AD-A099 322 KOLLMORGEN CORP WALLINGFORD CT INTOP DIV F/G 20/6
MM&T: PRECISION MACHINING OF OPTICAL COMPONENTS.(U)
FEB 81 A E HESS, G J WATT DAAK40-79-C-0255
UNCLASSIFIED PMC-006-1 DRSMI/RH-CR-81-7 NL

1 OF 1
AD
A099322

END
DATE
FILMED
6-81
DTIC

(12) LEVEL III

AD A099322

TECHNICAL REPORT RH-CR-81-7

MM&T: PRECISION MACHINING OF OPTICAL COMPONENTS

Arthur E. Hess
Gordon J. Watt
IntOp Division of Kollmorgen
Wallingford, CT 06492

February 1981

DTIC
ELECTE
MAY 26 1981
S D
B

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35898

Approved for public release; distribution unlimited.

DTIC FILE COPY

81 5 19 002

SMI FORM 1021, 1 JUL 79 PREVIOUS EDITION IS OBSOLETE

DISPOSITION INSTRUCTIONS

DESTROY THIS REPORT WHEN IT IS NO LONGER NEEDED. DO NOT RETURN IT TO THE ORIGINATOR.

DISCLAIMER

THE FINDINGS IN THIS REPORT ARE NOT TO BE CONSTRUED AS AN OFFICIAL DEPARTMENT OF THE ARMY POSITION UNLESS SO DESIGNATED BY OTHER AUTHORIZED DOCUMENTS.

TRADE NAMES

USE OF TRADE NAMES OR MANUFACTURERS IN THIS REPORT DOES NOT CONSTITUTE AN OFFICIAL INDORSEMENT OR APPROVAL OF THE USE OF SUCH COMMERCIAL HARDWARE OR SOFTWARE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1 REPORT NUMBER TI-CR-81-7	2 GOVT ACCESSION NO	3 RECIPIENT'S CATALOG NUMBER
4 TITLE (and Subtitle) MM & T: PRECISION MACHINING OF OPTICAL COMPONENTS		5 TYPE OF REPORT & PERIOD COVERED INTERIM July, 1979 September, 1980 6 PERFORMING ORG. REPORT NUMBER PMC 006-1
7 AUTHOR(s) Arthur E. Hess Gordon J. Watt		8 CONTRACT OR GRANT NUMBER(s) DAAK 40-79-C-0255
9 PERFORMING ORGANIZATION NAME AND ADDRESS IntOp Division of Kollmorgen 121-E North Plains Industrial Road Wallingford, CT 06492		10 PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS R-793445
11 CONTROLLING OFFICE NAME AND ADDRESS Directed Energy Directorate U.S. Army Missile Command Redstone Arsenal, AL 35898		12 REPORT DATE FEBRUARY 1981 13 NUMBER OF PAGES
14 MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) DCASMA, Hartford 96 Murphy Road Hartford, CT 06114		15 SECURITY CLASS. (of this report) Unclassified 15a DECLASSIFICATION DOWNGRADING SCHEDULE None

16 DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17 DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18 SUPPLEMENTARY NOTES

This report is a requirement of U.S. Government Contract No. DAAK 40-79-C-0255, Contract Item 0002 Sequence No. 006

19 KEY WORDS (Continue on reverse side if necessary and identify by block number)

Precision Machining; Diamond Turning; IR Optics; Technology Transfer

20 ABSTRACT (Continue on reverse side if necessary and identify by block number)

The first interim technical report describes the results of the Basic Effort Contract whose purpose is to establish a commercialmanufacturing base for cost-effective production of Army high energy laser and infrared optics and optical support items for Army systems applications.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

FOREWORD

This report is the IntOp Interim Manufacturing Methods Report called for under Contract DAAK 40-79-C-0255 at the conclusion of the Basic Effort. For convenience of distribution each section of the four major sections have been arranged so that independent distribution can be accommodated.

This interim report covers the period of July 1979 to September 1980. A presentation of the need for precision machined optics by the Army and DOD for use in the infrared along with the specification for machinery to manufacture these elements, metrology to measure the components and a facility to house this equipment is presented. A calculation for the return in investment forms part of this report.

The program is under the direction of the U.S. Army Missile Command. Mr. William Friday is the Project Engineer. The work at IntOp is under the general direction of Mr. Arthur E. Hess who is acting Program Manager. Technical support is assigned to the engineering department under the direction of Mr. Gordon J. Watt who is acting as Chief Investigator.

IntOp • Wallingford, Connecticut 06492
Division of Kollmorgen Corporation

CONTRACT DAAK 40-79-C-0255

DATA ITEM 006

INTERIM MANUFACTURING METHODS REPORT

BASIC EFFORT PARAGRAPH 3.3.5

form A-541

TASK I	3.3.1	SURVEY
TASK II	3.3.4.1	MACHINE SPECIFICATIONS
TASK III	3.3.4.2	METROLOGICAL SPECIFICATIONS
TASK IV	3.3.4.3	FACILITY SPECIFICATION

Accession For
NTIS GRA&I ☑
DTIC TAB ☐
Unannounced ☐
Justification
By
Distribution/
Availability Codes
Dist | Avail and/or Special
A

IntOp • Wallingford, Connecticut 06492
Division of Kollmorgen Corporation

CONTRACT DAAK 40-79-C-0255

DATA ITEM 006

INTERIM MANUFACTURING METHODS REPORT

3.3.1 TASK 1 - SURVEY

form A-541

SURVEY

Section 1	Forward
Section 2	Scope
Section 3	Sources of Survey Data
Section 4	Projected Requirements - Size Summary
Section 5	Total Projected IR/Laser Optics Requirements
Section 6	Machine Selection
Section 7	Conventional vs Precision Machining Processes
7.1	Basic Assumptions
7.2	Machine Requirements
7.3	Number of Machines Required
Section 8	Return on Investment
8.1	Machine Investment
8.2	Derivation of Estimated Costs

1.0 TASK 1, SURVEY

1.1 FOREWORD

Paragraph 3.3.1 of the Basic Effort of Contract DAAK 40-79-C-0225 requires that a survey be made of Army and other DOD applications and requirements for precision machined laser, infrared and optical support items.

2.0 SCOPE

A survey was made by means of document search, mailed survey questionnaires, telephone solicitation and personal meetings. This effort resulted in a compilation of programs with their associated components that are currently in design, prototype or production phases. Long range programs, those that are in the pre-planning or planning phase have not been included.

3.0 SOURCES OF SURVEY DATA

Field visits, supplemented by a comprehensive telephone solicitation campaign and mailed survey questionnaires to a broad base of government and civilian organizations, provided the data base.

Among Commerical Organizations contacted were, Ford Aeronutronics, TRW, Rock well International, Hughes Aircraft, McDonnell Douglas, General Dynamics, Aerojet General, Northrop Corp., Texas Instruments, Martin Marietta, Raytheon, Boeing Corp., ITEK, Kollsman Instrument, Emerson Electric, Magnavox Corp., Chrysler Corp., Teledyne Brown Eng'g., ITT Corp., International Laser Systems.

Among Military were: Naval Ocean Systems Center, Naval Weapons Center, Naval Research Laboratory, Naval Air Systems Command, Office of Naval Research, E/O & Night Vision Labs, MICOM, AVRADCOM, Air Force/RDQT HD, Air Force Systems Command, Wright Patterson Mat'l Lab., DARPA, TARCOM, ARRADCOM, TSARCOM, Fort Monmouth.

4.0 PROJECTED REQUIRMENTS - SIZE SUMMARY *

The following list is a tabulation of the total projected IR laser optics requirement. The programs involving these optics are all at least in the engineering model phase. The programs in early stages of planning or development were not included because of the uncertainty of their ever advancing to the production phase at this time. This of course implies that many more requirements than those detailed here will exist during the next ten (10) year period.

Geometry	Size	Projected Requirement (Now through 1990)
Flats	≤ 2" x 2"	145,000 to 169,000
Flats	> 2" x 2"	9,000 to 12,000
Polygon Scanners	≤ $3\frac{1}{2}$" dia.	96,200
Polygon Scanners	> $3\frac{1}{2}$" dia.	30,000
Spherics	≤ 5" dia.	541,908 to 625,908
Spherics	> 5" dia.	30,000
Aspherics	≤ 5" dia.	234,636
Aspherics	> 5" dia. but < 10" dia.	4,136

* Candidate Parts for Precision Machining Technology - Current State-of-the-Art.

TOTAL PROJECTED IR/LASER OPTICS REQUIREMENTS

MATERIALS SUMMARY

Geometry & Size	Material	Quantity
Flats ($\leq$ 2" x 2")	Aluminum	131,000
Flats ($>$ 2" x 2")	Germanium	14,000 to 38,000
Polygon Scanners ($\leq$ 3½" diameter)	Aluminum	9,000 to 12,000
Polygon Scanners ($>$ 3½" diameter)	Brass	96,200
Spherics ($\leq$ 5" diameter)	Aluminum	183,000
	Germanium	250,908 to 334,908
	Mag Flouride	78,000
	Zinc Selenide	30,000
Spherics ($>$ 5" diameter)	Zinc Selenide	30,000
Aspherics ($\leq$ 5" diameter)	Aluminum	65,400
	Beryllium (plated)	20,000
	Copper	8,000
	Fused Silica	7,200
	Germanium	1,336
	Zinc Selenide	136,000
Aspherics ($>$ 5" diameter)	Aluminum	3,000
	Germanium	1,136

6.0 MACHINE SELECTION

The variation of size and geometry of optical components tabulated in the survey call for two basic types of machine. This is in keeping with the IntOp philosophy of job related equipment.

The flats and polygon scanners require a milling type fly cutting machine. A single machine to cover all sizes is recommended. The spherical and aspherical elements require a different machine configuration. Spherical components can be produced with a spherical generator similar to that furnished as GFP under the subject contract. This machine performs its task as a function of the geometric location of a rotating work spindle and a rotating fly cutter spindle. The basic controls include start-stop switches and variable speed controls for spindles and slide.

The aspherical elements, however, require a machine of greater sophistication. The specification for such a machine is the subject of the following section of this report.

7.0 CONVENTIONAL vs PRECISION MACHINING PROCESSES

7.1 BASIC ASSUMPTIONS

In comparing the cost of conventionally processed versus precision machined optics the following factors were considered.

a) The cost of the basic substrate is the same in both cases.

b) Substrate process coating, such as electroless nickel, can be eliminated in most cases and the base material can be turned directly. This cost saving has not been added.

c) The finished optical surface produced by precision machining often does not require overcoating for reflectivity enhancement or surface protection. This is particularly true of optics used as high energy laser reflectors. Many aluminum reflectors do not require optical coatings. These savings have not been reflected.

d) Inspection time, particularly for aspherical elements, will be greatly reduced because whenever the geometry of the optical element permits, precision reference surfaces defining the optical axis and a face normal to the optical axis will be provided. It should further be noted that because of the precise electro mechanical control of the machine functions one hundred (100) percent inspection for surface figure is not required in most cases. This saving has not been added.

e) The time required for alignment and collination of the optical elements in their final subassembly or assembly will be greatly reduced by use of the aforementioned reference surfaces.

f) A further advantage of precision machined optical surfaces is that they can be incorporated as a part of the primary structure that would normally be used to support the optics in use. A considerable saving can be realized in the requirement for fewer parts and also the characteristic of automatic collimation by construction.

Because the above factors do not all apply in all cases and because many of them are uniquely interrelated to the system or component function it is extremely difficult to estimate a value for the savings attainable. Perhaps an increased overall saving of ten (10) to fifteen (15) percent is a reasonable figure to assume.

The survey identified 30,000 internally faceted scan mirrors. These elements were not included in the savings calculation because it is assumed that a special machine configuration will be required for their manufacture.

7.2 MACHINE REQUIREMENTS

7.2.1 FLAT ELEMENTS

The machines are vertical spindle milling type machines using a rotating tool head containing one or more diamond tool bits. They are used to manufacture flat surfaces including polygon scan mirrors.

7.2.1.1 ASSUMPTIONS

The following assumptions were made in the following calculations:

a) The size of the flats (not including polygon scan mirrors) permits the processing of twelve (12) flats per load.

b) Each load will require 0.5 hours of available machine time.

c) The maximum requirements as identified during the market survey effort will be used to compute the machine requirements.

$$\frac{154{,}000 \text{ flats}}{12 \text{ flats/load}} \times 0.5 \frac{\text{hours}}{\text{load}} = 6{,}417 \text{ hours of available machine time required to produce flats (min. requirement)}$$

$$\frac{181{,}000 \text{ flats}}{12 \text{ flats/load}} \times 0.5 \frac{\text{hours}}{\text{load}} = 7{,}542 \text{ hours of available machine time required to produce flats (max. requirement)}$$

d) Polygon scan mirrors have an average of eight (8) -facet (flats) per mirror, and will be stacked to process eight (8) polygons per load.

$$\frac{96{,}2000 \text{ polygons} \times 8 \frac{\text{flats}}{\text{polygon}}}{8 \frac{\text{polygons}}{\text{load}}} \times 1.5 \frac{\text{hours}}{\text{load}} = 144{,}300 \text{hrs of available machine time required to produce the polygons}$$

e) Since the Survey included requirements from 1980 through 1990, it is assumed the requirements will average over that period.

Therefore, the total required hours of available machine time per year to produce flats, including polygons, is:

$$\frac{7,542 + 144,300 \text{ hours}}{10 \text{ years}} = 15,184 \frac{\text{hours}}{\text{year}}$$

7.2.2 SPHERICAL ELEMENTS

The machines are in the form of a chordal generator in which two spindles, one holding the work piece and one the tool, are placed in configuration that causes a spherical surface to be generated when the spindles are activated.

7.2.2.1 ASSUMPTIONS

a) The size of the elements permits the processing of six (6) elements per load.

b) Each load will require 0.5 hours of available machine time.

c) The maximum requirements identified during the market survey effort will be used to compute the machine requirements.

$$\frac{544,908 \text{ spheres}}{6 \text{ spheres/load}} \times 0.5 \frac{\text{hours}}{\text{load}} = 45,409$$ hours of available machine time required to produce spheres (min. requirements)

$$\frac{635,908 \text{ spheres}}{6 \text{ spheres/load}} \times 0.5 \frac{\text{hours}}{\text{load}} = 52,992$$ hours of available machine time required to produce spheres (max. requirement)

$$\frac{52,992 \text{ hours}}{10 \text{ years}} = 5,299 \frac{\text{hours}}{\text{year}}$$

7.2.3 ASPHERICAL ELEMENTS

The machines are similar to the machines used for spherical surface configuration production. They have the added function of numerically controlled axes motion that causes a basically spherical surface to become aspherical.

7.2.3.1 ASSUMPTIONS

a. Aspheric elements are processed one at a time.

b. The average element is less than five inches in diameter

$$238.772 \text{ aspheres} \times 0.75 \frac{\text{hours}}{\text{asphere}} = 179.079 \text{ hours of available machine time required to produce aspheres.}$$

$$\frac{179.079 \text{ Hours}}{10 \text{ years}} = 17908 \frac{\text{Hours}}{\text{year}}$$

7.3 NUMBER OF MACHINES REQUIRED

7.3.1 MACHINE UTILIZATION

The following assumptions were made:

a. All machines have a 100% work backlog.

b. The average machine operator availability is:

$$\frac{40 \text{ hours}}{\text{week}} \left[52 \frac{\text{weeks}}{\text{Year}} - \left(\frac{2 \text{ weeks vacation}}{\text{year}} + \frac{1 \text{ week sick and personal time}}{\text{year}} + \frac{2 \text{ weeks holiday}}{\text{year}} \right) \right]$$

$$= 1880 \frac{\text{hours}}{\text{year}}$$

c. The average machine availability is:

1960 operating hours x 0.87 = 1636 hours

d. The average machine yearly running time is:

Overtime hours = 20% in 25% of the shops

$$1636 \times 0.2 \times .25 = 82 \frac{\text{hours}}{\text{year}}$$

Two shift operation in 10% of the shops

$$1636 \times 0.1 \times 1.937) \quad 317 \frac{\text{hours}}{\text{year}}$$

$$1636 \frac{\text{hours}}{\text{year}} + 82 \frac{\text{hours}}{\text{year}} \text{ overtime} + 317 \frac{\text{hours}}{\text{year}} \text{ 2 shift}$$

$$= 2035 \frac{\text{hours}}{\text{year}}$$

7.3.2 FLYCUTTER

The number of machines required for production of flat surfaces:

$$\frac{15,184 \text{ hours/year}}{2035 \text{ hours}} = 8 \text{ machines}$$

7.3.3 SPHERICAL GENERATOR

The number of machines required for production of spherical surfaces:

$$\frac{5,299 \text{ hours/year}}{2035 \text{ hours}} = 3 \text{ machines}$$

7.3.4 ASPHERICAL GENERATOR

The number of machines required for production of aspheric surfaces:

$$\frac{17,908 \text{ hours/year}}{2035 \text{ hours}} = 9 \text{ machines}$$

8.0 RETURN ON INVESTMENT

8.1 MACHINE INVESTEMENT

Average projected cost of flycutter	$125,000 each
Average projected cost of spherical generator	$ 75,000 each
Average projected cost of aspherical generator	$250,000 each

8.1 (continued)

The total machine investment is:

(125,000 x 8) + (75,000 x 3) + (250,000 x 9) $3,475,000.

8.2 DERIVATION OF ESTIMATED COSTS

Because the people contacted to assist in this survey refused to disclose part prices in consideration of their competative posture the estimates shown for both "Conventional" and "Precision Machining" categories were estimated by IntOp personnel. This reluctance to disclose part cost was met equally with personnel of both military and commerical organizations.

Because of the wide variety of geometries, materials and sizes, a true average was almost impossible to estimate. The costs used are purposely directed to err toward the conservative if indeed there is any error.

IntOp • Wallingford, Connecticut 06492

Division of Kollmorgen Corporation

5.5 ESTIMATE COST - TO - BUILD

Geometry	Estimated Conventional Methods	Estimated Precision Machining	Projected Savings
Flats 2" x 2"	$ 150 each	$ 100 each	$9,050,000. (for 181,000 units)
Polygons 3" diameter	$ 400 each	$ 250 each	$14,430,000. (for 96,200 units)
Spheres 4" diameter	$ 150 each	$ 100 each	$31,800,000. (for 635,900 units)
Aspheres 5" diameter	$ 2000 each	$ 600 each	$328,440,000. (for 234,600 units)
	TOTAL PROJECTED SAVINGS		$383,720,000.

Form A-541

8.4 PROJECTED TOTAL SAVINGS (PARTS PURCHASER)

Evaluating the amount to be saved by the purchaser using the costs tabulated in paragraph 8.3 can probably best be done on a discounted cash flow basis. For simplicity of calculation assume that the total projected savings of $383,720,000. is accomplished over a ten (10) year period and that this sum is equally distributed over this time span. Further assume an effective annual interest factor of twelve (12) percent. The net present value of the future savings in each category is then:

a)	Flycutter	13,274,000.
b)	Spherical Generator	17,968,000.
c)	Aspherical Generator	185,575,000.
	Total Net Present Value	216,817,000.

8.5 PROJECTED ROI (MANUFACTURER)

It is not possible to make a meaningful estimate of the Return on Investment from the manufacturer's point of view. A general flavor of the return can only be indicated if it is assumed that all of the equipment listed in the preceeding paragraphs were obtained by one manufacturer and all of the work was performed by this same group. The Return on Investment would then be 150 percent.

Of even more significance is the fact that, based upon all of the assumptions of this survey, a total saving of 7,674,300 man hours or 377 men per year will be saved. Of this number 323 of them are concerned with the production of aspherical surfaces. In light of the lack of available skills in this area it would appear that the numerically controlled precision machine may be more than a cost saving -; it may be the only practical way to produce these surfaces.

IntOp • Wallingford, Connecticut 06492

Division of Kollmorgen Corporation

CONTRACT DAAK 40-79-C-0255

DATA ITEM 006

INTERIM MANUFACTURING METHODS REPORT

3.3.4.1 TASK 2 - MACHINE SPECIFICATIONS

MACHINE SPECIFICATION

Section 1	Makeup of the System
Section 2	Reference Documents
Section 3	System Requirements
3.1	Mechanical Aspects
3.2	Pneumatic Supply & Control System
3.3	Numerical Control Systems
3.4	Programming Functions
Section 4	Inspection and Tests
Section 5	Documentation

TITLE: SPECIFICATION FOR A DIAMOND TURNING MACHINE TO PRODUCE SPHERICAL AND ASPHERICAL SURFACES OF REVOLUTION UP TO TWELVE INCHES DIAMETER.

FOREWARD: This specification is prepared to meet the requirements of Task 2 - Machine Specifications for Contract DAAK-40-79-C-0025. The machine is specified to meet the goals for shape, figure, and surface finish as set forth in paragraph 3.3.2 of said contract specifications.

1. SCOPE

A machine configuration similar to that described by Batelle in recent papers and publications is called out in this specification. The machine configuration and definition of axes is illustrated in the line perspective of drawing P-10004-209 attached. This is the general configuration of a chordal generator which will produce spheres and toroids with no dynamic control. For the types of aspherical surfaces turned up in the Task 1, Survey of this contract, a minimal dynamic correction is required to reach the desired surface configuration.

a. Dynamic range of the contour control system is minimized in the generation of aspherical surfaces.

b. Tool feed is primarily tangential to the surface being generated, thereby minimizing requirements for almost perfect tool geometry.

c. Qualification of the surface by in-process methods, more closely matches the natural machine motions, i.e., circular arcs which combine to give a spherical reference surface.

Other advantages become evident as particular points of the specification are set forth.

1.1 SUBASSEMBLIES OF THE SYSTEM

The machine supplied is intended to be a complete, self sufficient, turnkey system and shall consist of the following major components;

a. a multi-axis turning machine built along the lines of a chordal generator, having at least the capability for turning spheres up to twelve inches in diameter with F numbers between F-$\frac{1}{2}$ to Flats.

b. Adjustments and measuring means for centering the machine axes and for making precise limited offsets relative to the machine center positions.

c. Dynamic controlling means on specific machine axes to respond to contouring demands.

d. Computer based numerical control system which will store and/or generate contouring commands, control various machine functions, and correlate machine responses with apriori reference data to monitor machine preformance.

e. Pneumatic base isolation system, with self-leveling capability.

f. Machine control panel with capability for display, programming, and override of computer controlled machine functions.

g. Precision work-head spindle with appropriate means for holding work pieces accurately, without distortion. Equipped with integral drive motor, tachometer, and means for dynamic braking.

h. Precision tool setting means, means for verifying machine center and alignment, and means for verifying machine axis offsets.

i. Sources for storing and means for applying lubricants and coolants to the tool area during machining. These may be liquids or gases, or both.

j. Means for removing chips from the work area during the cutting operation in a manner to prevent contamination or scratching of the work surface.

k. Balancing means for adjusting spindle balance when the work is in place on the work-head spindle.

l. Optical means for viewing the cutting operation in close proximity to the tool while work is in progress.

m. An air supply system for the air bearings, chucks, controls, chip removal, etcetera, as required by the system.

n. Calibrated instruments and gages necessary for setting-up the machine and for setting the tools.

o. Control system software, including the post-processor and executive control routines for typical production.

p. Instructions and maintenance manuals necessary to get the machine in operation, calibrate performance, run parts, and maintain a

ninety percent up-time.

q. Defined warranty for parts, workmanship, and basic design including limited assistance for installation, instruction, and repairs included under the warranty.

r. Various shields, sumps, ducts, cables, lights, connectors, benchmarks, and the like which constitute a safe, useful, reliable machining system.

1.2 RESPONSIBILITY

The intent of this specification is to provide a complete machining system for the production of optical elements and the like.

a. It shall be the responsibility of the maker therefore to provide those features not specified but necessary for a complete operational system.

b. Certain metrology instruments, work samples, and personnel familiar with the requirements and use will be provided by the user for factory testing prior to shipment and acceptance.

c. The supplier shall provide similar assistance during installation and test at the user's site. Instruction and maintenance manuals will be available at this time.

2.0 REFERENCE DOCUMENTS

The following documents form a part of this specification to the extent specified. The issue used shall be the one in effect on the date of Request for Quotation.

2.1 USER DOCUMENTS

None

2.2 STATE AND LOCAL CODES

None

2.3 U.S. GOVERNMENT STANDARDS

Code of Federal Regulations Title 29, Chapter XVII, Part 1910 Occupational Safety & Health Administration Standards

2.4 NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)

NFPA-79 Electrical Standard for Metal Working Machine Tools

2.5 ELECTRONIC INDUSTRY ASSOCIATION (EIA)

RS-267 Axis and Motion Nomenclature for Numerically Controlled Machine Tools

RS-281 Construction Standards for Numerical Machine Control

2.6 AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)

X3.4 Code for Information Exchange
B5.51M Preferred SI Units for Machine Tools
B5.9 Spindle Noses

2.7 JOINT INDUSTRIAL CONFERENCE (JIC)

EL.1 Electronic Standard for Machine Tools

2.8 CONTRACT DAAK-40-79-C-0225

Paragraph 3.3.2 Goals for precision machined optical part specifications

3. REQUIREMENTS

The requirements set forth are for a turnkey machining system. Therefore the system provided must be useful in a reasonable environment, operated by reasonably skilled people, and must be capable of reasonable production under normal circumstances. The transition from parts' drawings to machine instructions must be within the capabilities of a reasonably skilled parts, programmer who generates information which can be interpreted by a competent machine operator as found today in NC shops. Specification of the machine, control system, and subsystem components shall not in any sense detract from the overall system goals and requirements as stated.

3.1 MACHINE DESIGN AND CONSTRUCTION

The machine constitutes the basic subsystem assembly, around which the basic components and controls are assembled. The machine configuration called out has been called out as a chordal generator similar to the machine described by Battelle. It is similar, so far as axes or degrees of freedom are concerned, to the spherical generators which have been used to grind optics for many years or to the machine which has been furnished as customer furnished equipment for Option I of the MICOM contract. In one sense it differs from the aforementioned machines, in that the workhead spindle axis is specified to be vertical and to have sufficient vertical travel to accomodate to the variety of concave and convex surfaces which are to be generated.

3.1.1 MACHINE BASE

The machine base shall be compact within the requirements for size and machine motions demanded by the class workpieces described in 1.1.a and within other useful requirements for parts handling and machine operation. Length and width dimensions shall be of the order of three times the diameter of the maximum sized parts to be handled. Depth of the base shall be of the order of one third the length and width dimensions. The design shall be aimed at maximizing structural rigidity, inherent damping of vibrations, and long term stability.

3.1.1(con't)

Symmetry of the machine structure around the work piece is important. A single piece of granite is preferred as a building block, although any better substitute would be considered within the bounds of cost restraints.

3.1.1.1 VIBRATION ISOLATION

The machine base must be isolated from earth tremors. It may be supported in a steel cradle to accomodate a pneumatic isolation system. The overall natural frequency of such a system should not exceed two (2) Hertz. The system must be self leveling within the same bandwidth constraints. Connectors and attachments shall offer similar isolation from outside sources including the floor vibrations. Effectiveness of the base isolation system shall be thoroughly tested as a separate condition for system acceptance.

3.1.1.2 GRANITE BASE

The machine base shall be made of a single piece of granite (or other suitable compounded structure) with provision for accomodating the other machine components. In particular the upper surface shall be finished to the quality of a laboratory grade surface plate and properly smoothed and filled to accomodate air bearing sliding components on the surface. Through holes and inserts shall be put in place before final finishing. The overall block shall be smoothed and trimmed for orthogonality.

3.1.2 SLIDEWAYS

Slideways shall be designed for maximum straightness and orthogonality. Of particular importance is their day to day stability for the useful life of the machine. All slideways shall operate on a film of air to facilitate accurate setting and control, as well as to minimize wear and contamination.

a) The top surface of the granite base is the basic reference against which machine coordinates are measured. It must be lapped and qualified for a flatness of 25 microinches over the total useful surface.

b. A vertical slideway penetrates the granite slab somewhere near the machine center. This way must be straight within a similar 25 microinch from top to bottom of the granite slab.

3.1.2.1 SPINDLE SLIDE (z axis)

The spindle slide moves vertically, normal to the granite surface. It shall have a useful range of eight inches travel and shall maintain orthogonality of the work spindle axis to the granite surface within three arc seconds over the full travel range. The work spindle shall sit on top of the spindle slide with axis aligned in the slide direction within three arc seconds. Combined weight of the spindle, chucking fixture, and workpiece may vary between one hundred and three hundred pounds. The spindle slide drive and locking mechanism must be capable of positioning and holding the spindle height to within twenty-five microinches of desired height with absolute locking stability within two microinches for five minutes. The spindle slide ways must be protected from contamination by coolant and chips by machine way bellows seal. Allowance must be made for later addition of a lasergage to monitor spindle height. Gaging surfaces will be provided on the slide to indicate height.

3.1.2.2 GANTRY SLIDE (x and y axes)

The tool drive spindle carriage, with related trunnions and trunnion axis controls, is carried on a gantry structure which may slide on air pads over the granite surface. This slide provides for positioning the tool drive spindle axis relative to the work spindle axis. Intersection of these two axes determine the geometric center of the machine. During operation of the machine, the gantry slide is locked by removing air from the pads which form the feet of the gantry. With the machine centered so that the trunnion axis lies above the tool axis, the gantry may slide two inches forward, two inches to one side, and six inches toward the back without interference between the work spindle and the gantry structure. Reference surfaces shall be provided along two edges of the granite surface and on the spindle axes relative to one another for machine setup. Provision must be made for later accomodation of lasergage to this measurement. Accumulation of error within the slide range shall not throw the trunnion

axes more than three arc seconds out of parallel with the granite surface.

3.1.2.3 TRUNNION AXIS

The trunnion axis is provided to permit tilting the tool spindle axis relative to the workpiece spindle axis, after the manner of the rotary table on the GFE machine. With the workpiece spindle axis vertical, as called for in this specification, the trunnion axis is horizontal, and perpendicular to the line of column travel. Provision must be made to move and set the tool spindle axis through a full range of ninety degrees plus five degrees at either end of travel. Within this range of travel, the tool spindle axis must lie in a plane which contains a line of travel of the column.

3.1.2.4 TRUNNION TILT ADJUSTOR

Since, in a spherical generator of this type, the spherical center is determined by intersection of the tool spindle axis and the workpiece spindle axis, it may be necessary to adjust the trunnion tilt to finally locate the surface relative to the workpiece body. Therefore a fine adjustment and readout on trunnion tilt angle is required. Location of this intersection is referred to as the machine center in the specification. Where the gantry may be set to one side to cut a toroid, the machine center is defined as the point in the tool spindle axis, directly above the tool tip point of contact with the workpiece when the tool is in its lowest position. Fine control of the trunnion tilt must permit accurate adjustment of the machine center above the workpiece surface to one part in five thousand.

3.1.2.5 TOOL HOLDER ARM

Provision must be made to accurately position the tool tip along and away from the tool spindle axis. One or several tool holder arms must be provided with necessary sliding surfaces and means for fastening to the tool spindle face. Each arm must be provided with an articulated tool holder which permits pre-setting to tool clearance angle, azimuth, and desired portion of the tool radius. The tool holder arm may be I shaped for concave surfaces and L shaped for convex surfaces. Since uniform feed of the tool across the surface is a necessity, it may be necessary to balance the tool arm assembly in order to minimize the servo errors in the tool feed

system. Extreme rigidity in the tool holder arm is a necessity, as is stability of the fastenings to the tool spindle face and to the tool itself.

3.1.2.6 MACHINE CENTER ADJUSTMENT AND STABILITY

In the composite machine structure heretofore described, it shall be possible to adjust and set the machine center within an error sphere of ten microinches diameter. The machine center may be defined by a gage ball which is mounted on the workpiece spindle relative to an electronic probe which is carried on the tool spindle. When the two spindles are simultaneously rotated with null indication of the electronic gage, the machine axes are deemed to intersect at the machine center which is also the center of the gage ball. Reference points and/or surfaces shall be provided on the moving members to measure and indicate the relative motions of the various slides and arms to the desired spherical error envelope for machine offsets within the specified limits of machine motions.

The machine center shall not deviate from the gage ball center more than five microinches in any direction as a result of thermal drift, vibration or forces usually encountered over three times the cutting period.

3.1.2.7 DYNAMIC CONTOUR CONTROL

The machine configuration so far specified may be used to produce a variety of spherical surfaces which may be concave or convex. Flat surfaces may be produced by bringing the tool spindle axis parallel to the workpiece spindle axis. For the production of aspherical surfaces, which may closely fit the machine's capability for certain spheres, provision must be made to dynamically adjust the workpiece relative to the tool tip continuously during the machining operation. When the tool axis is displaced laterally in the direction of x axis motion, the machine will cut a toroidal surface which may fit the desired aspherical surface much better than the closest fitting sphere. In this case only minor dynamic adjustments of the x axis will produce the desired aspherical surface.

3.1.2.7.1 CONTROL OF WORKPIECE SPINDLE AXIS

The column supporting the workpiece spindle may be dynamically controlled in the z direction to accomplish correction of the natural tool tip motion to produce the desired aspherical surface. In most cases where the toroidal fit is accomplished, dynamic corrections less than ± .001 is anticipated.

3.1.2.7.2 CONTROL OF TRUNNION AXIS SLIDE BEARING

Fit to the aspherical surface may be accomplished by dynamic control of this sliding axis. Depending on F number of the called for surface, slope may vary from five (5) or ten (10) degrees upward. Since this motion has a large component in the direction of the tool tip as results from rotation of the tool tip as results from rotation of the tool axis, this motion results in a raising or lowering of the dynamic machine center.

3.1.2.7.3 CONTROL OF THE TOOL ARM LENGTH

Corrections may also be obtained by dynamically changing the tool arm length by appropriate actuator means.

3.1.2.7.4 CONTOUR CONTROL SERVO SYSTEM

Howsoever this dynamic adjustment is accomplished, the actuators and transducers involved must be combined in a servo system with sufficient bandwidth and range to follow commands from a contouring control which is programmed to compensate for the differencebetween the desired asphere and the best fitting natural surface ordinarily produced by the machine.

3.1.3 MACHINE SPINDLES

The machine requires two precision spindles whose combined performance accounts for the ultimate finish and figure of the surface being relatively oriented by the slides and trunnions already described in 3.1.2. Since only the spindle housing are carried in these machine elements, the effective spindle axes suffer the additional errors of runout, camming, and coning which have been thoroughly define by Bryant at I.I.L. The effects of surface figure and finish are determined by components of these

spindle errors along the normals to the work surface.

3.1.3.1 WORKPIECE SPINDLE

The workpiece spindle will operate with spin axis vertical. Its face plate shall accomodate work pieces up to twelve (12) inches in diameter. Weight of the work piece plus suitable chucking appliances may be as much as two hundred (200) pounds. The spindle speed range is to be zero (0) to fifteen hundred (1500) RPM with the work piece - chuck assemblage dynamically balanced.

3.1.3.1.1 SPINDLE DRIVE

The spindle drive motor shall have sufficient torque to accelerate or decelerate the work piece combination to fifteen hundred (1500) RPM in one (1) minute and also to take a cut .010 inch feed/ revolution. Part height plus fixture may be as high as six inches above the spindle face plate. The spindle drive motor plus a tachometer shall be mounted integrally on the spindle bearing. A spindle speed tachometer display shall be provided to indicate speeds between zero (0) and fifteen hundred (1500) RPM at the contol panel. Control of spindle speed may be manual to provide a continuous range of speeds.

3.1.3.1.2 SPEED CONTROL BY COMPUTER

The motor-tachometer combination may also be used in a closed loop speed control as part of the machine control system.

3.1.3.1.3. SPINDLE BRAKING SYSTEM

Braking of the spindle may be effected by dynamic braking or reversal of the drive motor. The braking system may respond to control by the operator or interlocked into the control system to respond to emergency conditions such as loss of air pressure or control power. In an emergency, additional braking power may be applied to overload the motor temporarily.

3.1.3.2 TOOL DRIVE SPINDLE

The tool dirve spindle may operate at any attitude between horizontal and vertical. It must rotate the tool holder assembly at least one half revolution at very slow speeds, generally less

than one RPM. This spindle must be extremely stiff and stable, in order to provide an exact circular path for the tool tip during the cutting cycle.

3.1.3.2.1 TOOL DRIVE SPINDLE FEED

A feed system must be provided to rotate the tool drive spindle at slow precise speeds from one revolution per hour up to one revolution per five minutes. The speed must be smooth and firm without jerkiness, backlash, or softness in the feed mechanism. The idea is to have a uniform feed for each turn of the work piece spindle. A 10 percent irregularity in a .0001" feed is just about tolerable. Converted to angle for a five inch tool arc, this is two micon radians or 0.4 arc seconds.

3.1.3.2.2 TOOL DRIVE ANGULAR READOUT

Rotation of the tool drive spindle is the independent variable in the equations which described aspherical surfaces. Position of the tool tip should be known within .00025", or ten (10) arc seconds for a five (5) inch tool arm. An angular readout with analogue to digital conversion for entry into the numerical control system is required. The least number processed should be 0.° 001, over a range of 45°. (Note format of the digital entry.)

3.2 PNEUMATIC SUPPLY AND CONTROL SYSTEM

A Pneumatic Supply and Control System shall supply conditioned air to the bearings, control, and interlocks for the aspherical generator. It shall have sufficient controls, displays, regulators, and actuators necessary for operation of the complete system without the numerical control system being turned on. The machine may be set up and operated completely from the pneumatic supply and control system panels and actuators. Signals from the control system will be provided to the numerical control system for its proper functioning and safety features. This shall include signals which will actuate the spindle drive system and the tool spindle drive system. At this level of operation the aspherical generator may be used to turn spherical surfaces, flats, and toroidal surfaces which are produced by an offset of the X axis.

3.2.1 AIR PREPARATION AND CONDITIONING

This system shall be the interface between a suitable shop supply and the pneumatic control system. It shall condition the shop air by filtering, drying, and regulating so that the air is suitable for the control system.

3.2.1.1 The air preparation and conditioning system requires shop air within a range of 80 to 110 p.s.i. gage with an available flow of 10 s.c.f.m.

3.2.1.2 FILTERING AND DRYING

The filter system shall include a coalescent filter to remove excess oil from the shop system before it enters the filtering and drying system. The coalescent filter will be followed by a dryer which will be followed by a regulator and small particle filter which removes particles down to size of 2 microns. Air at this point will be distributed to the various controls, bearings and actuators of the control system.

3.2.1.3 A compensating tank with check valves shall be supplied upstream from the filtering and drying systems. It shall have sufficient capacity to provide at least 5 minute operation at the rate of 10 s.c.f.m. without reducing pressure to the regulators below the minimum of 70 p.s.i.

3.2.1.4 Connections between the air preparation system and the control enclosure shall be accomplished by shut-off disconnect fittings with 1/2 N.P.T. size.

3.2.2 CONTROL SYSTEM

This system shall perform all the necessary machine functions to be specified in this section, and contain all necessary components such as gages, regulators, indicators, logic elements, connectors, tubing with necessary mounting brackets and enclosures. They must be located in an easily viewed and accessible manner for proper machine operation and easy access to the operator.

3.2.2.1 CONTROL SYSTEM FUNCTIONS

(1) Is to supply constant regulated pressure to the following at ± 1% regulation.

A. Tool feed air bearing at a pressure of 80 p.s.i.g.

B. Work spindle air bearing at a pressure of 80 p.s.i.g.

C. Sleeve air bearings (two) at a pressure of 80 p.s.i.g.

D. Angular adjust ment sliding bearing at a pressure of 80 p.s.i.g.

E. U axis pre-load cylinder at a pressure of 50 p.s.i.g.

F. Z axis pre-load cylinder at a pressure between 3 and 10 p.s.i.g.

(2) Supply Controlled Regulated Pressure for the following items.

A. Gantry feet-an on-off control on the gantry body with regulated pressure of 80 p.s.i.g.

B. E Angular loading Mechanism - an on - off control on tool feed carriage with regulated pressure between 40 and 60 p.s.i.g.

C. Guide Bearings with 5 to 15 lbs. p.s.i.g. regulated pressure to the cylinder housing assembly.

3.2.2.2 Z AXIS LIFT CONTROL AND LOCK

Z axis actuator is a vertical lift column.
Column position is controlled by a three position spring centered switch, centering in the locked position. Functions of the switch are as follows:

A. Lift is accomplished by applying a regulated pressure of 10 to 15 p.s.i.g. to the cylinder housing. Time to pressurize the housing shall be no greater than 5 seconds. At this time the guide bearings are pressurized.

B. Locking is accomplished by dropping the pressure to the guide bearings and applying a regulated pressure of 3 to 10 p.s.i. ± 1% to the cylinder housing.

C. Lowering of the column is accomplished by applying pressure to the guide bearings and dropping pressure in the cylinder housing to atmospheric. Time to evacuate the cylinder housing is to be no greater than 5 seconds.

3.2.3 MACHINE INTERLOCKS

Machine interlocks are provided to assure operator safety and to prevent damage to machine components or parts being produced.

3.2.3.1 MACHINE FUNCTIONS

A. Gantry Feed
B. Index Gear Disengage
C. Work Spindle Column

are all machine set-up functions and are to be interlocked one to the other to prevent accidental motion of one while another is being operated.

3.2.3.2 MOTOR INTERLOCKS

1) If any function related to machine set-up, gantry feed, index gear disengage, or work spindle column is actuated a pressure switch in the control circuitry shall interrupt electrical power to either of the 2 spindle motors and engage any motor brakes or stops provided.

2) Motor Restart - When the interrupting function is released, a pneumatic timer in the control circuitry shall engage motor power and release all motor brakes and stops at a predetermined delay time between 0 and 30 seconds.

3.2.3.3 A low air pressure warning system shall be incorporated into the control circuitry to accomplish an orderly system shutdown and alert the operator to the problem when pressure ahead of the compensating tank drops below a predetermined level. A secondary low pressure warning system shall be provided to detect pressure drop to the

a) tool feed bearing
b) work spindle bearing
c) the sleeve air bearings

System shutdown may be accomplished by the N.C. system when it is in operation. In the event of manual control the shutdown signals shall go directly to the various motor relays, brakes, and pneumatic switches.

3.2.4 The pneumatic system described herein shall be tested at the seller's plant to demonstrate compliance with this specification. If the seller requires use of user supplied equipment, it shall be supplied upon agreement of user.

3.2.5 TEST PROCEDURES

Testing at the seller's plant shall be accomplished by using appropriate pressure gages to measure control system outputs in lieu of machine.

3.2.5.1 A. Using The Control Panel Gauges Set

1. Tool Feed Pressure at 70 PSI
2. Work Spindle at 70 PSI
3. Sleeve Air Bearing at 70 PSI
4. Angular Adj. Bearing at 45 PSI
5. U axis preload Cylinder at 50 PSI
6. Gantry Feet at 45 PSI
7. Index Mechanism Disengage at 45 PSI
8. Work Spindle Column
   a) Preload Bearing at 3.5 PSI
   b) Guide Bearings at 1.2 PSI
   c) Balance at 3.5 PSI
   d) Lift at 10 PSI

3.2.5.2 B. Function Test

1. Using proven accurate pressure gages measure output of control system at the following points.

   a) Gantry Feet
   b) Index Mechanism Disengage
   c) Guide Bearings
   d) Preload Bearings
   e) Balance Pressure (Work Spindle Column, Lift, Balance and Down)

2. With work spindle column in the lock mode:

   a) Engage Gantry Feet Function (in this mode)
      1. The Lock Disengage Operator and the Work Spindle Column Operator should not function.
      2. The Test Gages Should Read:
         a. Gantry Feet 45 PSI
         b. Gear Disengage 0 PSI
         c. Preload Bearings 3.5 PSI
         d. Guide Bearing 0 PSI
         e. Column Pressure 3.5 PSI

3. With Gantry feet and lock disengage function in the off position:

   a) Turn the Work Spindle Column Operator from the lock to the lift mode. (In this mode)
      1. The Gantry Feet Operator and the lock disengage Operator should not function.
      2. The Gages Should Read:
         a. 0 PSI
         b. 0 PSI
         c. 3.5 PSI
         d. 15 PSI
         e. 10 PSI

   b) Turn the Work Spindle Column Operator from the lock mode to the down mode. (In this mode)
      1. The Gantry Feet Operator and the Gear disengage Operator should not function.
      2. The Gages should Read:
         a. 0 PSI
         b. 0 PSI
         c. 3.5 PSI
         d. 15 PSI
         e. 0 PSI

3.3 NC SYSTEM

3.3.1 The Controller is a digital "CNC" positioner for automatic control of (2 to 4 axes). It uses a microprocessor to minimize the number of parts, and at the same time, provide maximum versatility. The system uses a 12 volt CMOS bus and logic to provide high-noise immunity which is 10 times better than TTL circuits. This capability enhances its use in industrial environment, providing high performance and reliability at low cost. This system is provided in either configuration listed below, or any combination:

Internal Memory NC-Programs are stored in large scale semiconductor memory. The data are entered from the front panel keyboard allowing easy editing and correction of data.

Commands can be: Incremental and absolute positioning, velocity, M functions, and offset, in addition to optional linear and circular interpolation, and subroutines. Standard memory enables the storage of 1800 characters (about 300 individual commands), with 20,000 character storage as an option.

PROM cards are available with built in PROM programmer, so that the data from the internal memory can be stored into the PROM cards. These can then be removed and re-used whenever the job has to be repeated.

The NC System shall perform the following:

1. Simultaneous axes positioning.
2. Linear or rotary stages, up to 4 axes.
3. Incremental or absolute format, mixed.
4. English or metric, switchable.
5. Resolution can be specified as .001", .0001", .00002", .01mm, .001mm or fraction or angular units.
6. Point-to-point positioning, linear and circular interpolation for contouring.
7. Home and offset home to repeat to a fraction of a count, even after power shut-down.
8. Programmable M functions.

9. Dwell for programmable delays.
10. Programmable speeds .01"/min. to 600"/min.
11. Manual command from keyboard or joystick.
12. Built-in memory that can be programmed from front panel.
13. Sequence number display and search for block number.
14. Subroutine storage, which can be recalled by one instruction.
15. Prom cards that copy internal memory and can then be plugged in at a later date to repeat the program.
16. "Edit" capability from keyboard.
17. Commands can be entered from the computer.
18. Uses linear or rotary encoders, and closed loop D.C. servo system for highest accuracy.
19. Step and repeat program.
20. C.R.T. display to monitor position and commands, and facilitate editing.

3.3.1.1 E TOOL AXIS

This axis, the independent variable, shall control the other axis.

a) Rotation: ± 135° Maximum
b) Friction: 1 - 5 inch-ounces
c) Inertia: Approximately 10×10^{-3} Lb-Ft-Sec^2
d) Speeds: Continuously adjustable

1) Cutting -- 5 minutes per revolution (max)
500 minutes per revolution (min)
2) Tool Return -- Approximately 30 seconds per revolution
3) Accuracy -- 1 to 3%

e) Speed Angular Steps: Adjustable Down to the resolution of the inductosyn or approximately 3 arc seconds per minimum step.

f) D.C. Motor: Torque: 60 inch ounce peak
Ripple: 6% Max
Torque Sensitivity: 30.5 oz. in./amp
D C Resistance: 8.4 ohms
Inductance: 8 mil hy
Static Friction: 1.5 oz. in.

g) D.C. Tachometer

Voltage Sensitivity:	2.2 volts/radian seconds
D.C. Resistance:	1230 ohms
Inductance:	1100 mil hy
Ripple Voltage:	0.5%
Static Friction	2.7 oz.in.

h) D.C. Power Amplifier

Linear Servo Drive Amp.

Output Voltage:	30 v max.
Current:	12 amps max. 5 amps continuous
Velocity Control:	Quartz crystal ± .1%

Dynamic Braking included in Amplifier

Amplifier Controls

1) Current Limit 0 to 12 amps
2) Rate Feedback Gain 0 to 100
3) Gain (with pre-amp) 10 to 1000
4) Gain (without pre-amp) 0-3
5) Offset ± 1 degree
(normalize to tool shaft)

i) Inductosyn

Size:	3 to 4 inches
Poles:	360 to 512 (sine & cosine)
Accuracy:	± 5 arc sec. (over 360 Deg.)
Sensitivity:	0.25 arc sec.
Carrier Frequency:	10KhZ ± 3%

3.3.1.2 Z AXIS (LINEAR)

Its position a function of E

a)	Linear Travel:	± 0.001 inches
b)	Friction:	0 to 2 inch/ounces
c)	Inertia:	150 pound mass
d)	Speeds:	0.001 inches per 5 seconds (max) 0.001 inches per 500 minutes (min)

2.1.2 (con't)

e) Operational Hi-Voltage Amplifier

Output Voltage:	0-1000v DC
Bias Adjust:	0-1000v DC
Band Width	100 HZ (@ 3 db points)
Output Current:	20 ma rms
Gain:	0-200 non-inverting
Input Impedance:	Approx. 120 kohms
Regulation:	0-1% for 10% line regulation
Ripple & Noise	20 mv rms max.

f) Feedback Components

Linear Range:	± .005 inchs
Linearity	0.25%
Sensitivity:	2.7 mv out/volt in/.001 inch
Phase Shift:	approx. +70 deg.
Carrier Freq.:	2500 HZ
Input Voltage:	3 v rms nominal

g) Feedback Amplifier

Analog. DC Output Signal :	0 to ± v DC
Output Current:	20 ma max.
Freq. Response:	250 HZ (-3 db internal filter)
Ripple & Noise:	15 mv max.
Stability:	± 0.05% (full scale, after 30 minutes)
Hysteresis:	0.05% max.
Output Impedance:	2 ohms max.
Gain:	500 mv rms in for 10v DC out
to	75 mv rms in for 10v DC out
Input Impedance:	100 K ohms
Regulation:	± 0.1% for ± 10% line voltage

NOTE: The linear feedback information can be obtained from the DTR 450 in BCD or Analog format or precessed directly from the LVDT via a buffer amplifier (2.5 KHz) as requested.

3.3.1.3 Z AXIS (ROTARY)

This speed a function of E

a) Rotation:	Continuous one direction
b) Friction and/or Torque:	1 - 10 inch/ounces
c) Inertia:	Variable 10×10^{-3} to 0.4 Lb-Ft-Sec^2
d) Speed:	Continuously adjustable from 20 RPM to 1700 RPM
e) Accuracy:	1 to 5%
f) DC Motor	
Torque:	143 Oz-In Continuous
Speed:	1775 RPM
Power Out:	1/4 HP
Current:	6.0 Amps
Voltage:	45 VDC
Resistance:	0.8 Ohms (@ 25°C)
Torque Constant:	29 Oz-In/Amp
Friction:	12 Oz-In Max
g) DC Tachometer	
Output:	10.5 Volts/KRPM
Ripple:	3%
Output Impedance:	1.0 Ohms
h) DC Power Amplifier	
Linear Servo Drive Amp	
Output Voltage:	60 Volts Max
Current:	15 Amps Max
	8 Amps Continuous
Dynamic Braking Circuits	Included
Velocity Control:	Quartz Crystal ± 0.1%
Amplifier Controls:	
1) Current Limit	0-15 Amps
2) Rate Feedback Gain	0 to 100
3) Gain(w/pre-amp)	10 to 1000
4) Gain(w/out pre-amp)	0 to 6
5) Offset Adjust	± 100 RPM
i) RPM Display	
Digital	
Accuracy	± 10%
Range	0 - 1800 RPM

3.3.2 OPERATING MODES:

3.3.2.1 1. Manual Data Input (M.D.I.) - The operator can enter data from the keyboard in all modes. Data is entered and executed one block at a time. It allows for such immediate operations as setting offsets, velocity, or moving the tables to specific positions. The commands are not entered into the N.C. memory.

3.3.2.2 2. JOG-ON/JOG-OFF - When the jog-on key is depressed, it allows the jog button to actuate the drive. In the job mode, the CRT display displays (JOG). When the jog-off switch is actuated the display of JOG is removed and the jog buttons are inhibited from actuating the drive.

3.3.2.3 3. Edit ON/OFF - The system contains an edit switch, which can be actuated, to allow editing. The CRT display will then change from the display of position to the display of commands stored in memory. To go back from edit mode to operate mode, the edit button must be depressed again.

3.3.2.4 4. Automatic Operation from Memory - When AUTO button is pushed, the system operates from the built-in memory.

3.3.2.5 5. *Automatic Operation for Prom Card*

3.3.2.6 6. Automatic Operation for Computer

3.3.3 NUMERICAL ENTRY - Data can be entered in a similar manner to that of calculator.

The entry of +2.500 is the same as 2.5.
The entry of -13.00 is the same as -13.
The entry of 01 is the same as 1.

3.3.4 KEYBOARD OPERATION - The following is a list of keys in the standard Anomatic keyboard with associated functions:

3.3.4.1 MANUAL DATA INPUT KEYS -

F - Indicates feedrate (axis speed)
G - Used for G functions - See section 4.2
I, J, K - Used for contour commands - determines the position of center of rotation.
I - Also used for Jump Commands IN20 - Jump to N20
K - Used for subroutine calls
Example: KN300. This calls the routines that start at sequence

N3ØØ and continues executing code until M6 is executing.

M - Used for M functions - See software Description Manual.

N - Also used for sequence numbering.

R - The Repeat Function.

X, Y, Z - Used when commanding any of 3 axes in the machine.

V - Indicates Variable.
V1 to V127

- Indicates 'EQUALS' used in equation notation.
Example - V1 X

- Divide

- Indicates quotation marks. Used when characters, symbols or numbers must be transmitted on the RS232 connection. Any characters, symbols or numbers transmitted between quotation marks are not operated upon used for headings, data clarity, etc.

- Multiply

Ø to 9 - Numbers

. - Indicates decimal point

SPCE - Indicates space (Blank Character) used typically for data transmission clarity.

+ - Sum (or positive number)

- - Difference (or negative number)

CE - Clear Entry (Clear last digit entered)

3.3.5 ENT/EXE

When depressed, the system executes the MDI, (Manual Data Input). When in the Edit Mode, it causes a carriage return to be stored in the memory. The carriage return causes the execute function to occur when the stored code is decoded by the CPU (Central Processing Unit).

3.3.5.1 CLR BLK - Clears the total entry (In MDI Mode) or clears block where the cursor appears (In EDit).

3.3.6 EDIT MODE KEYS

3.3.6.1 EDIT/EXIT - Depressing this key while the CRT displays the axes information, places the CPU system in the 'EDIT' Mode. Depressing this key while in the Edit Mode returns the system to the normal axes Mode.. The Edit Mode is used for:

1. Changing NC Code that is in RAM
2. Programming EPROMS
3. Searching for blocks of NC Code that have sequence numbers
4. Writing new NC Code that will go into EPROMS

3.3.6.2 PROG PROM

This is depressed when new NC Code is to be stored in EPROMS. This new NC Code must be in RAM. The CRT Display will display ' ARE YOU SURE ? (Y/N) ', after the PROG PROM key is depressed. If the user wants to program the PROM (S), the 'Y' key should be depressed. If it was an error, then 'N' should be depressed. When the programmer is finished, the CRT will display the number of Bytes programmed.

3.3.6.3 READ PROM

When depressed, the system reads all of the NC Code in the EPROM and stores it in RAM. This is used for editing NC Code.

3.3.6.4 SRCH

When depressed, the system displays the word 'SEARCH' on the bottom line of the CRT. The user then enters the sequence number of the line he wishes to find in RAM. Then the 'ENT/EXT' button is depressed. The display will be switched such that the requested sequence number is at the middle line of the CRT under the reversed field cursor. If the sequence number does not exist, the bottomline of the CRT displays 'NOT FOUND'

3.3.6.5 CLR MEM

When depressed, the entire edit RAM of the system is cleared. This is used, typically, after making new PROMS and wishing to test the operation from PROM.

3.3.7 JOG KEYS

3.3.7.1 JOG OFF

Eliminate JOG Mode - In addition this deactivates the following keys: 'HOME' 'RESET' ' + Y', ' - X', 'FAST', ' +X', ' -Y', '+C', 'CALIF', 'RETN JOG'. NOTE!!! WHEN SYSTEM IS FIRST POWERED, THE SYSTEM DOES NOT HAVE JOG MODE ON. THEREFORE, IT IS NECESSARY TO DEPRESS 'JOG' BEFORE SYSTEM CAN BE COMMANDED TO MACHINE HOME.

3.3.7.2 JOG ON

Enables jog keys described above

3.3.7.3 HOME

When depressed, all axes are commanded to machine HOME. All axes status are shown as 'HOME' until the system is HOME when 'READY' appears under the status Heading.

3.3.7.4 RESET

When depressed, sets current axis positions to zero. Also when depressed commands specified axis to JOG.

3.3.7.5 FAST

When depressed, increases JOG speed.

3.3.7.6 CALIB

Used when an axis or axes has been JOGGED. When depressed, changes the displayed value of the X, Y, and Z position to the positional number that the three axes were displaying prior to depressing any of the JOB buttons.

3.3.7.7 RETN JOG

Used when an axis or axes has been JOGGED. When depressed, moves any axis or all axes that have been JOGGED back to their original position - the position of each axis was at prior to JOGGED.

3.3.8 AUTOMATIC EXECUTION KEYS

3.3.8.1 AUTO

When depressed, commands the system to execute all incoming commands either from PROM or from memory. CRT Display shows 'Auto' on status line.

3.3.8.2 STEP

When depressed, commands the system to finish current command. (If not complete, CRT Display shows 'STEP' on status line. In order to continue executing NC Code internally stored, the operator must depress 'CONT').

3.3.8.3 CONT

Used to command the CPU to execute the next internal command. If system in step mode, one block at a time will be executed.

3.3.8.4 RWND

When depressed, causes the NEXT command Block to be at the beginning of NC PROM. Places system in step MODE.

3.3.8.5 RSTRT

When depressed, aborts current command and causes the next command Block to be at the beginning of NC PROM. Places system in step Mode.

3.3.8.6 MEM OUT

When depressed, while the system is in the axes mode, the CPU transmits the entire contents of the EDIT Mode onto the RS232 port.

3.3.9 JOG POSITIONING

Each axis is independently controlled by jog switches. All axes can be jogged simultaneously or independently. If one of the axis direction is depressed, the table moves by one step initially, then moves at a constant slow speed. If the fast key is also pushed simultaneously, then the axis will move at high speed. To move any axis one step at a time, depress the jog key momentarily, (and releasing the button quickly). At the end of jogging, the operator may exit by pushing calibrate, return from jog, or simply enter a new command.

3.3.9.1 CALIBRATE

This switch can be used after jogging. When depressed, the axes do not move, but the displays are set to the previous command. Example: If the position of the axis was 5.000 and the operator jogs the axis by .241 , then the axis moves to 5.241. Now, if the calibrate button is depressed, then the display goes to 5.000 without moving the axis ; in this manner, an offset is achieved which is equal to the amount of jog. Reset uses the same offset.

3.4 MISCELLANEOUS FUNCTIONS

3.4.1 M0: Program Stop

Machine stops after completion of all commands in the block. The system returns to step mode. Program can then be started by pushing either.

A. Continue Button: System remains in step mode acting on one block at a time.

B. Auto: System automatically performs steps in sequence, in accordance with data program.

3.4.1.2 M2: End of Program

A function indicates completion of program. The program is then restarted, (as with RSTRT key), execution of program continues. If M2 does not exist at end of program, operator must push restart to start the program again.

3.4.1.3 M6: End of Subroutine

3.4.1.4 M30: Clear Memory and wait for Input

3.4.1.5 M98: Programmable Reset

Resets current position to zero. (Does not show offset on display, will show it only when you push home). To clear it after Home: Reset again. To clear offset M99 ent/exec M98 ent/exec.

3.4.1.6 M99: Home on all Axes

(If one axis is to be home:M99y). If two axes to be homed M99 X M99Y. This sends machine home, independent of offset. If one wants to go to offset Home M99 XO YO ZO CO.

3.4.1.7 M100 to M195: Output Function

These are output functions. Each even # turns the function on, while the odd # turns it off. Example: the same function is actuated by 100-101, (100 turns it on, 101 turns it off).

3.4.1.8 M200 to M223: Input Function

These are input functions, such as switches or TTL input from external sources which are checked through the program.

3.4.2 [illegible] PREPARATORY FUNCTIONS

3.4.2.1 G00: Disable Continuous Velocity Mode

3.4.2.2 G1: Linear Interpolation

3.4.2.3 G2: Circular Interpolation (Clockwise)

3.4.2.4. G3: Circular Interpolation opposit direction of G2 (Counter-clockwise)

3.4.2.5 G4: Dwell Command

The dwell command permits programming of a time delay, to prevent advance to next block until the programmed time has elapsed. The dwelling time can be programmed from .001 seconds to 64 seconds, accurate to 3 msecs. The delay has to be preceded by (X). For example, G4 X 9.1 (seconds). Delay occurs after table motion and M Functions in that block.

3.4.2.6 G9: Continuous Velocity

3.4.2.7 G58: Used for output of messages and data

Output characters on the RS232 port, computer interface, or IEEE interface. Either axis data, variable values, alpha characters, or any combination. The G58 must appear at the beginning of the block. Any data or variables are stated as defined. Any messages to be included are to be enclosed in quotation marks. For example, "X" would transmit X. However, X without parenthesis would transmit the value of X.

EX. G58 "X"X "Y"Y "Z"Z "V1"V1

If the above command was executed, the following would be printed. XOO.OOOOYOO.OOOOZOO.OO V1 OO.OOOO

3.4.2.8 G59: This sets the dimensional value of each count of the axis that is displayed. To modify the axis, the user would type: X .001 Y .002 .002. This example would make each X count 0.001, and each Y and count 0.002.

3.4.3.0 G61 to G65: Undefined

3.4.3.1 G67: Standard Enable

The use of G67 permits the user to have a standard function or a standard subroutine to occur at the end of every executed block.

G67X5 - Would issue a 5 millisecond pulse at M100 for every executed block.

G67 N123 - Would cause subroutine N123 to be called for every executed block. Either standard operation is cancelled by G67 standing alone. The user is permitted to have either, at any time, but not both simultaneously.

3.4.3.2 G68: Command Scaling

The G68 command allows the effect of a command to an axis to be shrunken, magnified, or inverted; depending on whether the command is less than one, greater than one, or negative. When used with circular interpolation, both axes of the circle should be scaled the same. For example, G68 X.5 scales to [illegible].

3.4.3.3 G69: Comments

Allows the user to enter comments in his NC program. The system ignores anything in a G69 block up to and including, the carriage return.

3.4.3.4 G70: Convert Display to English Units (inches)

Converts display and interpretation of commands to English Units (inches) whenever G70 is executed.

3.4 G71 Convert Display to metric units (millimeters)

Convert display and interpretation of commands to metric units (millimeters) whenever G71 is executed.

3.4.4 SEQUENCE NUMBER (N) 60,00 MAXIMUM

The sequence number is preceded with the letter address "N".
It is used as a reference, identifying position and/or operations for subroutine definition and jumps.
The sequence number allows the operator to search for that block, and then start the program at the point.

3.4.5. AXIS SPEED (F) FOUR DIGITS, 1000 MAXIMUM

The speed of the Axes can be controlled by entering F, followed with the speed.

4. INSPECTION AND TEST

The machine and controls shall be tested at the maker's plant to demonstrate, with reasonable assurance, that this specification has been complied with. The user reserves the right to witness these tests. If the seller requests use of user equipment, it shall be operated by user personnel. Testing, equipment, and procedures described in the following represent the methods preferred by the user. Alternative test procedures usually agreed upon by the user and seller, which in the opinion of the user are deemed equivalent, may be substituted provided written approval is obtained from the user prior to award of the purchase order. Final tests as described below will be performed at the user's installation and may be supervised or observed by the seller's representative. Successful completion of these tests, and inspection to verify that all other requirements of this specification have been met, will be the basis for final acceptance. N/C control programs necessary to perform predelivery at the seller's plant will be furnished to the seller by the user. These programs will be requested by the seller at least 2 weeks prior to the actual date of testing. The total numerical control machine tool system, functioning in all modes, shall be available for verification of the user. Proms will be prepared at least 1 week prior to the start of the actual testing at the seller's plant. The program verification shall be performed by the seller's personnel. User personnel may witness the test runs.

4.1 TEST OF MACHINE ASSEMBLY, COMPONENTS, AND TRANSDUCERS

4.1.1 MACHINE BASE

The machine base shall be inspected for mechanical integrity, conformance to drawings, protection of the exposed surfaces, and the general mounting on the floor and leveling. Situation of the machine with adequate working room and the necessary environmental conditions such as temperature, humidity, absence of drafts, and general cleanliness shall be observed. Electrical power and the air supply shall be checked along with services for the testing instruments.

4.1.1.1 VIBRATION ISOLATION

Function of the pneumatic vibration isolators shall be [illegible] their specifications for lowest cut-off frequency and [illegible] the table. This may be accomplished by applying [illegible] force at each corner of the granite table and observing [illegible] tilt of the table as a function of amplitude and frequency of the

[illegible] These data will be recorded at [illegible] frequency for the system.

4.1.1.[illegible] [illegible]

The granite base shall be inspected for integrity and finish, and dimensionally against the drawings. Attachment between the granite table and the pneumatic actuators shall be observed for lack of misalignment and stress. Active surface of the granite table shall be inspected for damage. The surface shall be tested for flatness, and observed to be at least laboratory grade, as specified by the supplier. Effective flatness of the granite table will be test in section 4.1.2.2.

4.1.2. SLIDEWAYS

Ability to set up the machine and to hold tolerances during its operation depends upon several air slides and their respective alignments. These slides must be straight and stable during machine operation and must hold their straightness and relative alignment between operations. Any friction, drift, or hysteresis cannot be tolerated.

4.1.2.1 SPINDLE SLIDE

This slide which is embedded in the granite block, is used to raise and lower the workpiece spindle in a straight line which is nominally perpendicular to the granite surface. Its orthoganility to the granite surface is not absolutely essential, but its small inclination to the orthoganal must be known in magnitude and direction. If this inclination exceeds 15 arc seconds, measured around the y axis, it must be corrected by lapping the granite surface, or correcting the directions of the slide ways. Measurements may be made using an autocollimator on the granite surface, and electronic mechanical probe with sensitivity of one microinch, as measured against an optical flat at least 10 inches long placed along the line of travel against the surface of the slide. These data shall be recorded at one inch intervals of slide travel. A point in the spindle axis at the level of the spindle face plate shall travel in a straight line over the full 8 inches of slide travel. During this travel, the point shall not deviate from a straight line more than 10 millionths of an inch. The best fitting straight line so determined shall not be inclined greater than 15 arc seconds to the best normal to the granite table. When the spindle slide is locked, it shall remain at a height relative to the surface of the granite table within three millionths of an inch over a period of one hour or more.

4.1.2.2 GANTRY SLIDE AND RAILS

The upper machine structure is made to ride over the granite surface on three air pads. When air is removed, this so called gantry structure will remain fixed to the granite surface. Its position over the granite surface is determined by two orthoganal side rails which are measured against check points on the feet of the gantry by the use of gage blocks. Measurements and later application may require laser gage which is allowed for in the design. The gantry is made to slide six inches along the y axis and two inches along the x axis. Over this range of travel, the gantry structure shall not tilt in any direction more than one second of arc. This may be measured by an optical flat on the gantry and an autocollimator on the granite slide as the gantry is positioned over the granite surface. At the same time, orthoganality and straightness of the side rails may be checked against the optical flat, using the autocollimator and an (electromechanical) probe mounted on the granite surface. Assuming absolute accuracy of the gage blocks used in positioning the gantry, the combined straightness and orthoganality of the guide rails shall not produce an error of positioning greater than ten microinches in any position of the machine structure over the table.

4.1.2.3. TRUNNION AXIS

The tool spindle carriage is carried in a trunnion on the gantry. It may be elevated (turned) around this trunnion axis as well as slid ± one inch along the trunnion axis. The trunnion axis is nominally along the x axis of the machine as defined by the guide rails on the granite surface. The trunnion axis must be orthoganal to the direction of the motion of the workpiece spindle slide within ± one second of arc. Over the one inch travel, the tool spindle carriage shall not tilt more than one arc second as a result of the sliding motion. This may be checked by an autocollimator on the granite surface against an optical flat on the side of the tool spindle carriage.

4.1.2.4 TRUNNION TILT SLIPE

The tool spindle carriage is supported at the rear by a sliding bearing whose surface is carried in the gantry structure. As the tool carriage slides back and forth in the trunnion, the bearing at the rear slides against a surface which must be adjusted parallel to it. Unless the parallel surface is properly adjusted, the tool carriage will tilt as it slides back and forth in the trunnion. One inch motion shall not result in more than one second tilt. This again may be checked by an optical flat on the tool carriage against an auto collimator on the granite surface. Since the sliding bearing is loaded by weight of the tool carriage, its pressure must be carefully regulated so as not to change its clearance during operation. This clearance must be held accurately with ± 1 micron during machine operation. Its nominal clearance is approximately four (4) microns.

4.1.2.5 TOOL HOLDER ARM

The tool holder arm shall slide on a surface which is orthogonal to the tool axis spindle. Distance of the tool tip from this reference surface along the tool spindle axis must be known accurately for preset tooling. Also the distance of the tool tip from the spindle axis in the direction of the tool holder arm must be accurately known. When the tool axis is in its zero degree position, the tool tip must lie directly below the tool axis along the line of the work piece spindle travel. Deviations of the tool axis arm from its prescribed direction shall not exceed ten (10) microinches normal to its direction of motion over a distance of six (6) inches.

4.1.2.6 MACHINE CENTER

The machine center is defined as the position in the tool spindle axis directly above the tool tip when the tool spindle is in its zero position. Position of the machine center relative to the work spindle axis and the work spindle face must be accurately known when the machine is set up. When tranducers on the various slide axes are zeroed, the tool spindle axis shall intersect the work spindle axis within ten (10) microinches. This may be checked by mounting a gaging ball on the work spindle table and an electro-mechanical probe on the tool axis spindle. With all axes zeroed, the probe is adjusted to scan

the tooling ball until its center is located. This may be done with the tool carriage tilted forward at some angle such as 45°. For a zero setting, total indicated runout on the ball may not exceed twice the certified accuracy of the ball. Spindles are turned simultaneously to conduct this test. When the test is completed, height of the ball above the granite table must be accurately measured and then recorded. Without sliding the carriage and the trunnion axis, and holding the gantry on the granite table, another center at a different carriage inclination shall be found and recorded. Total indicated runout of this second measurement shall not exceed twenty (20) microinches for a change in carriage tilt of 45°.

4.1.2.6.1 ADJUSTMENT OF THE MACHINE CENTER

The machine center may be adjusted relative to the work spindle in several ways.

a) The gantry may be adjusted against mechanical blocks as heretofore described.
b) A micrometer in the trunnion slide may be adjusted.
c) A linear actuator carried against the micrometer tip to produce a fine control motion.
d) The work spindle column may be raised or lowered a prescribed amount.
e) The tool spindle carriage may be tilted in the trunnion axis.
f) The tool arm length may be used to change the position of the tool tip normal to the tool spindle axis.
g) The adjustment may be measured by the laser gage if available.

4.1.2.6.2 STABILITY OF THE MACHINE CENTER

Once the aforementioned are made and set, and the machine center determined, it shall remain stable within TIR of six (6) microinches on the gage ball for a period of one (1) hour or more. This is presuming a temperature of the environment held stable within ± 1° F over the test period.

4.1.3 MACHINE SPINDLES

It is the spindles which determine the machining accuracy and surface finish within the capabilities of the machine. The work piece spindle, of course, determines the symmetry of the axis

IntOp • Wallingford Connecticut 06492

Division of Kollmorgen Corporation

of revolution as well as indications in the [illegible] which may be harmonics of the speed of rotation. The tool spindle determines the surface figure so far as concentric aberrations are concerned. Since it feeds the tool across the work piece, it determines the periodicity of the grating lines which are normally formed in diamond machining.

4.1.3.1 WORK PIECE SPINDLE

This spindle shall be balanced and tested between five hundred (500) and fifteen hundred (1500) RPM. A gage ball shall be mounted on the spindle face at a height of approximately two (2) inches and centered within the tolerances of roundness of the gage ball. A capacitance gage may be used for dynamic checks at higher speeds. A plane mirror may be used on the spindle face, perpendicular to the axis of rotation, in order to measure wobble. An auto collimator may be used for low speed checks. At higher speeds, output from the split sensor may be displayed on an oscillosocope to determine dynamic spindle wobble. Spindle runout is determined by the gage ball and shall not exceed two (2) to three (3) microinches at low speeds. Spindle camming is measured atop the gage ball and shall not exceed one (1) to two (2) microinches at low speeds and shall not exceed two (2) to three microinches at the higher speeds. Spindle level at low speeds shall not exceed one (1) microradian and not exceed two (2) to five (5) microradians over the higher speed ranges.

4.1.3.2 TOOL DRIVE SPINDLE

The tool drive spindle may be checked in a similar manner to the work piece spindle. Low speed tolerances are the same as for the work piece spindle. The tool axis spindle should also be checked for axial and radial stiffness at the tool tip. Locating the tool tip two (2) inches outward from the tool axis spindle face and six (6) inches from the spindle axis, a force of ten (10) grams shall not deflect the tool tip more than one (1) microinch in any direction.

4.1.3.3 TRUNNION TILT AXIS

The trunnion tilt axis functions as a rotary spindle although it also provides a sliding motion. Runout and stiffness of the trunnion air bearings is specified to be one (1) to two (2)

microinches within limits of the trunnion tilt and to be at least two hundred and fifty (250) thousand pounds per inch radially. These parameters may be checked directly against the trunnion shaft in a radial direction.

4.2 Functional testing of the pneumatic supply and control system is discussed in section 3.2.5. These tests should be duplicated after the pneumatic supply and control system is connected to the machine. Much of the air system must be functional during testing of the spindles and slides. Satisfactory execution of the previous test in section 4.1.1, 4.1.2, and 4.1.3 shall be deemed a satisfactory demonstration of the pneumatic control system, with the following exceptions.

a) Safety interlocks and alarms must be demonstrated.

b) Signals to the N/C system must be demonstrated during the N/C System check out.

4.3 Functional testing of the N/C system and Servo Controls shall follow the precepts set forth in Section 3.3 when the N/C System has been installed.

a) Each servo and control shall be checked for performance per 3.3.1.1, 3.3.1.2, and 3.3.1.3.

b) Each of the operating modes shall be checked out as in 3.3.2 through 3.3.9.

c) A program shall be prepared to machine a sample part using the necessary miscellaneous functions described in section 3.4 and a sample part shall be cut and measured to determine overall function of the machine system. The user shall specify the program.

4.4 PERFORMANCE TESTING

The sample part(s) selected shall at least meet the requirements set forth in DAAE-40-79-C-0225, section 3.3.2 (Goals for precision Machined Optical Part Specifications) with the exception of section 3.3.2d.

5.0 DOCUMENTATION

5.1 LIASON INFORMATION

At a time specified in the purchase order, the seller shall furnish two copies each of the standard control panel details.

5.2 PRELIMINARY APPROVAL

By the time or date specified in the purchase order, the seller shall furnish two copies of each of the documents described below. Buyer will mark one of each "APPROVED" or "APPROVED AS NOTED" after which fabrication may begin. Approval of these documents shall not relieve the seller of the obligation to provide a system conforming to these specifications.

5.2.1 a) Electrical Circuit Diagrams

These drawings shall schematically outline:
1) electrical main power
2) monitoring signals and the interlock systems

5.2.2 b) Electrical Block Diagram

The complete electrical control systems shall be shown on a block diagram.

5.2.3 c) Outline Drawings

These drawings shall provide the outline dimensions of the machine tool and control cabinet.

5.3 FINAL DOCUMENTS

The seller shall furnish the documents described below. Except for the instruction manual, of which three copies are required, they shall be furnished as reproducible transparencies. They shall be "as built" and reflect all changes made to the system up to the date of final acceptance by buyer. They shall be furnished at the same time as the equipments except that revisions resulting from acceptance testing shall be furnished within 90 calendar days of the inspection.

5.3.1 a) Circuit Diagrams

Individual chassis and the complete system shall be shown schematically on these drawings. Drawing numbers, part numbers and symbols, terminal numbers and other identifying marks shall allow simple, positive cross-identification between the diagrams and the actual part of systems.

5.3.2 b) Logic Diagrams

A logic diagram shall be provided using logic symbols and a plan of connection to describe the function of each logic element and unit of the system. The logic diagram shall include a definition of logic "0" and logic "1" in terms of the voltage. It is preferred that this be done by means of a truth table, illustrating all possible input combinations. The diagram need not show power connections.

5.3.3 c) Voltage Charts

When required for operation, maintenance or checkout, a list of all critical voltages or wave forms between terminal points shall be given.

5.3.4 d) Instruction Manual

All necessary instruction for installation, operation, maintenance and calibration shall be provided.

5.3.5 e) Parts List

This list shall identify all components by name, size or rating, manufacturer's model or serial number and, where applicable, the JEDEC or other such identifying code. Ordering instructions for non-standard parts shall also be included.

5.4 TEST PROMS AND INSTRUCTIONS

The seller shall furnish test proms and instructions for the control system performance and reliability tests.

5.5 INSTALLATION SUPERVISION

The seller shall furnish the services of qualified field engineers, including a machine tool representative and control system representative, to supervise the installation, testing an initial operation of the system at buyer's site. Basic instruction of buyer's personnel in the operation and maintenance of the equipment is required.

5.6 INSTRUCTION AND TRAINING PROGRAM

The seller shall provide the following training programs and a schedule for when these training programs are offered. The schedule shall permit completion of this training a minimum of one month prior to delivery of the equipment. Manuals, drawings, and other printed materials shall be available.

5.7 PROGRAMMING AND MAINTENANCE INSTRUCTION

Machine tool operations programming and maintenance training shall include the theory, operation, installation and maintenance of the control system and related machine components, also the operation and maintenance of NC controls, and will be directly associated with the equipment being shipped.

IntOp • Wallingford, Connecticut 06492

Division of Kollmorgen Corporation

CONTRACT DAAK 40-79-C-0255

DATA ITEM 006

INTERIM MANUFACTURING METHODS REPORT

3.3.4.2 TASK 3 - METROLOGICAL SPECIFICATIONS

form A-541

IntOp • Wallingford, Connecticut 06492
Division of Kollmorgen Corporation

METROLOGICAL SPECIFICATIONS

Section 1 Measurements on the Machine

Section 2 Visual Techniques

Section 3 Measurements on Parts

Section 4 Metrology Equipment and Facilities

Section 5 Parts Qualification

InterOp • Wallingford Connecticut 06492

Division of Kollmorgen Corporation

[illegible]

[illegible]

[illegible]

MICRO-MACHINING IN-PROCESS CONTROL

Unlike other machining branches micro-machining lends itself to in-process-control and to contactless optical metrology.

Since micro-machining is usually performed on machines with spindles and slides with hydrostatic or aerostatic bearings, the geometry of turning and sliding components approaches the limits of optical metrology (resolution) in many cases.

Metrology of micro-machined parts is, therefore, best performed "on-the-machine" esp. "in-process". Also, most micro-machined surfaces have a shiny smooth appearance and reflect light specularly to some degree. Therefore, interferometric inspection methods can be applied without difficulty.

Achieving the figure compliance with regular geometric shapes like plane surfaces, spherical surfaces and cylindrical surfaces and certain conical surfaces are not a problem for machines that qualify for micro-machining (i.e. air bearing machines). As a matter of fact, interferometers should be embodied with machines for micro-machining to qualify and certify the machine and the parts. Interferometers also serve for continued surveillance of alignment of the machine. Typical is the tilting of flycut spindles with respect to slide motion in order to produce planar surfaces. This is accomplished best by an interferometer paralleling the spindle.

form A-541

The dynamics of well executed micro-machines are precise enough to allow the integrated interferometer to scan parts on the machine that are larger than its field of view. Typical of this is the scanning of flycut reflectors as large as the feed may allow using a small diameter interferometer. As the slide transports the finished part underneath the interferometer, pre-aligned interference fringes should not change their appearance (spacing and orientation). If they do there is either material misbehavior (deformation) or, the slide travels unevenly; or worse, the stiffness of machine components was inadequate to withstand the load through machining at full figure compliance.

The equivalent is true for spherical shapes. A micro-spherical wavefront interferometer put in place of or next to the diamond tool may be used to sweep across surfaces and verify the spherical geometry by fringe count.

Here, too, the combination of small size optics with precise air bearing quality motions leads to verification of surfaces on the machine to tolerances fully compatible with interferometry of the entire surface.

1.1 ON THE MACHINE INTERFEROMETERS

1.1.1 FLAT SURFACES

There is no technical problem at all with interferometers for flat surfaces. The instrument must, however, provide for:

a) Sharp image of sample as far as this is possible with laser illumination. Unwanted phase contrast effects are minimized if the screen shows an image well focused on sample.

   A size of 125 mm diameter seems appropriate to most applications. A reference accuracy of at least $\lambda/10$ is required.

b) The focus (or "diffraction" image) of the interferometer reference and the sample must be shown as well. This is used for alignment and for qualitative observation of scattered and transmitted light.

The longer the focal length of the interferometer collimator the more practical becomes the observation of scattered light around the zero order.

(c) The optical axis of the instrument must have references that allow its orthogonal alignment to the machine cutting plane.

[illegible] SPHERICAL AND QUASI-SPHERICAL SURFACES

More instrument complexity is involved with interferometers for spherical or quasi-spherical surfaces. The instrument is usually too bulky to remain in place during the cutting operation because of interference with the optical axis of a large aperture spherical interferometer must be mounted so that its axis is coincident with the axis of the work spindle.

The mount must be constructed so that the motion required to bring the instrument and part centers into coincidence will not cause loss of this alignment. The coincidence of these centers is indicated by the "uniform" tint of the interference pattern.

Many spherical micromachined parts (reflectors) have central through holes. The interferometer in this case might be mounted oblique to the spindle axis where it might not interfere with the tool holder. This off axis positon does, however, present the added task of two dimensional alignment.

To overcome these difficulties slim f/25 interferometric sensing probe no larger than the tool is indicated for scanning spheres or quasi-spheres. Because the field of view is small in such a probe, the information about the surface is assessed by counting fringes passing by the instrument optical axis rather than by viewing the entire aperture as with, for example, a f/84 spherical interferometer.

It need not be emphasized that recording the data by photography or video is part of the metrology system.

The machine integrated interferometer serves for:

a) Adjusting machine and spindle alignment.

b) Observing the effect of the de-chucking or otherwise loosening of the sample from its holding mechanism on the machine.

c) Observing effects on materials due to tool and lubricant action.

d) Observing lack of machine stiffness, resulting in form compliance lost during cutting.

e) Measuring vibrations in process.

In micro-machining with diamond tools even the poorest surface reflects light which allows for multiple-beam interferometry (Fizeau-type) to be performed. This also allows for easy-to-build and convenient-to-use interferometric configurations. As will be seen, this is not so when inspecting surfaces. Then two beam techniques are more appropriate.

2. VISUAL INSPECTION OF MICRO-MACHINED PARTS WITH THE NAKED EYE.

The inspection of a micro-machined surface for smoothness should also be done on the machine before finishing. This is particularly practical, since simple inspection often reveals whether the tool-setting was proper or not and whether a further cutting might be indicated.

Because of the large area regularity and periodicity of micro-structure on micro-machined surfaces all effects accompanying the reflection of light on such surfaces involved diffraction in various orders, spatial frequencies, harmonically related components and scattered light. The spectral density function (SDF) is most revealing about the surface. Relevant theory is described in ref. 1.

2.1 EFFECTS SEEN VISUALLY

Easily observed by the naked eye and by simple technical means are both diffracted light in higher orders and spatial beat frequencies between regularly spaced tool marks and general machine vibrations, superimposing the cutting process. Scatterel light due to other than random structural effects and low angle diffraction around the zero order (specular reflection) are less readily observed visually.

Whereas regularly spaced grooves, which, due to feed rate, are usually in the order of between two(2) and ten (10) micro-meters wide and mostly with circular cusp crossection cannot be observed by the naked eye individually, spatial beat frequencies (Moiré) between regular cutting grooves and vibrations caused by the machine are observed visually in form of Moiré patterns on the machined surfaces.

A very typical machine error is spindle coning. The spindle axis moves on a precision cone with a frequency much lower than its speed of rotation. This causes a periodic structure on micro-machined surfaces, usually as wide as in the order of ten (10) to one hundred (100) micro-grooves.

Beat frequencies or long-wave grooves are recognized quite easily with the naked eye. It is helpful to scan and observe any straight bright line which is somewhat distant and parallel to the expected grooves. Such a straight line might be an incandescent tube. The edge of the "straight" light line appears saw-tooth-like interrupted or corrugated. Little sense is seen in microscoping the effect, because the machine cause must be cured as far as to remove visually recognizable defects.

Another effect seen readily on micro-machined surfaces is that of periodic tool marks produced by poorly-set or damaged tools. The grooves produced by such tools are not smooth and diffraction takes place quite readily on tiny micro profiles superimposed to the regular cusp of the light beam reflected off the surface.

2.2 SIMPLE TECHNICAL MEANS

Practical illuminators are small single-filament or single point lamps. The lightbulb might be in a lamp-housing with an inexpensive collimation lens. The diffraction can be seen as rainbow colors and they should appear in a rather uniform tint, as the light is shown onto the sample. The tint appears more uniform, as the grooves become finer. The diffraction spectrum (several color sequences) is seen as the grooves become more widely spaced.

Micromachined specular surfaces of good quality should not exhibit "color". If only form compliance is required this phenomena will not be indicative of part quality.

The depth of the grooves (error depth) and tool marks has no influence on the spatial distribution of diffracted light but it imparts the intensity distribution in the diffracted light. The error depth must be determined by other means (section 3.5).

An expanded laser beam of about one(1) cm diameter reflected by the sample and focused onto a screen will usually produce a diffraction spectrum.

This display along with the previously noted color provides almost all the information needed for proper tool setting and machining parameters.

Of course, the highest quality specular surface will not produce any diffraction orders at all. While this is realistic, there remains the noise around the zero order (specularly reflected beam). Often this extends not only in the direction normal to the cutting grooves but all round the zero-order. This indicated random surface defects of a size larger than the groove width. The remedy for this requires a much more refined tool inspection than is possible on the machine.

2.4 The practical observation of the diffraction spectrum includes:

a) a single point light source to be secured in a convenient location to illuminate the surface.

b) a HeNe laser collimator defocussed such as to produce a light focus at a distance of about 1 m.

In effect, the theory of blazed reflection gratings predescribes the theory required to explain the diffraction effects on micro-machined surfaces (ref. 3).

3. MEASUREMENT OF PARTS - QUALIFYING TESTS OFF THE MACHINE

3.1 Error Depth

Interference fringes are a practical means for detection of mismatch of a general machined surface from a theoretical best fit spherical surface. This measurement can be used to determine a departure as small as $\lambda/10$. Local area departures from the theoretical best fit spherical surface can also be detected to a departure in the order of $\lambda/5$.

Multiple beam Fizeau techniques most practically tend to cover defects of depth to $\lambda/4$, if their lateral size falls between fringes (ref. 4). It's greatest value is for assessment of best fit surfaces, as opposed to measurement of depth of tool marks. For this, Tolansky's method is better if interferometry is to be used (ref. 5).

In interferometers that allow for long object distance and large area, lateral optical resolution is limited, obviously. Tolansky and other interference methods for detailed observation are best used with microscopes.

3.1.1 It is recommended that a two-beam interference microscope with fifty magnification be used as standard equipment for the investigation and control of surface defects of one (1) to twenty (20) μm width and depths of between 0.02 and one (1) μm. The micro-interference fringes are interpreted as is customary in interferometry.

3.1.2 A powerful tool for qualitative error depth assessment, especially on samples too large for microscope stages, is phase contrast.

Most optical instruments by aperature limitation will effect the loss of some parts of the total spectrum of reflected light forming the image. Minute discontinuities of surfaces illuminated in this manner can be resolved for evaluation. This simple form of phase contrast can be achieved with long focal length imaging optics.

3.1.2.1 It must also be pointed out, that any interferometer in a nulled state is also a phase contrast instrument. The zero order of the sample beam is compensated for by that of the reference beam. In addition, the reference beam may be blocked off and the classical knife-edge may be positioned in order to stop the zero-order light. Then only the diffracted light forms the image and it depicts all the surface defects.

3.1.2.2. With high speed collective optic imaging the most informative images are obtained by cutting off the zero order. By no means should lasers be used for phase contrast because small angle diffraction causes "Fresnel-type" diffraction, and interference tends to obscure the real information. A white light point source is best qualified to illuminate phase contrast optics.

4. METROLOGY, EQUIPMENT AND FACILITIES

Perhaps the most important ingredient of a good metrology facility is the area where the equipment and parts are stored and handled. The environment here must be as good as the evnironment where the parts are manufactured. It is here that the conglomerate effects of machining, fixturing, parts handling, thermal effects, etcetera, are evaluated. For this reason an area is reserved in the micro machining room for this purpose and is described under Task 4 - Facility Specification. This also calls for strict supervision and control of the metrology area of the facility.

4.1 THE METROLOGY AREA

First of all, this area should be free of all activities except measurement and qualification of parts. It should be kept clean and clear of apparatus which is not being used for the particular measurement in-process. Therefore, adequate cabinets and shelves should be provided for ready storage. The parts should be clean when brought to the area and carefully stored and handled in the area.

4.1.1 INSPECTION AREA ENVIRONMENT

Since parts configuration and geometry are often the question rather than absolute part size, it is necessary to suppress disturbing transients over a period which is usually much longer than the inspection period, without necessarily establishing a long term absolute control on the environment. The area should have controlled lighting, capable of establishing areas of sufficient illumination or darkness to perform the usual metrology procedures. These as has been mentioned, include visual inspection, measurement, recording data, photography, and adjustment procedures.

4.1.2. AUXILARY EQUIPMENT

The room should be equipped with tight cabinets where critical parts can be stored. A staging area for parts to be soaked to the thermal environment should be provided in the vicinity of the measuring instruments. A clean air-flow hood should be provided for final cleaning and visual inspection if the parts are to be packed in the metrology room. Sufficient electrical outlets for the measuring instruments should be readily accessible where the measurements are to be made.

4.1.3. METROLOGY BENCHES AND ISOLATION EQUIPMENT

The most important single piece of equipment for such a facility is a large granite table mounted on vibration isolation air pads. Optical benches and other measuring set-ups may be made on this table. The table itself may be an integral part of air slides and rotary tables which are used in the measuring process. It has been mentioned in the foregoing that the use of air bearing slides and rotary tables is an important part of scanning interferometry which can be such a powerful tool in the qualification of parts. Of course the table should be of sufficient size and capacity to handle the focal lengths and weight of parts to be qualified. At least a section of the table should be flatter than the measuring tolerance. The more mundane setups should not be allowed in this section of the table.

SECONDARY METROLOGY AREA

Not all of the product measurements require the same degree of environmental control An area that is suitably enclosed, clean and temperature controlled to within a few degrees fahrenheit will prove completely adequate.

This room might be well equipped with an optical tunnel with long optical bench or rail. This part of the facility would be used to measure diffraction effects, scattering, and the like. It might also be used for Lloyd interferometry. Corrollary to this bench and the measuring table, is a requirement for various optical mounts collimating lenses, gratings, lasers, light sources and fixtures for holding the measuring instruments and parts. The kind and amount of such equipment will depend greatly on the measuring tasks to be undertaken. The recording equipment and cameras will also depend a great deal on the degree of qualification undertaken.

5. PARTS QUALIFICATION

Considering the foregoing as well as the testing requirements called out in the machine specification, it may be derived that an extensive and expensive array of measuring instruments are required to produce diamond machined parts of optical quality. It is not reasonable to expect that every small shop or facility will be able to afford a complete set of measuring instruments. Therefore, one must take into account the jobs at hand and the overall capability of the manufacturing facility to produce parts. For instance, in the case of certain infrared optics, tolerances may be such that simple qualification tests will suffice. These might be limited to visual inspection and measurement of the energy collected in a least circle of confusion for the optical system. On the other hand, optical systems which are meant to operate in the visible region or in the ultraviolet, may call for tolerances which tax the capability of the machining system, and therefore require rather extensive qualification testing to tight tolerances. The most desirable system, of course, is a system which will qualify parts as they are produced on the machine. Acceptance of such data as a qualified source inspection is difficult to obtain from the buyer's qualify control department. The following system is specified to conform to the requirements of this Army Contract, as they may apply to the sample parts which are to be produced and to the results of the survey conducted on requirements by the military for the next few years. Exceptional cases of very loose tolerances, or of very tight tolerances for visible optics are not covered.

5.1 Qualification on the machine tool called out in this specification, establishes a configuration, accuracy, and stability which is capable of producing parts an order of magnitude better than may be required for infrared optical surfaces. One might term this capability an overkill, however, it has been established in practice that a higher degree of quality and production capability can be derived from such an arrangement with good economy. Therefore, if the machine functions are monitored with complementary measuring equipment during the manufacturing process, one may be assured that the parts produced on the machine will be of the desired geometry when finished on the machine. To assure the effectiveness of this in-process measuring capability, it is advisable occasionally to measure a sample part off the machine with complete thoroughness.

5.1.1 On a machine with numerical control, such as called forth here, complementary monitoring can begin in the control system itself with such devices as parity checks in the program. At the same time, limits can be established for servo errors in the control system which will indicate that the machine has properly followed the commands.

5.1.2 The machine may be equipped with other monitoring equipment, such as temperature sensors, vibration sensors, spindle speed monitoring devices, and pneumatic sensing devices. It is not difficult to conceive an array of such monitoring equipment which will assure that the machine is operating properly during the cutting cycle.

5.1.3 All this does not assure that a sufficiently smooth surface has been produced in the cutting cycle. Therefore, certain visual observations need to be made by the operator during the manufacturing cycle. These have been discussed in some detail in section one (1) of the earlier pages of this specification. For this purpose a laser light source, a monochromatic light source, possibly certain aperatures or stops, a knife-edge or grating, or other optical devices may be attached to the machine tool for the operator to use.

As has been discussed, interferometry also may be performed on the machine tool with integral interferometric setups. It is recommended that scanning interferometry is the best device for this purpose. At least it is possible then to determine whether or not the parts should be removed from the machine, or further finishing should be attempted. Such tests do not assure that the part will stay fixed when removed from the machine tool, during its further handling and installation in the optical system. For this reason off-the machine metrology is required.

Diagnostic Testing must often be done to determine faults in the manufacturing or metrology equipment. Probably the most difficult thing to determine is overall part geometry which includes relation of the called for surface to other reference surfaces on the part. An absolute positioning system is required for this purpose.

.2.1 The air mounted granite table with auxiliary equipment called for in section four (4) are required for determining absolute part geometry. Probably the greatest weakness of standard available interferometric equipment, is the type of positioning aparatus which is used to manipulate the part in the interferometer array. One usually establishes an interferogram on the display system without knowledge of the part position, except that its surface best fits the wavefront established by the interferometer. Therefore, one part of this metrology specification, is to call for suitable positioning equipment which is commensurate with the called for part geometry, and which will assure a quick and orderly part positio[illegible] so that measurements may be made from the correct r[illegible] [illegible]ines and planes relative to the surface. Conversely once the position of the surface is established in the measuring scheme, one should be able to determine the absolute position of mounting surfaces and holes which are integral with the parts. Air bearing tables and slides and appropriate actuators and scales are essential to this part of the metrology arrangement.

IntOp • Wallingford, Connecticut 06492

Division of Kollmorgen Corporation

With the call for interferometric equipment at hand, holography may well play a powerful role in establishing parts in compliance with the specifications. Holographic interferometry is nothing more than standard interferomentry which uses a specified wavefront for reference. This wavefront may be generated synthetically by so called holographic means.

REFERENCE 1

Stover, J. C., "Roughness Characterization of Smooth Machined Surfaces by Light Scattering", Applied Optics, Volume 14, Number 5, Pg. 1796.

REFERENCE 2

Strong, J. W., "Diffraction Gratings", Handbook of Physics XXIX, Optical Instruments.

REFERENCE 3

Stover, J. C., "Surface Characteristics of Machined Optics", Precision Machine Optics, San Diego, 1976.

REFERENCE 4

"Improving Accuracy of Visual Interferometric Angular Measurements", Applied Optics, Volume 8, Number 10, pg. 2029, 1969.

REFERENCE 5

Walters, H., "Schluren Phase Contrast and Lictschnitt Verfarer", 1956 Grundlagen in Optics.

IntOp • Wallingford, Connecticut 06492

Division of Kollmorgen Corporation

CONTRACT DAAE 40-70-C-0252

DATA ITEM 006

INTERIM MANUFACTURING METHODS REPORT

3.3.4.3 PASE 4 - FACILITY SPECIFICATION

form A 541

IntOp • Wallingford, Connecticut 06492

Division of Kollmorgen Corporation

FACILITY SPECIFICATIONS

Section 1	Foreword
Section 2	Scope
Section 3	Primary Enclosing Structure
Section 4	Environmentally Controlled Area
Section 5	Supplementary Control Units

form A-541

1.0 TASK 4 - FACILITY SPECIFICATIONS

1.1 FOREWORD

This specification is presented in response to paragraph 3.3.4.3 of the Technical Effort of the Basic Effort of Contract DAAE 40-70-C-0225.

2.0 SCOPE

Task 1 - Survey, the first section of this report details the future requirements for precision machined optical elements. The quantity of these elements indicates that a number of machines is required to meet the demand. It was further determined that the most economic approach is to provide a variety of basic machine configurations which are uniquely suited to the geometry, size and tolerance level of specific groups of parts. For this reason a room large enough to house several machines and, where necessary, appropriate metrology is specified.

The facility must provide an environment that will allow these machines to perform at the level of their design specification. Because the parts to be manufactured by these machines will require various tolerance levels and cutting cycles it has been decided that the general area should meet the majority of these requirements. Parts requiring environmental levels more closely controlled than that provided in the general area should be manufactured with machines having modularly constructed local enclosures that will provide more precise controls of temperature, humidity and acoustical isolation.

3.0 PRIMARY ENCLOSING STRUCTURE (General Plant)

A suitable location should be selected in the primary plant area to construct an environmentally controlled room. The ambient temperature of the enclosing structure shall have a year round excursion of not greater than 40° F. This shall occur in the range [illegible] F. to 95° F and shall occur at a seasonal rate. Daily changes shall not exceed 10° F.

All machinery having a vibratory output such as fans, pumps, etc. should be supported from the overhead of the primary structure where possible. Machinery that must be mounted to the floor should use isolation mounts that have a natural frequency below that of any [illegible] precision machinery. Connections between this equipment and the environmental room should be made with isolation joints.

ENVIRONMENTALLY CONTROLLED AREA

The environmentally controlled room should be free standing and structurally independent of all but the floor of the enclosing primary structure. No common walls or ceiling, should be used so that free circulation of ambient air around the outer walls of the controlled room is accommodated.

The interior walls, floor and ceiling of the controlled room should be smooth and free of crevices to prevent the collection and the removal of foreign matter.

The outer walls and ceiling should be insulated with a material having a factor of R 21 to minimize heat transfer and provide acoustic isolation and should be surrounded by a plastic thermal barrier. There should be one primary entrance to the room which should be of a size sufficient to accomodate the largest anticipated machinery and handling equipment. This entrance should be made through an anti-room which will prevent free flow of air from the primary structure and shall offer an observation vantage point while limiting access to the controlled area. An emergency exit door must be provided. The structure should have no windows other than those located in the doors:

The interior room dimensions should be:

Length	40' - 0"
Width	15' - 0"
Floor to Ceiling	7' - 6"

Air should be introduced into the room by means of appropriately distributed ceiling mounted registers. Louvers should be positioned in the exit air stream to direct the air down the outside walls to the floor. A series of returns should be located along the long axis of the room in the ceiling so that air flow will encompass the area. The placement of inlets and outlets should be such that direct drafts at a distance greater than three feet from the walls will be avoided.

The air flow shall be [illegible] with an inlet velocity of [illegible]

at the register. Room air will be changed at a rate of 25 to 30 times per hour. Air should be conducted through fibre glass ducting providing acoustical isolation.

A refrigeration unit must be provided to initially chill the air to 55 to 60° F. This air should leave the diffusers at 60-65° F ± 1° F. Temperature excursions over a 24 hour period must not exceed ± ½° F.

Trim heaters should be located in the air duct exiting the air conditioning unit. These heaters will be used in the final regulation of the air temperature. Dual sensors for both heat and cool should be located centrally in the short walls at both ends of the room. They should be located about five feet from the floor.

Relative humidity control will be provided by the air conditioning unit. The relative humidity should be controlled to 50 to 55 percent. The maximum heat load in the room is specified as:

2.0 watt / sq. ft.
6 people
1.2 horsepower

This load may vary considerably. For this reason appropriate valving for a hot gas by-pass must be provided. In addition the condensing unit must have provision for independent operation for use during cold weather. The humidity control unit should be mounted centrally on the long wall about five feet from the floor.

While it is not initially considered that the inlet air requires any more than good commercial practice filtration, the system should be capable of operation with 95% filtration.

4.0 SUPPLEMENTARY CONTROL UNITS

When it is determined that the tolerances of a part to be produced can not be held when thermal excursions of a magnitude to be expected in the controlled room are imposed, a separate enclosure enveloping the vital machine areas must be provided. This enclosure will also be required when working with hygroscopic materials that require relative humidity of less than 50 per cent.

These units must be self contained and should work on the same principle as the basic room thermal controller. Inlet air will be taken from the basic room area at a temperature of 68° F ± 1 °F. Provision must be made for chilling and then heating this inlet air so that a constant temperature of 68° F ± 0.1 °F may be maintained. Relative humidity must also be controlled to 40 to 45 percent. If required, filtration should be provided in these units. Care must be taken in the design of these enclosures to insure that they do not impart vibratory inputs of a mechanical or acoustical nature. Lighting within the enclosure should be provided by fibre optic transmission or similar means.

DISTRIBUTION

		No. of Copies
Defense Technical Information Center Cameron Station Alexandria, Virginia 22314		12
DRSMI-LP	Mr. Voigt	1
-R	Dr. McCorkle	1
-RPR		3
-RPT	(Reference Copy)	1
-RPT	(Record Copy)	1
DRSMI-RHL	Mr. Friday	30
-IYD	Ms. B. Batts	1
-QRT	Mr. Hutcheson	1
-ETT	Mr. Bobby Park	2
Inlop Div. of Kollmorgen Corp. 1111 North Plains Industrial Rd. Wallingford, CN 06492 ATTN: Arthur Hess		4

END

DATE
FILMED
6-81

DTIC