Modern Numerical Controlled Cutting Machines and Data Preparation for these by means of Mini Computors

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1. The drawing has always been the fundamental instrument for the mechanical production. It is therefore also used for the flame cutting process as the carrier of information. For this reason the oldest stationary cutting machines had already been equipped with a table for positioning a drawing or a template which had been a 1:1 scale picture of the workpiece to be manufactured.

The drawings had to be traced manually by means of a roller head whereas the templates had been followed by means of magnet or band drives. The accuracy when using templates in quite good if these are manufactured precisely. But a good template is expensive and only economical if large quantities of the same component have to be cut. The first stationary cutting machine came on the market in the twenties.

The machines had been designed as cantilevers or cross carriages whereby the tracing table had been positioned between the rails and the cutting area underneath an outrigger arm. The machines had to be stable but light in weight to achieve a minimum of drive force for a smooth and clean cut.

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A talk on this was given by Mr. Strauss to members of the Calcutta Branch of the Institute in October, 1979.

After the Second World War, the development started of an automatic tracer, the photo-electric tracing head. This unit allows an automatic following of black and white drawings with a good accuracy. The photo-electric tracer substituted through the years, nearly completely, the hand and template tracing systems. It is still used today in the majority of cutting machines and it is quite an economic way for guiding a machine to produce contoured components.

Many small and medium size manufacturers will use this system also in future. The economical limitations will show up if large quantities of different components have to be manufactured.

The development of the photo-electric tracer has been followed by the introduction of the so-called coordinate drive system whereby the movement of the machine was not more done by means of a knurled wheel running on the tracing board but by means of two motors, one for the longitudinal (X) direction and one for the transverse (Y) direction. The two motors are controlled by a sine-cosine resolver which is geared to the photo-electric tracer. This system created the basis for building larger and heavier machines and is still used for driving NC-controlled cutting machines.

The drawing in scale 1:1 proved to be not very practical for the production of large components used for example in shipbuilding. For this reason, machines have been developed which are working on reduced scale drawings. The first machine of this type had been the Schischau Monopol Machine which worked after negatives in scale 1:100. The machine had been a success on the market for many years especially in shipbuilding. It lost its potential in the early sixties due to limited accuracy and plate capacity.

The era of machines working from drawings in scale 1:10 and 1:5 started around 1960 and a lot of companies are still using this system. The machines, equipped with coordinate and rack and pinion drives are built in any required size. But the optical system does not allow a full automation of the cutting process. The operator has still to position the machine manually at all starting and marking points.

To automise the cutting process, the numerical control system had been introduced already in an early stage. The first NC-controlled flame cutting machines had been built in 1957 by BOC. The machine which was equipped with a magnetic tape control was actually too early on the market and the industries not yet prepared for this type of automation. The time for NC-controlled cutting machines started around 1965. But also then the introduction went quite slow. Only in the last five years a strong up-trend has been recognized. The reasons for this are the steady increase of labour costs which forces the industries into more automation with higher accuracy, and the development of electronic components which allow the manufacturers to offer today cheaper NC-controlled machines than at any time before.

A NC-controlled cutting machine is no longer an investment with a long pay-back/period. It is a full automatic tool in the production process like a NC-controlled lathe, drilling machine or boring mill. Another reason for the reluctance of the industries against the new system is the neutrality of the data carrier. A drawing provides for every technical person a good information of the work to be done. A punched or a magnetic tape is an element in which an engineer has to put his full trust without seeing anything.

But today systems are available which allow a programmer to prepare and to check his work so that reliability could be guaranteed. Mini computors and plotters give a first class help and more information to the production control than ever before. A further advantage of the development of the NC-controlled cutting machine is the possibility to use it as a full automatic marking machine.

2. Basic Design Features for NC-Controlled Cutting Machines

2.1 The machine must be rigid and equipped with drive systems to allow speeds up to 5 m/min. (in special cases 10 m/min.)

2.2 The drives must be designed for high accelerations and decelerations to achieve sharp corners also at high speeds.

2.3 For large machines, double side longitudinal drive is necessary.

2.4 A full portal machine provides maximum flexibility for the use with different sizes of plates positioned between the rails.

2.5 The machine rails should be lower than the workpiece table to allow safe loading and unloading.

2.6 Flame cutting machines are working in a dirty atmosphere. Therefore the construction must be simple and easy to be cleaned. All bearings and critical elements must be sealed against dirt and dust.

2.7 All components which may fail must be easy and quick to replace.

2.8 All elements which are suffering under wear must be adjustable and easy to replace.

2.9 The gas supply system should be widely automised to get a constant pre-heat and cutting pressure and a full automatic ignition and piercing process. Anti-backfire units for safety must be built in.

2.10 All carriages for single and multi burner cutting heads must also be attachable for punch and line marking systems.

2.11 For cutting thick materials above 100 mm air cooling must be provided.

2.12 The machine must be designed for use of plasma torches and Lasers.

3. The Influence of the type of Information Carrier in relation to the accuracy of the flame cutting machine.

The drawing in scale 1:1 as an information carrier is still and will in future also be used for workpiece sizes up to 2 or 3 m². This will be also the case if a number of smaller components should be cut out of one plate of the above-mentioned dimension. If the drawing in scale 1:1 gets large it is difficult to make and store it, and in addition the accuracy will be influenced by humidity and temperature changes.

The drawing in reduced scale which can be drawn and handled much easier can be used for workpiece and plate size up to 15 m length. In scale 1:10 the drawing is still only 1.5 m long. But here the problem starts with the accuracy in which this reduced scale image of the workpiece can be produced. The errors made in the drawing are multiplied by a factor of 10.

To avoid these disadvantages the punched or magnetic tape system has been introduced whereby practically no errors at the information carrier have to be considered.

In addition to the high accuracy which is essential for modern production, the use of a NC-control offers a full automation of the cutting process with a high duty cycle. The punched tape contains besides all the datas for the contour of the workpiece sufficient information in form of auxiliary functions to operate the machine independently from the influence of its operator.

Guiding accuracy depending on type of information carrier :

	Drawing 1:1	Drawing 1:5	Drawing 1:10	NC Control
Drawing error	±0.5	±0.15	±0.15	±0
Distortion of drawing	±0.5	±0.1	±0.05	±0
Reading error	±0.2	±0.1	±0.1	±0.1
Sum	±1.2	±0.35	±0.3	±0.1
Factor	1	5	10	1
Errors before C/M	±1.2	±1.8	±3.0	±0.1
Transmission error	±0	±0.1	±0.1	±0.1
C/M error	±0.4	±0.4	±0.4	±0.4
Total possible error	±1.6	±2.3	±3.5	±0.6

The above table is based on the following assumptions :

— Size of components about 3 m long
— Drawing paper with high stability against humidity and temperature change
— Guiding accuracy of the cutting machine does not include distortions of the material due to heat and cutting sequence.

The table shows the extreme accuracy which can be achieved with the NC technique. With mass production of the same components a lot of the drawing errors can be compensated. The advantage of the numerical control lies therefore in single or batch production with a certain reuse of programmed parts when cutting large plates.

4. Productivity of NC-Controlled Cutting Machines compared with Optical Controlled Machines

The NC-controlled machine guarantees a full automatic cutting process from starting and automatic piercing through high speed positioning between the different components and out cuts to finishing the whole process. Due to the high traversing speed, it is possible to produce punch marks and lines in a minimum of time. With optical tracing, the marking process needs manual positioning at the different lines to be marked. Furthermore, it is not possible to position a machine accurately at a specific spot for punch marking.

The NC-controlled machine can work in a point-to-point mode to mark a complete system for drilling holes—for example for cover plates of pressure vessels. Line marking for bending lines of assembling positions can be done with speeds of 5 to 6 m/min by using a metal powder spray gun. The 1 to 2 mm wide lines are clearly visible and last long also under corroding conditions.

Besides the advantage of using a NC-controlled cutting machine also as an effective marking machine, the duty cycles which can be achieved during the full automatic cutting process are much higher than with the semi-automatic controlled optical cutting machines.

From experience, the following productivity can be reached :—

1 : 1 photo-electric controlled machines	45 — 55%
ratio photo-electric controlled machines	55 — 65%
NC-controlled machines	75 — 85%

The following table shows that a yearly production of more than 1000 tons of flame cut components allows already the economic use of a NC-controlled machine. The figure "8 m cut per square m" takes smaller and medium size components into consideration. Larger components and thicker material increase the tonnage capacity of the machine.

Capacity of a cutting machine with 1:1 Photo-Electric tracer and with NC-Control

Material thickness	mm	10		20	
Cutting speed	mm/min.	550		450	
Burner in work	No.	2		2	
Type of control		1 : 1	NC	1 : 1	NC
Duty cycle	%	50	80	50	80
Cutting	m/h	33	53	27	43
Cutting meter per year (2000 h)	m/a	66000	106000	54000	86000
Cutting meter per m² plate	m/m²	8	8	8	8
Tons of cut steel per year	t/a	640	1030	1050	1680

5. Preparation of the Datas for NC-Controlled Cutting Machines

For photo-electric tracing, it is necessary to produce an accurate drawing in the right scale. The smaller the ratio the more care is necessary to draw an exact image of the workpiece to be cut. This means more time is used to draw a 1:10 scale drawing instead of a 1:1 scale drawing. On the other hand a large 1:1 scale drawing takes also considerable time and needs large space.

If a number of components should be cut out of one plate with a minimum of scrap, an extensive nesting plan must be developed. Each component which is repeated in the nesting plan must be redrawn or if possible copied and new positioned.

The programming of components for cutting with NC-controlled machines is in most cases faster than precise drawing. The actual size of a part does not affect the programming time, e.g. a joint plate with a hole in it takes the same time for programming whether it is 200 mm long or 5m long. In many cases, manual programming can be used. Only for complicated components and difficult nesting cases, computor programming is necessary.

5.1 Manual Programming

The contour of a component is described in sections of straight lines and parts of circles. The distance between start and end point of a section and the position of the centre point of a circle are dimensioned in their X and Y coordinates and are written into a table. The working functions for the machine are added at the right positions and the table copied into a punched tape. This provides already a full automatic programme which will be fulfilled by the machine. The manual programming is economical as long as the contours consist of straightlines and circle sections with a limited number of tangential intersections from or into circles. The use of a small electronic table calculator with trigonometrical functions will be fully sufficient. After programming, it is useful to check the programme with a plotter or with the machine. The new low cost machine version has the possibility to check programmes with the machine in the scales 1 : 10, 1 :5 and 1 : 2.

5.2 Computor Programming

Programming by means of a computor requires a suitable software—in other words a prescription of the calculating and storing procedures. There are quite a number of such programmes on the market which can be used, in most cases, on large computors. If the software programme is written in a general language for prescribing and calculating parts it is necessary to add a special post processor which translates the computor language into the machine control language. The important parameters for a post processor are the following :

(a) Code : ISO, EIA or other

(b) Numerical or alpha numerical language

(c) Which contour components will be understood e.g. straightlines, full circles, quadrants or circles, parabolas

(d) Smallest and largest programmable increment

(e) Sequence of informations

(f) Type of auxiliary functions

Computor programming avoids quite a number of informations and calculations normally done manually. The programmer describes the contour in a form of short-hand description and the intersection points between two straightlines and between circles and straightlines are calculated automatically.

The computor programme offers the following advantages :

(a) Straightlines have not always to be defined by start and end point positions. They can be defined by one point, an angle and an intersection with another straightline or a circle.

(b) Circles can be defined by either 3 points or the centre point and the radius or only a radius between two straightlines and the direction or rotation.

(c) Tangential intersections between straightlines and circles or two circles will be calculated automatically whereby only the basic positions of the circles and straightlines have to be defined.

(d) Repeating contour sections and complete contours can be stored and called off and rotated if they are wanted in other positions within the programme.

(e) Empirical curvatures which are defined by a number of points can be split into sections of circles and straightlines which fit into the empirical curve within a given tolerance.

(f) Automatic nesting has been developed from different institutes. This requires a large computor capacity and does not offer such good results than manual nesting. Therefore nesting a number of components together to achieve a minimum of scrap is always done partly manual and partly by the help of the computor.

The above points show generally the great help for the programmer if the right software system for prescribing the parts and for nesting is available. Standard parts description programmes do not always offer all versatilities which a good programme for flame cutting should have.

6. Use of Mini Computors with special software programmes for data preparation for flame cutting machines.

6.1 This development has been done to give the production control a handy instrument for a reasonable price and to get these departments independent from large computors which are in many cases overloaded with commercial tasks.

For shipyards, software systems have been developed which include all steps from the first design with all calculations through the procedure of fairing the ship contours to the development of the single components to be manufactured by means of cutting machines. For machine and steel construction industries with their varieties of different constructions such complete systems are not yet available on the market.

For design and calculations, software programmes are used but they are separate systems for these special tasks. In this stage, the mini computor for the production gives a useful additional help.

6.2 The hardware part of such a system should consist of :

A mini computor with a storage and calculation capacity of about 24 K byte.

A console writer for corresponding with the mini computor. A fast reader and a puncher for reading and producing the punched tapes.

A plotter or a drawing machine for checking the programmes before they are introduced into the production.

A disc storage is necessary in cases where a lot of information should be stored and called off in a fast way.

6.3 The software system is stored in the computor depending on its capacity in one whole or several part programmes.

To achieve an effective programming the following sections must be available :

Parts definition programme for easy description of the contour of a component including all necessary calculations :

Programme for plotting the components;
Nesting programme which provides a series of automatic calculations after establishing manually an optimised nesting plan. The components can be

rotated in any desired angle and the starting points for the cut and the cutting direction can be changed. In addition, bridges can be set to avoid distortion; The programme for management information provides datas as:
cutting length and time, idling time, marking time, weight of the components and the scrap.
Further programmes are available for:
Fairing lines for empirical curves to be translated into parts of circles and straightlines which will be understood from the machine control;
Kerf compensation for complicated contours and large offsets;
Data bank programme for storing of components and curves with a storage disc.

If no disc is included in the hardware, the programme is normally used in two sections :

first parts description
second nesting and management information.

In this case, small punched tapes with the different single components are used for storing.

7. Summary

A higher productivity with a NC-controlled cutting machine against conventional methods will be achieved by :

7.1 Higher accuracy of the whole process

7.2 Shorter production time due to full automation

7.3 Full automatic marking of components before cutting

7.4 Faster programming than exact drawing

7.5 Better usage of material by a good nesting performance

7.6 Easy storage and reuse of programmed components

7.7 Calculations for management information.

The above mentioned points have been duly prescribed and discussed. They lead into a strong consideration for the use of a NC-controlled cutting machine if a yearly production of 1000 to 2000 tons of cut steel is given.

Under these circumstances, a machine can be utilized in a single shift production and it is in most cases possible to calculate an efficiency with a pay back period for the investment of a few years only, especially today when NC-controlled cutting machines with integrated NC-systems are available at the market for prices 40% lower than two years ago.