NUMERICAL CONTROL

General Familiarization

BACS

BOEING WICHITA TRAINING SECTION

TM-814

THE BOEING COMPANY
WICHITA DIVISION WICHITA 1, KANSAS

NUMERICAL CONTROL GENERAL FAMILIARIZATION

TM-814

TRAINING

MARCH, 1961

NUMERICAL CONTROL GENERAL FAMILIARIZATION

The course consists of a non-technical explanation and discussion of Numerical Control and its application in manufacturing. This includes a brief history of the developments in Numerical Control, types of control systems and typical applications, discussion of a process flow effect on organizations, training requirements and some typical cost comparisons.

BOEING APPLIED COMPUTING SERVICES
The Boeing Company
Wichita 1, Kansas

NUMERICAL CONTROL GENERAL FAMILIARIZATION

I. Introduction and History
   A. Explanation of Numerical Control
   B. Capabilities

II. Machine Axis Designation
   A. Rectangular coordinates
   B. Machine orientation

III. Tapes and Tape Codes
   A. Explanation of different tapes
   B. EIA codes
   C. Tab sequential
   D. Binary codes
   E. Magnetic tapes

IV. Theory of Servo-Mechanisms
   A. Simple Servo
   B. Tracer versus tape control

V. Point to Point Systems
   A. Comparison with continuous path
   B. Typical applications
   C. Programming

VI. Continuous Path Systems
   A. Typical applications
   B. Programming
      1. Manual
      2. Computer assisted

VII. Process Flow
   A. Manuscript
   B. Punched cards or flexowriter
   C. Computers
   D. Card to tape converter
   E. Machine tool

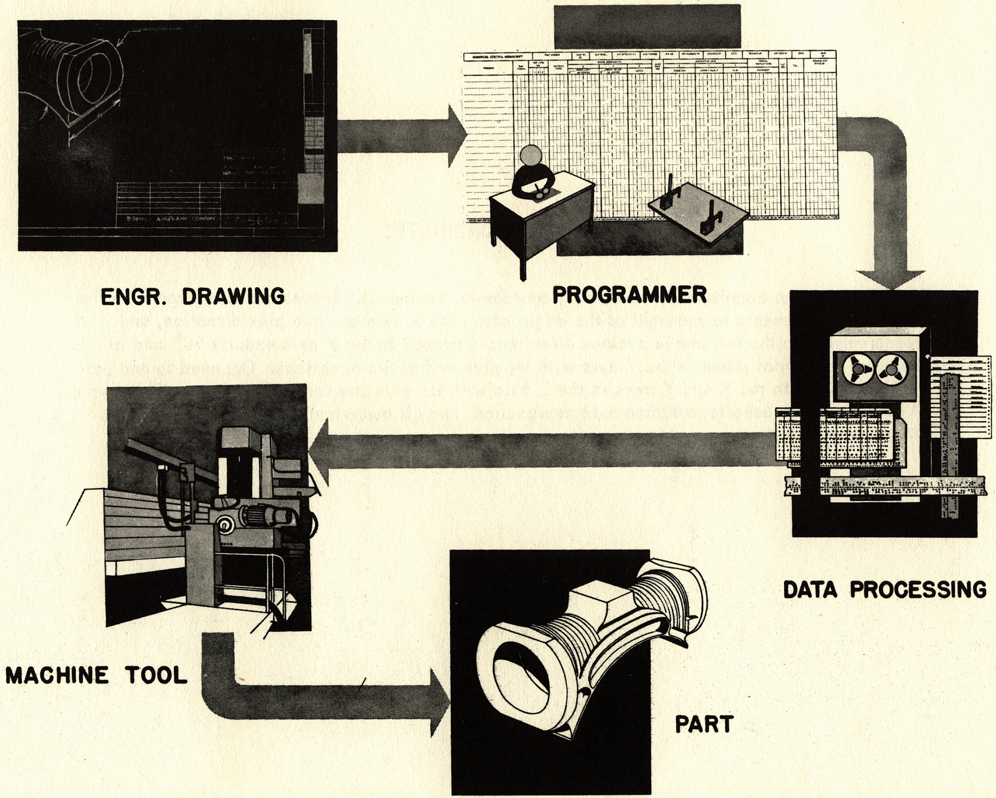
VIII. Selecting the Numerical Control Machine Tool
   A. Determine your costs
   B. Determine types of machines needed
   C. Compare N/C with conventional methods
   D. Spare requirements
   E. Cost comparisons
   F. Future requirements

IX. Question and Answer Period

BASIC AREAS OF NUMERICAL CONTROL

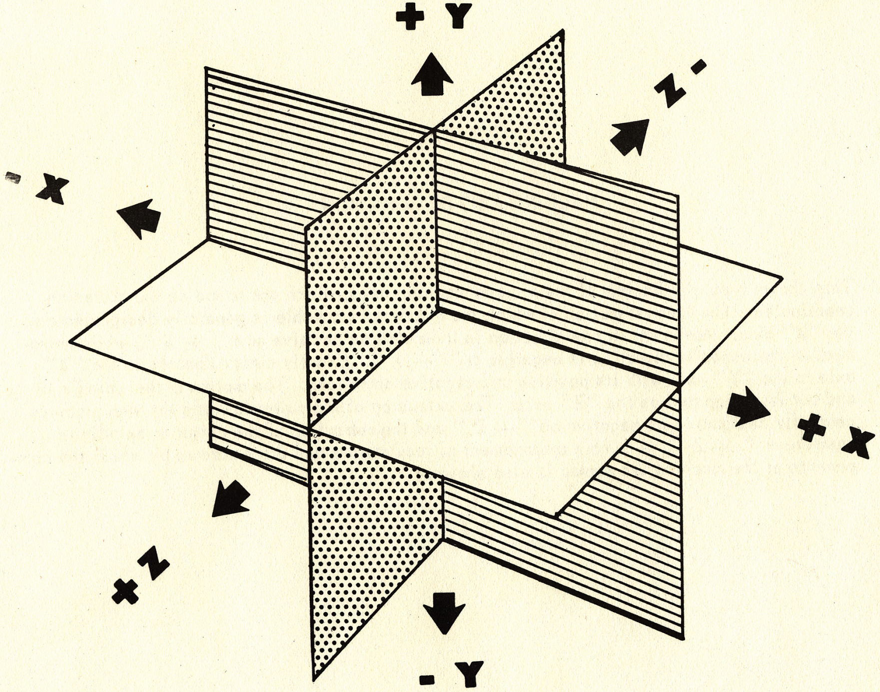
The basic areas through which the engineering design information passes from the original drawing to the finished part are depicted here. First the drawing is routed to the programmer who translates the information into a language suitable for the data processing equipment. From the data processing (which would include converting the programmer's information into punched cards, punched tape or magnetic tape), the information contained in engineering design in its final form goes to the machine tool where the part is made.

BASIC AREAS OF NUMERICAL CONTROL



RECTANGULAR COORDINATES

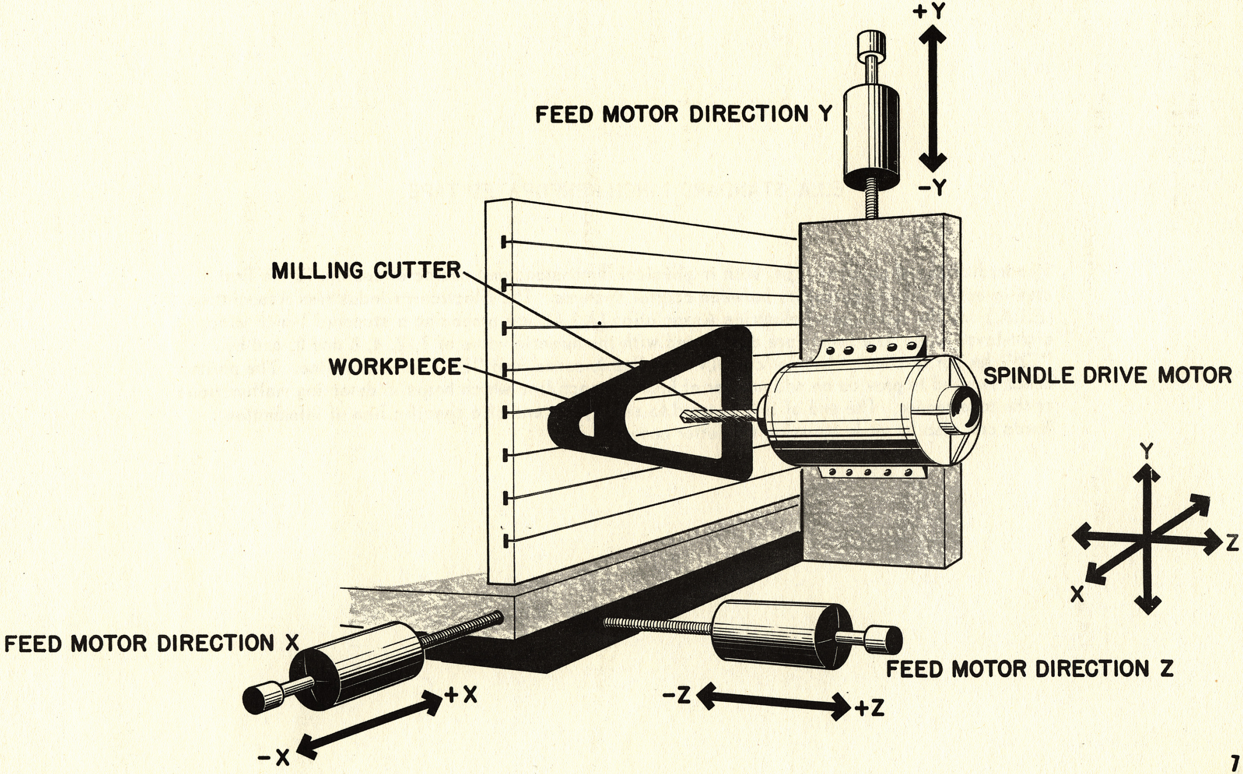
In the rectangular coordinate, or cartesian coordinate, system, all dimensions are given from the origin. Measurements to the right of the origin along the X axis are in a plus direction, and measurements to the left are in a minus direction. Opposed to the X axis exactly 90° and in the same horizontal plane is the Y axis with its plus and minus directions. Opposed to and perpindicular to both the X and Y axes is the Z axis with its plus and minus directions. This system of coordinates is used for machine axis designation, and all numerical control programming is based on this system.


+ Y
- Z
- X
+ X
+ Z
- Y

MACHINE AXIS DESIGNATION

This shows a single diagram of the various machine axes, which are based on the cartesian coordinates. The longest motion of which the machine is capable is generally designated as the "X" axis. Movement in one direction is indicated as positive or a " + X ", while movement in the opposite direction is negative or " — X ". Exactly ninety degrees to the "X" axis is the "Y" axis with its positive and negative directions. The motion of the spindle in and out is designated as the "Z" axis. The extension of the cutter towards the workpiece is generally designated as negative or " — Z " and the retraction of the cutter or spindle is positive or " + Z ". A simple arrangement of feed motors and drive screws by which the components of the machine are moved is also shown.

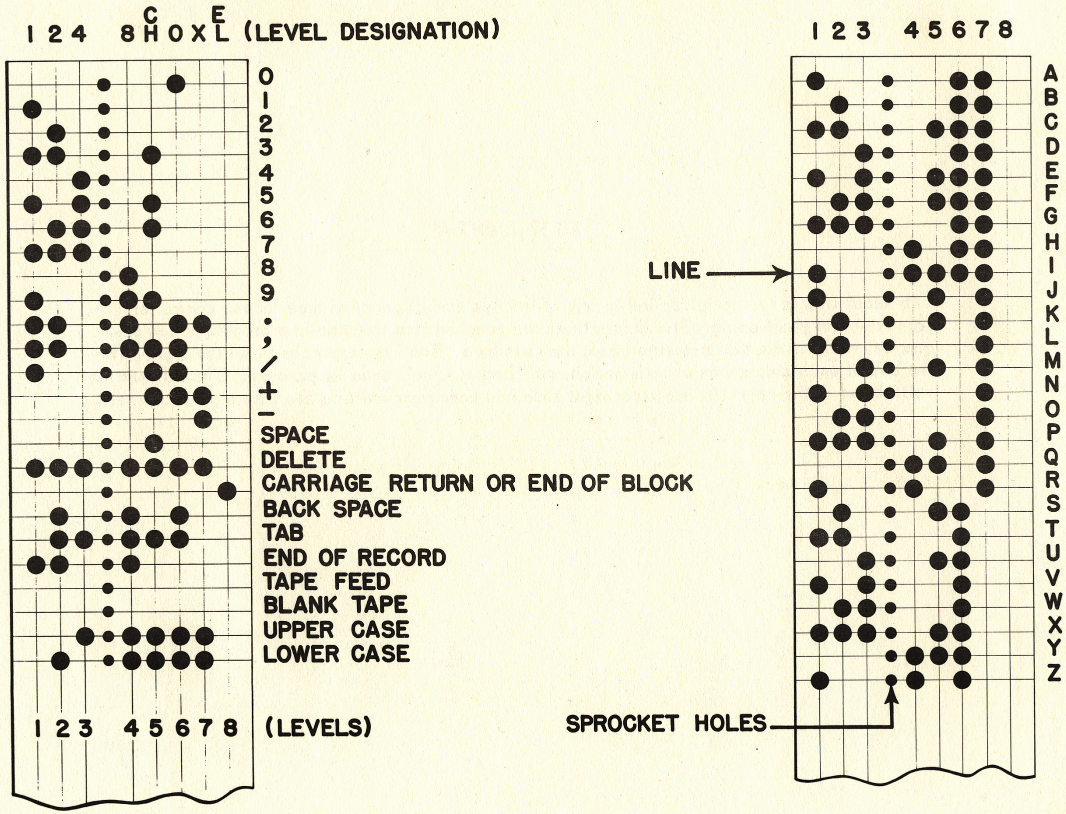
MACHINE AXIS DESIGNATION



E.I.A. STANDARD 1 INCH PERFORATED TAPE

Standardization of punched tape, both in physical dimensions and character coding, is the first step in achieving compatability between control systems. The Electronics Industries Association (E.I.A.) and the Aerospace Industries Association (A.I.A.) are proposing a standard 1-inch wide, eight-level tape. The levels are designated with the numeric value of 1, 2, 4, 8 and 0, and by "CH" for parity check, "X" for certain so-called X-codes, and "EL" for end of line. The parity check is used to provide an odd number of holes in each line which helps in detecting malfunctions at the tape reader. The end of line is used to signify the end of a specific line of information. Words can also be made by using the letter codes.

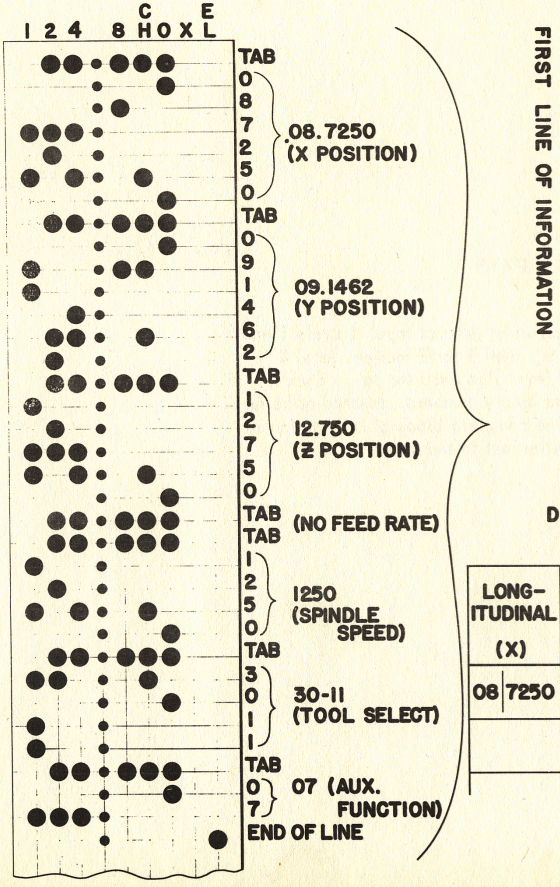
E.I.A. STANDARD 1 INCH PERFORATED TAPE

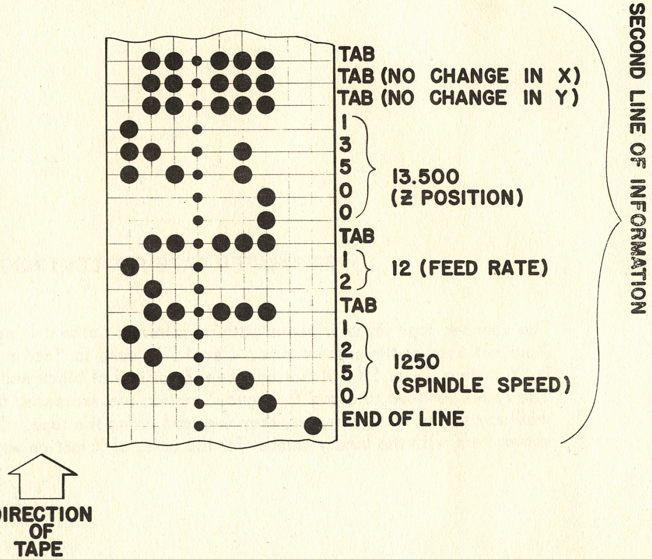


TAB SEQUENTIAL

Tab sequential is the name applied to one of the systems of punched tape for the control of point-to-point positioning. The instructions are punched into the tape in a predetermined sequence, each instruction separated from the next by a "Tab" code punched into the tape. At the end of each single line of information, an "End of Line" code is punched. The information written out in the chart in the lower right side has been punched into the tape reproduced here.

TAB SEQUENTIAL



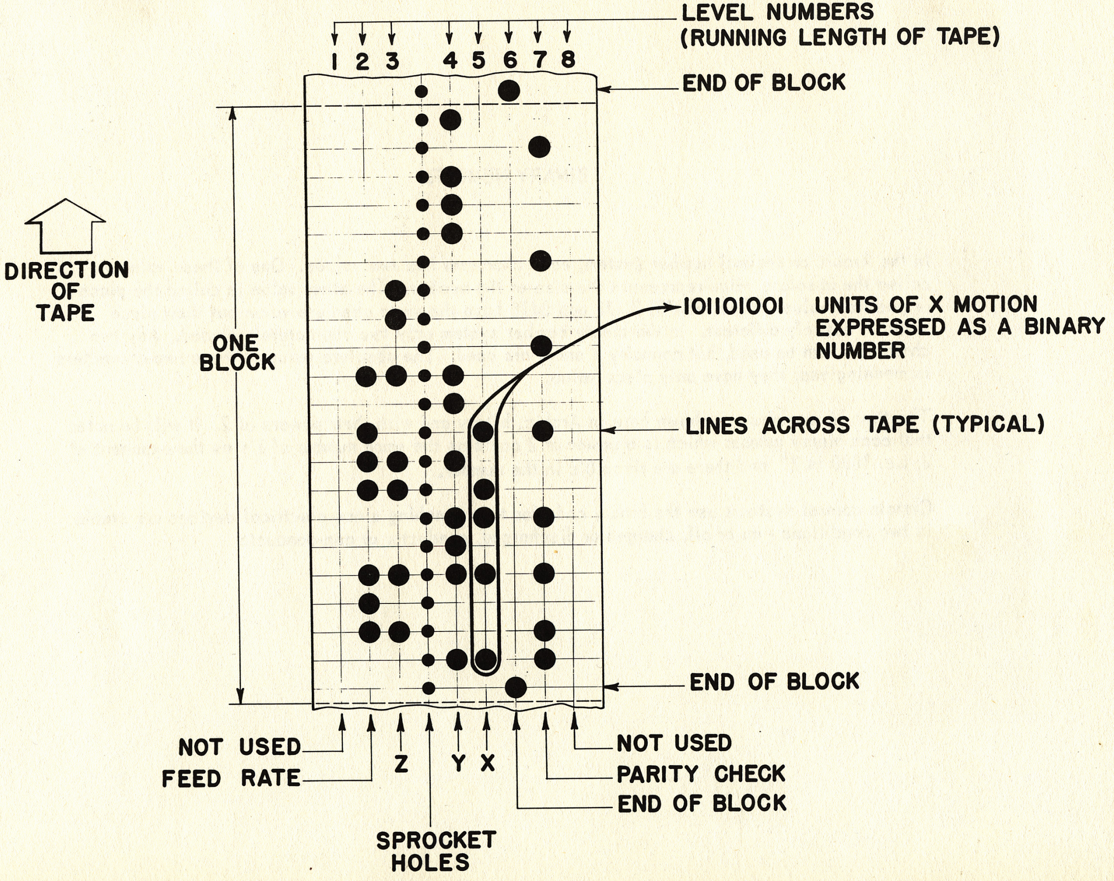


LONG-ITUDINAL (X)	VERTICAL (Y)	DEPTH (Z)	FEED RATE	SPINDLE SPEED	TOOL GROUP	TOOL NO.	AUX. FUNCT.	INDEX	SLOPE AND ARC START	SLOPE AND ARC END	SLOPE AND ARC RADIUS	SLOPE AND ARC DIR.
08 | 7250	09 | 1462	12 | 750		1250	30	11	07					
		13 | 500	12	1250								

PERFORATED TAPE FOR CONTINUOUS PATH

The punched tape for continuous path machining is also a 1-inch wide, 8-level tape. Levels 1 and 8 are not used at the present time. Level 2 is used for feed rate, level 3 for Z motion, level 4 for Y motion, level 5 for X motion, level 6 for end of block and level 7 is used for parity check. The codes for feed rate and X, Y and Z motion are expressed as binary numbers. Instead of being read across the tape, however, they are read along the tape. One complete block of information is shown here with the binary number for the units of X motion written out to the side.

PERFORATED TAPE FOR CONTINUOUS PATH



BINARY NUMBERS

In the Arabic or decimal number system, each character has two values. One of these values-called the absolute value-represents the size of the number. The other value is called the place or position value. Thus .03478, 3.478 and 3478 have the same absolute value but their place value is entirely different. In the binary number system only two characters are used. Any two characters can be used, but normally 1 and 0 are used. The absolute value of these two characters is meaningless; they have only place value.

The first 16 numbers are shown here in Arabic, binary and with their powers of 2. It will be noted that each binary number which is a power of 2 contains the same number of 0's as the exponent of 2; i.e. 1000 is 2^3 and there are three 0's in the number.

Certain control systems use the binary code for tape punching since electrical devices are stable in two conditions - on or off, charged or discharged, conductor or non-conductor.

BINARY NUMBERS

ARABIC	BINARY	POWERS OF 2
0	0	
1	1	2^0
2	10	2^1
3	11	
4	100	2
5	101	
6	110	
7	111	
8	1000	2^3
9	1001	
10	1010	
11	1011	
12	1100	
13	1101	
14	1110	
15	1111	
16	10000	2^4

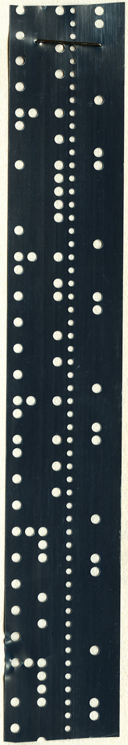
$$
\begin{aligned}
3 \times 10^3 &= 3000\\
4 \times 10^2 &= 400\\
7 \times 10^1 &= 70\\
8 \times 10^0 &= \underline{8}\\
3478 \longleftrightarrow &\ 3478
\end{aligned}
$$

$$
\begin{aligned}
1 \times 2^6 &= 64\\
1 \times 2^5 &= 32\\
0 \times 2^4 &= 0\\
1 \times 2^3 &= 8\\
0 \times 2^2 &= 0\\
0 \times 2^1 &= 0\\
1 \times 2^0 &= \underline{1}\\
1101001 \longleftrightarrow &\ 105
\end{aligned}
$$

	BINARY		ARABIC
	101	=	5
ADD	11	=	3
	1000	=	8

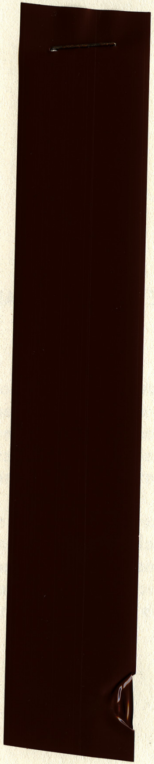
SAMPLES OF TAPE

The control units on the various numerical control machines require one or another of these types of tape for the operation of the machine tool. Some systems for continuous path machining require a magnetic tape as the machine is equipped only with a tape reader. Others use a punched tape and have a machine control unit to produce the analog signals required for continuous control of the cutter. Punched tapes or punched cards are generally used for all point to point positioning.

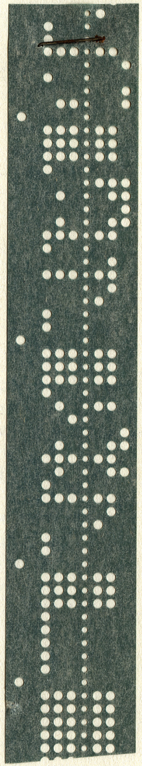


18/1000

PUNCHED TAPE FOR
CONTINUOUS PATH
MACHINE TOOL



MAGNETIC TAPE FOR
CONTINUOUS PATH
MACHINE TOOL



3/1000

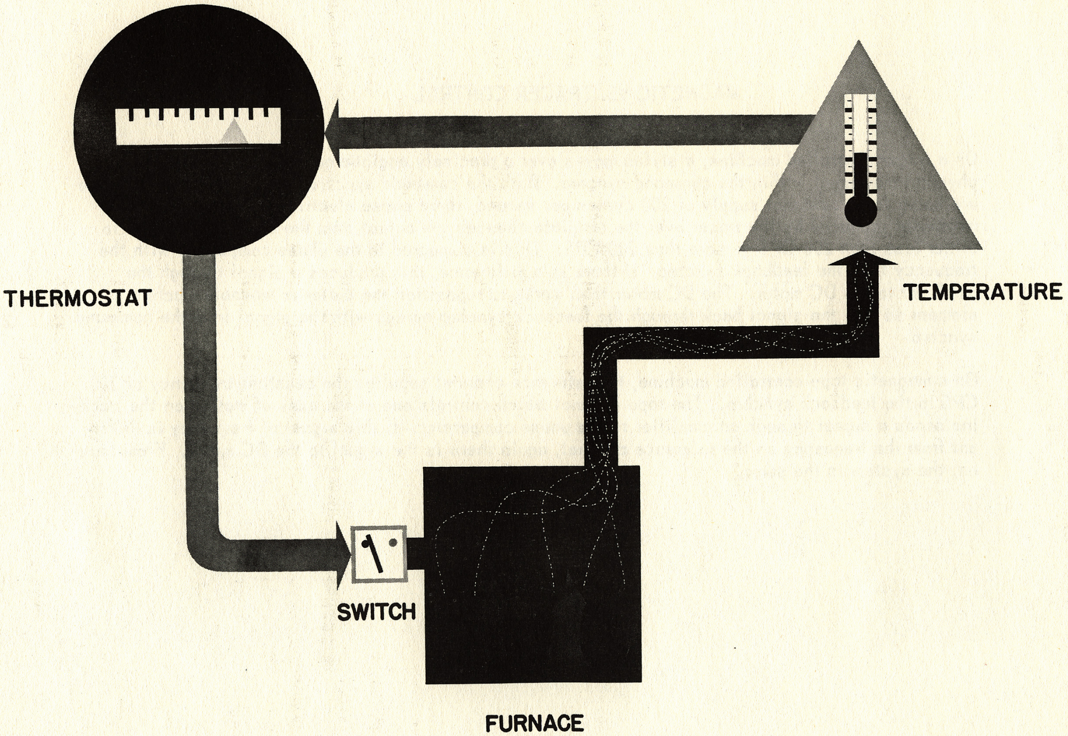
PUNCHED TAPE FOR POINT
TO POINT POSITIONING
MACHINE TOOL

SIMPLE SERVO MECHANISM

The principle of the simple servo is shown by the thermostat, thermometer and the furnace. This particular arrangement is an example of a closed loop servo. The thermostat is set at a predetermined temperature; and when the room temperature, as indicated by the thermometer, falls below this setting, an electrical circuit is closed through the switch to turn on the furnace. As the temperature in the room rises, the thermostat senses this and turns off the furnace.

This same principle is utilized by the servo mechanism on the machine tool to keep continually adjusting the position of the cutter. It electronically senses a difference between the actual position of the cutter and the desired position just as the thermostat senses a difference between the desired temperature and the actual temperature. As the cutter reaches the desired position, the signal is nullified and this one condition has been satisfied.

SIMPLE SERVO MECHANISM

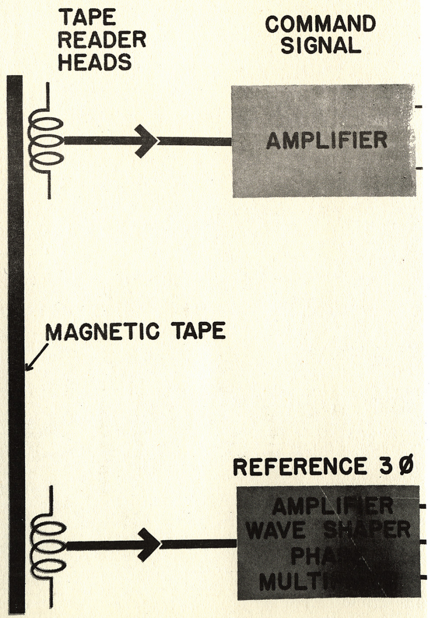


MAGNETIC VS. TRACER CONTROL

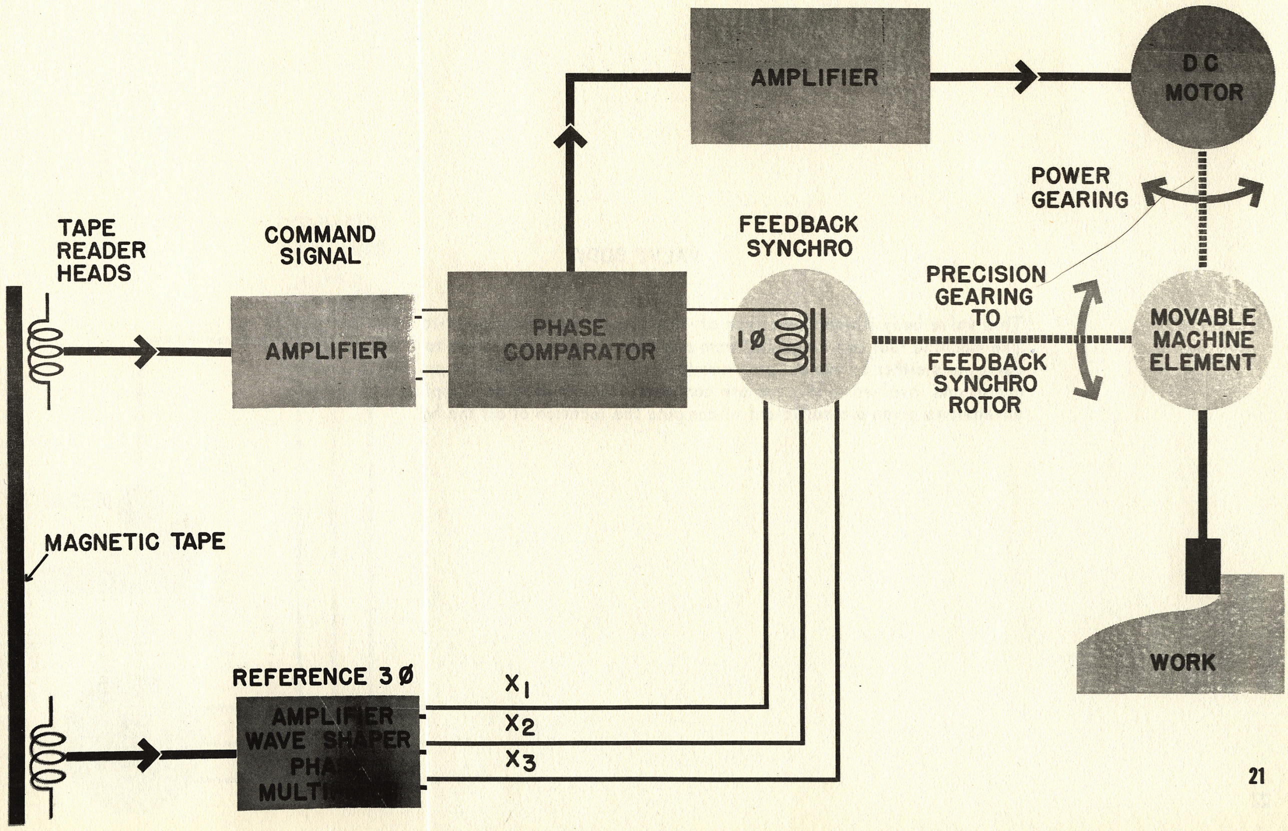
On a tracer controlled machine, a stylus moves over a precisely engineered template to produce a physical movement within the command synchro. Both the command synchro and the feedback synchro are being fed a constant supply of 200 cycles per second, three phase electricity. The physical movement produced by the tracer over the template changes the output from the command synchro to either less than 200 CPS or more than 200 CPS. This is compared in the phase comparator with the frequency from the feedback synchro. If there is a difference, this produces a signal through the amplifier to the DC motor. The DC motor then works to reposition the cutter or movable machine element so that the signal back through the feedback synchro agrees with the signal from the command synchro.

On a magnetic tape controlled machine, the reference channel supplies the constant frequency of 200 CPS to the feedback synchro. The tape channel which controls one of the axes of motion on the machine sends a signal through an amplifier to the phase comparator. If this signal or frequency is different from the frequency on the reference channel, again there is the signal to the DC motor. From here on, the system is the same.

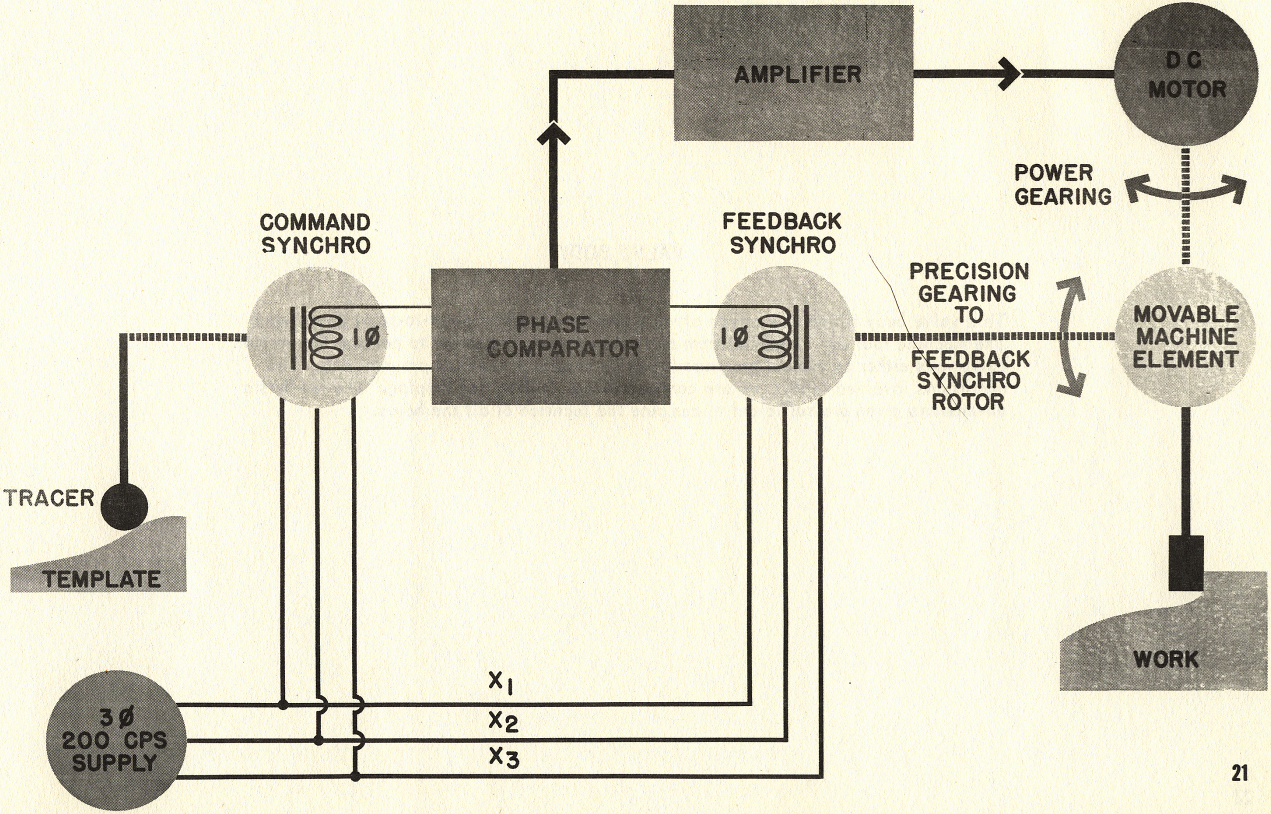
MAGNETIC


TAPE
READER
HEADS
COMMAND
SIGNAL
AMPLIFIER
MAGNETIC TAPE
REFERENCE 3 Ø
WAVE SHAPER

MAGNETIC CONTROL



TRACER CONTROL

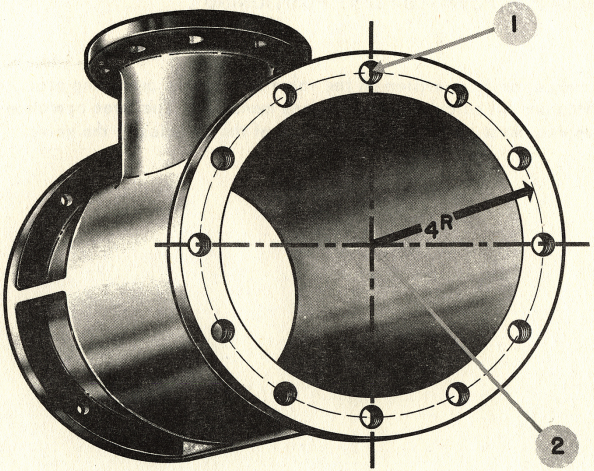


VALVE BODY

This valve body illustrates a type of work ideally suited for point-to-point positioning. The machine tool can be guided from one hole location to another to perform the various operations either by manual programming or by computer-assisted programming. The operations involved in this job are center-drilling, drilling and tapping. The few basic dimensions given are sufficient to compute the location of all the holes.

VALVE BODY

PT	X	Y	Z
1	8.0	12.0	1.0
2	8.0	8.0	1.0



MANUAL PROGRAM FOR POINT-TO-POINT POSITIONING

This is a reproduction of the manual program written on the valve body on the preceding page. Its 115 entries were hand written and all calculations were done manually. The three operations, center drilling, drilling and tapping, must be written out for each of the 12 holes in the valve body.

MANUAL PROGRAM FOR POINT TO POINT POSITIONING

NUMERICAL CONTROL PROCESS PLANNING SHEET

PART NO.	MODEL	EFF.	MCR NO.	ADCN	PLANNER	DATE	REV. BY	DATE	TAPE	PAGE
					CHECKER	DATE	CHECKER	DATE	1	1 OF 10

SEQ. NO.	OPERATION AND TOOL	DWG. PTS.	TIME	LONGITUDINAL (X)	VERTICAL (Y)	DEPTH (Z)	FEED RATE	SPINDLE SPEED	TOOL GROUP	TOOL NO.	AUX. FUNCT.	INDEX	SLOPE AND ARC START	END	RADIUS	DIR.
1	SELECT TOOL - CENTER DRILL-"A" DIM = 3.375- SPINDLE ROTATION CW			00 0000	12 0000	00 000			21	03	02	4				
2	TRANSFER TOOL										05					
3	FLOOD COOLANT ON POSITION # 1			12 0000	12 0000	00 000		1200			07					
4	POSITIONED IN Z TO CENTER DRILL					08 375		1200								
5	SELECT TOOL CENTER DRILL					08 775	08	1200	02	12						
6	RETRACT					08 375		1200								
7	POSITION # 2			14 0000	11 4641			1200								
8	CENTER DRILL					08 775	08	1200								
9	RETRACT					08 375		1200								
10	POSITION # 3			15 4641	10 0000			1200								
11	CENTER DRILL					08 775	08	1200								
12	RETRACT					08 375		1200								

NUMERICAL CONTROL PROCESS PLANNING SHEET

PART NO.	MODEL	EFF.	MCR NO.	ADCN	PLANNER	DATE	REV. BY	DATE	TAPE	PAGE 2
					CHECKER	DATE	CHECKER	DATE		OF

SEQ. NO.	OPERATION AND TOOL	DWG. PTS.	TIME	LONGITUDINAL (X)	VERTICAL (Y)	DEPTH (Z)	FEED RATE	SPINDLE SPEED	TOOL GROUP	TOOL NO.	AUX. FUNCT.	INDEX	SLOPE AND ARC START	END	RADIUS	DIR.
13	POSITION # 4			16 0000	08 0000			1200								
14	CENTER DRILL					08 775	08	1200								
15	RETRACT					08 375		1200								
16	POSITION # 5			15 4641	06 0000			1200								
17	CENTER DRILL					08 775	08	1200								
18	RETRACT					08 375		1200								
19	POSITION # 6			14 0000	04 5359			1200								
20	CENTER DRILL					08 775	08	1200								
21	RETRACT					08 375		1200								
22	POSITION # 7			12 0000	04 0000			1200								
23	CENTER DRILL					08 775	08	1200								
24	RETRACT					08 375		1200								

NUMERICAL CONTROL PROCESS PLANNING SHEET

PART NO.	MODEL	EFF.	MCR NO.	ADCN	PLANNER	DATE	REV. BY	DATE	TAPE	PAGE 3 OF
					CHECKER	DATE	CHECKER	DATE		

SEQ. NO.	OPERATION AND TOOL	DWG. PTS.	TIME	LONGITUDINAL (X)	VERTICAL (Y)	DEPTH (Z)	FEED RATE	SPINDLE SPEED	TOOL GROUP	TOOL NO.	AUX. FUNCT.	INDEX	SLOPE AND ARC START	SLOPE AND ARC END	SLOPE AND ARC RADIUS	SLOPE AND ARC DIR.
25	POSITION #8			10 0000	04 5359			1200								
26	CENTER DRILL					08 775	08	1200								
27	RETRACT					08 375		1200								
28	POSITION #9			08 5359	06 0000			1200								
29	CENTER DRILL					08 775	08	1200								
30	RETRACT					08 375		1200								
31	POSITION #10			08 0000	08 0000			1200								
32	CENTER DRILL					08 775	08	1200								
33	RETRACT					08 375		1200								
34	POSITION #11			08 5359	10 0000			1200								
35	CENTER DRILL					08 775	08	1200								
36	RETRACT					08 375		1200								

NUMERICAL CONTROL **PROCESS PLANNING SHEET**

PART NO.	MODEL	EFF.	MCR NO.	ADCN	PLANNER	DATE	REV. BY	DATE	TAPE	PAGE 4 OF
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SEQ. NO.	OPERATION AND TOOL	DWG. PTS.	TIME	LONGITUDINAL (X)	VERTICAL (Y)	DEPTH (Z)	FEED RATE	SPINDLE SPEED	TOOL GROUP	TOOL NO.	AUX. FUNCT.	INDEX	SLOPE AND ARC START	END	RADIUS	DIR.
37	POSITION #12			10 0000	11 4641			1200								
38	CENTER DRILL					08 775	08	1200								
39	TRANSFER TOOL RETRACT					00 000					05					
40	DRILL-"A" DIM. = 5.0 POSITION #1			12 0000	12 0000	00 000		1200								
41	POSITIONED IN Z TO DRILL					06 750		1200								
42	SELECT TOOL DRILL					08 000	08	1200	30	07						
43	RETRACT					06 750		1200								
44	POSITION #2			14 0000	11 4641			1200								
45	DRILL					08 000	08	1200								
46	RETRACT					06 750		1200								
47	POSITION #3			15 4641	10 0000			1200								
48	DRILL					08 000	08	1200								

NUMERICAL CONTROL PROCESS PLANNING SHEET

PART NO.	MODEL	EFF.	MCR NO.	ADCN	PLANNER	DATE	REV. BY	DATE	TAPE	PAGE 5
					CHECKER	DATE	CHECKER	DATE		OF

SEQ. NO.	OPERATION AND TOOL	DWG. PTS.	TIME	LONGITUDINAL (X)	VERTICAL (Y)	DEPTH (Z)	FEED RATE	SPINDLE SPEED	TOOL		AUX. FUNCT.	INDEX	SLOPE AND ARC			
									GROUP	NO.			START	END	RADIUS	DIR.
49	RETRACT					06 750		1200								
50	POSITION # 4			16 0000	08 0000			1200								
51	DRILL					08 000	08	1200								
52	RETRACT					06 750		1200								
53	POSITION # 5			15 4641	06 0000			1200								
54	DRILL					08 000	08	1200								
55	RETRACT					06 750		1200								
56	POSITION # 6			14 0000	04 5359			1200								
57	DRILL					08 000	08	1200								
58	RETRACT					06 750		1200								
59	POSITION # 7			12 0000	04 0000			1200								
60	DRILL					08 000	08	1200								

NUMERICAL CONTROL PROCESS PLANNING SHEET

PART NO.	MODEL	EFF.	MCR NO.	ADCN	PLANNER	DATE	REV. BY	DATE	TAPE	PAGE 6
					CHECKER	DATE	CHECKER	DATE		OF

SEQ. NO.	OPERATION AND TOOL	DWG. PTS.	TIME	LONGITUDINAL (X)	VERTICAL (Y)	DEPTH (Z)	FEED RATE	SPINDLE SPEED	TOOL GROUP	TOOL NO.	AUX. FUNCT.	INDEX	SLOPE AND ARC START	END	RADIUS	DIR.
61	RETRACT					06 750		1200								
62	POSITION # 8			10 0000	04 5359			1200								
63	DRILL					08 000	08	1200								
64	RETRACT					06 750		1200								
65	POSITION # 9			08 5359	06 0000			1200								
66	DRILL					08 000	08	1200								
67	RETRACT					06 750		1200								
68	POSITION # 10			08 0000	08 0000			1200								
69	DRILL					08 000	08	1200								
70	RETRACT					06 750		1200								
71	POSITION # 11			08 5359	10 0000			1200								
72	DRILL					08 000	08	1200								

NUMERICAL CONTROL PROCESS PLANNING SHEET

PART NO.	MODEL	EFF.	MCR NO.	ADCN	PLANNER	DATE	REV. BY	DATE	TAPE	PAGE 7
					CHECKER	DATE	CHECKER	DATE		OF

SEQ. NO.	OPERATION AND TOOL	DWG. PTS.	TIME	LONGITUDINAL (X)	VERTICAL (Y)	DEPTH (Z)	FEED RATE	SPINDLE SPEED	TOOL GROUP	TOOL NO.	AUX. FUNCT.	INDEX	SLOPE AND ARC START	SLOPE AND ARC END	SLOPE AND ARC RADIUS	SLOPE AND ARC DIR.
73	RETRACT					06 750		1200								
74	POSITION #12			10 0000	11 4641			1200								
75	DRILL					08 000	08	1200								
76	TRANSFER TOOL RETRACT					00 000					05					
77	TAP-"A" DIM.=7.50 POSITION #1			12 0000	12 0000	00 000		0200								
78	POSITIONED IN Z TO TAP					04 250		0200								
79	TAP					05 750	11	0200								
80	SPINDLE ROTATION CC RETRACT					04 250	10	0200			03					
81	SPINDLE ROTATION CW POSITION #2			14 0000	11 4641			0200			02					
82	TAP					05 750	11	0200								
83	RETRACT					04 250	10	0200			03					
84	POSITION #3			15 4641	10 0000			0200			02					

NUMERICAL CONTROL PROCESS PLANNING SHEET

PART NO.	MODEL	EFF.	MCR NO.	ADCN	PLANNER	DATE	REV. BY	DATE	TAPE	PAGE 8 OF
					CHECKER	DATE	CHECKER	DATE		

SEQ. NO.	OPERATION AND TOOL	DWG. PTS.	TIME	LONGITUDINAL (X)	VERTICAL (Y)	DEPTH (Z)	FEED RATE	SPINDLE SPEED	TOOL GROUP	TOOL NO.	AUX. FUNCT.	INDEX	SLOPE AND ARC START	END	RADIUS	DIR.
85	TAP					05 750	11	0200								
86	RETRACT					04 250	10	0200			03					
87	POSITION #4			16 0000	08 0000			0200			02					
88	TAP					05 750	11	0200								
89	RETRACT					04 250	10	0200			03					
90	POSITION #5			15 4641	06 0000			0200			02					
91	TAP					05 750	11	0200								
92	RETRACT					04 250	10	0200			03					
93	POSITION #6			14 0000	04 5359			0200			02					
94	TAP					05 750	11	0200								
95	RETRACT					04 250	10	0200			03					
96	POSITION #7			12 0000	04 0000			0200			02					

NUMERICAL CONTROL PROCESS PLANNING SHEET

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					CHECKER	DATE	CHECKER	DATE		OF

SEQ. NO.	OPERATION AND TOOL	DWG. PTS.	TIME	LONGITUDINAL (X)	VERTICAL (Y)	DEPTH (Z)	FEED RATE	SPINDLE SPEED	TOOL GROUP	TOOL NO.	AUX. FUNCT.	INDEX	SLOPE AND ARC START	END	RADIUS	DIR.
97	TAP					05 750	11	0200								
98	RETRACT					04 250	10	0200			03					
99	POSITION #8			10 0000	04 5359			0200			02					
100	TAP					05 750	11	0200								
101	RETRACT					04 250	10	0200			03					
102	POSITION #9			08 5359	06 0000			0200			02					
103	TAP					05 750	11	0200								
104	RETRACT					04 250	10	0200			03					
105	POSITION #10			08 0000	08 0000			0200			02					
106	TAP					05 750	11	0200								
107	RETRACT					04 250	10	0200			03					
108	POSITION #11			08 5359	10 0000			0200			02					

NOTES

NUMERICAL CONTROL PROCESS PLANNING SHEET

PART NO.	MODEL	EFF.	MCR NO.	ADCN	PLANNER	DATE	REV. BY	DATE	TAPE	PAGE 10
					CHECKER	DATE	CHECKER	DATE		OF

SEQ. NO.	OPERATION AND TOOL	DWG. PTS.	TIME	LONGITUDINAL (X)	VERTICAL (Y)	DEPTH (Z)	FEED RATE	SPINDLE SPEED	TOOL GROUP	TOOL NO.	AUX. FUNCT.	INDEX	SLOPE AND ARC START	SLOPE AND ARC END	SLOPE AND ARC RADIUS	SLOPE AND ARC DIR.
109	TAP					05 750	11	0200								
110	RETRACT					04 250	10	0200			03					
111	POSITION # 12			10 0000	11 4641			0200			02					
112	TAP					05 750	11	0200								
113	RETRACT					04 250	10	0200			03					
114	RETURN					00 000					04	0				
115	END OF TAPE										09					

COMPUTER ASSIST PROGRAM FOR POINT-TO-POINT POSITIONING

This is a reproduction of the computer assist program manuscript written on the same valve body that was used for the manual program. 21 entries will produce exactly the same results that required 115 entries on the manual program.

COMPUTER - ASSIST PROGRAM FOR POINT TO POINT POSITIONING

NUMERICAL CONTROL MANUSCRIPT POSITIONING SYSTEM	PART NUMBER	TAPE NO.	A/P MODEL	A/P EFFECTIVITY	ENG. CHANGE	W.O. NO.	PROGRAMMED BY	CHECKED BY	DATE	REVISED BY	CHECKED BY	DATE	PAGE
		1 OF 1											1 OF 1

REMARKS	DWG. POINTS	IBM CARD NO.	INSTRUCTIONS	TOOL TYP. CALC. NO. / COOL.	ENDING COORDINATES X	ENDING COORDINATES Y	ENDING COORDINATES Z	DEPTH / CLEAR / "A" TOOL SETTING	FEED RATE IPM	SPINDLE SPEED / TOOL CODE	DESCRIPTIVE DATA X	DESCRIPTIVE DATA Y / CENTER DRILL TIP LENGTH	DIA	TABLE INDEX / CIR. RAD. / TOOL ANGLE / TAP PITCH	CW / CC	REASON FOR REVISION
		1	MACH											P.A		
		2	PT 1		8.0	12.0	1.0									
		3	PT 2		8.0	8.0	1.0									
		4	CTRDL	1				3.375		2103		.109	.109	120	CW	
		5	DRILL	2				5.0		0212			.203	118	CW	
		6	TAP	3				7.5		3007				20	CW	
		7	SETPT		8.0	-2.0	-6.0									
		8	CLEAR					.125								
		9	TYP	1	PT 1						PT 2					
		10			PT 1			1.0					.250			
		11	CALC	12							PT 2			4.0	CW	
		12	ENTYP													
		13	INDEX											4		
		14	ONKUL	F												
		15	CUTR	1												
CENTER DRILL		16	RPTYP	1	PT 1				8	1200	PT 2					
		17	CUTR	2												
DRILL		18	RPTYP	1	PT 1				8	1200	PT 2					
		19	CUTR	3												
TAP		20	RPTYP	1	PT 1			.125		200	PT 2					
		21	END													

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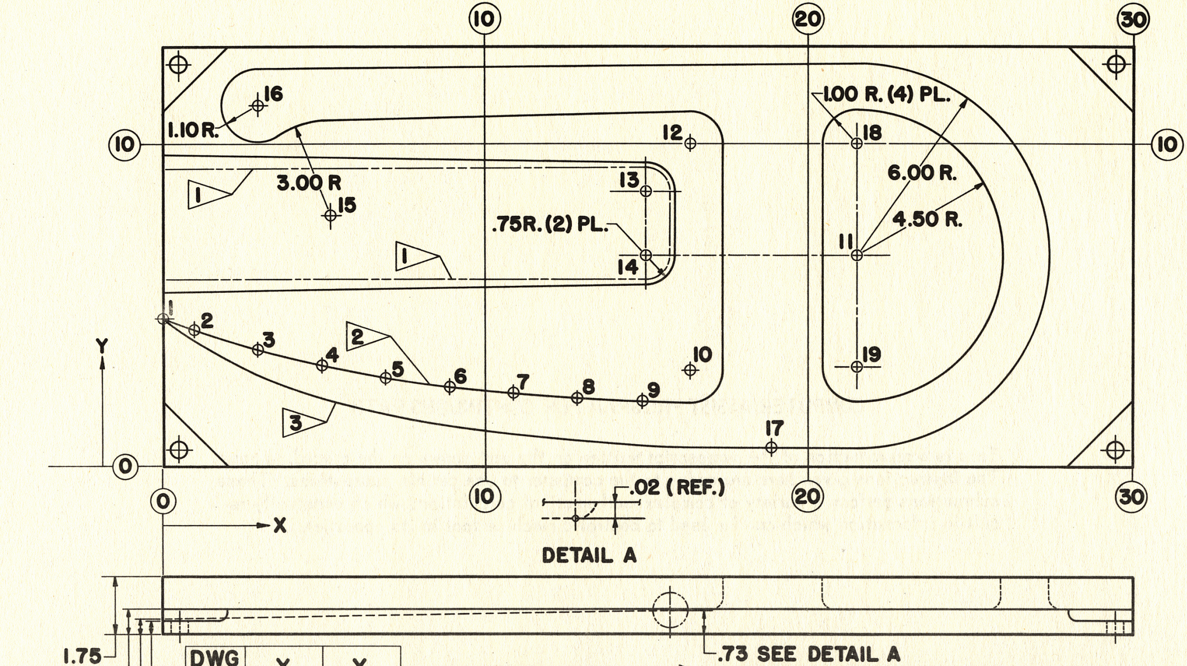
THE PART DRAWING

This is a reproduction of the drawing of the part which was programmed for continuous path or three-dimensional milling using a computer assisted program. The actual program manuscript which was written about this part is shown in the brochure under the title "Continuous Path Program".



DWG PT.	X	Y
1	0.	4.626
2	1.	4.24
3	3.	3.66
4	5.	3.18
5	7.	2.78
6	9.	2.48
7	11.	2.3
8	13.	2.14
9	15.	2.06
10	16.45	3.
11	21.55	6.5
12	16.55	9.956
13	15.	8.5
14	15.	6.5
15	5.281	7.843
16	3.	11.25
17	18.5	.5
18	21.55	10.
19	21.55	3.

1 STRAIGHT LINE TRACE OF TANGENT POINT

2 SMOOTH CURVE FROM POINT 1 TO 9

3 EQUATION OF ELLIPTICAL CURVE

$$\frac{(X-h)^2}{A^2} + \frac{(Y-K)^2}{B^2} = 1.0$$

VALUES OF K = 6.5
B = 6.0
A = 20.0
h = 19.0

ALL FILLET RADII .375 EXCEPT AS NOTED

COMPUTER ASSIST PROGRAM FOR CONTINUOUS PATH

This is a reproduction of the manuscript written on the part shown on the preceding page. The instructions given here are codes to the computer to use certain subroutines. These subroutines perform a variety of complex mathematical calculations which eventually result in information which can be used to control a machine tool in its operation.

COMPUTER - ASSIST PROGRAM FOR CONTINUOUS PATH

NUMERICAL CONTROL MANUSCRIPT	PART NUMBER	TAPE NO. OF	A/P MODEL	A/P EFFECTIVITY	ENG. CHANGE	W.O. NO.	PROGRAMMED BY	CHECKED BY	DATE	REVISED BY	CHECKED BY	DATE	PAGE OF
	NC-1001												1 OF 4

REMARKS	DWG. POINTS	IBM CARD NO.	INSTRUCTIONS	ENDING COORDINATES X RIGHT, LEFT, OR CENTER	ENDING COORDINATES Y ABOVE, BELOW, OR CENTER	ENDING COORDINATES Z DEPTH	FEED RATE IPM	DESCRIPTIVE DATA X DIAMETER	DESCRIPTIVE DATA Y CORNER RADIUS	DESCRIPTIVE DATA Z FLAT	SPECIAL INSTRUCTIONS THICKNESS	CUT. DIR.	TOL.	REASON FOR REVISION
		1	MACH								AA			
		2	CUTR	L	A	0.		1.5	.375	.75	0.			
		3	HEAD								2.			
		4	MODE								4.			
		5	SETPT	36.	0.	.1								
		6	RAISE			1.8	40							
		7	ONKUL											
		8	MOVE	31.1	2.44	1.8								
		9	POKET				10				.7	X		
		10	PLANE					3.	11.25	.75				
		11						3.	3.66	.75				
		12						29.5	6.5	.75				
		13	CLPLN							1.8				
		14	LINE	31.1	14.1		30							
		15	LINE	-1.6	✓									
		16	LINE	✓	-1.5									
		17	LINE	31.1	✓									
		18	LINE	✓	2.44									
		19	MOVE	21.55	.5									
	17	20	LINE	18.5	✓									
	1	21	CONIC	0.	4.626						3.6	CW004		
		22									0.			

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NUMERICAL CONTROL MANUSCRIPT	PART NUMBER	TAPE NO. OF	A/P MODEL	A/P EFFECTIVITY	ENG. CHANGE	W.O. NO.	PROGRAMMED BY	CHECKED BY	DATE	REVISED BY	CHECKED BY	DATE	PAGE OF
	NC-1001												2 OF 4

REMARKS	DWG. POINTS	IBM CARD NO.	INSTRUCTIONS	ENDING COORDINATES X RIGHT, LEFT, OR CENTER	ENDING COORDINATES Y ABOVE, BELOW, OR CENTER	ENDING COORDINATES Z DEPTH	FEED RATE IPM	DESCRIPTIVE DATA X DIAMETER	DESCRIPTIVE DATA Y CORNER RADIUS	DESCRIPTIVE DATA Z FLAT	SPECIAL INSTRUCTIONS THICKNESS	CUT DIR.	TOL	REASON FOR REVISION
		23									4.			
		24									-136.8			
		25									-520.			
		26									1549.6			
	2	27	CURVE	1.	4.24								004	
	3	28		3.	3.66									
	4	29		5.	3.18									
	5	30		7.	2.78									
	6	31		9.	2.48									
	7	32		11.	2.3									
	8	33		13.	2.14									
	9	34		15.	2.06									
		35	LINE	TANPT										
	10	36	CIR	TANPT				16.45	3.		1.	CC	002	
		37	LINE	TANPT										
	12	38	CIR	TANPT				16.55	9.956		1.	CC	002	
		39	LINE	TANPT										
	15	40	CIR	TANPT				5.281	7.843		3.	CC	004	
	16	41	CIR	TANPT				3.	11.25		1.1	CW	002	
		42	LINE	TANPT										
	11	43	CIR	21.55	.5			21.55	6.5		6.	CW	004	
		44	CLEAN											

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NUMERICAL CONTROL MANUSCRIPT	PART NUMBER NC-1001	TAPE NO. OF	A/P MODEL	A/P EFFECTIVITY	ENG. CHANGE	W.O. NO.	PROGRAMMED BY	CHECKED BY	DATE	REVISED BY	CHECKED BY	DATE	PAGE 3 OF 4

REMARKS	DWG. POINTS	IBM CARD NO.	INSTRUCTIONS	ENDING COORDINATES X: RIGHT, LEFT, OR CENTER	ENDING COORDINATES Y: ABOVE, BELOW, OR CENTER	ENDING COORDINATES Z: DEPTH	FEED RATE IPM	DESCRIPTIVE DATA X: DIAMETER	DESCRIPTIVE DATA Y: CORNER RADIUS	DESCRIPTIVE DATA Z: FLAT	SPECIAL INSTRUCTIONS: THICKNESS	CUT DIR.	TOL	REASON FOR REVISION
		45	MOVE	20.55	6.5	1.8	40							
		46	POKET				10				.7	Y		
		47	PLANE					3.	11.25	.75				
		48						3.	3.66	.75				
		49						29.5	6.5	.75				
		50	CLPLN							1.8				
		51	LINE	TANPT			30							
	19	52	CIR	TANPT				21.55	3.		1.	CC	002	
	11	53	CIR	TANPT				21.55	6.5		4.5	CC	004	
	18	54	CIR	TANPT				21.55	10.		1.	CC	002	
		55	LINE	20.55	6.5									
		56	CLEAN											
		57	MOVE	0.	7.38	1.8	40							
		58	CUTR					.75	.375	.75				
		59	MOVE	1.6	7.38	1.8								
		60	POKET				10				.7	X		
		61	PLANE					15.75	8.5	.73				
		62						15.75	6.5	.73				
		63						0.	7.38	.45				
		64	CLPLN							1.8				
		65	LINE	1.6	5.75		30							
		66	LINE	15.	⊥									

BOEING AIRPLANE COMPANY

NOTES

NUMERICAL CONTROL MANUSCRIPT	PART NUMBER	TAPE NO. OF	A/P MODEL	A/P EFFECTIVITY	ENG. CHANGE	W.O. NO.	PROGRAMMED BY	CHECKED BY	DATE	REVISED BY	CHECKED BY	DATE	PAGE OF
	NC-1001												4 OF 4

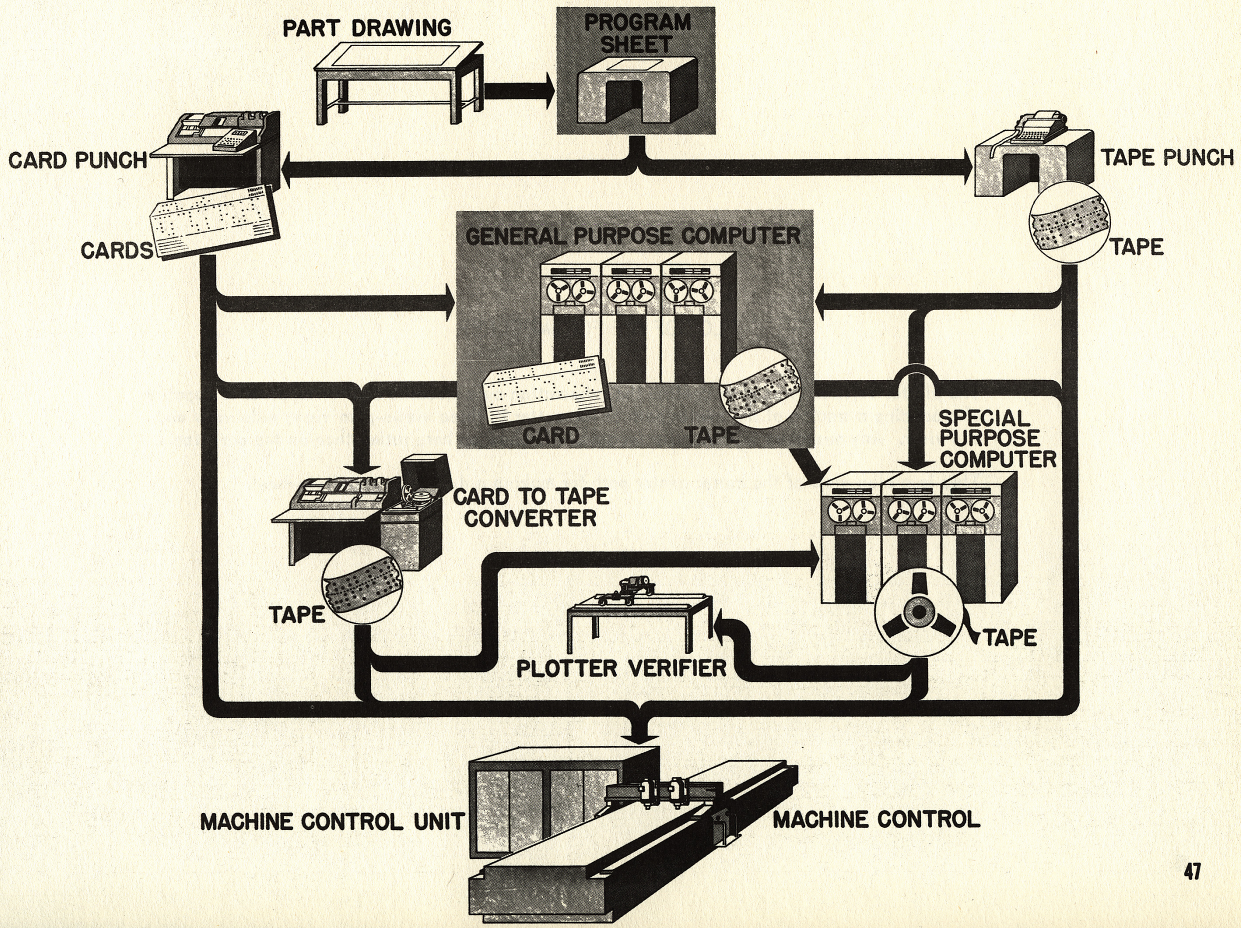
REMARKS	DWG. POINTS	IBM CARD NO.	INSTRUCTIONS	ENDING COORDINATES X RIGHT, LEFT, OR CENTER	ENDING COORDINATES Y ABOVE, BELOW, OR CENTER	ENDING COORDINATES Z DEPTH	FEED RATE IPM	DESCRIPTIVE DATA X DIAMETER	DESCRIPTIVE DATA Y CORNER RADIUS	DESCRIPTIVE DATA Z FLAT	SPECIAL INSTRUCTIONS THICKNESS	CUT. DIR.	TOL.	REASON FOR REVISION
	14	67	CIR	15.75	6.5			15	6.5		.75	CC	001	
		68	LINE	✓	8.5									
	13	69	CIR	TANPT				15	8.5		.75	CC	001	
		70	LINE	- 1.6	9.25									
		71	LINE	✓	7.38									
		72	CLEAN											
		73	OFKUL											
		74	MOVE	36	0	1.8	100							
		75	PLUNG			1	60							
		76	END											

BOEING AIRPLANE COMPANY 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

NUMERICAL CONTROL PROCESS FLOW

This is a composite flow chart showing the variety of ways that the engineering information can be translated from the drawing to the machine. The first step is to prepare a program sheet or manuscript of the information into a language and form acceptable to the system being employed. From here, the information can go either to a card punch or a tape punch machine. From this point on, many different paths are available. The punched cards or tape may go directly to the machine control unit to control the operation of the machine. Or they may go to a general purpose computer and emerge as a new deck of punched cards or a new punched tape with a more comprehensive set of output points. The cards could then go to a card-to-tape converter and thence to the machine control unit, or they could go through a special purpose computer to come out as a magnetic tape to control the machine through a tape reader on the machine. The magnetic tape can also be used to get a three-view picture of the part on the plotter verifier. Other combinations are available, depending upon the control system which is being used.

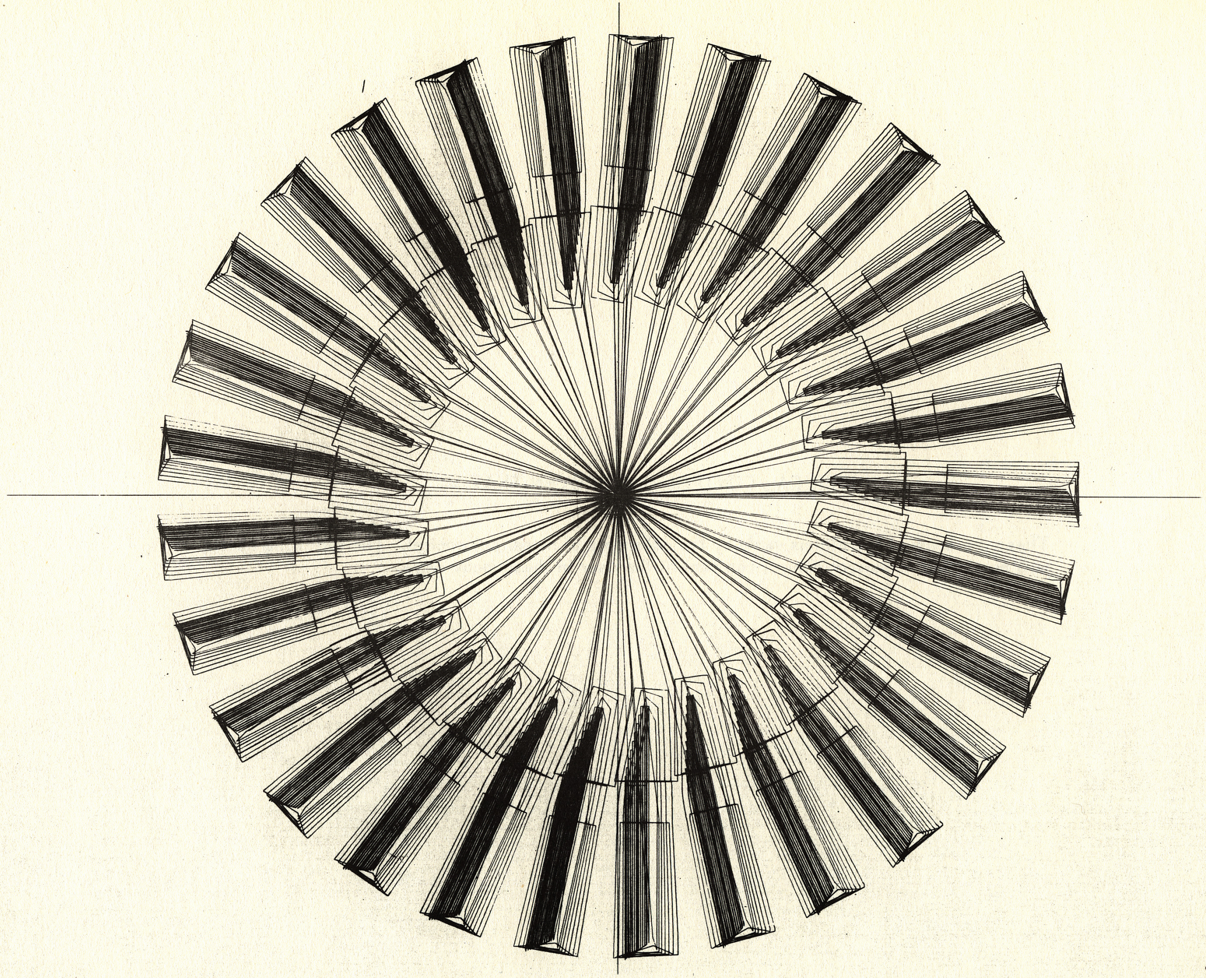
NUMERICAL CONTROL PROCESS FLOW



PLOT OF DIE FOR IMPELLER

The plotter verifier is used to confirm the information on a machine control tape. It is capable of producing a tracing of the center path of the cutter in three views-plan view, side view and end view. Any mistakes in the entire program will show up here rather than on the part itself.

This is a plan view of the cutter center path for making a die for an impeller wheel.



NUMERICAL CONTROL HAS PROVEN THAT —

These are some of the claims made by the adherents of numerical control. The following charts will prove that numerical control can benefit the user in these many ways.

NUMERICAL CONTROL

HAS PROVEN THAT IT CAN____

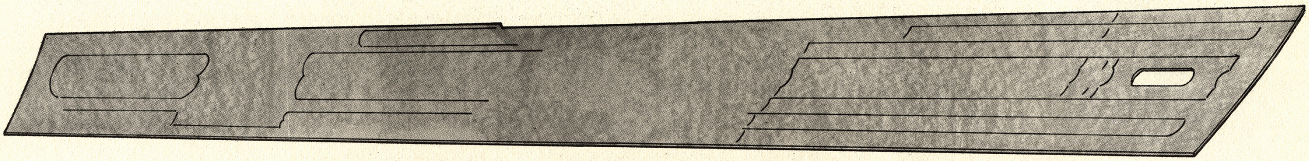
- **INCREASE...**
  - MACHINE RUN TIME EACH DAY
  - FLEXIBILITY
  - ESTIMATING ACCURACY
- **REDUCE...**
  - SET UP TIME
  - LEAD TIME
  - TOOLING COST
  - OPERATING COST
  - FLOOR SPACE REQUIREMENTS
  - MATERIAL HANDLING
  - INVENTORY
  - TOOL STORAGE REQUIREMENTS
- **IMPROVE QUALITY**
- **MAINTAIN CONSTANT MANUFACTURING CAPACITY**
- **PRODUCE ACCURATE DUPLICATION OF ENGINEERING DATA**

INCREASE PRODUCTION

One example of increased production is one of the lower panels on the wing of the B-52G. This panel is 7178-T6 aluminum alloy, approximately 76 feet long and 3 feet wide. By conventional machining methods, it required 20 hours of machine time to sculpture the inner surface. This was reduced to 2½ hours on a numerically controlled mill.

Another example is the chord on the rib where the wing joins the body on the B-52. On a conventional machine, it took 7¾ hours to machine and on a numerically controlled machine, it took only 2¼ hours.

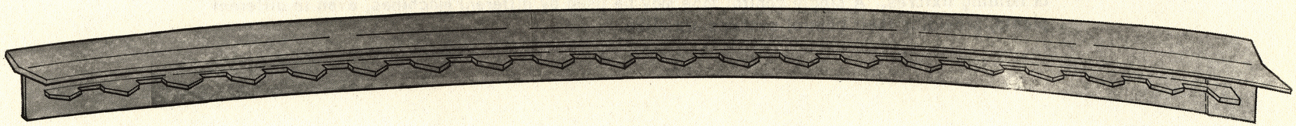
INCREASE PRODUCTION



B-52G LOWER PANEL #3

CONVENTIONAL MACHINE TIME 20 HRS

NUMERICAL CONTROL MACHINE TIME 2 1/2 HRS



B-52 BL 55 RIB

CONVENTIONAL MACHINE TIME 7 3/4 HRS

NUMERICAL CONTROL MACHINE TIME 2 1/4 HRS

FLEXIBILITY

The flexibility of numerical control is based on many things. Because of the ability to perform many different operations on a single numerical controlled machine, the number of setups is reduced. All types of parts can be machined because of the versatility of the machines. Tooling requirements very often consist of a simple vacuum chuck, thereby eliminating expensive tools or holding fixtures. A single control tape may be used by different machines, even in different plants, providing their control systems are alike.

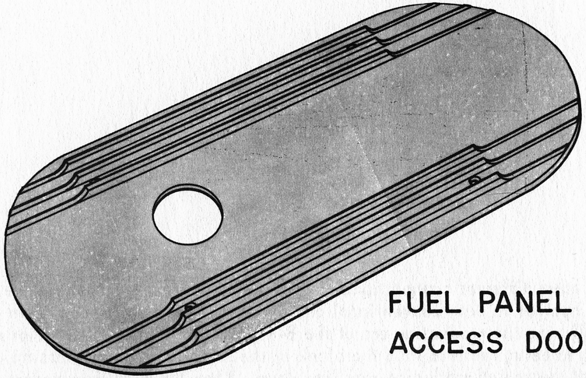
FLEXIBILITY

- CHANGE PART SETUP IN MINUTES
- MACHINE <u>ALL</u> TYPES OF PARTS
- PERFORM SEVERAL OPERATIONS DURING ONE SETUP
- REDUCE TOOLING REQUIREMENTS
- CONTROL TAPES CAN BE EXCHANGED BETWEEN MANY USERS

REDUCE SETUP TIME

The reduction in setup time is possible, not because the time of a single setup is decreased by numerical control but in that the total number of setups required is decreased. This fuel panel access door required two setups for conventional machining plus one handling between the two different machines needed to mill one part. With the numerical control, only one setup on one machine was required to machine four parts which were setup at the same time in one holding fixture.

REDUCE SETUP TIME



FUEL PANEL
ACCESS DOOR

CONVENTIONAL

MILL 2 STEP CUTS
MILL 1 HOLE 15 MIN.
MATERIAL HANDLING & 2ND SETUP
MILL CIRCULAR ENDS
ON ROTARY TABLE 10 MIN.
ONE PART... 25 MIN. TOTAL

NUMERICAL CONTROL

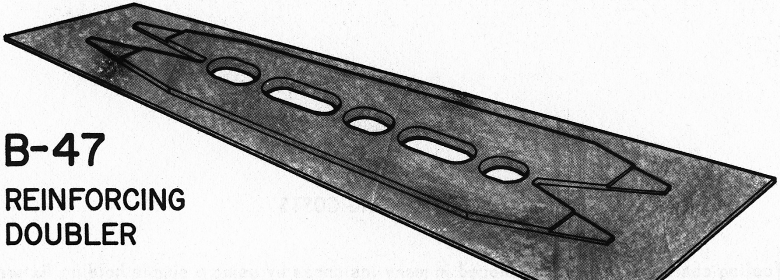
4 PARTS... 21 MIN.
VACUUM CHUCK - 1 SETUP

REDUCE LEAD TIME

Lead time may have different connotations at different factories; but if the same definition of lead time is applied to both conventional and numerical control methods, then the results will be valid. During the production era of the B-47, the lead time (from receipt of the drawing by planning to being ready to load the blank at the machine) on a reinforcing doubler for the conventional method of machining was five days. When the B-47 was modernized recently, this same doubler required a one-day lead time for the numerical control method.

The reduction of machining time under numerical control from 1.2 hours on the first part to an average of ½ hour for the production run was possible because of improved cutter design and a re-evaluation of feed rates.

REDUCE LEAD TIME



B-47
REINFORCING
DOUBLER

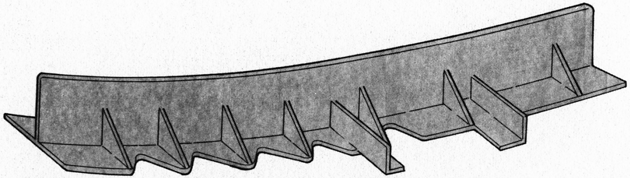
MACHINING METHOD	CONVENTIONAL	NUMERICAL CONTROL
LEAD TIME	5 DAYS	1 DAY
MACHINING TIME (FIRST PART)	25 HOURS	1.2 HOURS
MACHINING TIME (PRODUCTION)	6 HOURS	1/2 HOUR
HAND FINISHING	120 MINUTES	10 MINUTES

REDUCE TOOLING COSTS

Tooling costs can be greatly reduced in many instances by using a simple holding fixture rather than the more complicated tools required by conventional machines. This forging on the B-52 was originally machined on a 3-spindle Hydrotel using tooling which cost $33,712. On a numerical controlled profile mill, the tooling costs amounted to only $7,625, a savings of over $26,000.

Tooling costs on a 76-foot wing skin were $12,554 for an AMC-24 conventional mill. On a numerical controlled skin mill, this same wing skin required only $1,094 worth of tooling, a savings of $11,460.

REDUCE TOOLING COSTS

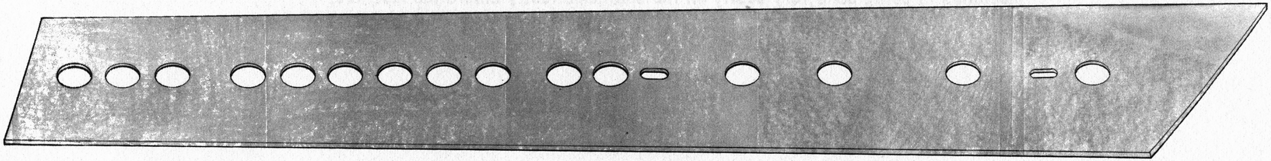


FORGING 35-2665-5 & 6

CONVENTIONAL 3 SPL. HYDROTEL TOOLING COST $33,712

NUMERICAL CONTROLLED PROFILER TOOLING COST 7,625

REDUCED COST $26,087



B-52 #2 WING SKIN

CONVENTIONAL AMC-24 TOOLING COST $12,554

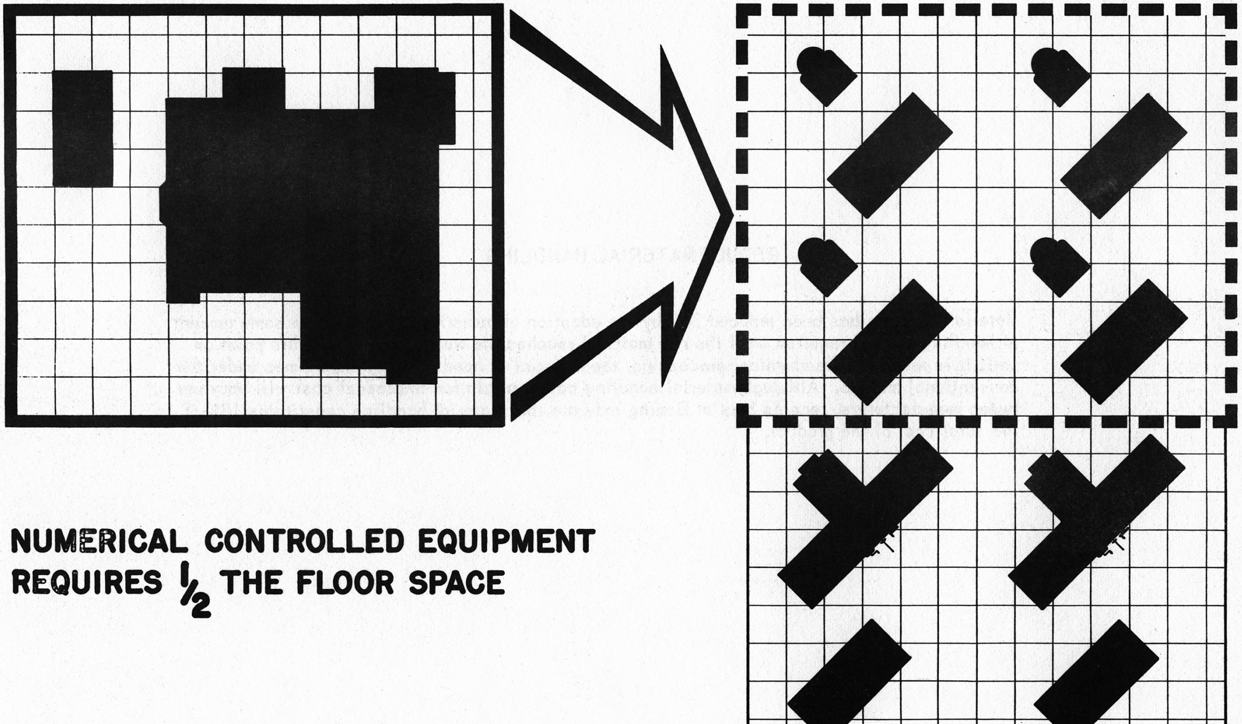
NUMERICAL CONTROLLED SKIN MILL 1,094

REDUCED COST $11,460

REDUCE FLOOR SPACE REQUIREMENTS

One numerically controlled multi-purpose machine and one bench replace two conventional milling machines, four drill presses and six benches, thereby accounting for a reduction of factory floor space to ½ the original requirement. The work done on the original conventional machines is being done very easily on the one numerically controlled machine.

REDUCE FLOOR SPACE REQUIREMENTS

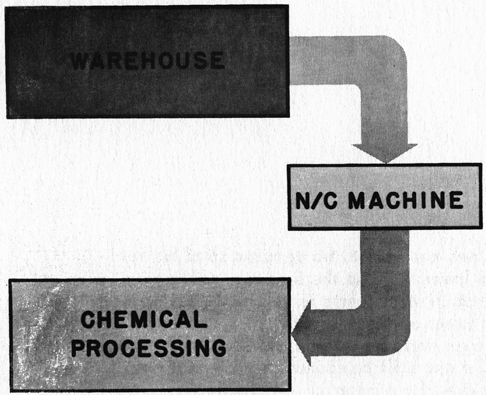


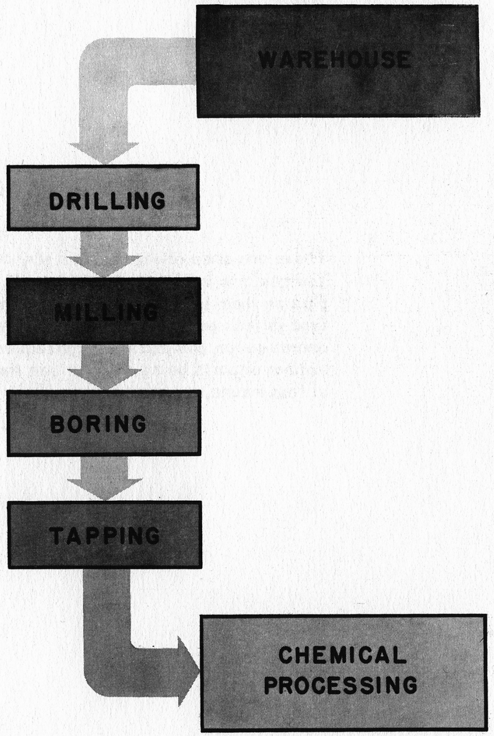
NUMERICAL CONTROLLED EQUIPMENT REQUIRES 1/2 THE FLOOR SPACE

REDUCE MATERIAL HANDLING

Material handling has been reduced 30% by the adoption of numerical control. The same amount of handling is still required until the raw material reaches the warehouse. From this point on until it is ready for the chemical processing, the material is handled many more times under the conventional method. Although material handling costs in relation to product cost will vary between manufacturers, records here at Boeing indicate that material handling constitutes 18% of the total cost of the product.

REDUCE MATERIAL HANDLING





REDUCES MATERIAL HANDLING

30%

NOTE:

MATERIAL HANDLING CONSTITUTES
18% OF PRODUCT COST

REDUCE INVENTORY

These are some of the reasons why a manufacturer does not need to tie up so much of his resources in a large inventory of parts. Stocks can be lower because the time required to replenish them is less. The overall time for the fabrication of the parts is shorter - machine run time is less per part. Often the parts are made with fewer operations or by combining many operations on one machine, consequently there are fewer parts in process of being made. The number of parts being made at one time can be smaller and still be economically feasible. All of this means, too, that there will be less money required for a material inventory.

REDUCE INVENTORY

FEWER PARTS IN STOCK INVENTORY BECAUSE OF:

SHORTER FLOW TIME FOR PART FABRICATION

FEWER PARTS IN PROCESS

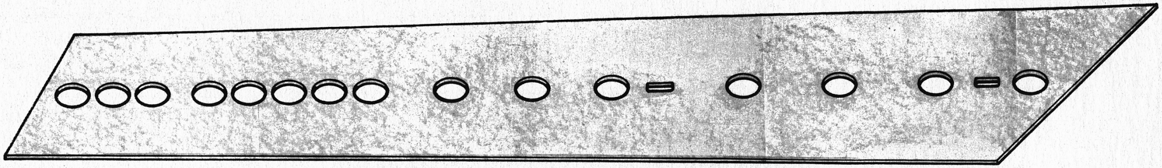
SMALLER "ECONOMIC LOT SIZE" DUE TO SHORTER WORK CYCLE

LESS WORKING CAPITAL REQUIRED FOR MATERIAL INVENTORY

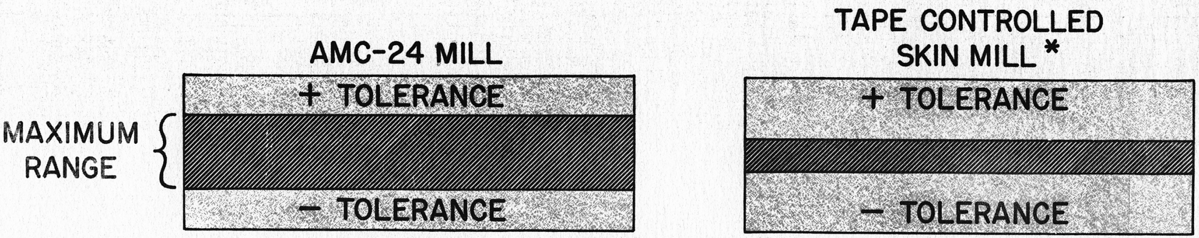
SUPERIOR QUALITY

Because of the closer control possible with numerical control, smaller tolerances are achievable on the finished product. A lower wing panel on the B-52 actually weighs 21 pounds less when milled on a numerical controlled skin mill than when machined on an AMC24 template controlled mill. Weight is highly important in the aircraft field and is becoming even more so in the field of missiles. Less hand finishing means fewer hours of production time and less cost per piece.

SUPERIOR QUALITY



B-52 LOWER PANEL #2



* 1. LESS HAND FINISH MANHOURS

2. WEIGHS 21 POUNDS LESS THAN AMC-24 PANEL

3. FEWER REJECTED PARTS

4. FEWER INSPECTORS REQUIRED

NOTES

Boeing Applied Computing Services
The Boeing Company
Wichita 1, Kansas

Attn: Robert C. Wilburn, Manager

Gentlemen:

Additional information is required in the following area(s) of numerical control:

____

____

____

____

____

____

____

Name____________________

Title____________________

Organization________________

Street Address______________

City____________________

Phone____________________