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[54] **SYSTEM FOR WORKING CYLINDERS ALONG A LINE OF INTERSECTION**

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[21] Appl. No.: **396,770**

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[52] **U.S. Cl.** **318/575,** 318/604, 266/23

[51] **Int. Cl.** **G05b 19/32**

[58] **Field of Search** 318/575, 569, 604; 266/23

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Attorney, Agent, or Firm—Fitzpatrick, Cella, Harper & Scinto

[57] **ABSTRACT**

In a system for working two cylinders (A and B) along a line of intersection thereof, a position (x) to which a working tool is driven in an axial direction of the cylinder (A) to be worked is attained, as functions of an angle of rotation (ωt) of the cylinder (A) in a direction perpendicular to the axis thereof and an angle of rotation (α) obtained by shifting the angle of rotation (ωt) to the cylinder (B), from a diameter (d) of the cylinder (A), a diameter (D) of the cylinder (B) and a connecting angle (θ) formed by the axis of the cylinders (A and B) by a static electrical digital operation performing a servo-operation, or a feed-back comparison operation, of an equation $d.\sin \omega t = D.\sin \alpha$ with the aid of digital differential analyzers.

10 Claims, 12 Drawing Figures

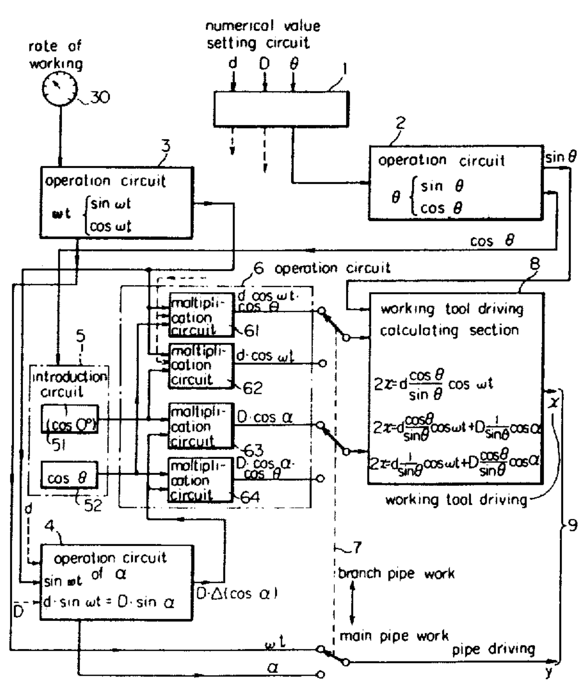
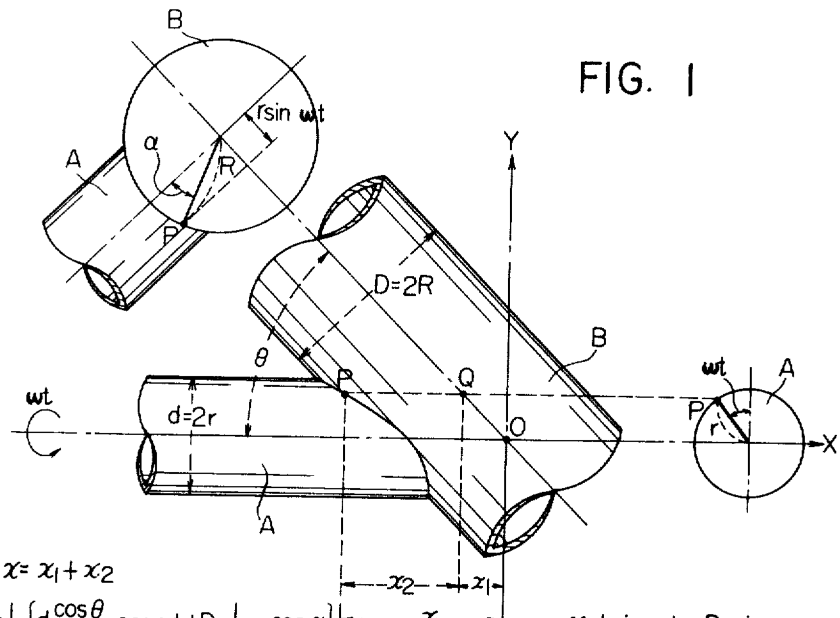


FIG. 1

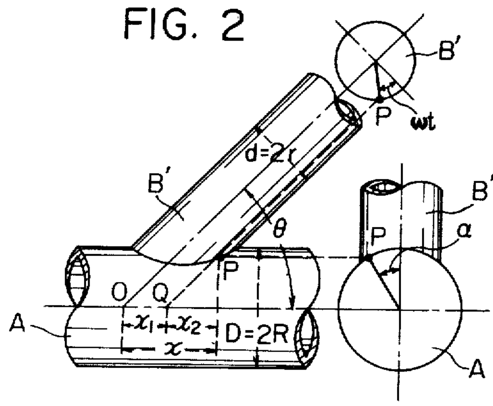


$x = x_1 + x_2$

$= \frac{1}{2}\left\{d\frac{\cos\theta}{\sin\theta}\cdot\cos\omega t + D\frac{1}{\sin\theta}\cdot\cos\alpha\right\}$

$\because d \sin \omega t = D \cdot \sin \alpha$

FIG. 2



$x = x_1 + x_2$

$= \frac{1}{2}\left\{d\frac{1}{\sin\theta}\cdot\cos\omega t + D\frac{\cos\theta}{\sin\theta}\cdot\cos\alpha\right\}$

FIG. 3

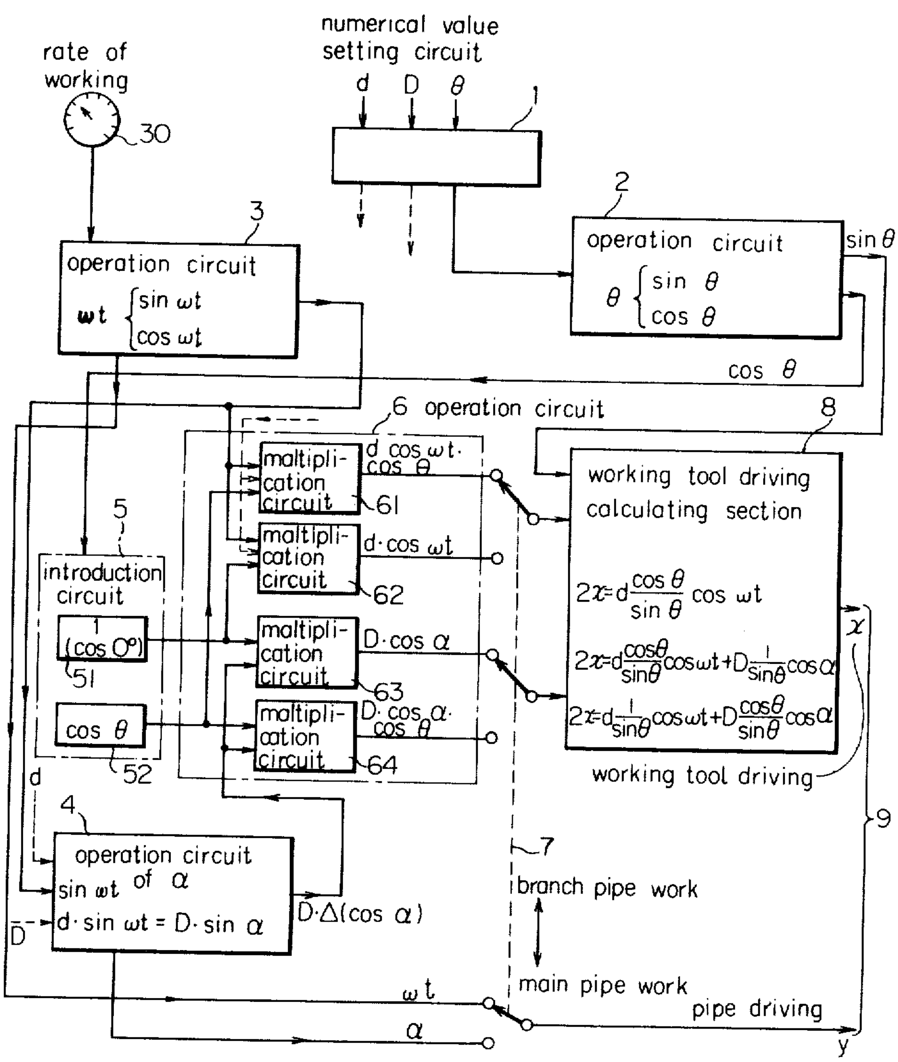

rate of working
30
numerical value setting circuit
d D θ
1
2
operation circuit
θ {sin θ, cos θ}
sin θ
cos θ
3
operation circuit
ωt {sin ωt, cos ωt}
6 operation circuit
8
d cos ωt · cos θ
maltipli-cation circuit
61
d · cos ωt
62
D · cos α
63
D · cos α · cos θ
64
5
introduction circuit
1 (cos 0°)
51
cos θ
52
working tool driving calculating section
2x=d cos θ / sin θ cos ωt
2x=d cos θ / sin θ cos ωt + D 1 / sin θ cos α
2x=d 1 / sin θ cos ωt + D cos θ / sin θ cos α
x
working tool driving
9
d
4
operation circuit of α
sin ωt
d · sin ωt = D · sin α
D · Δ(cos α)
D
7
branch pipe work
main pipe work
ωt
α
pipe driving
y

FIG. 4

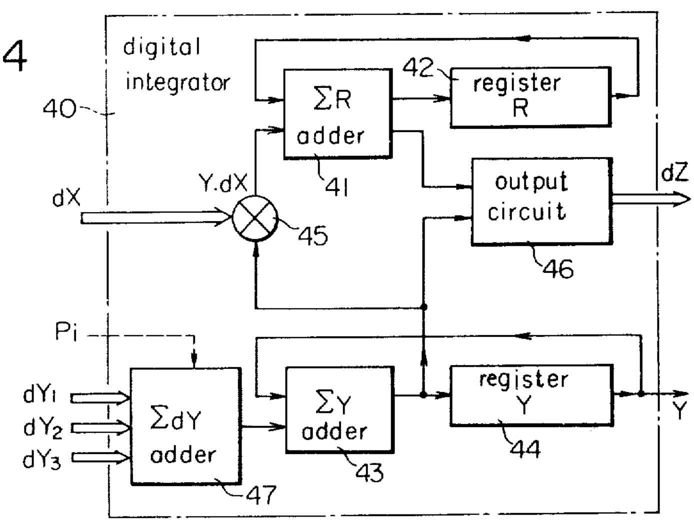


FIG. 5

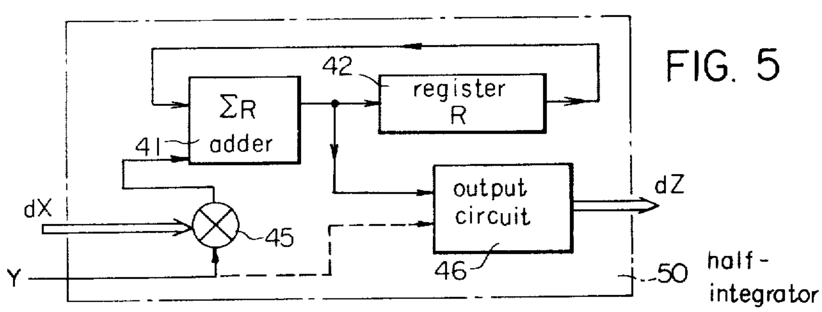


FIG. 6

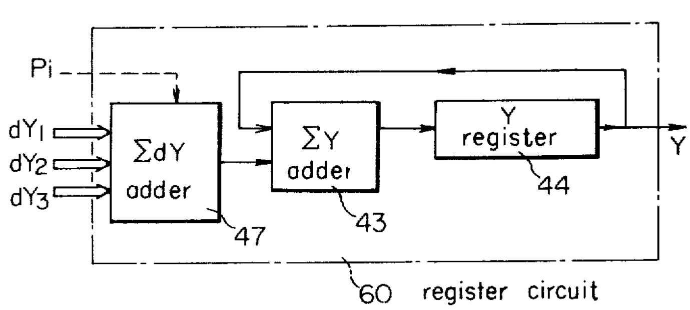


FIG. 7

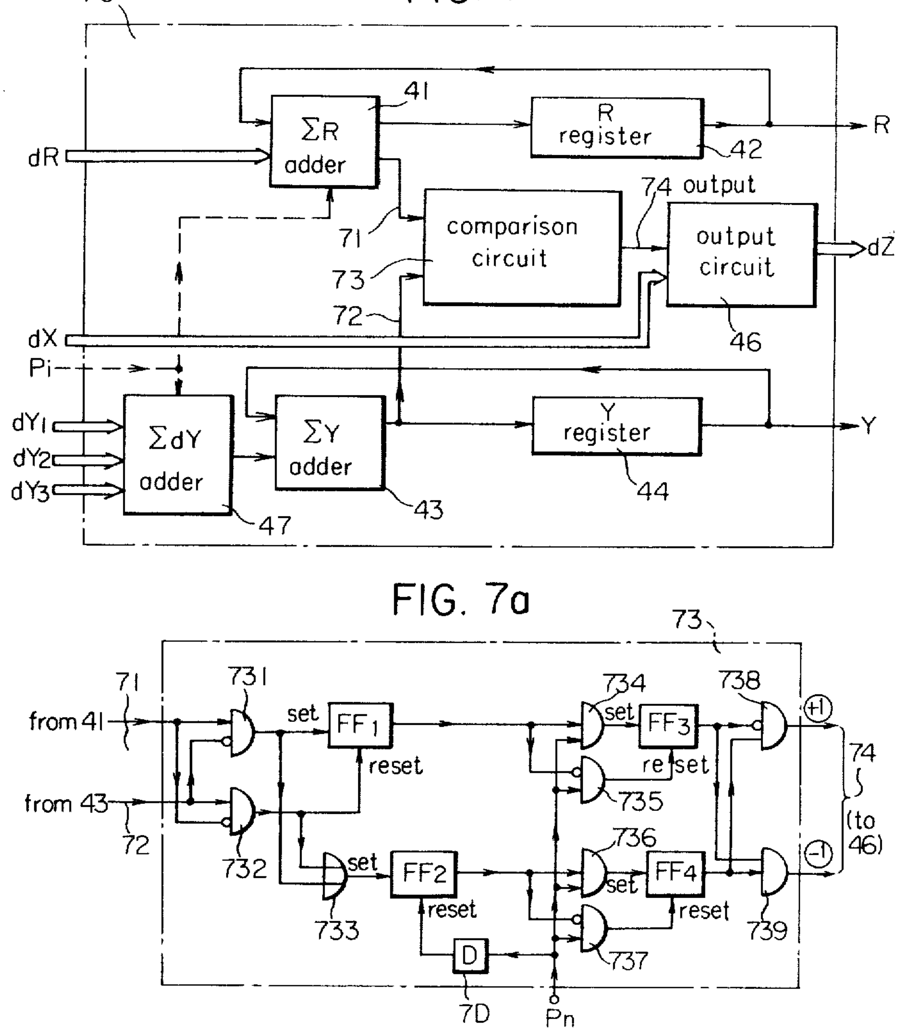

70
41
ΣR adder
R register
42
R
dR
74 output
comparison circuit
output circuit
dZ
71
73
72
46
dX
Pi
dY1
dY2
dY3
ΣdY adder
ΣY adder
Y register
Y
47
43
44
FIG. 7a
73
71
from 41
from 43
72
731
732
733
set
FF1
reset
FF2
reset
D
7D
Pn
734
735
736
737
738
739
set
FF3
re set
set
FF4
reset
+1
-1
74
(to 46)

FIG. 8

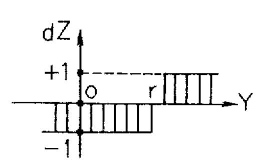
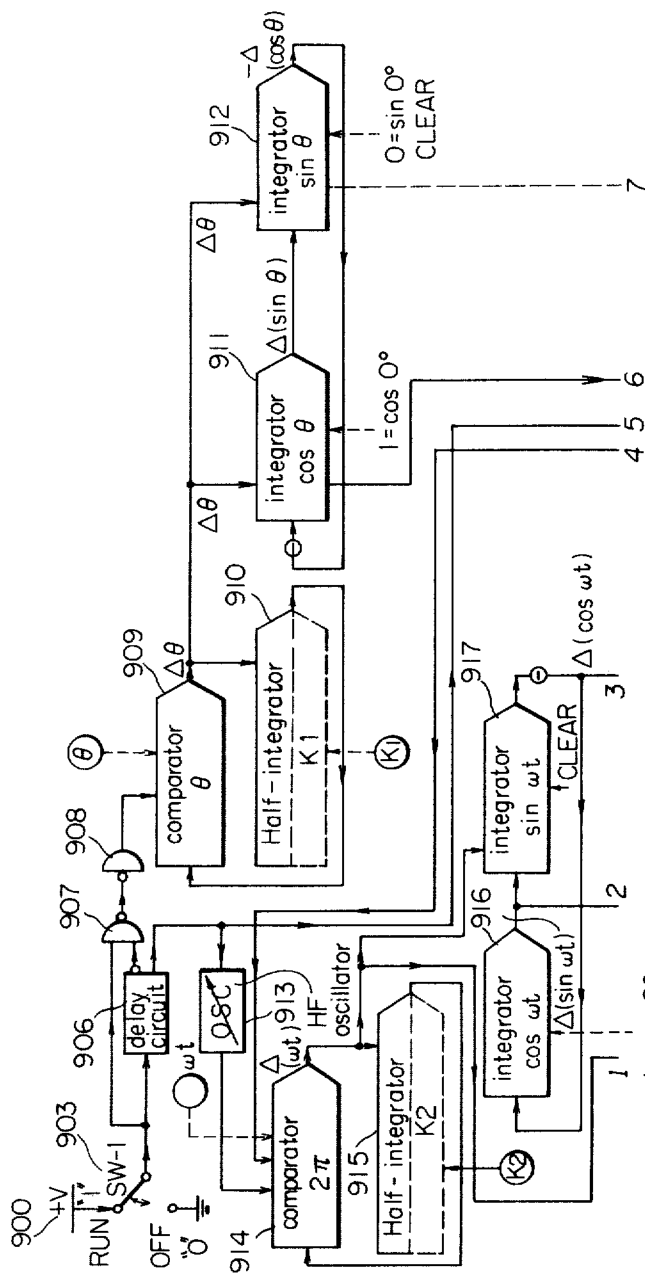
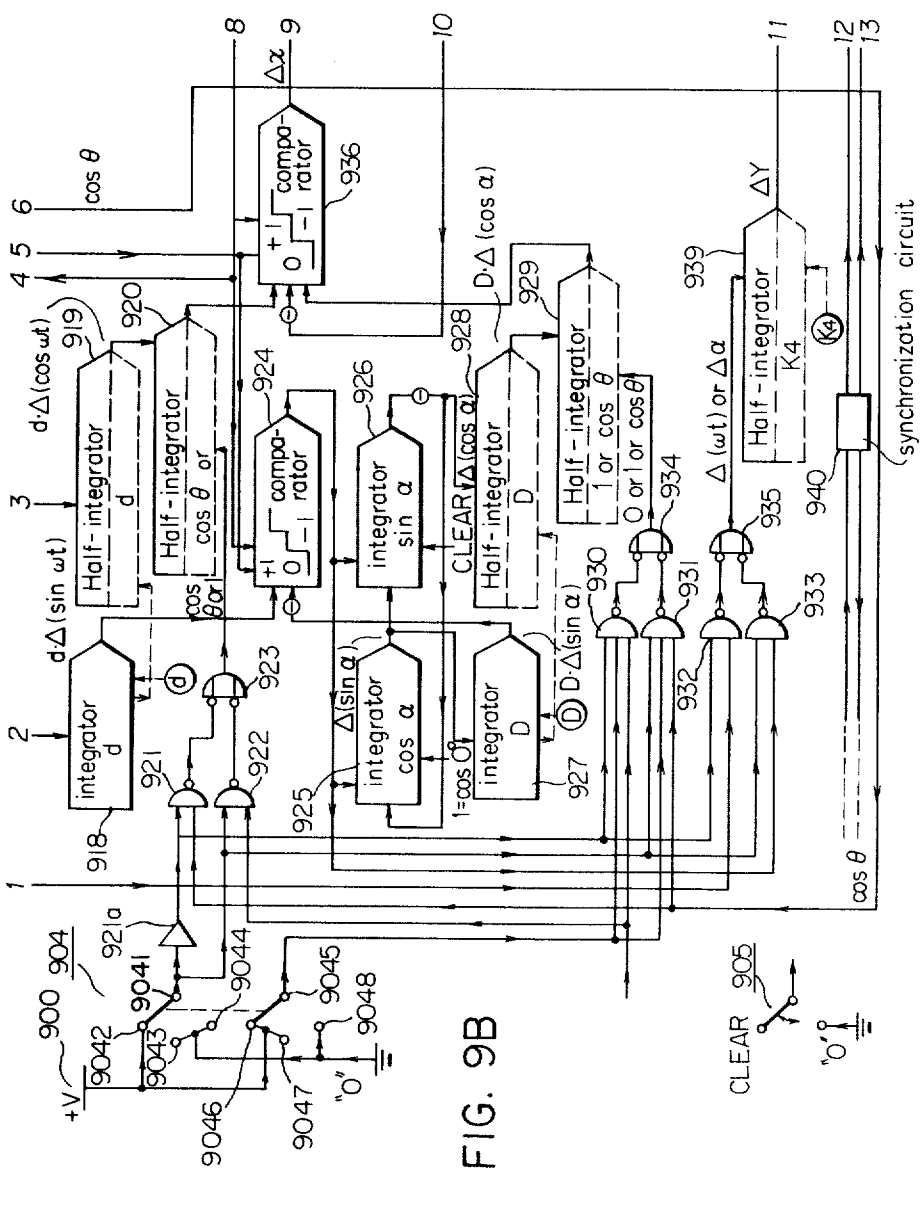

dZ
+1
o
r
Y
-1

FIG. 9A

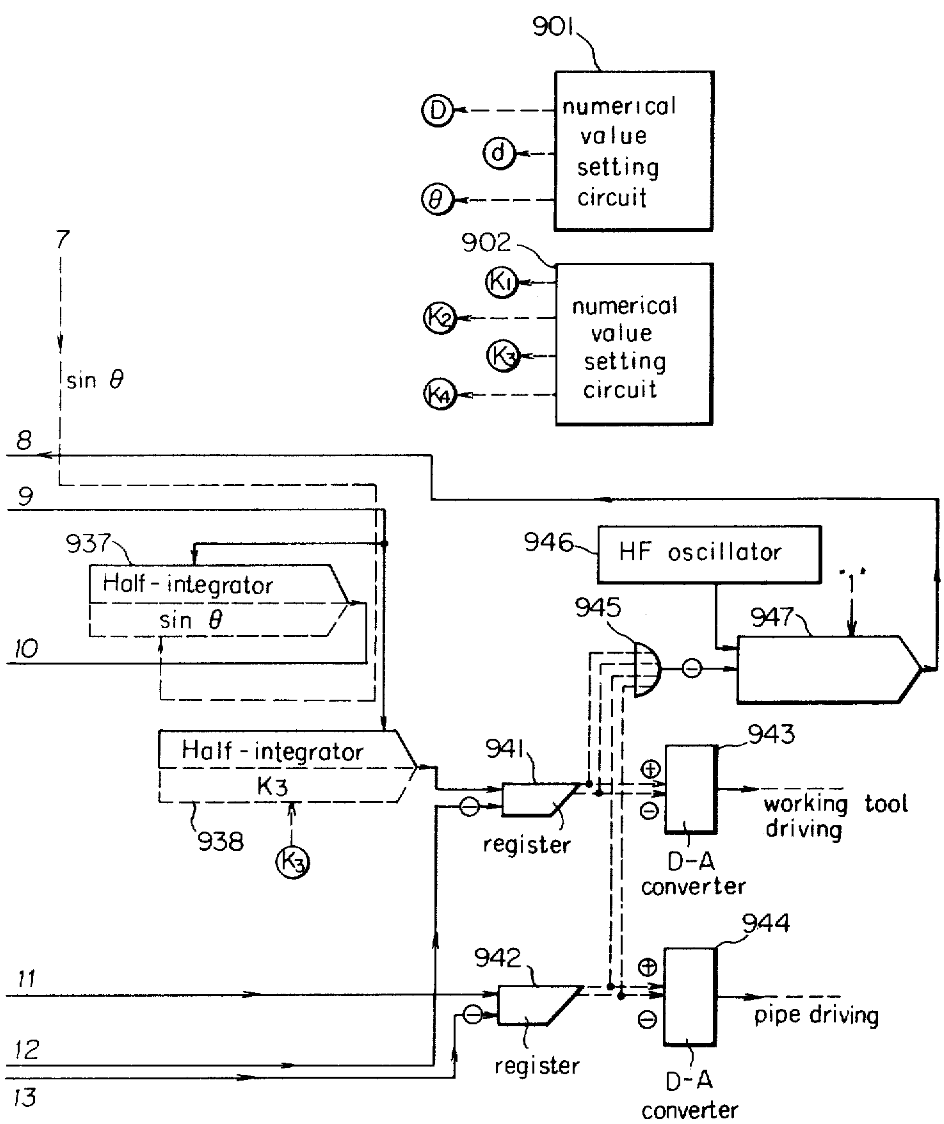

900
+V
RUN
OFF
"0"
"1"
SW-1
903
906
delay circuit
907
908
comparator θ
909
Δθ
910
Half-integrator K1
K1
θ
911
integrator cos θ
Δ(sin θ)
1=cos 0°
912
integrator sin θ
-Δ(cos θ)
0=sin 0°
CLEAR
913
OSC
HF oscillator
ωt
Δ(ωt)
914
comparator 2π
915
Half-integrator K2
K2
916
integrator cos ωt
Δ(sin ωt)
1=cos 0°
917
integrator sin ωt
CLEAR
Δ(cos ωt)
1
2
3
4
5
6
7



integrator d
Half-integrator d
Half-integrator cos θ or
compa-rator
integrator sin α
integrator cos α
integrator D
Half-integrator D
Half-integrator 1 or cos θ
0 or 1 or cos θ
Half-integrator K4
synchronization circuit
d·Δ(sin ωt)
d·Δ(cos ωt)
cos θ
Δx
ΔY
Δ(sin α)
Δ(cos α)
D·Δ(sin α)
D·Δ(cos α)
Δ(ωt) or Δα
CLEAR
+V
"0"

FIG. 9B

FIG. 9C


901
numerical value setting circuit
D
d
θ
902
numerical value setting circuit
K1
K2
K3
K4
7
sin θ
8
9
10
937
Half - integrator
sin θ
Half - integrator
K3
938
K3
946
HF oscillator
945
947
"1"
941
register
943
D-A converter
working tool driving
942
register
944
D-A converter
pipe driving
11
12
13

SYSTEM FOR WORKING CYLINDERS ALONG A LINE OF INTERSECTION

BACKGROUND OF THE INVENTION

This invention relates to a system comprising static electrical operation circuits for working cylinders along a line of intersection thereof, in which, when one of the cylinders is rotated in a direction perpendicular to the axis thereof, the line of intersection is obtained as a series of points lying in a direction of the axis by carrying out electrical operations with the aid of digital differential analyzers properly combined.

In this specification, the term "working" is defined as a process which is carried out by following the line of intersection of two cylinders. The process is for instance cutting, grinding, welding, blazing, forge welding, pressure welding and connecting of the two cylinders. The cylinder may be a cylinder made of wood or plastic material as well as a cylinder made of metal. In addition, the cylinder is not limited to a hollow cylinder like a pipe, that is, it may be a solid cylinder.

A system for working cylinders along a line of intersection thereof which comprises analog operation circuits with servo motors is known in the art. However, such a conventional system accompanies several difficulties as follows. An arc corresponding to an angle of rotation of one of two intersected cylinders in its axial direction increases with its diameter, the diameter being 1,000 mm or more, for instance. With increase of the arc, a curve obtained by the analog operation of this conventional system is liable to become inaccurate.

Furthermore, since the conventional system is based on the analog operation, it suffers from drift due to the disturbance such as variation of supply voltages provided for various elements in the analog operation circuits. Accordingly, the maintenance and control of the conventional system are troublesome.

In addition, in the conventional system, since a servo operation is performed with the aid of motor elements, it is difficult to increase the rate of operation and accordingly the rate of working cylinders along a line of intersection thereof is obliged to be slow.

SUMMARY OF THE INVENTION

Accordingly, it is a primary object of this invention to eliminate all of the difficulties accompanying a conventional system for working cylinders along a line of intersection thereof.

Another object of the invention is to provide a system for working cylinders along a line of intersection thereof in which non-linear elements such as multipliers are unnecessary for the operation of the system.

A further object of the invention is to provide a system for working cylinders along a line of intersection thereof in which generated functions such as a sine and cosine of an angle of rotation are not changed with time.

A still further object of the invention is to provide a system for working cylinders along a line of intersection thereof in which a number of cylinders having the same shape can be worked by setting numerical values only once.

A particular object of the invention is to provide a system for working cylinders along the line of intersection thereof in which a rate of electrical operation is on the order of micro-seconds.

The above objects and other objects of this invention have been achieved by the provision of a system for working cylinders along a line of thereof, which comprises: a numerical value setting section for setting a diameter (d) of a cylinder, a diameter (D) of another cylinder, a connecting angle (θ) for connecting the two cylinders; a circuit for attaining sin θ and cos θ; an operation circuit for attaining sin ωt and cos ωt from an angle of rotation

$$\int_0^t \omega \, dt \text{ (where } \int_0^t \omega \, dt = \omega t,$$

$\omega = 2\pi$, and t is the time period of rotation); an operation circuit of α for carrying out servo-operation of α and D.Δ (cos α) so as to meet an equation d.sin ωt = D.sin α (where the angle of rotation ωt of the first cylinder shifted on the second cylinder is represented by α); a multiplication circuit for operating d.cos ωt . cos θ, d.cos ωt, D.cos α and D.cos α.cos θ; and a working tool driving calculating section for calculating a horizontal driving distance from the point of intersection of the axes of the two cylinders, all of the operation being electrically performed by integrators, half-integrators hereinafter referred to, register circuits and comparison circuits.

The nature, principle and utility of this invention will become more apparent from the following detailed description and the appended claims when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIGS. **1** and **2** are diagrams illustrating geometrical analysis of a main cylinder and a branch cylinder to be worked;

FIG. **3** is a block diagram illustrating the arrangement and function of a system for working cylinders along a line of intersection thereof according to this invention;

FIGS. **4, 5, 6** and **7** are also block diagrams respectively illustrating a digital integrator, a half-integrater hereinafter referred to, a register circuit and a comparator employed in a system for working cylinders along a line of intersection thereof according to the invention;

FIG. **7A** is a circuit diagram illustrating in detail a comparison circuit shown in FIG. **7**;

FIG. **8** is a graphical representation indicating a mode of a comparison output in a system for working cylinders along a line of intersection thereof according to the invention; and

FIGS. **9A, 9B** and **9C** together constitute a block diagram showing one preferred example of the system for working cylinders along a line of intersection thereof according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

As conducive to a full understanding of this invention, the following consideration of the geometrical data of a main cylinder, or main pipe, and a branch cylinder, or branch pipe, connected thereto is first presented with reference to FIGS. **1** and **2** which respectively illustrate the cases of working the branch cylinder and the main cylinder hole.

In FIG. **1**, the axis (X) of a cylinder A to be worked makes an angle θ with the axis of a cylinder B and an angle or rotation of the cylinder A is represented by ωt

(where ω is the angular velocity and t is the time period of rotation). Strictly, the angle of rotation should be represented by

$$\int_0^t \omega \, dt.$$

Under these conditions, a distance or displacement x between a working point (not shown) and the origin 0 can be represented as follows:

As is apparent from FIG. 1,

$$d.\sin\omega t = D.\sin\alpha \tag{1}$$

and

$$x = x_1 + x_2$$

$$= \tfrac{1}{2}\left\{d \cdot \frac{\cos\theta}{\sin\theta} \cdot \cos\omega t + D \cdot \frac{1}{\sin\theta} \cdot \cos\alpha\right\} \tag{2}$$

where d is the diameter of the cylinder A (with a radius r), D is the diameter of the cylinder B (with a radius $R \geq r$), and α is the angle of rotation obtained when the angle of rotation ωt of the cylinder A is shifted to the cylinder B, a point P being positioned on both of the cylinders A and B.

In FIG. 2, a main pipe is a cylinder A while a branch pipe connected to the main pipe is a cylinder B. In this case, a displacement x between a working point and the origin O is represented by the following equation (3).

$$x = \tfrac{1}{2}\left\{d \cdot \frac{1}{\sin\theta} \cdot \cos\omega t + D \cdot \frac{\cos\theta}{\sin\theta} \cdot \cos\alpha\right\} \tag{3}$$

Incidentially, if the cylinder B in FIG. 1 is replaced with a plane, or if the cylinder A is connected to a plane substance (this work being referred to as "a plane work" hereinafter), then the displacement x is represented by the following equation (4).

$$x = \tfrac{1}{2} d \cdot \frac{\theta}{\sin\theta} \cos\omega t \tag{4}$$

FIG. 3 is a block diagram generally illustrating the functions of a system for working cylinders along a line of intersection thereof according to this invention, which comprises a numerical value setting section **1**. This section **1** sets numericals values such as the diameter d of the branch pipe, the diameter D of the main pipe, an angle θ formed by the axes of the main and branch pipes and, if necessary, an offset δ (not shown) between the main pipe and the branch pipe and produces outputs converted into serial binary numbers suitable for the operation of digital differential analyzers.

In this connection, it should be noted that this invention provides a system for working cylinders along a line of intersection formed by them in which the work is controlled by the operation of a digital differential analyzer. This operation is performed with the aid of clock pulses whose frequency is 1 MHz in a preferred example of the device according to the invention.

The system further comprises: a circuit **2** for obtaining from θ sin θ and cos θ which will be used later; a circuit **3** for operating sin ωt and cos ωt from the angle of rotation ωt by setting a rate of working with a rate of working setting device **30**; a circuit **4** for carrying out the operation of equation (1) to produce its outputs $D.\Delta(\cos\alpha)$ and α; a circuit **5** for introducing cos θ and cos $0°=1$ obtained in the circuit **2** through circuits **51** and **52** to an operation circuit **6**, respectively; the operation circuit **6** performing the electrical operations of $d.\cos\omega t.\cos\theta$, $d.\cos\omega t$, $D.\cos\alpha$ and $D.\cos\alpha.\cos\theta$ in multiplication circuits **61** through **64**; and switching means **7** adapted to switch the main pipe work and the branch pipe work (including the plane work).

The system further comprises: a section **8** for calculating the driving of a working tool, or performing the operations of addition in equations (2), (3) and (4) (hereinafter referred to as "a working tool driving calculating section **8**", when applicable); and an output section **9** having x pulses for (horizontally) driving the working tool and Y pulses for driving the pipes.

FIGS. 4 through 7 are block diagrams illustrating digital differential analyzer elements employed in this example.

FIG. 4 shows a digital integrator **40** which comprises: adders **41, 43** and **47**; an R-register **42**; a Y-register **44**; a multiplication gate **45**; and an output circuit, **46.** In FIG. 4, reference symbols dY_1, dY_2, dY_3 . . . represent input components at the Y-register side and reference symbol Pi represents a signal for designating the scales of the input components. The multiplication gate **45** multiplies an output Y of the Y-register **44** by dx. The output circuit **46** produces as an output an overflow pulse dZ of the R-register **42.**

Shown in FIG. 5 is a circuit **50,** or a multiplication element (hereinafter referred to as "a half-integrator circuit") which can be obtained by reducing the circuits relating to the Y-register from the circuits of FIG. 4. This half-integrator circuit **50** produces an output $dZ = Y.dx$.

As is apparent in comparison of FIG. 6 with FIGS. 4 and 5, a register circuit **60** shown in FIG. 6 can be obtained by reducing the circuit of FIG. 5 from that of FIG. 4.

Shown in FIG. 7 is a comparator **70** comprising a comparison circuit **73.** The circuit **73** operates to compare an input **71** (that is, a value in the R-register, which is positive at all times) with an input **72** (that is, a value in the Y-register) thus producing an output **74** to be applied to the output circuit **46.**

As a result, in the output circuit **46,** until an operational result in the present operation cycle (that is, in a period of time in which all the digits in the R-register and Y-register are subjected to comparison) is obtained, the operational result in the preceding operation cycle is maintained recorded and continues to produce its comparison output dZ.

The comparison circuit **73** described above is illustrated in detail in FIG. 7a, which comprises: AND (logical product) circuits **731, 732,** and **734** through **739**; an OR (logical sum) circuit **733**; flip-flops FF_1 through FF_4; and a delay circuit 7D. In FIG. 7a, circular symbols (○) provided on the input side of the AND circuits indicate that the logic of an input signal applied thereto is inverted. Furthermore, reference symbol Pn in FIG. 7a designates a synchronous pulse (or clock pulse) corresponding to 2^n, or the n-th digit, when the number of operational digits is n, and no synchronous pulse is applied for the operation of the digits other than the above-mentioned digit.

When the input **71** is greater than the input **72**, the output of the AND circuit **739** turns ON and the output **74** is therefore in a mode of −1. When the input **71** is smaller than the input **72**, the output of the AND circuit **738** turns ON and the output **74** is therefore in a mode of +1. When the input **71** is equal to the input **72**, both of the outputs of the AND circuits **738** and **739** turn OFF and the output **74** is in a mode of 0.

Shown in FIG. **8** are modes of the comparison output dZ in this embodiment. When the input **71** is, for instance, +7, the following three modes of comparison output dZ appear depending on the values of the input **72**.

a. When the input **72** $\leqq +6$, $dZ = -1$.
b. When the input **72** $= +7$, $dZ = 0$.
c. When the input **72** $\leqq +8$, $dZ = +1$.

With reference to FIG. **9**, there is shown one example of the system according to the invention, which comprises: a power source **900** of, for instance, DC +5 volts representing a logical signal 1 with a ground potential representing a logical signal 0; a numerical value setting circuit **901** for setting a diameter D of a main pipe, a diameter d of a branch pipe and an angle θ formed by the axes of the main and branch pipes (hereinafter referred to as "a connecting angle θ") and a numerical value setting circuit **902** for setting operational constants K_1 through K_4, these two circuits **901** and **902** forming a numerical value setting section **1** in FIG. **3**; switching means **903**, **904** and **905**; and a delay circuit **906** for delaying a logical signal output for 1 second for instance.

In FIG. **9**, symbols (○) marked on logical elements indicate that the logic of signals applied thereto is inverted as an inverter **921a** inverts its input signal.

The system shown in FIG. **9** further comprises: AND (logical product) circuits **907**, **921**, **922** and **930** through **933**; OR (logical sum) circuits **908** and **923** **934** and **935**; and comparators **909**, **914**, **924** and **936** such as shown in FIG. **7**. Some of the inputs of these comparators are marked by symbol ⊖ which indicates that signs of the numerical values of inputs applied thereto are inverted.

The system further comprises: integrators **911**, **912**, 916, 917, 918, 925, 926 and **927** as shown in FIG. **4**; half-integrators **910**, **915**, **919**, **920**, **928**, **929**, **937** and **938** as shown in FIG. **5**; register circuits **941** and **942** as shown in FIG. **6**; a variable frequency oscillator **913** to which a frequency control signal is applied by a command signal (not shown) to control a rate of generating an angle of rotation ωt, that is, a pipe driving speed; and digital-analog converters **943** and **944** for producing outputs (analog data) to drive a working tool and a pipe to be worked. The driving data of the tool and pipe are negatively fed back through a synchronization circuit **940** to the respective registers by pulse tachometer generators provided on the driving means of the tool and pipe.

A switch **904** is operated as follows. In the case of the main pipe hole work (equation 3), the switch **904** is operated so that output terminals **9041** and **9045** are respectively connected to input terminals **9042** and **9046**. In the case of the branch pipe work (equation 2), the output terminals **9041** and **9045** are respectively connected to input terminals **9043** and **9047**. In the case of the plane work (equation 4), the output terminals **9041** and **9045** are respectively connected to input terminals **9044** and **9048**.

The steps of working pipes, or cylinders, by the use of the system according to this invention will be described with reference again to FIG. **9**. It will be seen from the foregoing and from the drawings that the various components **1–8** of FIG. **3** are shown in greater detail in the diagram of FIGS. **9A**, **9B**, and **9C**. Thus it will be seen from the foregoing description and from the drawings that the numerical value setting circuit **1** of FIG. **3** comprises the components **901** and **902** of FIG. **9C**. The operation circuit of FIG. **3** comprises the comparator **909** and integrators **910**, **911** and **912** of FIG. **9A**. The operation circuit **3** of FIG. **3** comprises the oscillator **913**, the comparator **914**, and the inegrators **915**, **916** and **917** of FIG. **9A**. The operation circuit of FIG. **3** comprises the integrator **918**, the comparator **924** and the integrators **925**, **926** and **927** of FIG. **9B**. The introduction circuit **5** of FIG. **3** comprises the AND circuits **921**, **922**, **930** and **931** and the OR circuits **923** and **934** of FIG. **9B**. The operation circuit **6** of FIG. **3** comprises the integrators **919**, **920**, **928** and **929** of FIG. **9B**. The switching means **7** of FIG. **3** comprises the switch **904**, including its subcomponents **9042–9048** of FIG. **9B**. Finally, the working tool driving calculating section **8** of FIG. **3** comprises the comparator **936** of FIG. **9B** and the integrators **937** and **938** of FIG. **9C**.

Step 1

A switch **903** (SW–1) is thrown to the position RUN.

Step 2

Numerical data sin θ and cos θ are calculated from a connecting angle θ in initial approximately one second. For this purpose, pulses corresponding to $\Delta\theta$ and as many as necessary for the operation in the integrators **911** and **912** are generated by the comparator **909** and the half-integrator **910**.

The connecting angle θ indicated by a decimal degree in the form of □□□.□□° (**30.00°–150.00°**) is set in the R-register **42** in the comparator (FIG. **7**) operating in a servo-mode as indicated in FIG. **8**. In order to regulate the relationship between the value of the connecting angle θ and the number of pulses corresponding to $\Delta\theta$ (hereinafter referred to as pulses $\Delta\theta$, when applicable), the half-integrator **910** is provided in the feed-back loop of the comparator **909**, while a serial binary number which is a coefficient (constant) k_1 for the conversion of a numerical value is applied through the numerical value setting section **902** to the R-register **42** of the half-integrator **910** so as to satisfy the following equation (5).

$$\theta = k_1 . \Sigma\Delta\theta \tag{5}$$

For instance, when $\theta = 90.00°$ is set in the R-register, the value of the constant k_1 can be determined so that values of sin θ and cos θ turn from those when $\theta = 0°$ to those when $\theta = 90°$. In other word, in the case where the register has 16 digits, its 16th digit being provided for signs, the value of the constant k_1 can be determined so that a content in the register of the integrator 911 turns from 0111111111111111 to 0000000000000000 while that in the register of the integrator 912 turns from 0000000000000000 to 0111111111111111.

Step 3

The values of cos θ and sin θ are calculated by the use of the pulses $\Delta\theta$ in the integrators **911** and **912**, respectively. Calculation of these values is made in advance for the purpose of using them as constant in the operation which will be described later. Accordingly, in the calculation, an output 1 from the delay circuit **906** is not applied to the comparators **924** and **936**, the read gates (not shown) of which are therefore not opened so that an erroneous comparison operation is not carried out.

Step 4

Angles of rotation sin ωt and cos ωt are calculated in correspondence to a rotation of the branch pipe. In this connection, it should be noted that the rotation of the branch pipe represents an angle of rotation ωt required for the work and is not limited only to $\omega t = 2\pi = 360°$. The angle of rotation necessary for this operation is read in the register of the comparator **914** in advance by actually rotating the branch pipe. Then, pulses corresponding to $\Delta(\omega t)$ (hereinafter referred to as pulses $\Delta(\omega t)$, when applicable) as much as necessary for sin ωt and cos ωt are generated by the comparator **914** and the half-integrator **915**. Determination of a constant k_2 is carried out in the same manner as in the calculation of cos θ and sin θ by the use of pulses $\Delta\theta$.

By regulating an output frequency of the variable frequency oscillator **913**, a rate of driving a working tool and that of driving a pipe can be externally controlled to change with a rate of the operation. The output of the variable frequency oscillator **913** controls a rate of generation of $\Delta(\omega t)$ pulses.

With the aid of the pulses $\Delta(\omega t)$ thus generated, cos ωt and sin ωt are calculated in the integrators **916** and **917**, respectively.

Step 5

The following servo-operation, or feed-back comparison operation, is carried out to obtain an angle of rotation α which satisfies equation (1). A high frequency output is produced by the comparator **924** until the difference between two inputs in a digital servo circuit which is provided with the comparator **924** operating in a servo mode has become zero, that is, the difference between an output d.Δ(sin ωt) of the integrator **918** and an output D.Δ(sinωt) of the integrator **927** has become zero. This high frequency output is pulses corresponding to $\Delta\alpha$ (hereinafter referred as to pulses $\Delta\alpha$, when applicable).

In this operation, the diameter d of the branch pipe is written through the adders **47** and **43** into the Y-register **44** in the integrator **918** and the diameter d thus written is introduced to the half-integrator **919**. This is to use the half-integrator **919** as an element for storing the diameter d.

Similarly as described above, the diameter D of the main pipe is introduced through the integrator **927** to the half-integrator **928**.

Step 6

With the aid of the pulses $\Delta\alpha$ thus produced, sin α and cos α are calculated by the integrators **925** and **926**, respectively. The generation of the pulses $\Delta\alpha$ and the calculation of sin α and cos α are carried out whenever the output pulse $d.\Delta(\sin\omega t)$ from the comparator **918** is applied to the integrator **924**. The pulses $\Delta\alpha$ thus generated at high speeds carry out a servo operation so as to change a value in the Y-register **44** of the comparator **924** into zero.

The fact that the value in the Y-register of the comparator **924** is kept zero at all times means that an integral value of the outputs of the integrators **918** and **927** applied to the comparator **924** is zero, that is, the following relationship is established between d.sinωt and D.sinα.

$$\Sigma\{d.\Delta(\sin\omega t) - D.\Delta(\sin\alpha)\} = 0$$

Therefore, $d.\sin\omega t = D.\sin\alpha$. This is the same as equation (1).

Step 7

By using an output of the integrator **917** as an input dx of the half-integrator **919**, a multiplication of $d.\Delta(\cos\omega t)$ is carried out. Similarly, by using an output of the integrator **926** as an input dx of the half-integrator **928**, a multiplication of D.Δ(cos α) is carried out.

Step 8

The switch **904** for changing the modes of work is actuated to set a mode of work as was described previously, whereby the inputs of the Y-registers in the half-integrators **920** and **929** are switched through the respective logical elements (gates) and the multiplications necessary for the respective modes of work are carried out.

Table 1

Modes of work	Plane work	Branch pipe work	Main pipe hole work
Y-register of half-integrator 920	cos θ	cos θ	1
Y-register of half-integrator 929	0	1	cos θ

The value of cos θ indicated in Table **1** has been calculated in Step **3** and stored in the Y-register of the integrator **911**.

For instance, if it is assumed that each of the registers in the integrator, half-integrator and comparator has 16 digits such as 1000000000000000, its 16th digit being designated by a reference symbol P_{16}. The 16th digit P_{16} indicates a positive or negative sign, that is, 0 indicates the positive sign and 1 the negative sign. In the case where cos 0° = **1**, the content in the Y-register **44** is 0111111111111111. In case of 0 shown in Table 1, an input signal to the half-integrator **929** is inhibited.

Step 9

An operation for driving the working tool in a designated mode of work is carried out. A high frequency output is generated by the comparator **936** until the sum of three inputs of a digital servo circuit with the comparator **936** operating in a servo mode, that is, the sum of the values in a column in the following Table 2 has become zero in a mode of work designated.

Table 2

Modes of work / Outputs	Plane work	Branch pipe work	Main pipe hole work
Output of half-integrator 920	$d \cdot \Delta(\cos\omega t)$ cos θ	$d \cdot \Delta(\cos\omega t)$ cos θ	$d \cdot \Delta(\cos\omega t)$
Output			

Table 2-Continued

Modes of work	Plane work	Branch pipe work	Main pipe hole work
Outputs			
of half-integrator 929	0	D·Δ(cos α)	D·Δ(cos α) cos θ
Output of half-937	−Δx·sin θ	−Δx·sin θ	−Δx·sin θ

The product of this high frequency output and a constant k_3 is a working tool driving command pulse Δx.

Step 10

The output pulse Δx from the comparator **936** is multiplied by sin θ in the half-integrator **937** the value of this sin θ has been calculated in step 3 and stored in the Y-resister **44** of the integrator **912** as was described previously. This operation is carried out whenever the output from the halfintegrator **920** or **929** is applied to the comparator **936**, and the output pulse Δx therefrom carries out a servo-operation so as to change the value stored in the Y-register **44** of the comparator **936** into zero.

The fact that the value in the Y-register **44** of the comparator **936** is thus zeroed, means that an integral value of the inputs applied to the comparator **936** from the half-integrators **920, 929** and **937** is zero. That is, in the case of the plane work

$$\Sigma \left\{\frac{d}{2}\cdot\Delta(\cos\omega t)\cdot\cos\theta - \Delta x\cdot\sin\theta\right\} = 0$$

$$\text{therefor } 2x = d\cdot\cot\theta\cdot\cos$$

in the case of the branch pipe work

$$\Sigma \left\{\frac{d}{2}\cdot\Delta(\cos\omega t)\cdot\cos\theta + \frac{D}{2}\cdot\Delta(\cos\alpha) - \Delta x\cdot\sin\theta\right\} = 0$$

$$\text{therefor } 2x = d\cdot\cot\theta\cdot\cos\omega t + D\cdot\frac{1}{\sin\theta}\cdot\cos\alpha;\text{ and}$$

in the case of the main piple hole work

$$\Sigma \left\{\frac{d}{2}\cdot\Delta(\cos\omega t) + \frac{D}{2}\cdot\Delta(\cos\alpha)\cdot\cos\theta - \Delta x\cdot\sin\theta\right\} = 0$$

$$\text{therefor } 2x = d\cdot\frac{1}{\sin\theta}\cdot\cos\omega t + D\cdot\cos\alpha\cdot\cot\theta$$

The pulse Δx obtained by each of these operation is subjected to a numerical value conversion for the operation of the tool driving system, that is, it is multiplied by the constant k_3 in the half-integrator **938**, and the product of this multiplication is applied to the register **941**.

Step 11

On the other hand, the operation for driving the tool is carried out in a designated mode of work. The following outputs are applied, as an input dx, to the half-integrator **939** through the switching gate separately according to the modes of work, as indicated in Table 3.

Table 3

Mode of work	Plane work	Branch pipe work	Main pip hole work
Output			
Value	Δωt	Δωt	α
Comparators from which the output is produced	914	914	924

This output is subjected to a numerical value conversion for the operation of the pipe driving system, that is, it is multiplied by a constant k_4 in the half-integrator **939**, which produces an output pulse ΔY. This output pulse ΔY is introduced to the register **942.**

Step 12

The output pulse Δx for driving the working tool and the output pulse ΔY for driving the pipe, thus produced, are respectively applied, as command signals, to the registers **941** and **942.** In this operation, feed-back pulses from pulse tachometer generators connected to a working tool driving motor (not shown) and a pipe driving motor (not shown) are fed back to the registers **941** and **942** through the synchronization circuit **940.** The registers **941** and **942** are difference-storing registers each of which stores a difference between a command value and a present available value. This difference in value is introduced through an output circuit for analog conversion (not shown) to the digital-analog converters **943** and **944,** which produce analog difference signals. By these analog difference signals the working tool and pipe are respectively driven, thereby drawing a curve of intersection of solids so as to work the pipe as specified.

In addition, the rate of working a pipe can be arbitrarily regulated, according to this invention, in the following manner. The positive and negative output lines of the registers **943** and **944** are connected to the logical sum circuit **945** where the logical sum of the square roots of the squares of the pulses ΔX and ΔY are obtained. This logical sum output from the circuit **945** and an output pulse from the variable frequency generator **946** arbitrarily determining the rate of working the pipe are applied to the comparator **947**, to the register (R) of which 1 has been applied in advance.

Under these conditions if two output pulses or more are produced by the logical sum circuit **945** during the period of the output pulse of the generator **946,** the comparator **947** produces an output to stop the electrical operations in the comparators **914, 924** and **936.** The next output pulse from the generator **946** causes the comparator **947** to stop producing its output whereby the electrical operation of the comparators **914, 924** and **936** is carried out again. Thus, the outputs of the registers **941** and **942** are regulated by the period of the output pulse of the generator **946.**

As is obvious from the above detailed description, in this invention, it is unnecessary to particularly provide non-linear elements such as multipliers, and generated functions such as sin θ and cos θ are not changed with time. Furthermore, numerical values for controlling the work can be readily stored. Therefore, a number of pipes having the same shape can be worked by setting such numerical values only once. In addition, in this invention, a value of (accuracy) x (a rate of operation) is constant the regulation of this value depends on the number of digits in the registers built in the digital differential analyzer. However, since the rate of operation is on the order of micro-seconds, it is considerably superior to that in the conventional device employing a servo-motor.

What we claim is:

1. In a system for working along a line of intersection between first and second cylinders whose axes intersect, the combination of means adjustable to produce electrical signals (d), (D), and (θ) which represent, respectively, the diameters of the first and second cylinders and the angle of intersection of their axes, means responsive to the rotation of the first cylinder about its axis to produce a corresponding electrical signal (ωt), an electrical oscillator operative to generate a series of accurately spaced electrical impulses, first integrator means connected to receive said electrical impulses and said electrical signal (ωt) and to produce delta modulation pulses representative of the values (Δ sin ωt) and (Δ cos ωt), second integrator means connected to receive the electrical signal (d) and the delta modulation pulses (Δ sin ωt) and to produce delta modulation pulses ($d.\Delta$ sin ωt) in response thereto, third integrator means connected to receive the electrical signal (D) and feedback signals, and to produce delta modulation pulses (D.Δ sin α), first comparator means connected to receive the delta modulation pulses (d.Δ sin ωt) on the one hand and the delta modulation pulses (D.Δ sin α) on the other hand, the output of said first comparator being connected to supply said feedback signals to said third integrator means for operating same in a servo mode to produce a delta modulation signal (D.Δ sin α) where (α) is the angle of rotation obtained when the angle of rotation (ωt) of the first cylinder is shifted onto the second cylinder, second comparator means connected to receive the delta modulated signals and to produce working tool driving signals in response thereto and means for driving a working tool in response to said working tool driving signals.

2. A system according to claim 1 wherein said second comparator means comprises fourth integrator means comprising a third comparator connected to receive the electrical signals (θ) and a comparator feedback signal, said third comparator being operative to produce delta modulated pulses ($\Delta\theta$), a half integrator and first and second integrators, said half integrator being connected to receive said delta modulated pulses ($\Delta\theta$) and to produce said comparator feedback signals, a feedback loop connecting the output of said half integrator to an input of said third comparator, means connecting the output of said third comparator to said first and second integrators, said second integrator being operative to produce signals corresponding to the value (sin θ) in response to the application thereto of delta modulated pulses corresponding to (Δ sin θ) and ($\Delta\theta$) and operative further to produce a feedback output comprising delta modulated pulses corresponding to the value ($-\Delta$ cos θ), a feedback loop connecting the feedback output of the second integrator to the first integrator, said first integrator being operative to produce signals corresponding to the value (cos θ) in response to the application thereto of said feedback output and said delta modulated pulses corresponding to (Δ θ), said first integrator being operative to produce further output signals comprising delta modulated pulses corresponding to the value (Δ sin θ) and means for applying said further output signals from said first integrator to said second integrator.

3. A system according to claim 1 wherein said second comparator means comprises fourth integrator means connected to receive the electrical signals (θ) and to produce signals representative of the values (sin θ) and (cos θ), fifth integrator means connected to said third integrator means to receive therefrom delta modulation pulses (D.Δ sin α) and to produce signals representative of the value (D. Δ cos α), sixth integrator means connected to said second integrator means to receive therefrom delta modulation pulses (d.Δ sin ωt) and to produce signals representative of the value (d.Δ cos ωt), a comparator connected to receive the outputs of said fifth and sixth integrator means and a further feedback signal and to produce a comparator output signal corresponding to the comparison of said outputs of said fifth and sixth integrator means and said further feedback signal, seventh integrator means connected to receive said comparator output signal and the signal (sin θ) from said fourth integrator means and to produce said further feedback signal, eighth integrator means also connected to receive said comparator output signal and to produce a delta modulated driving command signal, a register connected to receive said delta modulated command signal and working tool driving means connected to receive outputs from said register.

4. A system according to claim 3 wherein said sixth integrator means is also connected to the output of said fourth integrator means to receive signals representative of the value (cos θ) and is operable to produce output signals representative of the value (d.Δ cos ωt cos θ) wherein said fifth integrator means is also connected to receive a signal representative of the value (1), wherein there is provided a ninth integrator means connected to receive said electrical signal (ωt), said ninth integrator means being operative to produce a delta modulated driving command signal corresponding to rotation of the first cylinder.

5. A system according to claim 3 wherein said sixth integrator means is also connected to receive a signal representative of the value (1), wherein said fifth integrator means is also connected to the output of said fourth integrator means to receive signals representative of the value (cos θ) and is operable to produce signals representative of the value (D.Δ cos α. cos θ) and wherein there is provided a ninth integrator means connected to receive delta modulated outputs corresponding to the value ($\Delta\alpha$) from said first comparator and to produce a delta modulated driving command signal corresponding to rotation of the second cylinder.

6. A system according to claim 3 wherein said sixth integrator means is also connected to the output of said fourth integrator means to receive signals representative of the value (cos θ) and is operable to produce output signals representative of the value (d.Δ cos ωt cos θ), wherein said fifth integrator means is also connected to receive a signal representative of the value (0) and to produce an output of value zero in response thereto, and wherein there is provided a ninth integrator means connected to receive the delta modulated electrical signals ($\Delta\omega t$), said ninth integrator means being operative to produce a delta modulated driving command signal corresponding to rotation of the first cylinder.

7. A system according to claim 3 wherein there is provided an adjustable frequency oscillator operable to

produce electrical pulses at different repetition rates, a control comparator connected to receive the pulses from said adjustable frequency oscillator and to receive working tool driving signals, said control comparator being operative to produce a stop producing signal when the repetition rate of working tool driving signals applied thereto is greater than that of the electrical pulses produced by said electrical frequency oscillator, and means for directing said stop signals from said control comparator to first and second comparator means to stop their operation until the occurance of a subsequent pulse from said adjustable frequency oscillator.

8. A system according to claim **7** wherein said control comparator is connected to receive first outputs from said register.

9. A system according to claim **8** wherein said control comparator is connected to receive additional outputs from a further register connected to process signals corresponding to the rotation of the first cylinder about its axis.

10. A system according to claim **9** wherein said first and additional outputs are applied to said control comparator via a logical sum circuit.

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