve. Turn broachings are carried out in two variants:

1. conventional turn-broaching with tools of spiral form (Fig.3.23) consisting of individual segments mounted on a drum for long production runs

2. the more flexible turn/ turn broaching- a combination of NC turning for roughing and turn broaching for finishing. (Fig.3.24)

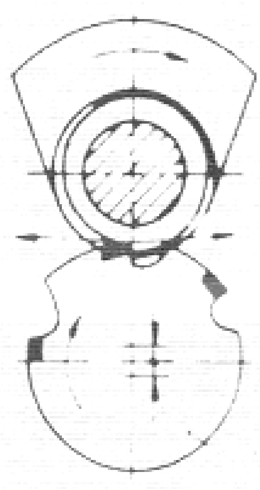


Fig. **3.23 Rotary Turn Broaching.**
(Spiral Turn Tool)

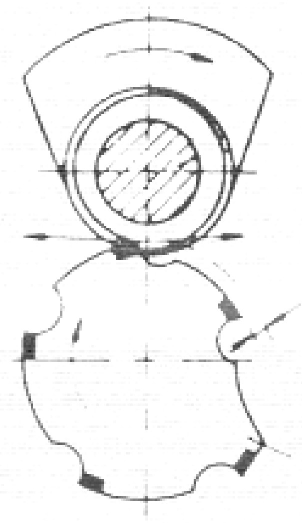


Fig. **3.24 Rotary Turn Broaching.**
(Circular Tool)

A typical cutting arrangement on the turn broach is shown in Fig.3.25.

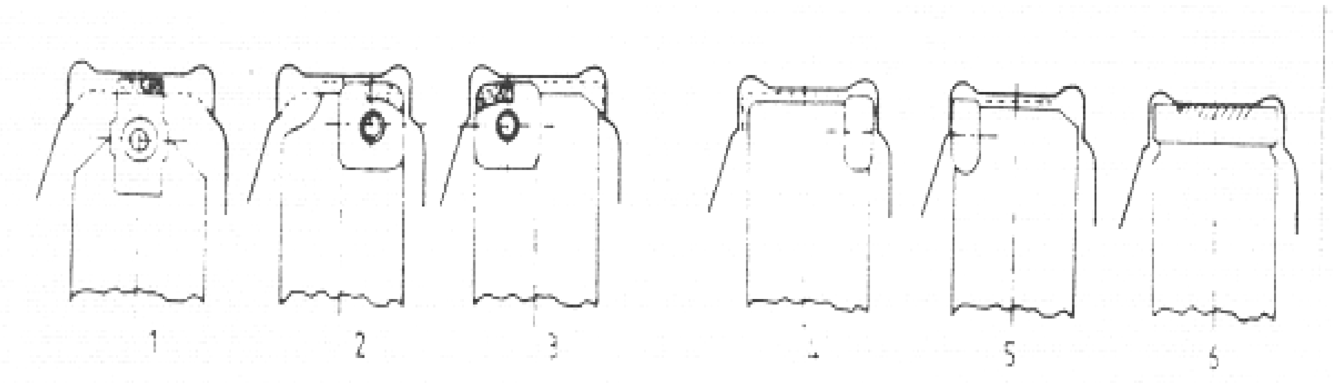


Fig. **3.25 Sequence of Machining in Turn Broaching.**

TRADITIONAL CRANKSHAFT TURNING

Each of series of tools enters the work simultaneously and each cuts to the full depth.

CRANKSHAFT MILLING

Each cutting edge engages the work many times.

TURN BROACHING

Each cutting edge engages each workpiece only once.

Turn broaching because of its inherent process dynamics, produces better surface finish. (In one case, R_t value for turn-broaching was 6-8 microns as against 20-35 microns from crankshaft milling.) For better surface finish, cutting speed for semifinishing and finishing sections of the tool engagement, is increased and feed is reduced on CNC machines. In case of turn-broaching, the roughing, semi-finishing and finishing can be combined in one tool that is a clear advantage over milling. Moreover, the cutting force in turn broaching, particularly in finishing cuts, is much less and so the shape deviations are ten times less in comparison with milling. The new turn broaching process eliminates rough-grinding. Finishing of diameter, bearing widths and grooves of main journals on turn-broaching requires minimum grinding allowances. The accuracies achieved from milling as well as turn broaching also depend on the heat treatment process followed in forging of crankshaft, the size and stiffness of design, the machining allowance and also precision of preparatory operations. Typical accuracies for the main and pin bearings machined by turn broaching Vs whirling/milling for similar passenger car 4-cylinder crankshafts are:

Features	Tolerances achievable in Turn broaching	Whirling / milling
Diameter	+/- 0.05 mm.	+/- 0.10 mm.
Length	+/- 0.04 mm.	+/- 0.07 mm.
Width	+/- 0.03 mm.	+/- 0.06 mm.
Stroke	+/- 0.05 mm.	+/- 0.07 mm.
Spacing	+/- 0.05 mm.	+/- 0.12 mm.
Ovality	+/- 0.005 mm	+/- 0.06 mm.

Both in milling as well as turn broaching, throw-away uncoated and coated carbide inserts of established grade are used on cutter body. 4-8 edges of the insert are used for cutting before the insert is replaced by a new one. Cutting speeds upto 250 m/min. for carbides or even faster with ceramics (particularly for finishing inserts) are used. In turn/turn broaching the various inserts are subjected to different conditions, the tooling layout has to be thus that the life of the inserts is equalised. The tooling is certainly more complex in turn broaching and requires optimisation in insert arrangement using CAD, modeling and simulation techniques. Tool manufacturers in collaboration with machine tool builders have perfected the technology that can also be used for machining of other automotive components such as camshafts, gearshafts, stub axles efficiently. With finish and size accuracy achievable with turn-broaching (even with whirling/ milling), the steps of rough grinding of mains and pins have been eliminated. Simultaneously, the process constraints are optimised to avoid any bend creeping in the crankshaft during machining through better fixturing as well as accurate pre-machining.

Oil holes in crankshaft connecting pins and journals presented a challenge to manufacturing engineers because of its small diameter with respect to the length (l/d more than 20) and difficult entry condition. Inside cleanliness and a need of very smooth chamfer at the entry are other essential features for maintaining the oil pressure for desired lubrication. Usual wood pecking drilling system with thicker web special chisel point drills still maintain certain advantages, though a large number of machines are using gun drilling for better productivity and better straightness.

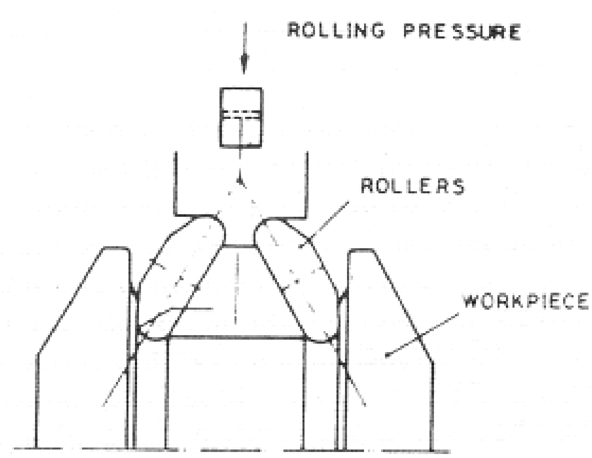


Fig. **3.26 Fillet Deep Rolling.**

For improved fatigue strength, ***deep rolling of fillet radii*** of journals and pins (Fig.3.26) is carried out particularly for cast crankshaft. The increase in fatigue strength of deep rolled components is through induced internal stresses. The process generates compressed radial stresses down to a depth of 5 mm from the surface, eliminates stress risers, and produces a geometrically true fillet geometry.

Techniques applied for deep rolling of fillets are: undercut fillet deep rolling prior to finish grinding and tangential fillet deep rolling after finish grinding. The objective of the undercut fillet deep rolling technique is to eliminate grinding of side walls and fillets that present a technical problem for efficient grinding. Instead, the side walls and fillet undercuts are easily finished to proper width and surface finish in a separate operation for all the journals in one setup, if so required. Undercut fillet with subsequent deep rolling increases fatigue strength upto 300%. A tangential fillet, deep rolled, is the most economical processing that increases the fatigue strength upto 160% without adding any undercutting operation. The process is carried out by forcing a special work roller (radius on the roller conforming to the radius of the fillet) against the fillet of a finished ground crankshaft. The fillet rolling of individual main and pin bearings is carried out in programmed sequence. For the high volume production requirement, all the fillets of journals and pins can be carried out simultaneously.

A patented angle dependent control of rolling force of Hegensceidt - the pioneer in crankshaft deep rolling technology - ensures application of maximum force in crank section and minimum force in the area of limited web support. It results in better accuracy of the bearing width and a maximum increase of the fatigue strength, as the deep rolling force is used in the highly stressed zones of the crankshaft. After deep rolling, another patented roller straightner unit integrated in the same machine, is used to straighten the crankshaft to the required total indicator value without any loss of fatigue strength. Additionally, the machining allowance for the finish grinding operation may be reduced upto 30%, as the roller straightening keeps the total indicator run out value to less than 0.08 mm. Sometimes nitriding is also used to improve the fatigue strength.

Thrust faces of crankshaft (usually the centre main bearing) require close width tolerance and excellent squareness of the two bearings faces relative to the component axis. An excellent surface quality with a high percentage contact area is also desired. The conventional process of turning followed by plunge grinding of the thrust faces is sometimes substituted by a single operation on a special crankshaft turning and roller finishing machine. It ensures the desired quality characteristics with better process capability due to one setup operation and roller finish that also enhances surface hardness besides surface finish.

Cold straightening at various stages - after rough turning/milling, after fillet rolling, before finish grinding of main journals - was the usual practice to ensure the accurate alignment of the main journals that is essential for satisfactory assembly and performance of automobile engines. However, conventional cold straightening that is carried out by applying force through a press ram on the middle journal with crankshaft supported at extreme ends (Fig.3.27), introduces tensile stresses into certain parts of the crankshaft and, as a result, the fatigue strength is reduced. For fillet rolled crankshaft, conventional cold straightening is very harmful, as the residual compressive stresses introduced by the rolling can be destroyed. So manufacturers control the crankshafts as forged and then throughout all subsequent stages of machining to ensure complete avoidance of conventional cold straightening. Indenter Method of Straightening is claimed to straighten the crankshaft without loss of fatigue strength. In the process, the crankshaft is supported on the main journal by a close fitting concave block, and on the upper side of the journal, the two arc-shaped indenters are pressed into the fillets so that the ends of the crankshaft arch away from the area which is treated. The process even improves the fatigue strength. The load requirement in the process is, however, significantly more for equivalent amount of straightening by conventional means.

For ***journal grinding*** where the walls are to be ground, a single wheel grinding is necessary. Multi-wheel grinder may be used if the volume justifies the same. However, the trend is to go for single wheel grinding. Improved abrasives such as SG or borazon with better designed machine tools are now being used for better productivity.

A new grinding system - QUICK POINT - is getting acceptance for cylindrical grinding of all diameters and faces of crankshaft such as flange, gear fixing diameter, mains, pins etc. where super hard wear resistant CBN grinding wheel of a width of only a few millimeters is used at high speed in plunge as well as oscillation mode, Fig.3.28. In this process, grinding wheel contacts the workpiece only at a peripheral point, Fig.3.29 (as against the peripheral line in conventional grinding). The point is reached by the angular displacement of the wheel axis with respect to the horizontal workpiece axis. The process enables to grind shoulder or radii because of the possibility to tilt the wheel axis creating a clearance angle in axial direction both for grinding from tailstock towards workhead spindle

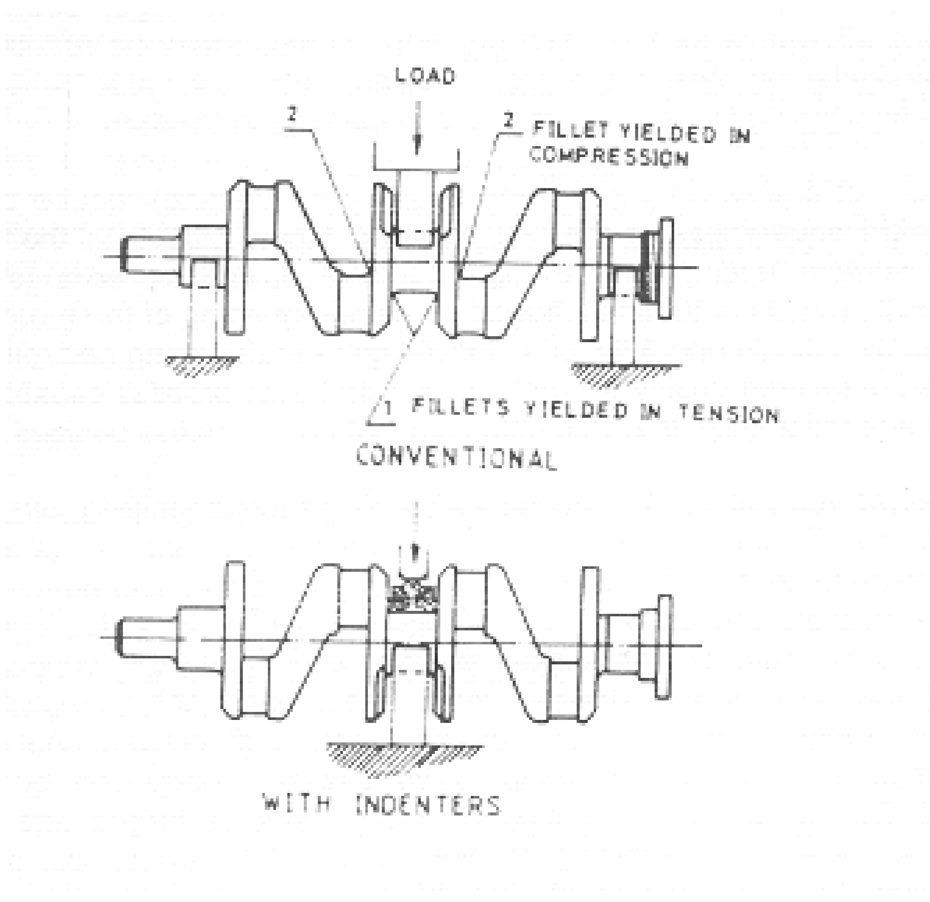
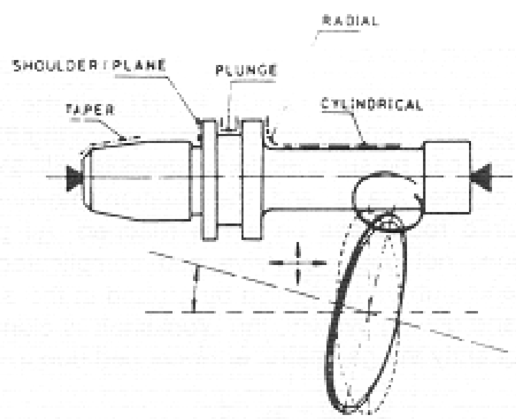
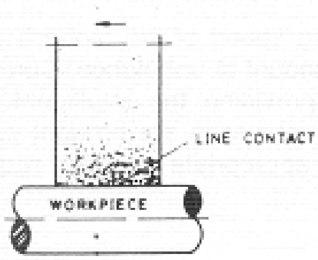


Fig. **3.27 Cold Straightening of Crankshaft.**

or from workhead spindle towards tailstock. With the CNC, even a concave or convex surface, Fig.3.30 on pin and/or main bearings, if required, can be generated.





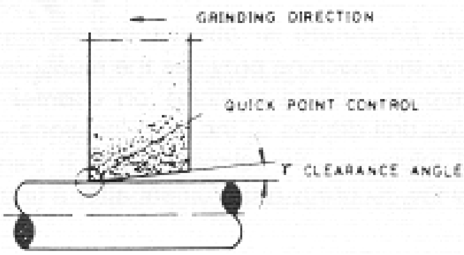


Fig. **3.28 Line Contact. (Conventional Grinding)**

Fig. **3.29 Quick Point Contact with Small. Axial Clearance Angle.**

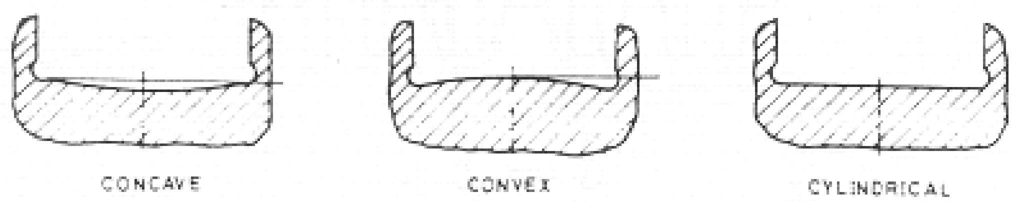


Fig. 3.30 Shape of Main / Pin Bearing.

Traditional indexing type ***crankpin grinders*** are still the same but with many machine-related improvements and CNC controllable indexing and grinding parameters. The indexers use electronically synchronised motorised spindle workheads. A throw adjustment feature brings in more flexibility. For higher volume of production, the machines are generally multiplied. However, two other methods have also been applied:

1. Single workhead machine with pin dedicated workhead thus with overall fewer mechanical parts (no need of a carriage traverse, indexing mechanism or work rest) and better accessibility for wheel change. Elimination of these parts results in less indexing variability and so more consistent radial positioning between pin to pin and a better finish for crank pin. Numbers of crankpins decide the number of machines.

2. Dual wheel crankpin grinders that simultaneously grind two same axis pins with 2 wheels on the grinding wheel spindle. For in-line 4 cylinder shafts, two dedicated machines are required.

In one system of high speed grinding - QUICK POINT, all the diameters of crankshaft including all crankpins, can be ground in one clamping (Fig.3.31). The crankshaft is clamped between centres and can be supported on a main journal. During the grinding of the pin the feed movement of the X-axis and the rotation movement of the C-axis are interpolated and the required roundness on pin is reached. All pins are ground in one clamping. The process does not use expensive and complicated eccentric chucks and indexing devices. Flange and stub end can also be ground in the same clamping. Because of the patented clamping and driving system, the crankshaft is clamped almost without any axial pressure, and consequently the geometric error caused due to the effect of clamping is avoided.

Dynamic balancing is absolutely essential for increasing speed of the modern engines. Basically, the machine provides the measurement of the amount of unbalance. Correction is done through drilling of holes on counter weights. By providing the intelligent logic in controlled drill depths at the best locations, the residuals unbalance are brought within the desired tolerance. Sometimes, a rough balancing at the appropriate stage is required to achieve the accuracy requirement after a final balancing.

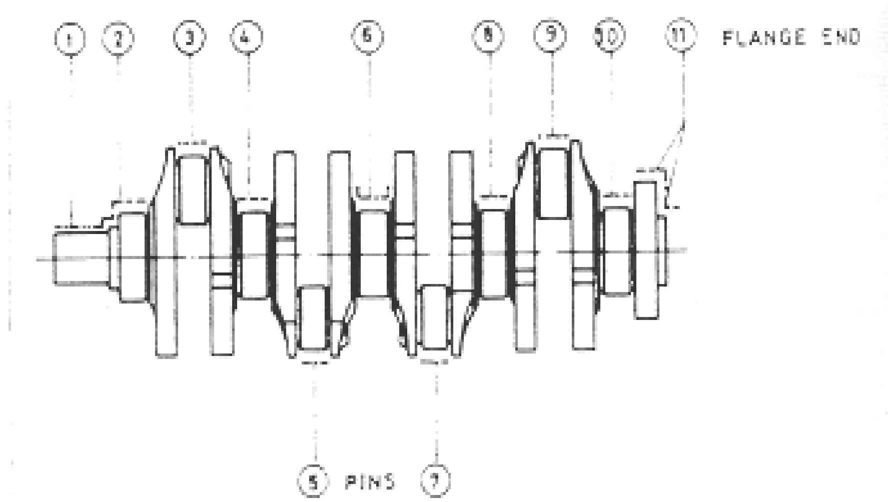


Fig. **3.31 All Diameters Possible to be Ground in all Set Up.**

Microfinishing of the precisely ground bearing diameters - mains, pins, oilseal - is necessary to remove wheel marks, fragmented metal and annealed surface (because of grinding burns), chatter, etc. to provide a precise fit to the mating part and to attain the designed service life, performance and reliability of the engine. A very high surface finish with no lobing and out-of-roundness can only ensure initial smooth running of crankshaft without increasing the clearance after bedding-in. The ferrite caps or nodules protruding above the bearing surface may cause bearing failures and so must be removed. The fillet radii between the journal and thrust face must blend well, as even minor irregularities in the zone can adversely affect engine performance including breakage. For oil seal surface, the lay of finish is also important to avoid leakage, so the direction of rotation of the workpiece is to be as specified. Microfinishing is the process that makes the surfaces suitable for the performance specifications. Different methods employed are:

Tape finishing uses a tape and a support and only improves the surface roughness but does not reduce the form error.

Stone finishing uses abrasive stones oscillating at high frequency to abrade the surface to be finished with capability of form correction

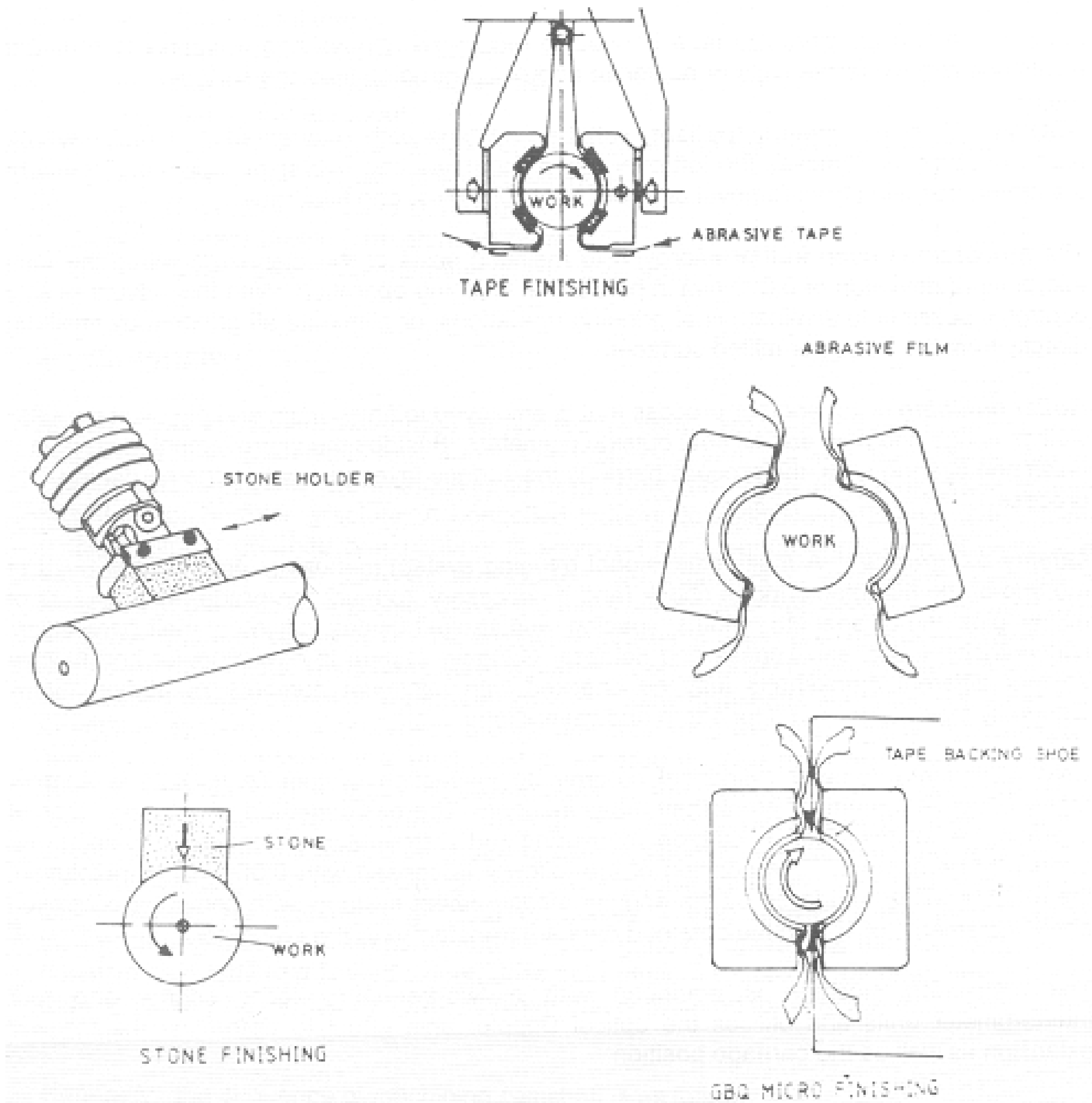


Fig. **3.32 Different Superfinishing Techniques.**

GBQ (generating bearing quality) microfinishing - the process developed by IMPCO, USA combines a non-resilient backing machined to conform to the shape of the finished part (the tooling surrounds the work surface) and a relatively non-compressible abrasive film. The process claims to improve surface texture, circularity, and straightness. Roundness improvement possible with this process is between 50 to 80% and surface microfinishes possible to be obtained in production are 0.05~0.08 micron. For GBQ III configuration, the process is carried out in three stages in a transfer type machine:

GBQ I At this stage, a medium grit abrasive tape is used to remove the decarburised layer from grinding, grinding marks, and correct or improve circular and profile geometry.

GBQ II A fine grit abrasive tape is used to reduce roughness and waviness to required levels and remove ferrite caps or austenite nodules protruding from the surface.

GBQ III A slurry coated, resilient, soft backed tape with unoriented and multi-layered abrasive particles, removes the left over micro scratches and deburr or radius the edges of the craters resulting from removal of ferrite caps, oil holes, and fillet radii.

The process has been further improved to maintain sizes of the diameters within the total tolerance or deviation of 0.010 mm in production finishing operation. With this advent of size control, it possible to eliminate final grinding operations, or eliminate all grinding by finishing directly from the turned or milled surfaces.

Roller finishing is yet another process that is employed to finish main and pin diameters as well as flange and post end oil seal outside diameters. Besides the improvement in surface finish and bearing area, the process hardens the surface layer eliminating the hardening process..

Quality assurance : A multi-dimensional gauging system manual or automatic is used at the end of the manufacturing to check (and if necessary, to mark the grade of) diameters of mains, pins and oil seal etc., widths, spacing, and stroke besides indicating their parallelism, concentricity, taper, squareness and flatness. Gauging system is now modular and flexible so that different crankshafts may be checked with minimum numbers of add-on items. Generally masters are used for setup and calibrations.

CNC laser interferometer cylindrical co-ordinate inspection system (ADCOLE) is another highly effective system for crankshaft measurements. The basic method of gauging uses of a probe. A follower with a carbide measuring rod - straight or spherical - contacts the surface to be gauged. The position of the follower is sensed with 0,00008 mm resolution, the readout will be triggered by the angular measurement systems with computer controlled angle increments of 1° and the obtained data are transferred to the computer.

The measuring machine is equipped with a two-frequency laser source and four interferometer units and utilises the optical Doppler shift effect to determine the follower extension as well as the carriage position.

Any motion of the follower/carriage results in a frequency shift of the received laser beam. The superposition of this beam with a constant reference gives a low frequency signal that is processed by digital counters. The laser counters are interrogated by the computer to calculate the actual position of the follower/carriage. The special assembly of multiple follower interferometers furthermore, enable correction of any inclination of the follower axis.

The laser technique also provides an immaterial reference for continuous machine calibration. The machine measures the following quality characteristics of a crankshaft:

- Main- and pin journal circumferential profile
- Main- and pin journal roundness
- Main- and pin journal diameter
- Main- and pin journal linear profile (straightness, barreling)
- Pin journal angular position
- Pin journal throw
- Main- and pin journal taper
- Main- and pin journal parallelism
- Main journal runout
- Main- and pin journal longitudinal position and spacing (part depending)
- Main- and pin journal width (optional)
- Flywheel, flange O.D. runout
- Linear profile (straightness, barreling)
- Waviness, circumferential of axial (optional)

4C. CAMSHAFT:

Material was conventionally forged carburised hardened steel, or induction hardened steel. Trend now is to use chilled cast iron, hardenable cast iron, SG iron, hardenable cast iron. Chilled cast camshafts are manufactured from unalloyed or low alloy high grade gray iron with flake or nodular graphite. A controlled ledeburitic solidification of the melt, i.e. pure carbide without graphite precipitation, is achieved by a partial application of chills in the mould where the work surfaces are located. No treatment is required to increase the hardness of the cam lobe profile, that is the major advantage. For increasing the mechanical efficiency and fuel economy of the engine, emphasis is being put on the development of low weight camshafts. Camshafts may be partly or continuously hollow axially cast if required for reduced weight potential of between 20-25%. Some camshafts are milled out of bar stock. In another system, on a centerless ground precision tube with high rigidity, the cams, drive pieces and, if necessary, the steel, cast or sintered bearing rings are assembled using a thermal process with a press fit. Advantages of the composite camshafts are: weight reduction potential upto 40%, free choice of cam material (steel, powder metal, cast iron), direct mounting on the tube, free choice of cam positioning and cam spacing, less stock for camlobe grinding with reduced cycle time. Composite camshafts with P/M precision cam-lobes require no additional grinding processes - that represent the most economic manufacturing method. Expensive and complex grinding operations that can only produce negative cam radii to a limited extent, does not remain a limitation. Required amount of cam radii can easily be formed by P/M technique that is required for effective functioning of roller tappets.

Generally, the sequence of machining camshaft is as follows:

1. Machine both ends and centre for preceding operations
2. Turn all main bearing diameters and other surfaces
3. Machine key slot and other features at both ends
4. Mill cam lobes, if required

7. Grind main bearings
8. Grind ends
9. Grind cam lobes
10. Superfinish main bearings and lobes
11. Inspect for surface defects and dimensional characteristics

Camshaft milling machines have come as a more efficient alternative to the mechanically complicated and totally dedicated cam turning machines to rough machine the cams of forged camshafts. External side mills were used to mill all cam forms with a rectilinear or even concave contour. Even the cam chamfer can be produced simultaneously with suitable profiling. The mechanical milling machine used a full size master camshaft that was copied by a tracer. Presently, CNC has replaced even the master camshaft, and any cam profile can be generated, thus making the process fully flexible. Productivity of the miller is almost 2~3 times of a camlobe turning lathe and the tool life of the carbide tips is almost 10~12 times the tool life of the conventional HSS form tools used on multi-slide, multi-tool lathe. Accuracies attainable are: base circle diameter +/-0.07 mm, profile allowance +/-0.20 mm, cam phase +/-15′, and longitudinal accuracy +/-0.1 mm. However, with closely controlled castings, the turning/milling operation is eliminated and cams are finished straight from cast condition, either in one step itself or if necessary in two steps, by grinding.

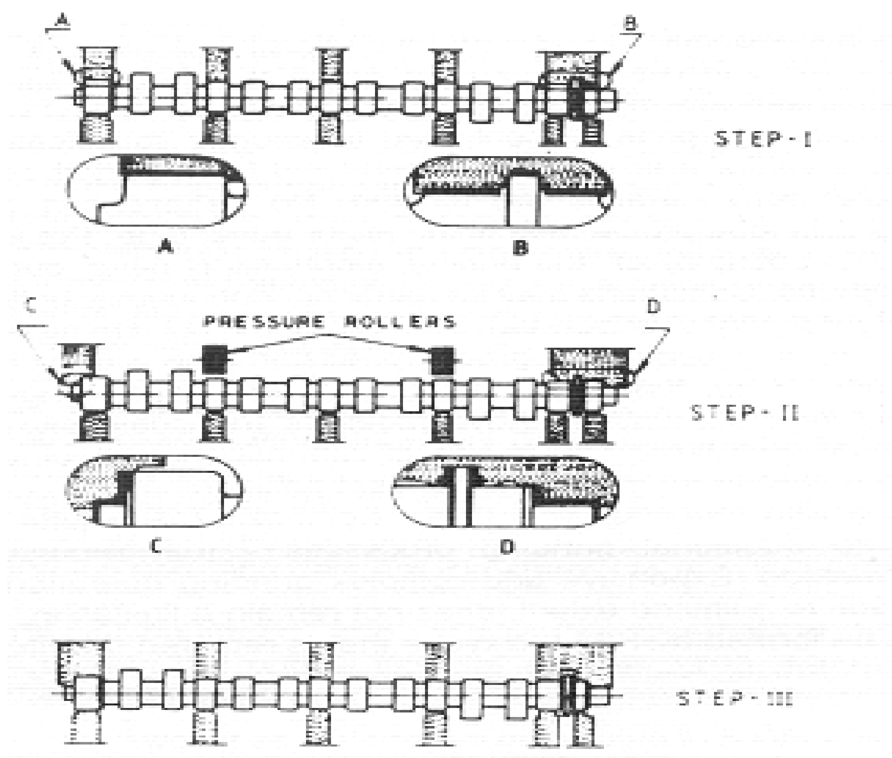


Fig. **3.33 3- Step Centerless Grinding of Camshaft.**

Grinding of main bearings are carried out on single wheel or multi-wheel cylindrical grinder depending on production requirement after turning. Sometimes for high production, centerless grinder is in use. Wide wheel centerless grinding machines have been in use for many years for rough grinding the bearing journals of camshafts instead of turning. The metal removal permissible may be to the extent of 3 to 5 mm if mismatch due to parting line is kept below 0.7 mm. Straightening operation after turning can be omitted when centerless grinding replaces turning. Presently, rough grinding is superfluous after machining on efficient and accurate CNC turning centres. However, even finish grinding of journals is being carried out on centerless grinding machine replacing grinding between centres with very clear advantages regarding production rate as well as precision. Other operations that were carried out earlier between centres can be done by locating the part from the bearing journals with better result in actual operation in engine. Fig.3.33 shows a 3-step high production (120 parts/hour) centerless grinding system for grinding main bearings, flange, and shoulder of cast iron camshaft to final tolerances (size tolerance 0.02 mm, and tolerances of roundness, straightness, and concentricity 0.005 mm).

High speed contour grinding as named by SCHAUDT, the famous grinding machine manufacturer of Germany, is another development that is being used for grinding of main bearings as well as the ends and is highly productive. In one plant, 4 machines using conventional wheels, were replaced by one High speed Contour grinding with CBN (Fig.3.34).

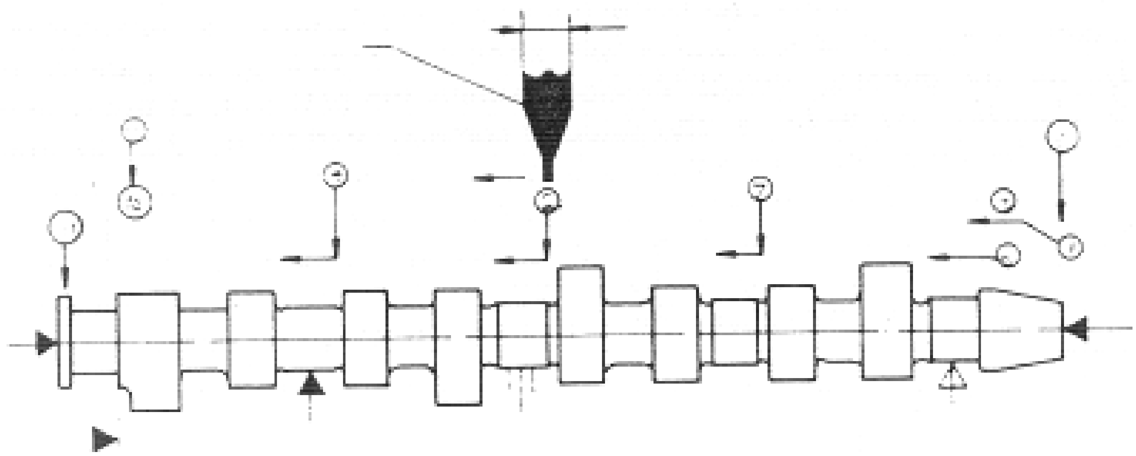


Fig. **3.34 High Speed Contour Grinding (Schaudt)**

Camshaft hardening : For hardenable materials, the cam profile is hardened by surface heating and rapid cooling using, generally the heating by electric induction. Care is required to prevent the creation of surface cracks during rapid quenching. To eliminate any possibility of distortion due to the rapid heating and quenching at localized points, the camshaft is processed in vertical position. Chilled cast iron camshafts do not require hardening. However, the chilling operation carried out in the foundry is expensive because the costly chills have to be inserted into the moulds manually with great care. Attempts to automate this manual process has not been successful A camshaft with chilled camlobes costs almost twice that of a normal casting with induction hardened camlobes. A local remelting process is used for the generation of wear resistant white iron layers on camlobes of gray cast iron. Through remelting the casting locally, the free carbon is brought into solution. The mass of the unaffected material behind will chill the molten spot to the desired ledeburite structure. TiG-torch has been successfully used for remelting a cast iron surface layer. An automatic hardening cycle starts by moving one or several torches (guided by master cams) independently to the cams to be followed by traverse motion and rotation of the camshaft. The process is highly reliable (rejection rate below 1% compared to 4% rejects in foundry for chilled camshaft). The process is very much cost effective with respect to induction hardening.

Cam grinding rarely now uses mechanical copy control via a swivel table of limited rigidity through a bank of master cam discs, where the accuracy of cam lobes was limited by various compromises such as the one between master cams and effective diameter of grinding wheel during its life. Finish cam grinding once CNC, does not require master cam banks. The cam profile is generated by superimposing the cam rotation on the wheelslide stroke motion. Grinding is carried out with continuous radial feed within a feed angle range on the cam base circle. The wheelslide performs the feed motion and also moves according to the controlled cam profile while the camshaft rotates. The angular velocity of the cam lobe has to be controlled with the cam profile due to the large changes in the metal removal rate. The relation between the rate of metal removed at the base circle and that at the flanks is approximately maintained at constant level to achieve the desired quality of grinding. Using just the cam-lift data, dimensions of the lobe, and the lobe location, the software can generate wheel size and various setup data for grinding of a new camshaft. The CNC machines now characterised by a high static and dynamic stability. CNC helps to achieve the same metal-cutting conditions over the entire cam circumference that ensures quality and a finely graded workpiece speed profile with smooth transitions is generated (Fig.3.35). Similarly, as the grinding wheel diameter affects the precision of the cam contour, the diameter reduction by wear is continuously compensated for by the control (Fig.3.36). Because of demands for more accuracy between the journal diameters and the lobe base circle runout, the camlobe grinding is carried out by supporting on its previously ground journals instead of between centres. With good well supporting steadies, the quality of finish ground camshaft depends on the quality of journals. Continuous dressing is another change incorporated for better productivity on cam lobe grinding machines using conventional grinding wheel.

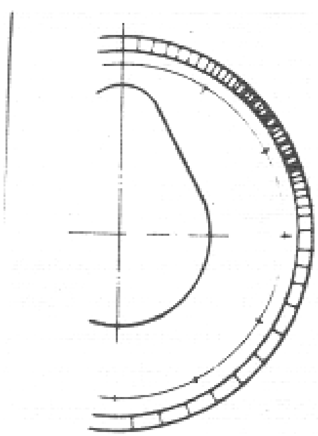


Fig. **3.35 Speed Profile Along the Cam Profile.**

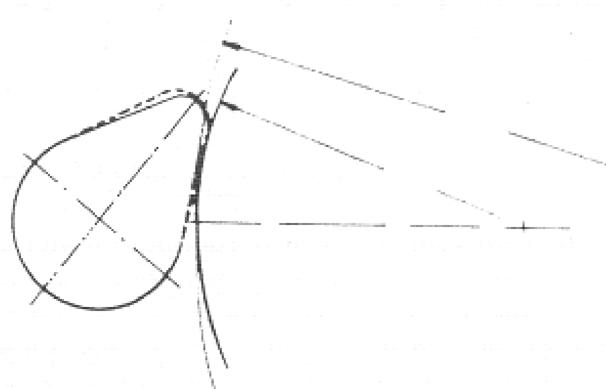


Fig. **3.36 Speed Adjustment with wear on Wheel Diameter.**

Cam grinding of chilled cast iron camshafts may require only one set up. A grinding wheel specification may be selected that can be suitable for both rough and finish grinding. Different circumferential speed for rough and finish grinding may be programmed. In rough grinding, the most of the stock upto even 4~5 mm may be removed in a number of rotations. Groove profile of the wheel in rough grinding ensures "cool" grinding. The wheel may be dressed during the cycle for finish grinding and some 0.20~0.25 mm on the diameter may be distributed in 3~ 4 rotations including one for sparkout.

If the cam lobes are heat treated by induction/nitriding/TiG welding, two setups are necessary. The rough grinding before heat treatment may be highly productive with the right wheel for roughing, the required dressing, the higher circumferential speed, etc. CBN comb-type wheel (Fig.3.37) is one such method used for very heavy metal removal, as the required optimal cooling is automatically provided. Surface design on the outside diameter of the grinding wheel incorporates several circular grooves according to the stock to be removed. By axial movement of the grinding wheel, the material left over after the first cut is removed. Because of the groove, the coolant reaches effectively in the grinding area, and assures heat dispersion and chip removal. Electroplated CBN wheel grinds about 10,000 cast iron camshafts with 8 cams with one coating. If the time cycle is not a constraint, it is possible to grind the journals as well as the cams in one clamping. The process will permit considerably reduced amount of stock for finish grinding and consequently the cycle time of finish cam grinding is substantially reduced.

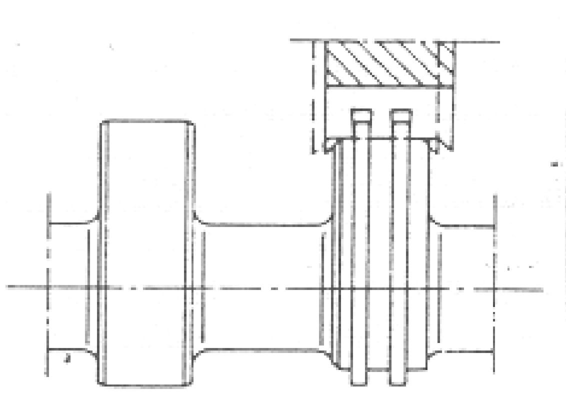


Fig**. 3.37 Patented CBN Comb Type Wheel for Rough Cam Grinder.**

For a separate finish cam grinding with a grinding allowance of 0.4~0.5 mm radially, a CNC takes about less than 2 minutes per camshaft. The accuracy is excellent, because of the better specification of the wheel and the dresser than the compromised one for larger material removal. The achievable accuracy is: Maximum error of form below 10 microns, the maximum error increase less than 10 microns per 5 degrees, the eccentricity about 5 microns, and surface finish on the cambase circle achievable 4.2 to 5.8 R_z and at the cam flanks to about 3.7 to 5.2 microns R_z. With process optimisation, the thermal surface damages that are very usual with conventional grinding, are almost eliminated and the surface integrity is excellent. Different forms on camprofiling (Fig. 3.38) are possible particularly with QUICK POINT system of grinding.

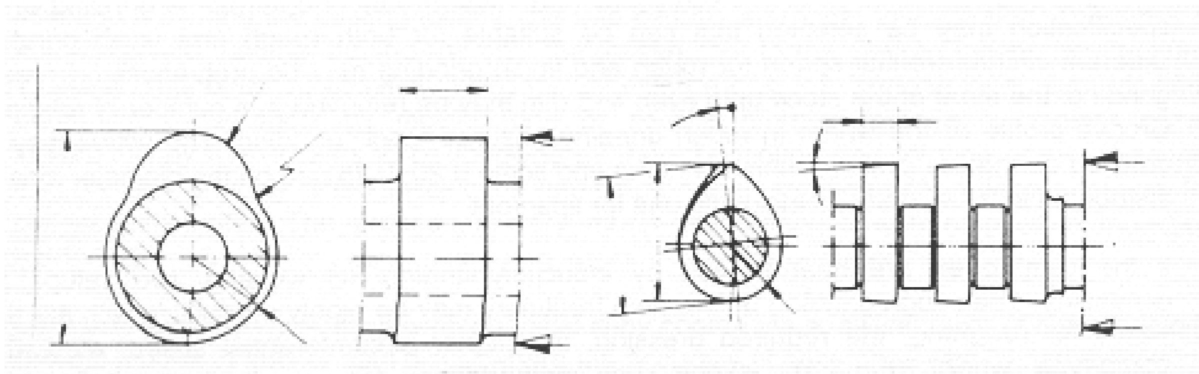


Fig. **3.38 Different Forms on Camprofiling.**

With plunge-cut grinding or with oscillating motions (with cylindrical cams), CBN-wheel is specially becoming popular for camshaft grinding. At least in Europe in the near future almost all new purchases for cam grinding will be CBN-machines. CBN lasts longer, sometimes 100 times or more - sometimes upto 660,000 camshafts or production of 6600 hours. Wheel dressing is less frequent. It aids in achieving better surface finish, greater part consistency, and tighter tolerances. CBN also induces residual compressive stress on the surface ground. CBN will be particularly advantageous for camlobe grinding whenever,

- considerable dressing times have previously had to be added to the grinding time proper, or expensive profile dressing rolls have to be dispensed with
- the camshafts have to be machined in two passes
- higher surface qualities have to be achieved to make superfinishing dispensable
- the camshaft material is particularly heat-sensitive and tends severely to grinding cracks or softening.

If the time cycle is not a constraint, it is possible to grind the journals as well as the cams in one clamping.

Belt grinding of cams is another area in which development work is being carried out. The belt grinding is being pursued by manufacturing engineers for two very clear advantages:

1. The process will provide the possibility of grinding all the cams simultaneously, that is not possible by conventional cam grinding.
2. The belt grinding can only produce severely concave (“re-entry”) profiles on the flanks that are required for the new fuel saving and roller follower valve actuation system for low pollution in modern engine. The limit for the radius of curvature of concave cam flanks produced by grinding wheels is about 50 mm. For severely concave profiles with radii of curvature of 20 ~25 mm can only be produced by abrasive belt grinding.

The belt grinding machine may be a single station one or multi- station depending on capacity requirement. Basically, the infeed for producing the cam profile and the compensation for belt wear are provided by the grinding head slide. The abrasive used on the belt may be conventional aluminium oxide, Zirconia alumina, silicon carbide, ceramic aluminium oxide or CBN that last many times longer. (The belts and bond systems that will last as much as CBN is still to be perfected.) Different form of multi-layer coating of the abrasive belt has been used to improve the efficiency of the process and the belt life. The belt width is about 25 mm or so, as required by the width of the cam and the length is about 4 metres to last for a considerable time. The belt is driven by a rubber coated driving pulley and a belt tensioning device takes up the stretch. The belt is kept pressed against the workpiece by a fixed contact shoe of ceramic or polycrystalline diamond (PCD). A diamond roll dressing attachment is also mounted on the workhead and for dressing, it is applied

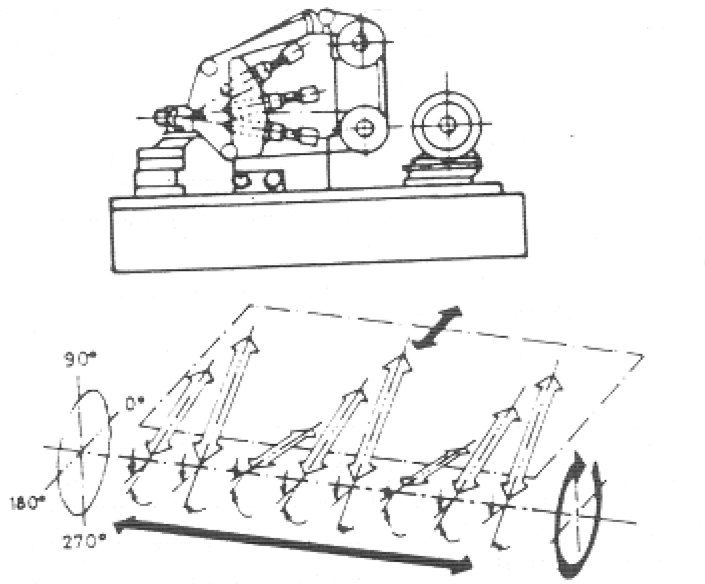


Fig. **3.39 Multi Station Vertical Grinding Machine's Schematic Layout.**
(Star Axis Configuration)

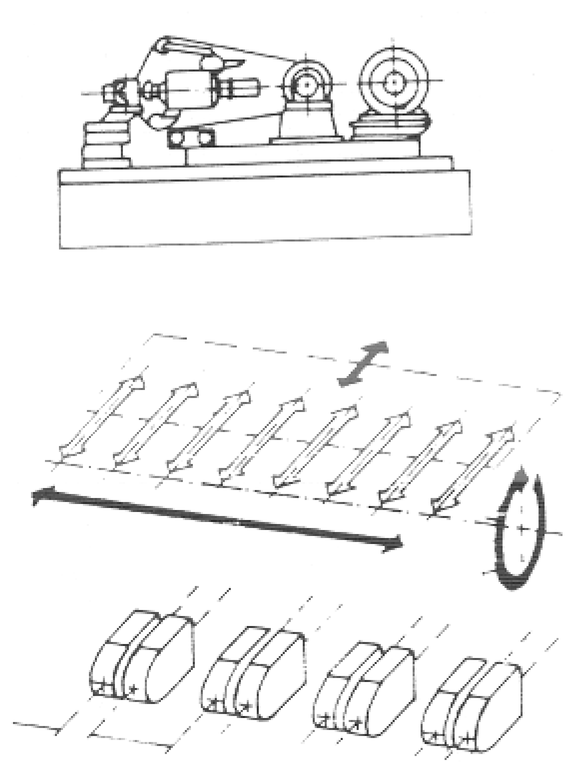


Fig. **3.40 Multi Station Belt Grinding Machine's Schematic Layout**
(Parallel layout)

against the contact shoe. A soluble oil emulsion coolant preferably at high pressure is directed into the grinding area. Inadequate cooling may destroy the fixed contact shoes. Multi-station production type belt grinding machines do have either star axis (Fig. 3.39) or parallel axis (Fig.3.40) configurations to meet the space requirement of specific camshafts.

Star profiling axis configuration, a closer spacing of the cams is possible. The machines are versatile with about 11 CNC axes. The surface speed upto 70 m/s may be used. However, with the limitation of the quality of abrasive belts available, the process is used for unhardened cams (about 35 Rc) with relatively small machining allowance (upto 0.50 mm). Mainly, the belts are being developed to make it commercially competitive and a practical replacement of cam grinding machines. Presently the soft camshafts are being ground by belt, then hardened and polished.

Cam superfinishing is necessary, as rough cam can cause high unit load concentrations. Cam finish is desired to be within a range. Finer surface finish is not desirable, as it may lead to starving of lubrication at contact area during operation. Superfinishing of cams and journals are either tape or stone type. The tool- finishing stone or grinding belt is pressed against the surfaces to be finished, ensuring that the tool follows the rotating cam profile. The camshaft is rotated in both directions - clockwise and anti-clockwise - to ensure complete finishing of both sides of the cam profiles. When machining with a grinding belt, the form and material of the shoe with which the belt is guided and pressed on the cam, has a considerable influence on the machining result. If the finish obtained after grinding is more than R_z 2 to 2.5 microns, and the design requirement is between R_z 1.3 and 1.5 microns, two step microfinishing with two different grades of stone or belt (grains) are essential. Main stock removal during prefinishing is carried out for the correction of distortion from earlier operations with coarser grade of stone at the lowest possible workpiece speed. Final finishing is carried out with a finer stone grain at higher speeds for relatively little stock removal.

Finishing cams with stones has some advantages over belt finishing. With stone finishing, it is possible to achieve excellent straightness in axial direction with almost no waviness. Cams

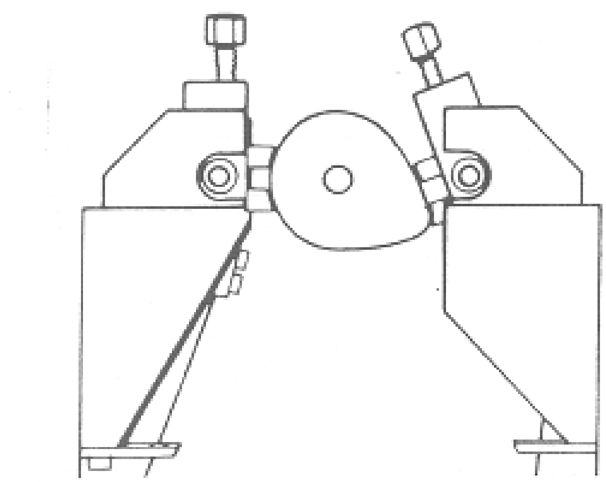


Fig. **3.41 Tool Carrier for Stone Superfinishing.**

are finished with special tool carriers designed in such a way that the stone follows the cam contours with constant contact pressure. Alternately opposed stones on journals and cam lobe prevent deflection of the parts. The camshafts are rotating and oscillating at the same time. All the cams and journals can be finished simultaneously. Machine with two heads - one for journals and the other for cam is flexible and is used when the volume of production is low.

Surface treatment such as phosphating is frequently applied to assist running-in and prevent early scuffing failures. Phosphating provides an oil retaining surface and has a lubricating property in itself. Some manufacturers use a salt bath nitriding (TUFTRIDING) that lowers the friction between the sliding surfaces and raises the fatigue strength of the material treated by a combination of stress relief and nitrogen impregnation.

Quality assurance **:** Tolerance for ground cam profiles may be in the range of 0.002-0.005 mm. Angular relationship between cam centrelines, for timing purposes, should be about 10-15 degree of arc. A new kind of measuring machine for the shop floor checks all the cams simultaneously in one revolution. The full inspection is completed in approximately 16 sec. and ensures that the profile (cam rise or lift), its variation (velocity), and the rate of variation (acceleration) are all within the desired tolerances. Velocity is more important than rise, and acceleration is even more important. Deviations in these quality characteristics may cause vibration, noise, tappet wear and local damages in the sealing area between the valve and valve seat, and even in increased emission. CNC laser interferometer cylindrical co-ordinate measuring system (ADCOLE) as discussed in section 3C is also used for camshaft to provide data processing/ computation /determination and output of :

- rise values
- rise errors, as it would be with all journals constrained or related to base circle
- rise error jumps (error between points of specified angle distance upto 5 degree)
- velocity (1. derivation) of nominal and measured data
- velocity errors
- acceleration (2. derivation) of nominal and measured data
- acceleration errors
- automatic zeroing of cam lobe
- phase angle from cam to cam
- phase angle from cam to cam
- phase angle from cam to part reference (keyway, dowel hole)
- base circle run out
- base circle eccentricity correction
- base circle radius
- journal eccentricity coefficients (journal concentricity)
- journal eccentricity correction
- cam lobe to journal centerline with or without bow removed
- cam lobe to base circle
- fuel pump eccentric angle and eccentricity
- cam taper and parallelism (referenced by end or adjacent journals or centers)
- journal taper
- journal roundness
- calibration
- part identification: by typing in a 6 character identification number
- linear profile (straightness, barreling) or journals and cams

Another very important quality requirement in camshaft manufacturing is to ensure that there are no faults of surface integrity on the profile of the whole lobe i.e., the base circle, ramps and nose. A machine using Eddy Current technique that scans the surface of every cam is used to detect all cam surface faults. A production machine that complete the total checks in approx. 12 sec. is now available.

5C CONNECTING ROD:

Materials used are forged, PM, or SG iron. Generally the rod and cap are integrally cast or forged. Closer weight tolerance with improved balance weight is aimed at casting or forging stage. PM may prove to be the best so far weight reduction is concerned and also ensures closer weight tolerances (eliminating the operation carried out for balancing the weight), reduced machining time.

Generally, the machining sequence for connecting rod is as follows:

1. Rough grind side faces.
2. Machine piston pin bore as reference hole.
3. Mill / broach faces at crankbore end, machine inside of crankbore and split.
4. Finish joint faces
5. Machine bolt holes in both cap and rod halves
6. Assemble rod and cap
7. Finish grind side faces
8. Finish crankbore and piston pin bore simultaneously
9. Hone crankbore and size piston pin bore
10. Balance for weight and final inspection

Grinding of both the side faces is done on rotary surface grinder or double-ended disc grinder with an advantage of balancing the material stock between both the wheels. Piston pin bore is machined to its finish size in 3~4 steps, generally, on rotary dial index machine for high volume of production. Piston pin bore is used as the reference bore for the next operations of connecting rod machining.

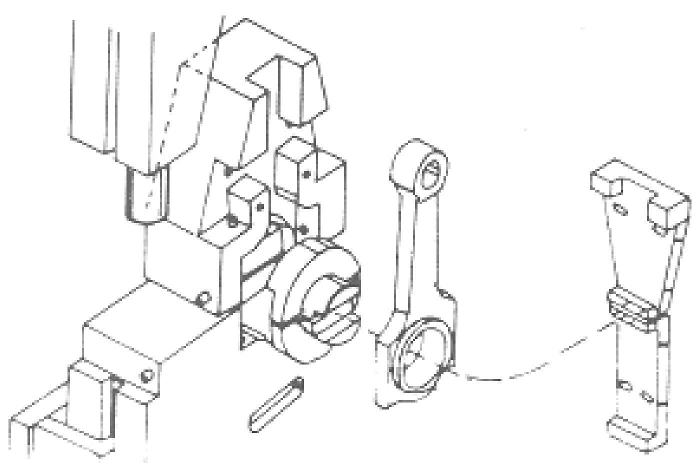


Fig**. 3.42 Impact Fracture Splitting Fixture.**
(Alfing Patent)

Splitting the rod and cap is carried out on milling, broaching or now by a very new process of Fracture Splitting with certain specific economic advantages. Two broached grooves determine the exact plane of the fracture. The cap is then split from the connecting rod by applying a hydraulically generated force in the bore (Fig. 3.42)

The characteristic structure of the resulting fracture faces guarantees perfect fits - the best possible location of cap and rod. Load capacity of this joint is increased because fracture surfaces have a larger surface area than conventional machined surfaces. The numbers of operations are much less with the system of manufacturing. In one case, the number was reduced to 6 from earlier 14 operations (Fig.3.43).

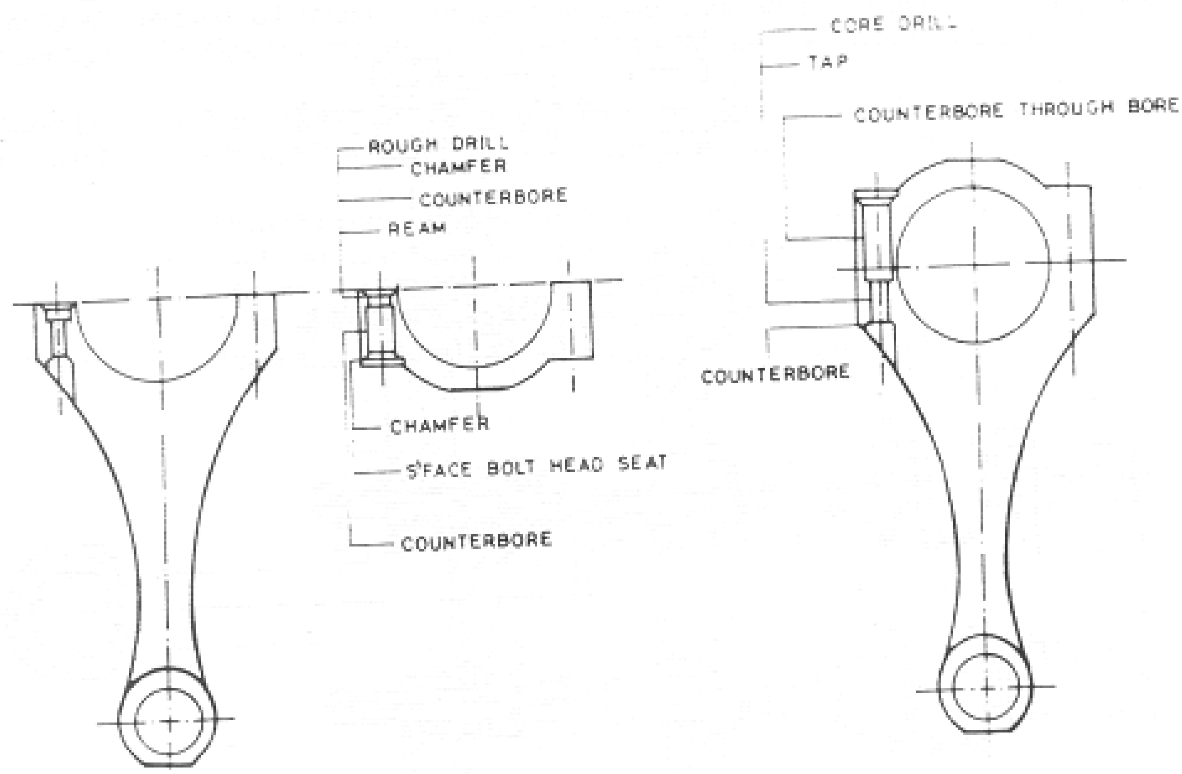


Fig. **3.43 Bolt Hole Machining Operations Conventional Method (After Splitting) Vs. Fracture Splitting.**

In traditional processing after sawing/slitting, the joining faces of connecting-rod and cap are ground and operations of bolt holes are carried out on two separate fixtures for rod and cap. Some manufacturers either broach or surface grind serration on the faces of rod and cap for a positive grip for assembly. Bolt hole operations are carried out before fracture splitting in same clamping. Investment is about 25% less. Naturally, there is a lot of reduction in floor space. The operating cost is greatly reduced. For bolt hole drilling, generally dedicated rotary dial index or linear transfer machines are preferred for maintaining correct centre distance between the bolt holes of rod and cap. Straightness and size accuracy of the holes are also demanding to eliminate any undue stress on bolts after assembly. With better controls and improved tools reducing the number of steps, even this dedicated machine can be built flexible to machine connecting rods with different centre distances between the bolt holes. Pallets are used for better flexibility on transfer, and the two holes are completed by indexing of individual heads. With CNC controls, the accuracy of centre distance has become achievable. Tooling is to be carefully planned for bolt hole finishing. The design, generally requires to place the two holes in an exact position and parallel to one another. Size and surface finish are also demanding. The exact position, in some cases, is maintained by guiding the reamer with front and rear guides (Fig 3.44). The play in the bush is less than 10 μm.

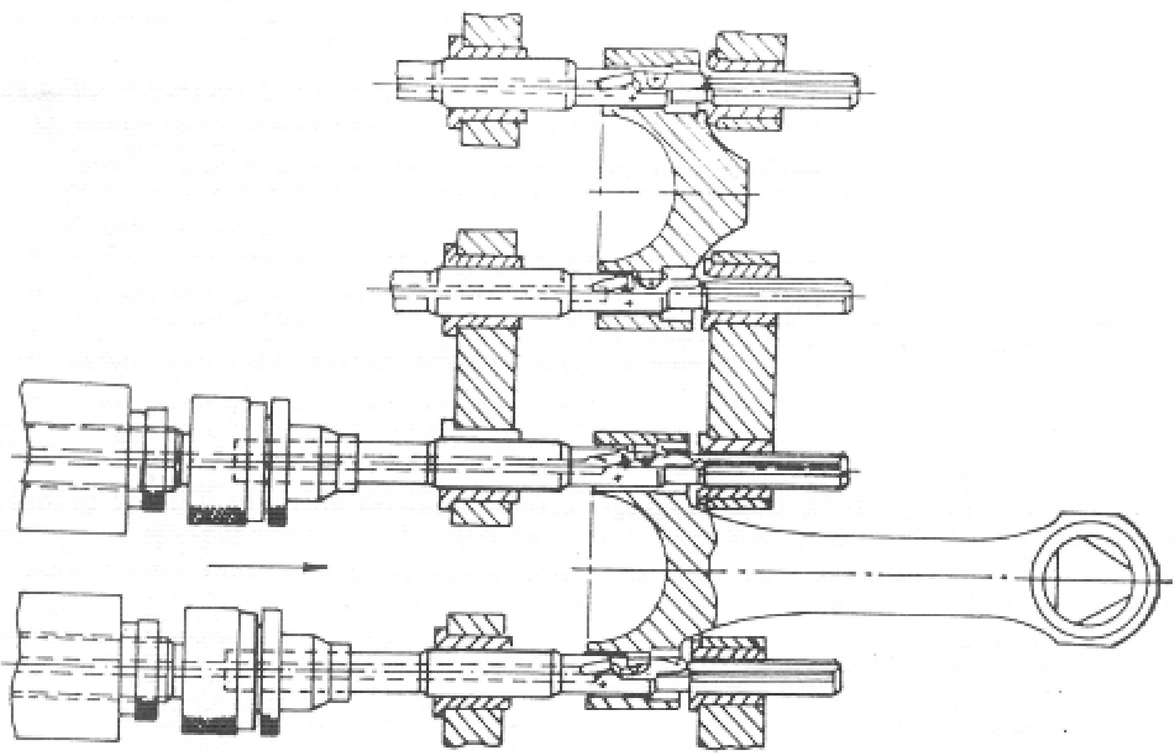


Fig. 3.44 Guiding the Reamers with Front and Rear Guides(Tungsten Carbide Bushes & Pilots) for Parallelity of Bores with Each Other.

In order to guarantee this tolerance over a long period, the bushes are made of tungsten carbide. To avoid any possible misalignment by the spindle, the reamer is held in a suitable floating holder. The coolant is fed through reamers to reach the cutting edges instead of through bushes.

Finish boring is used for final matching of crank and piston pin bores. Centre distances between the two bores are very important for gasoline engines and are closely controlled. With CNC controlled slides for boring heads, and cartridge type quick change fixtures, different connecting rods can be machined on same machine. Self compensating tooling (automatic tool wear compensation system of different types) with better tool material has helped in attaining better process capability. Final twist and bend of the assembled connecting rod are critical. Earlier, a correcting fixture was used by many manufacturers but now the process of correction is not accepted and manufacturing engineers take all preventive steps to eliminate any stress during clamping and handling at various stages of processing so that the twist and bend are not introduced. Any connecting rod having twist and bend more than required is scrapped.

Honing of Crankbore is carried out for close sizing and providing the surface pattern that helps in creating oil retention grooves at initial running of engine. Piston pin bore is bearingised for size consistency to ensure the desired interference during assembly.

Quality assurance : Connecting rods are grouped in set by weight for balanced mass to be carried by crankshaft. Final inspection is carried out for features such as:

- ✓ Diameter, taper and ovality of crankbore and piston pin bore
- ✓ Squareness between the axis of the crankbore with the two faces
- ✓ Thickness of the crankbore end of connecting rod
- ✓ Centre distance between the two bores
- ✓ Twist and distortion (bend) of the connecting rod (Fig.3.45)

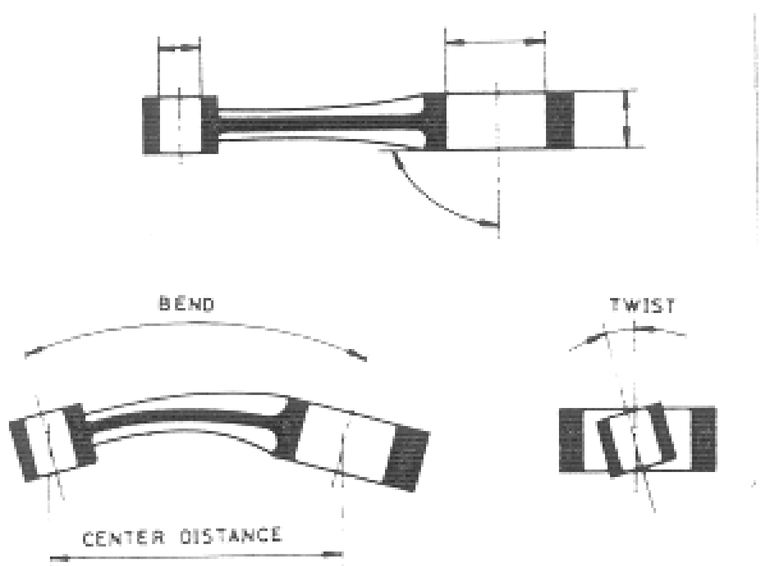


Fig. 3.45 Twist & Distortion (Bend) of the Connecting Rod.

All these can be undertaken individually on separate gauging fixtures or simultaneously on a single station gauging machine incorporating different level of logistics for acceptance, rejection or segregation and automation.

SUMMARY:

All these developments are aimed to meet changing manufacturing strategies, that are:

1. Flexibility to machine more variety of the component in the same line with minimum or no change over time, to get some changes incorporated without stoppage of the line, to switch over to new model within shortest possible time, to adapt to new tool and component material, etc.

2. Better quality by increasing process capability, positioning accuracy, repeatability, better tool life, etc.

3. Higher efficiency by using higher cutting parameters-speed and feed, minimisation of non-cutting time, combination or elimination of operations etc.

4. Conservation of energy and resources through all means , say by changing cutting coolant from oil to water soluble, etc.

5. Improving environmental pollution by switching over to dry machining from wet machining, etc.

For the engine components, the materials are being changed for reducing weight and improving manufacturability to attain better quality and productivity. Basic processes such as casting and forging are being improved to eliminate or reduce the processing steps and to produce near-net-shape parts. Highly flexible machining centres are becoming popular even for high production volumes, because of the advent of high speed machining. Machining at higher surface speed lowers the tangential load and so results in lower cutting forces and pressure on cutting tool. All these advances have been translated into increased metal removal rate e.g. reduced machining time with some significant benefits :

- Reduced heat effects, as most of the heat goes out with the chips and at much faster rate without affecting the part and its dimensional accuracy.

- Improved consistency from better tool life and better accuracy due to reduced cutting forces that deflect the part, fixture or elements of the machine tool used.

- Better surface finish resulting better performance, (appearance), and/or elimination of finishing operations.

- Simplified fixturing providing better accessibility and maintenance.

Equally promising advances in cutting tools - materials, design (geometry and computer-aided chip breaker of inserts), coating, coolant management etc.- are simultaneously coming. One example is the thin film, monocrystalline diamond coating of tools that will achieve for aluminium machining even higher metal removal rates than possible with PCD, as well as will be applied for the first time to tools of complex geometry such as form tools and taps.

Improved ceramics and CBN have already brought similar productivity improvement for gray cast iron components.

Agile manufacturing in sequential or parallel processing modes (Fig. 3.46) are being accepted as a necessity to keep the competitive edge. New accounting methodology to justify the agile manufacturing has been developed to take care of the drawbacks of conventional accounting system that does not take into account the intrinsic value addition through new manufacturing technology that is costlier.

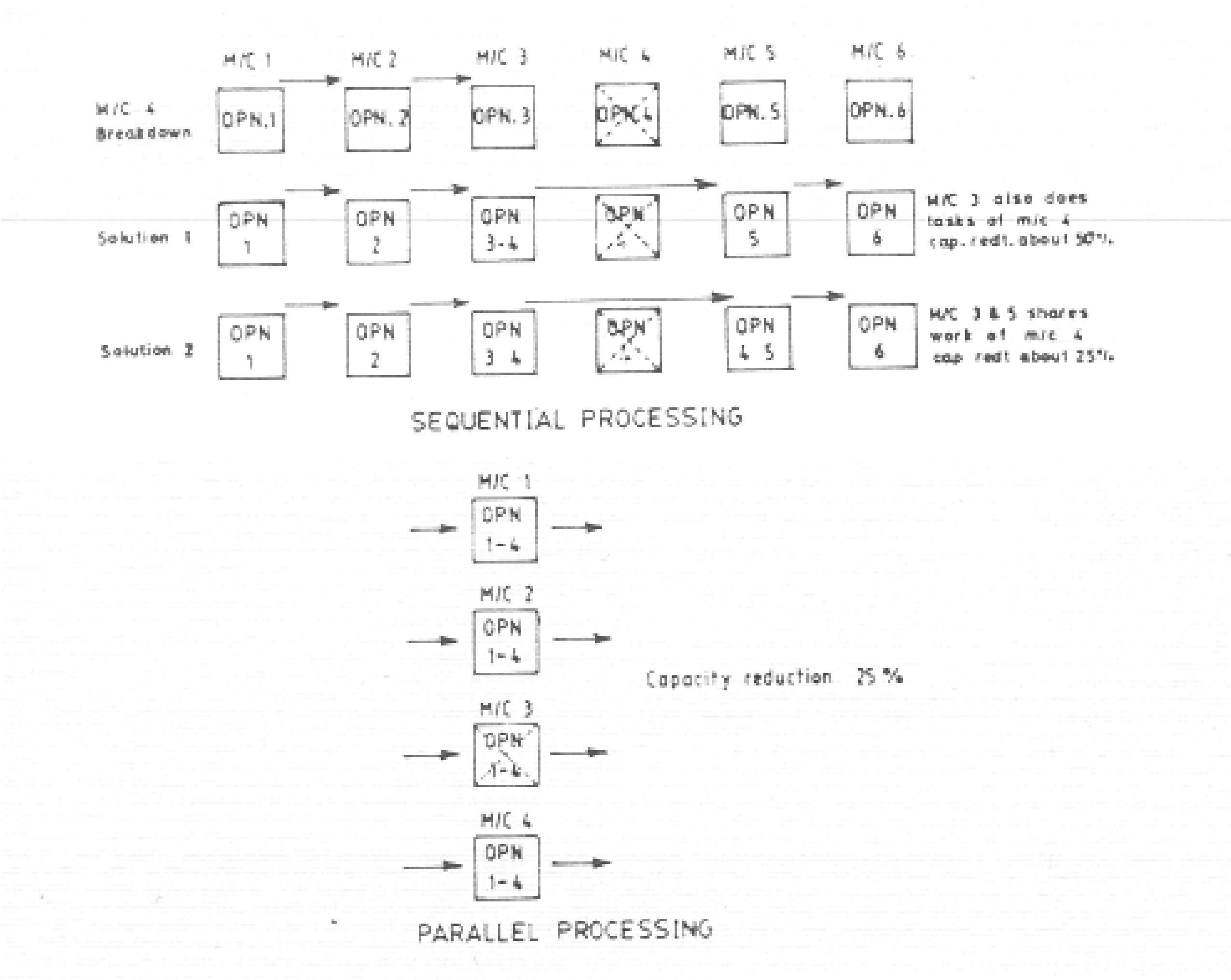


Fig. 3.46. 1 Agile Manufacturing Concept.

However, every manufacturer has a traditional manufacturing methodology that keeps on being followed and improved upon by newcomers. It requires a real and technically strong will to switch over to new technology. Appropriate technology must be preferred with the first opportunity. With known precautionary measures, the risk can be significantly reduced, and the promised productivity gains can be achieved.