

The present invention relates to the problem of control of machine tools. Conventional machine tools of the mechanical type, e.g., automatic lathes, are known to comprise cams, i.e., mechanical parts containing the
5 programme for machining the workpieces. Each cam communicates a movement to the tool by a description of the evolute of its profile. The connection between the feeler and the cam is continuously maintained so that the position of the tool is at all times a function of the radius of
10 the cam at the location where it is in contact with the feeler. Such a control may be likened to an open-loop control.

In recent years, besides these conventional machines, so-called NC (numerically controlled) machines have been
15 developed. The various "axes" of the machine are actuated by actuators. The programme calculates a sequence of instructions which are transmitted to regulators, and the motors of the different axes are controlled by these regulators. The control is of the closed-loop type. A
20 sensor gives the position of the axis at all times, so that a comparison can be made between the reference value and the actual value. The deviation determines an adjustment movement.

Moreover the document US-A-3 015 806 describes a
25 numerical control of standard type with linear displacement: starting from two given points, a certain path is defined and gone over at a certain speed, without, however, a pre-established optimal time being associated with each displacement, contrary to the subject matter of
30 the present invention.

The document US-A-4 489 260 concerns the optimization of the speed of displacement between two theoretical points regardless of the path between these points.

Ranges of acceleration and deceleration (Figs. 3 and 4)
35 permit generating optimal speeds. This method is funda-

mentally different from that which constitutes the subject matter of the present invention, since the path to be gone over has not been defined.

The document US-A-3 297 929 describes a control principle of the operational type "start/stop" using a "start/stop" control table set up as a function of time. The levers control the motors which are used solely in the "start/stop" mode, which greatly limits the speeds of use since it is not possible to have there a ramp of acceleration. The permitted displacements are very rudimentary and do not allow optimization of the path nor of the machining times.

In "*Die numerische Steuerung von Werkzeugmaschinen*" by Prof. Dr.-Ing. Wilhelm Simon, Carl Hanser Verlag, Munich 1971, pages 277 to 280, a calculation method is described illustrating the process of interpolation of numerically controlled machine tools. Concerned here is a mathematical proof in which Table 13 shows the result of a calculation as it would genuinely be carried out. On the other hand, the two axes are used successively rather than simultaneously as Figure 20 well illustrates.

It is thus a state-of-the-art method, and is applied in the majority of numerically controlled machine tools.

The object of the invention is to unite the advantages of machines with radial cams (speed of implementation, simplicity) by means of a special arrangement of the control device and with a different conception from that which one encounters in common numerically controlled machines, with data to be stored for commanding and controlling the movements of the axes.

Within this object, the present invention has as a first subject matter a method of controlling programmed displacements, defined in claims 1 to 8 as well as a control device of one or more axes in the machine tool, as set forth in claims 9 to 19.

Thus the invention resides principally in the fact that the simplicity of the open-loop cam-type control system is associated with the flexibility of modern actuators, which may be electric motors, hydraulic axes, etc. A workpiece programme can then be changed within a very short time as compared with that required for cam machines. Moreover, the possible variety of programmes is no longer limited by the finished size of the cams. With the inventive device, however, the advantage of the cam system, consisting in a fully reliable open-loop operation, is retained.

An essential feature of the invention is the concept of what is called the step table. The structure, operation, and development of the step table will be explained below.

To set up these tables, one skilled in the art can use the method of data compression which permits obtaining programmes of reduced length. The tables can be processed by simple machines thus enabling reduction of installation costs, and this without consequences for the variety of possible types of machining nor their precision.

According to one of the characteristics of the invention, one uses for each axis incremental motors or motors with incremental operation. Such motors are, for example, stepping motors or motors equipped with control systems and functioning in an analogous way to a stepping motor. An incremental motor within this patent could likewise be a hydraulic actuator, for example a controlled jack.

Based on the accompanying drawings, several preferred embodiments of the invention and their implementation will now be explained.

In the drawing, Figure 1 is a diagrammatic top plan view of a lathe equipped with a control device according to the present invention,

Figure 2 is an auxiliary graph used in developing a step table for machining a workpiece having the profile shown in the upper right-hand corner of Figure 2,

Figure 3 shows schematically the data contained in the step table which controls the programme forming the profile of the workpiece referred to in Figure 2,

Figure 4 is a partial, simplified flowchart illustrating the control of a turning tool during machining of the aforementioned workpiece.

Figure 5 is a detail drawing showing, in a highly simplified manner, the actual shape of the workpiece machined according to the diagram of Figure 2, and

Figures 6 and 7 are a graph and a diagram analogous to Figures 2 and 3 respectively, but relating to a variation of the step table.

The overall design of the machining apparatus equipped with the device to be described does not present any special particularities. The different axes are driven by incremental or incrementally operated motors.

The control device comprises a computer programme. The machining of a workpiece comprises the writing of a programme having as its essential element a step table. Starting from a predetermined profile of a workpiece P, the movements of the X- and Y-axes are traced step by step; and the cumulated intervals of time for producing the required movements, as a function of the characteristics of the machine and of the workpiece, are stored in the form of a table containing the movements Δt_{xi} and the movements Δt_{yi} . Readings of the steps carried out as a function of a suitable clock signal generator bring about the successive transmission of pulses which cause the X and Y axes to take their successive steps.

In Figure 1, a frame 2 disposed on a base plate 1 supports a headstock 3, the spindle of which is equipped with a chucking clamp 4. A bar 5 to be machined projects

at the front of headstock 3 and passes through a barrel 6 so that the end of bar 5 is situated opposite a turning tool 7 integral with a tool slide 8. A spindle motor 9 rotates clamp 4. A headstock motor 10 causes headstock 3 to move forward and back. The controls for opening and closing clamp 4 are not shown. A motor 11 moves tool slide 8 on a guide-block 12 so to control the radial position of the tool relative to the axis of rotation of bar 5. The machining of a repetitive profile on identical 10 workpieces formed successively in bar 5 involves a task in the X and Y axes, the X axis materialized by motor 10, and the Y axis by motor 11. The speed of rotation of the spindle is controlled by motor 9, which is here independent of the control device being described. It will be 15 seen below that, in certain cases, the driving motor of the spindle may likewise be considered like an axis.

The graph in Figure 2 explains the way to set up a step table capable of being incorporated in the electronic control device 13 of the machining apparatus. The profile 20 of a workpiece P to be machined is depicted diagrammatically in the upper right-hand quadrant of the graph. Axis X represents the symmetry axis of the bar, and axis y the radial deviations of the tool relative to axis x. The operations to be effected are broken down into tool 25 movements, which are in turn quantified in steps of a specific length, chosen in terms of the requirements imposed by the material and of an estimation of the most judicious movements. In this graph, the axis starting from the center and going horizontally toward the left, as 30 well as the one starting from the center and going vertically downward, are time axes. The radial movements of the tool are plotted on axis y, while the movements of the headstock are plotted on axis x. The point of origin of the machining is the point designated as $t=0$. Searching 35 for this origin position when machining each workpiece

will be discussed below. Starting from this point $t=0$, the path of the tool depicted in the upper right-hand quadrant of the graph is broken down into segments. The lower right-hand quadrant shows the successive axial
 5 movements of the headstock as a function of time, and the upper left-hand quadrant the successive movements of the tool as a function of time. These movements are broken down into fixed steps as a function of successive, variable intervals of time designated as Δt . The Δt_{xi} are a
 10 sequence of intervals of time, at the end of each of which the headstock must be moved by one step, i.e., its motor must have received an order to effect one increment. It is seen that between the time $t=0$ and the time $t=2$, the X axis must have effected one increment after each interval
 15 of time, whereas between the time $t=2$ and the time $t=8$, the headstock must effect one increment over two successive intervals of time. Between the time $t=8$ and the time $t=11$, the headstock makes no movement, while in the intervals of time which follow the time $t=11$ and up to the
 20 time $t=15$, the headstock effects one increment at each interval Δt_x .

As for the movement of the tool, i.e., the Y axis, an analogous breakdown takes place. Starting from the position of the tool at the time $t=0$, the sequence of inter-
 25 vals of time is reproduced on axis t toward the left, and the increments of the motor of the tool are plotted at ordinates so as to produce the curve of the upper left-hand quadrant between the time $t=0$ and the time $t=15$.

The sum of the intervals of time is the same for the
 30 Y axis (Δt_y) and for the X axis (Δt_x) (in this particular case, it is equal to 15, but this is, of course, a theoretical example). On the other hand, the distribution of the increment orders on each of the axes, as a function of the time elapsed, is different.

The step table itself is shown in Figure 3. Each of the columns Δt_{xi} and Δt_{yi} represents the number of intervals of time after which the corresponding axis must have moved by one increment. This table permits the control device to be programmed to machine a series of successive workpieces on bar 5 (Figure 1).

It will also be noted in connection with Figure 3 that, in certain cases, a reversal of the direction of movement of the tool may be required. In that case, the step table will comprise, for a particular position in the sequence of intervals of time Δt_{yi} , and instruction relating to a non-usual order (e.g. $\Delta t=0$), this order being interpreted as a reversal of the direction of movement of the Y axis.

The programme itself may easily be written on the basis of the recording of this step table. It is a repetitive programme which actuates the X axis and the Y axis independently. The first operation consists in searching for the origin position; this is an operation known per se, which need not be stressed. Once the origin position has been found, the reading sequences are started on the Δt_{xi} and on the Δt_{yi} .

The control device comprises a clock signal generator which determines the duration of the Δt_i . The numerical data contained in these tables always indicate the number of Δt to be counted before a pulse is transmitted to the motor of the corresponding axis in order to move it by one increment. The flow charts in Figure 4 indicate the operations effected during each reading sequence. Each sequence includes the taking into account of the period of time corresponding to Δt_{xi} or to Δt_{yi} , and the output of the following pulse is produced at the suitable moment. The actual profile of the machined workpiece is a profile whose appearance is as shown in Figure 5. When the programme is being written, the Δt and the increments are

to be chosen in such a way as to respect the dynamics of the system, considering the type of workpieces to be produced.

The graph in Figure 6 explains a variation in setting up the step table to be incorporated in electronic control device 13 of the machining apparatus. The profile of a workpiece P to be machined, and the successive movements of the tool and of the headstock, are depicted in a manner analogous to Figure 2. However, the movements are broken down into the number of steps as a function of fixed, successive intervals of time, designated as Δt . The ΔX_i and ΔY_i are sequences of movements. At the end of each interval Δt , the headstock must have effected a prescribed movement Δx , i.e., equal to a prescribed number of steps. Thus, in Figure 6, it is seen that at the end of the first Δt , the movement of the headstock must be four steps, etc.

As for the movement of the tool, i.e., the Y axis, an analogous breakdown takes place. Starting from the position of the tool at the time $t=0$, the sequence of intervals of time is reproduced on axis t toward the left, and the increments of the motor of the tool are plotted at ordinates so as to produce the curve of the upper left-hand quadrant between the time $t=0$ and the time $t=9$.

The step table itself is shown in Figure 7. Each of the columns ΔX_i and ΔY_i represents the number of steps the corresponding axis must effect at each Δt . This table permits the control device to be programmed so as to machine a series of successive workpieces on bar 5 (Figure 1).

As stated in connection with Figure 3, a reversal of the direction of movement of the tool may be required in certain cases. If so, the step table will comprise, for a particular position in the sequence of step intervals ΔX_i , an instruction relating to a non-usual order (e.g.,

$\Delta Y=100$), this order being interpreted as a reversal of the direction of movement of the Y axis.

The control device comprises a generator of clock signals of the duration Δt and synchronizes the reading of the step table on the X axis and on the Y axis. The numerical data contained in these tables always indicate the number of motor steps to be taken before the next pulse. During writing of the programme, the increments are to be chosen so as to respect the dynamics of the system, considering the type of workpieces to be produced.

It is known that if the motors are stepping motors, each increment order necessarily brings the movable part dependent on the motor into a predetermined position, so that the open-loop operation is reliable as long as no stepping error and no discontinuity or lack of synchronization occurs. Writing of the programme therefore needs no new checking of position and no interpolation. On the other hand, the steps provided must be compatible with the performances of the actuators.

A programme may be provided for calculating the step table, capable of being carried out on a computer separate from the machine. Existing auxiliary software, e.g., the "TB-Logic" software of the present assignee, may be adapted for writing a step table programme. In order to limit the size of these tables, it is possible to have recourse to means such as data compression, which allows the price of the computer memory to be reduced.

The step table having been calculated with a separate computer, it is then transferred into a control memory of the machine by any suitable means.

As stated above, the starting measurement of the point of origin at the beginning of each operation is an important programme element. The measurement of the point of origin depends upon the actual position of the tip of the tool and, consequently, upon its degree of wear. The

control device must therefore be equipped with a means permitting a shift of the point of origin in order to make possible a measurement of the point of origin capable of being corrected as a function of the characteristics of the tool. The shifting means must first of all permit a shift of initial point of origin as a function of the theoretical position of the tip of the tool relative to a reference on the axis, and then, if need be, a tool correction which modifies the origin position as a function of a possible variation of the shape of the tool as compared with its theoretical shape.

The shift of initial point of origin must be inserted in the programme which calculates the step table, whereas the tool corrections will be made by shifting the point of origin, either upon each reading of the table in a zone without anticipated movement, reserved for a movement of limited extent, or outside the reading of the table.

When the machining of a workpiece requires coordination between the rotation of the spindle and the position of the tool, e.g., when a workpiece is to be threaded, or a polygonal shape is to be turned on the bar, or the spindle is to be used on the C-axis, the driving motor of the spindle must operate like an axis incorporated in the programme. In this case, the step table may comprise a sequence of information relating to the control of the spindle axis. However, in view of the heavy stress on this motor, it is also possible to have the reading speed of the step table, i.e., the actual duration of the intervals Δt , controlled by the speed of rotation of the spindle. In this case, the intervals Δt are no longer directly calibrated by clock signals, but depend upon the instantaneous speed of the spindle.

The frequency $f = 1/\Delta t$ of clock signals can be chosen in a range of $+f_0$ to $-f_0$. A frequency of $f = +f_0$ corresponds to the maximum speed, and a zero frequency to stop,

and a negative frequency implies a reading of the step table in an opposite direction.

It has been indicated above that the risk of maladjustment or breakdown may be the result of a discontinuity or lack of synchronization of a stepping motor if, for example, the resistant torque becomes greater than the maximum motor torque. As it is an open-loop system, no feedback on the running of the programme exists in this case.

10 For each actuator, or each motor actuating an axis, however, the control device will include a monitoring means capable of detecting any abnormal operation and of generating an alarm which will stop the running of the programme. The detection means may comprise a detector of
15 the movement of the movable part connected to the axis or of rotation of the motor. In this case, an additional sensor and an alarm system are provided. It is also possible to equip the electric part of the actuators with systems for detecting the loss of steps and to cause the
20 alarm to go off when the course of the pulses is obviously such that the mechanical movement which ought to be produced by that pulse has not taken place. In this case, sensors reacting to the movements of the tangible mechanical parts are no longer necessary. The monitoring is
25 carried out solely by electronic means.

In the embodiment described above, the actuators are stepping motors. It should be noted, however, that identical results may be obtained, for example, with a DC motor, providing it is equipped with a control system
30 which, upon registering a pulse, necessarily brings about a movement of this motor of predetermined extent. It will be realized that this procedure allows the use not only of stepping motors, but also of position-controlled actuators, e.g., of the hydraulic type. The pulse received by

this actuator then amounts to a new nominal position value.

Patent Claims

1. Method to control programmed movements carried out by a plurality of drive means (10, 11) functioning incrementally, actuating one or more moving parts of a machine tool in a manner to carry out a machining operation on a rough workpiece fixed to a workpiece holder of said machine, wherein an operational programme uses numerical data stored in a step table for distributing to each drive means a series of incremental displacement orders (Δt_{xi} , Δt_{yi}) succeeding one another according to a dependent variable of time, the sequence of orders being included in the step table and wherein the said step table is set up to give the results of a calculation defining an optimal machining trajectory as a function of time and permits obtaining a given profile with a given material taking into account the characteristics of the machine tool.

2. Control method according to claim 1, wherein the numerical data of the said step table indicates, for each displacement, a variable number of increments or of steps to be carried out during a fixed number of time units.

3. Control method according to claim 2, wherein each displacement order of the series is given in the form of a variable number of increments, to be realized during a fixed time interval corresponding to a fixed number of time units, the said variable number of increments being established in the said step table.

4. Control method according to claim 1, wherein the numerical data of the said step table indicates, for each displacement, the number of time units after which the corresponding axis will have carried out a displacement by a fixed number of increments.



5. Control method according to claim 4, wherein each order of displacement of the series is given in the form of a fixed number of increments to be carried out during a variable time interval, the duration of the said time intervals being set out in the said step table as a function of a variable number of time units.

6. Control method according to one of the claims 3 or 5, wherein the value of the unit of time corresponds to impulses emitted by a clock signal generator.

7. Control method according to claim 6, wherein the clock signal generator determines time intervals of a fixed duration.

8. Control method according to claim 6, wherein the clock signal generator determines time intervals which are a function of an observed speed of rotation or of displacement on one of the axes.

9. Device for controlling one or more axes in a machine tool, comprising a drive means (10, 11) functioning incrementally on each of said axes and, for all of said axes (X, Y), a memory containing numerical data wherein the control device likewise includes a clock signal generator and an operational programme, and wherein the said operational programme, by means of numerical data contained in a step table as defined in claim 1, distributes to each drive means a series of displacement orders in the form of transmitted increment orders (Δ_{xi} , Δ_{yi}) of time intervals established by the clock signal generator.

10. Control device according to claim 9, wherein the step table includes for each axis, with respect to a series of time intervals, a series of command steps, each command being given at a time interval of the said series of time intervals, permitting the operational programme to



command execution of a variable whole number of steps by means of the drive attributed to the axis, the number of steps being equal to zero, to one or to any integer greater than one.

5 11. Control device according to claim 10, wherein the step table is laid out in such a way that each datum determines in addition for each axis a time limit for carrying out the said number of steps.

10 12. Control device according to claim 11, wherein the step table is laid out in such a way that at least one of the said predetermined time intervals causes an order of direction reversal on at least one of the axes, this time interval not causing any other order.

15 13. Control device according to claim 12, wherein the said clock signal generator determines the said time intervals, counts them and synchronizes the execution of the orders on the basis thereof.

20 14. Control device according to claim 13, wherein the clock signal generator determines intervals of time of fixed duration.

 15. Control device according to claim 14, wherein the clock signal generator determines time intervals which are a function of the speed of rotation or of displacement observed on one of the axes.

25 16. Control device according to one of the claims 9 to 15, wherein the operational programme includes means for repetitively carrying out, on each of said axes, origin-position searches each followed by an order to execute a step, and further comprises an origin-position
30 shifting means.



17. Control device according to one of the claims 9 to 15, wherein included are means for detecting abnormal execution of the programme and monitoring means allowing the running of said programme to be stopped upon detection
5 of abnormal execution.

18. Control device according to claim 17, wherein the means for detecting comprise, for at least one said motor of one of said axes, a step-loss detector associated with said motor.

10 19. Control device according to claim 17, wherein the means for detecting include, for at least one axis, a detector of displacement of a moving part associated with said axis.

