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[33] Great Britain

[31] 30577/66

[56] References Cited

OTHER REFERENCES

Aasnaes, H. B. et al. Integrating Ramp Analog-to-Digital Converter. In IBM Tech. Disc. Bull. 11(4): p 386- 387. September, 1968. TK7800.113.

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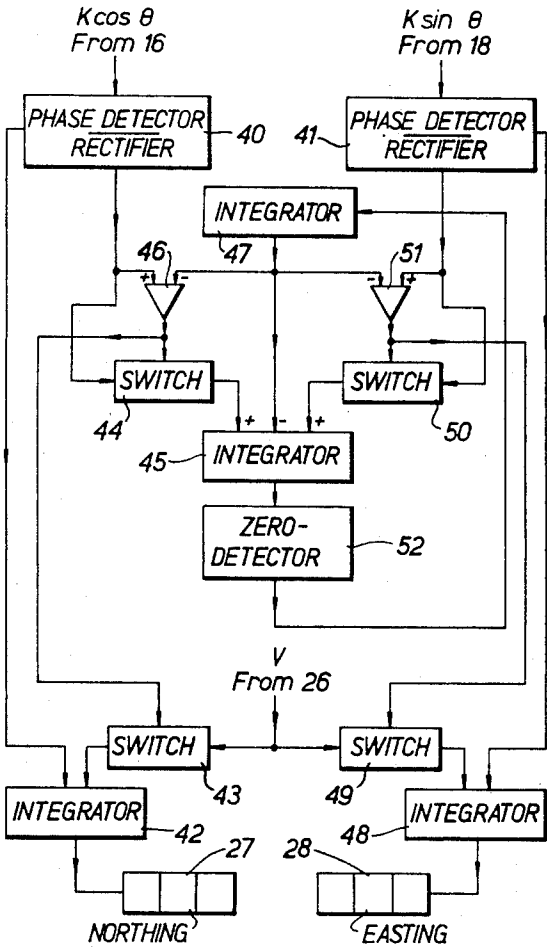
[54] TIMING MEANS
6 Claims, 4 Drawing Figs.

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235/183

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G06g 7/78, G06g 7/18

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183, 186

ABSTRACT: Timing means derives from input signals representative of $K \cos \theta$ and $K \sin \theta$ a signal having a period in accordance with factor K . The input signals are integrated in an integrator which also integrates in an opposite sense a voltage increasing progressively with time from an initial value. When the integral accumulated by the integrator reaches a predetermined value the said voltage is returned to its initial value. The input signals are integrated once during each progression of the said voltage for periods in accordance with respectively $\cos \theta$ and $\sin \theta$ so that the progressions of the said voltage vary in accordance with the factor K .



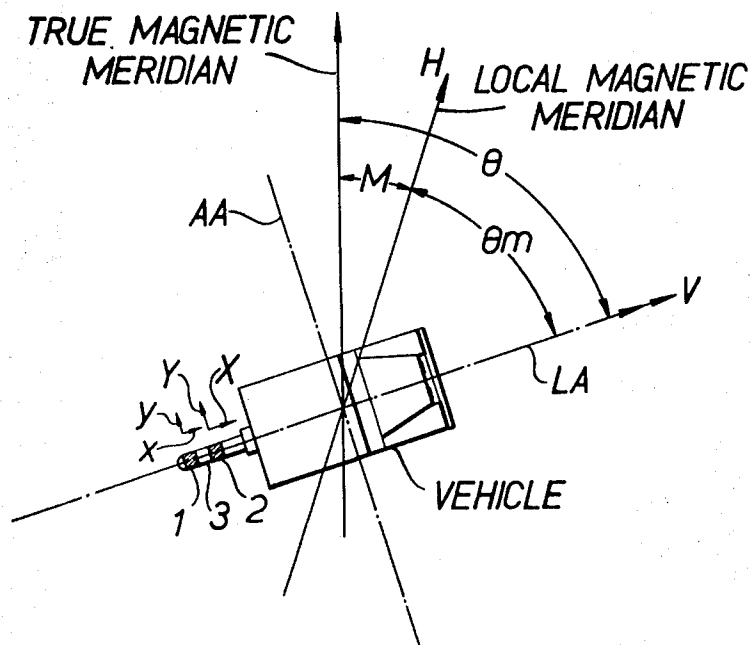
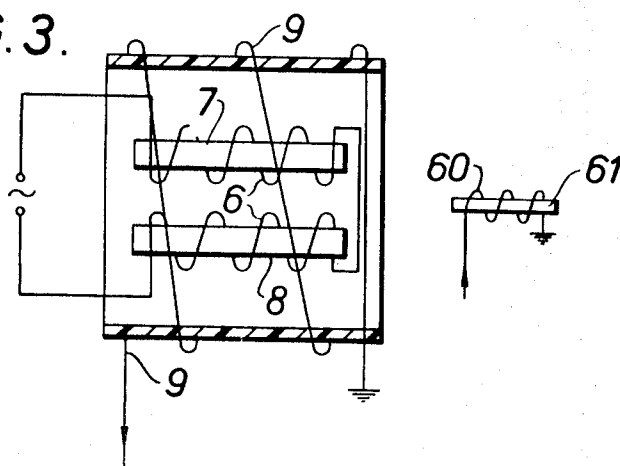


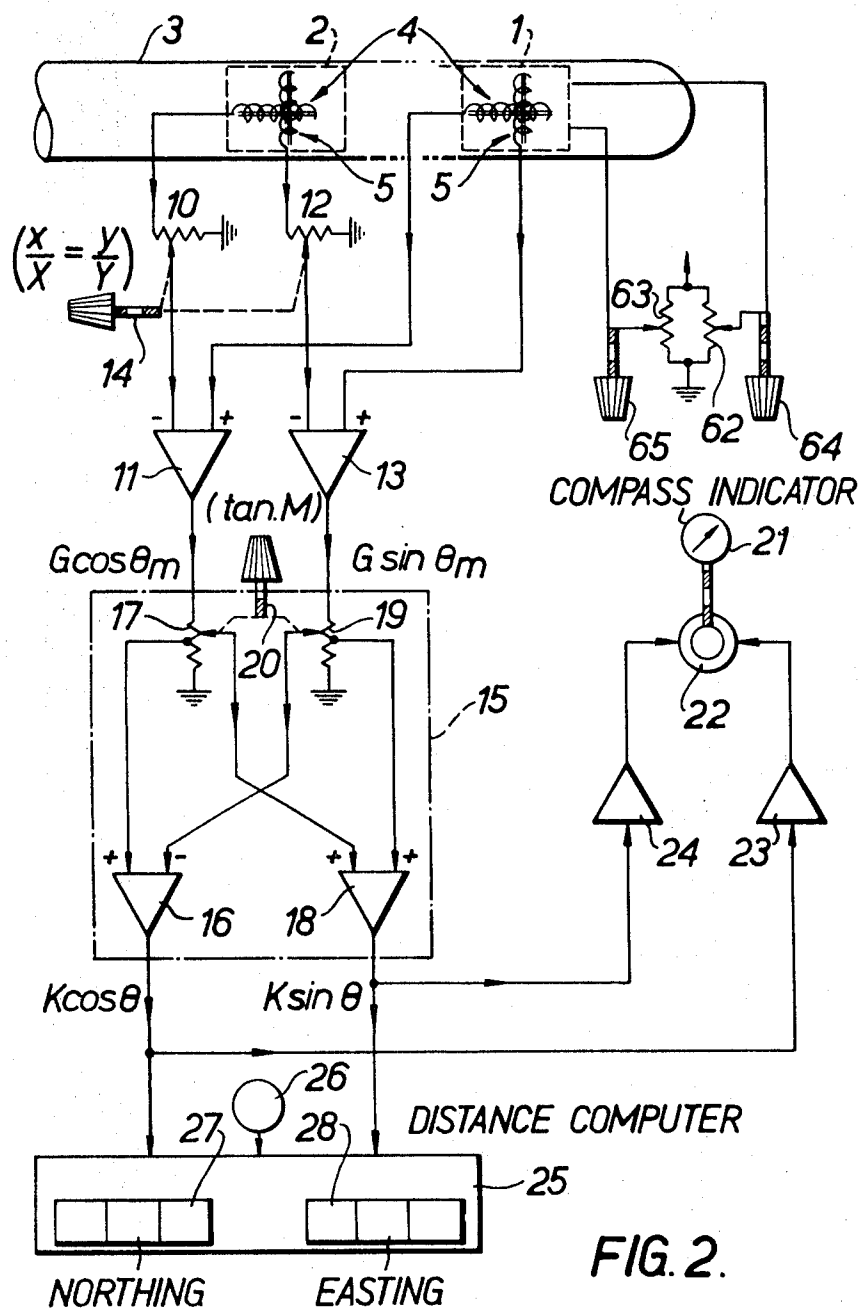
FIG. 1.

FIG. 3.



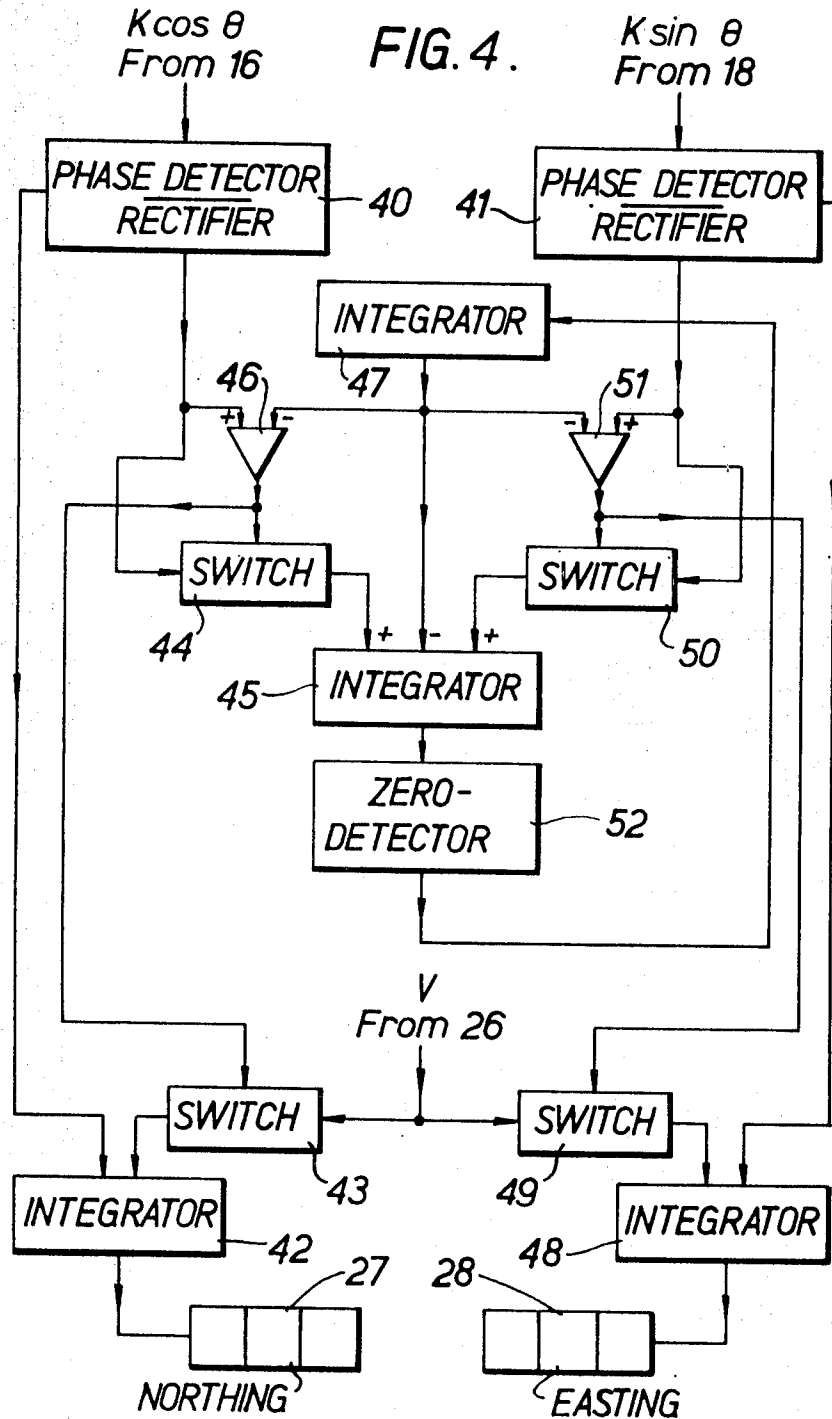
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TIMING MEANS

This application for United States Letters Patent is a division of U.S. application Ser. No. 650,544, filed June 30, 1967, for Navigation Apparatus, now Patent No. 3,541,853.

This invention relates to timing means.

According to the present invention there is provided timing means comprising first means for deriving two signals dependent upon a variable angle θ , a first of said signals being representative of $K \cos \theta$ and the second $K \sin \theta$, where K is a variable factor, a signal generator for generating a third signal that increases progressively with time from a predetermined initial value, the signal generator being resettable to a condition in which the third signal is returned to said initial value to recommence increase with time therefrom, a signal integrator for accumulating an integral with respect to time in accordance with signals supplied thereto, second means responsive to the integral accumulated by the integrator for resetting the signal generator whenever the integral reaches a predetermined value whereby the period of each excursion of the third signal from the said predetermined initial value varies in accordance with the value K , signal-supply means for supplying the third signal to the integrator for integration thereby, and further signal-supply means for supplying the said first and second signals to the integrator for integration thereby in an opposite sense to the third signal, said further signal-supply means comprising first and second switches for supplying respectively the first and second signals to the integrator, each switch being switchable from one to another state to interrupt the supply of the respective signal to the integrator, means for switching the first switch from the said one state when the third signal attains a predetermined relationship with respect to the first signal, and means for switching the second switch from the said one state when the third signal attains the said predetermined relationship with respect to the second signal.

The invention is particularly, although not exclusively, useful in apparatus of the kind for use in the navigation of a land-, air-, or seacraft.

One form of navigation apparatus incorporating a timing means in accordance with the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

FIG. 1 is a plan view of a craft carrying the navigation apparatus;

FIG. 2 is a schematic representation of the navigation apparatus;

FIG. 3 shows the form of a magnetic flux-valve device used in the navigation apparatus;

FIG. 4 is a schematic representation of a computer used in the navigation apparatus.

The navigation apparatus in the present instance will be described as provided on a land-craft, for example a military land-vehicle, but the apparatus is equally applicable to other forms of craft. The whole electrical circuit of the apparatus can readily be provided in compact and lightweight form using solid-state components microminiaturization techniques.

Referring to FIGS. 1 and 2, two magnetic detector units 1 and 2 are carried on a nonferromagnetic boom 3 that projects from the vehicle by a short distance; the boom 3 may be, for example, of aluminum and project rearwardly of the vehicle by a distance less than 4 feet. The detector unit 1 is mounted at the far end of the boom 3, whereas the detector unit 2 is mounted nearer to the vehicle at an intermediate point along the length of the boom 3. The exact location of the detector unit 2 along the boom 3 may be, in this context, chosen such that the magnetic effect of the vehicle as experienced by the detector unit 2, is about double that as experienced by the detector unit 1 at the far end.

Each detector unit 1 and 2 comprises two flux-valve devices 4 and 5 for sensing magnetic-field strengths in mutually perpendicular directions. The devices 4 and 5 each have, as shown in FIG. 3, an electrical excitation winding 6 that is arranged to be supplied with alternating current and is wound to embrace individually two elongated ferromagnetic elements 7 and 8 of the device. The ferromagnetic elements 7 and 8 ex-

tend parallel to one another with the winding 6 wound to magnetize them in opposite senses and with an output electrical winding 9 embracing the two elements 7 and 8 conjointly. An electrical alternating current signal of twice the frequency of the excitation current is induced in the output winding 9, this signal having an amplitude that provides a measure of the magnetic field strength acting in the lengthwise direction of the elements 7 and 8. The device 4 of each unit 1 and 2 is mounted on the boom 3 with its elements 7 and 8 parallel to the longitudinal (fore-aft) axis LA of the vehicle, whereas the device 5 in each case is mounted with its elements 7 and 8 parallel to the transverse (athwartships) axis AA of the vehicle. The output signals of the devices 4 and 5 in each case, accordingly provide measures of the longitudinal and transverse components, respectively, of the local horizontal magnetic field. The output signals of the devices 4 and 5 in the unit 1 provide measures of these field components experienced at the far end of the boom 3, whereas the output signals of the devices 4 and 5 in the unit 2 provide measures of the field components experienced at the intermediate position nearer the vehicle.

The magnetic fields at the spaced positions of the units 1 and 2 differ because of the differing distances of these positions from the vehicle. The signals supplied by the devices 4 and 5 of the unit 1 are representative respectively, of:

$$H \cos \theta_m + x \quad (1)$$

$$H \sin \theta_m + y \quad (2)$$

whereas those supplied by the unit 2 are representative respectively, of:

$$H \cos \theta_m + X \quad (3)$$

$$H \sin \theta_m + Y \quad (4)$$

where:

H is the local strength of the earth's magnetic field alone;

θ_m is the magnetic-heading of the vehicle (that is to say, the angle between the longitudinal axis LA of the vehicle and the local magnetic meridian);

x and y are respectively the strengths at the unit 1 of the longitudinal and transverse components of the magnetic field due to the vehicle itself; and

X and Y are respectively the strengths at unit 2 of the longitudinal and transverse components of the magnetic field due to the vehicle itself.

Referring more particularly to FIG. 2, the output signal of the device 4 in the unit 2 is supplied via a potentiometer 10 to a differential amplifier 11 for subtraction from the output signal of the device 4 of the unit 1. The output signal of the device 5 in the unit 2 is likewise supplied via a potentiometer 12 to a differential amplifier 13 for subtraction from the output signal of the device 5 of the unit 1. The potentiometers 10 and 12 are both set so as to reduce the amplitude of the relevant output signal of the unit 2 by a fractional factor, the factor in the case of the potentiometer 10 being (x/X) , and in the case of the potentiometer 12 being (y/Y) . The resultant difference-signals accordingly supplied by the amplifiers 11 and 13 are, respectively:

$$H (1 - x/X) \cos \theta_m \quad (5)$$

$$H (1 - y/Y) \sin \theta_m \quad (6)$$

In the present instance, the factor (x/X) is for practical purposes equal to the factor (y/Y) , and it is therefore satisfactory for the settings of the potentiometers 10 and 12 to be made by means of a common manual control 14. Accordingly, the expressions (5) and (6), upon rewriting with G equal to both $H (1 - x/X)$ and $H (1 - y/Y)$, are respectively of the form:

$$G \cos \theta_m \quad (7)$$

$$G \sin \theta_m \quad (8)$$

The output signals of the amplifiers 11 and 13, representative respectively of the expressions (7) and (8), are supplied to a unit 15 that effects correction for the local magnetic variation or grid variation (that is to say, for the local angular difference in azimuth between the magnetic and true meridians, or between the magnetic meridian and the grid lines). Within the unit 15, the output signal of the amplifier 11 is supplied in a fixed proportion to an amplifier 16 via a potentiometer

ter 17, and the output signal of the amplifier 13 is supplied in the same fixed proportion to an amplifier 18 via a potentiometer 19. In addition, the output signal of the amplifier 11 is supplied via the potentiometer 17 to the amplifier 18, and the output signal of the amplifier 13 is supplied via the potentiometer 19 to the amplifier 16, both in the same selectively variable proportion. The selectively variable proportion, in this latter respect, is controlled by a common manual control 20 which is set in accordance with $(\tan M)$, where M is the appropriate angular value of the magnetic or grid variation. The two signals supplied to the amplifier 16 are combined additively therein to provide a sum proportional to:

$$\cos \theta_m - \sin \theta_m \tan M$$

so that the output signal from the amplifier 16 is representative of:

$$K \cos (\theta_m + M)$$

that is to say, of:

$$K \cos \theta \quad (9)$$

where:

θ is the true heading of the vehicle; and

K is inversely proportional to $(\cos M)$.

The two signals supplied to the amplifier 18, on the other hand, are combined therein to provide a sum proportional to:

$$\sin \theta_m + \cos \theta_m \tan M$$

so that the output signal from the amplifier 18 is representative of:

$$K \sin (\theta_m + M)$$

that is to say, of:

$$K \sin \theta \quad (10)$$

The two signals representative of expressions (9) and (10) are used to provide an indication of the true or grid heading-angle θ of the vehicle, and also indications of the distances travelled in terms of northings and eastings. An indication of the heading-angle θ is provided by a compass indicator 21 that is driven by a two-phase synchro torque receiver 22, the output signals of the amplifiers 16 and 18 being supplied to the synchro-receiver 22 via amplifiers 23 and 24 respectively. (If a very high degree of precision is required, the synchro-receiver 22 and indicator 21 may be replaced by a synchro-resolver and an electrical zero-indicator responsive to any signal induced in the rotor winding of the resolver, the signals from the amplifiers 16 and 18 being supplied to the mutually perpendicular stator windings of the resolver; the angular position of the rotor is set manually to obtain zero-signal induced in the rotor winding so that the angular setting of the rotor in these circumstances indicates the heading-angle.)

The output signals of the amplifiers 16 and 18 are supplied to a distance computer 25 together with a signal which is representative of the forward velocity V of the vehicle. This latter signal is derived in the present instance by a pickoff 26 coupled to the transmission of the vehicle. The computer 25 in accordance with the three signals supplied to it, provides a digital indication of the appropriate northing on a digital indicator 27, and a digital indication of the appropriate easting on a digital indicator 28. The construction and operation of the computer 25 will now be described with reference to FIG. 4.

Referring to FIG. 4, the output signals of the amplifiers 16 and 18, representative respectively of expressions (9) and (10), are received in the computer 25 by input circuits 40 and 41. Each circuit 40 and 41 acts both as a phase detector and a rectifier to derive two output signals; a first of the output signals, being derived in dependence upon the phasing of the received signal, is representative of the sign of the relevant expression, and the second, being derived by a process involving rectification, is representative of the modulus of that expression.

The said first output signal of the circuit 40 is supplied to an integrator 42. The integrator 42 controls the digital indicator 27 in accordance with the integral with respect to time of the signal representative of forward speed V , this signal being supplied to the integrator 42 from the pickoff 26 via a switch 43. Each increment in the integration process is ascribed the sign

represented by the said first output signal supplied from the circuit 40 to the integrator 42.

The said second output signal of the circuit 40 is supplied through a switch 44 to an integrator 45, and also to a summing amplifier 46 that controls operation of the switches 43 and 44. The amplifier 46 compares the signal it receives from the circuit 40 with the output signal of an integrator 47 that integrates with respect to time a predetermined constant voltage that is supplied within the integrator 47. When, with the passage of time, the output signal of the integrator 47 reaches equality with the signal received from the circuit 40, the output signal of the amplifier 46 falls to zero. This causes both switches 43 and 44 to open and thereby breaks the supply to the integrator 42 of the signal from the pickoff 26 and the supply to the integrator 45 of the second output signal of the circuit 40.

The two output signals of the circuit 41 are utilized in a similar manner to those of the circuit 40. The said first output signal of the circuit 41 is supplied to an integrator 48 to control the sign of each increment of an integration process performed by the integrator 48. The integrator 48 controls the digital indicator 28 in accordance with the integral with respect to time of the signal representative of forward speed V , this signal being supplied to the integrator 48 from the pickoff 26 via a switch 49. The said second output signal of the circuit 41 is supplied through a switch 50 to the integrator 45 and also to a summing amplifier 51 that controls operation of the switches 49 and 50. The amplifier 51 compares the signal it receives from the circuit 41 with the output signal of the integrator 47, and when there is equality between them its output signal falls to zero. This causes both switches 49 and 50 to open and thereby breaks the supply to the integrator 48 of the signal from the pickoff 26 and the supply to the integrator 45 of the second output signal of the circuit 41.

The output signal of the integrator 47, in addition to being supplied to the amplifiers 46 and 51, is supplied to the integrator 45 in opposition to the two signals supplied via the switches 44 and 50. Thus, after the two switches 44 and 50 have both opened, the integral with respect to time provided by the integrator 45 is reduced progressively to zero. A zero-detector 52 is responsive to the condition in which the integral of the integrator 45 becomes zero, to reset the integrator 47 to zero.

When the integrator 47 is reset to zero, the switches 43, 44, 49 and 50 again close under control of the amplifiers 46 and 51. The switches 43 and 44 are then opened again after the period of time, proportional to $(\cos \theta)$, required for the integral provided by the integrator 47 to reach equality with expression (9). The integral accumulated in this period by the integrator 42 accordingly provides a measure of the integral with respect to time of $V \cos \theta$. The indicator 27, which is updated in accordance with this integral, thereby provides the required indication of the appropriate northing. Similarly, the switches 49 and 50 are opened again after the period of time, proportional to $(\sin \theta)$, required for the integral provided by the integrator 47 to reach equality with expression (10). The integral accumulated in this period by the integrator 48, accordingly provides a measure of the integral with respect to time of $V \sin \theta$. The indicator 28, which is updated in accordance with this integral, thereby provides the required indication of the appropriate easting.

The full integral accumulated by the integrator 45 in respect only of the two signals supplied through the switches 44 and 50 is equivalent to:

$$\cos^2 \theta + \sin^2 \theta$$

that is to say, to unity. When the integral with respect to time of the output signal of the integrator 47 has reached this value, the resultant integral provided by the integrator 45 is zero. The response of the zero-detector 52 to this, resets the integrator 47 to initiate another of a series of successive integrating cycles, the indications of northing and easting provided by the indicators 27 and 28 being appropriately updated during each successive cycle.

It is necessary with the computer of FIG. 4 to ensure that the integrator 47 is reset to zero rapidly. In order to meet this requirement it may be arranged that two capacitors are used for the integration process during alternate integration cycles. Furthermore, it is desirable to ensure that the integral of the integrator 45 is reduced to zero only after the switches 44 and 50 have both been opened. To this end, the output signal of the integrator 47 may be supplied to the integrator 45 via a potentiometer so as to modify the time scale and reduce the rate of accumulation of the integral of this signal within the integrator 45. Additionally, it may be arranged that the integrator 47 is reset only in response to the combined circumstances in which the zero-detector 52 emits a signal and both the switches 44 and 50 are open.

In a modification of the computer shown in FIG. 4, the indicators 27 and 28 are driven mechanically by respective electrical stepping-motors that replace the integrators 42 and 48. The pickoff 26 in these circumstances supplies pulses at a recurrence rate representative of the forward velocity V , and these pulses supplied to either motor via the relevant switch 43 or 49 each cause the motor to rotate one step. The rotation is forward or backward in dependence upon the sign of the increment as represented by the said first signal from the appropriate input circuit 40 or 41.

Provision may be made for applying a selectively variable magnetic field at either or both of the two positions on the boom 3, in order to reduce the magnetic deviation resulting from the vehicle itself. In particular, each device 4 and 5 of the unit 1 may include, as shown in FIG. 3, a further electrical winding 60 wound on an elongated ferromagnetic core 61 parallel to the cores 7 and 8. Direct current is supplied to the winding 60 to produce a magnetic bias of the appropriate magnitude and sense. As indicated in FIG. 2, direct currents may be supplied to the windings 60 of the devices 4 and 5 in the unit 1 from separate potentiometers 62 and 63, individual adjustments of the longitudinal and transverse components of deviation being made simply by adjustments to the settings of manual controls 64 and 65 of the potentiometers 62 and 63.

As an alternative, correction for the deviation resulting from the vehicle itself may be made by deriving an alternating current signal of the same frequency as the signals supplied by the flux-valve devices 4 and 5 and applying this signal in selectively variable proportions to the two amplifiers 11 and 13 of FIG. 2. In certain circumstances, however, it may be found that adequate correction can be made simply by slight tilting of the flux-valves 4 and 5 along their respective axes of measurement. Small angular adjustments of the flux-valves 4 and 5 may also be used to correct, for example, for asymmetry in the location of soft-iron components in the vehicle.

Although the magnetic detectors 1 and 2 described above with reference to FIGS. 1 to 3, are each of a form involving just two devices 4 and 5 arranged mutually perpendicular in azimuth, magnetic detectors involving, for example, three flux-valve devices equally angularly spaced from one another in azimuth, may be used instead. In these latter circumstances it may be arranged that signals comparable with those supplied directly by the devices 4 and 5 are derived by means of transformers from the signals supplied by the three devices. Alternatively, one of the three devices may be conveniently aligned with either the longitudinal or transverse axis, and then the signals supplied by the other two devices can be combined in opposition to one another to produce, after attenuation by a factor of 1.7321, a resultant signal appropriate to the other axis.

In the case of the system described above, the factor (x/X) is for practical purposes equal to the factor (y/Y) . If this were not so, then the desired signals representative of expressions (7) and (8) could be derived by supplying the signals from the amplifiers 11 and 13 via additional potentiometers. These additional potentiometers, which may be appropriately ganged to the potentiometers 10 and 12, are set such that the magnitude of the signal representative of expression (5) is multiplied by the factor $(1-y/Y)$ and the magnitude of the signal

representative of expression (6) is multiplied by the factor $(1-x/X)$. Alternatively, one or the other of the output signals from the amplifiers 11 and 13 can be attenuated or amplified in the ratio of $(1-y/Y)$ to $(1-x/X)$, or in accordance with difference in the settings of the potentiometers 10 and 12.

The variation-correction unit 15, rather than having the form described with reference to FIG. 2, may simply involve a resolver having a pair of mutually perpendicular rotor windings that are rotatable with respect to a pair of mutually perpendicular stator windings. In these circumstances the rotor of the resolver is set to an angular position with respect to the stator dependent upon the angle M , and the output signals of the amplifiers 11 and 13 are supplied to the windings of one pair; the output signals of the unit 15 are then taken from the windings of the other pair.

The operation of the navigation apparatus described above with reference to FIG. 2 can be readily checked. For example, the operation of the major parts of the apparatus can be checked simply by injecting a signal in place of the signal from the pickoff 26, and by then varying the setting of the control 20 to enter this signal selectively into either integrator 42 or 48.

I claim:

1. Timing means comprising

first means for deriving two signals dependent upon a variable angle θ , a first of said signals being representative of $K \cos \theta$ and the second of $K \sin \theta$, where K is a variable factor,

a signal generator for generating a third signal that increases progressively with time from a predetermined initial value, the signal generator being resettable to a condition in which the third signal is returned to said initial value to recommence increase with time therefrom,

a signal integrator for accumulating an integral with respect to time in accordance with signals supplied thereto, second means responsive to the integral accumulated by the integrator for resetting the signal generator whenever the integral reaches a predetermined value whereby the period of each excursion of the third signal from the said predetermined initial value varies in accordance with the value K ,

signal-supply means for supplying the third signal to the integrator for integration thereby, and

further signal-supply means for supplying the said first and second signals to the integrator for integration thereby in an opposite sense to the third signal, said further signal-supply means comprising

first and second switches for supplying respectively the first and second signals to the integrator, each switch being switchable from one to another state to interrupt the supply of the respective signal to the integrator,

means for switching the first switch from the said one state when the third signal attains a predetermined relationship with respect to the first signal, and

means for switching the second switch from the said one state when the third signal attains the said predetermined relationship with respect to the second signal.

2. Timing means according to claim 1, comprising second and third integrators, an input terminal for receiving an input signal, third and fourth switches for supplying the said input signal to the said second and third integrators respectively for integration with respect to time thereby, each said third and fourth switch being switchable from one to the other of two states to interrupt the supply of the said input signal to the respective integrators, and means for coordinating switching of the third and fourth switches with the switching of said first and second switches respectively.

3. Timing means according to claim 2, comprising means for deriving fourth and fifth signals representative of the sense of the first and second signals respectively, said second and third integrators being responsive to the fourth and fifth signals respectively to vary the sense in which the said input signal is integrated thereby, whereby the sense in which the

said input signal is integrated by the second and third integrators varies in accordance with the sense of $K \cos \theta$ and $K \sin \theta$ respectively.

4. Timing means according to claim 1, wherein the said signal generator includes an integrator for integrating a constant voltage with respect to time.

5. Navigation apparatus for a craft comprising means responsive to heading θ of the craft for deriving first and second signals representative respectively of $K \cos \theta$ and $K \sin \theta$ where K is a variable factor,

a signal generator for generating a third signal that increases progressively with time from a predetermined initial value, the signal generator being resettable to a condition in which the third signal is returned to said initial value to recommence increase with time therefrom,

a signal integrator for accumulating an integral with respect to time in accordance with signals supplied thereto, second means responsive to the integral accumulated by the integrator for resetting the signal generator whenever the integral reaches a predetermined value,

signal-supply means for supplying the third signal to the integrator for integration thereby,

further signal-supply means for supplying the said first and second signals to the integrator for integration in an opposite sense to the third signal, said further signal-supply means comprising

first and second switches for supplying respectively the first and second signals to the integrator, each switch being

switchable from one to another state to interrupt the supply of the respective signal to the integrator,

second and third integrators,

means for providing a signal dependent upon craft-speed,

means for supplying the said speed signal to the said second integrator only so long as said first switch remains in its said one state,

means for supplying the said speed signal to the said third integrator only so long as said second switch remains in its said one state,

means for switching the first switch from its said one state when the third signal attains a predetermined relationship with respect to the first signal, and

means for switching the second switch from its said one state when the third signal attains the said predetermined relationship with respect to the second signal,

whereby the integrals accumulated by the said second and third integrators are in accordance with components of the distance travelled by the craft.

6. Navigation apparatus for use with a craft, comprising a plurality of first magnetic-detector devices spaced apart from one another for sensing the earth's magnetic field as subjected to deviation by the craft, the said first magnetic-detector devices sensing respectively the magnitudes at their spaced locations of the component of the deviated field acting parallel to a first of two mutually inclined craft-axes,

a plurality of second magnetic-detector devices spaced apart from one another for sensing respectively the magnitudes at their spaced locations of the component of the deviated field acting parallel to the second of the two axes,

means for deriving from each said magnetic-detector device an electric signal in accordance with the magnitude of

deviated-field component sensed by that individual device,

first circuit means responsive to the signals derived from said first magnetic-detector devices to provide a signal in accordance with the component of undeviated field acting parallel to said first axis,

second circuit means responsive to the signals derived from said second magnetic-detector devices to provide a signal in accordance with the component of undeviated field acting parallel to said second axis,

variation-correction means responsive to the two component-signals provided by said first and second circuit means to derive therefrom two signals dependent on a variable angle θ and representative respectively of the said components of undeviated field corrected for local magnetic-variation, a first of said two signals being representative of $K \cos \theta$ and the second of $K \sin \theta$, where K is a variable factor,

a signal generator for generating a third signal that increases progressively with time from a predetermined initial value, the signal generator being resettable to a condition in which the third signal is returned to said initial value to recommence increase with time therefrom,

a signal integrator for accumulating an integral with respect to time in accordance with signals supplied thereto, second means responsive to the integral accumulated by the integrator for resetting the signal generator whenever the integral reaches a predetermined value,

signal-supply means for supplying the third signal to the integrator for integration thereby,

further signal-supply means for supplying the said first and second signals to the integrator for integration in an opposite sense to the third signal, said further signal-supply means comprising

first and second switches for supplying respectively the first and second signals to the integrator, each switch being switchable from one to another state to interrupt the supply of the respective signal to the integrator,

second and third integrators,

speed-sensing means for providing a signal dependent upon speed of the craft,

third and fourth switches for supply the said speed signal to the said second and third integrators respectively for integration with respect to time thereby, each of said third and fourth switches being switchable from one to another state to interrupt the supply of the said speed signal to the respective integrators,

means for switching the first and third switches from their said one state when the third signal attains a predetermined relationship with respect to the first signal,

means for switching the second and fourth switches from their said one state when the third signal attains the said predetermined relationship with respect to the second signal, and

means for varying the senses with which the speed signal is integrated by said second and third integrators in accordance with the senses of the first and second signals respectively, whereby the integrals accumulated by the said second and third integrators are in accordance with components of the distance travelled by the craft along earth-defined axes.