TOOL DESIGN FOR THE PRODUCTION OF A COLLIMATOR ON A 3-AXES VERTICAL MILLING CENTRE

By

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DECLARATION

I make a declaration in Lieu of an Oath that I wrote this dissertation myself.

Lusaka, 03/07/2007

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APPROVAL

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ABSTRACT

The continuous quest for modernization and industrialization has brought a great challenge upon the third world countries such as Zambia in that these countries have to keep on importing production machinery whose spares cannot be obtained locally but from outside. This problem has been compounded by these countries' lack of funds to acquire machinery that could produce the much-needed spares. However, the high cost of initial investment of Computer Numeric Control (CNC) machines is a huge obstacle to many companies. It is, therefore, imperative that avenues of adapting these machines to perform a variety of operations than what they were initially designed for are sought and thereby make the investment much more cost effective.

A cobalt refinery plant at *Chambishi Metals Plc* running at normal capacity consumes about one collimator in every three to four weeks. The cost of replacement of each collimator is approximately US$3800 from *Mitutoyo and Fowyer* in America. *Chambishi Metals Plc* notes that it is spending thousands of dollars in importing the component and is looking for means to have local manufacturers to produce it locally since this would be cheaper and readily available. However, local companies have so far failed to achieve the required tolerances using conventional machining and have very little or no capacity in ordering CNC machine tools.

The collimator assembly is a water-cooled frontal electrode, used on the plasma arc torch. This torch is used in the reheating of the alloy prior to atomizing. A collimator is an assembly made up of two separate components whose metallurgical composition is 90 to 99 percent copper. In order to accommodate plasma gas flow, process thermodynamics and to prevent coolant leakages, collimator components are normally produced by precision machining, a process that is best performed on CNC lathe machine tools. It is for this reason that it was identified as a test piece for production.

In 2001, Mwanza S. M., University of Zambia, successfully adapted a Supermax 65A, 3-axes CNC Vertical Milling Centre (VMC) to include turning operations. Later, in 2002, Daka B., University of Zambia, looked at turning tools that could produce various profiles using the adaptations made on the same machine tool. After having done the modifications, it was imperative that a specific commercial product was produced to test the applicability of the adaptations. In addition, this was to answer and reduce on queries and shortcomings that were unanswered in the previous two studies. These included improvement in dimensional tolerances and surface texture of the products, use of CAD/CAM software and DNC to accommodate complex products.

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Thus, this research started by designing the production process and production tools which involved coming up with turning, threading and boring tools and also the workpiece and tool holding mechanisms. The designed production process, tools and fixtures were further used in the configuration of

the 3-axes CNC VMC machine tool. Since no software capable of generating NC part programs for turning and compatible with VMC machine tools exists, it was imperative that less time consuming methodologies of generating such programs were developed. Thus, Mastercam Lathe V9, an advanced CAD/CAM software, was modified to generate turning NC part programs to run on the VMC machine tool with the application of a unique remote operation of direct numeric control (DNC). Hence, with these techniques, the collimator assembly was produced and examined for dimensional accuracy and surface finish. An analysis of generated forces was also done to avoid overloading the machine tool. After costing, the total cost of producing one collimator came out to be *ZMK 9,975,686.00.*

The produced collimator assembly was inspected and tested on a plasma arc torch-testing rig found at *Chambihsi Metals Plc*, Ultra-modern Smelter Plant, and it was found to conform to ISO 9001 standards.

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ρ	[kg/m^3]	Material density;
M	[kg]	Material mass;
c, c1, c2, c3, c4	[-]	Constants;
P, p	[W, watts]	Power;
V, v	[m/s]	Velocities;
N	[1/min]	Rotational speed;
T	[Nm]	Torque;
D	[mm]	Drill diameter;
f	[mm per minute]	Feed;
d	[mm]	Depth of cut;
A_0	[mm^2]	Uncut chip cross-sectional area;
A_C	[mm^2]	Cut chip cross-sectional area;
F_F	[N]	Friction force on tool face;
F_N	[N]	Normal force on tool face;
F_c	[N]	Cutting force on workpiece;
F_t	[N]	Thrust force on workpiece;
F_n	[N]	Normal force on shear plane;
F_s	[N]	Shear force on shear plane;
R	[N]	Resultant force on shear plane resultant force on chip face;
T	[s]	Tool life;
α		Rake angle of tool;
ϕ		Shear angle;
τ		Friction angle;
μ		Coefficient of friction.

LIST OF ABBREVIATIONS

PC	Personal computers
AC	Alternating Current
ATC	Automatic Tool Changer
CNC	Computer Numerical Control
DNC	Direct Numeric Control
CRT	Cathode Ray Tube
DC	Direct Current
EIA	Electronic Industrial Association
ISO	International Standard Organisation
MDI	Manual Data Input
MIT	Massachusetts Institute of Technology
NC	Numerical Control
TDAU	Technology Development & Advisory Unit
UNZA	University of Zambia
VMC	Vertical Machining Centre
ZRP	Zero Reference Point

Some Numerical Control ISO Code

O	Programme number for identification
N	Sequence number for line identification
G	Preparatory functions
X	X axis designation
Y	Y axis designation
Z	Z axis designation
R	Radius designation
F	Feed rate designation
S	Spindle speed designation
H	Tool length designation
D	Tool radius designation
T	Tool designation
M	Miscellaneous function

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The continuous quest for modernization and industrialization has brought a great challenge upon the third world countries such as Zambia in that these countries have to keep on importing production machinery whose spares cannot be obtained locally but from outside. This problem has been compounded by these countries' lack of funds to acquire machinery that could produce the much-needed spares. This research looked at one of the ways of circumventing this problem by the use of Computer Numerical Control (CNC) technology in producing such spares locally. However, the high cost of initial investment of CNC machines is a huge obstacle to many companies in the third world countries like Zambia. It was therefore imperative that avenues of adapting these machines to perform a variety of operations than what they were initially designed for were sought. This would make the investment much more cost effective.

Mwanza (2001) and Daka (2002) carried out some investigations in the adaptation of a milling centre. In the first research, a 3-axes Computer Numerical Control (CNC) Vertical Milling Centre (VMC) situated at the University of Zambia, School of Engineering, Department of Mechanical Engineering workshop was adapted to include turning operations. These adaptations enabled the 3-axes CNC VMC produce turned profiles in addition to its default milling operations. However, there were limitations on the tooling in that complex profiles could not be done. This necessitated the second research by Daka (2002) where a multi-purpose turning tool that could machine a number of part profiles was successfully designed. Here Daka (2002) concluded that a multi-point cutting tool was more superior to a single point cutting tool. Nevertheless, a multi-point cutting tool also had a limitation in that it could not turn smaller radius profiles, as the tool was becoming progressively weaker at smaller radii.

This research applied findings from the investigations by Mwanza (2001) and Daka (2002) in the production of a Collimator Assembly. It went further by including boring in addition to turning operations. Other challenges that were explored were quality problems related to products produced using the same technology.

A Collimator Assembly is a product that was identified as a test piece for production. The collimator assembly is a water-cooled frontal electrode used on the plasma arc torch in the copper smelting process. This torch is used in the reheating of the alloy prior to atomization. It is an assembly made up of two separate components whose metallurgical composition range between 90 percent and 99 percent copper **(Plasma Arc Smelting SCIES, 2006)**. In order to accommodate plasma gas flow, process thermodynamics and heat transfer and to prevent coolant leakages, collimator components are produced by precision machining, a process that is best performed on CNC machine tools.

A cobalt refinery plant at Chambishi Metals Plc running at normal capacity consumes about one collimator in every three to four weeks. The cost of replacement of each collimator is approximately US$3800 from an American source (Mitutoyo and Fowler precision machinists). The company noted that it was spending thousands of dollars in importing the component and was therefore looking for means to have local manufacturers produce the collimator locally since this would be cheaper and readily available. However, local companies have so far failed to achieve the required tolerances using conventional machining methods and have very little or no capacity to order and use CNC machine tools.

1.2 PROBLEM STATEMENT

After having performed modifications on the 3-axes CNC VMC machine tool so that it included turning operations, and having had designed a multi-profile cutting tool for turning on the same machine tool, it was imperative that a specific commercial product was produced to test the applicability of the adaptations. In addition, this would answer and reduce on queries and shortcomings that were unanswered in the previous two studies. These included improvement in dimensional tolerances and surface texture of the products, use of CAD/CAM software and DNC to accommodate complex products.

1.3 RESEARCH OBJECTIVES

The core focus of this research was to produce components of a collimator by employing turning and boring operations on a 3-axes Computer Numerical Control Vertical Milling Centre (CNC VMC).

To achieve this, the following were identified as specific objectives:

i. to design and manufacture turning and boring tools that could machine the collimator components;

ii. to design and manufacture or identify workpiece or tool(s) holding fixture(s) in the machining of the collimator components;

iii. to investigate the suitability of the use of Mastercam software in the production of collimator components; and

iv. to assess the surface finish and dimensional accuracy of the final product(s).

1.4 STUDY RATIONALE

The justification of this research can be drawn from the fact that it complements the two previous studies by Mwanza (2001) and Daka (2002). Further, a Collimator Assembly is a reasonably expensive component, whose highly precise dimensional tolerances validate its production by use of CNC technology.

Although a number of CNC machine tool manufacturers have come up with innovations that are able to combine turning and milling operations, these machines are too expensive. This prohibits most engineering companies in the third world countries to invest in such equipment. For example, one of latest Spinner Turning and Milling Centre (TM) is a complete type of machine tool for machining of precision parts at the highest level of quality in small and medium quantities. It costs $360,000, which is three times higher than the cost of an equivalent Vertical Milling Centre (VMC) **(Spinner Machine Tools, 2006)**. It was therefore justifiable to extend the capabilities of the existing single CNC machine tools as a way forward for enhancing their use in the third world countries such as Zambia.

1.5 METHODOLOGY

In view of the sophistication and advanced construction of CNC machine tools and considering the fact that the collimator is made up of a variety of profiles which require great precision in machining, this research was set to cover engineering production aspects such as parts' production, tooling/jigging, Computer Aided Manufacture (CAM), CNC programming, CNC machining and programming and quality control **(Loraine Blaxter, 2001)**.

In order to accomplish the set goals, the following methodology was adopted:-

1. Review literature on metal cutting technologies, Mastercam software and CNC programming.

2. Study the collimator and produce a production drawing and production schedule;

3. Experimental setup **(Douglas, 1997)**:

    - Choice of factors (e.g. spindle speed), levels and ranges and selection of response variables (e.g. size of chip);

    - Formulate methods of measurement of the chosen factors and variables and setup the equipment;

    - Design and select appropriate tools for drilling, turning and boring operations and their fixture(s);

- Design or select workpiece holding fixtures (and setups for drilling);
- Generate CNC programs for drilling, turning and boring operations using Mastercam software;

4. Produce collimator components using CNC VMC machine tool and take dimensions of the work piece and the chip formed;
5. Analysis of data, using statistical control charts and comparative methods;
6. Conclusions and recommendations.

1.6 SCOPE OF RESEARCH AND ORGANISATION OF THE DISERTATION

The focus in as far as this study went was on the production of the plasma arch torch collimator assembly. Thus, production processes and methodologies, drawings, and programs contained herein are tailored for such and may or may not be applicable to other products.

This chapter has introduced, in a general way, the topics and contributions of the research presented in this dissertation. The remainder of this dissertation is organised as follows:

In Chapter 2, principles of tool design concepts are presented. It gives a theoretical outline of operations that are later used in the machining of the collimator. In this context a review of relevant research is given. It further gives details on the machineability of the tool and fixtures used in achieving various machining operations in the run of production experiments.

Chapter 3 focuses on the development of a model for the production process of a collimator. It starts with a description of the collimator and its application. Production drawings and production sheets are also presented here.

Chapter 4 introduces the machine tool setup, the 3-axes Vertical Milling Centre (VMC). This is where all setups, i.e. production and machine hardware and software, are outlined.

Chapter 5 introduces Computer Numerical Control (CNC) programming. Various ways of programming from manual to software are explored.

Chapter 6 is a presentation of the results of the production process. In other words, this is where the Collimator components are produced. Information collected during the runs of the experiments is presented here.

Chapter 7 centres on the discussion of the productions of the products. Analysis of the collimator holder and insert, chips formed, forces and the surface finishes are also presented.

Chapter 8 concludes this dissertation with a summary of the results of this research and recommendations for future research in the area of production of precision parts such as the Collimator on the 3-axes CNC VMC.

Appendices A, B and D are A3 production drawings of the collimator and its components, the turning tool holding fixture and the boring tool holding fixture, respectively. Appendices D and E are lists of NC part programs for the collimator insert and holder, respectively.

Appendix F shows DNC setup and operation for the 3 axes CNC VMC machine tool. Appendix G shows expected range of CLA values for different machining operations. Appendices H and I shows sample calculations from different chapters and a list of G-codes, respectively.

Finally, appendix J shows the standard inspection sheet and results of the tests done on the produced collimator.

CHAPTER 2

TOOL DESIGN CONCEPTS AND WORK HOLDING FIXTURES

2.1 INTRODUCTION

The basic principles underlying the action of cutting metal have been the subject of many investigations by engineers. Investigators in metal cutting field have attempted to develop an analysis of metal cutting processes which gives a clear understanding of the mechanisms involved, and which enables the prediction of the cutting parameters, without the need for empirical testing. Certain aspects of the technique of metal cutting are up to date controlled by experience rather than well-defined laws.

Metal cutting is broadly referred to as machining as it involves the removal of material from a workpiece. Machining encompasses several processes and these processes fall into three categories. The most distinct of the various categories are:

i. cutting using tools with clearly defined geometry. These can be either single-point or multi-point cutting tools. These are used in turning, milling and profiling;

ii. abrasive processes, such as grinding and lapping; and

iii. non-traditional processes, such as electro-chemical machining, Electro-Discharge Machining (EDM) and Laser Discharge Machining (LDM).

Metal cutting technology is a very vast subject. It is practically impossible to exhaust all areas of this subject in this research. The study was therefore narrowed to the technologies related to turning, threading, drilling, boring and grinding as these were the main processes used in the manufacture of the collimator.

Many types of machining processes exist, but most may be regarded as those employing either single or multi-point cutting tool. Single-point cutting tools are those found in turning, shaping and planing operations, while multi-point cutting tools include those found in grinding and milling operations. It is common to associate multi-point cutting tools to only milling and grinding operations, and single-point cutting tools to turning, shaping and planing operations. However, multi-point cutting tools are also used in turning operations that involve profiling **(Kalpakjian, 1995)**.

2.2 PRINCIPLES OF METAL CUTTING

The most important principles of metal cutting are **(Kalpakjian, 1995)**:

i. the work piece material must be softer than the tool material;

ii. optimisation of metal removal rate by proper design as regard to tool shape and angles;

iii. there must be two relative motions in any metal cutting operation; the two relative motions may be either in the workpiece or in the tool or one in workpiece and the other in the tool;

iv. proper selection of speed, feed, depth of cut, cutting fluid used and machine rigidity;

v. operator's alertness.

Concisely, metal removal processes are desirable in the manufacturing operations for the following reasons:

i. closer dimensional accuracy may be required than is available from casting, forming, or shaping processes alone;

ii. parts may have external and internal profiles, as well as sharp corners and flatness that cannot be produced by forming and *shaping processes;*

iii. to produce special surface characteristics or texture that cannot be produced by other means but are required on all parts of the surfaces of the product;

iv. machining the parts may be more economical than producing it by other processes, particularly if the number of parts desired is relatively small.

2.2.1 MACHINING

In metal cutting, a wedge-shaped tool is used to remove material from the workpiece in the form of a 'chip'. Two motions are required: the 'primary motion', e.g. the rotation of the workpiece in a lathe; and the 'secondary motion', e.g. the feed of a lathe tool.

Single-point tools are used for turning, shaping, planing, etc., and multi-point tools are used for milling, etc. It is necessary to understand the forces acting on the tool and their defects on power requirement, tool life and production cost.

Machine tools remove metal from a workpiece to produce the desired size and shape. Kalpakjian (1995), cites that all machine tools should be able to:

i. have an acceptable degree of perfection in construction and ability of high precision work;

ii. hold and support the workpiece in proper position on a table or any accessories;

iii. hold the required tool on a tool post or on a spindle;

iv. arrange the required speed, feed and depth of cut with respect to the workpiece material and required operation;

v. give the two desired relative movements on the tool or on the workpiece or one on the tool and the other on the workpiece depending on the machine tool and operation to be performed.

2.2.2 TURNING OPERATION

Turning, basically, means rotating the workpiece while an appropriate tool is used to machine the workpiece (see figure 2.1). The initial stock material is, in most cases, made by other processes such as casting, forging, extrusion and drawing. The various shapes that can be obtained illustrate the versatility of the turning process. Turning could produce straight conical, curved or grooved profiles.

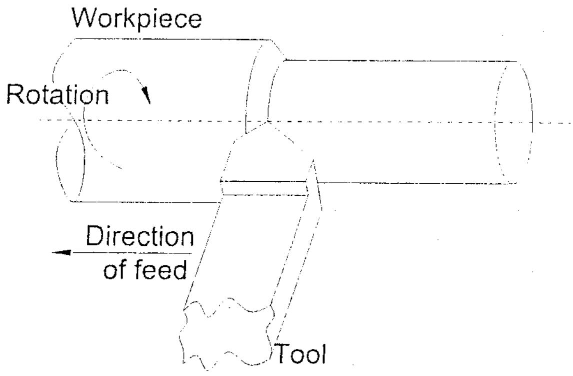


Figure 2.1: Typical turning operation **(Komanduri R., 1993)**.

Turning is an effective flexible machining method of producing round work pieces, in a large variety of sizes and materials, with a single or multi-point cutting tool. Turning can be broken into a number of basic operations for selected tool types, cutting data and programming. The following are some turning operations **(Komanduri R., 1993)**:

- facing,
- straight turning,
- shoulder turning,
- chamfering,
- taper turning,
- radius turning,
- parting and
- grooving.

2.2.2.1 DESIGN CONSIDERATIONS FOR TURNING OPERATIONS

Certain considerations are important in designing parts to be manufactured economically by turning operations. Because cutting takes considerable time, waste material, and is not as economical as forming or shaping parts to final dimensions, machining should be minimised as much as possible. When turning operations are necessary, the following general design guidelines as cited by Kalpakjian (995) should be used:

i. Parts should be designed so that they can be fixtured and held in work holding devices with relative ease. Thin, slender workpieces are difficult to support properly to withstand clamping and cutting forces.

ii. Dimensional accuracy and surface finish specified should be as wide as permissible for the part to function properly.

iii. Sharp corners, tapers, and drastic dimensional variations in the part should be avoided.

iv. Blanks to be machined should be as close to final dimensions as possible, so as to reduce production time.

v. Parts should be designed so that cutting tools can travel across the workpiece without obstruction.

vi. Design features should be such that standard, commercially available cutting tools, inserts and tool holders can be used.

vii. Materials should, as much as possible, be selected for their machinability.

One of the most important considerations regarding design of turning tools is the elimination of vibration and chatter. Vibration during cutting can cause poor surface finish, poor dimensional accuracy and premature tool wear and failure. Because of the complexity of the problem, however, some of the guidelines have to be implemented on a trial-and-error basis **(Kalpakjian, 1995)**. The guidelines are briefly:

i. Minimise tool overhang.

ii. Support workpiece rigidly.

iii. Increase the stiffness of the machine tool and its components by improving design, using materials with higher elastic modulus.

iv. When tools begin to vibrate and chatter, modify one or more of the process parameters, such as tool geometry, cutting speed, feed rate, depth of cut, and cutting fluid.

v. Improve the damping capacity of the machine tool.

2.2.2.2 TURNING AND BORING TOOLS

The single-point cutting tools (figure 2.2) used for turning and boring processes may have a solid shank, be made of a tool bit held in a holder, consist of a small tool carried in a bar (chiefly in boring), or consist of a shank to which a tip of the cutting material is brazed or clamped.

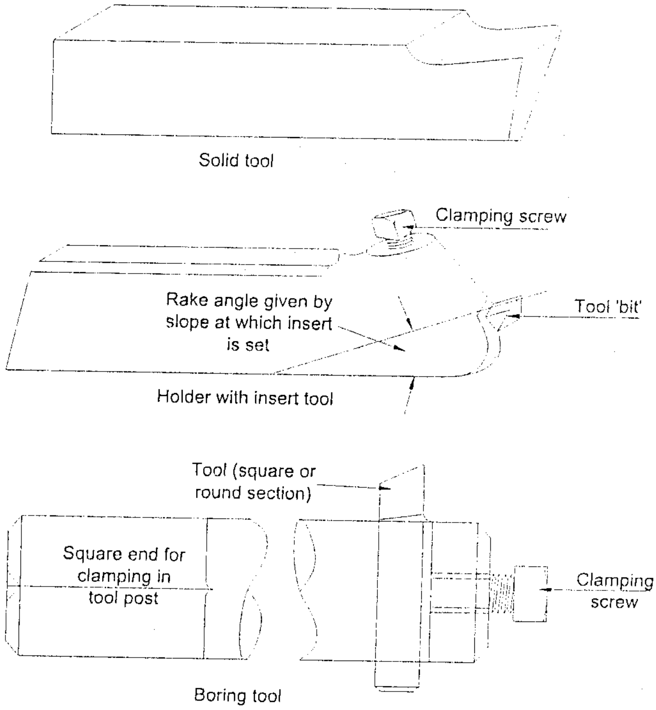


Figure 2.2: Single-point cutting tools **(Chapman, 1986)**

The following is an examination of the disposition of the cutting angles as they are influenced by the type of cutting being done:

***Rake angle**:* Consider a tool such as that shown in figure 2.3(a) having 15° front rake and 15° side rake. The line of greatest slope on the face of this tool will be the line AE and it will be inclined at an angle of about 21° with the horizontal.

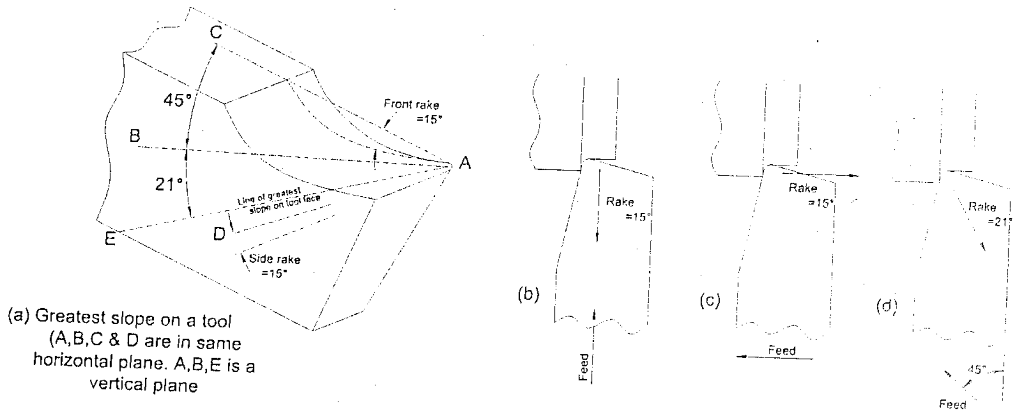


Figure 2.3: Effect of cut disposition on rake value **(Chapman, 1986)**.

Suppose now that this tool is made to cut by feeding parallel to its length it will cut with top rake of 15°, and if fed at 45° to its length the top rake will be 21°. Then conditions are shown at (b), (c) and (d), and observe that the disposition under which a tool must cut influences the effective values of its rake angles. For example, at (b) the side rake has very little effect on the tool action and could be omitted, whilst at (c) the tool would cut almost the same without any top rake. These considerations are important when a tool such as a side tool is used for more than one purpose. In figure 2.4 (a), (b), (c) and (d) are four possible cutting conditions with the same tool and the best cutting conditions are obtained when the line of greatest slope on the cutting face is approximately according to the arrow shown. When a tool bit is used in a holder, the bit is generally set with an initial back slope as shown at figure 2.3(b). This gives a flat-topped tool, a front rake equal to the slope angle of the tool, which should be taken, into account when grinding the tool bit.

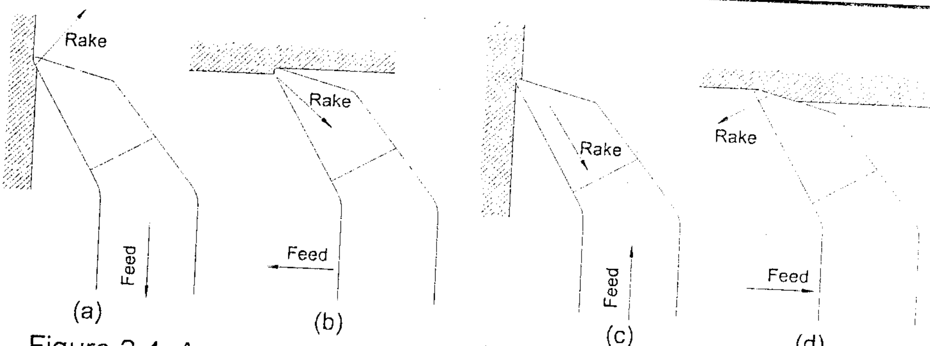


Figure 2.4: Approximate direction of rake necessary for different cutting conditions **(Chapman, 1986)**.

Clearance: The remarks mentioned above about rake apply in general terms to clearance. The tool must be provided with sufficient clearance *relative to the surface being machined*, and if this is not achieved the tool will be prevented from a free cutting action by its front rubbing against the metal. In figure 2.4, the clearance for the examples shown must have its general direction inclined towards the arrow, and clearances should be ground in planes parallel and perpendicular to the surface being machined. The amount of clearance should be no more than is necessary to permit the tool to cut cleanly, and 5° to 10° is usually sufficient **(Chapman, 1986)**. If more than this is allowed the tool point is made sharper and robbed of metal which would otherwise help it to survive and conduct away the large amount of heat generated when cutting.

A little more clearance is generally necessary for boring than for external turning. This is illustrated in figure 2.5, where it can be seen that in external turning (a) the surface AB slopes away from the tool immediately below the centreline. For flat facing, shaping and planing (b) the surface does not change in direction, while for boring (c) it slopes towards the tool. When boring a small hole, a double clearance angle as at (d) helps to strengthen and leave more metal round the tool nose. On tool holders where the tool slopes back the clearance which must be put on the tool is the sum of the clearance required, and the slope angle of the tool (figure 2.3(b)).

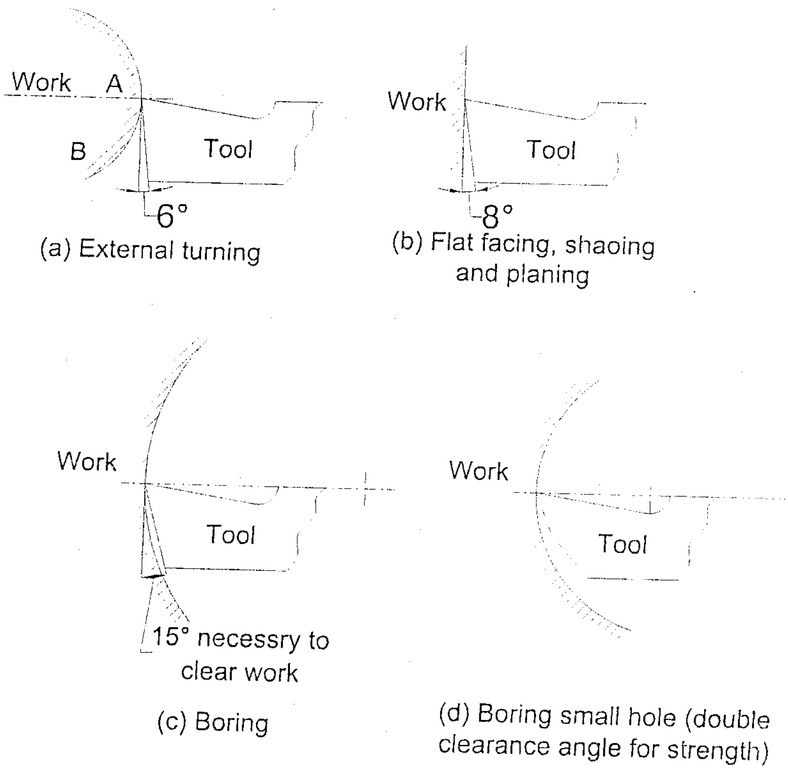


Figure 2.5: Effect of cutting conditions on tool clearance **(Chapman, 1986)**.

Table 2.1 gives an idea of the rake, which should be used for cutting various metals. The angle given in the table is that of the line of greatest slope on the tool as explained in figure 2.4. Depending upon the conditions of cutting (see figure 2.5), this angle may be obtained by a combination of front and side rake (for ordinary surfacing, e.g. Figure 2.4(a); by front rake only, e.g. for a parting tool; or by side rake only, e.g. for a knife tool).

Table 2.1: Rake angles for cutting various metals **(Chapman, 1986)**

Angle given is that of the true rake on the tool

Metal being Cut	Hard Brass, Bronze and Cast-iron	Hard steel, Medium Cast Iron, Brass and Bronze	Medium Steel, Soft Cast Iron, Brass and Bronze	Mild and Soft Steel	Aluminium and light Alloys
Rake	0°	8°	14°	20° to 27°	40°

CLEARANCE

This should be no more than is necessary to allow the tool to cut efficiently and may be approximately as follows:

External turning, 6° to 10°.
Facing, shaping and planning, 8° to 17°.
Boring, sufficient to allow heel of tool to clear.

2.2.2.3 OTHER PROFILES OF TOOLS

The top profiles of the more usual tools are shown in figure 2.6, and an indication of their uses is as follows:

a) Straight rougher: Facing ends of bars in lathe. Finish facing generally.

b) Side Tool: Surfacing up to a corner facing down a side.

c) Parting Tool: Parting-off in lathe, cutting grooves.

d) Boring Tool: Boring in lathe.

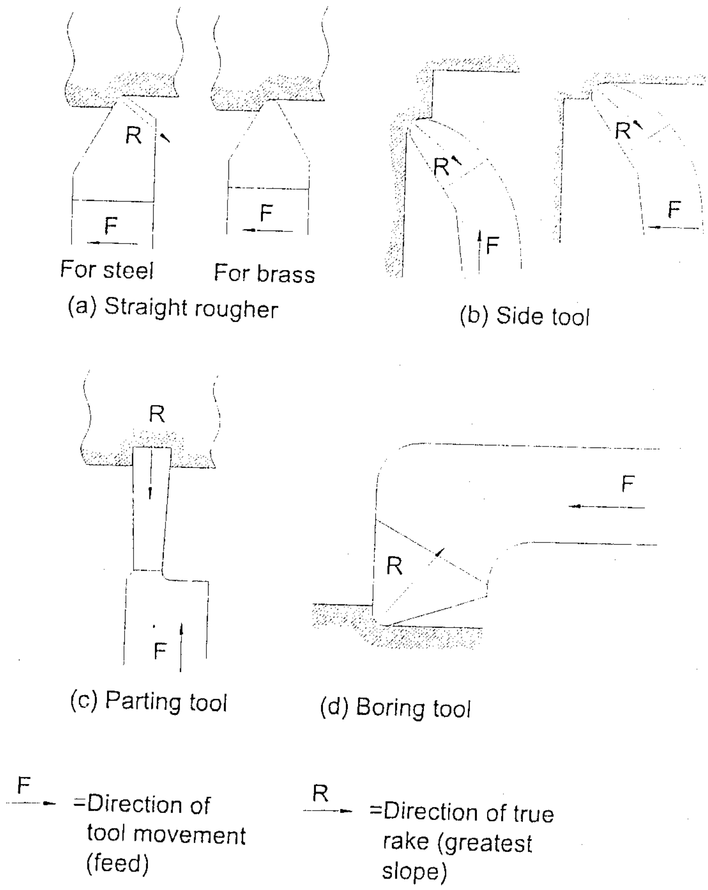


Figure 2.6: Top profiles of tools **(Chapman, 1986)**.

The tools for lathes should have a good solid shank and should be well supported by not protruding from the tool holder any more than necessary.

2.2.2.4 CUTTING SPEED FOR TURNING

During the turning process, the workpiece rotates on a machine, with a spindle speed *N*, at a certain number of revolutions per minute (*rpm*) in relation to the diameter *D*, measured in *mm*, of the workpiece. This is the speed at which the periphery of the diameter passes the cutting edge. It should be noted that the cutting speed is only constant for as long as the spindle speed and/or part diameter remains the same.

It is also important to know, from previously experimentally determined results, the cutting speed V_c *of a given material so that the revolution of the workpiece* could be determined from the following expression **(Kalpakjian, 1995)**;

$$V_c = \pi \frac{DN}{1000} \ (m/min) \tag{2.1}$$

The following are some important parameters that need to be well defined when turning:

i. Feed speed or feed per revolution (V_f, *mm/min* or *mm/rev*) – This is the machine feed, which moves the tool axially It is the movement of the tool in relation to the revolving workpiece. This is a key value in determining the quality of the surface being machined and for ensuring that the chip formation is within the scope of the tool geometry. This value influences both chip thickness and chip breaking;

ii. The cutting depth (*d, mm*) – This is the difference between the uncut and cut surface. Mathematically this value should be half the difference in the uncut and cut diameters and is always measured at right angles to the feed direction;

iii. The entering angle (*k*) – This is a parameter which expresses the way in which the edge approaches the workpiece. This is the angle between the cutting edge and the direction of the feed.

Table 2.2 gives speeds that may be taken as a single guide for the initial setting of the machine.

Table 2.2: Cutting speeds for turning **(Chapman, 1986)**

(The speeds given are for average cuts with high-speed steel tools)

Material being cut	**Cutting Speed (meters per minute, *m/min*) V_c**
Mild steel	20 to 28
Cast iron	18 to 25
High carbon steel	12 to 18
Brass	45 to 90
Bronze	15 to 21
Copper	20 to 120
Aluminium	Up to 300

It may be possible to exceed these speeds for light finishing cuts. For heavy roughing cuts, they should be reduced. One empirical formula for cutting speed in which the cut and feed are taken into account is as follows **(Chapman, 1986)**;

$$\text{Cutting Speed } (V_c) = \frac{C}{\sqrt[3]{A}} \ (m/min) \qquad (2.2)$$

Where, A = Area of cut = feed (mm) X depth of cut (mm)

C = a constant. Typical values are given in Table 2.3.

Table 2.3: Values of C

Material being cut	Soft Steel	Hard Steel	Cast-iron	Bronze	Brass	Copper
C	24	13	18	21	48	30

2.2.2.5 CUTTING SPEED FOR DRILLING

Equation 2.1 for cutting speed in turning will apply to drilling if D is made to represent the drill diameter instead of the work diameter.

Thus for a 5mm drill to cut at 20 metres per minute

$$\text{Speed of drill } (rev/min) = \frac{1000V_c}{\pi D} = \frac{1000 \times 20}{\frac{22}{7} \times 5} = 1273$$

For drilling speeds, a factor $\frac{2}{3}$ is multiplied to those in Table 2.2.

2.2.2.6 CUTTING FEEDS

A metal-cutting operation consists of causing the tool to travel relative to the work and feeding it in such a way that it cuts the metal. In turning, the tool is fed along the bar for turning a cylinder, and across for a flat face. This gives the effect of removing the metal by turning a very fine thread (figure 2.7). The feed of the tool is the distance it moves along for each revolution of the work.

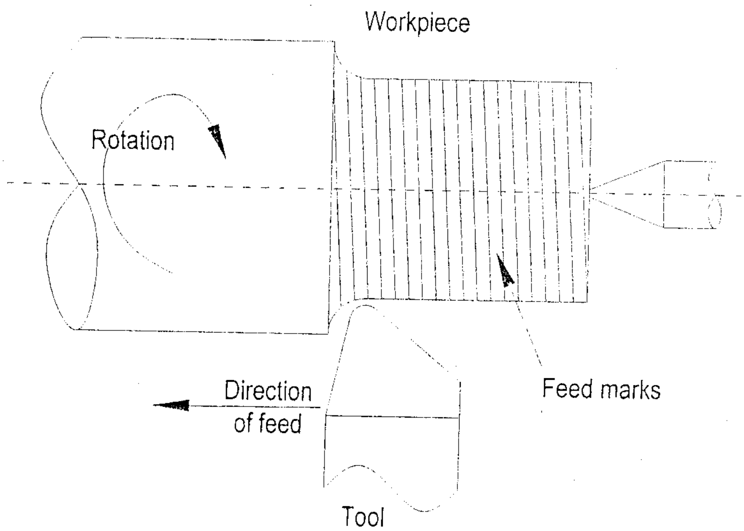


Figure 2.7: Turning with a feed **(Komanduri, 1993)**.

For turning, the feed that should be used depends on the following:

a) The smoothness of the finish required. A coarse feed will give wider and deeper machining marks, and an inferior finish to fine feed. The shape of the tool enters into this as well because a blunt-nosed tool will give a better finish than a sharp tool for the same feed.

b) The power available, the condition of the machine and its drive. The product of speed, feed and depth of cut gives the amount of metal that is being removed, and hence the power necessary. A coarse feed on a poor or badly driven machine may be too much for the machine or tool, or cause the drive or belt to slip.

These two considerations are guides in the choice of a proper feed. Generally, during rough cutting the coarsest feed is used since surface finish is not important. When finishing the feed is adjusted so that it is fine enough to give the class of finish required.

2.2.3 TOOL FORCES

To measure cutting tool forces, a dynamometer may be used. This is an instrument designed to detect small deflections of the cutting tool when it is subjected to forces. There are many different types of dynamometers embodying different principles. The main design features are that they should be as rigid as possible so as not to be influenced by machine tool vibrations, and also have sufficient sensitivity to detect small displacements of the cutting tool. The lathe tool dynamometer can be used to measure the following forces when turning (see figure 2.8):

(a) the radial force, F_r,

(b) the vertical force, F_c and

(c) the axial force, F_a.

When measuring cutting tool forces in practice the force F_r is often ignored, since it is too small to be of any significance. The vertical cutting force, F_c, also called the tangential force is the one that does all the work, and it is operating at a cutting velocity V_c. The cutting power is the product of F_c and V_c. The other two forces acting are the radial force, F_r, and the axial force, F_a. The radial force is produced by the approach angle of the tool, and is the force needed to hold the tool against the workpiece. It usually has zero velocity and thus zero power. The axial force, F_a, has a very low velocity, and thus very small power consumption. The directions in which these forces act depend on the angle at which the tool is cutting. Thus for a profile having different contours, the orientation of forces will be changing according to the inclination of the contour being turned with respect to the orientation of the workpiece.

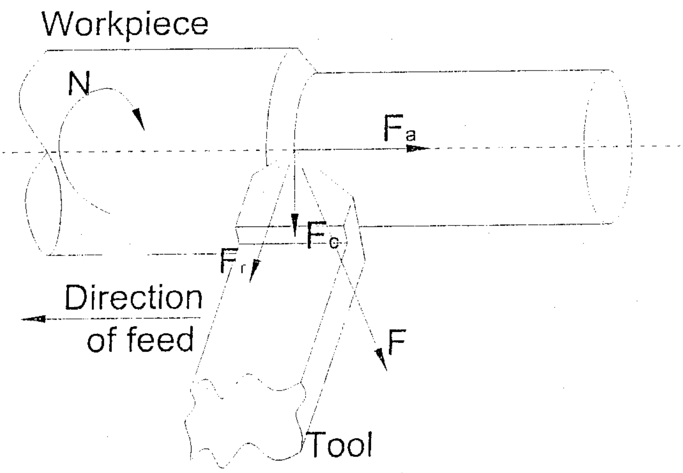


Figure 2.8: Components of the main cutting force, F **(Kalpakjian, 1995)**.

The three forces can be resolved to determine the total resultant force, F. The radial cutting force component, F_r, is directed at right angles to the tangential force from the cutting point. The axial cutting force component is directed along the feed of the tool, axially along the direction of machining component.

Geometry, especially the entering angle, will determine the size of the two force components F_r and F_a. Their relationship becomes especially important when deflection of the tool with a large overhang or a slender workpiece is a factor as regards accuracy and vibration tendencies. The rake angle also influences the size of the radial force component. Generally, positive rake angles also mean lower cutting forces.

For some materials, increasing cutting speed leads to lower forces **(Kalpakjian, 1995)**. The higher temperature in the shear zone and reduced contact area contribute towards this effect.

As may be expected the size relationship between the force components varies considerably with the type of machining operation. The tangential force often dominates in milling and turning operations. The radial force is of particular importance in boring operation and the axial force in drilling operations. All three components increase in size with increasing chip cross-section, with the tangential force being the most affected.

Vibration tendency is one consequence of the cutting forces. As well as tool or work piece deflection, these can be affected by vibrations in the cutting process such as varying working allowance or material conditions as well as the formation of built–up edges.

The cutting speed V_c is the relative velocity of workpiece and tool at the tool edge. For any point on the tool edge, it can be considered as a vector and the cutting force F_c is measured along the line of this vector. The elementary relationships should be noted:

Power consumed in cutting,

$$P = \frac{F_c V_c}{60} (Watts) \qquad (2.3)$$

Metal removal rate,

$$w = \frac{V_f V_c d}{60} (mm^3/\sec/rev) \text{ or } (mm^3/\sec/\min) \qquad (2.4)$$

where,

F_c is the vertical cutting force in N,

V_c is the cutting speed in mm/min,

V_f is feed speed in mm/rev or mm/min and

d is the depth of cut in mm.

The formula for power is an approximation, because the efficiency of the drive under varying loads is not taken into account. Measurement of the input to the electric motor of a machine tool provides a convenient method of measuring the power consumed in cutting. If the value of the power supplied when the machine is running idle is subtracted from the power reading taken under the cutting load, a reasonable estimate of the power consumed in cutting is obtained.

2.2.4 MERCHANT'S ANALYSIS OF METAL CUTTING

Merchant deduced an idealised concept of chip formation for which a precise geometry as a basis for the studies of mechanics of cutting is based **(Merchant M. E., 2003)**. Ernst was an inquisitive and imaginative inventor and researcher. Among other things, he was particularly curious about the mechanism by which a cutting tool removes metal from a workpiece, i.e. the process of chip formation. To investigate this, he had previously carried out such activities as studying the action of chip formation through the microscope during cutting and taking high-speed motion pictures of such. He also made photomicrographs of sections through chips still attached to workpieces (obtained by suddenly stopping a cut while in process). He published the findings of his research in a variety of technical papers, of which his classic paper titled "Physics of metal cutting", published in the book titled "Machining of metals" by the American Society for Metals **(Ernst, 1938)**, is typical. As a result of this type of empirical research, he arrived at the concept of the "shear plane" in chip formation, i.e. the very narrow plastic zone ("plane") between the body of the workpiece and the body of the chip that is being removed by the cutting tool.Merchant joined Ernst's staff (as a graduate student in a unique post-graduate cooperative education programme at the University of Cincinnati) in 1936, having just graduated from the University of Vermont in Mechanical Engineering. Ernst asked him to undertake research on the mechanism of chip formation and, in particular, on the mechanism of the sliding friction between the chip and the cutting tool in chip formation.

As Merchant's friction research progressed (resulting, incidentally, in his theory of the nature of friction between chemically clean metal surfaces that is still in use today), he studied, considered and discussed with Ernst the latter's thoughts about chip formation and the empirical "shear plane" model. This led Merchant to reason that the chip could well be considered a body in stable mechanical equilibrium between the shear plane and the tool face. He therefore tried applying the science of the mechanics of solid bodies to such a concept. This resulted in the model of the equilibrium force system acting in the chip-tool-workpiece system shown in figure 2.9. Combining ("condensing") the two equal and opposing sets of forces into one (based on the equality of the two opposing resultant forces), as shown in figure 2.10, then made it possible to derive the mathematical relationships governing such forces, as set forth in Merchant's (1994) paper. The outcome was thus a science-based, predictive model of the basic process of chip formation – the first of its kind – and one which made possible engineering calculation of such quantities as the friction force acting between chip and tool, the coefficient of friction between them, shear stress at the shear plane etc.

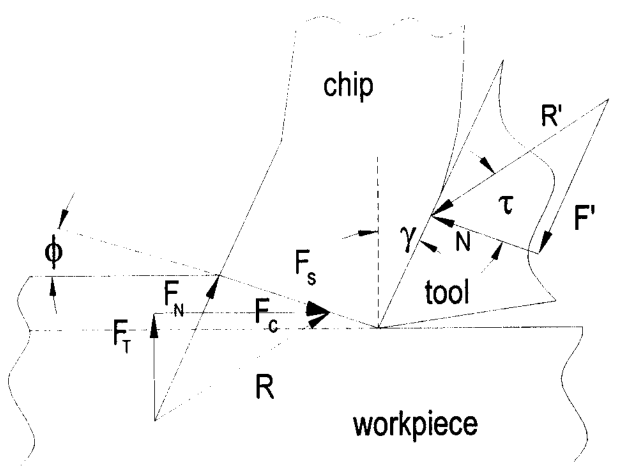


Figure 2.9: Equilibrium force system acting on chip during cutting **(Merchant, 1944)**.

From the circle diagram (figure 2.10), the following are obtained;

Chip ratio, $r_c = t_1/t_2 =$ depth of cut (t_1) / chip thickness (t_2).

For shear plane angle, $\tan\phi = r_c \sin\gamma/(1 - r_c \cos\gamma)$,

Thus,

$$F_F = F_c \sin\gamma + F_t \cos\gamma \qquad (2.5)$$

$$F_N = F_c \cos\gamma - F_t \sin\gamma \qquad (2.6)$$

Where,

$\gamma =$ Rake angle,

ϕ = Shear plane angle and

τ = Friction angle.

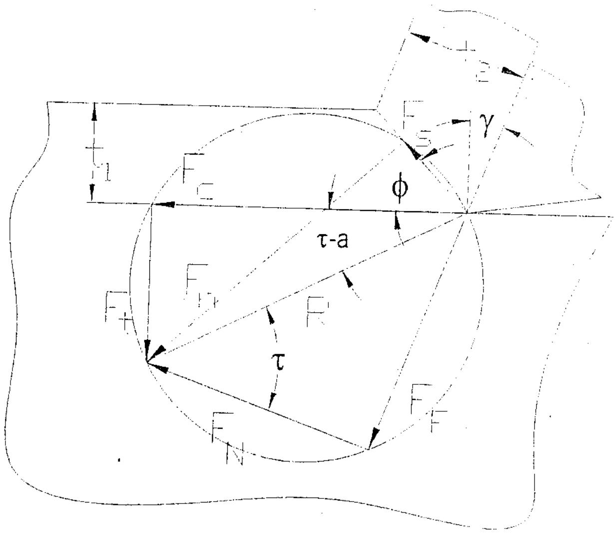


Figure 2.10: Condensed form of tool-chip-workpiece force system showing geometrical relationships between force components **(Merchant, 1944)**.

Coefficient of friction, $\mu = \tan\tau = F_F/F_N$,

$$F_s = R\cos(\phi + \tau - \gamma) \qquad (2.7)$$

Shear stress, $t_s = F_s/A_c = F_s \sin\phi/A_0$ and A_c and A_0 are areas across the cutting shear plane after and before cutting respectively.

Publication of this initial, basic model suddenly made it clear to those engaged in manufacturing research that a new approach to the modelling of the machining process was actually possible, namely that of science-based, predictive, modelling. This discovery thus ushered in a new era in metal cutting research, that which Komanduri (1993) has characterised as "the golden age of metal cutting and grinding research", lasting from about 1940 to 1960. As a result, a worldwide effort to develop a substantial scientific basis for the modelling of the machining process gradually emerged, and then continued unabated through that whole period. In particular though, it was the academic community that responded, with research on science-based modelling of machining blossoming handsomely among manufacturing-oriented university researchers and faculty. During the period substantial progress in developing that science base was made, with a major part of that coming from the efforts of American engineering researchers and manufacturing engineers.

2.2.5 CHIP FORMATION

The majority of metal cutting operations involve the separation of small segments or chips from the workpiece to the required shape and size of the manufactured parts. Chip formation involves three basic requirements:

i. There must be a cutting tool that is harder and more wear resistant than the workpiece material,

ii. There must be interference between the tool and the workpiece material as designated by the feed and depth of cut, and

iii. There must be a relative motion or cutting velocity between the tool and the workpiece material.

Further, observations during metal cutting reveal several important characteristics of chip formation Thus;

i. The cutting process generates heat,

ii. The thickness of the chip is greater than the thickness of the layer from which it came,

iii. The hardness of the chip is usually harder than the hardness of the parent material, and

iv. The above relative values are affected by the changes in cutting conditions and in the properties of the material to be machined, to produce chips that range from small lumps to long continuous ribbons.

These observations indicate that the process of chip formation is one of deformation or plastic flow of the material, with the degree of deformation dictating the type of chip that will be produced. Some of the manipulating factors that provide some control of the metal cutting characteristics are velocity, size of cut, tool geometry, cutting fluids and material of workpiece.

2.2.6 MACHINABILITY OF SOFT METALS

Cobalt-base alloys are abrasive and highly work hardening. They require sharp and abrasion-resistant tool materials and low feeds and speeds. Wrought copper on the other hand can be difficult to machine because of built up edge formation, although cast copper alloys are easy to machine. Brasses are easy to machine, especially with the addition of lead (leaded free-machining brass). Bronzes are more difficult to machine than brass.

2.2.7 TOOL LIFE

The relationship giving the tool life in terms of the cutting speed is contained in the expression **(Kalpakjian, 1995)**:

$$VT^n = C \tag{2.8}$$

where, V = cutting speed (m/min)

T = tool life (min)

C = a constant

$n = \frac{1}{7}$ to $\frac{1}{8}$ for roughing cuts in steel (using HSS)

$n = \frac{1}{12}$ to $\frac{1}{8}$ for roughing cuts in cast iron (using HSS)

$n = \frac{1}{10}$ to $\frac{1}{8}$ for light cuts in steel (using HSS)

$n = \frac{1}{5}$ to $\frac{1}{8}$ for roughing cuts in cast iron (using tungsten-carbide tools)

The above values of n are only approximate and are influenced by tool shape, use of cutting fluid, cutting speed and feed. The relationship enables us to estimate probable tool life.

2.2.8 MINIMIZING MACHINING COST

As in all manufacturing processes and operations, all relevant parameters in machining can be chosen and specified in such a manner whereby the machining cost per piece, as well as machining time per piece, can be minimized. Various methods and approaches have been developed to accomplish this goal, and with the increasing use of software, this task has now become easier. However, in order for the results to be reliable, it is essential that input data be accurate and up-to-date. Described below is one of the more common and simple methods of analysing machining costs in a turning operation **(Kalpakjian, 1995)**.

In machining a part by turning the total machining cost per piece, C, consists of:

$$C = C_1 + C_2 + C_3 + C_4, \qquad (2.9)$$

where,

C_1 = *non-productive cost:* labour, overhead, and machine-tool costs involved in setting up for machining, mounting the cutting tool, preparing the fixtures and the machine, advancing and retracting the tool, and so on.

C_2 = *machining cost*: labour, overhead, and machine tool costs while the cutting operation is taking place.

C_3 = *machine-tool cost*: labour, overhead, and machine tool costs during tool change.

C_4 = *cost of cutting tools.*

This analysis indicates the importance of identifying all relevant parameters in a machining operation, determining various cost factors, obtaining relevant tool-life curves for the particular operation, and properly measuring the various time intervals involved in the overall operation. The importance of obtaining accurate data is illustrated in figure 2.11. Small changes in cutting speed can have a significant effect on the minimum cost or time per piece.

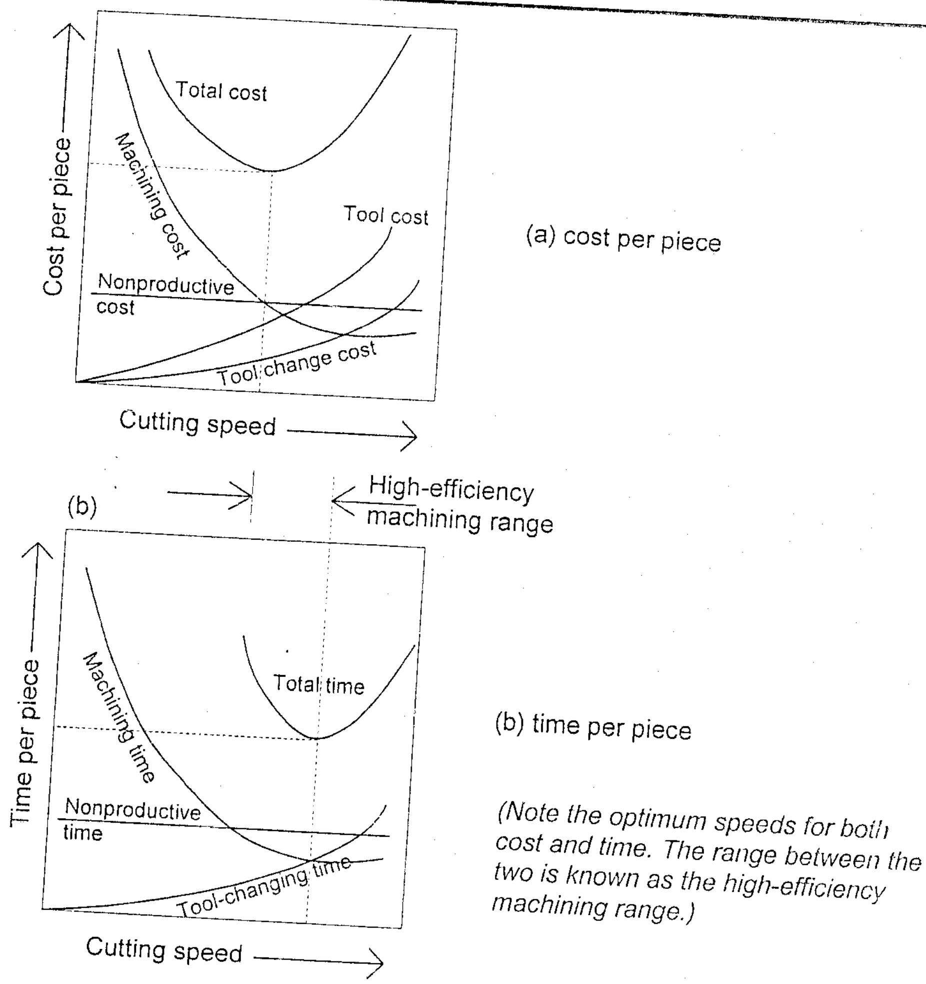


Figure 2.11: Graphs of cost/time per piece in machining **(Kalpakjian, 1995)**.

Three of the four cost variables in equation 2.9 depend on cutting speed. As cutting speed increases, the machining time for a particular workpiece (hence cost per piece) decreases. However, tool life generally decreases with cutting speed. Hence, tool cost increases, as does the tool-changing cost since tools have to be changed or indexed more frequently. Nevertheless, the non-productive cost C_1 does not vary with the cutting speed.

Each of these costs can be described by a mathematical equation in terms of its own relevant parameters, and added together as is equation 2.9. This equation is then differentiated with respect to the cutting speed V to determine the optimum cutting speed for minimum cost per piece. Likewise the total time required for machining the part is obtained by a similar mathematical equation, adding together the times involved in various phases of the total operation, such as loading and unloading the part, actual machining, changing the tool, etc. This equation is then differentiated with respect to the cutting speed to obtain minimum time per piece. It could be noted from figure 2.11 that there is a difference in the two optimum cutting speeds. The range between these two speeds is the high-efficiency machining range.

2.3 WORKPIECE HOLDING FIXTURES

The employment of fixtures is an important aspect of workshop engineering, and their application is worthy of some consideration on all but the simplest types of production, small orders and tool room work.

Fixtures are appliances used in manufacture or assembly to facilitate the operation to which they are applied. The primary object of their use is to facilitate the holding and support of an awkward or frail article for some machining operation to position a component and guide the cutters so that every component will be uniform, to accommodate several components at one setting to take advantage of multiple machining, to hold a component which could not be held conveniently without a fixture, and so on.

2.3.1 GENERAL DESIGN PRINCIPLES

Although the forms and applications of fixtures differ very widely, there are certain general principles applicable to all. The form and operation of fixtures for carrying out the same operation may vary depending on the design.

2.3.1.1 LOCATION

An important aspect of design is concerned with the location of the component. Correct location influences the accuracy of the finished component, and particularly its positional relationship with other surfaces on the component. Furthermore, unless location arrangements are reliable and consistent, the fixture will not produce uniform components and all the reasons for using the fixture will be nullified. Location arrangements are closely related to other aspects of fixture application; for example, a perfectly satisfactory method of location might be spoiled by faulty methods of clamping causing the component to lift away from the locating face, or due to poor design, a locating face might be clogged by swarf and so be rendered useless.

2.3.1.2 PRINCIPLES OF LOCATION

In order to fix the position of a body in space, it is necessary to account for six degrees of freedom, and these may be referred to three perpendicular axes which in figure 2.12 are referred to as OX, OY and OZ.

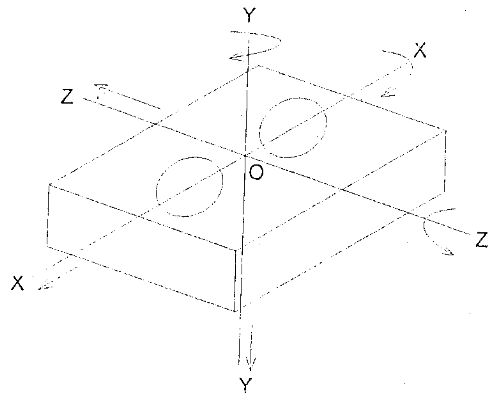


Figure 2.12: Six degrees of freedom **(Chapman, 1986)**.

The body shown may move laterally in the directions OX, OY or OZ, in addition to which it may rotate about any of these axes, giving six possibilities in all. When designing location facilities, it should be noted that the arrangements will provide positive restraint as well as ensuring the surface relationships necessitated on the job in hand. There are, in addition certain natural location relationships between surfaces, points and lines which should be noted. Considering the location of a triangle of points; that is, a three legged object, unlike a four legged one, will always stand on its legs regardless of the surface profile. A triangular, three point location system on a horizontal plane, therefore will restrain movements along axis OY, and rotations about OX and OZ – three of six degrees of freedom (figure 2.13(a)).

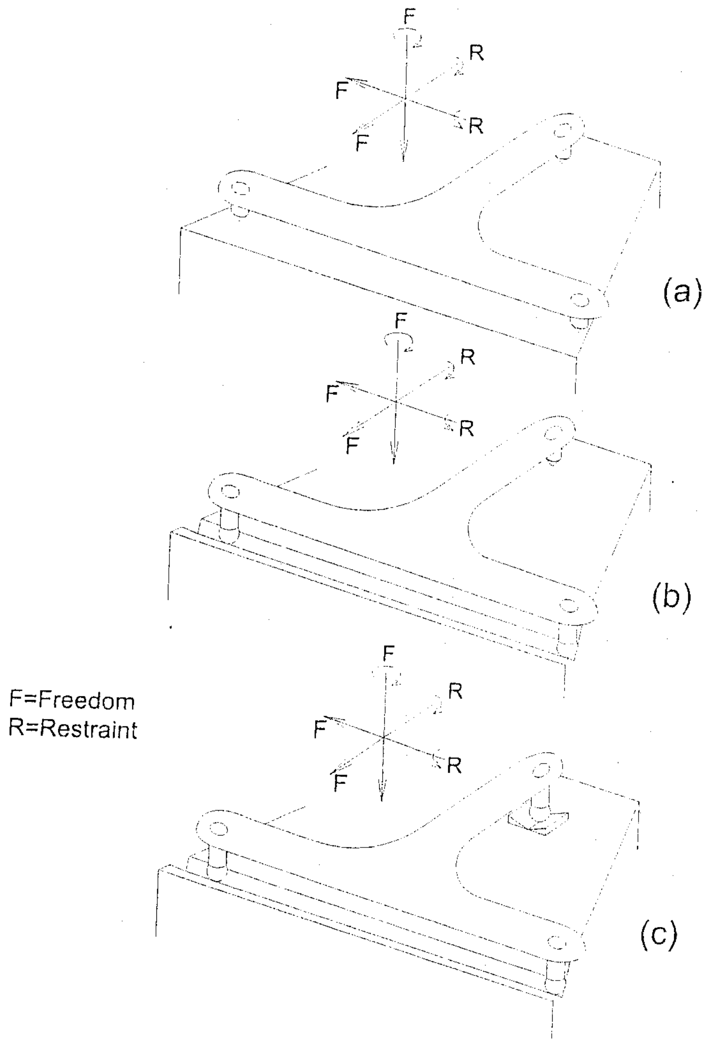


Figure 2.13: Location of a triangle of points **(Chapman, 1986)**.

Suppose now that the arrangement is modified by fitting ball ends to the feet and place two of them in a vee groove, the natural contact conditions between circles and a vee will result in perfect mating in the vee, and by resting the third foot on a flat surface we have put a restraint on two more of the outstanding degrees of freedom (i.e. movement along OX and rotation about OY (figure 2.13(b)). Finally, by placing the third foot in a vee formed perpendicular to the other we may restrain freedom of movement along OZ, thus accounting for the entire six degrees (figure 2.13(c)).

2.3.1.3 METHODS OF LOCATION

Locating plugs

Since the cylindrical hole is such a common feature of engineering components, locating plugs play an important part in the design of fixtures. According to the conditions of application, a plug may be fixed as a permanent part of the construction or it may be loose. Unless the jig is of a very simple nature for use with only a few components, locating plugs should be hardened and ground, casehardening steel being suitable as the soft core lends toughness. When the plug is a permanent part of the fixture, it may be a drive fit into a bored hole or it may be secured by a nut and washer. The latter method is necessary if the end of the plug carries a screw and nut for clamping the component, and for such cases a snug or a key should be added to counteract the torque involved when clamping.

Redundancy of location

When any one of the six degrees of freedom has been covered by a location, it is unwise to duplicate the location. As can be observed from figure 2.14, a full circle for the second plug would duplicate the work of the principal location and would lead to difficulties in assembling the component. Any attempt to improve matters on the subsidiary location by maintaining the full circle but reducing it to accommodate variations in centre distance would introduce the possibility of angular variations and render it worthless as a location.

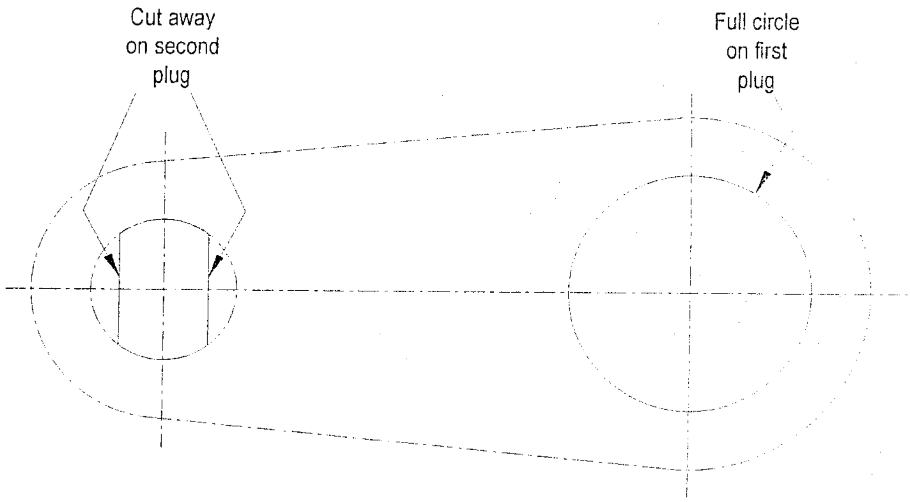


Figure 2.14: Location of a lever on two plugs **(Chapman, 1986)**.

External cylindrical locations

For the location of male cylindrical forms, either holes in the fixture or vee blocks constitute the principal methods of location. For the holes, there is little to be said except that when extended use is required the hole should be bushed so that wear may be rectified by a renewal of the brush. The vee is a common method for locating a cylindrical surface and has the property that the centre of the circle is always located on the centre of the vee. When the vee is fixed however any variation in the diameter of the circle will result in a variation of its position from the point of the vee.

Facing and stop-screws

Facings incorporated on the jig and various forms of stop-screws are widely used for providing distance location for components. For a facing it is advisable to design it in the form of hardened steel plate or insert so that it will last longer and may easily be renewed when necessary. If a plate is required to locate any length on a rough surface it is advisable to clear away all the extremities of the length being used, to minimise the possibility of high spots leading to error.

Dowels

These are used more as locations in the construction of fixtures themselves than for the positioning of components. For maximum effectiveness dowels should be spaced as far apart as possible.

Tenons and spigots

These also are commonly used for locating the component parts of fixtures. Both of them give constraint in all directions but one, and require a dowel or some additional location if complete fixturing is required.

Locating rough components

It is often necessary to provide a location from or a support to a rough face whose surface may be uneven. This necessitates some flexibility in the location or support provided, as otherwise redundancy might be introduced.

Clamping

In all forms of fixtures it is necessary to provide facilities for clamping the work, and there are several aspects to this:

i. Work should be held rigidly to the fixture, and to locating faces, but should not be distorted in any way. This involves the use of efficient clamping methods, applied at points where they will act against solid metal, with the avoidance of forces where there is no support. Thin, fragile components require particular consideration if distortion is to be avoided.

ii. Clamping should be simple, quick and foolproof. Fixtures are often used by unskilled operatives who do not possess the mechanical instincts necessary to tighten clamps intelligently. Generous allowance must be made for this in the design of clamping arrangements.

iii. The components of the clamping system must be robust, and as far as possible made non-detachable. The first point is obvious, but cases are often seen where clamps are too thin for the forces put on them and become bent in as a consequence. Detachable parts often get mislaid.

Cylindrical clamping

When a boss is located onto a peg, the most usual method of clamping is to use a nut carried on the reduced end of the peg. A C-shaped washer avoids removing the nut each time the component is changed. Components may also be secured by a split peg with a central expanding screw, but in this case there is no assurance that the face of the boss is in contact with the shoulder peg, a location which might be important.

2.3.2 DIVIDING FIXTURES

A proportion of the work of milling machines is concerned with cylindrical work where the necessity arises for dividing the circle (e.g. flatting bolt heads, notching lock nuts, etc). This demands a fixture which reproduces the function of the dividing head but arranged for more rapid operation and adapted to accommodate the particular work in question. The ideals to be achieved in the design of these fixtures are rigidity and reliability of division in the minimum of time. In the hands of the average production-shop machinist the ordinary dividing head would fail on both accounts. When it is used in the upturned position (axis vertical) it is not the most rigid of structures, and a large proportion of production jobs necessitates this method of arrangement. Rigidity may be obtained by designing the fixture to be as low as possible.

The indexing of divisions may be carried out through either a notched or a bushed indexing plate. The slots in the notched plate are tapered so that a spring-loaded index finger of the corresponding taper form will always seat home. The bush indexing plate is provided with 12 positions so that it deals with works requiring 2,3,4,6 or 12 divisions, a range which covers most of the usual jobs. There is little likelihood of much error being present in their spacing and the only errors likely to arise will be due to wear in the plunger pivots or dirt preventing full engagement. The arrangements for holding the work on these fixtures are generally universal.

CHAPTER 3

PRODUCTION AND MANUFACTURING ASPECTS OF THE COLLIMATOR

3.1 INTRODUCTION

This chapter begins with a brief description of the Collimator and its components, the insert and the holder. Production sheets of the insert and the holder, and how they were assembled together then follow. The chapter concludes with an outline of the weldability of copper and its alloys.

3.2 THE PLASMA-ARC TORCH COLLIMATOR

A collimator is a water-cooled frontal anode electrode, used on the plasma arc torch in the copper smelting reactor or furnace highlighted in figures 3.1 and 3.2 and caption 3.1. This torch is used in the re-heating of the copper alloy prior to atomization. It is an assembly made up of *two separate components* (insert and holder) whose metallurgical composition ranges between 90 percent to 99 percent copper (figure 3.3).

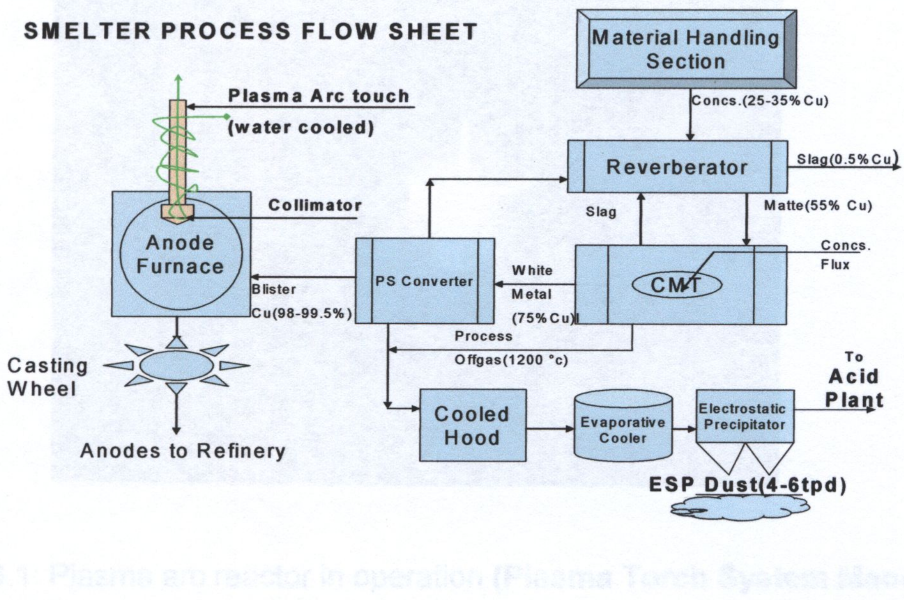


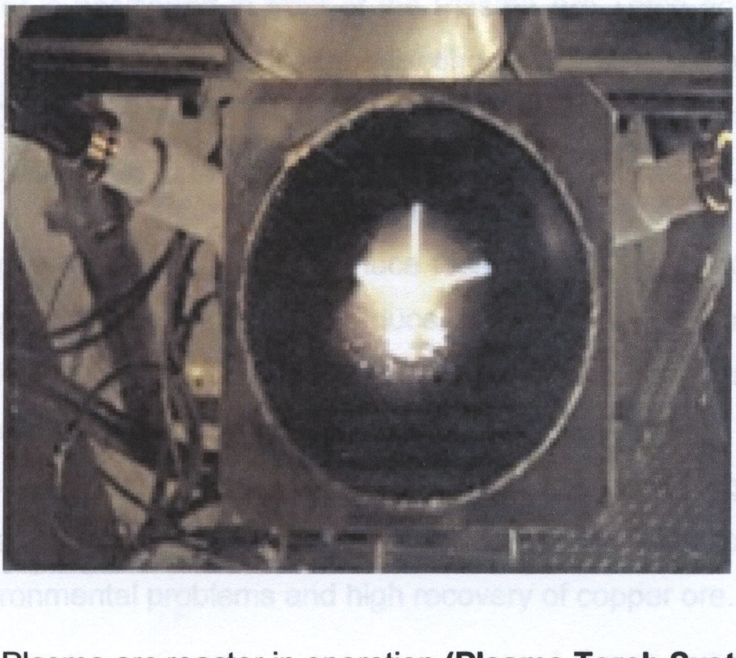
Figure 3.1: Process flow sheet showing the situation of the collimator.

In order to accommodate plasma gas flow, process thermodynamics and to prevent coolant leakages, collimator components are produced by precision machining, a process that is best performed on CNC machines.

Three problem areas of great practical importance for the collimator assembly can be emphasized:

- Heat exchange by convection and radiation between the arcs and the reactor surfaces,
- Heat exchange by conduction and convection between the walls of the collimator and flowing water (within the assembly) and
- Mass and momentum transfer across the metal-plasma inter-phase including mass diffusion in the arc region (corrosion).

Hence, two material properties of paramount significance are electrical and thermal conductivity. Thus, the composition of material is 93 percent copper, 4 percent cobalt, 2 percent zinc and 1 percent aluminium (93Cu4Co2Zn1Al) **(Plasma Torch System Manual, 2006)**.



Caption 3.1: Plasma arc reactor in operation **(Plasma Torch System Manual, 2006)**.

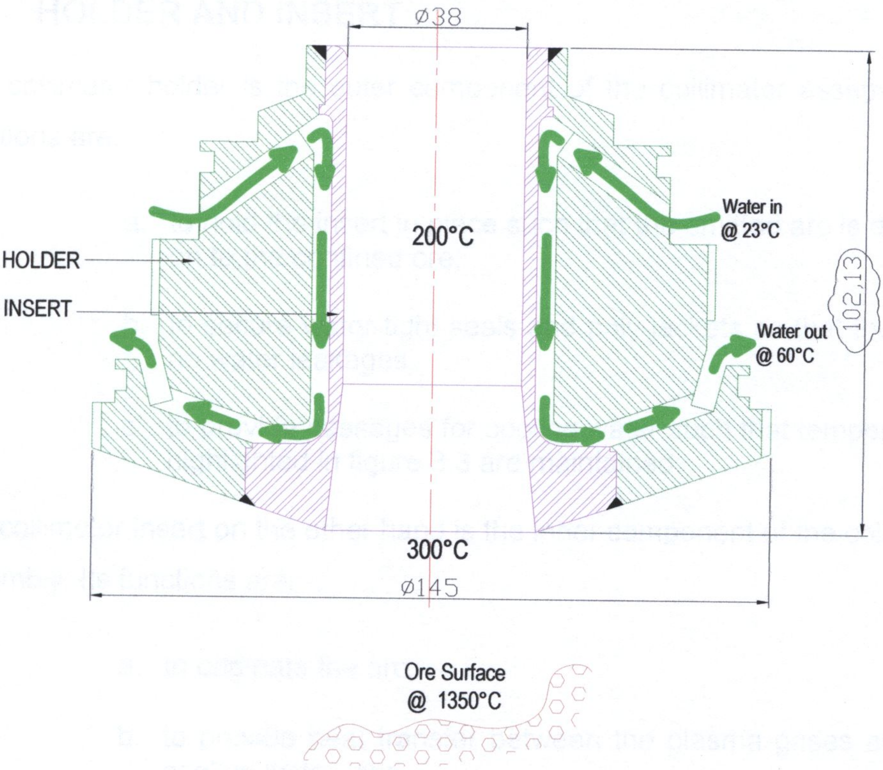


Figure 3.2: The Collimator assembly.

The operating environment of the Plasma Arc Torch is such that the ore surface is as high as 1350°C, which is way above copper melting temperature. The Collimator is positioned in front of the Plasma Arc Torch right above the ore surface. This location increases the likelihood of premature melting of the Collimator. Circulating cooling water helps reduce the temperature of the Collimator to within 200°C to 300°C, at which it can operate safely.

The advantages of the plasma arc furnace technology are significant. Plasma arc technology offers opportunities to reduce overall cost of smelting, improved recovery efficiency of copper-ore and use of fine-grained domestic ores. Technical advantages of the plasma-arc process include less critical requirements for ore and carbon reductions, a relatively large range of suitable slag compositions, continuous feeding of the smelting furnace materials, reduced environmental problems and high recovery of copper ore.

3.3 HOLDER AND INSERT

The collimator holder is the outer component of the collimator assembly. Its functions are:

a. to hold the insert in place such that the emitted arc is directed on to the confined ore,

b. to secure water-tight seals and poly-jackets so that there are no water leakages,

c. to provide passages for cooling water such that temperatures highlighted in figure 3.3 are maintained.

The collimator insert on the other hand is the inner component of the collimator assembly. Its functions are:

a. to originate the arc,

b. to provide heat transfer between the plasma gases and the cooling water, and

c. to shield cooling water from leakages.

Failure to operate within the above-specified functions would render the assembly unusable. Thus, a water leakage at temperatures as in figure 3.3 would lead to explosions that could cause permanent damage to the reactor.

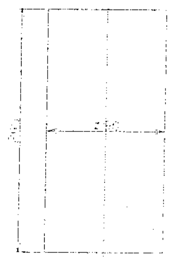
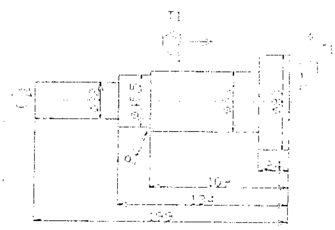
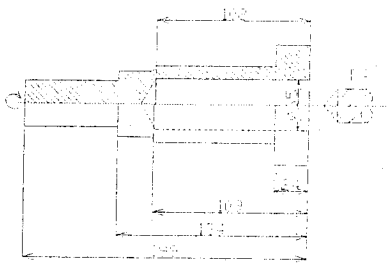
3.4 PRODUCTION PROCESS SHEET

A production drawing of the collimator assembly was developed from collimator samples as well as from the armature drawings provided by the user, *Chambishi Metals Plc.* Primary production drawings were done in AutoCAD 2006 platform. Solid model drawings were in Solidworks 2005 platform. Appendix A shows the production drawing.

Tables 3.1, 3.2 and 3.3 are production sheets that were designed prior to and whilst the works were going on. Both workpiece billets were cast using a Cupola furnace situated at *Heroes Foundry Limited* in Lusaka heavy industrial area. All pre-machining works were done on a turret lathe (situated at

University of Zambia – Mechanical Workshops). The Supermax 3-axes CNC VMC, on the other hand, was used to perform precision machining.

Table 3.1: Collimator insert process sheet.

Part Name: **Collimator Insert**		Part no. COL001		
Date: N/A		Material: 93Cu4Co2Zn1Al		
		Quantity: 01		
Operation no.	**Operation description**	**Standard Machine/ Tool**	**Alternate machine**	**Other specs e.g. design sketches, etc.**
1	-Cast insert workpiece	-Cupola furnace		
2	-Pre-machine (turning and facing)	-Turret lathe		
3	-Pre-drill to Ø35	-Turret lathe		

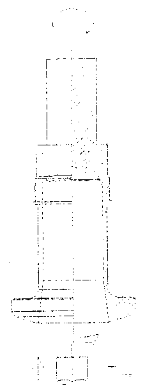
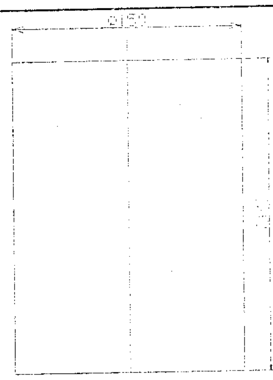
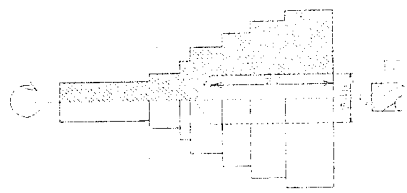
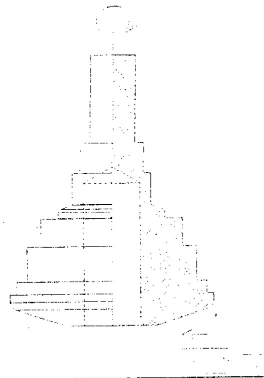
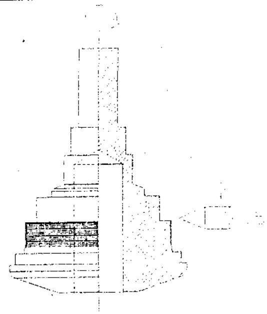
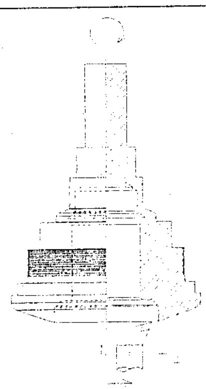
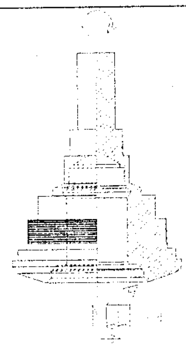
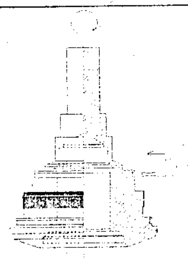
4	-Mounting work piece -Mounting turning tool -Zeroing -Turning (CNC insert program no.1) -Record force readings, chip dimensions, iteratively.	-Supermax CNC VMC		
5	-Re-mounting turning tool -Zeroing -Turning (CNC insert program no.2) -Record force readings, chip dimensions, iteratively.	-Supermax CNC VMC		
6	-Mounting boring tool -Zeroing -Boring (CNC insert program no.3) -Record force readings, chip dimensions, iteratively.	-Supermax CNC VMC		

Table 3.2: Collimator holder process sheet.

Part Name: **Collimator Holder**		Part no. COL002		
Date:		Material: 93Cu4Co2Zn1Al		
		Quantity: 01		
Operation no.	**Operation description**	**Standard Machine/ Tool**	**Alternate machine**	**Other specs e.g. design sketches, etc.**
1	-Cast holder workpiece	-Cupola furnace		
2	-Pre-machine (turning and facing)	-Turret lathe		
3	-Pre-drill to Ø40	-Turret lathe		
4	-Mounting work piece -Mounting turning tool -Zeroing -Turning (CNC holder program no.1) -Record force readings, chip dimensions, iteratively.	-Supermax CNC VMC		

5	-Re-mounting turning tool -Zeroing -Turning (CNC holder program no.2) -Record force readings, chip dimensions, iteratively.	-Supermax CNC VMC		
6	-Mounting threading tool -Zeroing -Threading (CNC holder program no.3) -Record force readings, chip . dimensions, iteratively.	-Supermax CNC VMC		
7	-Mounting boring tool -Zeroing -Boring (CNC holder program no.4) -Record force readings, chip dimensions, iteratively.	-Supermax CNC VMC		
8	-Boring/Chamfer (CNC holder program no.5) -Record force readings, chip dimensions, iteratively.	-Supermax CNC VMC		
9	-Boring/Chamfer (CNC holder program no.6) -Record force readings, chip dimensions, iteratively	-Supermax CNC VMC		

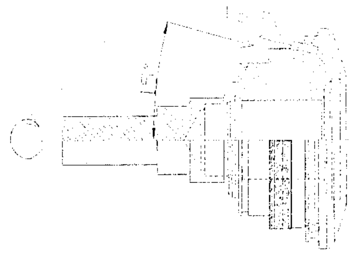
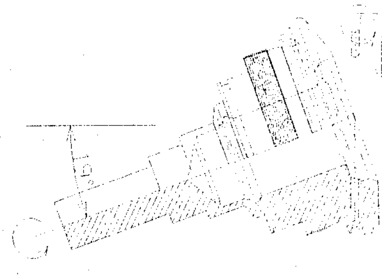
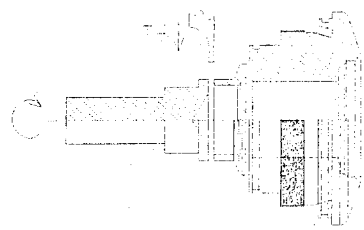
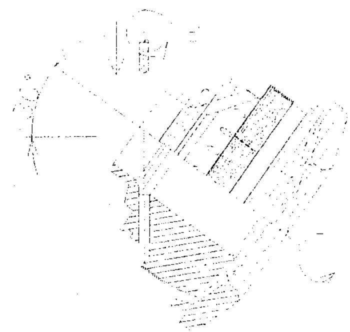
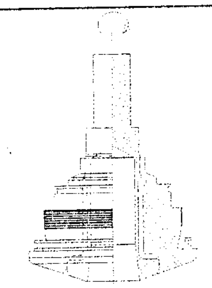
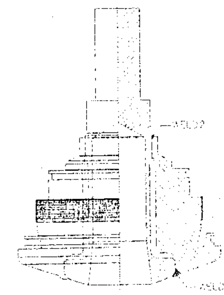
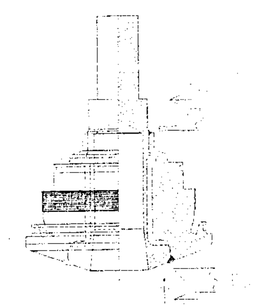
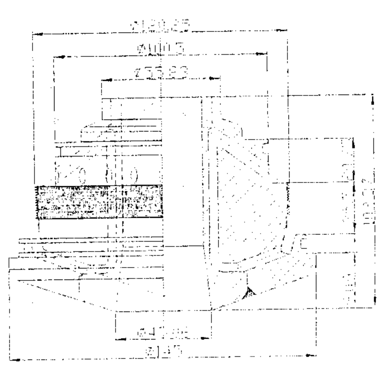
10	-Mounting and setting. -Grooving (circular slot)	-Turret lathe		
11	-Mount dividing head on supermax CNC VMC -Zeroing -Drilling 24xØ5 holes (using CNC drilling program no.1)	-Supermax CNC VMC -Dividing head		
12	-Mounting and setting. -Parting	-Turret lathe		
13	-Mount dividing head on supermax CNC VMC -Zeroing -Drilling 16xØ6 holes (using CNC drilling program no.2)	-Supermax CNC VMC -Dividing head		

Table 3.3: Collimator assembling process sheet

Part Name: **Collimator Holder**		Part no. COL003		
Date:		Material: 93Cu4Co2Zn1Al		
		Quantity: 01		
Operation no.	**Operation description**	**Standard Machine/ Tool**	**Alternate Machine**	**Other Specs e.g. design sketches, etc.**
1	-Place cut collimator holder and insert together as shown.	Work table		
2	-Mount in bench vice. -Conduct weld1 -Conduct weld2 (employing welding procedures at section 3.5)	Work bench		
3	-Clean up weld -Parting	-Turret lathe		
4	-Filing and sanding sharp edges	-Work bench -File -Fine grade sand paper		

3.5 WELDABILITY OF COPPER AND COPPER ALLOYS

Copper and copper alloys remain to this day among the most important engineering materials due to their good electrical and thermal conductivity, corrosion resistance, metal-to-metal wear resistance and distinctive aesthetic appearance. Copper and most copper alloys can be joined by welding, brazing and soldering. This section gives a brief guidance on processes and techniques that are used in fabricating copper alloy components without impairing their corrosion or mechanical properties or introducing weld defects. **(Copper Welding Procedures, 2006).**

Welding processes such as Gas Metal Arc Welding (GMAW) and Gas Tungsten Arc Welding (GTAW) are commonly used for welding copper and its alloys, since high-localized heat input is important when welding materials with high thermal conductivity. Manual Metal Arc Welding (MMAW) of copper and copper alloys may be used although the quality is not as good as that obtained with the gas shielded welding processes. The weldability of copper varies among the pure copper grades A, B and C. The high oxygen content in tough pitch copper can lead to embitterment in the heat-affected zone (HAZ) and weld metal porosity. Phosphorus deoxidized copper is more weldable, with porosity being avoided by using filler wires containing deoxidants (Al, Mn, Si, P and Ti). Thin sections can be welded without preheat although thicker sections require preheats up to 200°C. Copper alloys, in contrast to copper, seldom require preheating before welding. The weldability varies considerably amongst the different copper alloys and care must be taken to ensure the correct welding procedures are carried out for each particular alloy to reduce the risks of welding defects.

CHAPTER 4

THE 3-AXES VERTICAL MILLING CENTRE (VMC)

4.1 INTRODUCTION

Machine tools are the basis of all industrial production. Neither mining and mineral processing, agriculture, car industry, medical health nor aeronautics could exist without precise machine tools.

This chapter describes the experimental setup of the research in totality. It starts with a highlight of machine features of the current and unmodified machine tool and compares it with the modified one. Features such as work holding, cutting tools, tool holding and tool force measurements are discussed here. Ways of establishing the Zero Reference Point (ZRP) are also explored.

4.2 THE SUPERMAX 65A

The Supermax 65A is part of the 3-axes Vertical Centre Series (VC-series) of powerful, economical and compact Vertical Machining Centres (VMCs) manufactured by *Yeong Chin Machinery Industries* of Taiwan. It is made from a full-casting design with large sized ball screws and sliding guide ways, which provide for digital control and drive for precision **(Supermax - Operator Manual, 1969)**.

The machine tool used in the works of this study is called YCM-VMC-65A Supermax (trade name). It is also known as the Supermax 3-axes CNC VMC (technical name). Its basic design and construction features include the following:

i. **A rigid cast iron base:** this is the main member that provides a basis for and a connection between the spindles and slides. The base and bed are hardened, ground, and are automatically lubricated to minimize the friction resistance and stick up.

ii. **Vertical spindle:** it fits the requirements of the various materials and working conditions. It is provided with an orientation mechanism which allows both clockwise and counter-clockwise rotation about the spindle axis. The main spindle is installed with high accuracy and high-speed angular ball bearings. It has infinitely variable speeds of between 0 to 6000 rpm.

iii. **Sideways:** these are designed to respond quickly to command signals and offer constant frictional resistance.

iv. **Three axes:** these are the X, Y and Z axis. Each of which has its own servo stepper motor. The motors are designed to control slide positioning and acceleration.

v. **Armless automatic tool changer unit:** this is the feature used when changing the tools. It delivers and collects tools pneumatically to and from the machine tool spindle.

vi. **Coolant system:** the coolant is pumped from a reservoir tank situated somewhere under the machine to where the cutting process is taking place.

vii. **Control panel:** this is where the machine is controlled.

4.3 MODIFIED MACHINE TOOL SETUP

The Indexable Horizontal Turret concept is the design concept that was used in this work. In this setup, a tool-holding fixture was carried on the existing machine tool table. The existing 'live' vertical spindle was provided with a specially designed mechanism to allow holding of the workpiece.

4.3.1 WORKPIECE HOLDING

The term workpiece holder includes all devices that hold, grip, or chuck a workpiece during manufacturing operations. The holding force may be applied mechanically, electrically, hydraulically or pneumatically.

A work holder must position or locate a workpiece in a definite relation to the cutting tool and must withstand holding and cutting forces while maintaining that precision location. A work holder is made up of several elements, each performing a certain function. The locating elements position the workpiece; the structure or tool body withstands the forces; brackets attach the work holder to the machine; and clamps, screws and jaws apply holding forces. These may have manual or power activation. All functions must be performed with required firmness holding, accuracy of positioning, and with a high degree of safety for the operator and the equipment **(Kalpakjian, 1995)**.

The work-holding fixture adopted during the research work was an existing standard tool holder (BT 40 taper). To use the standard tool holder, the workpiece diameter was reduced at one end to 32mm so that it could fit in the hole of the tool holder (figure 4.1). The workpiece was then fitted into the tool holder hole and the two fastening screws for holding the tool were tightened. The assembly was then held in the machine spindle in the same way an ordinary tool is mounted in the spindle using the pneumatic botton.

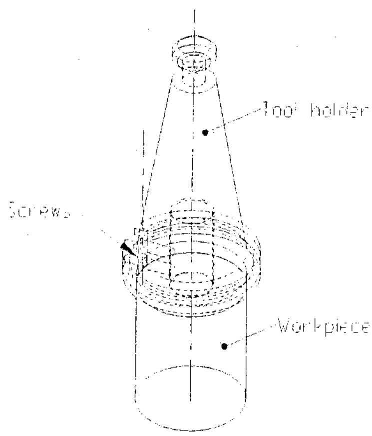


Figure 4.1: Tool holder workpiece assembly.

4.3.2 TOOL HOLDING FIXTURES

The turning tool holding fixtures used in Mwanza's (2001) and Daka's (2002) work were employed. The fixture was made of a round rigid base and a stem. Welded on top of the stem was a grooved block. The groove was in such a way that makes it possible for a standard tool holder to be fastened with screws. The standard tool holder supports various sizes of standard HSS tool profiles. Drawings of the turning tool-holding fixture and its components are shown in appendix B.

Unlike the turning tool-holding fixture, the boring tool-holding fixture had a hole drilled in the stem. A standard boring tool with a carbide insert was placed in the drilled hole and fastened by screws. Drawings of the boring tool-holding fixture and its components are shown in appendix C.

4.3.3 CUTTING TOOLS

Tools that could turn as many profiles in the same tool setup as possible were designed and manufactured by following guiding principles outlined in chapter 2. These tools were:

a) Turning tool,

b) Threading tool and

c) Boring tool.

All tools were made of high speed steel (HSS) except for the boring tool which, in this case, was a standard diamond shaped carbide tip. Some of the considerations that were incorporated in the design of the tools were:

a) **Workpiece size:** the shape, dimensions and working allowances of the workpiece determined the size and angles of the tool.

b) **Limitations:** the tool was made such that there were as little vibrations as possible so that accuracy and surface finish were maintained within the parameters specified on the production drawings.

c) **Stability:** stability relating to rigidity to absorb the vibrations generated from the machining process.

d) **Setup:** the tool was also designed in such a way that it was easy to setup and to position.

e) **Method of Manufacturing:** the principle operation that was used in forming the cutting tools was fine stone grinding.

Figures 4.2 and 4.3 are designs of the turning tool and the threading tool, respectively. For the turning tool, the rake angle was six degrees whilst the clearance angle was nine degrees. Note that as stated earlier the boring tool tip was a standard carbide tip.

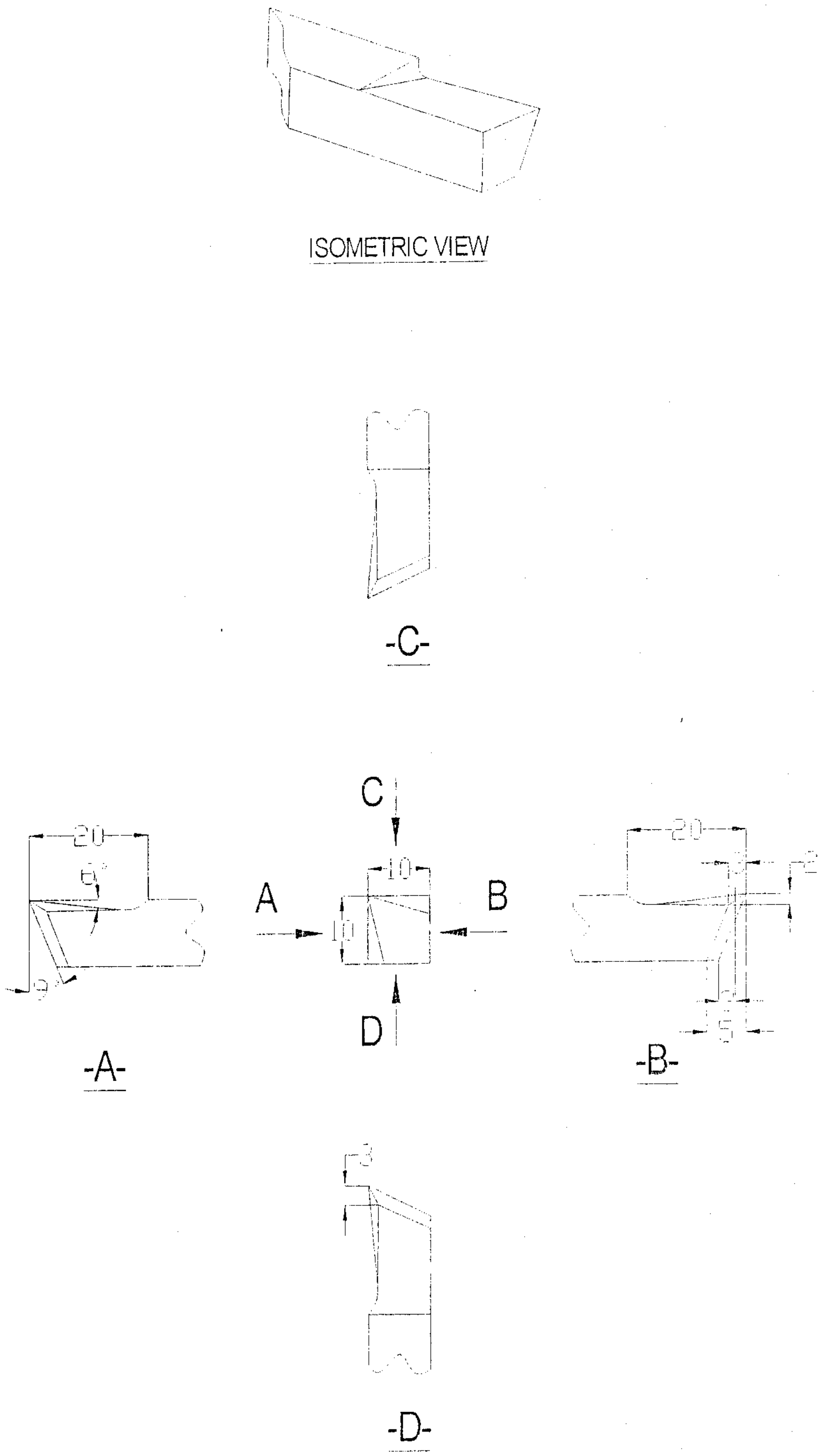


Figure 4.2: Turning tool tip.

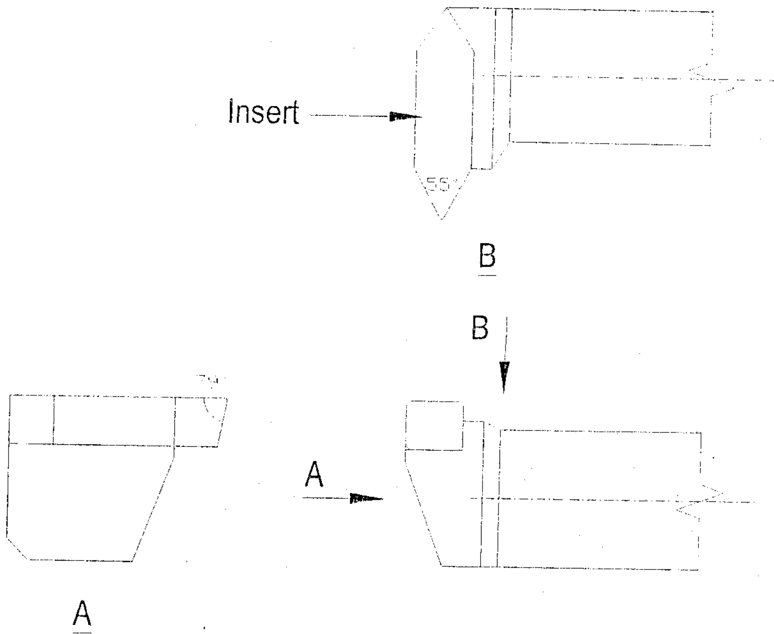


Figure 4.3: Standard threading tool tip.

Even though the multi-point cutting tool developed by Daka (2002) was the most suitable to perform machining operations with a better surface finish yield, the size of the workpiece and certain small radii in the workpiece finishing profiles, could not permit its use. With the help of Mastercam software, a single-point cutting tool was employed and was able to give equally better surface finish yield.

4.3.4 WORKPIECE DESIGN

The following procedure was followed:

a) Two copper billets (93Cu4Co2Zn1Al) were cast. One for the insert and the other for the holder, with dimensions ∅90x205 and ∅150x205, respectively.

b) The two billets were then pre-machined on turret lathe to dimensions shown in figure 4.4 and figure 4.5. The reason for pre-machining was to reduce the weight for handling purposes as well as to have material enough only for finishing on the CNC machine tool.

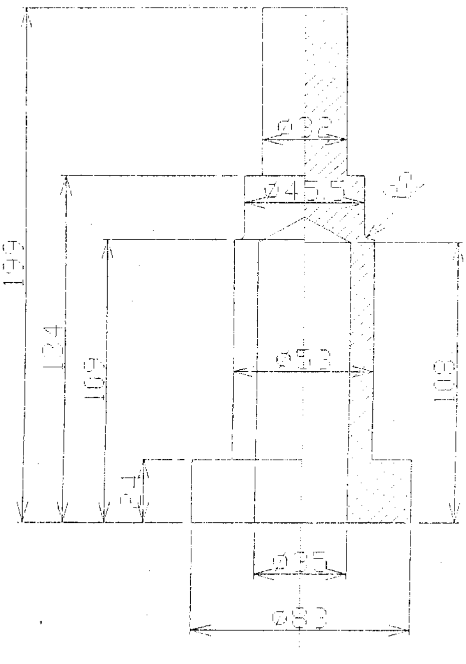


Figure 4.4: Insert workpiece.

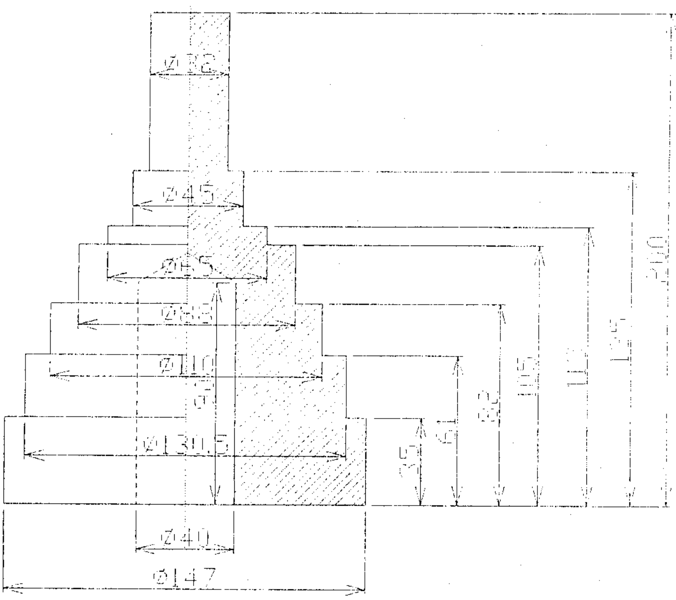


Figure 4.5: Holder workpiece.

4.4 DRILLING SETUP

The drilling setup was designed to drill radially and angularly positioned holes on both ends of the collimator holder. It was also meant to take advantage of the precision of the CNC machine tool and the ability of the dividing indexing head to position the workpiece at various angles. Figure 4.10 shows the drilling setup.

4.5 EXPERIMENTAL SET-UP PROCEDURES

4.5.1 PROCEDURE FOR TURNING, THREADING AND BORING

The setups for turning, threading and boring were similar, so the procedures were more or less the same. The following procedure was followed to set up the experimental rigs as shown in figure 4.7, for turning, figure 4.8, for threading, figure 4.9, for boring and figure 4.10, for drilling. Thus;

1) The manufactured appropriate tool was clamped in its right position as per operations' setup,

2) The workpiece was clamped in the standard tool holder using the two screws for clamping tools. The workpiece assembly was then mounted onto the machine spindle using the manual tool clamp button,

3) The zero reference point was then established as outlined in section 4.5.3,

4) Depending on the size of the part program, either it was loaded onto the MCU from a remote terminal where it was used to run the machine tool, or it was run from the remote terminal to operate the machine tool via DNC. The former case was applicable for short part programs while the latter for long ones,

5) After a short dry run, the machine was then run to produce the required profile.

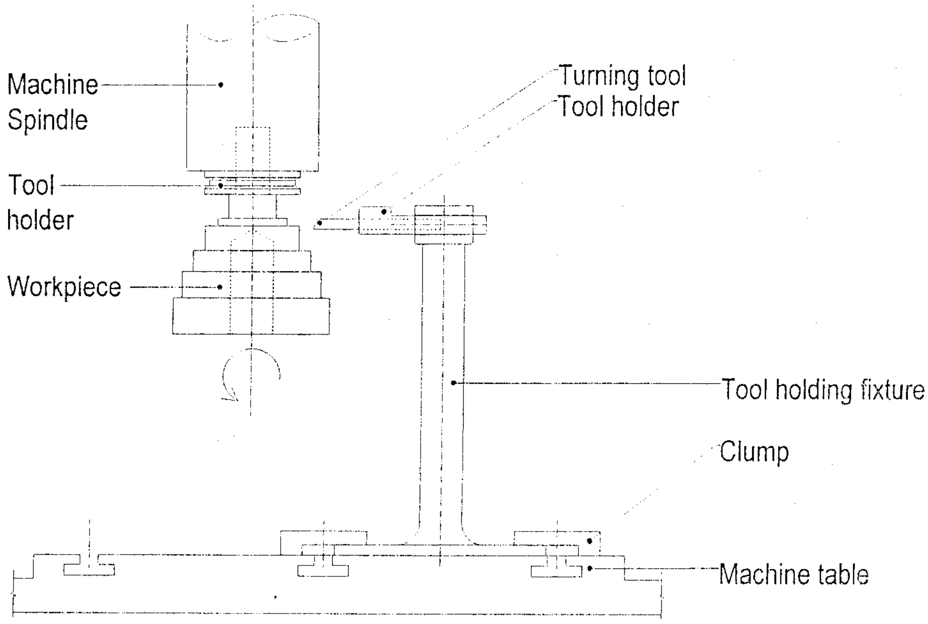


Figure 4.7: Turning setup.

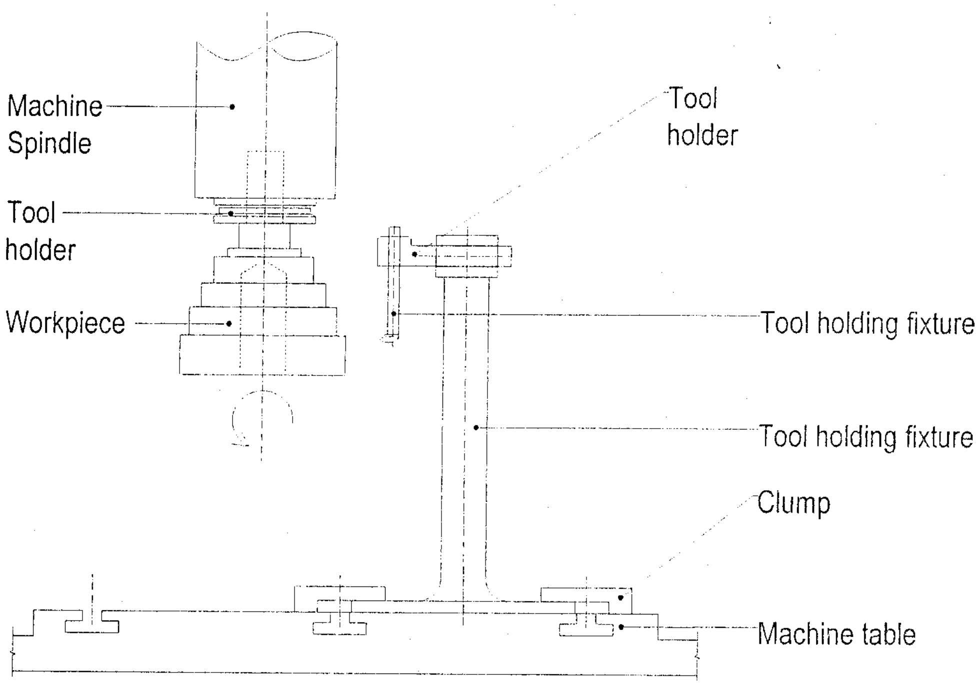


Figure 4.8: Threading setup.

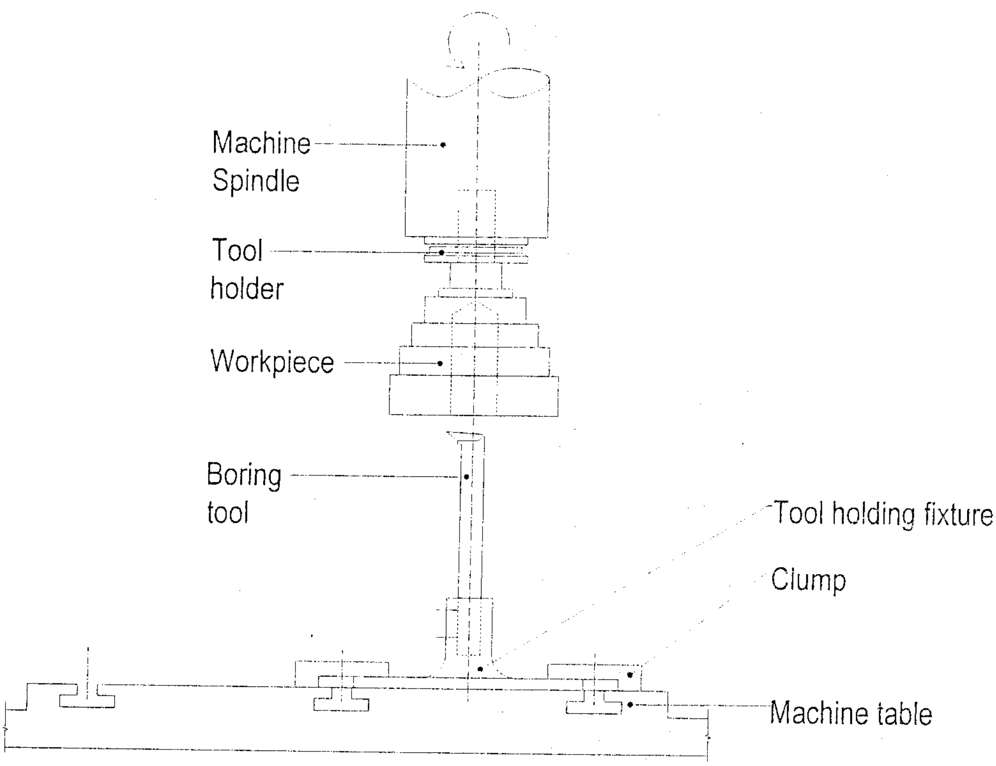


Figure 4.9: Boring setup.

4.5.2 PROCEDURE FOR DRILLING

The setup for drilling operation was more complex.

1) The machine tool was loaded with appropriate centre drill and drill bits in the tool spindle.

2) The dividing indexing head was loaded with the workpiece and set on the machine table.

3) The dividing indexing head – workpiece configuration was then set at an appropriate angle and position of the hole as defined in the production drawings.

4) The zero reference point was then established.

5) With the machine tool in 'handle mode' and the centre drill in the spindle, the dividing indexing head was reset for each successive hole position until all were centre drilled.

6) The machine was then run to drill each successive hole, every time resetting the dividing indexing head for the next hole until all were drilled (see caption 4.1 and 4.2).

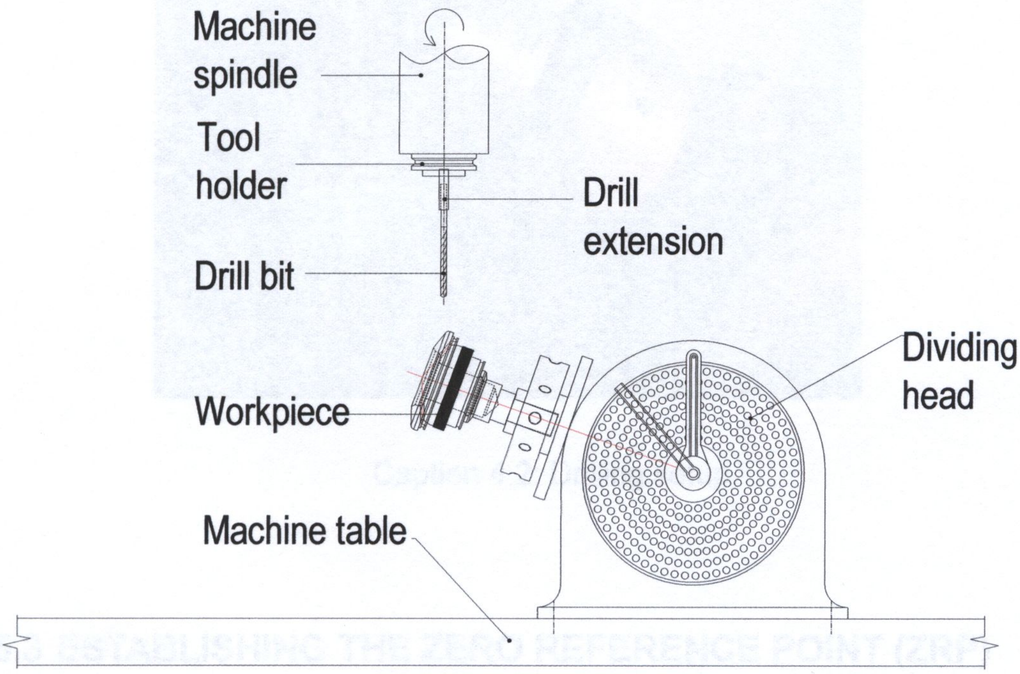
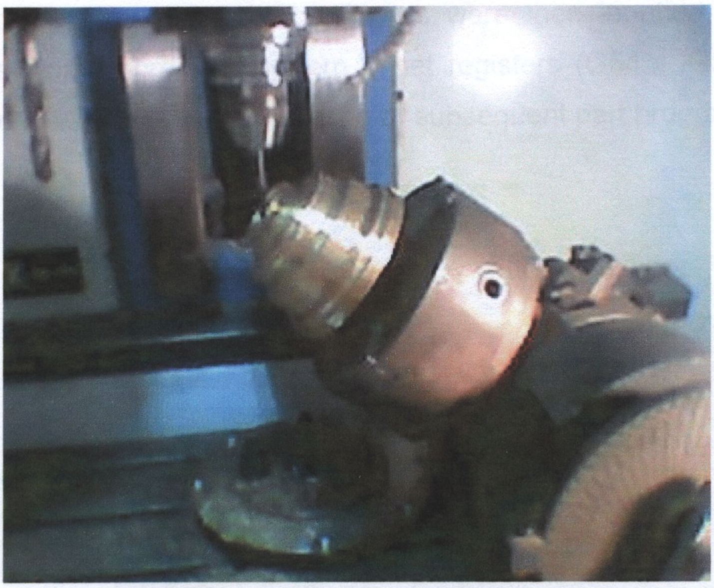


Figure 4.10: Drilling setup.

Caption 4.1: Setting the dividing head.



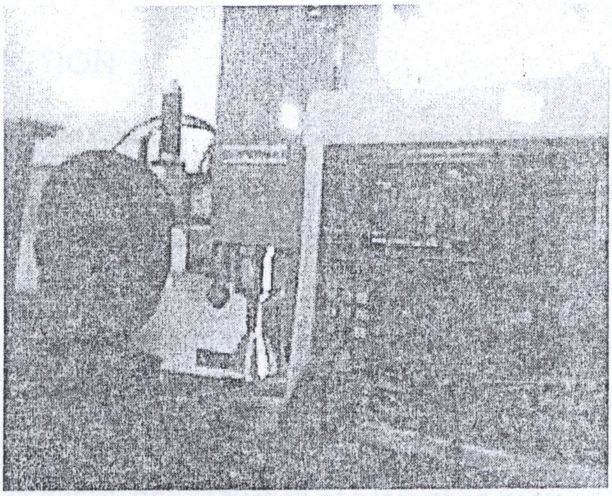
Caption 4.2: Drilling setup.

4.5.3 ESTABLISHING THE ZERO REFERENCE POINT (ZRP)

Before performing any operations on the Supermax 65A CNC VMC, the zero reference point must be established. In this work, the following procedure was adopted when setting the ZRP. First, the spindle, carrying the workpiece, was switched on at a low speed, say 100 rpm, and the control display set to POS (overall positions setting). The workpiece was brought near the fixed and stationery tool on the machine table. Then carefully the bottom of the workpiece was made to touch (or rub) against the top of the cutting tip of the tool. When the tool just established contact (which normally is detected by a rubbing noise created by the light impact), the Z coordinates appearing on the display were recorded (see caption 4.3).

When setting for the X and Y coordinates, the workpiece was replaced with the XYZ (3D) dial gauge probe, but this time with the spindle off. The equator of the ball probe was made to touch the tip of the tool (the pointer on the probe deflects when contact is established) from the X and Y directions, whilst recording the X and Y coordinates simultaneously from the control display. The radius of the ball was incorporated in the recordings accordingly.

The recorded X, Y and Z coordinates were then inputted into any of the machine work coordinate system offset registers (G54,...,G59), which must correspond with that in the incoming or subsequent part program.



Caption 4.3: Establishing the Zero reference point (ZRP).

CHAPTER 5

COMPUTER NUMERICAL CONTROL PROGRAMMING

5.1 INTRODUCTION

Controlling a machine tool by means of a prepared program is called Numerical Control (NC), as defined by the Electronic Industrial Association (EIA). The precursor of the CNC-technology was Numerical Control. With Numeric Control, the machine tool is controlled with the help of characters. The system automatically converts them into output signals. These signals, in turn, control various machine components such as turning spindles on and off. The vitality of Numerical Control is in the fact that it takes care of the increased concern over product quality and reduction of production costs.

This chapter seeks to explain how Numerical Control (NC) programs for the production of a collimator were developed from the process sheets outlined in chapter 3. Various ways of programming were used in coming up with a perfect code.

5.2 METHODS OF PROGRAMMING

The Supermax 3-axes CNC VMC has successfully been adapted to perform both milling and turning operations. Therefore, in this context, programming involves determining the position of the tool with regards to the workpiece in a Standard ISO Alfa-Numeric code. This code is processed by the machine control unit (MCU) and read by the control system.

Prior to writing a program, it is essential to have knowledge of the following;

i. material of the workpiece,

ii. the cutting speed,

iii. the sequence of machining,

iv. methods of production; type of machine tool, fixtures and tools available,

v. workpiece drawings,

vi. workpiece holding techniques and

vii. metal removing technologies, for example milling, drilling, turning, et cetera.

A process sheet is used to organise the operations. Collimator process sheets were developed in Tables 3.1, 3.2 and 3.3. A starting point when planning to machine a workpiece is to study the workpiece drawing and the selected appropriate stock. This assists the programmer to determine the part that has to be cut to get to the desired profile.

Programming can be done directly at the machine or on an offline PC (personal computer). Programming on the machine can be done by Standard ISO Alfa-Numeric code programming or by conversation. Offline programming can be done with a word processor or CAD/CAM software.

5.2.1 ONLINE PROGRAMMING

G-code programming on the machine is only convenient when it involves simple products with minimum calculations (see caption 5.1). The more modern CNC-machine tools offer the possibility to simulate the cutting process graphically. In this way, the operator can easily check the program and avoid accidents.

Even though it is easy to manipulate programs in online programming, it is ideal for relatively short programs (less than 50 lines). The longer the program the more cumbersome it becomes to handle.

This method of programming was combined with the CAD/CAM software and thus avoiding the cumbersome way of having to calculate all the points of the contours.

5.2.4 EXTERNAL PROGRAMMING WITH CAD/CAM SOFTWARE

The CAD/CAM software that was used in this study was Mastercam V9, an integrated CAD/CAM software package created by *CNC Software, Inc.*

With this software, the basic geometry of the workpiece was drawn in a CAD environment. After this, tool parameters were defined and toolpaths generated in a CAM environment. After verification of the toolpaths, the next stage that followed was post processing, where two file formats were generated, the NCI file and the NC file. NCI is the acronym for numerical control intermediate, the Mastercam intermediate toolpath file format. It is the intermediate file that contains the coordinate values of a series of cutter paths, along with machining information such as feed rate, spindle speed, coolant control, etc. The post processor converts the NCI file into an NC program. NC is an acronym for numerical control; it is the file format output from Mastercam post processors.

The NC program can be opened and read using any text editor. One or two of the following file editors is incorporated in Mastercam software:

a) MCEDIT – A Mastercam text editor that also provides utilities for editing NC and NCI files.

b) PFE32 – The usual default Mastercam text editor.

c) CNCEDIT – A Mastercam text editor that also provides NC utilities for editing NC and NCI files and DNC capabilities (for example, the ability to download information from an NC file to the machine tool).

d) CIMCOEDIT – An- editor that provides utilities for editing NC and NCI files along with transmission capabilities.

e) Notepad – The default editor for Mastercam's Draft and Demo products.

f) Other – Allows one to choose another editor executable file.

The CNCEDIT text editor was used. Its capabilities were most desired in the works of this study.

5.2.5 PROGRAMMING FOR TURNING AND BORING OPERATIONS

Ideally, conventional vertical milling centres (VMCs) are designed to accommodate the cutting tool in its spindle and the workpiece stationed at the machine table. As a result, the tool rotates and is fed into the workpiece. The modification adopted meant that, the workpiece rotated about the spindle (Z-axis) while the tool moved only in the X-Y plane. Considering the modifications, programming was not as straight forward as it required that the machining was carried out in such a way that material was removed from the tool, which in this case was the rotating workpiece. To overcome these difficulties, it was found that the use of Mastercam provided a better solution.

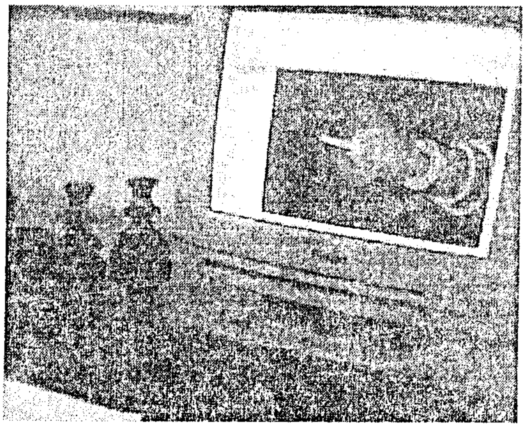
The following is a basic way of writing programs for turning operations for the Supermax 3-axes CNC VMC using Mastercam V9 software package. This procedure requires understanding of Mastercam Mill and Mastercam Lathe, and to know differences between a Mastercam Mill and Mastercam Lathe NC part program. Further, the programmer must understand the basic operations of the Supermax 3-axes CNC VMC machine tool. With this understanding, the procedure used was:

1. to draw the part programmes in Mastercam Lathe or any other CAD graphics software (such as AutoCAD which can be read by Mastercam converters) and have it imported to Mastercam environment. Since in turning operations, workpieces turn about the line of symmetry, only half of the profile is drawn. It would be better to have a part drawing with the chuck, the workpiece stock and the workpiece final profiles. This serves time of having to configure them independently at a later stage.

2. move the elements of the drawing such that the intersection between the line of symmetry and the furthest point on the stock profile lies at (0,0) on the (D+,Z) plane. This step is essential since this point coincides with point (0,0,0) on the machine tool.

3. configure the Mastercam Lathe Job Setup sheet boundary options for the stock, chuck and display options and the general options for workpiece material.

4. use the Operations Manager to generate, sort, edit, regenerate, verify, backplot, and verify any operation (see caption 5.2). For any operation, tool number is equal to the offset number which is equal to the station number.



Caption 5.2: Mastercam Verify simulation of machining of a collimator holder.

5. when posting any operation do not choose the post processor for Lathe, MPLFAN.PST. MPFAN.PST is a general Lathe post processor for Fanuc series of machines. Choose the one for Mill, MPFAN.PST, which is also for Fanuc series of machines.

Having generated an NC file, it should be examined using a text editor. Note that the generated NC file cannot be used in its raw form since it contains several "bugs" that need rectification. The text editor's 'find' and 'replace' capability makes it easy for any neophyte to rectify the "bugs" if they are known. The following is a list of changes that needs to be made:

1. *Replace 'G17' with 'G19'*, since circular interpolations are now in Y-Z plane.

2. *Delete 'A0.'*, since there is no angular positioning on the principle axis, which in this case is the Z-axis.

3. *Delete 'G43H0'*, since the tool length compensation was taken care of at stage when the reference point was shifted to the *origin* in Mastercam Lathe.

4. *Swap 'G2' for 'G3' and vice versa*, tool radius compensation in Mastercam Lathe is a mirror of that in Mastercam Mill.

5. *Swap 'X' for 'Y'* and vice versa, this is in accordance with the tool setup on the machine table, which gives more room for tool movement in the Y-axis direction than the X-axis. Swapping the two axis was found to be the best solution.

6. Depending on the direction of feed, either leave the spindle rotation direction at 'M3', for clockwise, or 'M4', for anticlockwise,

7. Introduce 'G54' or any other work co-ordinate G-code.

For step 4, the following algorithm was used;

Let, G2 = $$$$. Then, G3 = G2. And finally let, $$$$ = G3. $$$$ is an arbitrarily chosen character. Any other character which Mastercam post processor does no use in its NC programs could be employed.

For step 5, which is similar to step 4,

Let, Y = $$$$. Then, X = Y. And finally let, $$$$ = X. Similar reasoning as in step 4 applies.

The part program is now ready to be sent to the machine tool via DNC. Appendix F shows an outline of how to prepare the CNC machine tool and configure the remote computer to perform DNC operations.

5.2.6 PROGRAMMING FOR THREADING OPERATIONS

The threading program needs a different approach since the 'usual' post processor MPFAN.PST cannot generate essential workpiece profile coordinates needed to machine a left handed thread of gauge 12G 1/2 9/16" on the Supermax CNC VMC.

When programming for threads using Mastercam V9, the procedure from section 5.2.5 is followed, except that in step 5, the normal post-processor for Mastercam V9 Lathe, MPLFAN.PST was used.

Having generated an NC file, it should be examined using a text editor The following is a list of changes that needs to be made to the generated NC program:

1. Introduce a number system in the program starting with 10, and then increasing in steps of 10,

2. Insert the standard initialisation line, N__ G54 G19 G40 G49 G80 G90,

3. *Replace "G32" with "G33"*. "G33" is the standard numeric code for threading in a Milling Centre while "G32" is a Turning Centre.

4. *Replace "E" with "F"*. "E" is the standard numeric code for feed in Milling Centre while "F" is for a Turning Centre.

5. *Replace "M3" with "M4"*, for an anticlockwise spindle rotation so that a left-handed thread is generated.

6. *Swap "X" for "Y"* and vice versa, similar reasoning as in section 5.2.5, step 5 apply.

7. *Divide all "X" and "Y"* coordinates by 2,

8. Line by line, eliminate all codes and lines unfamiliar to the CNC machine tool. Note that the flow of lines is repetitive in nature,

The part program is now ready to be sent to the CNC VMC machine tool using procedures in appendix F.

CHAPTER 6

EXPERIMENTATION AND RESULTS

6.1 INTRODUCTION

This chapter presents the outcome of the production processes of the collimator assembly. The results were segmented into four categories; namely, part-programs, dimensional tolerances, surface roughness, forces and chip formation and process durations. The manufacturing process was done by following the production sheets discussed in chapter 3.

6.2 PART PROGRAMS

Experimental runs were done in three stages. These were:

i. machining of the insert,

ii. machining of the holder and

iii. drilling of holes on the holder.

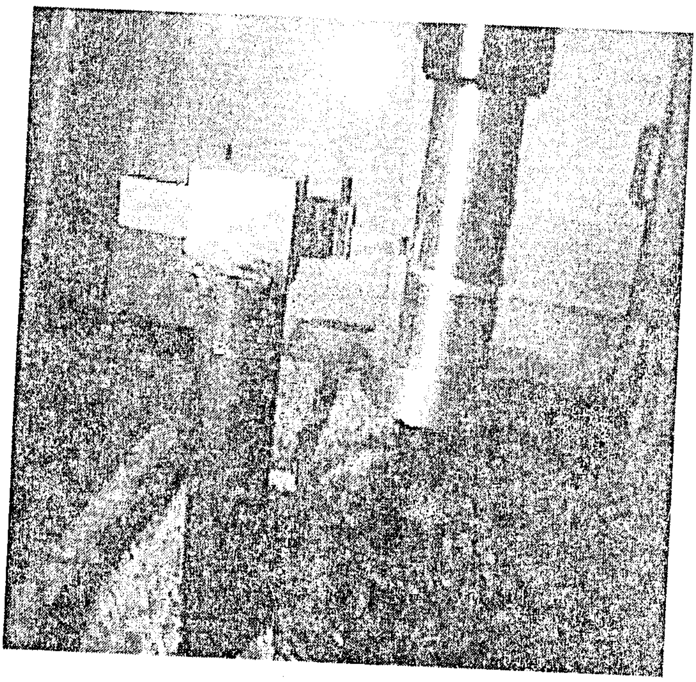
Appendices D and E present original and modified part programs for the insert and the holder including durations of the machining processes. Differences between an original and modified line are boldfaced.

Program 6 and 7 in Appendix E are drilling programs. There was no need of converting them since they were generated first hand for 'milling' (drilling) operations. Program number 6 underwent 24 cycles (was repeated 24 times) in order to drill 24 holes whilst program number 7 underwent 16 cycles in order to drill 16 holes. Therefore, their cycle times are sums of individual drilling cycles.

Cycle times for all the production processes are presented in Tables 6.1, 6.2 and 6.3, and are captioned in captions 6.1, 6.2, 6.3, 6.4, 6.5 and 6.6. Note that the processes are as depicted in chapter 3.

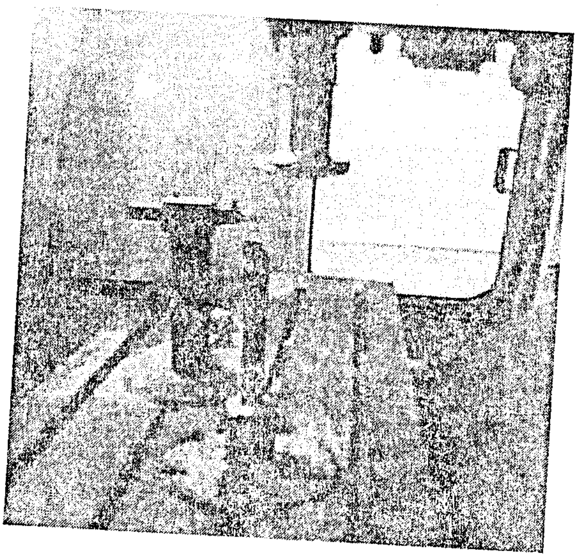
Table 6.1: Actual production cycle times for the collimator insert.

Part Name: **Collimator Insert**		Part no. COL001	
Date: N/A		Material: 93Cu4Co2Zn1Al	
		Quantity: 01	
Operation no.	**Operation description**	**Standard Machine/ Tool**	**Cycle time in minutes**
1	-Cast insert workpiece	-Cupola furnace	540
2	-Pre-machine (turning and facing)	-Turret lathe	90
3	-Pre-drill to Ø35	-Turret lathe	30
4	-Mounting work piece -Mounting turning tool -Zeroing -Turning (CNC insert program no.1) -Record force readings, chip dimensions, iteratively.	-Supermax CNC VMC	120
5	-Re-mounting turning tool -Zeroing -Turning (CNC insert program no.2) -Record force readings, chip dimensions, iteratively.	-Supermax CNC VMC	105
6	-Mounting boring tool -Zeroing -Boring (CNC insert program no.3) -Record force readings, chip dimensions, iteratively.	-Supermax CNC VMC	110



Caption 6.1 Turning of the collimator insert:

Caption 6.2: Boring of the collimator insert.

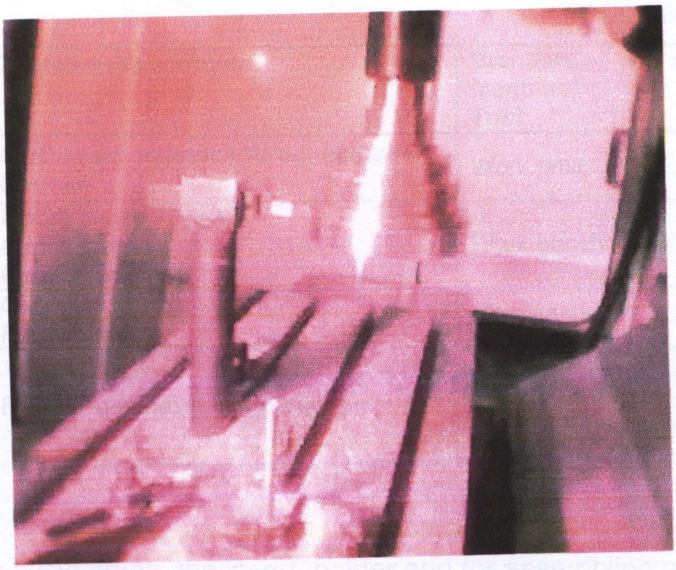


Caption 6.3: Turning and boring tools after completion of turning and boring operations on the collimator insert.

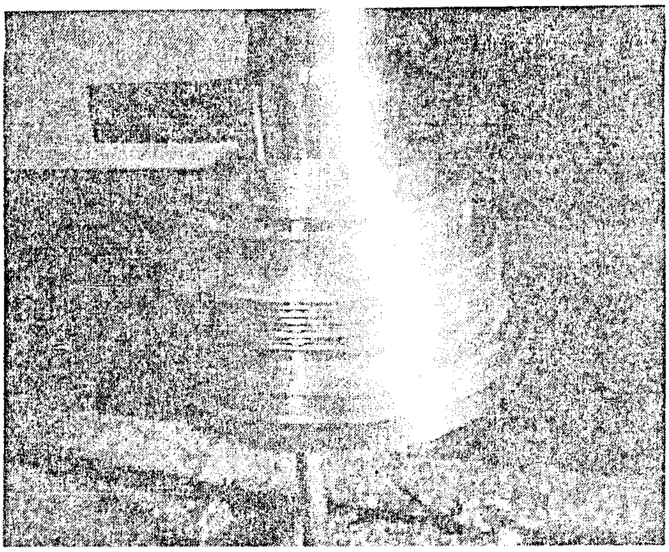
Table 6.2: Actual production cycle times for the collimator holder.

Part Name: **Collimator Holder**			
Date:		Part no. COL002	
		Material: 93Cu4Co2Zn1Al	
		Quantity: 01	
Operation no.	**Operation description**	**Standard Machine/ Tool**	**Cycle time in minutes**
1	-Cast holder workpiece	-Cupola furnace	540
2	-Pre-machine (turning and facing)	-Turret lathe	110
3	-Pre-drill to Ø40	-Turret lathe	30
4	-Mounting work piece -Mounting turning tool -Zeroing -Turning (CNC holder program no.1) -Record force readings, chip dimensions, iteratively.	-Supermax CNC VMC	125
5	-Re-mounting turning tool -Zeroing -Turning (CNC holder program no.2) -Record force readings, chip dimensions, iteratively.	-Supermax CNC VMC	105
6	-Mounting threading tool -Zeroing -Threading (CNC holder program no.3) -Record force readings, chip dimensions, iteratively.	-Supermax CNC VMC	60
7	-Mounting boring tool -Zeroing -Boring (CNC holder program no.4) -Record force readings, chip dimensions, iteratively.	-Supermax CNC VMC	135
8	-Boring/Chamfer (CNC holder program no.5) -Record force readings, chip dimensions, iteratively.	-Supermax CNC VMC	121
9	-Boring/Chamfer (CNC holder program no.6) -Record force readings, chip dimensions, iteratively	-Supermax CNC VMC	22
10	-Mounting and setting. -Grooving (circular slot)	-Turret lathe	60
11	-Mount dividing head on supermax CNC VMC -Zeroing -Drilling 24xØ5 holes (using CNC drilling program no.1)	-Supermax CNC VMC -Dividing head	95
12	-Mounting and setting. -Parting	-Turret lathe	30
13	-Mount dividing head on supermax CNC VMC -Zeroing -Drilling 16xØ6 holes (using CNC drilling program no.2)	-Supermax CNC VMC -Dividing head	86

Caption 6.4: Threading of the collimator holder.



Caption 6.5: Turning of the collimator holder.



Caption 6.6: Boring of the collimator holder

Table 6.3: Actual production cycle times for the collimator assembling.

<table>
<tr><td colspan="2">Part Name: Collimator Holder</td><td colspan="2">Part no. COL003</td></tr>
<tr><td colspan="2">Date:</td><td colspan="2">Material: 93Cu4Co2Zn1Al</td></tr>
<tr><td colspan="2"></td><td colspan="2">Quantity: 01</td></tr>
<tr><td>Operation no.</td><td>Operation description</td><td>Standard Machine/ Tool</td><td>Cycle times in minutes</td></tr>
<tr><td>1</td><td>-Placing cut collimator holder and insert together</td><td>Work table</td><td>10</td></tr>
<tr><td>2</td><td>-Mount in bench vice.
-Conduct weld1
-Conduct weld2</td><td>Work bench</td><td>50</td></tr>
<tr><td>3</td><td>-Clean up weld
-Parting</td><td>-Turret lathe</td><td>10</td></tr>
<tr><td>4</td><td>-Filing and sanding sharp edges</td><td>-Work bench
-File
-Fine grade sand paper</td><td>45</td></tr>
</table>

Summing the cycle times, the insert, holder and for assembling gives the total production time as *2,089 minutes*. This though excludes the time spent on the programming.

6.3 DIMENSIONAL MEASUREMENTS

Important dimensions were taken as per inspection criteria defined by the end user, Chambishi Metals Plc, as well as that given by the original manufacturer of the Plasma arc torch Collimator Assembly, Mitutoyo and Fowler (see Appendix J). Thus, Table 6.4 is a presentation of dimensional measurements and tolerances from the Production Drawings and the actual dimensions as machined. Figures 6.1 and 6.2 show the important dimensional marks whose relations are shown in Tables 6.4 and 6.5, respectively.

The main test measuring instruments that were used were micrometer screw gauges, with precision plus/minus 0.005mm, vernier callipers, with precision plus/minus 0.05mm, inside and outside callipers and a combination square for angles.

Table 6.4: Dimensional measurements for the assembly.

MARKS ON DRAWING	DRAWING (MM)	TOLERANCE (MM)	1 ACTUAL (MM)	2 RESULT (PASS/FAIL)
DIM A	120.650	+ 0.050 - 0.100	120.600	PASS
DIM B	100.500	+ 0.000 - 0.043	100.505	PASS
DIM C	55.800	+ 0.080 - 0.000	55.833	PASS
DIM D	145.000	+ 0.000 - 1.000	141.053	FAIL
DIM E	45.000	+ 0.056 - 0.000	45.056	PASS
DIM F	38.000	+ 0.000 - 0.025	37.995	PASS
DIM G	6 deg.	+ 0.000 - 0.000	6 deg.	PASS
DIM H	102.000	+ 1.000 - 0.000	102.100	PASS
DIM I	20.000	+ 0.880 + 0.600	20.703	PASS
DIM J	25.500	+ 0.005 - 0.005	25.504	PASS
DIM K	9.050	+ 0.080 - 0.000	9.050	PASS
DIM L	135.500	+ 0.002 - 0.000	135.500	PASS

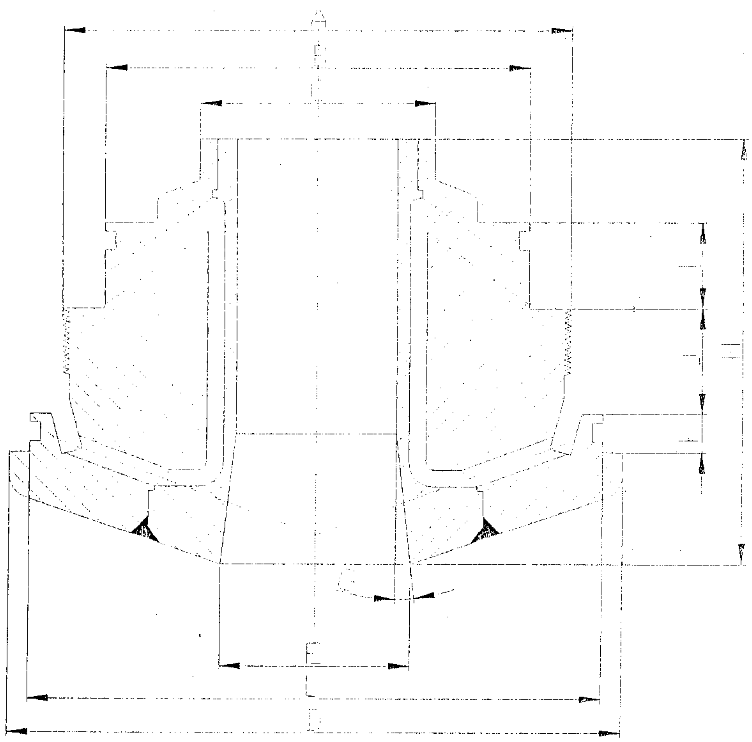


Figure 6.1: Dimensional marks on the assembly.

Table 6.5: Dimensional measurements for the insert.

MARKS ON DRAWING	DRAWING (MM)	TOLERANCE (MM)	1 ACTUAL (MM)	2 RESULT (PASS/FAIL)
DIM M	76.370	+ 0.050 - 0.000	76.350	PASS
DIM N	72.50	+ 0.050 - 0.050	72.55	PASS
DIM O	6.0	+ 0.05 - 0.05	6.0	PASS
DIM P	72.55	+ 0.05 - 0.05	72.55	PASS
DIM Q	71.32	+ 0.5 - 0.5	71.30	PASS
DIM R	47.46	+ 0.02 - 0.00	47.46	PASS
DIM S	50.000	+ 0.000 - 0.035	50.000	PASS

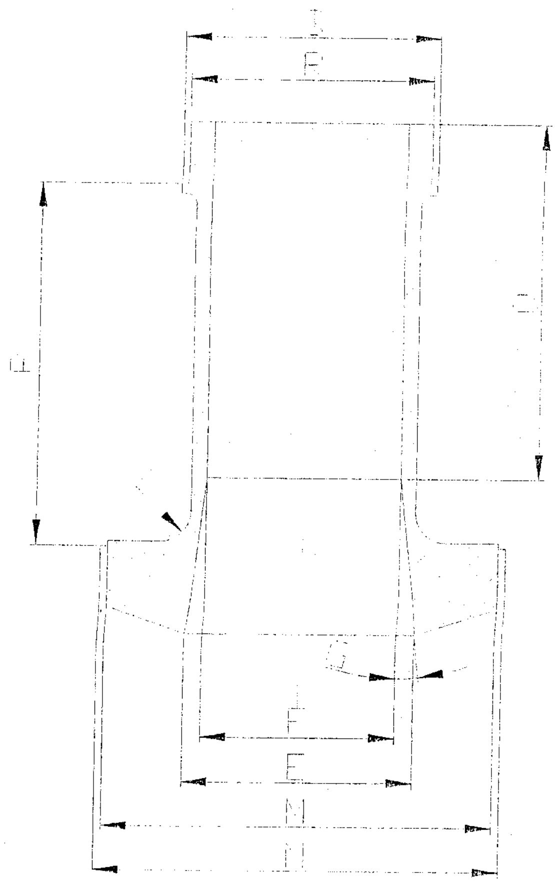


Figure 6.2: Dimensional marks on the insert.

6.4 SURFACE FINISH

Surface finish was measured using the Rank Taylor Hobson 'Talysurf' 4, a method which provides information about the surface in two forms, a graphical representation of the surface profile and a meter indication of the Centre-Line-Average (CLA). This method is recommended in the British (BS 1134:1961) and USA (USA B46:1955) standards and in the ISO R468 recommendations. **(Talysurf 4 - Operator's Handbook)**. Figures 6.3 and 6.4 show markings of regions on the collimator holder profile and the collimator insert profile, respectively, that were measured for surface finish.

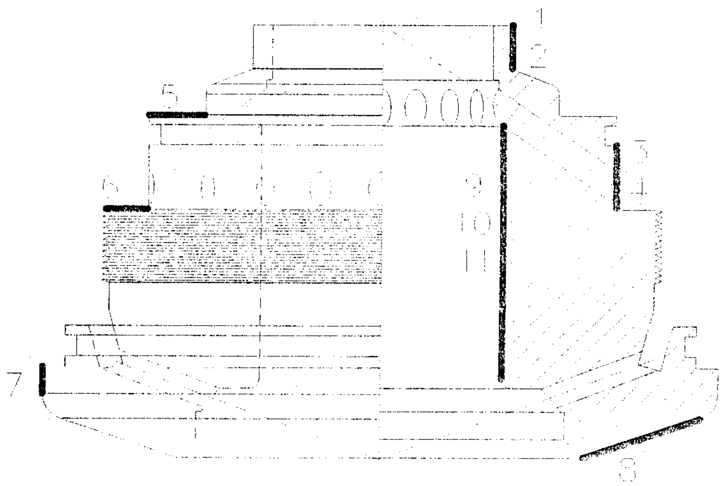


Figure 6.3: Selected areas of surface finish tests on the collimator holder.

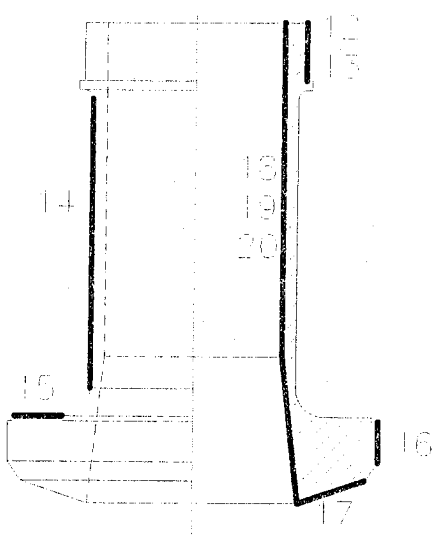


Figure 6.4: Selected areas of surface finish tests on the collimator insert.

Table 6.6 shows results of the tests that were obtained.

Table 6.6: Results of surface finish tests.

Surface of test	Test piece	CLA (microns)
1	Collimator insert	1.68
2	Collimator holder	1.38
3	Collimator holder	0.70
4	Collimator insert	1.18
5	Collimator insert	2.00
6	Collimator holder	1.00
7	Collimator holder	0.92
8	Collimator holder	2.50
9	Collimator holder	2.25
10	Collimator holder	0.60
11	Collimator holder	0.82
12	Collimator holder	1.10
13	Collimator insert	0.50
14	Collimator insert	0.60
15	Collimator insert	0.40
16	Collimator insert	1.60
17	Collimator insert	1.12
18	Collimator holder	2.40
19	Collimator insert	0.50
20	Collimator holder	1.20

6.5 FORCES AND CHIP FORMATION

Table 6.7 presents results that were taken from the machine tool during the runs of the production processes, as shown in figure 6.4 and figure 6.5. Diameters where measurements were taken were marked from '1' to '12'.

The Supermax CNC VMV machine tool has inbuilt load sensors on each of the X, Y and Z-axes. By monitoring the average percentage load on each of the X, Y and Z-axes during the machining processes, first on no load (A) and then on load (B), all percentage force readings were noted and entered in Table 6.7. The differences between "on load" and "no load" were then computed and recorded accordingly. The product of the difference of the percentage load reading and the recommended maximum load (1kN) on each of the axes gave the actual load being exerted on each the axes.

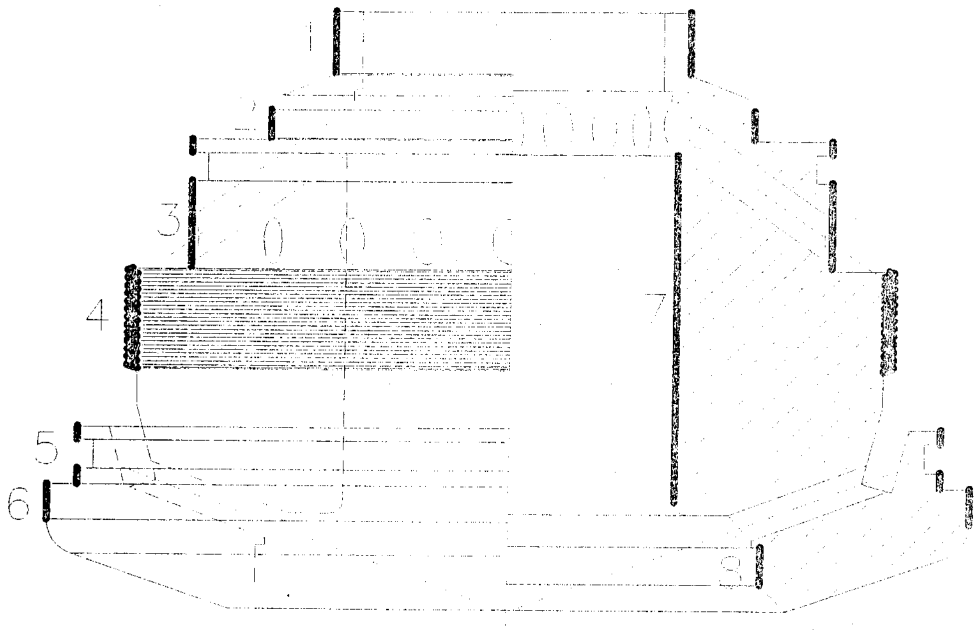


Figure 6.5: Load measurements - collimator holder.

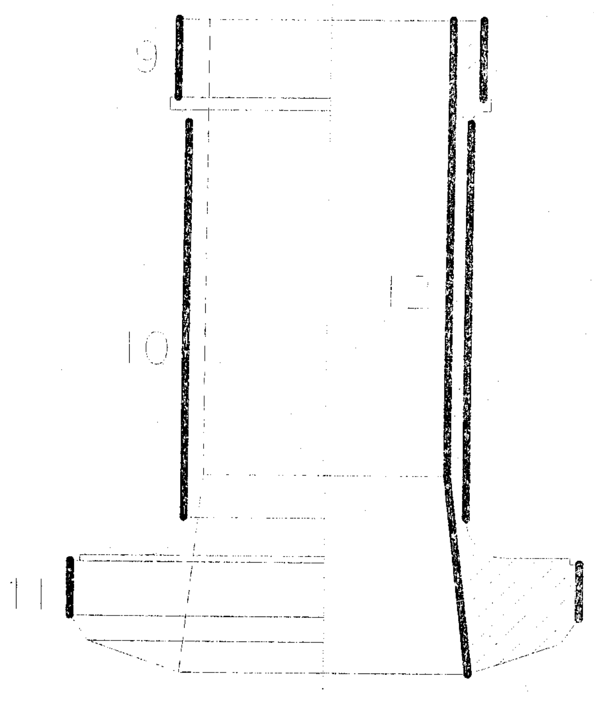


Figure 6.6: load measurements - collimator insert.

Table 6.7: Results of load readings.

No.	Machining at diameter (mm)	% Force reading						Δ (B-A)			Force (N)		
		No load (A)			On load (B)								
		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	56	1%	3%	9%	12%	3%	20%	9%	2%	11%	90	20	110
2	76	2%	2%	12%	15%	4%	22%	13%	2%	10%	130	20	100
3	101	1%	2%	10%	18%	5%	18%	16%	4%	8%	160	40	80
4	121	0%	0%	11%	18%	5%	22%	18%	5%	11%	180	50	110
5	136	1%	1%	8%	25%	6%	25%	24%	5%	17%	240	50	170
6	142	2%	2%	13%	25%	6%	27%	23%	4%	14%	230	40	140
7	50	0%	1%	11%	11%	3%	22%	10%	3%	11%	100	30	110
8	80	2%	1%	13%	15%	4%	22%	14%	2%	9%	140	20	90
9	47	1%	2%	12%	10%	3%	23%	8%	2%	11%	80	20	110
10	44	2%	1%	10%	12%	3%	22%	11%	1%	12%	110	10	120
11	79	0%	0%	10%	14%	4%	25%	14%	4%	15%	140	40	150
12	38	1%	1%	12%	9%	2%	20%	8%	1%	8%	80	10	80

Due to the nature of the workpiece material, which was slightly brittle, it was not possible to measure the size of the chip formed. In most cases, the chip was in form of powder with a mixture of aggregate size rather than continuous. Nevertheless, it was observed that the smaller the depth of cut the finer the size of the aggregate.

CHAPTER 7

ANALYSIS OF RESULTS AND DISCUSSION

7.1 INTRODUCTION

This chapter discusses the results of the study of the production process of the Collimator Assembly, mainly as presented in chapter 6. It starts with an analysis of the surface finish were control charts show the quality of the surface finish. Analysis of forces and how spindle speed and diameter of the workpiece influences the cutting forces, which in the end affects the design of the tools.

7.2 SURFACE FINISH ANALYSIS

Analysis of the surface finish measurements were aimed at establishing whether the specified surface finish of 3.2 microns was obtained. To achieve this the method of 'control charts for individual measurements', where the sample size used for process control is *n=1*; that is, the sample consists of an individual unit, was employed **(Douglas C.M., George C.R., 1994)**. Thus, the centre line and upper and lower control limits for a control chart from an individual sample are;

$$\begin{aligned} UCL &= \bar{x} + 3\frac{\overline{mr}}{d_2} \\ CL &= \bar{x} \\ LCL &= \bar{x} - 3\frac{\overline{mr}}{d_2} \end{aligned} \qquad (7.1)$$

Where,

$\overline{mr}$ is the mean of the moving range,

$\bar{x}$ is the mean of the CLA and

d_2 is a factor obtained from tables for constructing variables control charts.

Table 7.1 computes $\overline{mr}$ and $\bar{x}$.

Table 7.1: Calculations of the means of CLA and Moving range ($\bar{x}$ and $\overline{mr}$).

Test observation	CLA (microns)	Moving Range
1	1.68	
2	1.38	0.30
3	0.70	0.68
4	1.18	0.48
5	2.00	0.82
6	1.00	1.00
7	0.92	0.08
8	2.50	1.58
9	2.25	0.25
10	0.60	1.65
11	0.82	0.22
12	1.10	0.28
13	0.50	0.60
14	0.60	0.10
15	0.40	0.20
16	1.60	1.20
17	1.12	0.48
18	2.40	1.28
19	0.50	1.90
20	1.20	0.70
Mean	1.22	0.73

Thus, from equations 7.1, if the moving range of n = 2 observations is used, then d_2 = 1.128. Hence for the data in Table 7.1;

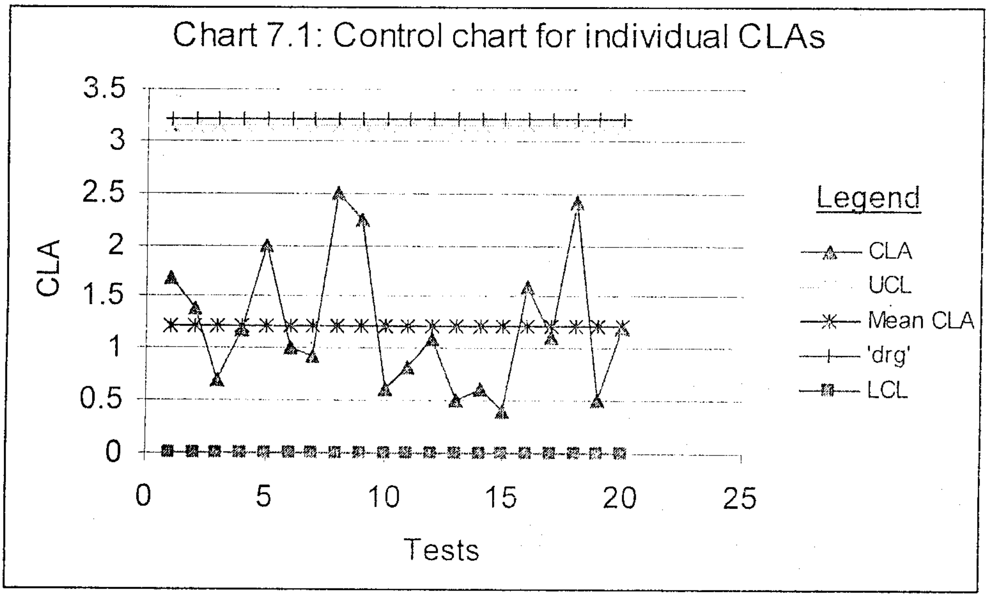
$$UCL = 1.22 + 3\frac{0.73}{1.128} = 3.15$$

$$CL = 1.22$$

$$LCL = 1.22 - 3\frac{0.73}{1.128} = -0.71 \cong 0$$

Note that LCL was -0.71 but the feasible minimum CLA is zero (0).

Because no points exceed the upper control limit, the control chart was set up for individual CLA measurements as shown in Chart 7.1. This control chart was constructed using Microsoft Excel application package. It was observed from the chart that there was no indication of an out-of-control condition, that is, there were no CLA points lying outside the upper and lower control limits.



Another observation was that the mean CLA (=1.22 microns) was way below 3.2 microns which was specified in the production drawings (Appendix A).

The two observations indicated that;

- The surface finish of the product, the collimator assembly was acceptable;
- The tools that were used to produce the surface were also satisfactory.

7.3 ANALYSIS OF DIMENSIONS

After carrying out an analysis of the critical dimensions as shown in Table 6.5 it was found that most results were within the specified tolerances. Correct dimensions, which were within tolerances were labelled as "PASS" whilst those falling out were labelled as "FAIL". Only one measurement had a "FAIL".

However, upon investigations it was discovered that the programmer erred when inputting the drawing into Mastercam. The error was rectified and the program regenerated.

7.4 ANALYSIS OF FORCES AND CHIP FORMATION

The analysis of forces was meant to check whether the generated forces were within what the machine tool would withstand. The manufacture's hardware manual specifies a maximum force of 1.0kN on each of the three axes. (The trip switch would activate at 1.3kN whilst the safety cotter pin would snap at 1.6kN.) The analysis was also meant to verify whether the recommended cutting-speed for copper (Table 2.2) was not exceeded.

Thus, Table 7.2 was developed from the analysis of Table 6.7 and using the velocity equation 2.1 and the power equation 2.3.

Table 7.2: Calculations of forces, velocity and power.

No.	Machining at diameter (mm)	N (rpm)	Force (N)				V_c (m/min)	P (watts)
			$X=F_c$	$Y=F_r$	$Z=F_a$	F		
1	56	280	90	20	110	143.5	49.27	73.90
2	76	280	130	20	100	165.2	66.86	144.87
3	101	120	160	40	80	183.3	38.08	101.55
4	121	120	180	50	110	216.8	45.62	136.87
5	136	120	240	50	170	298.3	51.28	205.11
6	142	150	230	40	140	272.2	66.92	256.54
7	50	250	100	30	110	151.7	39.28	65.46
8	80	350	140	20	90	167.6	87.98	205.28
9	47	250	80	20	110	137.5	36.92	49.22
10	44	80	110	10	120	163.1	11.06	20.28
11	79	80	140	40	150	209.0	19.86	46.33
12	38	80	80	10	80	113.6	9.55	12.74

For sample calculations of Table 7.2, refer to Appendix H.

A closer look at the forces in Table 7.2 revealed that none of the generated forces exceeded 1kN. Besides, the percentage load factor of the machine tool with regards to the maximum load attained in the machining operation was;

$$\frac{298.3}{1000} \times 100\% = 29.3\%$$

A load factor of 29.3% was within the normal (or white) operation zone.

According to Table 2.2 the recommended cutting speed for copper is 20m/min to 120m/m. Thus, from Table 7.2 it was observed that all cutting-velocities were within range with a maximum of 87.98m/min.

Another observation drawn from Table 7.2 tied with the velocity and power equations (equation 2.1 and equation 2.3, respectively). The bigger the diameter and speed of rotation of the workpiece the higher the cutting forces and thereby the power consumed. This observation suggested that the design of the workpiece holding and the cutting tools should be done at biggest diameter and highest speed parameters. Also in order to minimise on the power consumed in the machining process, it would be better to reduce the rotation speed at bigger diameters.

7.5 COSTING

After completion of the production process of the collimator assembly it was necessary that it be given a 'cash value'. The standard costing method was used to ascertain the total cost. Table 7.3 iterates all costing items, which gave a total selling price of *ZMK 9,975,686.00.*

Table 7.3: Costing of the collimator assembly.

No.	Description	UoM	Quantity	Unit cost (ZMK)	Total cost (ZMK)
A.	Material				
1	Copper - insert	Kg	11	30,000	330,000
2	Copper - holder	Kg	30	30,000	900,000
B.	CNC Machine Tool	Hr	23.9	145,000	3,465,500
C.	Turret Lathe	Hr	2.1	20,000	42,000
D.	Labour				
1	Design and Programing	Hr	8	50,000	400,000
2	CNC Machine Tool	Hr	26.3	20,000	525,800
3	Turret Lathe	Hr	2.3	15,000	34,650
Total prime cost					5,697,950
Add: Fixed costs @		30%			1,709,385
Add: Preliminary and General Items @ 5%					284,898
Add: Profit @		14%			797,713
Total Cost Before VAT					8,489,946
Add: VAT @ 17.5%					1,485,740
Selling Price VAT Inclusive					**9,975,686**

7.6 COLLIMATOR TESTS ON THE PLASMA ARC TORCH RIG

The site tests were meant to check whether the produced collimator would fit in the plasma arc torch and operate without any defects.

The inspection criteria in appendix J was used as a standard guide for the tests and was meant to comply with ISO 9001 which *Chambishi Metals Plc* employs on all equipment commissioned on the plant. The following parameters were used as a basis for inspection and one of the quality assurance (QA) personnel in the presence of the Plant Engineer did the inspection:

1. dimensions,
2. weight,
3. 'O' rings,
4. coolant passages and
5. visual inspection.

Results are displayed in the inspection sheet in appendix J.

Having been satisfied with the physical inspection, the Collimator was now mounted on the Plasma arc torch testing rig and pressure tested on water as well as the arc.

As the pressure was gradually increased, a leak was noticed on the weld at a pressure of about 4.5 bars before it could reach the 6.0 bars operating pressure level. In order to prevent leaking and for purposes of arc tests, the pressure was reduced to 50 percent of the operating level. The arc voltage was also reduced by 50 percent to avoid overheating. After running for exactly 5 minutes the rig was switched off and the collimator dismantled for a visual inspection. The inspection showed that the arcing surface on the collimator had been unaffected. This implied that the temperature as well as the electrical conductivity of the material from which the collimator was produced was satisfactory. This ended the rig tests.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

This final chapter consists of two sections. The first section summarises the conclusions of the research presented in this dissertation. The second section gives recommendations for future research in the same area.

8.1 CONCLUSIONS

This research addressed the design of tools for the manufacture of the collimator assembly on a 3-axes CNC VMC. The goals of this work were detailed in section 1.3. Thus, in summary, this research has;

- designed and manufactured turning and boring tools and manufactured the collimator components;
- identified workpiece holding mechanisms used in the production processes;
- investigated the use of and used Mastercam V9 software in the production processes; and
- analysed the surface finish and dimensions of the products.

The results of the design and production processes were analysed in five ways, namely; surface finish, cutting forces, dimensional measurements, costing and site rig tests. The results resounded the suitability of the designed tools and methodologies in the manufacture of the collimator components.

One major problem that was encountered during the course of the research process was that of acquiring a good casting of the workpiece material. Many were times when the castings were rejected because they contained numerous pores and cavities. This caused a lot of delays on the duration and course of the research. Another problem that was encountered was that of welding. It was difficult to establish the best temperature and/or current mix that would give a good watertight weld.

Nevertheless, this research designed the tools for the production of the collimator assembly (caption 8.1) on a 3-axes CNC VMC using Mastercam Lathe V9 software. The produced components were tested on the end user's (*Chambishi Metals Plc*) plasma arc torch testing rig and were found to be satisfactory (see section 7.6 and appendix J), despite the weld defect.

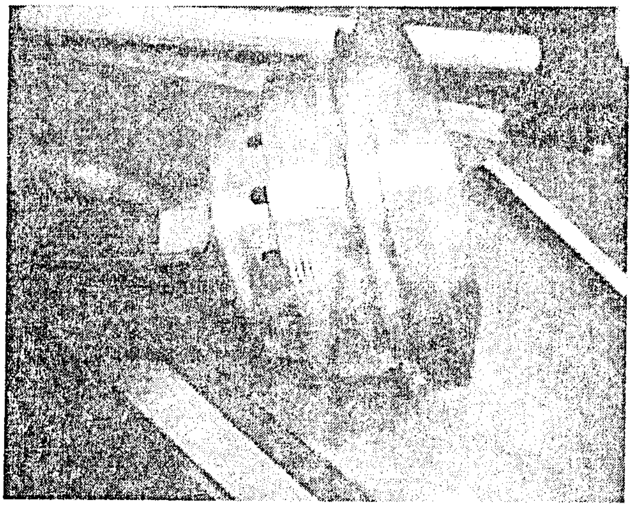
8.2 RECOMMENDATIONS FOR FUTURE WORK

Since there is always a new horizon of research in any research work, the following areas were recommended for future investigations:

- Investigate whether the developed procedures would be able to work with Mastercam X software, a more recently released CAD/CAM package, instead of Mastercam Lathe V9 software, which was used in this research.

- The water leakage encountered during pressure tests on the plasma arc testing rig showed that more investigations should be done on methods of welding copper-based materials using the available welding machines, that is in the School of Engineering, Mechanical workshops.

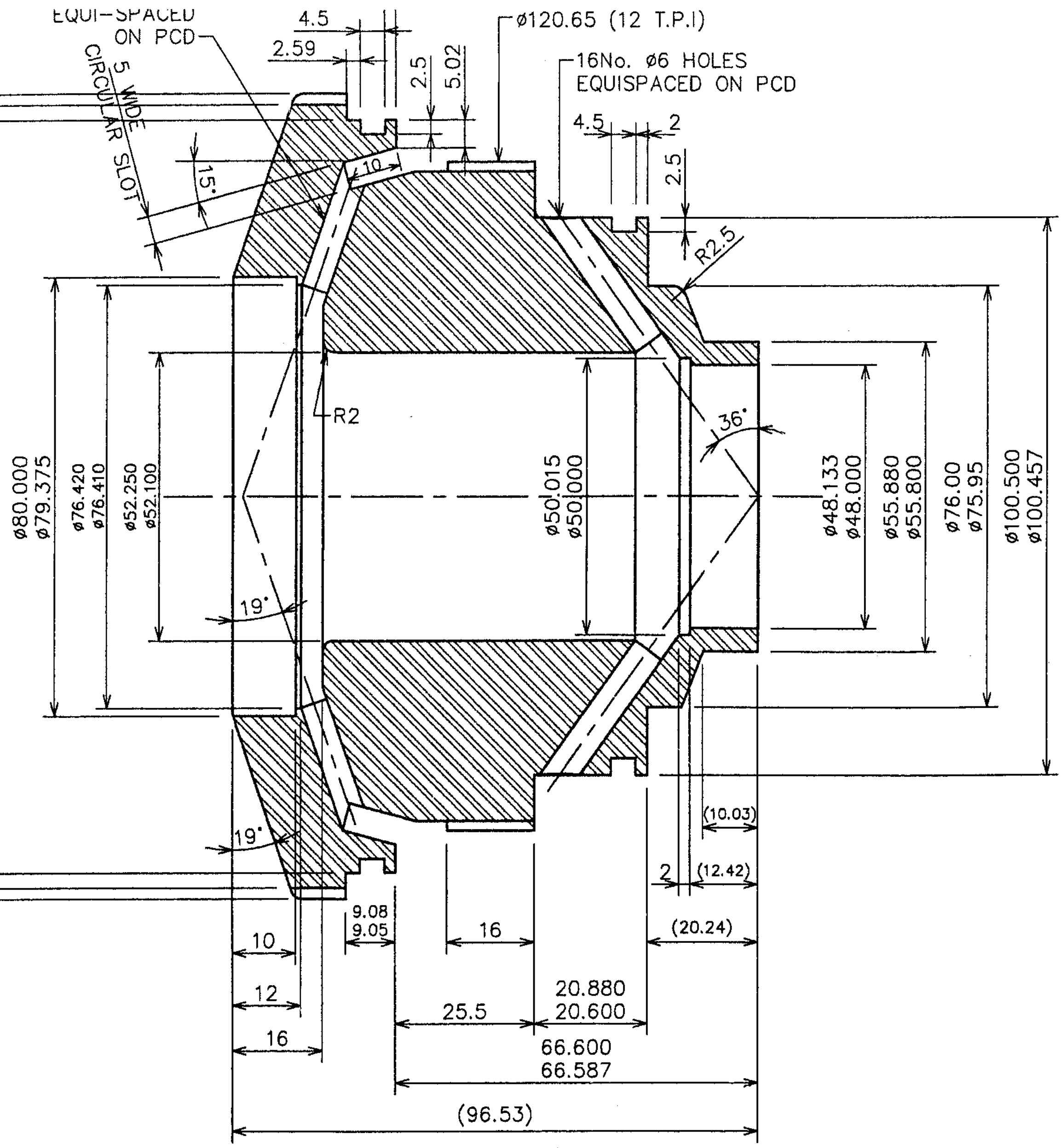
- Since it took several trials of castings of the stock material for the collimator insert and holder done at one of the local foundries in Lusaka, it would help to consider an upgrade of the furnace at the School of Engineering, Mechanical workshops so that all castings are done in-house.



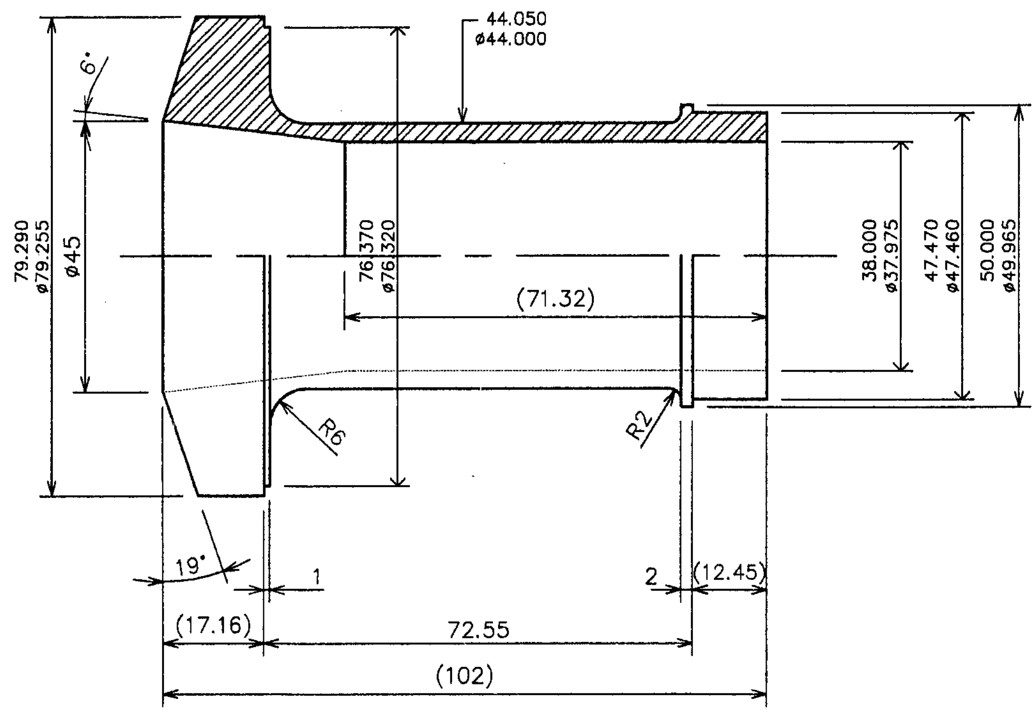
Caption 8.1: The Collimator as produced using the 3-axes Supermax CNC VMC.

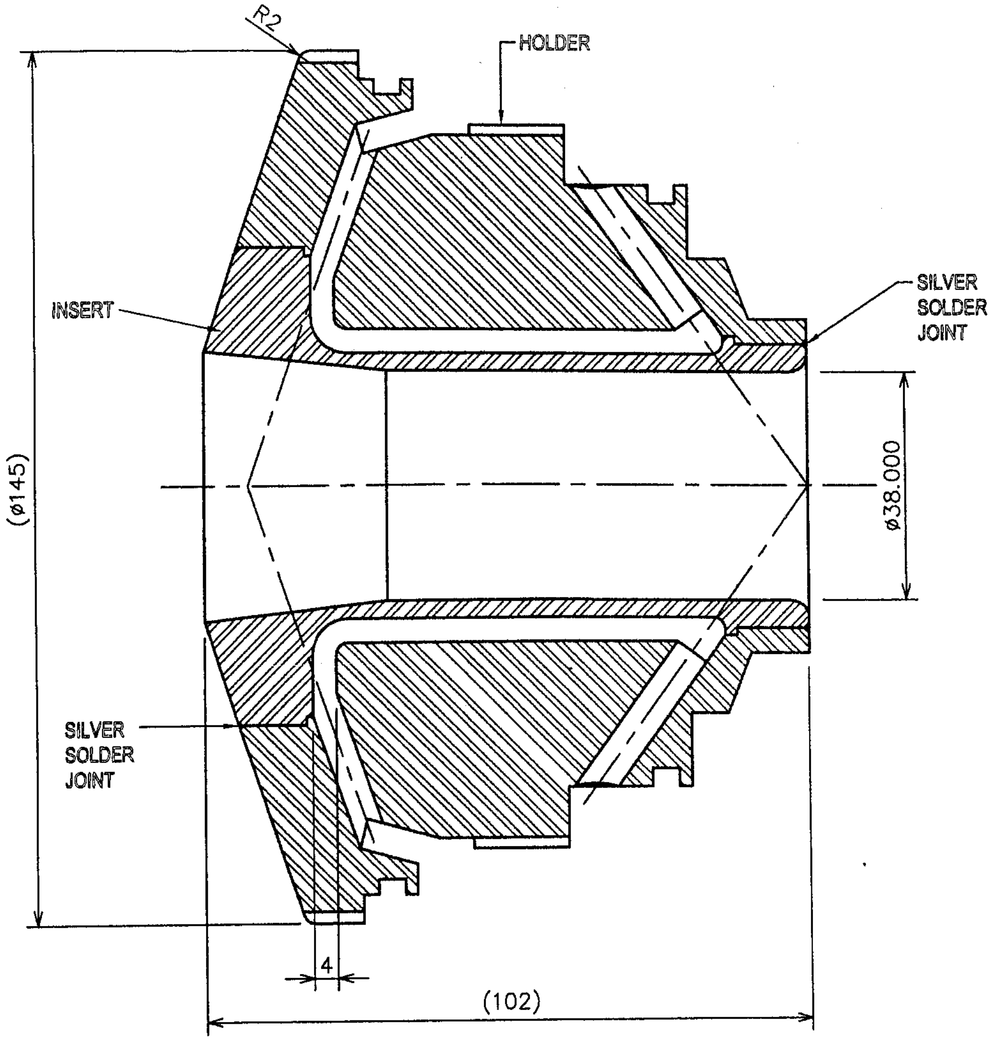
APPENDIX A

PRODUCTION DRAWINGS OF THE COLLIMATOR ASSEMBLY


EQUI-SPACED
ON PCD
5 WIDE
CIRCULAR SLOT
4.5
2.59
2.5
5.02
ø120.65 (12 T.P.I)
16No. ø6 HOLES
EQUISPACED ON PCD
4.5
2
2.5
R2.5
15°
10
R2
36°
19°
19°
ø80.000
ø79.375
ø76.420
ø76.410
ø52.250
ø52.100
ø50.015
ø50.000
ø48.133
ø48.000
ø55.880
ø55.800
ø76.00
ø75.95
ø100.500
ø100.457
(10.03)
2
(12.42)
9.08
9.05
16
(20.24)
10
12
16
25.5
20.880
20.600
66.600
66.587
(96.53)

HOLDER

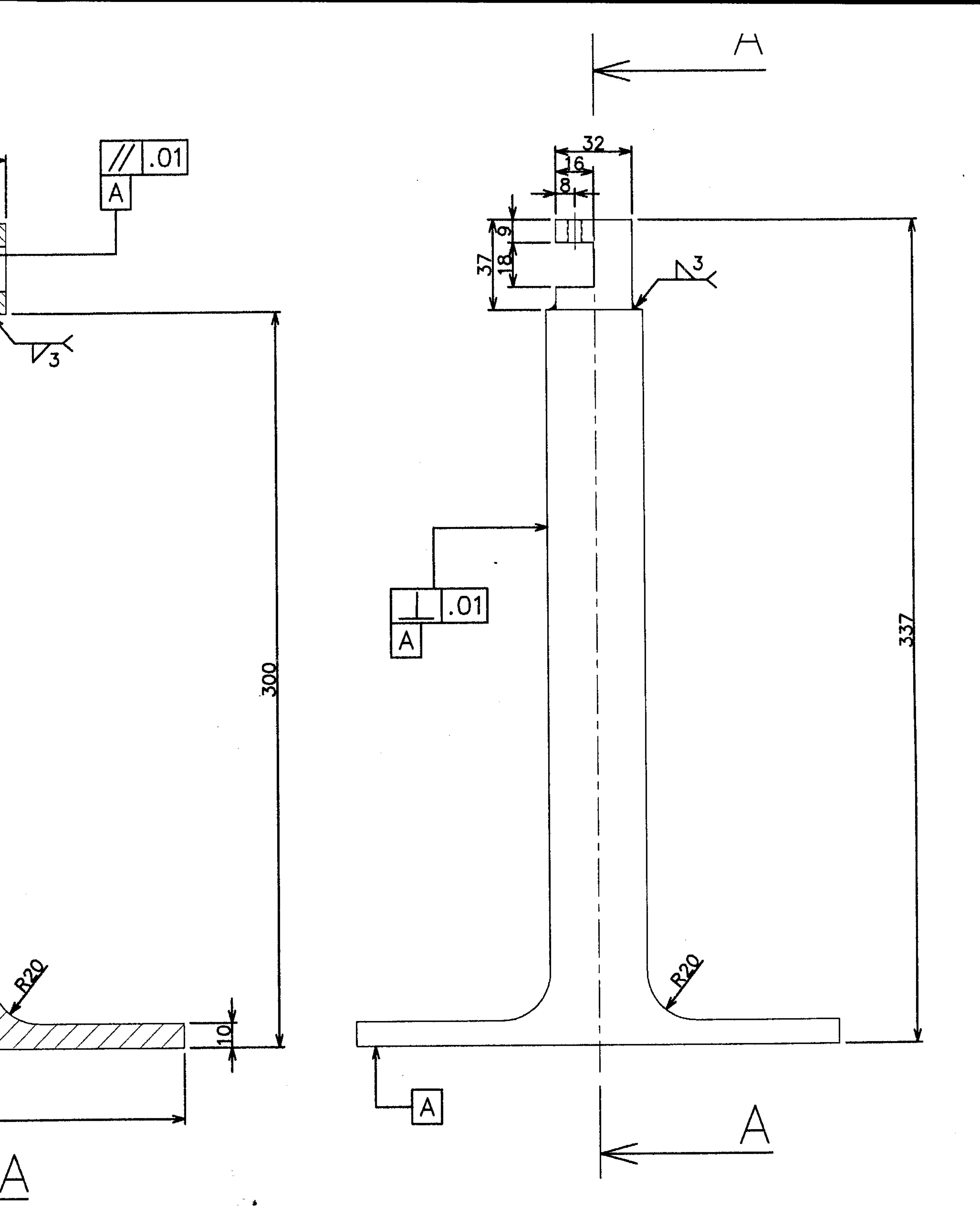

44.050
ø44.000
6°
79.290
ø79.255
ø45
76.370
ø76.320
(71.32)
38.000
ø37.975
47.470
ø47.460
50.000
ø49.965
R6
R2
19°
1
2
(12.45)
(17.16)
72.55
(102)



COLLIMATOR ASSEMBLY

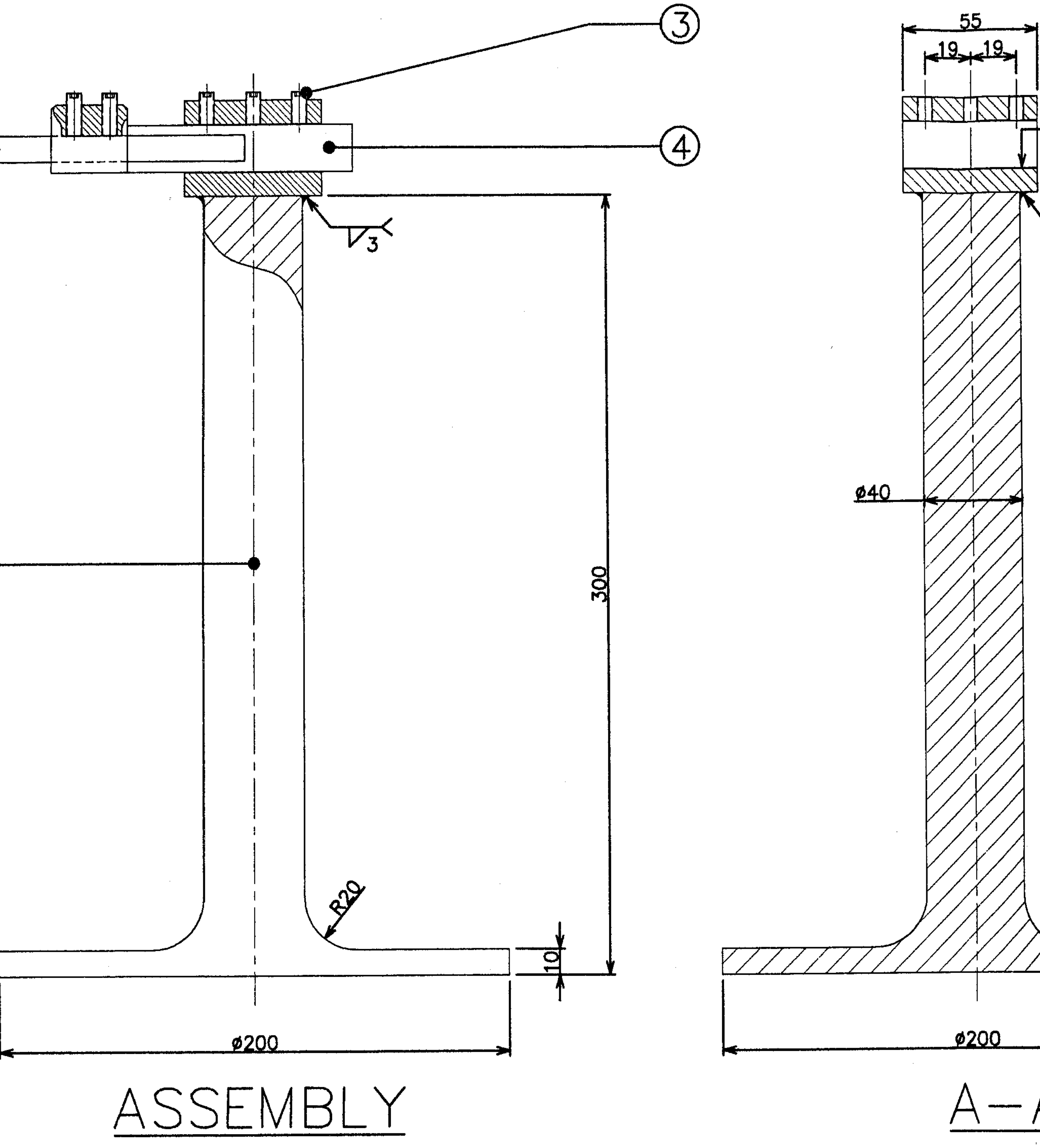
NOTE
1. ALL DIMENSIONS IN MM UNLESS OR OTHERWISE STATED
2. SURFACE FINISH FOR WATER WAYS 6.3 MICRONS OTHERWISE 3.2 MICRO

02	01	COLLIMATOR INSERT, COPPER ALLOY (93Cu4Co2Zn1Al)		CMH02
01	01	COLLIMATOR HOLDER, COPPER ALLOY (93Cu4Co2Zn1Al)		CMH01
Itemref	Quantity	Title/Name, designation, material, dimension etc		Article No./Ref
Designed by TERENCE MALAMA	Checked by BK, JP	Approved by - date 21/05/2006	File name PROJ DRGS	Date 01/08/2006
UNZA - SCHOOL OF ENG.		COLLIMATOR ASSEN		
		CHAMBISHI METALS PLC		Editi

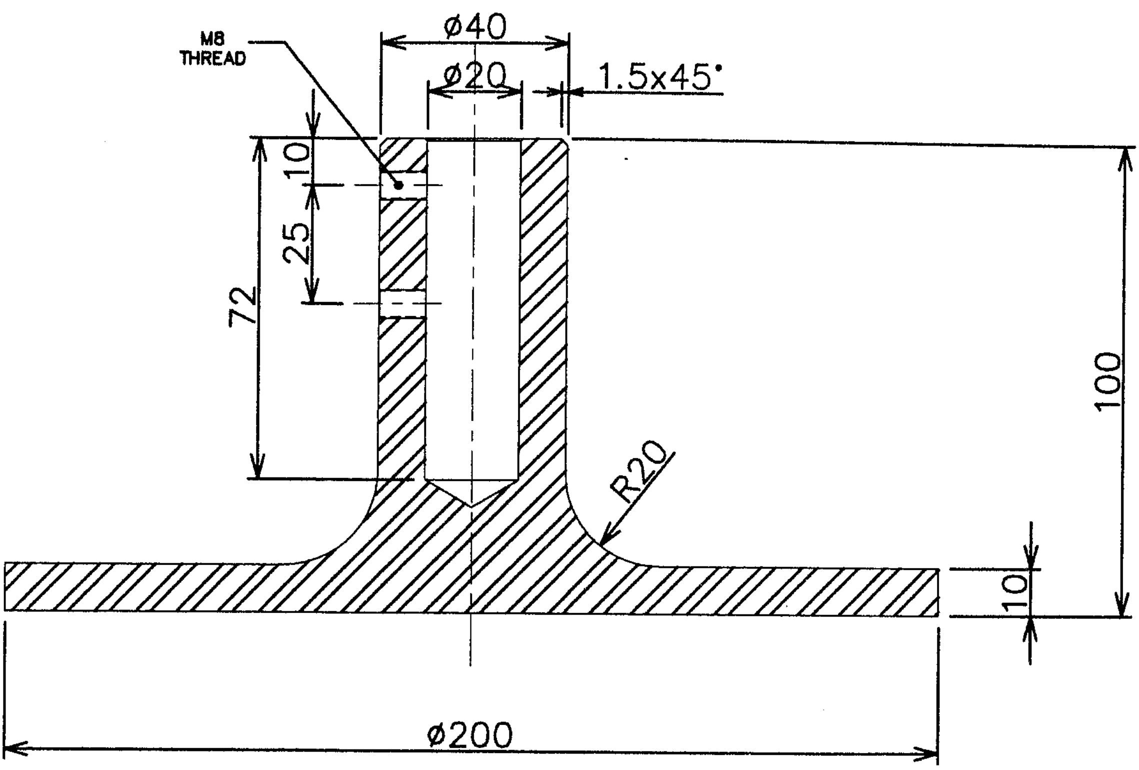


05	-	—		-
04	01	STANDARD TALET TOOL HOLDER		COMMERCIAL
03	05	M8x25 ALEN KEY SCREWS		HT-STEEL
02	01	10x10x100 FORMING TOOL		HSS
01	01	TOOL HOLDER		MS
Itemref	Quantity	Title/Name, designation, material, dimension etc		Article No./Refe
Designed by TERENCE MALAMA	Checked by -	Approved by - date 21/05/2006	File name PROJ DRGS	Date 01/08/2006

UNZA - SCHOOL OF ENG | TURNING TOOL HOLDING F



DIMENSIONS IN MM UNLESS OR OTHERWISE STATED
RFACE FINISH 6.3 MICRONS



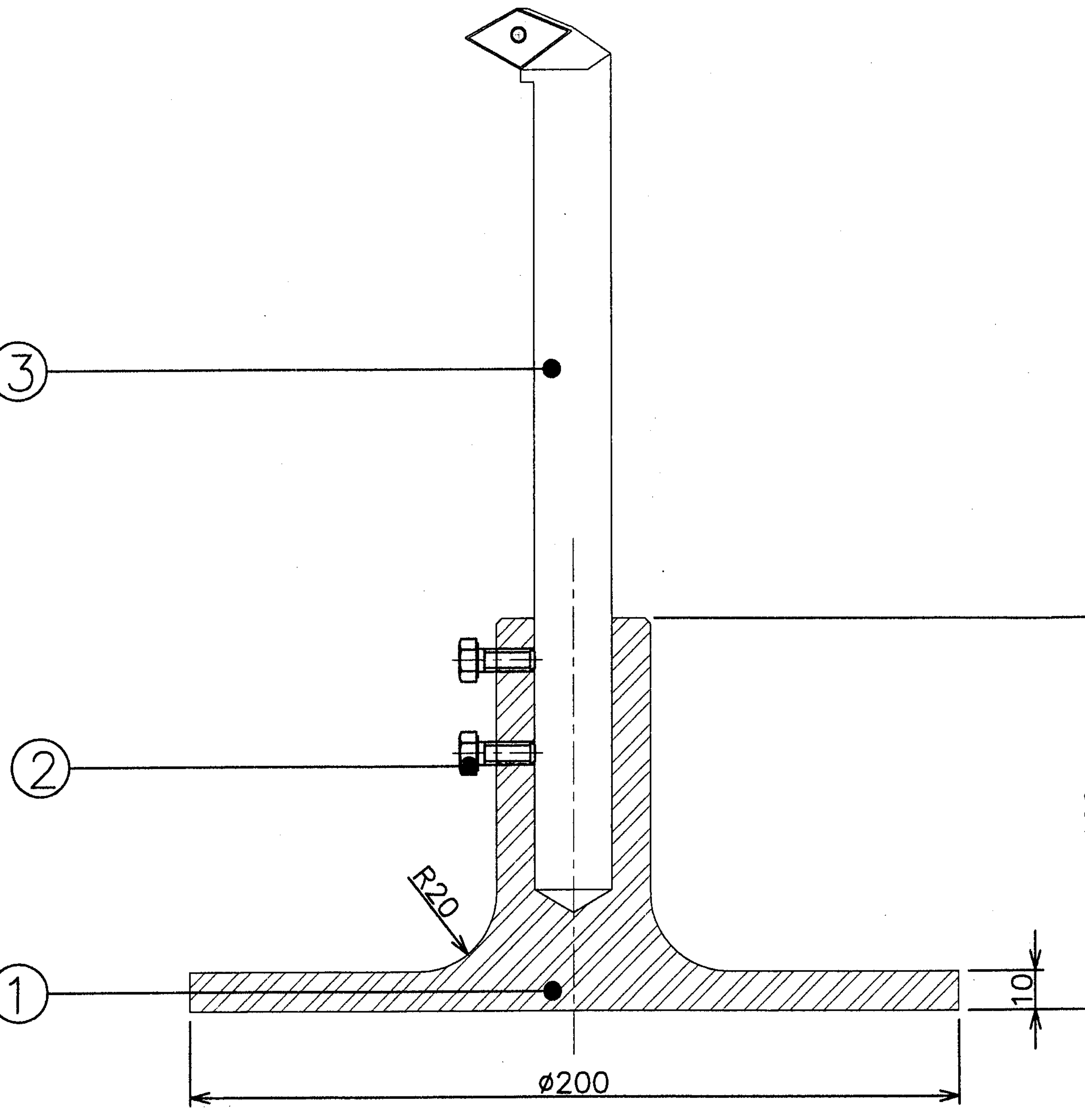
1

Itemref	Quantity	Title/Name, designation, material, dimension etc	Article No./Refere
03	01	STANDARD BORING TOOL (ø20 SHANK)	COMMERCIAL
02	03	M8x25 HTS BOLTS	COMMERCIAL
01	01	TOOL HOLDER	MS

Designed by	Checked by	Approved by - date	File name	Date
TERENCE MALAMA	-	21/05/2006	PROJ DRGS	01/08/2006

UNZA SCHOOL OF ENG

BORING TOOL HOLDING FIX



NOTE
1. ALL DIMENSIONS IN MM UNLESS OR OTHERWISE STATED
2. SURFACE FINISH 6.3 MICRONS

APPENDIX D

PART PROGRAMS FOR THE COLLIMATOR INSERT

INSERT PROGRAM NO.1	
ORIGINAL	**MODIFIED**
%	%
O0700	O0700
(PROGRAM NAME - INSERT PROFILE TURNING1-B4)	(PROGRAM NAME - INSERT PROFILE TURNING1)
(DATE=DD-MM-YY - 15-12-06 TIME=HH:MM - 12:23)	(DATE=DD-MM-YY - 06-11-06 TIME=HH:MM - 13:50)
N10G21	N10G21
N20G0**G17**G40G49G80G90	N20G0**G19**G40G49G80G90**G55**
(OD FINISH LEFT - 35 DEG. TOOL - 15 DIA. OFF. - 15 LEN. - 0 DIA. - 0.)	(OD FINISH LEFT - 35 DEG. TOOL - 15 DIA. OFF. - 15 LEN. - 0 DIA. - 0.)
(ROUGHING PROFILE NO.1)	(ROUGHING PROFILE NO.1)
N30T15M6	N30T15M6
N40G0G90**X**42.8**Y**0.**A0.**S250M3	N40G0G90Y42.8X0.S250**M4**
N50**G43H0**Z-111.697	N50Z-111.697
N60**X**25.641	N60Y25.641
N70G1Z-92.155F10.	N70G1Z-92.155F10.
N80**X**26.499	N80Y26.499
N90**X**27.914Z-93.569	N90Y27.914Z-93.569
N100G0Z-111.697	N100G0Z-111.697
N110**X**24.783	N110Y24.783
N120G1Z-92.155	N120G1Z-92.155
N130**X**25.841	N130Y25.841
N140**X**27.255Z-93.569	N140Y27.255Z-93.569
N150G0Z-115.097	N150G0Z-115.097
N160**X**23.924	N160Y23.924
N170G1Z-109.28	N170G1Z-109.28
N180Z-92.155	N180Z-92.155
N190**X**24.983	N190Y24.983
N200**X**26.397Z-93.569	N200Y26.397Z-93.569
(ROUGHING PROFILE NO.2)	(ROUGHING PROFILE NO.2)
N210G0**X**40.535	N210G0**Y**40.535
N220Z-26.699	N220Z-26.699
N230G1Z-19.609	N230G1Z-19.609
N240**X**41.5	N240Y41.5
N250**X**42.914Z-21.023	N250Y42.914Z-21.023
N260G0Z-26.699	N260G0Z-26.699
N270**X**39.57	N270Y39.57
N280G1Z-19.609	N280G1Z-19.609
N290**X**40.735	N290Y40.735
N300**X**42.149Z-21.023	N300Y42.149Z-21.023
N310G0Z-26.699	N310G0Z-26.699
N320**X**38.605	N320Y38.605
N330G1Z-19.609	N330G1Z-19.609
N340**X**39.77	N340Y39.77
N350**X**41.184Z-21.023	N350Y41.184Z-21.023
N360G0Z-26.699	N360G0Z-26.699
N370**X**37.64	N370Y37.64
N380G1Z-20.609	N380G1Z-20.609

```
N390X38.17
N400G2X38.37Z-20.409R.2
N410G1Z-19.609
N420X38.805
N430X40.219Z-21.023
N440G0Z-26.699
N450X36.675
N460G1Z-20.609
N470X37.84
N480X39.254Z-22.023
N490G0Z-26.699
N500X35.71
N510G1Z-20.609
N520X36.875
N530X38.289Z-22.023
N540G0Z-26.699
N550X34.745
N560G1Z-20.609
N570X35.91
N580X37.324Z-22.023
N590G0Z-26.699
N600X33.78
N610G1Z-20.609
N620X34.945
N630X36.359Z-22.023
N640G0Z-26.699
N650X32.815
N660G1Z-20.609
N670X33.98
N680X35.394Z-22.023
N690G0Z-26.699
N700X31.85
N710G1Z-20.609
N720X33.015
N730X34.429Z-22.023
N740G0Z-26.699
N750X30.885
N760G1Z-20.609
N770X32.05
N780X33.464Z-22.023
N790G0Z-26.699
N800X29.92
N810G1Z-20.609
N820X31.085
N830X32.499Z-22.023
N840G0Z-26.699
N850X28.955
N860G1Z-20.609
N870X30.12
N880X31.534Z-22.023
N890G0Z-26.699
N900X27.99
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N920X28.
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N960X27.025
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N480Y39.254Z-22.023
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N500Y35.71
N510G1Z-20.609
N520Y36.875
N530Y38.289Z-22.023
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N580Y37.324Z-22.023
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N600Y33.78
N610G1Z-20.609
N620Y34.945
N630Y36.359Z-22.023
N640G0Z-26.699
N650Y32.815
N660G1Z-20.609
N670Y33.98
N680Y35.394Z-22.023
N690G0Z-26.699
N700Y31.85
N710G1Z-20.609
N720Y33.015
N730Y34.429Z-22.023
N740G0Z-26.699
N750Y30.885
N760G1Z-20.609
N770Y32.05
N780Y33.464Z-22.023
N790G0Z-26.699
N800Y29.92
N810G1Z-20.609
N820Y31.085
N830Y32.499Z-22.023
N840G0Z-26.699
N850Y28.955
N860G1Z-20.609
N870Y30.12
N880Y31.534Z-22.023
N890G0Z-26.699
N900Y27.99
N910G1Z-20.609
N920Y28.
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N950G0Z-26.699
N960Y27.025
```

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N970G1Z-20.691
N980G3X28.Z-20.609R5.8
N990G1X28.19
N1000X29.604Z-22.023
N1010G0Z-94.855
N1020X26.06
N1030G1Z-20.943
N1040G3X27.225Z-20.661R5.8
N1050G1X28.639Z-22.075
N1060G0Z-94.855
N1070X25.174
N1080G1Z-92.155
N1090Z-89.955
N1100Z-89.939F5.
N1110X25.095Z-88.945
N1120Z-21.389F10.
N1130G3X26.26Z-20.876R5.8
N1140G1X27.674Z-22.29
N1150G0Z-94.855
N1160X25.174
N1170G1Z-92.155
N1180Z-89.955
N1190Z-89.939F5.
N1200X24.13Z-76.822
N1210Z-22.089F10.
N1220G3X25.295Z-21.278R5.8
N1230G1X26.709Z-22.692
N1240G0Z-79.335
N1250X24.33
N1260G1X23.165Z-64.699F5.
N1270Z-23.205F10.
N1280G3X24.33Z-21.917R5.8
N1290G1X25.744Z-23.332
N1300G0Z-67.212
N1310X23.365
N1320G1X22.2Z-52.576F5.
N1330Z-26.409F10.
N1340G3X23.365Z-22.922R5.8
N1350G1X24.779Z-24.336
(ROUGHING PROFILE NO.3)
N1360G0X40.665
N1370Z-22.309
N1380G1Z-11.052
N1390X41.5
N1400X42.914Z-12.466
N1410G0Z-22.309
N1420X39.831
N1430G1Z-19.609
N1440Z-11.052
N1450X40.865
N1460X42.28Z-12.466
(FINISHING PROFILE NO.1)
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N1490G1Z-109.28
N1500Z-92.028
N1510X24.974
N1520X26.389Z-93.442
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N990G1Y28.19
N1000Y29.604Z-22.023
N1010G0Z-94.855
N1020Y26.06
N1030G1Z-20.943
N1040G2Y27.225Z-20.661R5.8
N1050G1Y28.639Z-22.075
N1060G0Z-94.855
N1070Y25.174
N1080G1Z-92.155
N1090Z-89.955
N1100Z-89.939F5.
N1110Y25.095Z-88.945
N1120Z-21.389F10.
N1130G2Y26.26Z-20.876R5.8
N1140G1Y27.674Z-22.29
N1150G0Z-94.855
N1160Y25.174
N1170G1Z-92.155
N1180Z-89.955
N1190Z-89.939F5.
N1200Y24.13Z-76.822
N1210Z-22.089F10.
N1220G2Y25.295Z-21.278R5.8
N1230G1Y26.709Z-22.692
N1240G0Z-79.335
N1250Y24.33
N1260G1Y23.165Z-64.699F5.
N1270Z-23.205F10.
N1280G2Y24.33Z-21.917R5.8
N1290G1Y25.744Z-23.332
N1300G0Z-67.212
N1310Y23.365
N1320G1Y22.2Z-52.576F5.
N1330Z-26.409F10.
N1340G2Y23.365Z-22.922R5.8
N1350G1Y24.779Z-24.336
(ROUGHING PROFILE NO.3)
N1360G0Y40.665
N1370Z-22.309
N1380G1Z-11.052
N1390Y41.5
N1400Y42.914Z-12.466
N1410G0Z-22.309
N1420Y39.831
N1430G1Z-19.609
N1440Z-11.052
N1450Y40.865
N1460Y42.28Z-12.466
(FINISHING PROFILE NO.1)
N1470G0Z-111.28
N1480Y23.797
N1490G1Z-109.28
N1500Z-92.028
N1510Y24.974
N1520Y26.389Z-93.442
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N1530G0Z-111.28
N1540X23.722
N1550G1Z-109.28
N1560Z-91.955
N1570X23.724Z-91.953
N1580X24.974
N1590X26.389Z-93.367
(FINISHING PROFILE NO.2)
N1600M8
N1610G0Z-93.955
N1620X25.047
N1630G1Z-91.955
N1640Z-89.955
N1650Z-89.949
N1660X22.072Z-52.578
N1670X23.487Z-53.992
N1680G0X26.347
N1690Z-93.955
N1700X24.972
N1710G1Z-91.955
N1720Z-89.955
N1730X21.998Z-52.584
N1740X23.412Z-53.998
(FINISHING PROFILE NO.3)
N1750M9
N1760G0X23.457
N1770Z-54.584
N1780X22.073
N1790G1Z-52.584
N1800Z-26.409
N1810G3X28.Z-20.482R5.927
N1820G1X29.414Z-21.896
N1830G0Z-54.584
N1840X21.998
N1850G1Z-52.584
N1860Z-26.409
N1870G3X28.Z-20.407R6.002
N1880G1X29.414Z-21.821
N1890G0Z-22.482
N1900X28.
N1910G1Z-20.482
N1920X38.17
N1930G2X38.243Z-20.409R.073
N1940G1Z-19.409
N1950X39.658Z-20.823
N1960G0Z-22.407
N1970X28.
N1980G1Z-20.407
N1990X38.168
N2000Z-19.409
N2010X39.583Z-20.823
N2020G0Z-21.482
N2030X38.17
N2040G1Z-19.482
N2050X39.631
N2060X41.045Z-20.896
N2070G0Z-21.407
N2080X38.17
```

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N1530G0Z-111.28
N1540Y23.722
N1550G1Z-109.28
N1560Z-91.955
N1570Y23.724Z-91.953
N1580Y24.974
N1590Y26.389Z-93.367
(FINISHING PROFILE NO.2)
N1600M8
N1610G0Z-93.955
N1620Y25.047
N1630G1Z-91.955
N1640Z-89.955
N1650Z-89.949
N1660Y22.072Z-52.578
N1670Y23.487Z-53.992
N1680G0Y26.347
N1690Z-93.955
N1700Y24.972
N1710G1Z-91.955
N1720Z-89.955
N1730Y21.998Z-52.584
N1740Y23.412Z-53.998
(FINISHING PROFILE NO.3)
N1750
N1760G0Y23.457
N1770Z-54.584
N1780Y22.073
N1790G1Z-52.584
N1800Z-26.409
N1810G2Y28.Z-20.482R5.927
N1820G1Y29.414Z-21.896
N1830G0Z-54.584
N1840Y21.998
N1850G1Z-52.584
N1860Z-26.409
N1870G2Y28.Z-20.407R6.002
N1880G1Y29.414Z-21.821
N1890G0Z-22.482
N1900Y28.
N1910G1Z-20.482
N1920Y38.17
N1930G3Y38.243Z-20.409R.073
N1940G1Z-19.409
N1950Y39.658Z-20.823
N1960G0Z-22.407
N1970Y28.
N1980G1Z-20.407
N1990Y38.168
N2000Z-19.409
N2010Y39.583Z-20.823
N2020G0Z-21.482
N2030Y38.17
N2040G1Z-19.482
N2050Y39.631
N2060Y41.045Z-20.896
N2070G0Z-21.407
N2080Y38.17
```

N2090G1Z-19.407	N2090G1Z-19.407
N2100**X**39.631	N2100Y39.631
N2110**X**41.045Z-20.821	N2110Y41.045Z-20.821
(FINISHING PROFILE NO.4)	(FINISHING PROFILE NO.4)
N2120G0Z-21.409	N2120G0Z-21.409
N2130**X**39.704	N2130Y39.704
N2140G1Z-19.409	N2140G1Z-19.409
N2150Z-10.852	N2150Z-10.852
N2160**X**41.118Z-12.266	N2160Y41.118Z-12.266
N2170G0Z-21.409	N2170G0Z-21.409
N2180**X**39.629	N2180Y39.629
N2190G1Z-19.409	N2190G1Z-19.409
N2200Z-10.852	N2200Z-10.852
N2210**X**41.043Z-12.266	N2210Y41.043Z-12.266
N2220G0**X**42.8	N2220G0Y42.8
N2230M5	N2230M5
N2240G91G28Z0.	N2240G91G28Z0.
N2250G28**X**0.**Y**0.**A0.**	N2250G28Y0.X0.
N2260M30	N2260M30
%	%
CYCLE TIME IN MIN (A) =	73.03

INSERT PROGRAM NO.2

ORIGINAL	MODIFIED
%	%
O0710	O0710
(PROGRAM NAME - INSERT PROFILE TURNING2-B4)	(PROGRAM NAME - INSERT PROFILE TURNING2)
(DATE=DD-MM-YY - 15-12-06 TIME=HH:MM - 12:33)	(DATE=DD-MM-YY - 06-11-06 TIME=HH:MM - 18:47)
N10G21	N10G21
N20G0**G17**G40G49G80G90	N20G0**G19**G40G49G80G90**G55**
(OD FINISH RIGHT - 35 DEG. TOOL - 15 DIA. OFF. - 15 LEN. - 0 DIA. - 0.)	(OD FINISH RIGHT - 35 DEG. TOOL - 15 DIA. OFF. - 15 LEN. - 0 DIA. - 0.)
(CONTOUR NO.1)	(CONTOUR NO.1)
N30T15M6	N30T15M6
N40G0G90**X**40.559Y0.**A0.**S230M3	N40G0G90Y40.559**X**0.S230M3
N50**G43H0**Z2.5	N50Z2.5
N60G1Z-10.852F10.	N60G1Z-10.852F10.
N70**X**41.973Z-9.438	N70Y41.973Z-9.438
N80G0Z2.5	N80G0Z2.5
N90**X**39.617	N90Y39.617
N100G1Z-10.832	N100G1Z-10.832
N110**X**39.631Z-10.852	N110Y39.631Z-10.852
N120**X**41.045Z-9.438	N120Y41.045Z-9.438
N130G0Z2.5	N130G0Z2.5
N140**X**38.676	N140Y38.676
N150G1Z-9.515	N150G1Z-9.515
N160**X**39.631Z-10.852	N160Y39.631Z-10.852
N170**X**41.045Z-9.438	N170Y41.045Z-9.438
N180G0Z2.5	N180G0Z2.5
N190**X**37.734	N190Y37.734
N200G1Z-8.198	N200G1Z-8.198
N210**X**38.876Z-9.795	N210Y38.876Z-9.795
N220**X**40.29Z-8.381	N220Y40.29Z-8.381
N230G0Z2.5	N230G0Z2.5
N240**X**36.793	N240Y36.793

```
N250G1Z-6.881
N260X37.934Z-8.478
N270X39.348Z-7.063
(CONTOUR NO.2)
N280G0Z2.5
N290X35.842
N300G1Z-6.555
N310X36.793Z-6.881
N320X38.207Z-5.466
N330G0Z2.5
N340X34.891
N350G1Z-6.23
N360X36.042Z-6.624
N370X37.456Z-5.209
N380G0Z2.5
N390X33.94
N400G1Z-5.904
N410X35.091Z-6.298
N420X36.505Z-4.884
N430G0Z2.5
N440X32.989
N450G1Z-5.579
N460X34.14Z-5.973
N470X35.554Z-4.559
N480G0Z2.5
N490X32.038
N500G1Z-5.254
N510X33.189Z-5.648
N520X34.603Z-4.233
N530G0Z2.5
N540X31.087
N550G1Z-4.928
N560X32.238Z-5.322
N570X33.652Z-3.908
N580G0Z2.5
N590X30.136
N600G1Z-4.603
N610X31.287Z-4.997
N620X32.701Z-3.583
N630G0Z2.5
N640X29.185
N650G1Z-4.278
N660X30.336Z-4.671
N670X31.75Z-3.257
N680G0Z2.5
N690X28.234
N700G1Z-3.952
N710X29.385Z-4.346
N720X30.799Z-2.932
N730G0Z2.5
N740X27.283
N750G1Z-3.627
N760X28.434Z-4.021
N770X29.848Z-2.606
N780G0Z2.5
N790X26.332
N800G1Z-3.301
N810X27.483Z-3.695
```

```
N250G1Z-6.881
N260Y37.934Z-8.478
N270Y39.348Z-7.063
(CONTOUR NO.2)
N280G0Z2.5
N290Y35.842
N300G1Z-6.555
N310Y36.793Z-6.881
N320Y38.207Z-5.466
N330G0Z2.5
N340Y34.891
N350G1Z-6.23
N360Y36.042Z-6.624
N370Y37.456Z-5.209
N380G0Z2.5
N390Y33.94
N400G1Z-5.904
N410Y35.091Z-6.298
N420Y36.505Z-4.884
N430G0Z2.5
N440Y32.989
N450G1Z-5.579
N460Y34.14Z-5.973
N470Y35.554Z-4.559
N480G0Z2.5
N490Y32.038
N500G1Z-5.254
N510Y33.189Z-5.648
N520Y34.603Z-4.233
N530G0Z2.5
N540Y31.087
N550G1Z-4.928
N560Y32.238Z-5.322
N570Y33.652Z-3.908
N580G0Z2.5
N590Y30.136
N600G1Z-4.603
N610Y31.287Z-4.997
N620Y32.701Z-3.583
N630G0Z2.5
N640Y29.185
N650G1Z-4.278
N660Y30.336Z-4.671
N670Y31.75Z-3.257
N680G0Z2.5
N690Y28.234
N700G1Z-3.952
N710Y29.385Z-4.346
N720Y30.799Z-2.932
N730G0Z2.5
N740Y27.283
N750G1Z-3.627
N760Y28.434Z-4.021
N770Y29.848Z-2.606
N780G0Z2.5
N790Y26.332
N800G1Z-3.301
N810Y27.483Z-3.695
```

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N820X28.897Z-2.281
N830G0Z2.5
N840X25.381
N850G1Z-2.976
N860X26.532Z-3.37
N870X27.946Z-1.956
N880G0Z2.5
N890X24.43
N900G1Z-2.651
N910X25.581Z-3.045
N920X26.995Z-1.63
N930G0Z2.5
N940X23.479
N950G1Z-2.325
N960X24.63Z-2.719
N970X26.044Z-1.305
N980G0Z2.5
N990X22.528
N1000G1Z-2.
N1010X23.679Z-2.394
N1020X25.093Z-.98
(CONTOUR NO.3)
N1030G0X40.931
N1040Z-48.834
N1050X24.231
N1060G1Z-89.955
N1070X24.974
N1080X26.389Z-88.541
N1090G0Z-48.834
N1100X23.487
N1110G1Z-89.888
N1120G2X23.999Z-89.955R2.
N1130G1X24.431
N1140X25.845Z-88.541
N1150G0Z-48.834
N1160X22.743
N1170G1Z-89.511
N1180G2X23.687Z-89.93R2.
N1190G1X25.101Z-88.516
N1200G0Z-48.834
N1210X22.
N1220G1X21.999Z-87.955F5.
N1230G2X22.943Z-89.653R2.F10.
N1240G1X24.357Z-88.239
(CONTOUR NO.4)
N1250G0Z-50.98
N1260X22.351
N1270G1X21.998Z-51.334
N1280X21.997Z-87.955
N1290G2X23.999Z-89.957R2.002
N1300G1X24.353Z-89.603
N1310G0X23.646
N1320G1X23.999Z-89.957
N1330X24.974
N1340X25.474
N1350G0X40.931
N1360Z-8.352
N1370X39.631
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N820Y28.897Z-2.281
N830G0Z2.5
N840Y25.381
N850G1Z-2.976
N860Y26.532Z-3.37
N870Y27.946Z-1.956
N880G0Z2.5
N890Y24.43
N900G1Z-2.651
N910Y25.581Z-3.045
N920Y26.995Z-1.63
N930G0Z2.5
N940Y23.479
N950G1Z-2.325
N960Y24.63Z-2.719
N970Y26.044Z-1.305
N980G0Z2.5
N990Y22.528
N1000G1Z-2.
N1010Y23.679Z-2.394
N1020Y25.093Z-.98
(CONTOUR NO.3)
N1030G0Y40.931
N1040Z-48.834
N1050Y24.231
N1060G1Z-89.955
N1070Y24.974
N1080Y26.389Z-88.541
N1090G0Z-48.834
N1100Y23.487
N1110G1Z-89.888
N1120G3Y23.999Z-89.955R2.
N1130G1Y24.431
N1140Y25.845Z-88.541
N1150G0Z-48.834
N1160Y22.743
N1170G1Z-89.511
N1180G3Y23.687Z-89.93R2.
N1190G1Y25.101Z-88.516
N1200G0Z-48.834
N1210Y22.
N1220G1Y21.999Z-87.955F5.
N1230G3Y22.943Z-89.653R2.F10.
N1240G1Y24.357Z-88.239
(CONTOUR NO.4)
N1250G0Z-50.98
N1260Y22.351
N1270G1Y21.998Z-51.334
N1280Y21.997Z-87.955
N1290G3Y23.999Z-89.957R2.002
N1300G1Y24.353Z-89.603
N1310G0Y23.646
N1320G1Y23.999Z-89.957
N1330Y24.974
N1340Y25.474
N1350G0Y40.931
N1360Z-8.352
N1370Y39.631
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N1380G1Z-19.409F5.	N1380G1Z-19.409F5.
N1390**X**41.045Z-17.994F10.	N1390**Y**41.045Z-17.994F10.
N1400M5	N1400M5
N1410G91G0G28Z0.	N1410G91G0G28Z0.
N1420G28**X**0.**Y**0.**A0.**	N1420G28**Y**0.X0.
N1430M30	N1430M30
%	%
CYCLE TIME IN MIN (B) =	**39.50**

INSERT PROGRAM NO.3	
ORIGINAL	**MODIFIED**
%	%
O0720	O0720
(PROGRAM NAME - INSERT PROFILE BORING-B4)	(PROGRAM NAME - INSERT PROFILE BORING)
(DATE=DD-MM-YY - 15-12-06 TIME=HH:MM - 12:41)	(DATE=DD-MM-YY - 07-11-06 TIME=HH:MM - 14:57)
N10G21	N10G21
N20G0**G17**G40G49G80G90	N20G0**G19**G40G49G80G90**G57**
(ID ROUGH MIN. 32. DIA. - 80 DEG. TOOL - 15 DIA. OFF. - 15 LEN. - 0 DIA. - 0.)	(ID ROUGH MIN. 32. DIA. - 80 DEG. TOOL - 15 DIA. OFF. - 15 LEN. - 0 DIA. - 0.)
(ROUGHING)	(ROUGHING)
N30T15M6	N30T15M6
N40G0G90**X**17.748**Y**0.**A0.**S115M3	N40G0G90**Y**17.748X0.S115M3
N50**G43H0**Z2.7	N50Z2.7
N60G1Z-106.709F16.	N60G1Z-106.709F16.
N70**X**17.5	N70**Y**17.5
N80**X**16.086Z-105.295	N80**Y**16.086Z-105.295
N90G0Z2.7	N90G0Z2.7
N100**X**17.997	N100**Y**17.997
N110G1Z-106.709	N110G1Z-106.709
N120**X**17.548	N120**Y**17.548
N130**X**16.134Z-105.295	N130**Y**16.134Z-105.295
N140G0Z2.7	N140G0Z2.7
N150**X**18.245	N150**Y**18.245
N160G1Z-106.709	N160G1Z-106.709
N170**X**17.797	N170**Y**17.797
N180**X**16.383Z-105.295	N180**Y**16.383Z-105.295
N190G0Z2.7	N190G0Z2.7
N200**X**18.494	N200**Y**18.494
N210G1Z-106.709	N210G1Z-106.709
N220**X**18.045	N220**Y**18.045
N230**X**16.631Z-105.295	N230**Y**16.631Z-105.295
N240G0Z2.7	N240G0Z2.7
N250**X**18.743	N250**Y**18.743
N260G1Z-106.709	N260G1Z-106.709
N270**X**18.294	N270**Y**18.294
N280**X**16.88Z-105.295	N280**Y**16.88Z-105.295
N290G0Z2.7	N290G0Z2.7
N300**X**18.991	N300**Y**18.991
N310G1Z-31.392	N310G1Z-31.392
N320**X**18.801Z-33.066	N320**Y**18.801Z-33.066
N330**X**18.8Z-33.089	N330**Y**18.8Z-33.089
N340**X**18.799Z-106.709	N340**Y**18.799Z-106.709
N350**X**18.543	N350**Y**18.543
N360**X**17.128Z-105.295	N360**Y**17.128Z-105.295
N370G0Z2.7	N370G0Z2.7
N380**X**19.24	N380**Y**19.24

N390G1Z-29.203	N390G1Z-29.203
N400X18.801Z-33.066	N400Y18.801Z-33.066
N410X18.8Z-33.089	N410Y18.8Z-33.089
N420X18.799Z-106.709	N420Y18.799Z-106.709
N430X18.791	N430Y18.791
N440X17.377Z-105.295	N440Y17.377Z-105.295
N450G0Z2.7	N450G0Z2.7
N460X19.488	N460Y19.488
N470G1Z-27.013	N470G1Z-27.013
N480X19.04Z-30.965	N480Y19.04Z-30.965
N490X17.625Z-29.55	N490Y17.625Z-29.55
N500G0Z2.7	N500G0Z2.7
N510X19.737	N510Y19.737
N520G1Z-24.823	N520G1Z-24.823
N530X19.288Z-28.775	N530Y19.288Z-28.775
N540X17.874Z-27.361	N540Y17.874Z-27.361
N550G0Z2.7	N550G0Z2.7
N560X19.985	N560Y19.985
N570G1Z-22.633	N570G1Z-22.633
N580X19.537Z-26.585	N580Y19.537Z-26.585
N590X18.122Z-25.171	N590Y18.122Z-25.171
N600G0Z2.7	N600G0Z2.7
N610X20.234	N610Y20.234
N620G1Z-20.443	N620G1Z-20.443
N630X19.785Z-24.395	N630Y19.785Z-24.395
N640X18.371Z-22.981	N640Y18.371Z-22.981
N650G0Z2.7	N650G0Z2.7
N660X20.482	N660Y20.482
N670G1Z-18.254	N670G1Z-18.254
N680X20.034Z-22.206	N680Y20.034Z-22.206
N690X18.619Z-20.791	N690Y18.619Z-20.791
N700G0Z2.7	N700G0Z2.7
N710X20.731	N710Y20.731
N720G1Z-16.064	N720G1Z-16.064
N730X20.282Z-20.016	N730Y20.282Z-20.016
N740X18.868Z-18.602	N740Y18.868Z-18.602
N750G0Z2.7	N750G0Z2.7
N760X20.979	N760Y20.979
N770G1Z-13.874	N770G1Z-13.874
N780X20.531Z-17.826	N780Y20.531Z-17.826
N790X19.117Z-16.412	N790Y19.117Z-16.412
N800G0Z2.7	N800G0Z2.7
N810X21.228	N810Y21.228
N820G1Z-11.684	N820G1Z-11.684
N830X20.779Z-15.636	N830Y20.779Z-15.636
N840X19.365Z-14.222	N840Y19.365Z-14.222
N850G0Z2.7	N850G0Z2.7
N860X21.476	N860Y21.476
N870G1Z-9.495	N870G1Z-9.495
N880X21.028Z-13.446	N880Y21.028Z-13.446
N890X19.614Z-12.032	N890Y19.614Z-12.032
N900G0Z2.7	N900G0Z2.7
N910X21.725	N910Y21.725
N920G1Z-7.305	N920G1Z-7.305
N930X21.276Z-11.257	N930Y21.276Z-11.257
N940X19.862Z-9.843	N940Y19.862Z-9.843
N950G0Z2.7	N950G0Z2.7
N960X21.973	N960Y21.973

N970G1Z-5.115	N970G1Z-5.115
N980X21.525Z-9.067	N980Y21.525Z-9.067
N990X20.111Z-7.653	N990Y20.111Z-7.653
N1000G0Z2.7	N1000G0Z2.7
N1010X22.222	N1010Y22.222
N1020G1Z-2.925	N1020G1Z-2.925
N1030X21.773Z-6.877	N1030Y21.773Z-6.877
N1040X20.359Z-5.463	N1040Y20.359Z-5.463
N1050G0Z2.7	N1050G0Z2.7
N1060X22.47	N1060Y22.47
N1070G1Z-.735	N1070G1Z-.735
N1080X22.022Z-4.687	N1080Y22.022Z-4.687
N1090X20.608Z-3.273	N1090Y20.608Z-3.273
(FINISHING)	(FINISHING)
N1100S80M3	N1100S80M3
N1110G0Z1.25	N1110G0Z1.25
N1120X22.595	N1120Y22.595
N1130G1Z-.75F8.	N1130G1Z-.75F8.
N1140X18.925Z-33.08	N1140Y18.925Z-33.08
N1150Z-33.089	N1150Z-33.089
N1160X18.924Z-106.909	N1160Y18.924Z-106.909
N1170X17.51Z-105.495	N1170Y17.51Z-105.495
N1180G0Z1.242	N1180G0Z1.242
N1190X22.669	N1190Y22.669
N1200G1Z-.758	N1200G1Z-.758
N1210X19.Z-33.089	N1210Y19.Z-33.089
N1220X18.999Z-106.909	N1220Y18.999Z-106.909
N1230X17.585Z-105.495	N1230Y17.585Z-105.495
N1240G0Z-.75	N1240G0Z-.75
N1250M5	N1250M5
N1260G91G28Z0.	N1270G91G28Z0.
N1270G28X0.Y0.**A0.**	N1260G28Y0.X0.
N1280M30	N1280M30
%	%
MACHINE TIME IN MIN (C) =	**75.50**

Total Cycle Time In Minutes (A+B+C) = 188.03

APPENDIX E

PART PROGRAMS FOR THE COLLIMATOR HOLDER

HOLDER PROGRAM NO.1	
ORIGINAL	**MODIFIED**
%	%
N100 O0600	N100 O0600
(PROGRAM NAME - HOLDER PROFILE1)	(PROGRAM NAME - HOLDER PROFILE1)
(DATE=DD-MM-YY - 11-10-06 TIME=HH:MM - 12:25)	(DATE=DD-MM-YY - 11-10-06 TIME=HH:MM - 12:25)
N102 G21	N102 G21
N104 G0**G17**G40G49G80	N104 G0**G19**G40G49G80**G54**
(OD ROUGH LEFT - 80 DEG. TOOL - 15 DIA. OFF. - 15 LEN. - 0 DIA. - 0.)	(OD ROUGH LEFT - 80 DEG. TOOL - 15 DIA. OFF. - 15 LEN. - 0 DIA. - 0.)
N106 T15M6	N106 T15M6
N108 G0G90**X**73.8**Y**0.**A0.**S280M3	N108 G0G90**Y**73.8**X**0.S280M4
N110 **G43H0**Z-37.697	N110 Z-37.697
N112 **X**72.002	N112 **Y**72.002
N114 G1Z0.F.5	N114 G1Z0.F.5
N116 G0Z-37.696	N116 G0Z-37.696
N118 **X**71.504	N118 **Y**71.504
N120 G1Z-23.602	N120 G1Z-23.602
N122 **X**71.528	N122 **Y**71.528
N124 **G2X**71.778Z-23.352R.25	N124 **G3Y**71.778Z-23.352R.25
N126 G1Z3.185	N126 G1Z3.185
N128 G0Z-37.696	N128 G0Z-37.696
N130 **X**71.006	N130 **Y**71.006
N132 G1Z-23.602	N132 G1Z-23.602
N134 **X**71.504	N134 **Y**71.504
N136 G0Z-37.696	N136 G0Z-37.696
N138 **X**70.507	N138 **Y**70.507
N140 G1Z-23.602	N140 G1Z-23.602
N142 **X**71.006	N142 **Y**71.006
N144 G0Z-37.696	N144 G0Z-37.696
N146 **X**70.009	N146 **Y**70.009
N148 G1Z-23.602	N148 G1Z-23.602
N150 **X**70.507	N150 **Y**70.507
N152 G0Z-37.696	N152 G0Z-37.696
N154 **X**69.511	N154 **Y**69.511
N156 G1Z-23.602	N156 G1Z-23.602
N158 **X**70.009	N158 **Y**70.009
N160 G0Z-37.696	N160 G0Z-37.696
N162 **X**69.013	N162 **Y**69.013
N164 G1Z-23.602	N164 G1Z-23.602
N166 **X**69.511	N166 **Y**69.511
N168 G0Z-37.695	N168 G0Z-37.695
N170 **X**68.515	N170 **Y**68.515
N172 G1Z-23.602	N172 G1Z-23.602
N174 **X**69.013	N174 **Y**69.013
N176 G0Z-37.695	N176 G0Z-37.695
N178 **X**68.017	N178 **Y**68.017

N180 G1Z-23.602
N182 **X**68.515
N184 G0Z-37.695
N186 **X**67.518
N188 G1Z-32.693
N190 **X**67.75
N192 **G2**X68.Z-32.443R.25
N194 G1X68.002Z-23.602
N196 **X**68.017
N198 G0Z-37.695
N200 **X**67.02
N202 G1Z-32.693
N204 **X**67.518
N206 G0Z-37.695
N208 **X**66.522
N210 G1Z-32.693
N212 **X**67.02
N214 G0Z-37.694
N216 **X**66.024
N218 G1Z-32.693
N220 **X**66.522
N222 G0Z-37.694
N224 **X**65.526
N226 G1Z-32.693
N228 **X**66.024
N230 G0Z-63.198
N232 **X**65.028
N234 G1Z-32.693
N236 **X**65.526
N238 G0Z-63.198
N240 **X**64.529
N242 G1Z-32.693
N244 **X**65.028
N246 G0Z-63.198
N248 **X**64.031
N250 G1Z-32.693
N252 **X**64.529
N254 G0Z-63.198
N256 **X**63.533
N258 G1Z-32.693
N260 **X**64.031
N262 G0Z-63.198
N264 **X**63.035
N266 G1Z-32.693
N268 **X**63.533
N270 G0Z-63.198
N272 **X**62.537
N274 G1Z-32.693
N276 **X**63.035
N278 G0Z-63.198
N280 **X**62.039
N282 G1Z-32.693
N284 **X**62.537
N286 G0Z-63.198
N288 **X**61.54
N290 G1Z-32.693
N292 **X**62.039
N294 G0Z-63.198

N180 G1Z-23.602
N182 **Y**68.515
N184 G0Z-37.695
N186 **Y**67.518
N188 G1Z-32.693
N190 **Y**67.75
N192 **G3Y**68.Z-32.443R.25
N194 G1**Y**68.002Z-23.602
N196 **Y**68.017
N198 G0Z-37.695
N200 **Y**67.02
N202 G1Z-32.693
N204 **Y**67.518
N206 G0Z-37.695
N208 **Y**66.522
N210 G1Z-32.693
N212 **Y**67.02
N214 G0Z-37.694
N216 **Y**66.024
N218 G1Z-32.693
N220 **Y**66.522
N222 G0Z-37.694
N224 **Y**65.526
N226 G1Z-32.693
N228 **Y**66.024
N230 G0Z-63.198
N232 **Y**65.028
N234 G1Z-32.693
N236 **Y**65.526
N238 G0Z-63.198
N240 **Y**64.529
N242 G1Z-32.693
N244 **Y**65.028
N246 G0Z-63.198
N248 **Y**64.031
N250 G1Z-32.693
N252 **Y**64.529
N254 G0Z-63.198
N256 **Y**63.533
N258 G1Z-32.693
N260 **Y**64.031
N262 G0Z-63.198
N264 **Y**63.035
N266 G1Z-32.693
N268 **Y**63.533
N270 G0Z-63.198
N272 **Y**62.537
N274 G1Z-32.693
N276 **Y**63.035
N278 G0Z-63.198
N280 **Y**62.039
N282 G1Z-32.693
N284 **Y**62.537
N286 G0Z-63.198
N288 **Y**61.54
N290 G1Z-32.693
N292 **Y**62.039
N294 G0Z-63.198

N296 X61.042
N298 G1Z-32.693
N300 X61.54
N302 G0Z-63.198
N304 X60.544
N306 G1Z-58.068
N308 **G2X**60.575Z-57.948R.25
N310 G1Z-32.693
N312 X61.042
N314 G0Z-63.198
N316 X60.046
N318 G1Z-58.198
N320 X60.325
N322 **G2X**60.544Z-58.068R.25
N324 G0Z-63.198
N326 X59.548
N328 G1Z-58.198
N330 X60.046
N332 G0Z-63.198
N334 X59.05
N336 G1Z-58.198
N338 X59.548
N340 G0Z-63.198
N342 X58.551
N344 G1Z-58.198
N346 X59.05
N348 G0Z-63.198
N350 X58.053
N352 G1Z-58.198
N354 X58.551
N356 G0Z-63.198
N358 X57.555
N360 G1Z-58.198
N362 X58.053
N364 G0Z-63.198
N366 X57.057
N368 G1Z-58.198
N370 X57.555
N372 G0Z-63.198
N374 X56.559
N376 G1Z-58.198
N378 X57.057
N380 G0Z-63.198
N382 X56.061
N384 G1Z-58.198
N386 X56.559
N388 G0Z-63.198
N390 X55.563
N392 G1Z-58.198
N394 X56.061
N396 G0Z-83.943
N398 X55.064
N400 G1Z-58.198
N402 X55.563
N404 G0Z-83.943
N406 X54.566
N408 G1Z-58.198
N410 X55.064

N296 Y61.042
N298 G1Z-32.693
N300 Y61.54
N302 G0Z-63.198
N304 Y60.544
N306 G1Z-58.068
N308 **G3Y**60.575Z-57.948R.25
N310 G1Z-32.693
N312 Y61.042
N314 G0Z-63.198
N316 Y60.046
N318 G1Z-58.198
N320 Y60.325
N322 **G3Y**60.544Z-58.068R.25
N324 G0Z-63.198
N326 Y59.548
N328 G1Z-58.198
N330 Y60.046
N332 G0Z-63.198
N334 Y59.05
N336 G1Z-58.198
N338 Y59.548
N340 G0Z-63.198
N342 Y58.551
N344 G1Z-58.198
N346 Y59.05
N348 G0Z-63.198
N350 Y58.053
N352 G1Z-58.198
N354 Y58.551
N356 G0Z-63.198
N358 Y57.555
N360 G1Z-58.198
N362 Y58.053
N364 G0Z-63.198
N366 Y57.057
N368 G1Z-58.198
N370 Y57.555
N372 G0Z-63.198
N374 Y56.559
N376 G1Z-58.198
N378 Y57.057
N380 G0Z-63.198
N382 Y56.061
N384 G1Z-58.198
N386 Y56.559
N388 G0Z-63.198
N390 Y55.563
N392 G1Z-58.198
N394 Y56.061
N396 G0Z-83.943
N398 Y55.064
N400 G1Z-58.198
N402 Y55.563
N404 G0Z-83.943
N406 Y54.566
N408 G1Z-58.198
N410 Y55.064

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N412 G0Z-83.943
N414 X54.068
N416 G1Z-58.198
N418 X54.566
N420 G0Z-83.943
N422 X53.57
N424 G1Z-58.198
N426 X54.068
N428 G0Z-83.943
N430 X53.072
N432 G1Z-58.198
N434 X53.57
N436 G0Z-83.943
N438 X52.574
N440 G1Z-58.198
N442 X53.072
N444 G0Z-83.943
N446 X52.075
N448 G1Z-58.198
N450 X52.574
N452 G0Z-83.943
N454 X51.577
N456 G1Z-58.198
N458 X52.075
N460 G0Z-83.943
N462 X51.079
N464 G1Z-58.198
N466 X51.577
N468 G0Z-83.943
N470 X50.581
N472 G1Z-58.198
N474 X51.079
N476 G0Z-83.943
N478 X50.083
N480 G1Z-78.943
N482 X50.252
N484 G2X50.502Z-78.693R.25
N486 G1Z-58.198
N488 X50.581
N490 G0Z-83.943
N492 X49.585
N494 G1Z-78.943
N496 X50.083
N498 G0Z-83.943
N500 X49.086
N502 G1Z-78.943
N504 X49.585
N506 G0Z-83.943
N508 X48.588
N510 G1Z-78.943
N512 X49.086
N514 G0Z-83.943
N516 X48.09
N518 G1Z-78.943
N520 X48.588
N522 G0Z-83.943
N524 X47.592
N526 G1Z-78.943
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N414 Y54.068
N416 G1Z-58.198
N418 Y54.566
N420 G0Z-83.943
N422 Y53.57
N424 G1Z-58.198
N426 Y54.068
N428 G0Z-83.943
N430 Y53.072
N432 G1Z-58.198
N434 Y53.57
N436 G0Z-83.943
N438 Y52.574
N440 G1Z-58.198
N442 Y53.072
N444 G0Z-83.943
N446 Y52.075
N448 G1Z-58.198
N450 Y52.574
N452 G0Z-83.943
N454 Y51.577
N456 G1Z-58.198
N458 Y52.075
N460 G0Z-83.943
N462 Y51.079
N464 G1Z-58.198
N466 Y51.577
N468 G0Z-83.943
N470 Y50.581
N472 G1Z-58.198
N474 Y51.079
N476 G0Z-83.943
N478 Y50.083
N480 G1Z-78.943
N482 Y50.252
N484 G3Y50.502Z-78.693R.25
N486 G1Z-58.198
N488 Y50.581
N490 G0Z-83.943
N492 Y49.585
N494 G1Z-78.943
N496 Y50.083
N498 G0Z-83.943
N500 Y49.086
N502 G1Z-78.943
N504 Y49.585
N506 G0Z-83.943
N508 Y48.588
N510 G1Z-78.943
N512 Y49.086
N514 G0Z-83.943
N516 Y48.09
N518 G1Z-78.943
N520 Y48.588
N522 G0Z-83.943
N524 Y47.592
N526 G1Z-78.943
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N528 X48.09
N530 G0Z-83.943
N532 X47.094
N534 G1Z-78.943
N536 X47.592
N538 G0Z-83.943
N540 X46.596
N542 G1Z-78.943
N544 X47.094
N546 G0Z-83.943
N548 X46.097
N550 G1Z-78.943
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N554 G0Z-83.943
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N558 G1Z-78.943
N560 X46.097
N562 G0Z-83.943
N564 X45.101
N566 G1Z-78.943
N568 X45.599
N570 G0Z-83.943
N572 X44.603
N574 G1Z-78.943
N576 X45.101
N578 G0Z-107.251
N580 X44.105
N582 G1Z-78.943
N584 X44.603
N586 G0Z-107.251
N588 X43.607
N590 G1Z-78.943
N592 X44.105
N594 G0Z-107.251
N596 X43.108
N598 G1Z-78.943
N600 X43.607
N602 G0Z-107.251
N604 X42.61
N606 G1Z-78.943
N608 X43.108
N610 G0Z-107.251
N612 X42.112
N614 G1Z-78.943
N616 X42.61
N618 G0Z-107.251
N620 X41.614
N622 G1Z-78.943
N624 X42.112
N626 G0Z-107.251
N628 X41.116
N630 G1Z-78.943
N632 X41.614
N634 G0Z-107.251
N636 X40.618
N638 G1Z-78.943
N640 X41.116
N642 G0Z-107.251
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N530 G0Z-83.943
N532 Y47.094
N534 G1Z-78.943
N536 Y47.592
N538 G0Z-83.943
N540 Y46.596
N542 G1Z-78.943
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N546 G0Z-83.943
N548 Y46.097
N550 G1Z-78.943
N552 Y46.596
N554 G0Z-83.943
N556 Y45.599
N558 G1Z-78.943
N560 Y46.097
N562 G0Z-83.943
N564 Y45.101
N566 G1Z-78.943
N568 Y45.599
N570 G0Z-83.943
N572 Y44.603
N574 G1Z-78.943
N576 Y45.101
N578 G0Z-107.251
N580 Y44.105
N582 G1Z-78.943
N584 Y44.603
N586 G0Z-107.251
N588 Y43.607
N590 G1Z-78.943
N592 Y44.105
N594 G0Z-107.251
N596 Y43.108
N598 G1Z-78.943
N600 Y43.607
N602 G0Z-107.251
N604 Y42.61
N606 G1Z-78.943
N608 Y43.108
N610 G0Z-107.251
N612 Y42.112
N614 G1Z-78.943
N616 Y42.61
N618 G0Z-107.251
N620 Y41.614
N622 G1Z-78.943
N624 Y42.112
N626 G0Z-107.251
N628 Y41.116
N630 G1Z-78.943
N632 Y41.614
N634 G0Z-107.251
N636 Y40.618
N638 G1Z-78.943
N640 Y41.116
N642 G0Z-107.251
```

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N644 X40.12
N646 G1Z-78.943
N648 X40.618
N650 G0Z-107.251
N652 X39.621
N654 G1Z-78.943
N656 X40.12
N658 G0Z-107.251
N660 X39.123
N662 G1Z-78.943
N664 X39.621
N666 G0Z-107.251
N668 X38.625
N670 G1Z-78.943
N672 X39.123
N674 G0Z-107.251
N676 X38.127
N678 G1Z-85.28
N680 G2X38.247Z-85.066R.25
N682 G1Z-78.943
N684 X38.625
N686 G0Z-107.251
N688 X37.629
N690 G1Z-85.478
N692 X38.088Z-85.299
N694 X38.127Z-85.28
N696 G0Z-107.251
N698 X37.131
N700 G1Z-85.672
N702 X37.629Z-85.478
N704 G0Z-107.251
N706 X36.632
N708 G1Z-85.866
N710 X37.131Z-85.672
N712 G0Z-107.251
N714 X36.134
N716 G1Z-86.06
N718 X36.632Z-85.866
N720 G0Z-107.251
N722 X35.636
N724 G1Z-86.255
N726 X36.134Z-86.06
N728 G0Z-107.251
N730 X35.138
N732 G1Z-86.449
N734 X35.636Z-86.255
N736 G0Z-107.251
N738 X34.64
N740 G1Z-86.643
N742 X35.138Z-86.449
N744 G0Z-107.251
N746 X34.142
N748 G1Z-86.837
N750 X34.64Z-86.643
N752 G0Z-107.251
N754 X33.643
N756 G1Z-87.031
N758 X34.142Z-86.837
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N644 Y40.12
N646 G1Z-78.943
N648 Y40.618
N650 G0Z-107.251
N652 Y39.621
N654 G1Z-78.943
N656 Y40.12
N658 G0Z-107.251
N660 Y39.123
N662 G1Z-78.943
N664 Y39.621
N666 G0Z-107.251
N668 Y38.625
N670 G1Z-78.943
N672 Y39.123
N674 G0Z-107.251
N676 Y38.127
N678 G1Z-85.28
N680 G3Y38.247Z-85.066R.25
N682 G1Z-78.943
N684 Y38.625
N686 G0Z-107.251
N688 Y37.629
N690 G1Z-85.478
N692 Y38.088Z-85.299
N694 Y38.127Z-85.28
N696 G0Z-107.251
N698 Y37.131
N700 G1Z-85.672
N702 Y37.629Z-85.478
N704 G0Z-107.251
N706 Y36.632
N708 G1Z-85.866
N710 Y37.131Z-85.672
N712 G0Z-107.251
N714 Y36.134
N716 G1Z-86.06
N718 Y36.632Z-85.866
N720 G0Z-107.251
N722 Y35.636
N724 G1Z-86.255
N726 Y36.134Z-86.06
N728 G0Z-107.251
N730 Y35.138
N732 G1Z-86.449
N734 Y35.636Z-86.255
N736 G0Z-107.251
N738 Y34.64
N740 G1Z-86.643
N742 Y35.138Z-86.449
N744 G0Z-107.251
N746 Y34.142
N748 G1Z-86.837
N750 Y34.64Z-86.643
N752 G0Z-107.251
N754 Y33.643
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N758 Y34.142Z-86.837
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N762 X33.145	N762 Y33.145
N764 G1Z-87.225	N764 G1Z-87.225
N766 X33.643Z-87.031	N766 Y33.643Z-87.031
N768 G0Z-114.703	N768 G0Z-114.703
N770 X32.647	N770 Y32.647
N772 G1Z-87.419	N772 G1Z-87.419
N774 X33.145Z-87.225	N774 Y33.145Z-87.225
N776 G0Z-114.751	N776 G0Z-114.751
N778 X32.149	N778 Y32.149
N780 G1Z-87.613	N780 G1Z-87.613
N782 X32.647Z-87.419	N782 Y32.647Z-87.419
N784 G0Z-114.751	N784 G0Z-114.751
N786 X31.651	N786 Y31.651
N788 G1Z-87.807	N788 G1Z-87.807
N790 X32.149Z-87.613	N790 Y32.149Z-87.613
N792 G0Z-114.751	N792 G0Z-114.751
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N796 G1Z-88.001	N796 G1Z-88.001
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N800 G0Z-114.751	N800 G0Z-114.751
N802 X30.654	N802 Y30.654
N804 G1Z-88.196	N804 G1Z-88.196
N806 X31.153Z-88.001	N806 Y31.153Z-88.001
N808 G0Z-114.751	N808 G0Z-114.751
N810 X30.156	N810 Y30.156
N812 G1Z-88.39	N812 G1Z-88.39
N814 X30.654Z-88.196	N814 Y30.654Z-88.196
N816 G0Z-114.751	N816 G0Z-114.751
N818 X29.658	N818 Y29.658
N820 G1Z-88.584	N820 G1Z-88.584
N822 X30.156Z-88.39	N822 Y30.156Z-88.39
N824 G0Z-114.751	N824 G0Z-114.751
N826 X29.16	N826 Y29.16
N828 G1Z-88.778	N828 G1Z-88.778
N830 X29.658Z-88.584	N830 Y29.658Z-88.584
N832 G0Z-114.751	N832 G0Z-114.751
N834 X28.662	N834 Y28.662
N836 G1Z-88.972	N836 G1Z-88.972
N838 X29.16Z-88.778	N838 Y29.16Z-88.778
N840 G0Z-115.38	N840 G0Z-115.38
N842 X28.163	N842 Y28.163
N844 G1X28.167Z-89.165	N844 G1Y28.167Z-89.165
N846 X28.662Z-88.972	N846 Y28.662Z-88.972
N848 G0X73.078	N848 G0Y73.078
N850 M5	N850 M5
N852 G91G28Z0.	N852 G91G28Z0.
N854 G28X0.Y0.A0.	N854 G28Y0.X0.
N856 M30	N856 M30
%	%
CYCLE TIME IN MIN (A) =	90.20

HOLDER PROGRAM NO.2

ORIGINAL	MODIFIED
%	%
O0640	O0640
(PROGRAM NAME - HOLDER PROFILE2	(PROGRAM NAME - HOLDER PROFILE2

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(DATE=DD-MM-YY - 31-10-06 TIME=HH:MM - 11:10)
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(ROUGHING)
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N80X73.914Z-24.238
N90G0Z2.7
N100X71.509
N110G1Z-25.652
N120X72.205
N130X73.619Z-24.238
N140G0Z2.7
N150X71.014
N160G1Z-25.652
N170X71.709
N180X73.124Z-24.238
N190G0Z2.7
N200X70.519
N210G1Z-14.081
N220G3X70.728Z-15.218R3.2
N230G1Z-25.652
N240X71.214
N250X72.628Z-24.238
N260G0Z2.7
N270X70.024
N280G1Z-13.215
N290G3X70.719Z-14.982R3.2
N300G1X72.133Z-13.567
N310G0Z2.7
N320X69.528
N330G1Z-12.72
N340G3X70.224Z-13.494R3.2
N350G1X71.638Z-12.08
N360G0Z2.7
N370X69.033
N380G1Z-12.394
N390G3X69.728Z-12.895R3.2
N400G1X71.143Z-11.48
N410G0Z2.7
N420X68.538
N430G1Z-12.181
N440X68.564Z-12.19
N450G3X69.233Z-12.51R3.2
N460G1X70.647Z-11.096
N470G0Z2.7
N480X68.043
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N520G1X70.152Z-10.841
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TURNING)
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(ROUGHING)
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N80Y73.914Z-24.238
N90G0Z2.7
N100Y71.509
N110G1Z-25.652
N120Y72.205
N130Y73.619Z-24.238
N140G0Z2.7
N150Y71.014
N160G1Z-25.652
N170Y71.709
N180Y73.124Z-24.238
N190G0Z2.7
N200Y70.519
N210G1Z-14.081
N220G2Y70.728Z-15.218R3.2
N230G1Z-25.652
N240Y71.214
N250Y72.628Z-24.238
N260G0Z2.7
N270Y70.024
N280G1Z-13.215
N290G2Y70.719Z-14.982R3.2
N300G1Y72.133Z-13.567
N310G0Z2.7
N320Y69.528
N330G1Z-12.72
N340G2Y70.224Z-13.494R3.2
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N360G0Z2.7
N370Y69.033
N380G1Z-12.394
N390G2Y69.728Z-12.895R3.2
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N420Y68.538
N430G1Z-12.181
N440Y68.564Z-12.19
N450G2Y69.233Z-12.51R3.2
N460G1Y70.647Z-11.096
N470G0Z2.7
N480Y68.043
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N600G1Z-11.673
N610X67.747Z-11.911
N620X69.161Z-10.497
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N650G1Z-11.503
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N680G0Z2.7
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N720X68.171Z-10.158
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N1090X62.099
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N3050G1Z-3.369
N3060X43.479Z-3.607
N3070X44.893Z-2.193
N3080G0Z2.7
N3090X42.288
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N3270X42.912Z-1.515
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N3290X40.307
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N3310X41.002Z-2.76
N3320X42.417Z-1.346
N3330G0Z2.7
N3340X39.812
N3350G1Z-2.353
N3360X40.507Z-2.591
N3370X41.921Z-1.176
N3380G0Z2.7
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N3420X41.426Z-1.007
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N2930G0Z2.7
N2940Y43.774
N2950G1Z-3.708
N2960Y44.469Z-3.946
N2970Y45.884Z-2.532
N2980G0Z2.7
N2990Y43.279
N3000G1Z-3.539
N3010Y43.974Z-3.777
N3020Y45.388Z-2.363
N3030G0Z2.7
N3040Y42.783
N3050G1Z-3.369
N3060Y43.479Z-3.607
N3070Y44.893Z-2.193
N3080G0Z2.7
N3090Y42.288
N3100G1Z-3.2
N3110Y42.983Z-3.438
N3120Y44.398Z-2.024
N3130G0Z2.7
N3140Y41.793
N3150G1Z-3.03
N3160Y42.488Z-3.268
N3170Y43.902Z-1.854
N3180G0Z2.7
N3190Y41.298
N3200G1Z-2.861
N3210Y41.993Z-3.099
N3220Y43.407Z-1.685
N3230G0Z2.7
N3240Y40.802
N3250G1Z-2.692
N3260Y41.498Z-2.929
N3270Y42.912Z-1.515
N3280G0Z2.7
N3290Y40.307
N3300G1Z-2.522
N3310Y41.002Z-2.76
N3320Y42.417Z-1.346
N3330G0Z2.7
N3340Y39.812
N3350G1Z-2.353
N3360Y40.507Z-2.591
N3370Y41.921Z-1.176
N3380G0Z2.7
N3390Y39.317
N3400G1Z-2.183
N3410Y40.012Z-2.421
N3420Y41.426Z-1.007
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N3770X37.959Z.179
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N3850G1Z-.658
N3860X35.554Z-.896
N3870X36.969Z.518
N3880G0Z2.7
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N3490Y38.326
N3500G1Z-1.844
N3510Y39.021Z-2.082
N3520Y40.435Z-.668
N3530G0Z2.7
N3540Y37.831
N3550G1Z-1.675
N3560Y38.526Z-1.913
N3570Y39.94Z-.498
N3580G0Z2.7
N3590Y37.335
N3600G1Z-1.505
N3610Y38.031Z-1.743
N3620Y39.445Z-.329
N3630G0Z2.7
N3640Y36.84
N3650G1Z-1.336
N3660Y37.535Z-1.574
N3670Y38.95Z-.16
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N3690Y36.345
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N3710Y37.04Z-1.404
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N3740Y35.85
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N3760Y36.545Z-1.235
N3770Y37.959Z.179
N3780G0Z2.7
N3790Y35.354
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N3820Y37.464Z.349
N3830G0Z2.7
N3840Y34.859
N3850G1Z-.658
N3860Y35.554Z-.896
N3870Y36.969Z.518
N3880G0Z2.7
N3890Y34.364
N3900G1Z-.489
N3910Y35.059Z-.726
N3920Y36.473Z.688
N3930G0Z2.7
N3940Y33.869
N3950G1Z-.319
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N3970Y35.978Z.857
N3980G0Z2.7
N3990Y33.373
N4000G1Z-.15
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N4020X35.483Z1.027	N4020Y35.483Z1.027
N4030G0Z2.7	N4030G0Z2.7
N4040X32.383	N4040Y32.383
N4050G1Z.189	N4050G1Z.189
N4060X33.078Z-.049	N4060Y33.078Z-.049
N4070X34.492Z1.366	N4070Y34.492Z1.366
(FINISH)	(FINISH)
N4080G0Z3.892	N4080G0Z3.892
N4090X32.965	N4090Y32.965
N4100G1Z1.892F5.	N4100G1Z1.892F5.
N4110X69.146Z-10.487	N4110Y69.146Z-10.487
N4120**G3**X72.528Z-15.218R5.	N4120**G2**Y72.528Z-15.218R5.
N4130G1Z-25.852	N4130G1Z-25.852
N4140X73.942Z-24.438	N4140Y73.942Z-24.438
N4150G0Z2.	N4150G0Z2.
N4160X32.318	N4160Y32.318
N4170G1Z0.	N4170G1Z0.
N4180X68.499Z-12.379	N4180Y68.499Z-12.379
N4190**G3**X70.528Z-15.218R3.	N4190**G2**Y70.528Z-15.218R3.
N4200G1Z-25.852	N4200G1Z-25.852
N4210X71.942Z-24.438	N4210Y71.942Z-24.438
N4220M5	N4220M5
N4230G91G0G28Z0.	N4230G91G0G28Z0.
N4240G28X0.Y0.**A0.**	N4240G28Y0.X0.
N4250M30	N4250M30
%	%
CYCLE TIME IN MIN (B) =	60.30

HOLDER PROGRAM NO.3	
ORIGINAL	MODIFIED
%	%
O0630	**N10** O0630
G21	**N20** G21
	N30 G54G19G40G49G80G90
(PROGRAM NAME - HOLDER PROFILE THREADING DATE=DD-MM-YY - 05-01-07 TIME=HH:MM - 22:06)	(PROGRAM NAME - HOLDER PROFILE THREADING22 DATE=DD-MM-YY - 25-10-06 TIME=HH:MM - 11:52)
(TOOL – 15 OFFSET - 15)	(TOOL - 15 OFFSET - 15)
(LTHREAD OD THREAD LEFT INSERT - R166.0G-16UN01-100)	(LTHREAD OD THREAD LEFT INSERT - R166.0G-16UN01-100)
(THREADING)	(THREADING)
G28U0.W0.	
G0T1500	
G0T1515	**N40** T15M6
G97S120**M03**	**N50** S120M4
G0**X145.655**Z-60.524	**N60** G0Y72.8275**X0.**
	N70 Z-60.524
X125.748	**N80 Y62.874**
X119.988	**N90 Y59.994**
G99**G32**Z-39.E2.1167	N100 G99**G33**Z-39.F2.11667
G0**X125.498**	**N110** G0**Y62.874**
Z-60.452	**N120** Z-60.452
X119.729	**N130 Y59.8645**
G32Z-39.E2.1167	N140 **G33**Z-39.F2.11667
G0**X125.748**	**N150** G0**Y62.874**
Z-60.38	N160 Z-60.38
X119.729	**N170 Y59.7345**

G32Z-39.E2.1167	N180 G33Z-39.F2.11667
G0X125.748	N190 G0Y62.874
Z-60.308	N200 Z-60.308
X119.209	N210 Y59.6045
G32Z-39.E2.1167	N220 G33Z-39.F2.11667
G0X125.498	N230 G0Y62.874
Z-60.236	N240 Z-60.236
X118.95	N250 Y59.475
G32Z-39.E2.1167	N260 G33Z-39.F2.11667
G0X125.748	N270 G0Y62.874
Z-60.164	N280 Z-60.164
X118.69	N290 Y59.345
G32Z-39.E2.1167	N300 G33Z-39.F2.11667
G0X125.748	N310 G0Y62.874
Z-60.092	N320 Z-60.092
X118.43	N330 Y59.215
G32Z-39.E2.1167	N340 G33Z-39.F2.11667
G0X125.748	N350 G0Y62.874
Z-60.02	N360 Z-60.02
X118.171	N370 Y59.0855
G32Z-39.E2.1167	N380 G33Z-39.F2.11667
G0X125.748	N390 G0Y62.874
Z-59.948	N400 Z-59.948
X117.911	N410 Y58.9555
G32Z-39.E2.1167	N420 G33Z-39.F2.11667
G0X125.748	N430 G0Y62.874
Z-59.876	N440 Z-59.876
X117.651	N450 Y58.8255
G32Z-39.E2.1167	N460 G33Z-39.F2.11667
G0X125.748	N470 G0Y62.874
Z-59.876	N480 Z-59.876
X117.651	N490 Y58.8255
G32Z-39.E2.1167	N500 G33Z-39.F2.11667
G0X125.748	N510 G0Y62.874
Z-60.524	N520 Z-60.524
X145.655	N530 Y72.8275
T1500	N540 M5
G28U0.W0.M05	N550 G91G28Y0.X0.
	N560 G28Z0.
M30	N570 M30
%	%
CYCLE TIME IN MIN (B) =	20.20

HOLDER PROGRAM NO.4

ORIGINAL	MODIFIED
%	%
O0620	O0620
(PROGRAM NAME - HOLDER PROFILE BORING)	(PROGRAM NAME - HOLDER PROFILE BORING)
(DATE=DD-MM-XX - 18-10-06 TIME=HH:MM - 12:00)	(DATE=DD-MM-YY - 18-10-06 TIME=HH:MM - 12:00)
N10G21	N10G21
N20G0**G17**G40G49G80G90	N20G0**G19**G40G49G80G90**G54**
(BORING TOOL - 15 DIA. OFF. - 15 LEN. - 0 DIA. - 0.)	(BORING TOOL - 15 DIA. OFF. - 15 LEN. - 0 DIA. - 0.)
(ROUGHING PASSES)	(ROUGHING PASSES)
N30T15M6	N30T15M6
N40G0G90X20.413Y0.**A0.**S350M3	N40G0G90Y20.413**X0.**S350M3

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N70X19.924Z-107.001
N80X18.51Z-105.586
N90G0Z2.65
N100X20.902
N110G1Z-106.428
N120X20.313Z-106.773
N130X18.899Z-105.359
N140G0Z2.65
N150X21.391
N160G1Z-106.142
N170X20.802Z-106.487
N180X19.388Z-105.072
N190G0Z2.65
N200X21.88
N210G1Z-105.856
N220X21.291Z-106.2
N230X19.877Z-104.786
N240G0Z2.65
N250X22.369
N260G1Z-105.569
N270X21.78Z-105.914
N280X20.366Z-104.5
N290G0Z2.65
N300X22.858
N310G1Z-105.283
N320X22.269Z-105.628
N330X20.855Z-104.214
N340G0Z2.65
N350X23.347
N360G1Z-104.997
N370X22.758Z-105.342
N380X21.344Z-103.927
N390G0Z2.65
N400X23.836
N410G1Z-86.457
N420X23.761
N430G2X23.611Z-86.607R.15
N440G1X23.609Z-104.843
N450X23.247Z-105.055
N460X21.833Z-103.641
N470G0Z2.65
N480X24.325
N490G1Z-86.457
N500X23.761
N510X23.736Z-86.459
N520X22.322Z-85.045
N530G0Z2.65
N540X24.814
N550G1Z-86.457
N560X24.225
N570X22.811Z-85.043
N580G0Z2.65
N590X25.303
N600G1Z-84.202
N610X24.913Z-84.485
N620G2X24.851Z-84.607R.15
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N90G0Z2.65
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N110G1Z-106.428
N120Y20.313Z-106.773
N130Y18.899Z-105.359
N140G0Z2.65
N150Y21.391
N160G1Z-106.142
N170Y20.802Z-106.487
N180Y19.388Z-105.072
N190G0Z2.65
N200Y21.88
N210G1Z-105.856
N220Y21.291Z-106.2
N230Y19.877Z-104.786
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N250Y22.369
N260G1Z-105.569
N270Y21.78Z-105.914
N280Y20.366Z-104.5
N290G0Z2.65
N300Y22.858
N310G1Z-105.283
N320Y22.269Z-105.628
N330Y20.855Z-104.214
N340G0Z2.65
N350Y23.347
N360G1Z-104.997
N370Y22.758Z-105.342
N380Y21.344Z-103.927
N390G0Z2.65
N400Y23.836
N410G1Z-86.457
N420Y23.761
N430G3Y23.611Z-86.607R.15
N440G1Y23.609Z-104.843
N450Y23.247Z-105.055
N460Y21.833Z-103.641
N470G0Z2.65
N480Y24.325
N490G1Z-86.457
N500Y23.761
N510Y23.736Z-86.459
N520Y22.322Z-85.045
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N540Y24.814
N550G1Z-86.457
N560Y24.225
N570Y22.811Z-85.043
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N590Y25.303
N600G1Z-84.202
N610Y24.913Z-84.485
N620G3Y24.851Z-84.607R.15
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N760X25.692Z-83.92
N770X24.278Z-82.505
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N760Y25.692Z-83.92
N770Y24.278Z-82.505
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N790Y26.77
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N820G1Y24.767Z-18.546
N830G0Z2.65
N840Y27.259
N850G1Z-19.051
N860G3Y26.67Z-19.393R2.15
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N1070Y28.626
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N3660Z1.25	N3660Z1.25
N3670M5	N3670M5
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N3690G28X0.Y0.**A0.**	N3690G28Y0.X0.
N3700M30	N3700M30
%	%
CYCLE TIME IN MIN (D) =	81.30

HOLDER PROGRAM NO.5	
ORIGINAL	MODIFIED
%	%
O0650	O0650
(PROGRAM NAME - HOLDER PROFILE BORING CHANFER)	(PROGRAM NAME - HOLDER PROFILE BORING CHAMFER)
(DATE=DD-MM-YY - 05-01-07 TIME=HH:MM - 23:06)	(DATE=DD-MM-YY - 01-11-06 TIME=HH:MM - 10:37)
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N20G0**G17**G40G49G80G90	N20**G54**G0**G19**G40G49G80G90
(BORING TOOL - 1 DIA. OFF. - 15 LEN. - 0 DIA. - 0.)	(BORING TOOL - 1 DIA. OFF. - 15 LEN. - 0 DIA. - 0.)
(CHAMFERING)	(CHAMFERING)
N30T1M6	N30T15M6
N40G0G90X39.731Y0.**A0.**S280M3	N40G0G90Y39.731X0.S280M3
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N70G1Z-7.432F4.	N70G1Z-7.432F4.
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N90X38.218Z-6.089	N90Y38.218Z-6.089
N100G0Z-1.621	N100G0Z-1.621
N110X39.829	N110Y39.829
N120G1Z-7.362	N120G1Z-7.362
N130X39.632Z-7.503	N130Y39.632Z-7.503
N140X38.218Z-6.089	N140Y38.218Z-6.089
N150G0Z-1.621	N150G0Z-1.621
N160X39.928	N160Y39.928
N170G1Z-7.291	N170G1Z-7.291
N180X39.632Z-7.503	N180Y39.632Z-7.503
N190X38.218Z-6.089	N190Y38.218Z-6.089
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N1340Y40.482Z-4.47
N1350G0Z-1.621
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N1380Y41.995Z-5.814
N1390Y40.581Z-4.4
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N1540X40.877Z-4.189
N1550G0Z-1.621
N1560X42.688
N1570G1Z-5.319
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N1850G0Z-1.621
N1860Y43.279
N1870G1Z-4.896
N1880Y42.981Z-5.11
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N2060X43.674
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N2280X43.769Z-4.546
N2290X42.355Z-3.132
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N2320G1Z-4.262
N2330X43.868Z-4.476
N2340X42.454Z-3.061
N2350G0Z-1.621
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N2370G1Z-4.192
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N1990Y41.764Z-3.555
N2000G0Z-1.621
N2010Y43.575
N2020G1Z-4.685
N2030Y43.276Z-4.898
N2040Y41.862Z-3.484
N2050G0Z-1.621
N2060Y43.674
N2070G1Z-4.615
N2080Y43.375Z-4.828
N2090Y41.961Z-3.414
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N2180Y43.572Z-4.687
N2190Y42.158Z-3.273
N2200G0Z-1.621
N2210Y43.969
N2220G1Z-4.403
N2230Y43.671Z-4.617
N2240Y42.256Z-3.202
N2250G0Z-1.621
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N2270G1Z-4.333
N2280Y43.769Z-4.546
N2290Y42.355Z-3.132
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N2310Y44.166
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N2430Y42.651Z-2.921
N2440G0Z-2.871
N2450M5
N2460G91G28Z0.
N2470G28Y0.X0.
```

N2480M30 %	N2480M30 %
CYCLE TIME IN MIN (E) =	11.80

HOLDER PROGRAM NO.6
% 0001(HOLE) N10G54G40G49G80G69 N20G00G91G28Z0 N35S800M3 N40G90Z5 N30G01Z-23.5F20 N40G00Z5 N50M30 %
CYCLE TIME IN MIN (F) = 48.00 (= 2MIN X 24 HOLES)

HOLDER PROGRAM NO7.
% 0002(HOLE) N10G54G40G49G80G69 N20G00G91G28Z0 N35S800M3 N40G90Z5 N30G01Z-31.5F20 N40G00Z5 N50M30 %
CYCLE TIME IN MIN (G) = 32.00 (= 2MIN X 16 HOLES)

APPENDIX F

DNC OPERATION

In DNC operation, the machine is not operated by a program registered in memory of the CNC, instead being operated by a program read directly from a connected input/output unit. This mode is used when the program used is too large to be registered in the memory of the CNC machine tool.

Procedure for DNC Operation

1. Select the MDI mode and specify the channel for the connected input/out put unit in the I/O field on the setting screen.
2. Select TAPE mode.
3. Press the cycle start key.
4. Send the program from the input/output unit.

DNC operation starts. The operation can be stopped and resumed in the same way as for memory operations.

Remote PC configuration for DNC Operation

A. Serial Port Settings

1. Port configuration
    - Ports: *COM1*
    - Stop Bits: *2*
    - Baud Rate: *9600*
    - Data Bits: *7*
    - Parity: *Even*

2. Flow Control Settings

   - *Software and hardware* or *software.*

   - Hardware Handshaking: *DTR/DSR*

3. Advanced Port Settings

   - XON Character: *17.*

   - XOFF Character: *19*

B. Sending Configurations

1. Send Settings

   - CR/LF: *\10\13\13*

   - Remove characters: *None*

   - Break after receiving characters: *4*

   - Send timeout (seconds): *0*

   - Delay before each line: *0*

   - Remove white space

C. Receive Configuration

1. Receive settings

   - CL\LF: *Auto*

   - Timeout: *360*

   - Remove characters: *None*

APPENDIX G

EXPECTED CLA RANGE

Finishing process	Approximte range of CLA values to be expected (microns)
Superfinishing	0.025 - 0.20
Lapping	0.025 - 0.40
Polishing	0.025 - 0.40
Buffing	0.10 - 0.40
Honing	0.10 - 0.80
Grinding	0.10 - 1.60
Diamond boring	0.20 - 0.40
Diamond turning	0.20 - 0.40
Turning	0.40 - 6.30
Boring	0.40 - 6.30
Reaming	0.80 - 3.20
Broaching	0.80 - 3.20
Milling	0.80 - 6.30
Spark machining	1.60 - 6.30
Shaping	1.60 - 12.50
Planing	1.60 - 12-50

APPENDIX H

SAMPLE CALCULATIONS

As a sample calculation of Table 7.2, consider readings for number 1 with 56mm diameter;

The resultant force;

$$F = \sqrt{F_a^{\ 2} + F_c^{\ 2} + F_r^{\ 2}} = \sqrt{110^2 + 90^2 + 20^2} = 143.50N$$

The cutting speed;

$$V_c = \frac{\pi DN}{1000} = \frac{3.142 \times 56 \times 280}{1000} = 49.27m/\min$$

Hence, cutting power;

$$P = \frac{F_c V_c}{60} = \frac{90 \times 49.27}{60} = 79.90 watts$$

APPENDIX I

G CODE LIST

G code	Group	Function	
G00		Positioning	
G01	01	Linear interpolation	
G02		Circular interpolation/Helical interpolation CW	
G03		Circular interpolation/Helical interpolation CCW	
G04		Dwell, Exact stop	
G05		High speed cycle machining	
G09		Exact stop	
G10	00	Data setting	
G11		Data setting mode cancel	
G15	17	Polar coordinate command cancel	
G16		Polar coordinate command	
G17		XpYp plane selection	Xp: X axis or its parallel axis
G18	02	ZpXp plane selection	Yp: Y axis or its parallel axis
G19		YpZp plane selection	Zp: Z axis or its parallel axis
G20	06	Input in inch	
G21		Input in mm	
G22	04	Stored stroke check function on	
G23		Stored stroke check function off	
G27		Reference position return check	
G28		Return to reference position	
G29		Return from reference position	
G30	00	2nd, 3rd and 4th reference position return	
G31		Skip function	
G33	01	Thread cutting	
G37	00	Automatic tool length measurement	
G39		Corner offset circular interpolation	
G40		Cutter compensation cancel	
G41	07	Cutter compensation left	
G42		Cutter compensation right	
G43	08	Tool length compensation + direction	
G44		Tool length compensation – direction	
G45		Tool offset increase	
G46		Tool offset decrease	
G47	00	Tool offset double increase	
G48		Tool offset double decrease	
G49	08	Tool length compensation cancel	
G50	11	Scaling cancel	
G51		Scaling	
G52	00	Local coordinate system	
G53		Machine coordinate system selection	
G54	14	Workpiece coordinate system 1 selection	

G55		Workpiece coordinate system 2 selection
G56		Workpiece coordinate system 3 selection
G57		Workpiece coordinate system 4 selection
G58		Workpiece coordinate system 5 selection
G59		Workpiece coordinate system 6 selection
G60	00	Single direction positioning
G61	15	Exact stop mode
G62		Automatic corner override
G63		Tapping mode
G64		Cutting mode
G65	00	Macro call
G66	12	Macro mode call
G67		Macro mode call cancel
G68	16	Coordinate rotation
G69		Coordinate rotation cancel
G73	09	Peck drilling cycle
G74		Counter tapping cycle
G75	01	Plunge grinding cycle
G76	09	Fine boring cycle
G77	01	Direct constant-dimension plunge grinding cycle
G78		Continuous-feed surface grinding cycle
G79		Intermittent-feed surface grinding cycle
G80	09	Canned cycle cancel/external operation function cancel
G81		Drilling cycle, spot boring cycle or external operation function
G82		Drilling cycle or counter boring cycle
G83		Peck drilling cycle
G84		Tapping cycle
G85		Boring cycle
G86		Boring cycle
G87		Back boring cycle
G88		Boring cycle
G89		Boring cycle
G90	03	Absolute command
G91		Increment command
G92	00	Setting for work coordinate system or clamp at maximum spindle speed
G94	05	Feed per minute
G95		Feed per rotation
G96	13	Constant surface speed control
G97		Constant surface speed control cancel
G98	10	Return to initial point in canned cycle
G99		Return to R point in canned cycle
G107	00	Cylindrical interpolation
G150	19	Normal direction control cancel mode
G151		Normal direction control left side on
G152		Normal direction control right side on
G160	20	In-feed control function cancel
G161		In-feed control function

APPENDIX J

STANDARD INSPECTION SHEET

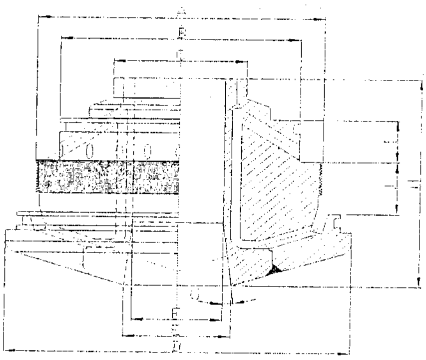
The University of Zambia
School of Engineering
Department of Mechanical Engineering

STANDARD INSPECTION RECORD SHEET

PLASMA ARC TORCH SYSTEM COLLIMATOR ASSEMBLY (TORCH)

A. PRODUCT DETAILS

Part Name: Collimator assembly	Part no. COL001
Date: 21/12/2006	Material: 93Cu4Co2Zn1Al
MANUFACTURER: UNZA-CNC LAB CUSTOMER: CHAMBISHI METALS PLC	Quantity: 01 of 01



B. INSPECTION CRITERIA

MARKS ON DRG	DRAWING (MM)	TOLERANCE (MM)	1 ACTUAL (MM)	2 RESULT (Pass/Fail)	3 ON SITE Comment
DIM A	120.650	+.050/ -0.100	120.600	Pass	Ok
DIM B	100.500	+0.000/ -0.043	100.505	Pass	Ok
DIM C	55.800	+0.080/ -0.00	55.833	Pass	Ok
DIM D	145.000	+0.000/ -1.000	141.053	Fail	Ok
DIM E	45.000	+0.056/ -0.000	45.056	Pass	Ok
DIM F	38.000	+0.000/ -0.025	37.995	Pass	Ok
DIM G	6 Degrees		6 degrees	Pass	Ok
DIM H	102.000	+1.000/ -0.000	102.100	Pass	Ok
DIM I	20.000	+0.880/ +0.60	20.703	Pass	Ok
DIM J	25.500	+0.005/ -0.005	25.504	Pass	Ok

1. CHECK WEIGHT 5.90 kg ____5.9031Kg OK.____.
2. CHECK 'O' RING GROOVES____YES____.
3. CHECK ALL COOLANT PASSAGES FULLY BORED AND FREE OF BURRS YES____.
4. VISUAL INSPECTION____ACCEPTABLE____.
5. JUDGEMENT CRITERIA VISUALLY ACCEPTIBLE, TOLERANCES WITHIN SPEC.

RESEARCH TITLE: : TOOL DESIGN FOR THE PRODUCTION OF A COLLIMATOR ON A 3-AXES CNC VERTICAL MILLING CENTER BY TERENCE MALAMA. SUPERVISORS: DR H.M. MWENDA, DR L. SIAMINWE, DR. T.J TAMBATAMBA. TEL: +260 1 293791, EMAIL: mech@eng.unza.zm, terencemalama@lycos.com.

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