CONFERENCE PAPER

Advances in Metal Working

by J. Vande Vegte

A Paper Prepared for the Conference

"Productivity Through New Technology"

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FOREWORD

The author of this paper, Dr. John Vande Vegte, is Assistant Professor of Mechanical Engineering at the University of Toronto, and a principal in the consulting firm of Systems Engineering Associates Limited, Toronto.

Dr. Vande Vegte is one of a group of specialists commissioned jointly by the Economic Council of Canada and the Ontario Economic Council to undertake special studies and prepare papers, such as this one, for the Conference on Productivity Through New Technology, held at Ryerson Polytechnical Institute, Toronto, May 27 and 28, 1965.

The purpose of the Conference was to inform senior executives of small- and medium-sized businesses about the practical application of the new management, production and handling concepts, techniques and tools available to them, including the use of computers and automatic production equipment. The Conference participants -- approximately 300 businessmen -- were afforded the maximum opportunity of informal discussion with the authors of the papers.

In publishing these Conference papers, the Economic Council of Canada hopes that the material will be useful to others, and perhaps serve as the basis of similar conferences. A list of the studies being published, with a brief description of each, will be found at the end of this document. The views in these papers remain the responsibility of the authors.

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The author is greatly indebted to Mr. Frank K. Gardner of the Machinery Branch of the Department of Industry, in Ottawa, for very useful discussions and for sharing some of his extensive experience and detailed knowledge of numerical control and cutting and forming. Mr. Gardner also helped in arranging plant visits in Montreal and Ottawa.

Thanks are also due to the management and engineering departments of many companies, too numerous to mention, for giving so generously of their time to discuss their experiences with particular methods and machines.

The author also wishes to acknowledge the help he received from Dr. J.M. Ham, Professor and Head, Department of Electrical Engineering, University of Toronto, in establishing outlines and aims of the paper.

INTRODUCTION

In the last few years a wide range of new methods of manufacture have reached production status, and have a growing effect on the operations of the average machine shop.

The purpose of this paper is to provide guidance to the owner-manager concerning the importance of these new developments for his own operation. This is done by presenting a discussion of the methods, and by giving numerous examples, including cost data, to permit the owner-manager to relate a particular method to the operations in his own plant.

The paper is based on information obtained through numerous plant visits, from interviews with editors and manufacturers, and from extensive study of the literature.

The first section of the paper is devoted to detailed consideration of all aspects of the "Numerical Control of Machine Tools", which is undoubtedly the most important new development in manufacturing technology.

The second section is on "Developments in Cutting and Forming", and covers a wide range of methods, such as electrical discharge machining, chemical milling, friction welding, fluid forming, explosive forming, etc. Techniques of more restricted use, such as hot and cold machining, or those based on the use of lasers, are not covered.

The last section "Improving the Productivity and Versatility of Machine Tools", discusses some relatively low-cost methods for getting more out of an existing machine tool, such as by contour tracing attachments, or by conversion to numerical read-out of positions.

Literature References are given in the text, to facilitate further investigation.

CONCLUSIONS

The conclusion is inescapable that any owner-manager in the metal working industry who does not investigate the possible use of numerically controlled machine tools in his plant, is making a serious mistake. His competitors who are using it are gaining important competitive advantages in reduced lead time and costs. A number of successful installations in very small Canadian plants, with average skills, are proving that, although careful organization is necessary, the use of numerically controlled machine tools is well within the capability of the average machine shop.

For further investigation, references throughout the text give literature on particular topics; numbers 18 and 23 of the List of References are recommended for introductory study. Discussion with manufacturers and users will provide further guidance.

On the whole, the application of the newer cutting and forming methods in Canada is very limited. Nevertheless, for the right type of work they can offer significant savings. There is little doubt, for example, that electrochemical machining will become in the near future a major technique for die manufacture.

Numerical read-out conversion is proving to be a relatively low-cost method for increasing the productivity of existing machine tools, and lowering the cost of tooling. Modern contouring attachments also deserve serious consideration, as a means of increasing the productivity and versatility of machine tools.

SECTION 1

THE NUMERICAL CONTROL OF MACHINE TOOLS

THE NUMERICAL CONTROL OF MACHINE TOOLS

I. THE STATUS AND FUTURE OF NUMERICAL CONTROL

I.1 Status and Future of Chipmaking Tools

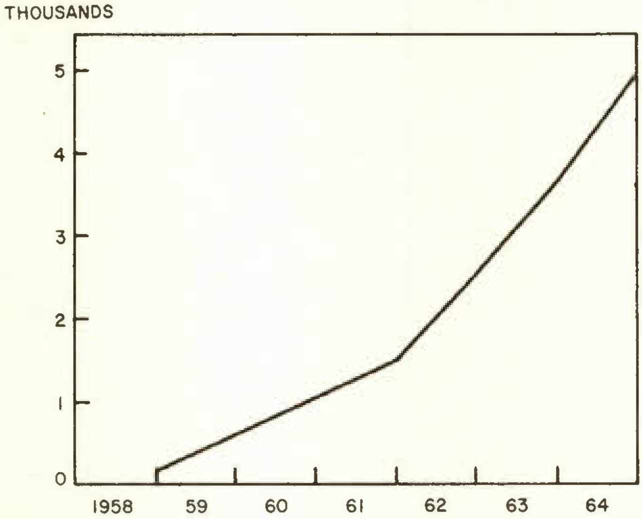
For our purpose, "numerical control" can be defined as the control of a process, machine tool or other, by a series of numbers, usually represented by holes in a tape.

The application of numerical control to machine tools has advanced rapidly since its introduction about 14 years ago.

This is evident from Figure 1, which shows the estimated number of NC machine tools in operation in the U.S. at the end of each year since 1958. (References 1, 18).

FIGURE I

NUMBER OF NC MACHINE TOOLS IN THE U.S.A.



Developments outside the U.S. have been much slower but are now accelerating sharply. Great Britain had about 400 units in operation in the summer of 1964, but this number is expected to double by the end of 1965.

About 600 units are in operation in Western Europe.

As for Canada, we have about 46 NC machine tools at the present time. It has been estimated recently (Ref. 26) that we should have about 350 units to maintain the same ratio to the U.S. in NC as in general cutting and forming machine tools. However, rapid growth can be expected, since over half of these machines were installed within the past year. As an illustration which gives food for thought, we observed two companies, each with about 40 employees, where one has just installed, and the other just ordered, its second NC machine tool.

At present the total number of NC machines in the U.S. is not more than a quarter of one percent of the total number of machine tools. But this percentage is growing rapidly. The U.S. Labor Department estimates that about 12000 NC machine tools may be in operation by 1967, and some experts are said to believe that by 1970 75% of all machine tool sales will be NC (Ref. 1).

Although one may question such exuberant optimism, there is no doubt that the availability of versatile, relatively low cost machines since about 1961 has led to greatly increased application of NC in machine shop operations. The graph in Figure 1 shows increasing growth since about that time.

I.2 Status and Future in Other Than Chipmaking Tools

Many believe that the growth of NC in chipmaking machine tools will be matched by that in machines for other cutting and forming methods, for inspection, for assembly, and for drafting (Ref. 23). Machines, usually a number of makes, exist for all of these, and are finding increasing application.

(1) Both single tool and tool turret type NC machines are available for the piercing, notching and layout of plates. Table sizes up to 144" x 216" can be obtained. One small machine is reported to have paid for itself in six months.

NC machines are also on the market for: tube bending; flame cutting; gas-, arc-, fusion-, and spot welding; riveting; plating; grinding.

(2) Numerical control has shown rapid growth in the area of testing and inspection, a bottleneck for numerous companies. Electronic circuit and component testers are used extensively, for example, for testing the thousands of connections and components in the control systems of NC machine tools.

The present importance of measuring machines is best judged from the fact that of one popular make alone over 500 are in operation. About 4 of these are in Canada, with at least an equal number under negotiation. Mostly used are manually operated two-axis machines, but multi-axis machines under tape control are also available. On these the required dimensions are put on the tape as instructions to the machine. The machine then positions all slides but one, to the dimensions on the tape, and then the last slide moves to measure the remaining coordinate. The measurement difference is provided to the operation as a digital read-out or print-out (Ref. 7i). Users of these measuring machines report great savings in inspection time (Ref. 23).

(3) Coil and filament winders can perhaps be considered as an application of numerical control to assembly, but this is certainly the case for a machine such as the Gardner Denver Wire Wrap, for the automatic wiring of circuit boards. Sperry Gyroscope in Montreal use this machine for automatic wiring between the many hundreds of closely spaced pins of the main circuit boards of their well-known numerical control systems.

(4) NC drafting machines, which automatically prepare drawings from data on the tape, are available up to very large sizes. One of their uses is to check designs made by the use of computers.

II. TYPES OF NUMERICALLY CONTROLLED MACHINE TOOLS

II.1 "Point-to-Point" and "Continuous Path" Systems

The heading of this section indicates the two classes of numerically controlled machine tools which are available.

In "Point-to-Point" systems only the end points of a motion are important, and not the path. For example, in drilling holes the path of the moving members from one hole to the next is of no interest.

In "Continuous Path" or "Contouring" systems, however, machining a given contour to within specified tolerances is the purpose of the operation.

For general machine shop work point-to-point operations are common, while contouring is unusual. It is not surprising, therefore, that point-to-point machines make up 80% of the total, and show the strongest growth.

II.2 Classification of NC Machine Tools. Retrofits

An important classification of NC machine tools is by number of axes under tape control. In simple 2-axis systems only the position of the table is tape controlled, in X-Y coordinates.

In 4- and 5-axis systems capability exists for changing the relative orientation of tool and work.

In the early years of NC retrofitting of conventional machine tools with numerical control was not unusual. Selection of the machine tool has proven to be a decisive factor in the success or failure of the undertaking. Examples of both are available (Ref. 12, 13). Retrofitting is not recommended for machine tools with an original cost of less than, say, $50,000.

A large (about 50%) and increasing percentage of all NC machine tools are classed as drilling machines. However, the name is somewhat misleading, because most also do tapping, boring, and light straightline milling, and even simple two-dimensional contour milling is possible. They are really a half-way station to the so-called "machining center", where all, or almost all, operations on a part are done in a single set-up.

Before considering this group from single-spindle drill to machining center, which is best suited to the work load of the average machine shop, we will review the application of NC to turning, boring, and milling machines.

II. 3 NC Lathes, Boring Machines, Milling Machines and Automatics

At least nine different makes of NC lathes are available on the market, ranging from simple point-to-point systems (for turning stepped diameters) to contouring systems with three separate tool turrets. One Canadian company operates a turret lathe, and another has recently ordered a horizontal turret type contouring lathe.

NC contour milling machines run the gamut from simple 2-axis machines to the highly complex 5-axis profilers, costing about half a million dollars, in the aerospace industry. Two NC contour milling machines are in operation in Canada at the present time, and a third one has been ordered.

At least eight NC boring machines, usually jig borers, are in operation in Canada. High-precision jig borers, with accuracies of ± .0002" and less, in many cases require air-conditioned environments. Jig borers may cost anywhere from about $60,000 to $150,000. The price of a large horizontal boring, milling and drilling machine is roughly $200,000.

As for special machine tools, United Aircraft in Montreal have an NC controlled Warner and Swasey chucking automatic. Addition of tape control to standard machines of this type requires relatively few changes.

II. 4 From Single-spindle Drill to Machining Center

Many types and makes belong somewhere in this group. All are point-to-point systems, although machining centers may in addition be equipped with contouring controls.

Machines in this group can be classified as follows:

(1) X-Y tape controlled positioning table.

These tables, of which several makes are available, can be mounted on, or in place of, the tables of standard drill presses. All operations except positioning of the table are performed by the operator.

(2) Single-spindle drills.

This is by far the largest group, and the most popular makes are being produced at the rate of one or more per day each.

At least 17 are in operation in Canada, mostly in the smaller machine shops, and several more are on order. The principal reasons for this popularity are the relatively low cost, and versatility in handling the work load of the average machine shop.

Most can be equipped with a milling spindle, and do light straightline milling besides drilling, boring, and tapping. In fact, one small Canadian company does twice as much milling as drilling, including even some contour milling.

Usually tool speeds, feeds, and depths are pre-selected manually. The tape controls the cycle until a tool change is required, at which time the operator will also adjust tool speed and feed. Depth settings can be made for a number of tools simultaneously, using cams.

Depending upon size, optional equipment, and tooling, the cost of the installation varies between about $15,000 and $35,000. Quick-change tooling is usually necessary.

(3) Turret drills.

These have a six, eight or even ten tool turret, to eliminate the need for manual tool changes. At least 9 machines of this type operate in Canada, a third being very recent installations, and at least one more is on order.

On some types tool speeds, feeds, and depths are pre-selected manually for all tools simultaneously, while on others these settings are completely under tape control.

Costs of installations range from about $25,000 for a small turret drill without milling capability, to roughly $110,000 and up for larger machines with complete tape control.

(4) Toolchanger drills.

A toolchanger drill is equipped with a magazine with positions for 30, 40 or even more tools. Under tape control, the tool on the machine spindle can be replaced automatically by a selected tool from this magazine. The tape also specifies speeds, feeds, and depths for each of the tools.

No toolchanger drills are operating in Canada as yet, and in the U.S. their number is also small. But growth is good, because the number of tool positions available on a turret is frequently insufficient, so that the cycle must be interrupted to change tools (and also settings, on machines with manual pre-selection). Most experts believe that toolchangers will become standard in the future, since a turret does for many jobs not having a sufficient number of tool positions.

(5) Machining centers.

Machining centers are also equipped with automatic toolchangers, but in addition have at least a part indexing capability, or several machining heads, to permit operations on different sides of the work.

There is considerable confusion in the use of the name machining center, which is sometimes even used to advertise equipment in class 2. The name is meant for machines which complete a part, or almost complete it, in a single set-up (Ref. 14). This usually requires operations on several faces of the work.

The first machining center was introduced in 1958. At least 450 (probably quite a few more) have been sold in the U.S., and in Canada two have been ordered, and one has just been installed.

The price range - from about $120,000 up to almost $500,000 - is evidence of the variety of equipment available.

Five-axis machines capable of point-to-point as well as contouring work stand near the top of this scale. The fourth axis on these machines is usually table rotation - as distinct from the more restricted indexing capability. The fifth axis may be either table tilt or a rotating machining head.

The great majority, however, are three-axis machines. Depending on the control system, these machines are capable of contouring as well as point-to-point work, or point-to-point work only (including, of course, straightline milling).

An automatic toolchange cycle takes about 10 seconds. These machines are often equipped with pallet shuttles, to enable loading and unloading of parts without loss of machine time.

III. ADVANTAGES OF NUMERICAL CONTROL. EXAMPLES AND CASE STUDIES.

III. 1 Some Figures on Overall Savings Experienced with Numerical Control

Before describing the savings on some particular parts, and before attempting to list the advantages more formally, we will consider the overall picture.

From a variety of sources the following case studies of overall savings were obtained.

The U.S. Air Force has 350 NC machine tools, and figures its overall savings in product processing costs to be about 45%.

Westinghouse Electric Corp. in the U.S. expect a return of 20% on the over 5 million dollars invested in NC (Ref. 3). The Homewood Division has found elimination of jigs to be the greatest advantage in their case, because large inventories of jigs, required to make spares for products no longer sold, could be eliminated.

Miehle-Goss-Dexter Inc., with over 50 NC machine tools, figure their overall savings anywhere from 10 - 40% (Ref. 16, 23). In 1962, after one year of operation of 3 NC drills, with average runs of 25-35 parts, the Miehle Div. reported 33% labor cost savings, and $5500. savings in tooling. Miehle-Goss-Dexter have scrapped many fixtures, and have reduced their cost for tooling a given product by about 80%.

The British Aircraft Corp., with 9 NC machines figure the following average ratios of NC time to time with conventional manufacture: 1/2 for tool design and manufacture, 1/6 for set up, 1/3 for floor-to-floor.

The Hamilton Standard Division of United Aircraft report 3:1 labor savings, 2:1 savings in tooling, and 80% reduction of set-up time due to their five machining centers.

Schlumbergen Well Surveying Corp. (Ref. 16) obtained labor savings of 49% for a sample of 60 jobs on their turret drill.

Another U.S. user of a turret drill (Ref. 11) estimated savings of $10,000 in fixture costs and $17,000 in labor costs over the 100 jobs programmed for the machine.

A third user of a turret drill (Ref. 15) programmed 2000 parts over a 3 year period, for lot sizes averaging 12 - 20 parts. About 310 jigs, costing $100 - $6000 each, were eliminated.

Stanac Manufacturing Co. in New York increased production rate by 30%, on runs of usually 10 - 35 parts. Average tooling costs dropped from about $175 to $35.

McKay Machine Co. saved an average of 52% on 5 parts using an NC lathe. The average time required for programming and preparing the tape was 4 hours.

Brown and Sharpe realized the following savings after one year's operation of an NC horizontal boring, milling and drilling machine: Time savings $8,594, Tooling savings $36,000.

Assembly Engineers (Ref. 23) will pay off their NC turret drill in less than a year from tool cost savings alone.

Following are some figures from Canadian companies.

Northern Electric (Ref. 26) save $20,000 a year in tooling costs on a special NC spotting drill, and $10,000 a year on a turret drill.

York Gears' jig borer (Ref. 24) over an 18 month period has tripled output and halved tooling cost.

Aviation Electric (Ref. 25) have realized savings of $25,000 in tooling in the first 5 months of operation of their jig borer.

A Canadian company owning an NC single-spindle drill have no definite data for comparison, but estimate their machine time savings to be 30 to 50%.

Another Canadian company have programmed a job for their new turret drill, without building any of the several thousand dollars worth of tooling which would be required for manufacture by conventional means.

III. 2 Examples of Savings for Particular Parts

(1). A survey of References 10, 11, 15 16, 23, and information from Dexter Machine Co (U.S.), Hyster Co. (U.S.), Pratt and Whitney (U.S.), and United Aircraft (Montreal) yielded a total of 35 examples of parts produced on NC single-spindle drills and turret drills.

The data given can be summarized as follows. The average machining time saving was 52%, assuming zero savings for the 6 parts for which no data were given. Set up time savings averaged 43% over the 14 parts for which definite figures were given. Many of the others noted savings without specifying how much. Savings were large where conventional manufacture required several set ups, often on a number of machines. Tooling savings for 12 of the parts added up to $9,120. For another 6 the averages were much higher.

Generally, of course, savings are largest where conventional manufacture requires an expensive jig or fixture. Where a jig borer is used for layout and spot drilling, tool savings may be negligible, but one gains in set-up time.

Of the 20 parts for which lot sizes were given only two were 50 and over, eleven were 10 or less (down to 2), and the remainder were between 10 and 35.

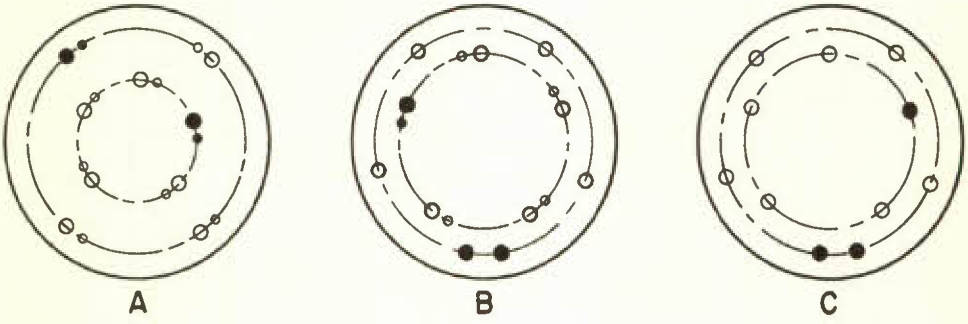
Drastic reductions of lead time were noted for eight of the parts, especailly where expensive jigs and fixtures were eliminated, as one would expect.

Additional considerations given for some cases were the virtual elimination of scrap, the improved accuracy, and the fact that the operator can often perform secondary operations on an adjacent machine.

(2). United Aircraft in Montreal provided data comparing an NC turret drill and a 4-spindle sensitive drill for three typical parts.

Figure 2 outlines the hole patterns to be made. All holes form circular patterns. The holes which are shown shaded fall outside the equally spaced 4- or 5-hole patterns predicted by the other holes at the same radii.

FIGURE 2
THREE PARTS FOR COMPARING TURRET DRILL AND FOUR-SPINDLE SENSITIVE DRILL



The outside diameters are about 3.5 inches.

Part A: Centerdrill and drill 18 holes of 4 different diameters (36 operations).

Part B: Centerdrill and drill 16 holes of 3 different diameters (32 operations).

Part C: Centerdrill 11 holes; drill and ream 6 holes; drill, countersink and tap 5 holes. (38 operations).

The table below shows the results.

Part:	A	B	C	Averages
Programming and tape preparation	8.0 hrs	8.0 hrs	6.0 hrs	
Set-up time savings	33%	23%	20%	25.3%
Savings in time per piece	44%	28%	11%	27.7%
Fixture savings	53%	74%	20%	52 %
(Conventional fixture cost)	($285)	($180)	($142)	

Programming time is high, because the locations of the holes, given on a circular pattern, must be recalculated to obtain X- and Y-coordinates for each hole. (United Aircraft normally uses a computer to aid in programming; programming times for these parts are then 0.7, 0.7, and 0.5 hrs, respectively.)

The lower savings for part C could be due to the smaller number of hole locations and the relatively slower reaming and tapping operations.

(3). Finally some examples including some data on times required for programming and tape preparation.

At Westinghouse in Hamilton one job done on their NC single-spindle drill is the drilling of about 60 holes of two sizes in a rectangular plate. Programming this job took about 2 1/2 hours, and preparing the tape about 20 minutes. The improved accuracy compared to conventional manufacture, and consequently easier assembly, proved of particular advantage here. Another part is a plate which used to be bought in the U.S. because the required accuracy could not be obtained at a low enough cost. This part requires about 24 different sizes of tools, and programming takes about 4 hours.

III. 3 Advantages of Numerical Control

The case studies and examples considered in the preceding sections have demonstrated numerous important advantages. But many others exist, as the listing below will show.

(1) Machining time and labor savings were shown in most of the case studies. All decisions are made beforehand; no time is lost for checking measurements; optimum feeds and speeds are programmed.

(2) Tool and fixture savings are frequently quite large. In fact, this is often the largest single source of savings. Instead of a jig or template, the machine tool provides the accuracy.

(3) Reduced set-up time is often the result of fewer set-ups. As an extreme example, at The Bendix Corp.

manufacture of a bracket by conventional means took 11 machines and 4 hours. It is now done on one NC machine in 11 minutes. An NC machine tool does more operations in one set-up. But the fact that detailed set up instructions are provided, in conjunction with the use of a special base plate with an accurate pattern of numbered dowelpin holes (used by at least two companies in Canada), is another important factor.

(4) Improved accuracy and repeatability, and as a consequence easier assembly, was for at least one small Canadian Company originally the main reason for buying an NC single spindle drill. They have, incidentally, just installed a second one. NC machine tools are generally heavier and more accurate than their conventional counterparts, to meet the requirements of dynamic response of the servo systems. For most machines positioning accuracy is ± .001", and repeatibility ± .0005".

(5) NC has made costs essentially independent of tolerance, and has strongly reduced hand fitting and rework, as a direct consequence of (4). One company paid for its machine in less than two years because of savings in the cost of assembly.

(6) Increased machine utilization for numerous companies tops the list of advantages. Conventional machine tools, typically, are making chips only 25% of the time. With NC most companies aim for 80%. For larger machines and frequent set-ups this figure is lower. One Canadian company (Ref. 24) achieved 60% cutting time on its jig borer, and another realized an average of 62% cutting time on its large horizontal, over a 5 month period, including the effect of a major breakdown which in one month pulled the percentage down to 40. (These figures are for three shift operations.)

(7) Reduced lead time, as a consequence of point (2), has for many job shops been the main reason for buying NC machine tools. Examples of lead time reductions from months to weeks, weeks to days, and days to hours are numerous (Ref. 10, 23, 26). This competitive advantage is quite valuable for job shops.

(8) Reduction of inventory and floor space requirements is often an area of great savings. With the reduced lead time of NC, it is no longer necessary to maintain large stores of spares; only the tapes need to be stored. A number of plants have either completely eliminated or strongly reduced their tool storage area also.

(9) The flexibility of NC is a point of particular value for most of the smaller machine shops. It has been said that NC "eliminates the small lot cost penalty". Changeover from job to job is fast. Minor differences in similar parts or modifications in engineering prototypes can be allowed for by changing the tape, instead of using a different jig. NC can be used for initial production runs, or to make the templates and jigs for large scale production, where NC cannot compete.

(10) Reduced inspection costs and less scrap have been experienced by most users. Inspection costs are easily reduced by more than 50%. In many cases only the first off is inspected. Sometimes only the first and last holes of a program are inspected. Provided the tape is checked carefully, scrap is reduced in most instances, since the accuracy is better and there is less chance of human error. York Gears consider this to be one of their principal gains (Ref. 24). Aviation Electric have reduced inspection by 90%, and have no scrap losses (Ref. 25). On the other hand Miehle-Goss-Dexter have about the same scrap losses as with conventional tools.

(11) Management has control of the process. This has been called the "key gain" of numerical control (Ref. 23). The job is planned by skilled personnel, and is no longer "operator paced". Product costs can be predicted with much greater accuracy.

(12) Last, but certainly not least, NC forces management to reconsider the entire organization, because lack of adequate planning of all phases can be quite expensive.

IV. METHODS AND ORGANIZATION FOR PRODUCTION BY NUMERICAL CONTROL

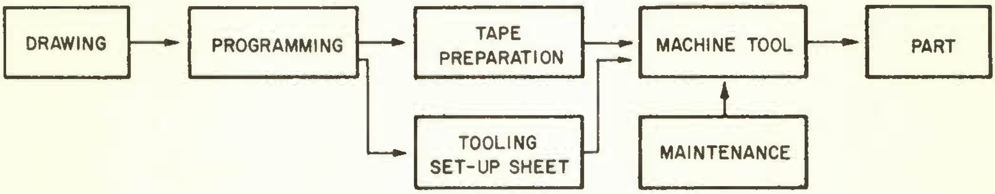
IV.1 Organization

To show that the idea, still held by some people, that numerical control is something which is out of the league of the "ordinary" machine shop, is without foundation, we will consider what is involved in making parts on NC machine tools, including service requirements.

The block diagram in Figure 3 shows the basic organization.

FIGURE 3

ORGANIZATION FOR PRODUCTION BY NC MACHINE TOOLS



The sequence begins, as usual, with making a drawing. To simplify the programmer's job it is desirable that all dimensions on the drawing be shown as distances to the axes of a given coordinate system.

IV.2 Programming

The programmer decides exactly how the part is going to be made, how and where it will be put on the machine table, what feeds and speeds will be used, etc.

If any fixtures are required he initiates their design or designs them himself.

His main job, however, is to prepare a "program", with instructions to the operator and instructions to the machine. The instructions to the machine must later be transferred to tape, so here he has to follow certain rules in organization. Instructions to the operator tell him, for example, what tool speeds, feeds, depths to set (on those machines where these are pre-selected manually), or what tool to insert if the machine stops for a manual toolchange. Set-up instructions and a sketch or drawing of the part may be given on a separate sheet, or included on the program sheet.

On preparation of the instructions to the machine, let us state first of all that a computer is not at all required, unless one would buy a machine for generating three dimensional contours. For point-to-point machine tools manual programming is by far the most common method.

Even programming for two-dimensional contouring systems is often done manually, using the "circular" or "parabolic interpolator" of contouring control systems, which permits the programmer to specify only relatively few points of a contour.

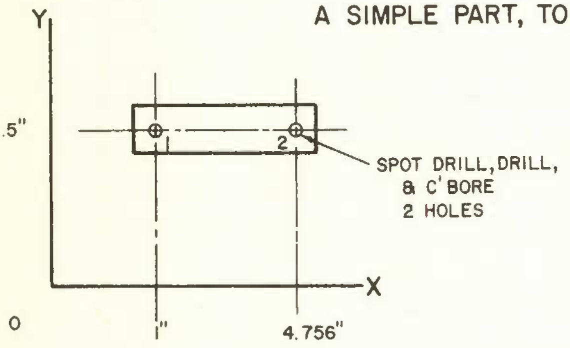
Returning to manual programming for point-to-point work, essentially we must tell the machine, by some sort of code number, what type of machine cycle to execute, for example a drill cycle, and then the dimensions must be filled in.

There are several ways of "addressing" the various memory registers of a machine where input information is stored, depending on the type of machine. In the "word address" system each channel of information is preceded by an address telling the machine where to put the information. It will stay unchanged until other information enters, so only data which have changed from the preceding operation need to be written into the program.

To illustrate the simplicity of point-to-point programming, let us program the part shown in Figure 4 for a single-spindle drill with manual tool changes, and manual pre-selection of tool feeds, speeds, and depths. It is well to point out that programming of more complex parts is not "more difficult", but only means "more of the same".

FIGURE 4

A SIMPLE PART, TO ILLUSTRATE PROGRAMMING



We will assume a word address system, and only write the instructions to the machine, which must subsequently be transferred to tape, since instructions to the operator are easy to visualize.

The program is shown in Figure 5. The first column gives the number of each operation. Machines are frequently equipped with a read-out counter showing this number. The preparatory function tells the machine what type of cycle of operations it must perform.

Sequence No.	Preparatory Function	x Position	y Position	Miscellaneous Function	Position Number
001	G81	X01000	Y01500	M51	1
002		X04756		M06	2
003	G81			M52	2
004		X01000		M06	1
005	G85			M53	1
006		X04756		M02	2

Figure 5: Program for the part in Figure 4.

G81 stands for a drilling cycle: Rapid advance, feed, rapid retract. G85 is for a boring cycle: Rapid advance, feed in, feed out, rapid retract. The next two columns show the X and Y coordinates of each point relative to a certain coordinate system. Only when changes occur is an entry required.

In the Miscellaneous Function column, the code M02 stands for "end of program". M06 is the code for a tool change: The machine will stop and the tool change warning light will light up, after the operation on the same line has been completed. Codes M51 to M59 tell the machine to choose a particular set of the 9 sets of cams, on each of which a final tool depth and a depth for the end of rapid advance have been set by the operator. Note that the program implies that on the lines with M02 and M06 codes the same cam set is used as specified in the preceding lines. The last column shows the position numbers, corresponding to the hole numbers in Figure 4.

Using this type of coding, which varies with the type of machine tool - the system for a well-known make has been followed above - programming for more complex parts follows in identical fashion.

As for the time required for programming, it has been estimated at anywhere from 1 minute to 5 minutes per hole location. Finding X-Y coordinates of holes in a rectangular pattern is naturally much quicker than converting hole locations in a circular pattern to X-Y coordinates. Examples given earlier give an idea of the order of magnitude of the time required. One man can do the programming for a number of machines.

IV.3 The Programmer

The programmer decides on sequence of operations, set-up procedure, and feeds and speeds, so he must be experienced in machine shop practices. He must also consider fixture design, and must know some trigonometry. Men with a tool design background often make good programmers. At one small Canadian company three of the tool designers do the programming in between their regular work. Another Canadian company uses a toolmaker who had just finished his apprenticeship. Generally, programmers in small plants are often men who came up from the shop. In most cases they are trained in the plant, by the NC coordinator, who himself has often, but by no means in all cases, followed a two or three day programming course at the manufacturer's plant.

Generally, it can be stated without hesitation that programming has not proved to be a problem for any of the users of NC machine tools in Canada.

IV.4 Tape Preparation

The instructions to the machine are put into a form which the machine can "understand" by representing them by definite patterns of holes in a tape.

Preparation of this tape from the written program does not require any understanding of the type of coding used, since a special typewriter takes care of the conversion. This typewriter has an ordinary keyboard and incorporates a punching unit which punches holes in the tape in the proper locations.

Nearly all machine tools use standard 1" wide 8-channel tape, usually made of paper, sometimes of mylar plastic.

Training a typist to operate the typewriter takes about half a day. The time required for tape preparation is sometimes estimated to be 15 - 20% of that required for programming, but higher percentages have been quoted.

A very popular make of typewriter, which also can do many things other than preparing tapes, costs roughly $4,500. It will print out the decoded contents of a tape inserted in its tape reader. This facility can be used for addressing of envelopes, but in tape preparation it is used for tape-check out. The printed output is compared with the hand written program. There are means of correcting tapes if errors are made during typing.

IV.5 Job Prove-out

The completed tape is inserted in the tape reader of the machine tool, the job is set-up, and machining of the first part can begin. All too often it is considered to be a mistake on the part of the programmer if the tape is changed at this stage (Ref. 14). Thus the programmer will tend to play it safe. This can be quite a serious problem. It must be recognized that uncertainties concerning vibrations and deflections will frequently make an accurate estimate of optimum feeds and speeds impossible. Also, it may be possible to eliminate a certain finishing operation. The programmer should be encouraged to be at the machine during the prove-out of unusual jobs, and to make changes in the conservative estimates he will have made during programming.

IV.6 Machine Operator

In principle, with most decisions made beforehand, a less experienced operator is required. However, the practice, here as well as in the U.S. has been to use experienced machinists, mainly because the machine represents a considerable investment. Of course, this depends on the machine and on the work. One small Canadian company uses a two month apprentice to operate its single spindle drill.

A practice frequently followed is to use a very experienced man to work with the manufacturer's crew during installation, and operate the machine for a shakedown period. Later a less skilled operator, often a second or third year apprentice for the simpler machines, replaces him, but he will know the machine, and can often help to diagnose breakdowns.

IV.7 Maintenance

This is a function of critical importance, and one where a number of Canadian companies have had problems, especially the small ones who cannot afford the new and specialized maintenance skills required for in-plant maintenance capability.

These companies must rely for fast emergency repairs on the manufacturer or their representatives, and the experiences of some in this connection have not always been happy ones. It is recommended that one make a special point of checking on this with other users.

On the other hand, the problem should not be overemphasized, and the situation is improving as the number of installations increase. Canadian representatives are gradually getting service men who have not just attended the manufacturer's maintenance courses, but have also built up experience.

A preventive maintenance program is stongly recommended. Small plants often find it advantageous to sign a preventive maintenance contract with the manufacturer.

In practically all cases at least one man is sent to the manufacturer's maintenance course, usually of two to three weeks duration. The man selected for NC maintenance should have some background in electronics, and his main problem is likely to be diagnosis of a breakdown. The control system consists of plug-in solid-state units, and once the trouble is located all that is needed is to replace a unit by a spare. The manufacturers offer a spares kit ($500 to $1500) with all important spares. Fortunately many of the plug-in units are identical.

Modern solid-state circuitry has greatly improved system reliability over that of a few years ago. Also, most systems have numerous special provisions to aid in locating failures (Ref. 7c). Using checking procedures given in detailed maintenance and troubleshooting manuals, even relatively inexperienced men can often locate the trouble area. These procedures make use of diagnostic test tapes, test panels, circuit isolating switches, trouble indicator lights, check points, etc. These features form an important consideration in equipment selection.

A carefully kept log book of all maintenance problems has proven to be an important aid in failure diagnosis.

As for times actually lost for maintenace, one Canadian company, with six NC machine tools had 10% down time for maintenance over 2000 hours of operation. It is interesting to note that 90% of this down time was due to their old machines. Another Canadian company (Ref. 24) reported down time of about three times that of the conventional equipment.

Case histories of U.S. companies, with relatively large numbers of NC machine tools, indicate an average down time of about 5%, with some notable exceptions (Ref. 23).

V. FACTORS FOR MANAGEMENT DECISION

V.1 Some Problems, Real and Imagined. Costs

One might well ask: If NC is all that advantageous, why is there not more of it?

The two main reasons usually advanced to explain this are:

(1) Misconceptions and lack of understanding on the part of management.

(2) The lack of cost evaluation methods and equipment buying formulas which take into account all significant advantages of numerical control, most of which are often not on the manufacturing floor.

Some of the misconceptions, which only education and the reality of many successful installations, even in very small plants, can cure, are (Ref. 1, 18, 23):

(1) "NC is mass-production automation". In reality it is just the opposite, and has been called "small lot automation". The usual lot size is 5-50 parts. On the other hand, this varies widely, and many program even a lot of 1, if the part is complex or another order is expected later. The maximum is also quite flexible. Lots of more than 200, or even more than 500, are often run on NC. But NC is not a mass production tool, and cannot compete on large lot sizes, where its reduced tool requirements are a relatively insignificant advantage.

(2) "NC is too expensive and too complex". As will be evident from preceding chapters, this not true: one does not require a computer, programming is simple, and low-cost systems are available. Besides, if in the Toronto area alone four, shortly to be five, installations are found at three plants with each about 40 employees, of average skills, then any manager who thinks that his company cannot handle it had better check again.

(3) "The downtime is excessive". Except in very few cases, this is certainly not true, although maintenance is usually higher than on conventional equipment. Modern solid state circuitry has greatly improved reliability, and much attention has been paid to facilitating failure diagnosis.

Inadequate planning and preparation tops the list of real problems. Production scheduling is quite important. The machine has a work turnover rate of two to three times that of conventional equipment, and careful planning is required to keep it going. The penalty of making no provisions for this is much higher than with conventional equipment.

This problem has forced most managers to review all phases of their oganization, which in turn usually has led to improved overall efficiency. Numerical control affects the entire company and will show up any weak links. It requires cooperation of programming, production control, tool section, inventory control, etc., since all work on a job is done simultaneously, rather than in sequence. Inventory can be smaller, but must be controlled more closely, since its turnover rate is faster.

It follows that numerical control is likely to prove a disappointment unless management is fully involved, and ensures the cooperation of all sections. The NC coordinator must have full management backing in requesting the assistance of all sections, and management must recognize that unusual problems are likely to arise for some time.

Other problems have arisen in estimating the cost of the installation, and in estimation of machine time costs.

As for the cost of the installation, it is important to realize that it does not just consist of the cost of the machine. Costs of tooling, tape preparation equipment, and training must be added to this.

One Canadian company installed an NC machine with a basic cost of $33,500, but the total cost of the project was $47,000, the difference being due to:

$5000, for quick-change tooling
$5000, for tape preparation equipment
$3500, for training.

Thus, the total cost was about 1.4 times that of the basic machine.

Determining the cost of machine time, and cost accounting generally, is another problem area. Especially the smaller plants often do not know their costs well, sometimes neglect the special overhead caused by NC, and tend to under-price machine time (Ref. 1).

Since, at present, the number of NC machine tools in a given shop is relatively small, it is important to charge costs to the machine wherever possible. For example, programming should not be lumped into a general overhead percentage, but should be a direct cost.

V. 2 Justification of NC Machine Tools

Inadequate cost accounting methods, and too much reliance on equipment buying and replacement formulas which can only account for a few of the advantages, are generally considered to be the main hurdles against acceptance of NC.

A review of the list of advantages given earlier will demonstrate the problem. Most do not show up using present replacement formulas. What is the dollar value of an intangible such as greatly reduced lead time, and how does one evaluate the savings which may result from greater accuracy? Present formulas will usually not justify NC, because no procedures are available for determining the advantages (Ref. 1, 6, 7g, 21, 22, 23). Indirect savings are often found to be more important than direct ones, but are hard to predict beforehand, and therefore do not figure in the estimates.

Generally in this area much remains to be done to eliminate some of the guesswork, and give the NC machine tool credit for more of the savings which it has brought to those actually using it, who usually bought their first machine on faith. Some trust that "so many can't be wrong", and the importance of keeping up with what is already today's technology, will for many, until better methods are devised, have to replace extreme reliance on outdated formulas.

A very important consideration is whether one has enough work to keep the machine operating for at least two shifts. Because of the high initial cost, even three shift operation is not unusual. Generally, at least two shifts are required. One small Canadian company began operating a skeleton second shift after installation of its NC machine, and most other Canadian users also operate on a two-shift basis.

It is interesting to review some of the reasons why Canadian companies originally bought NC. The competitive advantage due to lead time reduction figured as number one. Increased productivity was number two. Reduction in tooling, and increased accuracy and repeatibility, were the main factors for others. The expected payback period for these companies varies from two to four years, with an average of about two and one half.

It may well be that the difficulties of justification have been described from a very pessimistic point of view. Mr. Hugh Love, NC coordinator at Westinghouse in Hamilton, fully justified purchase of an NC single spindle drill in terms of dollars and cents, and, incidentally, will in actual fact exceed his estimated savings.

VI. EQUIPMENT SELECTION AND INSTALLATION

VI.1 Preparation. Work Selection

Any manager who thinks that he can order a machine, have it installed, and operate the next day, is in, or out, for a rude awakening. Depending on the type of machine, a period of from 4 to 18 months is required to prepare a company for NC.

Small plants usually appoint an NC coordinator to investigate numerical control thoroughly, to talk to equipment manufacturers and other users, and to recommend type and make of the machine to be ordered. To ensure a cooperative atmosphere he will organize formal and informal consultations with all sections of the company, and create an awareness of the possibilities, limitations, and requirements of NC.

After the machine has been ordered, training should begin immediately. In some cases only the NC coordinator attends the manufacturer's programming and maintenance courses, and trains others at the plant. Most prefer to send others also, in particular maintenance people. Manufacturers often give aptitude tests to applicants for the maintenance course. Once the programmer has been trained he should program a number of parts, to get experience, and to create a backlog when the machine arrives. This permits him to spend time with the manufacturer's crew and the operator during the debugging period.

What work should be selected for NC? For very simple parts NC usually gives no advantage. The best jobs for NC are those which for conventional manufacture require expensive tooling, or a large number of set-ups.

Other considerations in selecting work for NC machine tools are (Ref. 1):

(1) Delivery time (shorter lead time).
(2) Accuracy requirements.
(3) Lot size (not critical).
(4) Probability of a repeat order (may make a tape for one part if repeat order expected).

VI.2 Equipment Selection

It is generally considered wise to select a relatively simple NC machine tool for the introduction to manufacture by numerical control. Also strongly recommeneded is that one talk to other users before deciding on the type as well as the make of machine to buy. A practice usually followed is to have test parts, of which conventional costs are known, programmed and run on proposed equipment.

In many cases the machine tool and the numerical control are built by different manufacturers. In such cases it is highly desirable that the interface of responsibility be clearly defined. There are numerous cases, in the U.S. as well as Canada, where this has led to problems. The location of service centers for emergency repairs, and the experiences of other users in this connection, are also quite important.

To decide what type of machine to buy requires careful analysis of the workload. If the average number of tools required for a job usually exceeds the number of positions on the turret, then some of the advantage of a turret drill is lost. If most of the work requires operations on several sides one should seriously consider the simpler types of machining centers now available.

Besides the normal considerations, such as price, delivery, capacity, general construction, lubrications, fire protection, etc., and some considerations discussed earlier, such as maintenance, training, and estimated and real production times on trial parts, there are a number of factors which are of great importance in equipment selection:

(1) Accuracy and repeatibility; in most cases ± .001 and ± .0005 inches, respectively. Remember that it is the accuracy on the table which counts, and not that of the control system.

(2) Manual input capability for all machine functions. This is generally considered a very important point, for job set-up and prove-out.

(3) Visual read-out screens showing the sequence number of the operation are often considered desirable.

(4) Visual read-out screens of X and Y dimensions, either those of the tape or the actual position of the table. Make sure which. Read out of actual positions is not usually found on installations in Canada.

(5) Tool offset. It is generally considered more desirable to have provision in the control system for setting the tool depth than to use so-called "pre-set" tools, carefully adjusted to a programmed length in the toolroom. Of course, this is only a consideration on those machine tools where all data on the Z-axis are completely under

tape control. Most systems, including those made by Sperry Gyroscope in Montreal, a major manufacturer of NC control systems, have means whereby the operator can quickly set all tools for depth.

(6) Automatic zero shift. Most systems have at least partial zero shift, with full range zero shift as an option. Zero shift is an important aid to facilitate set-up.

(7) Straightline milling capability is at least optional in most cases, and a user should be sure of his workload if he would not buy it.

(8) Tape search facilitates returning to a point where a cut was interrupted due to, for example, breakage of a tool. Most users recommend it.

(9) Test tapes and other facilities for failure diagnosis, as mentioned before, are of great value.

(10) Mirror image attachments (for cutting mirror images), reciprocating feed attachments (for chip clearance in deep hole drilling), etc., are options which can be quite useful.

(11) The split responsibility problem is repeated here for emphasis.

VI. 3 After Installation

Depending on how complex the system is, and also on whether it is "standard" or not, it may take up to 6 months after installation before the machine is working at full efficiency. This was the experience of York Gears (Ref. 24), and of numerous other users (Ref. 5, 7d).

For the larger systems one must be prepared for a considerable period of debugging. One Canadian company, after installation of a large horizontal, experienced the following percentages downtime in each of the first six months: 60%, 32%, 31%, 17%, 18%, 1.5%, .7%.

Aviation Electric (Ref. 25-1962), on the other hand, had a down time of less than 50 hours total in the first 1500 hours of operation, so the picture is not all black.

With the simple single spindle drill systems these problems are relatively much less severe.

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SECTION 2

DEVELOPMENTS IN CUTTING AND FORMING

I. EDM - ELECTRICAL DISCHARGE MACHINING

Status and Applications

EDM has become an established technique over the last ten years.

It is estimated (Ref. B1) that over 2500 EDM machine tools are in operation in the U.S.A., and that this number is rising by 20% every year. A prediction has been made (Ref. B2) that by 1970 5 to 10% of all metal removal will be by EDM and its newer companion, ECM.

There are about 40 to 45 EDM machine tools operating across Canada.

A number of the reasons which are responsible for this strong growth will be detailed later, but the essential advantage of EDM can be summarized as follows:

> The ability to machine complex contours, in conductive materials of any hardness, even with fragile parts.

Applications of EDM can be roughly divided into three groups:

(1) Manufacture of parts.
(2) Manufacture of dies.
(3) Modification and repair on hard materials.

Most rapid growth is in group two, the manufacture of piercing-, blanking-, forging-, extrusion-, and molding dies.

At one U.S. Company (Ref. B2) 80% of the cavity-type dies are made by EDM, in lots from 1 to 4, realizing savings of 25 to 50% of the cost of conventional manufacture.

Other percentage savings cited in the literature for new dies are:

20 to 60%; 30 to 50% (Ref. B3); 15 to 30% (conservative - Cincinnati Milling Machine Co.).

For re-sinking worn dies these sources claim cost savings of "up to 60%", "20 to 40%", and "20 to 60%".

Examples of applications will be given later. The repair or modification of parts, tools and dies made of hard or hardened material is of course a natural for EDM. One can, for example, replace a damaged section of a large and expensive die, or modify a prototype.

Process and Equipment

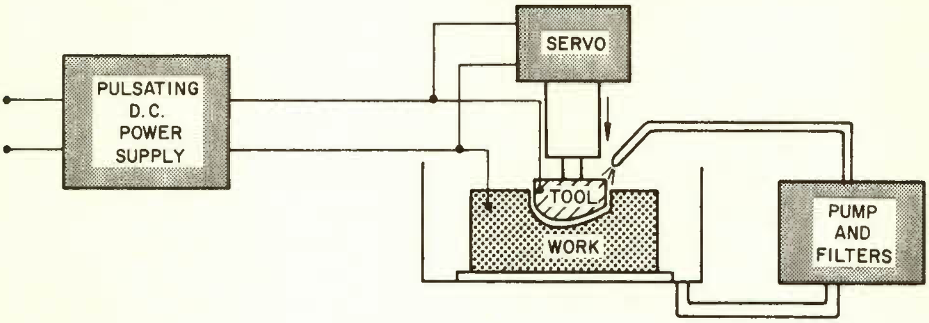
EDM, also called spark erosion machining, has been defined (Ref. B4) as the controlled erosion of electrical conductors by rapidly recurring spark discharges.

See Figure B1. The power supply, which provides a pulsating d.c. voltage, is connected between the workpiece (anode) and the tool or electrode (cathode).

The space between work and electrode is filled with a dielectric fluid. If the gap between them is about 0.001" then at a voltage difference of about 70 volts a discharge will cross the gap where it is narrowest. High local temperatures and pressures result in local melting and partial evaporation of the metal. When the supply voltage

FIGURE B1

DIAGRAM OF THE EDM-PROCESS



drops this channel of conductivity collapses, and surrounding fluid, in some manner not yet fully understood, rushes in and knocks out the softened metal, leaving a small crater. The dielectric fluid carries the particles away, and filters in the pump circuit remove them.

By the use of high frequency power supplies, many of these discharges occur per second (up to 300,000).

Except by increasing the frequency, metal removal rates can be raised also by providing more energy per discharge. This, however, causes large craters, so a rough finish, and is limited to roughing cuts.

As material is removed, the electrode must be lowered to maintain the desired gap. This is the function of the servo, which compares the measured voltage across the gap with the preselected reference value, and adjusts the tool slide to keep the two in balance.

At least four different types of power supplies are available. Most common is the pulse-type circuit, which uses a solid-state switch, and is capable of high frequencies.

Numerous makes and sizes of EDM machine tools (including power supply cabinets) are available.

Prices range from about $15,000 for a small machine to about $35,000 and up for larger models.

Process Variables; Accuracy and Finish

The dielectric fluid has an important effect on the results obtained. To ensure good distribution over the entire tool area it is frequently pumped through holes in the electrode. Since the pressures may be as high as 100 psi in some cases, adequate rigidity of the set-up is vital.

The second main process variable, even more important than the first, is the electrode. The problem is that the same process which removes metal from the work also removes it from the electrode.

Brass and copper, both common electrode materials, have "wear ratios" of about 2 or 3, i.e., the ratios of metal removed from the work to that removed from the electrode is 2 or 3 (Ref. B2).

Zinc alloy electrodes can readily be cast and therefore find much use in the production of forging and molding dies, but their wear ratio is 1 to 2.

High density carbon, probably by far the most common material, has a wear ratio of from 5 to 10.

Use of a good dielectric fluid will not only improve the finish, but may also lower electrode wear by a factor of three. For example, it has been found that a silicon oil mixture will double metal removal rate and half electrode wear compared to the ordinary hydrocarbon oils commonly used

(Ref. B3). Ordinary tapwater, carbon tetrachloride, and others, are also being used.

Electrode manufacture often presents a problem, since it requires considerable experience. Machining, casting, forging, coining, and metal spraying, all find their uses. Lowering the cost of electrode manufacture is particularly important because, due to tool wear, from two to six electrodes may be required to machine forging and molding dies to the required accuracy. Electro Processors Ltd., a small EDM job shop, suggest that users make 6 zinc alloy electrodes off their original die while it is still new.

Besides tool wear, the gap required between tool and work, called the "overcut", is important. The smaller it is, the better the accuracy of reproduction of the tool in the work near corners. Higher frequencies permit lower voltage for a given removal rate, so the tool will move closer to the work before discharge is initiated. The manufacturers provide charts to estimate the overcut for given conditions. Electro Processors consider a .005" corner radius about the minimum possible, although one may need three electrodes to achieve it.

Tolerances can easily be held to ± .003". Using lower removal rates, an experienced operator will have little or no trouble maintaining ± .001". Tolerances down to a few tenth of a thou have been produced.

As for finish, about 60 microinches is a reasonable value for normal work. For precision work, using very low metal removal rates, 10 microinches can be achieved on a production basis.

Limitations of EDM

Apart from the requirement that the work material must be electrically conductive, probably the principal limitation of EDM is the low metal removal rate (Ref. B1, B5).

Compared to a removal rate of the order of 10-30 cuinch/min on a lathe, the removal rate for roughing work on EDM is roughly 0.3 cuinch/min.

For a normal finish this drops to 0.1 cuinch/min or less, while for precision work much lower values are quoted. These values, however, are much better than a few years ago, and are still rising.

Roughing out by conventional means is frequently desirable. Finishing operations, if required, are often more economically done manually. The amount of metal to be removed by EDM can in many cases also be reduced by suitable electrode design. For example, moving wire electrodes or trepanning electrodes made out of sheetmetal can be used.

EDM produces a thin skin harder than the base metal, due to the rapid quenching of softened metal in the spark craters. This skin frequently exhibits cracks. Low power finishing operations will minimize this. If necessary the skin can be removed by chemical or abrasive means, but the experience has been that in most cases this is not necessary. In fact, the longer life obtained with tools manufactured by EDM is usually attributed to this hardened skin.

Applications and Advantages

Before listing advantages we will consider some applications in the main groups given earlier.

(a) Manufacture of parts.

General Electric uses EDM for the machining of vacuum tube grids, with web thicknesses of .002" to .004". The fact that EDM produces no burrs and no machining forces except fluid pressure, is also responsible for its application to many other fragile parts, such as honeycomb assemblies. Burr free operation has been found advantageous in machining the porting in hydraulic valves.

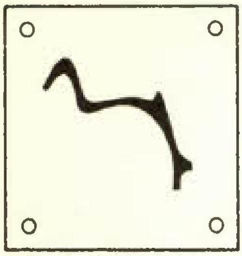
EDM can also be used for machining very small holes and narrow slots. Electro Processors have drilled 0.010" dia. holes using an 0.008" O.D. tube (for fluid circulation) as the electrode. This tube was spun at 1700 rpm for added stiffness.

As for large parts, at Republic Aviation EDM is used to machine 400 holes simultaneously in an aircraft speed brake door.

(b) Punching and blanking dies.

Figure B2 shows a carbide trim die, machined in 4.5 hours, using silver tungsten as electrode material. The electrode, as is usually recommended for single hole shapes, is a so-called "stepped electrode": the lower section has a larger clearance to the desired hole size than the top section, so that roughing and finishing can be done using the same electrode. One electrode could be used to make four dies.

FIGURE B2



CARBIDE TRIM DIE
2 x 2 x 1 INCHES

Another application of this type is the machining of solid carbide dies for razor blades; these dies are made by EDM at one-third of the previous cost (Elox Corporation).

Some very important advantages are gained in the production of multi-punch dies by EDM. Essentially one can assemble the punch plate, and use it as the electrode for manufacturing the die plate by EDM. The result is uniform clearances on all punches, and the elimination of almost all expensive rework and hand fitting. One company figures 60% savings on this score alone.

Usually multi-punch dies are made by a combination of EDM and conventional machining, the function of the latter being to reduce the volume of metal to be removed by EDM. The Cincinnati Milling Machine Co. gives the example of a printed circuit stamping die, with a total of 514 holes. Closer to home, General Electric in Peterborough (Ref. B2) reduced the machining time of a multi-punch die for motor laminations to 500 hrs, from the 800 hrs required for machining by conventional methods.

Perhaps more common than using the punches as electrodes, and cutting the worn sections off afterwards, is to bond pieces of electrode material to the ends of the punches, and then machine the combination to finish size.

(c) Cavity-type dies.

As mentioned before, this is the area of most rapid growth, and all equipment manufacturers can provide numerous examples. Reference B6 gives the following list:

Forging dies for jet engine turbine blades, small tools, automotive connecting rods and universal joints.
Molding dies for automotive speedometer gears and faces, control knobs, instrument panels, switch blocks, terminal blocks, etc.

Elox Corporation give an example of a forging die for automotive connecting rods, produced at 35% savings.

The Cincinnati Milling Machine Co. has the example of a two-crank crankshaft forging die, and also of a forging die for small bevelgears.

Much of the savings in these applications are due to reduced cavity polishing time.

Another, often major, source of savings is that with the ability of EDM to produce complex contours, expensive sectionalizing of dies can often be avoided.

In addition to the advantages of hard materials, complex contours, flexibility for modification, low machining forces, burr free operation, uniform clearances, and reduced need for sectionalizing mentioned before, the following additional advantages can be cited: (Ref. B3 and others).

(1) Heat distortions are avoided because the material is machined in the hardened condition.

(2) Carbide dies can be made at about the same cost as steel dies.

(3) Increased tool life, due to the hardened skin and uniform clearances, is a general experience.

(4) Hand finishing time greatly reduced. Generally it has been found that die polishing is seldom required.

(5) Machines, provided with automatic shut-off, are often kept operating overnight and unattended.

II. ECM - ELECTROCHEMICAL MACHINING

The Process, Advantages and Limitations

Electrochemical machining, like EDM, can be used for conductive materials of any hardness. As far as applications are concerned, the main differences between the two processes are:

(1) Metal removal rates of ECM are roughly ten times those of EDM.

(2) ECM is less accurate, and less suitable for complex contours with fine detail.

Mr. I. Filshie, of ISF Electro Methods, in Toronto, who are developing an ECM machine (Ref. B8), calls EDM the "grinding operation" of ECM.

In Electrochemical Machining metal is removed by a controlled d.c. current flow between tool (electrode) and work in an electrolytic solution. In principle it is the opposite of electro plating, but much higher currents are used.

The diagram for an ECM system is very similar to that given earlier for EDM, except that a d.c. power supply and an electrolytic solution must replace the pulsating supply and the dielectric fluid. Thus, ECM can be, and is, used for many applications similar to those of EDM. For example, hole sinking, or cavity sinking. But, because of the higher removal rates, ECM can also be used for planing cuts, and even ECM lathes are available, where the work is rotated in front of a stationary electrode. Electrolytic grinding, the forerunner of ECM, is an important area of application.

Another major difference between ECM and EDM machines is that the former require a much higher capacity of the pumping and filtering circuit . For large parts flowrates of 150 - 200 gpm, at pressures up to 300 or even 350 psi may be used. On small to medium size cuts 10 - 20 gpm and 150 psi are common. Rigid set ups are therefore required (Ref. B9, B7).

These high flowrates are a consequence of the higher removal rates. Boiling of the electrolyte must be prevented, and the debris must be carried away.

The high flowrates prevent the debris from attaching itself to the electrode. The result, and a very important advantage over EDM, is that there is essentially no tool wear.

Thus, tool costs tend to be lower for ECM, also because ECM is not used for work with fine detail.

There are at least five major manufacturers of ECM equipment. Metal removal rate is directly proportional to current density, and therefore machines are rated by their power supply. Machines with power supplies from 100 amp up to 20,000 amp are available. The low operating voltages - in the 2 to 30 volts range - facilitate raising the currents.

Price of a 100 Amp machine is about $14,000 (Ref. B11). For 5,000 and 10,000 Amp machines prices are roughly $80,000 and $170,000, respectively.

It is generally believed that ECM, like EDM, will become a major technique (Ref. B9). Including electrolytic grinding, there are at present over 800 installations of the best known make only.

General Electric, General Motors and Ford use it extensively, for deburring jobs mostly. Pratt and Whitney (U.S.A.) have 35 ECM machines, from small 300 Amp up to 20,000 Amp units.

Examples of applications will be given later.

The advantages of ECM are partly the same as those of EDM, such as machining of hard materials, burr free operation, and fluid pressure as only machining force. In addition, however, there are some special advantages (Ref. B7):

(1) No thermal damage.
(2) No residual stresses.
(3) Essentially no tool wear.

What keeps ECM from replacing EDM is its lower accuracy, and the larger gap widths between electrode and work, which make sharp corners difficult to obtain, so that the definition is not as good as with EDM. The requirements of well distributed fluid flow at very high rates are frequently difficult to achieve, and make the process less suitable for complex work than EDM.

Process Variables - Accuracy and Finish

The rule of thumb for rate of metal removal is .1 cuinch/min per 100 Amp of current, but varies between about .13 cuinch/min for iron, and about .06 cuinch/min for tungsten. It rises linearly with current density, so that the shape, which determines the rate at which the electrolyte can carry away the debris is usually the limiting factor.

Penetration rates therefore vary between about .5 inch/min for a round through hole, and about .25 inch/min for simple cavities (Ref. B9).

Most metals are machined using a simple sodium chloride solution. Sulfuric acid is used for a few other metals. Much sludge is produced in the salt water solution, and since concentration and a clean electrolyte are important, filtration is often a considerable problem at the high flow rates (Ref. B7, B9, B11).

Obtaining proper distribution of electrolyte flow, by means of holes through the electrode, rates as one of the main problems.

Conditions must be controlled to ensure good accuracy. For example, high electrolyte temperature is desirable, to increase conductivity. But from 75 to 160 °F conductivity increases by about 100% , which would just about double the gaps between tool and work (Ref. B7). Constant voltage operation is usually preferred to constant current control.

Copper, brass, stainless steels and titanium are used as electrode materials. When cutting, for example, a round hole, the current should be directed ahead of the cutting face. This requires good insulation of the sides of the tool. Not all problems in this connection have been solved as yet.

Finishes obtained average about 20 to 30 microinches for careful work. Tolerances of ± .001" are possible under carefully controlled conditions, but 3 to 5 thou are more reasonable. The gap between tool and work is usually about 2 to 3 thou, limiting the definition obtainable.

Applications

Electrolytic grinding, where the electrolytic action is augmented by some abrasive action of the particles of the grinding wheel, was the original application, and is still used extensively. It has been found to give great savings in the wear of expensive diamond wheels.

Good examples of the cost cutting abilities of ECM are found in References B8, B10, and B11. The time for making a die for pipe elbows was reduced from 14 hours to 10 minutes. Automotive connecting rod dies are sunk in about 16 minutes. Individual blades are machined at the circumference of a titanium turbine wheel, at the rate of about 1 minute per blade, using four machines to work on two wheels simultaneously. ECM reduced the cost of machining square holes in die buttons to $1.60 per part, from the $8.60 cost using EDM (± .002" accuracy was maintained). Another example of cost reductions sometimes obtained by replacing EDM by ECM is the drop from $309.25 to $14.00 in deep hole drilling of turbine parts.

ECM is used extensively for deburring operations and frequently yields great savings over conventional methods (Ref. B8).

Some companies (Ref. B11) do not hesitate to use ECM for lot runs of as few as 6 pieces in ordinary steels, and many obtain productivity improvements of up to 400% in using ECM on ordinary steels in runs of 50 to 200 parts.

III. ULTRASONIC MACHINING. CHEMICAL MILLING. WELDING

Ultrasonic Machining

EDM and ECM are limited to conductive materials. Ultrasonic machining can be used to machine very hard non-conductors (Ref. B5). This process is relatively old, and a number of Canadian companies have machine tools for ultrasonic machining. The machines are generally small, and may cost about $12,000. Smaller and lower priced bench models are available.

The machines have an electronic generator which generates power at a high frequency of about 20,000 cps. A transducer then converts this electrical energy into mechanical energy, and causes high frequency linear oscillations of the tool, with amplitudes which can be varied between about .0005 and .004 inches by choosing from a range of specially shaped tool holders.

An abrasive slurry, using boron carbide, silicon carbide, or aluminum oxide particles, is circulated between tool face and work. The fast oscillation of the tool face drives the abrasive particles into the work surface at very high speeds, machining away minute particles of the work, and generating the mate of the formed tool in the work.

The coarser the abrasive grit, and the more brittle the material, the faster will the machining be. Glass can be cut at the rate of 0.25 inches per minute. Finish, using a fine grit, can be 10 microinches.

The tool, usually made of soft copper or soft steel, wears, so that accuracy depends on the number of parts made or the number of tools used. Also, there is the tapering effect, as in EDM and ECM, when drilling holes. Tolerances down to ± .0005" are possible, but Northern Electric in Ottawa feel that ± .002" for the first part is probably more reasonable.

The process is good only for hard materials, such as carbides, ceramics, glass, quartz, etc., and cannot be used for soft material.

Northern Electric use their machine mostly to dice small transistor wafers out of a disc, using a "honeycomb" type of tool. This is a common application. So is slicing of the disc from which the wafers are cut, from a bar of transistor material, usually with a tool consisting of a number of parallel knife edges, to take a multiple cut.

ISF Electro Methods have used their machine to drill 4 thou holes through carbide, and 2 thou slots in hard steel.

The method is also used for machining glass, cutting gems, machining odd shaped ports in hydraulic valve sleeves, sinking complex shapes of blind and through holes, engraving, etc.

The removal rate is on the average considerably lower than that of EDM, say by a factor of 5, so that application tends to be limited.

Chemical Milling

This is an etching process (Ref. B15). Masking is applied to areas which must not be machined. The process is used extensively in the aircraft industry, to take shallow cuts from large sections. Particularly when the surfaces are curved or the sections thin, this is a very economical method of reducing the weight of aircraft components. It can also be used to machine tapers and other formed sections, by withdrawing the part from the etchant at a controlled rate.

Many parts can be milled simultaneously, on both sides, in the etching tank. Etching cuts deeper than about 0.5 inch are not recommended. The rate of etching is about .001 inch/minute. For shallow cuts ± .002" is a reasonable tolerance. A finish of 30 to 125 microinches can be expected.

The limitations of the process are:

(1) Surface irregularities in most cases are reproduced, and tend to be accentuated on deep cuts.

(2) Corner fillet radii are about equal to the depth of cut.

(3) The process is not suitable for taking narrow cuts or for cutting all but a narrow land.

Friction Welding

The number of welding methods which have reached production status in recent years discourages an attempt to discuss them here. Detailed discussions of many of these techniques can be found in a Special Report on Welding in the

May 1964 issue of Canadian Metalworking/Machine Production; in a Special Report, "The Status and Future of Metals" , in the Jan./Feb. 1965 issue of Product Design and Value Engineering; and in Reference B25. Methods discussed are: Plasma Arc Welding (plasma arc cutting torches are used in Canada), Electron Beam Welding, High Frequency Induction Butt Welding, Electroslag Welding, Explosive Welding, and Pulse-Arc Welding. Most of these methods are rather specialized, and applications in Canada are few.

Friction welding, which is not covered in these references, was first introduced in the U.S. about 4 to 5 years ago, and appears to be a process of which considerably more will be heard in the future (Ref. B26, B27, B28). The method consists of holding one part stationary while rubbing (by rotation) the other part against it, under application of pressure. This heats the material at the interface, and at a critical point the rotation is stopped, and the parts are forced together under increased pressure. It is also possible to use a reciprocating rubbing motion, so there are in principle no geometrical restrictions, but in all applications to date at least one of the parts has been round.

In October of 1964 there were only 11 friction welders in operation, several of them in production. But 7 more machines were being built, and the applications indicate the potential:

(1) Automotive drive shaft (steel stubs welded to the end of a tubular section, in 4 seconds, at estimated savings of 6 cents over conventional arc welding, and with better tolerances and therefore less straightening and balancing.)

(2) Steering shaft and wormgear assembly (in 8 seconds, at estimated savings of 8 cents over conventional flash welding, and reduced scrap rate).

(3) Automotive axle shaft assembly (in 21 seconds, at estimated savings of 5 cents over conventional forging).

(4) Welding of shanks to pinions, splined sections, valves, and bicycle steering forks.

As a rule of thumb, 10 hp is required for each square inch of friction area for mild steel. Available machine capacities range from 15 to 300 hp.

Advantages of the process are claimed to be:

(1) Economical use of power, since heat is developed where it is needed.

(2) Lower initial costs of the equipment.

(3) Entrapped materials are forced out of the weld zone, and little surface preparation is required.

(4) The process can weld dissimilar metals, such as brass to copper, and brass to aluminum.

(5) No weld spatter, and narrow heat affected zones.

(6) Speed of operation .

The major limitation of the process at the present time appears to be the selection of contact pressure, rubbing speed, welding time, and final forging pressure, which usually requires trial and error welding for any particular application. Depending on parts and materials, rubbing pressures vary from 4,000 to 28,000 psi, forging pressures from 8,000 to 60,000 psi, rotational speed from 1700 to 5600 rpm, and welding time from 3 to 21 seconds (Ref. B28).

It is probably reasonable to expect that this trial and error approach will be largely replaced by definite guides as more experience is gained with this new process.

IV. DEVELOPMENTS IN FORMING

The following methods, some considerably more established than others, will be discussed briefly:

(1) Internal Contour forming.
(2) Power spinning.
(3) Fluid forming.
(4) High-energy-rate forming.
(5) Urethane rubber die forming.

(1) Internal Contour Forming

Hollow cylindrical stock is placed over a mandrel with the shape of the desired internal profile, and is squeezed by rapidly pulsating forming dies as they rotate around the outside diameter of the work. Parts from 3/8" to 3" O.D. can be formed, with good accuracy and finish.

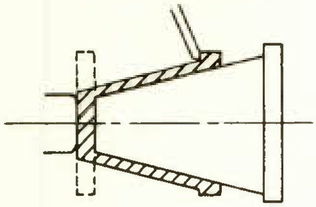
It has been used for forming internal splines, ratchets, sockets (for wrenches), trim dies, laminated tubing, etc. The form need not be symmetrical.

Production rates vary from about 300 parts per hour for an internal ratchet to about 25 parts per hour for rifle barrels, with form chamber and rifling. Set up time is of the order of 20 minutes.

(2) Power Spinning

In power spinning, or shear spinning, the work is forced to take the shape of a hardened rotating mandrel. As shown in Figure B3 , this is done by a shearing deformation.

FIGURE B3



POWER SPINNING

The operation is usually performed cold, resulting in work hardening and increased tensile strength. A finish of about 20 to 30 microinches can be obtained, and tolerances of about ± .002". The hardened rollers which form the work are mounted on the machine slides, which in turn are controlled by templates. A variety of machine models are available.

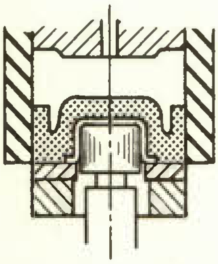
The process is applicable to and used for a wide range of parts with symmetry about an axis of revolution, such as diffusor cones, lamp bases, missile nose cones, television cones, truck wheel rims, and even lamp posts (aluminum). It is also applied for tubular parts. For example, an 8 3/4" long tube with an inside dia. of 3" and .155 wall thickness was spun in one pass to a 31" long tube with the same inside diameter, and a wall thickness of .030" over most of the length.

(3) Fluid Forming

This is not a new process, but has shown increased growth since the introduction of automatic high production presses a few years ago. The method is also applicable to short runs since tooling costs are relatively low.

The process is illustrated in Figure B4. A fluid chamber is sealed by a flexible die member. This chamber is lowered on the flat blank lying on the blank holder ring. Initial pressure is applied to hold the blank down. Then the punch rises, and the controlled hydraulic pressure "wraps the metal around the punch".

FIGURE B4



FLUID FORMING

A range of press sizes is available. Production rates from 600 - 1800 strokes per hour are possible, but 300 - 600 parts per hour are considered more realistic for complex parts. The punch may be cast or machined from steel, cast iron, aluminium, brass, kirksite, or even wood.

The process has a number of important advantages (Ref. B16, B17):

(1) The female half of the die is eliminated, with obvious savings.

(2) No tool alignment problems, and blank thickness is immaterial.

(3) The rubber pad does not mar the surface, frequently saving considerable finishing costs.

(4) First draw reductions may be 1 1/2 to 2 times those in conventional deepdrawing because the metal is held tightly against the sides of the punch, so that all pull is not against the top of the punch.

(5) As a consequence, there is also less thin-out, and blank thickness can sometimes be reduced by 30%.

One application is cookware, frying pans with teflon coating being a particularly interesting example.

The Cincinnati Milling Machine Co. gives the example of a water pitcher body, drawn from a 12" dia blank of .032" copper to a depth of 6 3/16" and a maximum diameter of 4 7/8" in one draw, at a saving of 70% over the conventional multi-draw operation in direct labor cost, and almost 90% tool savings.

References B16 and B17 give a number of good examples, including irregularly shaped parts with concave sections. The advantages of this method deserve serious consideration.

(4) Forming and Drawing with Urethane Rubber (Ref. B18)

Here the punch pushes the sheetmetal into a thick pad of urethane rubber, which then forces the sheetmetal to deform to the shape of the punch. An important application is on press brakes. Massey-Ferguson Ltd. has experienced working lives of over 30,000 strokes per pad, provided the depth of punch indentation does not exceed about one third the thickness of the rubber pad.

The process has also been adapted to deepdrawing.

(5) High-energy-rate Forming Methods

(References B19, B20, B21, B22, B23, B24.)

There are a number of methods in this group, differing in the medium used to generate the forming forces. These methods are based on the fact that a metal can withstand higher than normal stresses and deformations provided the load is only applied for very short time intervals, of the order of microseconds. An additional advantage is that springback is generally quite small.

(a) Explosive forming

Both high and low explosives are used. High explosives are often an economical means of forming large and heavy sections, since it is a cheap energy source.

Of more general interest are perhaps flexible sheet explosives, which have been used by Dupont of Canada for workhardening of irregular surfaces, such as switches in railway track equipment, and can also be used for cladding.

(b) Electrohydraulic forming

An electrical spark is discharged under water and produces shock waves which deform the metal into the shape of the die. Repeated shots may be used. Tubular bulging, and forming of flat blanks into die cavities are good applications.

Production machines are available. Through adjustment of the voltage, control of the process is better than with the use of explosives.

An example of application is a wheel cover with radial ribs. It is also possible to make internal and external threads in tubing.

(c) Compressed gas forming and forging

Compressed gas is released instantly from storage, and drives the ram to high velocity. For application to forming, the ram is driven into a liquid, which then forces the blank into the die.

Application to forging is more common, and here the action is somewhat similar to that of a drop hammer, except that the pneumatic-mechanical press can do more work in a single blow. If a number of blows are required a drop hammer is considered more advantageous. This process is sometimes considered to be the most promising of the high-energy-rate forming methods. It has reached full production status, and at least two makes of machines are available. Gas pressure and stroke length are adjustable. Most work is in super alloys and exotic materials, for example molybdenum.

Bendix Corp. also use their machine for precision forging, holding tolerances of ± .005". They have recovered their investment in 14 months, doing a variety of parts at rates up to 50 pieces per hour.

(d) Magnetic forming

This process uses magnetic forces for forming. The energy stored in a capacitor is discharged suddenly into a coil held close to the conducting workpiece. This induces currents in the work, which create a secondary field. The repulsive forces between the two fields form the work into the die. Pressures up to 50,000 psi are generated in pulses lasting about 10 to 20 microseconds.

This process has also moved onto the production floor, and several machine models can be bought.

One application, using flat pancake coils, is the forming of a flat blank into a die, for example to form reinforcing ribs. Applications also exist in blanking, piercing, and shearing.

Operations on tubular parts, however, are most common. A tube can be bulged into a die, or into another part, by placing the coil inside it, and it can be forced onto a mandrel, or onto another part, by a coil on the outside. These operations in many cases cannot be performed as economically by other means.

Most applications are in the assembly of ringshaped parts. For example, attaching fittings to tubing, expanding tubing into bushings, swaging fittings onto hydraulic hose lines, swaging an aluminium ring onto a ceramic bushing, swaging a copper terminal cap onto a thin fiberglass cylinder, swaging terminals on cables, etc.

Aluminium tubing from 0.5" to 11 5/8" dia, and wall thickness from .040" to .125", has been swaged onto end fittings. Because of the space required for the coil, the minimum tube diameter for bulging is about 1".

The method is used also, for example, to swage square tubing onto end inserts, using a suitably shaped coil. One mass production job done by magnetic forming is to shrink clamping rings onto ball-joint rubber seals.

The principal limitation of the process is the design of the coils, which must be able to withstand Ohmic heating effects and the mechanical reaction forces of the forming operation.

SECTION 3

IMPROVING THE PRODUCTIVITY AND VERSATILITY OF MACHINE TOOLS

IMPROVING THE PRODUCTIVITY AND VERSATILITY OF MACHINE TOOLS

Introduction

Five topics related to the increased productivity and versatility of machine tools will be discussed.

(1) Numerical read-out conversion of existing machine tools.
(2) Contour tracing attachments.
(3) Abrasive machining.
(4) Cutting tools.
(5) Peg board control of machine cycles.

Numerical Read-out Conversion of Existing Machine Tools

"Read-out" is a measuring system which measures the displacements of the machine tool slides from a datum point, and displays the result in digital form, on counters.

Installation on existing machine tools does not require much rework, and is certainly a relatively simple and low cost approach for upgrading the productivity of many machines.

Ferranti started about a year ago to adapt the measuring system of their well known measuring machines to this application. At present it has been installed on about 20 machine tools in the U.S., and on another 20 in the U.K. Ferranti in Toronto are converting an old knee-and column type milling machine, with about 5 thou slops in the drives.

These errors do not affect the results, since measurements are taken directly off the machine tool slides. Measurement is based on the Moire fringe concept. A grating assembly must be mounted on the machine tool slide along the length of travel. A photoelectric reading head, mounted adjacent to the slide, counts the number of fringes. A digital read-out shows the total count.

Most installations are two-axis. The cost of reading heads and counters is then about $6500. The cost of grating and of machine tool conversion for mounting gratings and reading heads, both depending on type and size of machine, must be added to this.

However, Ferranti can provide case studies showing that users are getting a fast payback on their investment. The system has been installed on many different types of machine tools, including jig borers, horizontal boring, milling and drilling machines, lathes, and planers.

From the fact that time consuming measurements are performed automatically and accurately derive many advantages similar to those of numerical control.

(1) Higher utilization, and reduced set-up and machining time. Users report savings up to 40%. Using the read-out, positioning from hole to hole on a jig borer is quite fast, and less time is spent on checking dimensions. A zero reset button permits the operator to set the datum position anywhere, and speeds set-up.

(2) Reduced tooling cost. As with NC, the machine ensures accuracy, and eliminates the need for a jig.

(3) The ease of checking dimensions on the machine has reduced scrap and rework. and has improved accuracy for a number of users.

(4) Reduced inspection time is also reported. A print-out unit, as a permanent record of actual dimensions, is optional.

Ferranti provide a number of case studies comparing conventional manufacture, tape control and read-out. Numerical control reference no. 26 also gives an example of this nature. For most efficient operation read-out also requires some pre-production planning. Therefore, if conventional manufacture does not require any special tooling it may be most economical for very small lot sizes. Then, typically, may follow a range of lot sizes where read-out gives lowest cost. For larger lot sizes the automatic cycle control of NC pays off. If conventional manufacture does require special tooling, then read-out tends to show lower cost up to a critical lot size where NC becomes more efficient.

The table below gives times and relative costs (shown in brackets) for the example, courtesy Ferranti Electronics, of a rectangular plate with about 60 holes, using 13 tools to drill, counterbore and tap.

Machine Tool:	NC Turret Drill	Conventional Drill	Coordinate Drill with read-out
Planning: Tooling	1.5 hrs(1.5)	40.25 hrs(50.25)	0.6 hrs(0.78)
Set-up	2.0 (3.0)	1.0 (1.0)	0.3 (0.34)
Machining	0.25 (0.36)	1.12 (1.2)	1.2 (1.56)

Comparing tape control and read-out, the break-even point is at a lot size of 4. For a single part the cost with read-out is about half of that using tape control, while for a lot size of 20 this situation is exactly reversed. At a lot size of 25 the cost using read-out is half of that with conventional manufacture, and only for very large lot sizes will the somewhat lower machining time of conventional manufacture be able to offset the tooling cost to show an advantage over read-out. In fact, in most of the other case studies available, the curve for cost of conventional manufacture vs lot size rises more steeply than that using read-out.

Contour Tracing Attachments (Ref. B33, B34, B35).

Compared to Numerical Control Contouring Systems, tracing attachments certainly represent a low cost contouring capability. Also, even for short runs on simpler parts these attachments can frequently give marked increases in productivity. If a job involves more than about three hours total running time, including set-up, a tracer can be about two to ten times faster than conventional operations. (Ref. B34) In some cases it may be advantageous to do certain operations manually. Actual savings on all Mimik tracing attachments installed in the two years prior to 1962 averaged 44% over conventional methods, according to a 1962 report.

The renewed interest of the last few years in tracing attachments is due to the increased versatility of modern systems, and the ease of fitting them to machine tools. In fact, one can easily transfer an attachment between several similar machine tools, as the need arises.

The Mimik tracing attachments of Retor Developments, in Galt, are available in a range of sizes, and can be mounted on lathes (horizontal, vertical, turret), shapers, planers, and milling machines. Besides the simpler single-axis systems, where the machine tool itself provides the constant feed for carriage or cross slide, while the attachment traces, one can also install a hydraulic motor to drive this member, and obtain constant feed along contours by the modulated feed control provision of the system, which controls the flow to the hydraulic motor. Modulated feed control permits the tracing of 90° opposed shoulders.

The potential savings and the low investment required make contour tracing attachments worthy of consideration in most machine shop operations.

Abrasive Machining

Abrasive machining is done on a grinding machine, using a grinding wheel, but is different from ordinary grinding in that not finishing but metal removal, in direct competition with turning and milling, is the purpose of the operation.

If grinding feed rates are increased from low values then, after a range over which good parts are produced, a point will be reached where the part surface will show burns. Instead of backing off, the operator should be trained to increase the feed rate still further, because there comes a point where the abrasive particles are replaced faster than they dull, so that free cutting action is restored.

Now, high removal rates are nothing unusual for snagging grinders, used for example to clean up castings, and modern slab grinders and billet grinders can remove over 500 lbs/hr. However, it is only since about 1961 that abrasive machining was defined as a primary metal removal process for general machining.

The advantages are greatest on high power grinders, with spindle power from 75 to over 125 hp. But it is also quite practical on the usual 25 to 35 hp machines (Ref. B31). Instead of using these machines far below capacity, as is usually the case, they must work at close to 100% of rated spindle power, using the highest feed rates compatible with the desired tolerances and the rigidity of the machine.

Availability and selection of grinding wheels is still a considerable problem, and usually requires testing for a given application (Ref. B30, B31, B32). The heavy stock removal requires a coarser and harder wheel, but at the same time the wheel must be soft enough to be self-sharpening.

Advantages of the process are:

(1) High metal removal rates (Ref. B29b, B29c, B29d, B30, B31). Gray iron has been machined at the rate of 40 cuinch/min on a 125 hp machine, taking 1/8" from one side and 3/8" from the other, and achieving .001" flatness. Removal rates for steel are about half of those for cast iron. A gray iron clutch pressure disc has been ground on a 40 hp machine to a flatness of .0005", at the rate of 5 cuinch/min.

(2) Reduced stock allowances on castings and forgings are possible, since a grinding wheel does not have to cut well under the scale.

(3) Secondary finishing operations are eliminated.

(4) Parts can be redesigned to reduce machining area to a minimum without fear of interrupted cuts.

(5) Although abrasive machining requires much more power than milling at the same rate (about four times as much for cast iron), the power required to remove one cuinch/min decreases with increasing feed rate. This can be particularly helpful for applications to low-power machines (Ref. B29c, B31).

(6) Fixture costs are frequently lower, because of the use of magnetic holding, and a number of parts of sufficiently small size can perhaps readily be machined simultaneously.

(7) Minimum production costs occur at a feedrate beyond which increasing wheel costs outweigh the gains due to increased productivity. However, it has been found that frequently higher feed rates can be used with relatively small increases over minimum costs.

According to a survey (Ref. B32), about half of the users have experienced problems, burning being the principal one. Finish, work hardening, wheel life, and equipment feed and speed limitations were also mentioned as problems. Many plants are still sitting on the fence as to whether they will increase use of abrasive machining, or start to use it. Allis-Chalmers Manufacturing Co. expect a return of 28% on a $20,500 investment in abrasive machining, but give it less than all-out endorsement, using other methods where these are more profitable.

The application of abrasives to disc cutting is well known. Apart from this, the method is used mostly for surface and form grinding operations (Ref. B29c, B29d, B30). Cylindrical operations are still relatively rare. An example of combined operations is the production of taps, finished from hardened high speed steel blanks.

Ref. B29d gives an example of abrasive machining of a gray iron casting on a vertical spindle rotary table surface grinder with 35 hp at the spindle. About 1/8" must be machined from top and bottom. Changing from milling on a 20 hp vertical milling machine using an 8" carbide tipped face milling cutter, set-up time was reduced from 34 min. to 14 min., machining time from 26.18 min. to 20.72 min., tool cost per piece from $.524 to $.382, and machine operating cost increased from $.073 to $.136. Total cost per piece fell from $2.346 to $1.900. The Norton Co. can provide numerous similar examples, usually showing higher savings.

Cutting Tools

Throwaway carbide tips are gaining increasing acceptance in Canada. Carefully ground to size, the tip can be indexed to expose a new cutting edge. When all have been used up the tip is disposed of, so tool grinding is eliminated. These inserts are also used on milling cutters.

To date, ceramic cutting tools have, to put it mildly, not been a success in Canada. Annual sales of carbides represent a dollar value at least 500 times that of ceramics. Brittleness and the need for heavy machine tools are the main problems. However, quite a few remember much the same type of problems with carbides, and most expect increased use.

Ceramics have been quite successful for special applications. In the turning of cast iron brake drums, which requires a continuous cut at high speed, ceramics permit 2 or 3 times the speed of carbides, and have saved $15,000 on 240,000 parts.

Peg Board Controls

Several makes of turret lathes and milling machines are available with peg board controls. The machine tool can be programmed for any sequence of operations within its capacity, including feeds and speeds to be used, by inserting plugs in a peg board or drum.

Depending upon make, at least two different methods are used for setting lengths of travel. In one case the next event is triggered by limit switches tripped by dogs. In another, stroke lengths are set on rotary cam discs.

Quick set-up of the automatic cycle makes these systems suitable also for short runs. Peg board systems are most useful where the type of control required is mainly functional.

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OTHER PAPERS PREPARED FOR THE CONFERENCE

"PRODUCTIVITY THROUGH NEW TECHNOLOGY"

TORONTO, MAY 27-28, 1965

The following papers prepared for the Conference are also being published by the Economic Council of Canada. They are available from the Queen's Printer, Ottawa. A brief description of the papers begins overleaf.

The views expressed in the papers are those of the authors themselves.

MODERN MANAGEMENT, by Gerald W. Fisch; Price 50¢; Catalogue No. EC 22-4/1

PRACTICAL APPLICATION OF DATA PROCESSING IN MEDIUM-SIZED AND SMALLER MANUFACTURING COMPANIES, by H. S. Gellman and R. C. Carroll; Price 75¢; Catalogue No. EC 22-4/2

A PRACTICAL APPROACH TO AUTOMATIC PRODUCTION, by J. W. Abrams, R. W. P. Anderson and Donald J. Clough; Price 50¢; Catalogue No. EC 22-4/3

IMPROVING MATERIAL MOVEMENT THROUGH THE MANUFACTURING CYCLE, by J. A. Brown and B. D. Beamish; Price 50¢; Catalogue No. EC 22-4/5

THE ECONOMIC JUSTIFICATION OF NEW EQUIPMENT, by C. G. Edge; Price 75¢; Catalogue No. EC 22-4/6

The following two addresses delivered at the Conference are available without charge from the Economic Council of Canada, Post Office Box 527, Ottawa.

OUR CHANGING ECONOMY, by John J. Deutsch
Chairman, Economic Council of Canada

TECHNOLOGY AND PEOPLE, by William Dodge
Executive Vice-President
Canadian Labour Congress

MODERN MANAGEMENT, by Gerald G. Fisch

Mr. Fisch is Managing Partner of P. S. Ross and Partners, Management Consultants, and a Principal of Touche, Ross, Bailey and Smart, Chartered Accountants.

This paper is a concise account of the widespread successful application of some of the new techniques, new approaches and new concepts of business management now being used in or available to businesses in Canada. The author points out that these new techniques involve greater precision in management. He argues that this precision -- and an end to the old "seat of the pants" approach to management -- is demanded by the accelerating tempo of change, the demands of a growing ambitious population, and the pressures of rapidly developing technology.

PRACTICAL APPLICATION OF DATA PROCESSING IN MEDIUM-SIZED AND SMALLER MANUFACTURING COMPANIES, by Dr. H. S. Gellman and R. C. Carroll

Dr. Gellman is Vice-President, Research and Analysis, and Mr. Carroll is Chief Analyst, of DCF Systems Limited, Malton, Ontario.

At the beginning of 1965 there were more than 24,000 computers at work in the United States and approximately 650 in Canada. This paper is designed to show the managers of small- or medium-sized manufacturing companies what can be done with some of the modern equipment for automatic data processing, towards improving the operation and control of the business. The paper includes the results of a questionnaire survey of several hundred Ontario companies on their use of data processing. Thirteen case studies show the actual cost, application and benefits of ADP in the individual companies.

IMPROVING MATERIAL MOVEMENT THROUGH THE MANUFACTURING CYCLE, by James A. Brown and B. D. Beamish

Mr. Brown is a Partner in Woods, Gordon and Company, Toronto. Mr. Beamish is an automation consultant in Toronto.

This paper is broad in scope, describing how firms might reduce or eliminate material handling and minimize the movement of material through the manufacturing process and to the customer. It pays particular attention to the new developments in the shipment of raw materials and finished goods, warehousing, in-plant handling, and handling at the workplace. One of the authors' findings from a survey of manufacturing companies in Ontario was that few if any of the firms had usable data on their material-handling costs.

A PRACTICAL APPROACH TO AUTOMATIC PRODUCTION, by J. W. Abrams, R. W. P. Anderson, and Donald J. Clough.

Mr. Abrams and Mr. Clough are Associate Professors, and Mr. Anderson an Assistant Professor, at the University of Toronto. All are members of Systems Engineering Associates Limited, Toronto.

Their paper is designed to focus attention on some of the thorny, practical problems faced by small Canadian manufacturing companies as a result of technological change. The objective is to give small companies some indication of the major factors in mechanization. The paper includes a definition of automation and mechanization; a discussion of ways that automation was approached by 12 representative Ontario firms surveyed by the authors; certain observations and conclusions resulting from that survey; and an outline of the more important technological, economic and other factors that must be considered as mechanization is implemented.

THE ECONOMIC JUSTIFICATION OF NEW EQUIPMENT, by C. G. Edge

Mr. Edge is Director of Management Services for Chemcell (1963) Limited, and Assistant to the President, Columbia Cellulose Limited.

This is a paper on how to appraise capital expenditures through the use of sound methods of relating the future benefits to the outlay, estimating future benefits, and administering and controlling projects. Various methods of determining the economic justification of capital expenditures are discussed but emphasis is given to the use of the Discounted Cash Flow method. Three ways of using the DCF general method are described -- internal rate of return, present value, and equivalent annual costs. Adequate examples plus tables and charts provide sufficient information for the understanding of the significance of each of these methods.