

Nov. 28, 1961

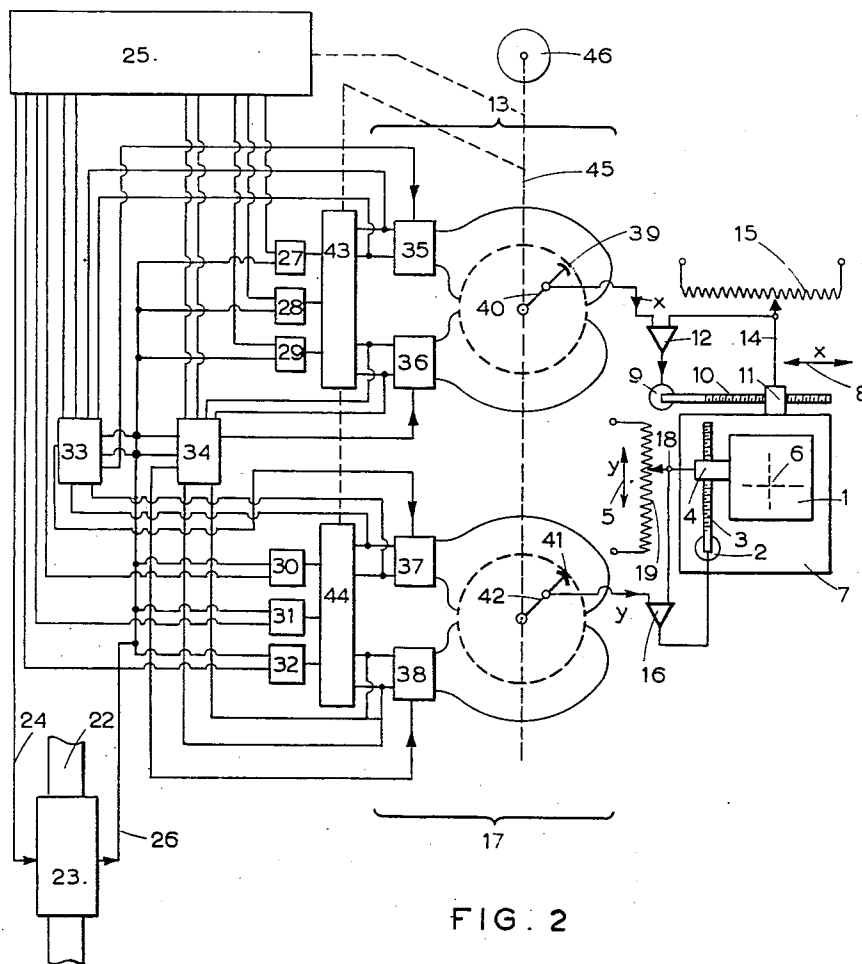
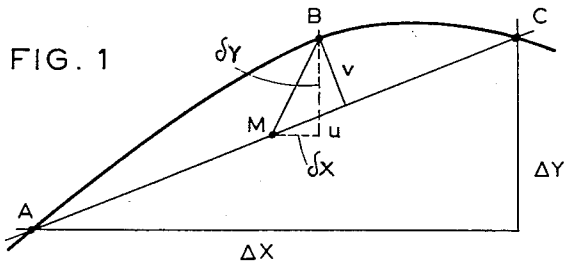
R. E. SPENCER

3,010,656

INTERPOLATOR DEVICES

Filed Aug. 2, 1957

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INTERPOLATOR DEVICES

3,010,656

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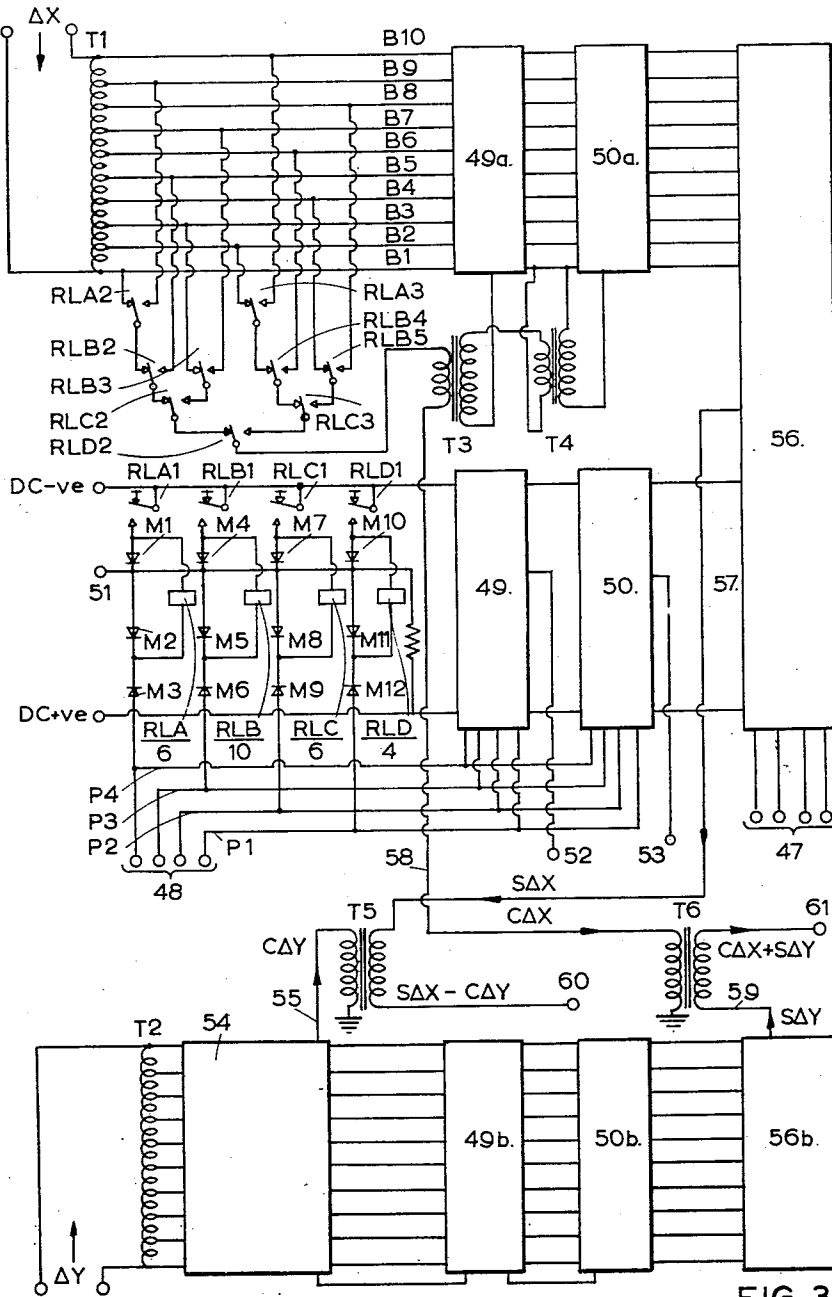


FIG. 3.

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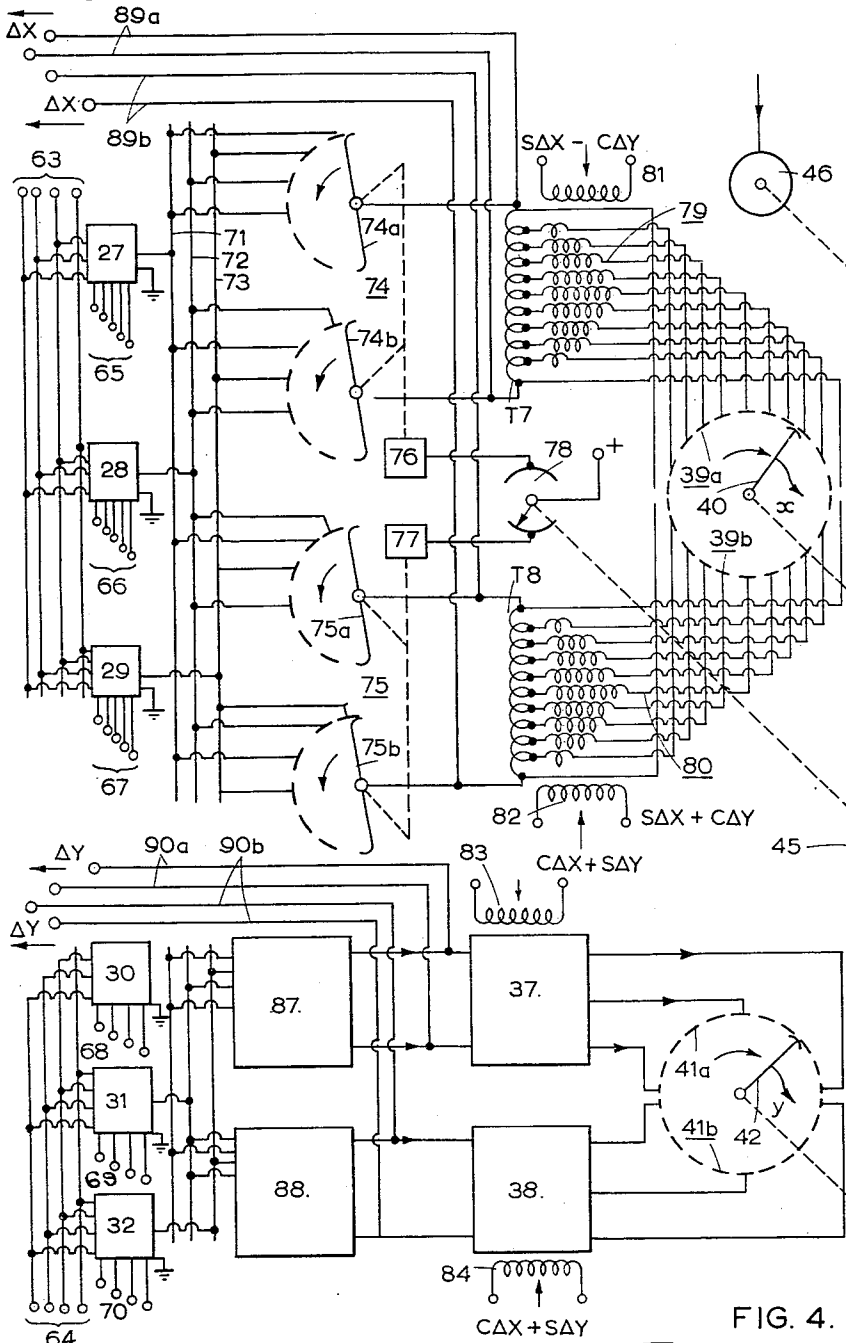


FIG. 4.

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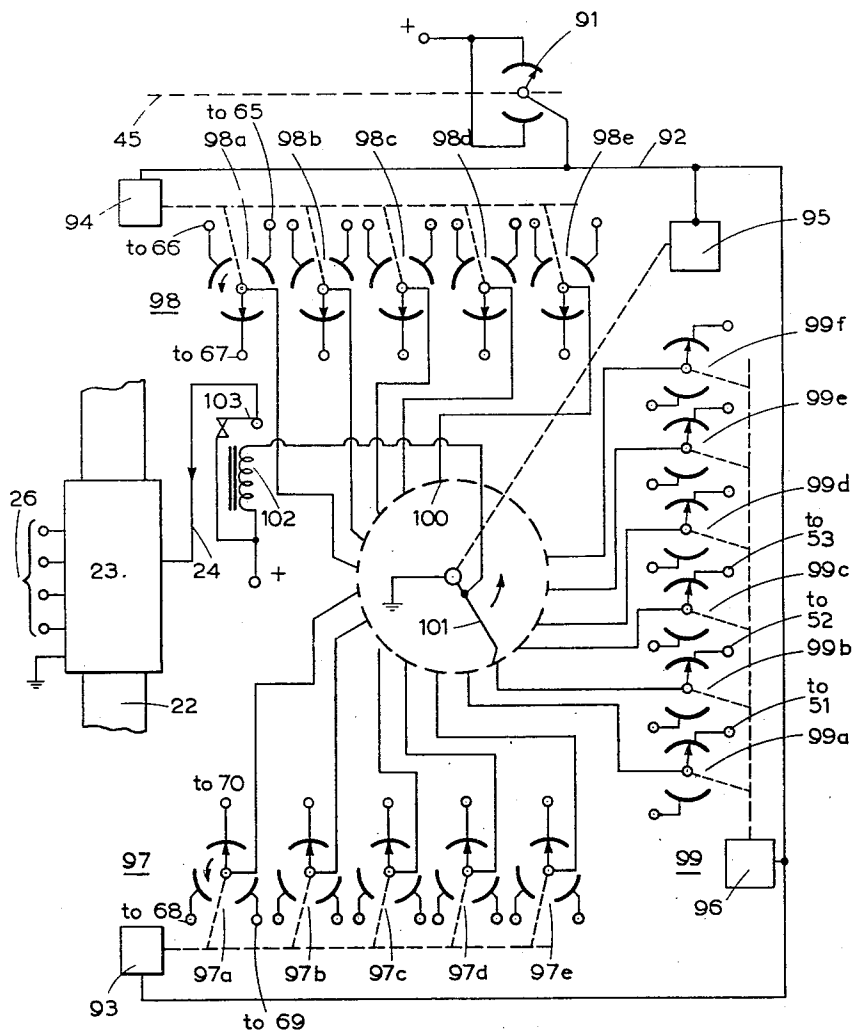
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INTERPOLATOR DEVICES

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5 Sheets-Sheet 4



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INTERPOLATOR DEVICES

3,010,656

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5 Sheets-Sheet 5

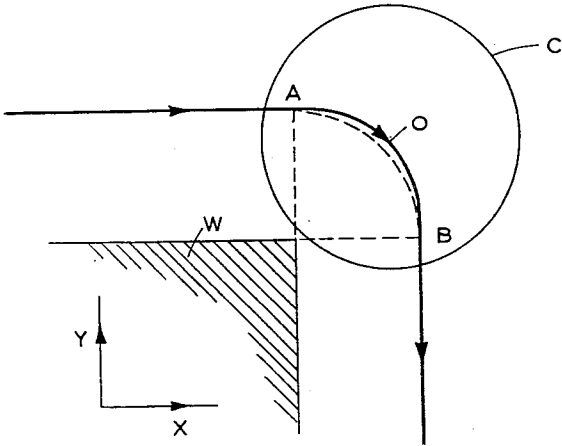


FIG. 6

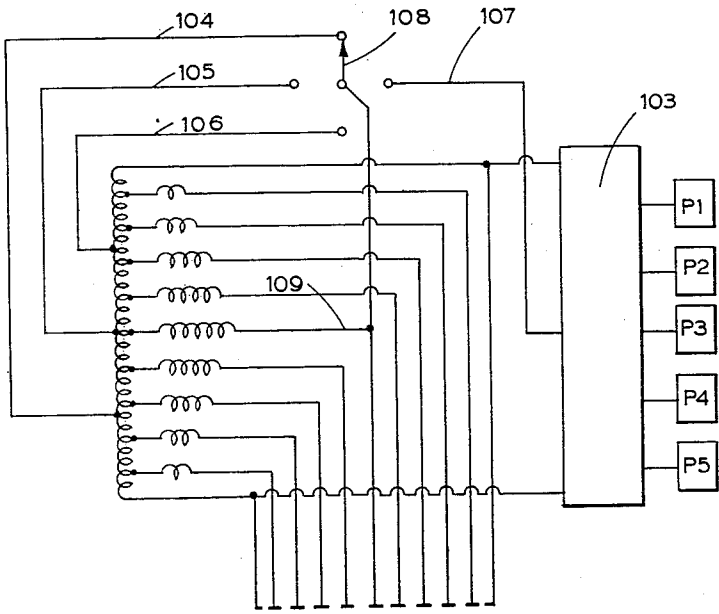


FIG. 7

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3,010,656

INTERPOLATOR DEVICES

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Claims priority, application Great Britain Aug. 4, 1956
8 Claims. (Cl. 235-197)

This invention relates to interpolating devices and especially, though not exclusively to interpolating devices employed in automatic machine tools.

In United States patent applications Serial Nos. 459,814 and 581,038, now Patent Nos. 2,928,604 and 2,929,555, respectively, there are described quadratic interpolating devices comprising a series of output contacts which are intercoupled by two systems of transformer windings in such a way that on feeding alternating signals to three points on the system of windings, alternating signals are set up at the output contacts which represent consecutive values of a co-ordinate along a quadratic curve drawn through points having the co-ordinates represented by the applied signals.

One system of transformer windings is such as to provide potentials representing points on the chord joining first and third, or primary reference points and are therefore termed chordal windings and the other system of transformer windings are effective to provide the requisite lifts from the chord to the quadratic curve through the three points and are therefore termed lift windings. The second reference point or the reference point which is effective to determine the parabolic lifts, will be referred to hereafter as a secondary reference point.

In the above mentioned United States patent application Serial No. 581,038, the use of such quadratic interpolating devices to produce what is termed parametric interpolation is described. In this case, independent interpolation is effected over consecutive values of two co-ordinates, the two co-ordinates being functions of a third non-geometric parameter. Continuous interpolation for each co-ordinate in general requires two parabolic interpolators and five temporary stores, in order that reference input signals between which interpolation is required may be held in the temporary stores which are connected in groups of three by a suitable sequencing arrangement to the interpolator input points. The signals in stores which are not connected to interpolators at a particular instant are free to be replaced by fresh reference signals. As explained in the said co-pending application parametric interpolation allows freedom of choice as regards the axis of the parabola generated by the interpolation process, or in the case of linear spans, allows the rate of cutting to be controlled, as for example when it is required to cause a cutting tool to slow down relative to the workpiece or to come to rest in order that a sharp change of direction of cut may be negotiated.

These advantages are achieved by appropriate selection of secondary reference points, and by the calculation of the co-ordinates thereof. However it is always desirable to reduce the number of co-ordinates which have to be calculated, not only to save time in computation but also in some cases to reduce the time required by the machine which may for example be an automatic milling machine to read the programme, which may sometimes be the limiting factor in its operational speed.

According to the present invention, there is provided an interpolating arrangement comprising at least one curvilinear interpolating device having at least one output terminal and at least three input terminals requiring the application of constraining signals to all said input terminals to produce an interpolated signal at said output terminal and comprising synthesising means for linearly

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transforming input signals to derive another input signal and means for applying said derived signal and said other signal to said input terminals as constraining signal for said device.

The invention is especially applicable to speed control when employing parametric interpolation and in such applications of the invention, the lift voltage is preferably derived by a linear transformation of the signals representing primary reference points.

In order that the invention may be clearly understood and readily carried into effect, the invention will be described with reference to the accompanying drawings, in which:

FIGURE 1 is a geometrical figure which is to be referred to,

FIGURE 2 illustrates an example of the present invention applied to a milling machine,

FIGURE 3 illustrates in greater detail the synthesising means shown in block form in FIGURE 2,

FIGURE 4 illustrates in greater detail the construction and operation of one form of interpolator according to the invention,

FIGURE 5 illustrates in greater detail a programme unit such as employed in the arrangement of FIGURE 2,

FIGURE 6 illustrates a particular application of the invention in machine tool control, and

FIGURE 7 illustrates mainly in block form a further embodiment of the invention.

Referring to FIGURE 1, the points A, B, C are primary, secondary and primary reference points respectively in two-dimensional figure. Interpolation is required along the curve ABC and as explained in the United States patent application Serial No. 581,038 this may be performed parametrically employing quadratic interpolators to interpolate between the y-co-ordinates of A, B and C and the x-co-ordinates of A, B and C where these co-ordinates are represented by signals derived from a tape reader. According to the invention, signals representing the points A and C are recorded and when required are provided by the tape reader. The co-ordinates of the secondary reference point B however are not recorded as such but are derived implicitly from suitable instructions recorded on the tape. If M is the mid-point of the chord AC, then the lift MB to the curve may be specified by the lengths δX and δY of the respective x and y-lifts. These may be programmed on the tape and injected in a suitable way into the windings of the lift transformers or alternatively δX and δY may be programmed on the tape, expressed as fractions of the respective span voltages ΔX and ΔY .

A rather more versatile arrangement is as follows. Suppose a perpendicular be dropped from B to AC and is of length v, the foot of the perpendicular being a distance u along AC from M. Then the tape may be employed to specify ratios of u and v to the chord length AC. Clearly, u and v are signed and so therefore are the ratios S and C where,

$$\begin{aligned} S &= u/AC \\ C &= v/AC \end{aligned}$$

Now

$$\begin{aligned} \delta X &= MP = u \cos \frac{PMR}{PBR} - v \sin \frac{PBR}{PMR} \\ \delta Y &= BP = v \cos \frac{PBR}{PMR} + u \sin \frac{PMR}{PBR} \end{aligned}$$

But triangles BQR and MQR are similar so that

$$\frac{PBR}{PMR}$$

Therefore,

$$\delta x = S.A.C. \frac{\Delta x}{AC} - C.A.C. \frac{\Delta Y}{AC}$$

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$$\delta Y = C.A.C. \frac{\Delta x}{AC} + S.A.C. \frac{\Delta Y}{AC}$$

whence

$$\begin{aligned}\delta X &= S.\Delta X - C.\Delta Y \\ \delta Y &= C.\Delta X + S.\Delta Y\end{aligned}$$

where ΔX and ΔY are indicated in FIGURE 1.

Since by employing such an arrangement as this the secondary reference points are synthesised as fractions of the span between the primary reference points, which are determined by the values of S and C , it is possible to obtain equivalent accuracy in the present invention to that obtained when all three reference points are programmed implicitly even if the accuracy to within which S and C are provided is considerably less than that of the primary reference points. This feature enables, as will become clear after following the description of the main embodiment of the invention, certain economies in storage means to be made.

Referring to FIGURE 2 of the drawings which illustrates mainly in block form one method of applying the present invention to an automatic milling machine provided with control on movement of the worktable in two directions, the worktable is denoted by reference 1 and it is mounted on a slide so that it can be displaced in a horizontal plane in one co-ordinate direction by a servo motor 2 through the intermediary of a lead screw 3 and nut 4. The servo motor 2 can produce displacement in the directions denoted by the arrow 5 and it controls what will be referred to as the y -co-ordinate displacement of the worktable with respect to the axis of the tool-holder, which is represented in the drawing by reference 6, and may be regarded as determining the origin of a two dimensional cartesian co-ordinate system. The slide upon which 1 is mounted is represented by the rectangle 7 and the slide can be moved in a horizontal plane in the directions indicated by the arrow 8 by means of a servo motor 9 via the lead screw 10 and the nut 11. This co-ordinate direction will be referred to as the x -co-ordinate direction for the worktable 1 relative to the axis 6 of a tool-holder. The tool-holder itself is not illustrated in the drawing for it is not relevant to the description of the present invention. Displacements between the tool-holder and the worktable 1 will be denoted respectively by x and y and controlled to cause the axis of the tool to describe a locus such that a desired profile is cut on the workpiece which is clamped to the worktable 1. Clearly in providing the displacement between the origin 6 and the axes of the cutting tool allowance must be made for the finite dimensions of the cutting tool itself and although such a mechanism is not described herein it may be provided that the control mechanism itself is arranged to compensate for the radius of the cutting tool. The operation of the servo motor 9 is controlled by the output of an amplifier 12 which receives virtually continuous variable input signals from quadratic interpolating means denoted by general reference 13 to be described in greater detail hereafter, and negative feedback signals from the tap 14 on the potentiometer 15, this tap being driven in a suitable manner to provide a voltage analogue signal representing the instantaneous value of x .

In a similar manner, the servo motor 2 derives its input signal from an amplifier 16 which receives a virtually continuous variable input signal from quadratic interpolator means 17. The amplifier 16 also receives negative feedback analogue signals representing the instantaneous value of y , by means of the tap 18 on the potentiometer 19. The interpolator means 13 and 17 set up output signals comprising alternating voltages having amplitudes which are analogues of the desired values of x and y at any instant and the potentiometers 15 and 19 are energised by alternating voltages of fixed amplitude, being co-phased with the output voltages from 13 and 17.

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The interpolator means 13 and 17 are responsive to coordinate value signals representing discrete values of x and y together ratio signals representing values of S and C , where S and C are defined as described above with reference to FIGURE 1. These values are recorded on a punched tape 22 in binary decimal coded form. Thus a value of x for example may comprise 5 decimal characters and to define each character four perforations are required on the tape, so that for a single value of x or a single value of y , five rows of four perforations may be required. In the present example of the invention it will be regarded that three decimal characters provide sufficient accuracy for the present invention to determine values of S or C . Thus three rows of four perforations are required for a single value of S or C . Signals representing successive discrete values of x , y , S and C are therefore recorded sequentially on the tape 22 and are read off in a similar order by the tape reader 23. The reader 23 may be similar to a standard teleprinter tape reader arranged to operate in a line by line manner in response to pulses received via the lead 24 from a programme unit 25 which as will be seen hereafter is synchronised with a master shaft 45 for the control mechanism. The output signals from 23 are fed via the line 26 to the inputs to the x -stores denoted by references 27, 28 and 29, to the y -stores denoted by references 30, 31 and 32 and to the S and C stores which are included within the synthesising units 33 and 34. Although all output signals from 23 are fed to all the stores the signals are only stored in those stores which are conditioned by conditioning pulses provided by 25, the conditioning pulses are arranged moreover to occur in such an order that only stores which are not being employed to provide reference signals at a particular instant have their stored signals changed. The operation of the stores for successive values of x and y and also for values of S and C is described hereafter in greater detail with reference to FIGURE 3. The interpolator means 13 comprises two quadratic bridges 35 and 36 each having two input terminals connected to a switching unit 43 and third input terminals connected to 33 and 34 respectively and signals are derived from these bridges by means of a movable contact on a stud circle comprising studs 39 respectively connected to the respective output terminals of bridges 35 and 36. Connections to only four of these studs are shown in the figure for simplicity. Clearly the bridges 35 and 36 are brought into service alternately and a switching unit 43 is synchronised with the shaft 45 upon which 40 is mounted, to connect pairs of the stores 27, 28 and 29 cyclically to the inputs to 35 and 36 whereby a continuous signal is derived from the output of 40. The shaft 45 is driven by a motor 46 at a predetermined speed which determines the variations of the common non-geometric parameter and also mounted on 45 is a movable contact 42 which scans a series of studs 41 which are associated with another pair of parabolic bridges 37 and 38 and a switching unit 44 which constitute the y interpolator 17. The operation of the interpolators and switching units is described in greater detail hereafter with reference to FIGURE 4. Third inputs to the interpolator bridges 35 and 36 are derived from the synthesising means 33 and 34 and similar inputs are derived from these units for interpolator bridges 37 and 38. These signals as will be seen hereafter comprise representations of $S\Delta X - C\Delta Y$ and $C\Delta X + S\Delta Y$, and give the lift information for the interpolators between successive primary reference points.

In order that the mode of operation of the respective stores and synthesising means for deriving the above mentioned signals which are injected into the interpolators to represent the lift information may be understood, FIGURE 3 will now be described. In FIGURE 3 the groups of four terminals 47 and 48 receive signals from the tape reader 23 of FIGURE 2, representing successive decimal characters in reference values of S and C respec-

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tively. Although it is not mentioned above, the lead 26 in FIGURE 2 in practice comprises 4 leads each of which carries a signal corresponding to a binary digit derived from the tape 22 and as mentioned above the output signals from 23 are fed to all the stores in the control mechanism. Considering now the four input terminal points 48, these points are connected via the lines P1, P2, P3 and P4 respectively to each of three relay operating units. These relay units are of similar construction and operation so that only one such unit is shown in detail and the other two are denoted by blocks 49 and 50. The relay operating units are constructed as shown and a full description of such circuits may be found in United States patent applications Nos. 459,794 and 518,912. The relays themselves are denoted by RLA, RLB, RLC and RLD, the switches of these relays being denoted for example as RLA1, RLA2 and so on. The notation

$$\frac{RLA}{6}$$

for example denotes that associated with the RLA there are six relay switches and similar notations are also applicable to the other relays.

In describing the operation of the relay circuits it will be assumed that the tape reader senses a hole in the tape representing a "1" and so transmits a positive digital pulse to the line P1 from the positive D.C. supply. Simultaneously with this sensing operation a similar conditioning pulse but with a negative polarity is transmitted from the terminal 51, which is normally connected to the positive D.C. supply, so that a current flows via the metal rectifiers M12 and M10 thereby energising the relay RLD. Energisation of the relay RLD causes the switch RLD1 to change position so that when the sensing operation of the output reader 23 is complete and the terminal 51 receives the D.C. positive potential whilst the tape reader again produces a zero signal, the energisation of the relay RLD continues by virtue of conduction from the terminal 51 via the metal rectifier M11 and switch RLD1 to the negative supply. The rectifiers M12 and M10 are therefore non-conducting when the sensing operation is completed.

If during the following sensing operation of this relay unit a "0" is sensed by the tape reader then no positive digital pulse is applied to the line P1. A negative conditioning pulse is however applied to the terminal 51 which is effective to de-energise the relay RLD by inhibiting the conduction of the metal rectifier M11. Thus any binary number presented to the tape reader simultaneously with a conditioning pulse at 51 will cause a corresponding state for the relays RLA, RLB, RLC and RLD and a resultant state of the associated relay switches which is unique for each binary coded decimal digit. The switches RLA2, RLA3, RLB2 to RLB4, RLC2, RLC3 and RLD2 may be said to comprise a decoding tree. The contacts of the relay switches are connected as indicated to ten bus bars B1 to B10 which are connected to equally spaced tapping points on an auto-transformer T1 so as to be maintained at alternating potentials of like phase. This auto-transformer is energized by a reference source of alternating potential ΔX which is derived as is explained hereafter from the primary input reference points to the X interpolators. The connections of the relay switch contacts to the bus bars are such that the sensing of a binary representation of a decimal digit on the tape causes energisation of the relays to connect the movable contact of the switch RLD2 to alternating potential analogues to the decimal digit, via other movable contacts and the appropriate bus bar. On sensing the binary number 0101 for example, equivalent to the decimal digit 5, relays RLB and RLD are energised so that the bus bar B6 is connected via the movable contacts RLB4, RLC3, RLD2 and the secondary winding of transformer T3 to the lead 58. The lead 58 is connected to the

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secondary winding of the transformer T6 and the operation of transformer T3 will be described hereafter.

The relays RLA, RLB, RLC and RLD control a second decoding tree identical to that just described. This tree is included in the circuit denoted by block 54 and is associated with a further set of bus-bars which are connected at equal intervals along a second auto-transformer T2 which receives reference voltage ΔY from the Y interpolators. This second decoding tree is operated in an identical manner to that described above and the output lead 55 is connected to a winding of the transformer T5 which again will be described hereafter. Blocks denoted as 49 and 50 represent two further relay operating units and comprise relays identical to those described and associated with 49 and 50 are decoding trees 49a and 50a coupled to autotransformer T1, and 49b and 50b coupled to the auto-transformer T2, 49 and 50 having conditioning leads which are connected to terminals 52 and 53 respectively, so that on reading out a value of S from the punched tape the terminals 51, 52 and 53 received conditioning pulses sequentially in that order. Considering the decoding trees associated with the transformer T1 the analogue signal appearing at the output of 50a is applied to a primary of a transformer T4 and the secondary of this transformer which has a 10-1 reduction is coupled to the primary of the above mentioned transformer T3 and the secondary is coupled as stated above to the output lead 58 for the unit. Since the sets of relay switches established analogue signals representing decimal characters and furthermore, the transformers T4 and T3 have a 10-1 reduction the decimal characters are added with proportionate magnitudes to provide a sum output in 58 which is the analogue of the binary decimal stored information. Since moreover the input points 48 receives signals representing C when conditioning signals are applied to 51, 52 and 53 and the reference voltage applied across T1 is ΔX the analogue voltage in 58 represents $C\Delta X$. In a similar way the signal in the output lead 55 of 54 represents $C\Delta Y$.

As mentioned above the input terminals 47 also receive signals from the tape reader 23 and block 56 represents a series of 3 sets of relay operating units and decoding trees also associated with the auto-transformers T1 and T2 and these relay operating units are conditioned to be operated by signals representing S. Alternatively the circuit represented by the block 56 may have its ten bus bars connected toappings on a separate auto-transformer, like T1, connected directly between the ends of T1. This reduces sectional loading of T1. Block 56b represent the decoding trees associated with the transformer T2 and which are operated by the relays in 56. In a similar manner to that described above the output leads 57 and 59 of 56 carry analogue signals representing $S\Delta X$ and $S\Delta Y$ respectively. Since 57 is coupled to the secondary of the transformer T5 and 55 is coupled to the primary of T5 the output which is derived from the secondary of T5 and connected to the terminal 60 is an analogue signal representing $S\Delta X - C\Delta Y$. Again, since the lead 58 is coupled to the primary of T6 and the lead 59 is coupled in a like sense to the secondary of T6 the output signal which appears at the terminal 61 is an analogue signal representative of $C\Delta X + S\Delta Y$.

As will become clear following the description of the operation of the interpolators, two such devices as described with reference to FIGURE 3 are required for the operation of the present embodiment of the invention, these two such devices having been previously mentioned as synthesising means 33 and 34 in FIGURE 2.

The derivation of the signals for the terminals such as 51, 52 and 53 is described in greater detail with reference to FIGURE 5.

In order to avoid confusion in the explanation of FIGURE 4 about to be made it is to be understood that each store for values of x and y associated with the interpolators comprises five relay units and relay switches com-

plete with associated bus-bars such as B1, B2 . . . B10 in FIGURE 3. Thus the stores 27, 28, 29, 30, 31 and 32 are each capable of storing five decimal characters.

Referring to FIGURE 4 which as aforementioned illustrates in greater detail the construction and operation of the interpolator means 13 and 17 comprising 35 and 36 and 37 and 38 of FIGURE 2, together with the switch units 43 and 44 and the associated stores, those components of FIGURE 4 which are identical with those of FIGURE 2 are indicated by the same reference numerals. The stores which carry signals representing the x-co-ordinate of primary reference points are the stores 27, 28 and 29 respectively and the stores which carry signals representing the y-co-ordinate of primary reference points are 30, 31 and 32. The former three stores have common input points denoted by reference 63 and the latter three stores have common input points 64, 63 and 64 only being separated for convenience of illustration. Each store has five conditioning input terminals corresponding to five decimal characters and which are grouped together and referred to as 65, 66, 67, 68, 69 and 70. These conditioning terminals receive conditioning signals sequentially from the programme unit of FIGURE 5. It is assumed moreover as mentioned above that the stores, apart from storing five decimal characters instead of three are substantially as described with reference to FIGURE 3 for storing the successive values of S and C. In FIGURE 4, the x-interpolator only is shown in detail and the y-interpolator since it is identical with the x-interpolator is shown in block form. Three successive primary reference point x-co-ordinates are stored in 27, 28 and 29 respectively, and as indicated these stores are coupled to three bus-bars 71, 72 and 73 which are connected to contacts on banks of two uniselector switches 74 and 75, the movable contacts 74a and 74b, 75a and 75b of these uniselectors being of the break-before-make variety, and being operated by stepping units 76 and 77 which receive signals from a commutator device 78 which is coupled mechanically to the interpolator shaft 45. The commutator device 78 is merely for convenience of illustration but in actual practice it may be more suitable to employ a cam operating a micro switch or the like so that in the event of a machine being switched off and switched on again during the operation of the machine it is not possible for 74 or 75 to be stepped on twice where they should only be stepped on once. The movable contacts 74a and 74b are connected to the terminals of the transformer winding T7 which has connected to it at equal intervals along its length a series of further transformer windings wound on a separate core and having turns ratios which are quadratically related to the position of the connections to T7. These latter windings which are denoted by the general reference 79 are referred to as parabolic lift windings and are connected to the studs 39a on the stud circle 39 which is scanned by the make-before-break contact 40. In a similar manner the movable contact 75a and 75b are connected to the terminals of a transformer winding T8 associated with which are a further series of parabolic lift windings 80 which are connected to the studs on the half circle 39b in the manner indicated. Inductively coupled moreover with 79 is a transformer winding 81 which receives signals representing $S\Delta X - C\Delta Y$ from 33 and similarly inductively coupled to the windings 80 is a transformer winding 82 which also receives signals representing $S\Delta X - C\Delta Y$ from 34. These signals are derived as described above with reference to FIGURE 3; the signals representing ΔX and ΔY being derived from the pairs of terminals 89a and 89b and 90a and 90b which are connected to the lift transformer windings T1 and T2. The additional windings for injecting the lift information into the interpolators 37 and 38 of the Y interpolation means from 33 and 34 respectively are denoted by references 83 and 84 respectively. When the uniselector contacts rest in

the positions indicated the stores 27 and 28 are clearly connected to the transformer winding T7 and T7 is referred to as the chordal winding of the parabolic bridge 35 since the voltages at successive points along T7 may be regarded as representing the x-co-ordinates of points along a cord of a parabola joining points whose co-ordinate values are stored in 27 and 28. Since therefore the signals applied to 81 represent the synthesised information which gives the parabolic lift for a point intermediate the values of x represented by the co-phased signals applied to T7 the signals set up on the studs 39a are analogous of the co-ordinates of successive points along a quadratic curve joining the above two points and passing through the original mid point for 40 midway along 39a. The wiper 40 scans these studs at a speed which is determined by the servo motor 46, and on arrival at the end half stud of the half circle interpolation then begins employing the series of studs 39b and it is clear that the signal stored in 28 is common to both half circles but the fresh signal stored in 29 and fed to the lower end of T8 is now brought into service. Thus when the moving contact 40 has traversed about a stud of its path round the half circuit 39b the commutator 78 has moved round to energise the stepping unit 76 associated with the movable contact 74a and 74b of the uniselector 74 and the store 27, now not in service is free to have its signal changed. This change of signal is effected by means of the programme unit. Study of the connections of the two uniselectors 74 and 75 will immediately show that as the moving contact 40 scans successive half circuits the stores 27, 28 and 29 are connected cyclically in pairs to the two interpolator bridges comprising T7 and windings 79 and T8 and windings 80 so that a virtually continuous output is derived from the contact 40. This output represents successive values of x along the required profile for the workpiece to be cut and as mentioned above in the present embodiment of the invention is used to operate the servo motor 9 of FIGURE 2.

Although such means are not included in the present embodiment of the invention it may be desirable to include in the interpolating devices means for providing linear interpolation between the successive outputs of the interpolator thereby reducing still further the granularity, or steps between the derived output signals. One form of linear subinterpolation means is described in United States co-pending patent application Serial Number 459,814.

Since the movable contact 41 of the y interpolation means is coupled to the same master shaft 45 which is driven by the servo motor 46, signals which are derived from 42 are signals representing values of y which correspond to those values of x which are being derived at the same instant. Blocks 87 and 88 represent the uniselector switching units associated with the y interpolators 37 and 38 respectively and since these are identical to those described with reference to the x interpolators and are operated in exactly the same manner they will not be described further, apart from indicating that the signals which are applied to the extra transformer windings 83 and 84 represent $C\Delta X + S\Delta Y$ which are derived as described above.

Having now described the machine tool and its operation with the associated interpolators it is desirable to indicate the manner in which conditioning signals may be applied to the various stores in the control mechanism. Reference will be made for this purpose to FIGURE 5 in which 45 again represents the master shaft mentioned above and 23 is the tape reader reading the punched tape 22 which also is described in greater detail above. Coupled to the master shaft 45 is a contact of a commutator device 91 which on each half revolution of the interpolator contacts causes a positive potential to be applied to the line 92 which is connected to a series of stepping devices 93, 94, 95 and 96. The stepping devices 93, 94,

96 are associated with uniselectors 97, 98 and 99 and the stepping device 95 is coupled to the movable contact 101 of a stud switch comprising the stud circuit 100. On energisation of 95 the movable contact 101 which is of the break-before-make variety executes a complete revolution thereby scanning all the studs in the circle. These studs are connected to the movable contacts of the banks of uniselectors so that successive contacts are energised sequentially. The contact 101 homes on a vacant or open circuited contact after each cycle. In addition the stepping device 93, 94 and 96 are arranged to be such that when they are energised the movable contacts of the associated uniselectors are stepped round by one stud position. As indicated in the drawing the banks of uniselectors 98 comprise three studs each, the banks of the uniselectors 97 comprise three studs each and those of 99 comprise two studs each. Each stud on the uniselectors have output terminals which are connected in prescribed manner to the various conditioning leads for the stores in the control mechanism. Considering for example the unselector 98 whose respective banks of studs are denoted by 98a, 98b, 98c, 98d and 98e and as described above each store for signals represent x and y comprises means for storing five decimal characters and the latter banks are those which correspond to the said five characters. The stud circuit 98a has three output terminal which are connected to the highest order conditioning terminals 65, 66 and 67 of the stores 27, 28 and 29 respectively. The other terminals of the successive banks of this unselector are connected to the successive conditioning terminals of the same three stores. Considering in a similar manner the unselector 97 which has successive banks 97a, 97b, 97c, 97d and 97e, these banks have output terminals which are connected to the conditioning leads 63, 69 and 70 in a similar manner to that described above, of the y interpolator stores 30, 31 and 32. The unselector 99, has six banks comprising 99a, 99b, 99c, 99d, 99e and 99f. The banks 99a, 99b and 99c have output terminals which are associated with conditioning leads for the stores for C and the banks 99d, 99e and 99f have output terminals which are associated with the conditioning leads for the stores S. As mentioned above two stores are provided for S and two for C although only one such device is described herein with reference to FIGURE 3 since they are identical. These stores moreover each comprise a storage means for three decimal characters hence only three banks of decoding trees are provided for each pair of stores, and as indicated in particular in the figure, the conditioning terminals for the store shown in detail in FIGURE 3, namely 51, 52 and 53, are connected as indicated to one stud of the banks 99a, 99b and 99c respectively.

In operation of the device of FIGURE 5 it will be assumed that as shown in FIGURE 4 interpolation is taking place over values of x lying between those which are stored in stores 27 and 28 and the position of the commutator brush of the commutator 91 is such that the stepping units 93, 94, 95, 96 have just been energised. The commutator 91 is therefore arranged to be in the upright position when 40 and 42 are in such a position. Thus considering the unselector 98, the movable contacts on this unselector are clearly in a position which permits energisation of the conditioning leads for the store 29 and similarly the movable contacts of the unselector 97 are in a position permitting energisation of the conditioning leads 70 of the store 32. Moreover the movable contacts of the unselector 99 are in a position permitting energisation of the conditioning leads for the S and C stores in 33 of FIGURE 2 and which are shown in detail in FIGURE 3, the alternative position for these contacts being that corresponding to the other S and C stores which are not indicated in detail but are included in block 34 in FIGURE 2. In addition to this the movable contact 101 is scanning the circle of studs 100 and since this contact is connected via the relay energising

coil 102 to a positive source of potential the above mentioned conditioning leads are energised sequentially and each time a stud is energised a current is passed by 102 thereby operating the relay switch 103 which also causes a positive potential to be applied to the lead 24 to cause the tape reader 23 to read a line on 22. Therefore, every time a conditioning pulse is applied to one or other of the conditioning leads in the arrangement a row of perforations are read from the tape 22 and since the perforations on the tape correspond row by row to successive characters to be stored in the various stores and the order is arranged to be such that it corresponds to the order of application of conditioning signals to the conditioning leads, the decimal characters are stored in the correct order and manner against the various storage devices in the mechanism.

Although the various uniselectors employed in FIGURE 5 are shown as having in some cases two studs and in other cases three studs, the uniselectors may in practice have a greater number, for example, twenty-four, and every alternative stud or every third stud, as the case may be, can be connected together.

As is explained in the United States co-pending patent application Serial Number 581,038, where parametric interpolators are described with reference to automatic control of machine tools, on a straight or almost straight run of a cutting tool acceleration or deceleration of the cutting tool is determined by the position of the intermediate reference points. "Stopping," "very slow" and "slow" demands may for example be instrumented in the X-direction by the intermediate reference point dividing the span in the ratios 3:1 given by $S=\frac{3}{4}$, $C=0$, 7:3, given by $S=\frac{7}{8}$, $C=0$ and 5:3 given by $S=\frac{5}{8}$, $C=0$, respectively. Clearly the present invention may have considerable advantages when used in machine tools in that by programming on the tape particular choices of S and C, the required slowing or speeding up of a cutting tool when rounding a corner or cutting a cusp is conveniently achieved. Moreover, by making $s>\frac{1}{4}$, slight overswings at outside corners may be instrumented in order to take up backlash in a particular co-ordinate direction before proceeding with the cutting in a fresh direction. Furthermore, supposing for example, that the span ABC of FIGURE 1 is that of a circular arc, subtending an angle θ at its centre, the appropriate value of S and C to provide B are,

$$S=0 \\ C=\frac{1}{2} \tan \theta/4$$

and these may be instrumented.

A further specific case may be referred to, namely when it is desired to provide in a machine tool an abrupt change of direction of cut from a direction parallel to the X-direction to a direction parallel to the Y-direction or vice versa. This is required when a right angled outside corner is to be programmed, the two directions at which are parallel to the axes. The ideal arrangement is for the tool to lift from the work after cutting in one direction and to return to the work to commence a cut in a fresh direction. If therefore the required change of direction of cut at a corner is from the X direction to the Y direction as shown in FIGURE 6 an intermediate reference point for the cutter axis programme may be programmed as mentioned above, as a stopping code for the X-direction and a starting code for the Y-direction. The resulting motion of the axis 0, of the cutter C, between points A and B in the figure is a parabola whose axis is at $\pi/4$ to the co-ordinate directions and which lies outside the sector of the circle (shown dotted) round the corner of the workpiece W. More generally a change of direction θ , of the normal to the required directions of cut at a corner is provided by programming $S=0$ and $C=\frac{1}{2} \tan \theta/2$ virtually no diagonal burring of the workpiece occurs, since the tool thus programmed leaves

the required workpiece contour while the fresh direction of cut is set up.

In a modified form of the invention applicable specially when the required locus represented by signals at the output points of a quadratic interpolator is rectilinear. In this case, the path is determined implicitly by co-ordinates of the two end points and instead of using both cross and self feed ratios, provision may be made for using an auxiliary programme signal to connect the arch leads such as 79 in FIGURE 7 which are normally connected to a store carrying a secondary reference signal or coupled to an additional transformer winding for injecting this signal, to intermediate points of their own chordal winding. Suitable choice of the intermediate reference point allows speed variations to be programmed. In a limiting case, if the lift winding is short-circuited, as by connecting the lead 109 to the mid-point of the chordal winding, a linear span at constant speed will result.

Such an arrangement as applied to one parabolic bridge of an interpolating device such as described in the above mentioned United States co-pending patent application Ser. No. 459,814 is illustrated in FIGURE 7. Since in normal operation of the interpolator in question interpolation is effected amongst three reference points, being discrete points on the curve along which further points are to be interpolated, it is necessary in order to provide a virtually continuous output by employing two bridges alternately as described herein, to provide five stores for successive values of each co-ordinate. These stores are shown as P1, P2, P3, P4 and P5 in FIGURE 7 and between the stores and the interpolator is a switching unit 103 which can be similar in construction to that described above with reference to FIGURE 4. The construction of the interpolator itself is similar to those described above and will not be described further, and only one set of transformers is moreover illustrated, the associated output studs being shown in a straight line for convenience. A rotary switch 108 may be set to make contact with either of the leads 104, 105, 106 or 107. The first three leads are connected to points at distances of $\frac{1}{4}$, $\frac{1}{2}$ and $\frac{3}{4}$ of its length along the chordal winding of the interpolator bridge and can provide accelerating runs, steady runs and decelerating runs as mentioned above. The lead 107 is the normal intermediate reference signal input lead for the normal non-linear operation. The switch 108 may be operated manually or in response to extra coded signals stored on a programme tape for the arrangement.

The input terminals to the interpolators described in the above mentioned United States co-pending patent application Serial Number 581,038 are connected two of them to the ends of the chordal windings and the third to the central lift winding of the interpolator bridges and reference signals are applied directly thereto whereas in the embodiment of the present invention described in detail above, the reference signals to the third input points are not applied directly but are induced by means of a further winding on the lift transformer. The operation of the interpolator itself is however exactly the same and the input points can be regarded as the same since the voltages set up at these points are under similar conditions the same in both inventions. No discrimination of input points is therefore required since the only distinction which exists is the means for applying the reference potentials to these points.

As mentioned above, an interpolator device such as described in the above-mentioned patent applications requires five stores to be associated with it for continuous operation. Each store may comprise storage facility furthermore for five decimal characters. In the present invention however an interpolator requires three such stores together with means for storing the corresponding values of said C. The storage means for S and C however may not require such a great accuracy and as in

the present embodiment storage facility for only three decimal characters may be required. Thus the present invention has the advantage of economy in storage facilities together with a reduction of switching devices required. The invention has moreover the further advantage associated in particular with its use in automatic control mechanisms for machine tools, that decelerating, accelerating and stopping codes are readily provided so that corners to be machined may readily be negotiated. Therefore the amount of computation needed to prepare a programme may be substantially reduced.

Although moreover the invention has been described with reference to a two dimensional control mechanism using a cartesian system of co-ordinates, the invention may apply to three dimensional control mechanisms and other systems of co-ordinates.

What I claim is:

1. An interpolating device comprising a curvilinear interpolator having at least one output terminal and at least three input terminals and transformers intercoupling said output terminal and said input terminals to produce a signal at said output terminal representing the value of a coordinate of one point on a curve in response to signals representing the value of said coordinate for other points applied to said input terminals, first storage means for storing coordinate value signals having a predetermined maximum value said storage means only having the capacity for signals less in number than the number of said input terminals, second storage means for storing at least one signal having a smaller maximum value, synthesising means for linearly transforming signals derived from said first storage means in dependence upon at least one signal derived from said second storage means to increase the number of coordinate value signals to equal the number of said input terminals and means for applying said increased number of coordinate value signals to said input terminals to produce a desired output signal at said output terminal.

2. An interpolating device according to claim 1 comprising a second curvilinear interpolator having at least one output terminal and at least three input terminals, two transformers intercoupling said latter output terminal and said latter input terminals to produce a signal at said latter output terminal representing the value of a second coordinate of said one point on a curve in response to signals representing the value of said second co-ordinate for said other points applied to the input terminals, further storage means for storing co-ordinate value signals having a predetermined maximum value said further storage means only having the capacity for signals less in number than the number of said latter input terminals and said second storage means comprising means for storing at least another signal having a smaller maximum value, said synthesising means being operative to linearly transform signals derived from said first storage means and said further storage means in dependence upon signals derived from said second storage means to increase the number of said first and second co-ordinate value signals to equal the respective numbers of input terminals and means for applying said increased number of co-ordinate value signals to said input and latter input terminal to produce respective desired output signals at said output terminals.

3. An interpolating device according to claim 2 each of said curvilinear interpolators comprising two transformers one of said transformers being of linear law and the other of said transformers being of quadratic law with means for applying to said transformer of linear law via two of the respective input terminals, reference signals representing the values of the respective co-ordinate at the ends of a cord of a curve and said synthesising means comprising means for inducing into windings of the respective transformers of quadratic law signals representing the lifts in the respective directions

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of said co-ordinates from said chord to a point on said curve.

4. An interpolating arrangement according to claim 3 said transformers being arranged to cause said curvilinear interpolator to produce quadratic interpolation, said synthesising means comprising means responsive to two input signals for each of said interpolating devices to derive two signals representing lifts in the respective two co-ordinate directions to the curve defined by input and output signals to said interpolators from a chord of said curve and means for selectively injecting said derived signals into the respective transformers of quadratic law.

5. An arrangement according to claim 3 one of said curvilinear interpolators being provided with a switch for selectively connecting one of said input terminals to one of a number of tapping points spaced along the respective transformer of linear law.

6. An interpolating arrangement according to claim 4, said synthesising means comprising differencing means for deriving a first difference signal proportional to the difference between two input signals for one of said interpolation differencing means for deriving a second difference signal proportional to the difference between two input signals for the other of said interpolators, means

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for deriving two ratio signals from said second storage means, means for multiplying said difference signals and said ratio signals each by each, and adding means for combining two of the products involving said first and second difference signals to produce one of said signals representing a lift and means for combining the other two products to produce the other of said signals representing a lift.

7. An interpolating arrangement according to claim 4 said means for injecting the respective derived signals representing lifts into said transformers of quadratic law comprising respective additional transformer windings thereon.

8. An interpolating arrangement according to claim 6 said differencing means comprising the respective transformers of linear law for the respective curvilinear interpolators.

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