ENGINEERING YOUNG AND OLD—13

Roll Isaac, roll—Part I

by E. R. Laithwaite*

The title for this article was suggested to me by memories of the early days of Pop Music, deplored by my parents' generation, some of whom suggested that it would make the Great Masters turn in their graves. One composer took up this theme and wrote a piece of music that he thought would be particularly offensive to conventionalists and called it "Roll over Beethoven". What I have to say now will, I trust, be equally offensive to those among us who have a sound bedrock of fundamental mechanics. But like the popular music, it will not be something on which they can casually turn their backs. It will be as Omar Khayyam described:

The moving finger writes; and, having writ, Moves on: — — —

I have not put pen to paper without first —the experiment. Nor have I attempted to overthrow a sacred law without putting a better one in its place. The late Gabriel Kron had a habit of saying: "The electrical engineer is 50 years ahead of the mechanical engineer in his methods of solving problems. I have offended many mechanical engineers by saying this but really they should not be offended. They need me most." I am not prepared to go quite so far! But I would begin by asking, not Newton himself of course, but *some* of his followers, a few pertinent questions.

Of course, if I could ask Isaac himself my questions would be very different. I would probably begin by saying: "You have been interpreted as saying many helpful things, by very many people. But did you know how quite a number of their several interpretations differ from each other?" School teachers for example are not all agreed that it is equally correct to speak of *centrifugal* force as it is to speak of *centripetal* force. "I keep telling them, Isaac, whenever I can, that it all depends on which end of the string they are holding—and they look perplexed. I explain that when you whirl a chestnut around on the end of a string, the string is in tension, so there are obviously *forces* involved.

"Now if you hold the end of the string remote from the chestnut you will always feel the nut trying to get away from you. You will experience a centrifugal force. But if you happen to be sitting on the nut (which is unlikely, but you can get the same effect in a car when cornering), you will be aware of forces that are pushing you inwards, the nut (or the car) will be exerting a centripetal force on *you*, so I don't know why some of them get so dogmatic about it. Apparently they don't understand your third law about action and reaction, but I know that they would claim to do so.

"Others wax eloquent and 'explain' centri-whatever forces as the result of a vector product and I have warned them against this.† They argue that a particle moving in a circle at uniform speed has a linear velocity, v (due to having radial displacement r) and an angular velocity ω, which, like other angular quantities, can be represented as a vector along its spin axis, and because such vectors can be moved to any other position of action, so long as the axis remains in the same direction, you can multiply v by ω vectorially and get $\bar{v} \times \bar{\omega} = \overline{v\omega}$ where the latter is a vector perpendicular both to $\bar{v}$ and to $\bar{\omega}$, i.e. radial. The magnitude is obviously correct: $|\overline{v\omega}| = v^2/r = r\omega^2$. The question of which vector you take first gets them off the hook with regard to the centripetal or centrifugal argument for $\bar{v} \times \bar{\omega}$ will give the one and $\bar{\omega} \times \bar{v}$ the other, but can you see what they did wrong, Isaac? They used the ω *twice*, once as $r\omega$ and once as ω, and *you* knew that they couldn't do this."

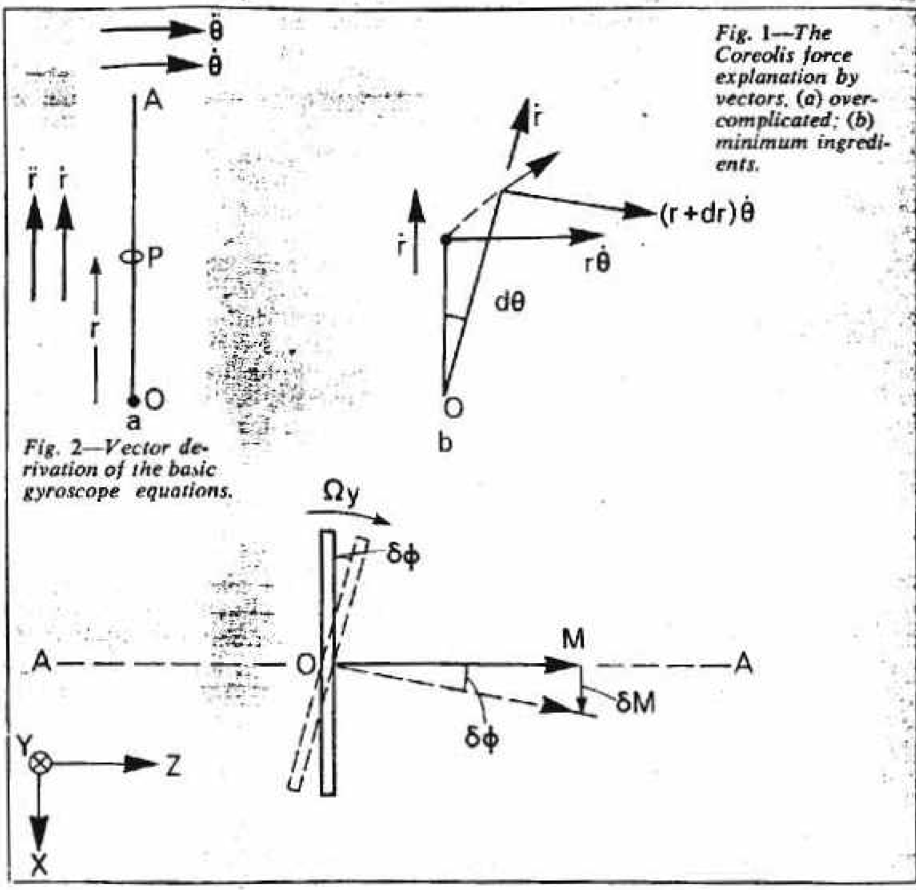

Fig. 1—The Coreolis force explanation by vectors. (a) over-complicated; (b) minimum ingredients.

Fig. 2—Vector derivation of the basic gyroscope equations.

Coreolis and all that

Let us move on to that more obscure quantity, the Coreolis force. An air of mystery surrounds this quantity even to some mechanical engineers—something to do with the water going down the plug-hole in a helix of opposite handedness in the Southern Hemisphere from that in the Northern? It is often taught by means of an example as illustrated in Fig. 1(a) where a ring P slides freely on a rod OA which is being rotated about an axis through O at right angles to the plane of the diagram.

Treating the situation by what is misleadingly called a "general" method, the ring is taken to be at radius r when having both a velocity $\dot{r}$ and an acceleration $\ddot{r}$ relative to the rod, whilst the latter has both an angular velocity $\dot{\theta}$ *and* an angular acceleration $\ddot{\theta}$. The problem is to find the

*Professor of Electrical Engineering, Imperial College, London.

†"The multiplication of bananas by umbrellas", "Electrical Review", 20/27 December, 1974.

instantaneous radial and tangential components of acceleration as seen by an observer at rest with respect to O. The poor student is so befuddled by all the dotted and double-dotted quantities that he is convinced that some curious involvement of the $\ddot{r}$ and the $\ddot{\theta}$ is responsible, for the answers emerge as:

Radial: $\ddot{r} - r\dot{\theta}^2$ (the sign of the second term justifying the centripetal protagonists absolutely!)

Tangential: $r\ddot{\theta} + 2\dot{r}\dot{\theta}$ (the second term being the dreaded Coreolis).

"But as you well know, Isaac, you need neither $\ddot{r}$ nor $\ddot{\theta}$ to have a Coreolis phenomenon. All you need is a combination of r, $\dot{r}$ and $\dot{\theta}$, as shown in Fig. 1(b). There are then two effects:

1. In time δt, $\dot{r}$ has changed direction by an angle $d\theta$, giving rise to a tangential change in velocity $\dot{r}\delta\theta$, which makes for a tangential acceleration $\dot{r}\frac{d\theta}{dt} = \dot{r}\dot{\theta}$.

2. In the same time, r has increased to $r + \delta r$ so $r\dot{\theta}$ has become $(r + \delta r)\dot{\theta}$ and the increase in tangential velocity due to this is $(r + \delta r)\dot{\theta} - r\dot{\theta} = (\delta r)\dot{\theta}$, which in time δt gives an acceleration $\frac{dr}{dt}\dot{\theta} = \dot{r}\dot{\theta}$, so we have in all, $2\dot{r}\dot{\theta}$ and you and I don't see what all the fuss was about—*unless*—some of them tried it by vector product!"

Once again $v(= \dot{r})$ and $\omega(= \dot{\theta})$ are vectors at right angles, but this time they really do have separate origins and the result should therefore be "correct" with much more conviction than before. There is now no doubt about handedness and which should be taken first, the product $\bar{v} \times \bar{\omega} = \overline{v\omega}$ is tangentially in the direction of motion (so the centrifugalists were right?)—but look at the *magnitude*! $|\bar{v} \times \bar{\omega}| = v\omega = \dot{r}\dot{\theta}$ and we know that there are *two* of them.

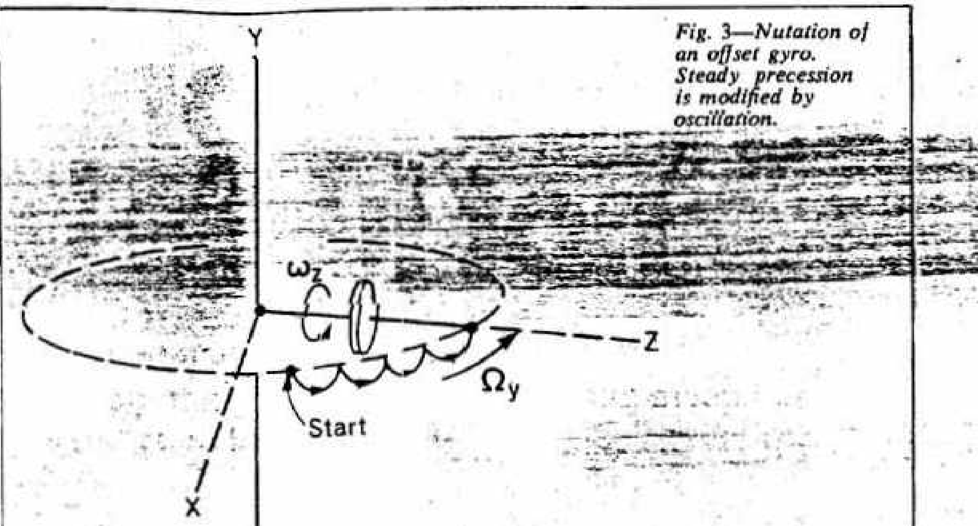

Fig. 3—Nutation of an offset gyro. Steady precession is modified by oscillation.

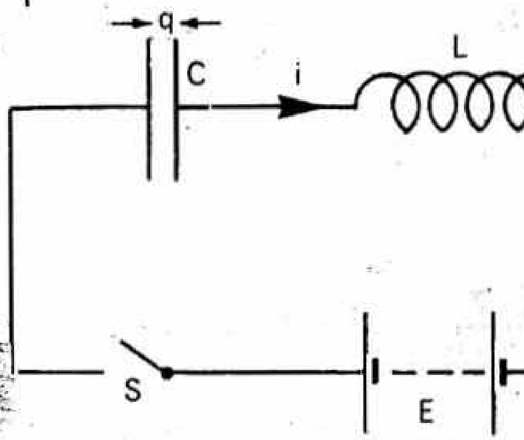

Fig. 4—Electric circuit analogue for a nutating, offset gyro.

That confounded gyroscope again

"This, Isaac, is where I begin to twist their tails. Nothing I have said so far has so much as a single pebble at vector addition. The basic equation of a gyroscope is most easily derived by the use of this technique (see Fig. 2). A wheel, centre O, spins on the axis AA′ (Fig. 2 shows a view with the wheel edge-on). If the axis of spin is changed by a small angle $\delta\phi$ in time δt the situation can be abstracted to the vector diagram shown where the wheel angular momentum vector M is turned through $\delta\phi$, giving rise to a change in angular momentum δM, which by geometry equals $M\delta\phi$. Now $\frac{dM}{dt}$ is interpreted from your own work, Isaac, as being the torque T, so:

$$T = M\frac{d\phi}{dt} = M\Omega = (I\omega)\Omega \qquad (1)$$

on the understanding that if the spin axis is denoted z, the torque axis x and the precession axis Y, the quantities in equation (1) are to be annotated:

$$T_X = (I_Z\,\omega_Z)\Omega_Y \qquad (2).$$

Incidentally, it is customary to denote a rotary quantity by an arrow so directed that it is, as it were, the point of a right-handed corkscrew in which the directions of rotation, torque, and so on are clockwise when viewed from the backs of the arrows. In which case the directions of the arrows M and δM in Fig. 2 would indicate a torque in precisely the opposite direction than is the case in practice—but never mind! So if the spin momentum remains constant (and why shouldn't it, if we postulate a wheel in perfect bearings?), then a torque T is seen to give rise to an angular velocity Ω (and for an electrical engineer it can easily be seen as the reverse way around, for a current can be seen as the cause of a voltage in a series circuit). Since when has an angular *velocity* been capable of producing a back reaction? I thought only angular accelerations could do that, as in $T = I\dot{\Omega}$.

"What did you say, Isaac—you were feeling uneasy—you would like to turn over? Look, if the shaft of that wheel did not spin *with* the wheel, and had a finite mass of its own, it would have a moment of inertia about the precession axis, Y, and we should need to include a term $I_Y\,\dot{\Omega}_Y$ were any motion to occur on the Y-axis (and you *must* have had an angular acceleration at some time on the way to attaining an angular velocity Ω_Y)."

Now it so happens that a gyro is like an electrical machine. What happens in one pair of axes has no effect on what goes on in the other—Generalised Machine Theory, no less. So at the same time as equation (2) exists, so can:

$$T_Y = (I_Z\,\omega_Z)\Omega_X \qquad (3)$$

so long as we remember Lenz's law, or work it out the hard way by vectors, or the easy but laborious way of tracing through all instantaneous directions of motion, any one of which will show that equation (2) demands that equation (3) carry a minus sign, thus:

$$I_Y = -(I_Z\,\omega_Z)\Omega_X \qquad (4).$$

Now let us add the acceleration terms on the appropriate axes. $I_X\dot{\Omega}_X$ acts on the X-axis and $I_Y\dot{\Omega}_Y$ on the Y, so equations (2) and (4) can be re-written:

$$T_X = (I_Z\omega_Z)\Omega_Y + I_X\dot{\Omega}_X \qquad (5)$$

$$T_Y = -(I_Z\omega_Z)\Omega_X + I_Y\dot{\Omega}_Y \qquad (6).$$

The next derivative

Let us now apply these to a well-known situation, the toy gyroscope on an Eiffel Tower (Fig. 3). If released from rest with the shaft in a horizontal position it is well known that the gyro will nutate, i.e. perform oscillations of a kind indicated by the dotted line and, as Professor Maunder pointed out in a letter to *Engineering* (May 1975, p.388), at each cusp, the centre of the wheel and the shaft are momentarily at rest and the system at no time has any vertical angular momentum (mostly because you never gave it any!) because the resolved part of $I_Z\omega_Z$ (when the shaft is not horizontal) can be shown at all times to cancel exactly the "apparent momentum" $I_Y\Omega_Y$. The analysis of such motion must surely be very difficult? Let us try solving equations (5) and (6). For this particular case $T_X = MgR$, whilst $T_Y = 0$. Hence, from (6):

$$\Omega_X = \left(\frac{I_Y}{I_Z\omega_Z}\right)\dot{\Omega}_Y \qquad (7)$$

and differentiating and substituting for $\dot{\Omega}_X$ in (5):

$$MgR = (I_Z\omega_Z)\Omega_Y + \left(\frac{I_X I_Y}{I_Z\omega_Z}\right)\ddot{\Omega}_Y \qquad (8).$$

This is of the form:

$$K = C_1\,\Omega_Y + C_2\,\ddot{\Omega}_Y$$

an equation well known to electrical engineers in the form:

$$E = \left(\frac{1}{C}\right)q + L\frac{d^2q}{dt^2} \qquad (9)$$

—the equation of the very simple circuit shown in Fig. 4, where closing the switch S is equivalent to releasing the gyro from rest. Now we electrical engineers need no formal solution to equation (9). We know it backwards! It is expressed by the graphs in Fig. 5 in which q is seen never to go negative, whilst $i = \frac{dq}{dt}$ oscillates + and −.

But by comparison with equation (8), "Ω_Y maps into q" as modern maths would t... us, so Ω_Y never goes negative, i.e. the gyro never reverses its precession direction, it merely comes to rest once every cycle. But from equation (7), Ω_X is $k\dot{\Omega}_Y$ and is the analogue of i.[††] Put the two motions together, and you have the nutation pattern at least to a first order of accuracy. Note how both Ω_X and Ω_Y come to zero together once every cycle, i.e. at each cusp. But look at equation (8)—horror of horrors, we have an equation in which each term has the dimensions of a torque, and yet the last term contains a quantity $\ddot{\Omega}$, the second derivative of angular velocity—the *third* derivative of angular displacement!

"What was that Isaac?—You never dabbled with third derivatives? Yes I know, but I don't suppose you mind my doing so, even though I know that some of your faithful flock will object strongly. Worse than that Isaac, I propose to imagine that the quantity $I_Y\Omega_Y$, the 'apparent' angular momentum about the vertical can be written in as $jI_Y\Omega_Y$ where $j = \sqrt{-1}$, as if we wrote $jL\omega I$ for the voltage across a pure inductor, knowing that when multiplied by I the result is zero. 'Reactive momentum' I propose to call it—you wanted to turn over again? Of course, why not?

"Now let us suppose that both horizontal and vertical pivots at the top of the Eiffel Tower put frictional torques $K\Omega_X$ and $K'\Omega_Y$ into the equations (5) and (6) respectively. The resulting equation is of the form:

$$MgR = C_1\Omega_Y + C_2\dot{\Omega}_Y + \left(\frac{I_X I_Y}{I_Z\omega_Z}\right)\ddot{\Omega}_Y \qquad (10)$$

where C_1 is different from $I_Z\omega_Z$, as it now contains K and K' and C_2 is another constant made up from I_X, I_Y, I_Z, ω_Z, K and K'. Equation (10) maps into:

$$E = \left(\frac{1}{C}\right)q + R\frac{dq}{dt} + L\frac{d^2q}{dt^2}$$

just as equation (8) mapped into equation (9). The nutation is now damped. An electrical engineer has no need to solve equations (8) and (10). The answers are commonplace to him. Now if a simple LCR circuit will explain all this, just think Isaac, what the counterpart of electromagnetic radiation might be in the inertial system?"

Part II of "Roll Isaac, roll" will be published shortly.

††Do not be worried by the fact that ΩX is the analogue of $\frac{dq}{dt}$ whilst ΩY is that of q alone. The other time dimension is built into the constant k, which equation (7) shows to be $\frac{I_Y}{I_Z W_Z}$.

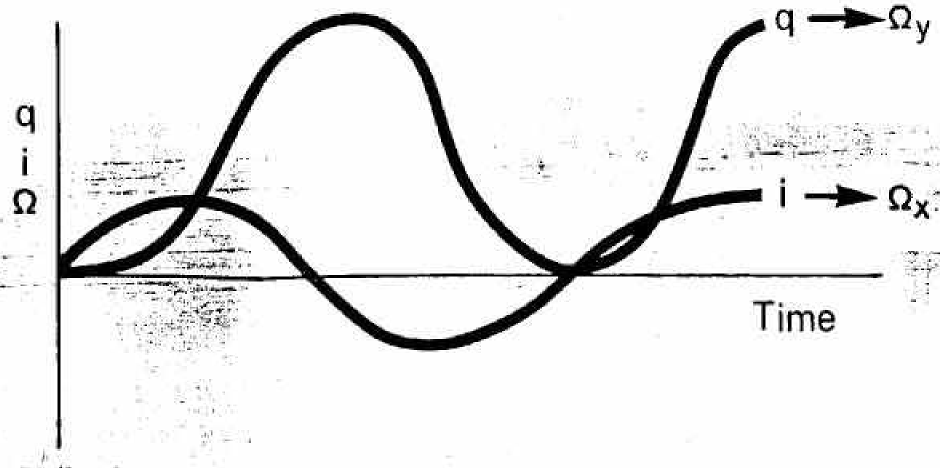

Fig. 5—The oscillations analysed.

standards

Insulation

... 3924: *Pressure-sensitive adhesive ...es for electrical insulating purposes* deals with the classification, dimensions, properties, packing and marking of these tapes and replaces the 1965 edition of the standard. It takes account of technological improvements and implements some of the international agreements embodied in IEC Publication 454. New materials have been introduced and some backing materials previously included have been omitted.
Price £6·40

Microwave signal generators

IEC Publication 592: *Microwave signal generators* is applicable to such generators generating substantially sinusoidal radio frequency voltages. They can be frequency modulated, amplitude modulated and/or on/off pulse modulated.
Price SFr68

Coaxial lines

IEC Publication 457-4: *Rigid precision coaxial lines and their associated precision connectors. Part 4—21mm rigid precision coaxial line and associated hermaphroditic precision coaxial connector, characteristic impedance 50Ω (Type 9/21)—characteristic impedance* 75Ω (*Type* 6/21) should be used in conjunction with IEC Publication 457-1: *General requirements and measuring methods.* Included in the new publication are criteria applicable to environmental requirements, dimensions, the bending moment on the outer conductor and the centre contact deflection. Additional information relates to a mechanical endurance test, attenuation, reflection factor, contact resistance and the screening effectiveness of connectors (leakage).
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Insulation materials

BS 5664: *Solventless polymerisable resinous compounds used for electrical insulation. Part 1—Definitions and general requirements* deals with resinous or elastomeric compounds composed of one or more chemically reactive components, with or without fillers. The new standard is identical with IEC Publication 455-1 and will be supplemented later by further parts covering methods of test and specifications for individual materials.
Price £1·40

Terminology

IEC Publication 50(151): *International electrotechnical vocabulary. Chapter 151—Electrical and magnetic devices* represents the 38th of a series of chapters forming the International Electrotechnical Vocabulary that are devoted to general scientific and technical concepts and which constitute the revision of *Group* 05: *fundamental definitions,* published in 1956.

British Standards are available from BSI Sales Department, 101 Pentonville Road, London N1 9ND. IEC Publications are available from IEC, 1-3 Rue de Varembe, 1211 Geneva 20, Switzerland.

Roll Isaac, roll—Part II

by E. R. Laithwaite*

I have mistrusted momentum since my school days. I knew that to conserve it was to maintain Σmv constant. But energy, too, must be conserved, and this means that Σmv^2 must be constant. When you investigate a pendulum you use the latter; when you fire a bullet into a block of wood you use the former, and let the lost energy be said to be lost as heat. But how did you *know* when to use which?

At the age of 18 I concluded that you conserved whichever gave the answer at the back of the book. At over three times that age I am now more or less forced to the same opinion! "But I can be pretty sure how *you* came to need the momentum concept, Isaac. If a body is displaced by x in time t, according to the line OA in Fig. 1, we say it has constant velocity and that no forces are involved. If the relationship is parabolic, as in OB, the body has constant *acceleration*, f, and needs a force to sustain it. But if the relationship is a cube law, as in OC, or a fourth-power law as in OD, we shall need terms in $\frac{d^3x}{dt^3}\left(=\frac{df}{dt}\right)$, $\frac{d^2f}{dt^2}$, $\frac{d^3f}{dt^3}$ and so on, so that if a body should change direction as in OPQ (like we hit it with a sledge hammer!) we shall need all derivatives to infinity to describe its motion; and Isaac, you only told us how to handle the first two $\left(\frac{dx}{dt} \text{ and } \frac{d^2x}{dt^2}\right)$."

It was surely here that momentum conservation was found to be the panacea for all the ailments of an x-derivative approach. "But who *really* said that the rate-of-change of momentum was proportional to the force producing it? Was it *you*, Isaac, or some lesser man? I know that the dimensions are right. Momentum is $[MLT^{-1}]$ and the rate of change of it is $[MLT^{-2}]$ which is the same as the dimension of force, but you can't use that as an argument for an equation. For example, it is easy to envisage the application of a torque without energy being involved: there is no motion whatever. It is motionless torque. But nothing is more "motionful" than kinetic energy. Yet both torque and kinetic energy have the dimension $[ML^2T^{-2}]$. Does this bother you, Isaac?"

It bothers me. The whole of dimensional analysis bothers me. The mechanical engineer can express all his quantities in terms of mass, length and time. The poor electrical engineer needs a fourth. It used to be fashionable to call it "permeability" but to please De Gaulle we now call it "current". It really doesn't matter. It can be any electromagnetic quantity so long as it always gives, if pursued long enough, the equation $\mu_0\varepsilon_0 = 1/c^2$.

"But Isaac, I have news for you. That fourth thing in electro-magnetism is a 'spin thing'. The very concept of magnetism is one of spinning dipoles. Are you sure *you* don't need a fourth thing also—a *spin* thing?

"Why I ask Isaac, is because most, if not all, of your followers do the most dreadful, thing in dimensional analysis in relation to the gravitational equation:

$$\text{Force} = \frac{G\,M_1\,M_2}{d^2};$$

they set down this same equation in dimensional form like this:

$$[MLT^{-2}] = [GM^2L^{-2}] \qquad (1).$$

"Do you know what they do then, Isaac? They *cancel* an M on each side!"

The M on the left is an inertial or motional mass. Those on the right are gravitational or forceful mass. And the numerical value of G was "fiddled" to make them the same numerically. But the equation relating the one to the other is at least as remote as that relating the forces in electrostatics to those in electromagnetics where, if only $i—\frac{dq}{dt}$—is concerned, you need the Special Theory of Relativity to relate them, and if $\frac{di}{dt}$ is involved you need the General Theory also.

From equation (1) it is easy to find the dimensions of G and an odd monstrosity it turns out to be: $[M^{-1}L^3T^{-2}]$—volume per second per second per unit mass!

A bit of Science Fiction

I have many bright young men pass through my post-graduate section and one or two of them think more deeply about my ramblings on gyros than do many of their elders and betters. One in particular, Nigel McQuin, said this to me about two months ago:

"If we had been born so small that we could live on an electron, as we now live on the earth, our world would orbit its sun, and our planet would revolve on its own axis. But we would be held on to our planet's surface by electric charge, and we would know that our planet was held in orbit by its total charge and that of the sun. Gravitation would be of lesser interest and we would work out all our quantities in terms of *charge*, length and time."

What a splendid thought, even though the rules have to be "bent" to conceive it, for as far as we know life could not exist at that level, and an electron is only solid in the past. (In the future it is a wave packet—and so on.) But it brings out with great clarity the difference in approach between electrical and mechanical engineers. The former write as their fundamental equation:

$$\text{Force} = \frac{q_1q_2}{\varepsilon_0 d^2}$$

and teach their pupils that we know the dimension neither of q, nor of ε_0**; all we know is that they are related as $[q] = [\varepsilon_0^{1/2}M^{1/2}L^{3/2}T^{-1}]$.

If we lived on an electron, however, we would apparently be allowed to calculate the dimensions of force in terms of magnetic effects—magnetic flux density for example. Our present treatment of such effects is to write the force F as equal to Bqv where B is the flux density and v the velocity of the charge q relative to the field. But if we were prepared to fiddle the value of ε_0, as we apparently are allowed to do to the value of G, then we might write the magnetically-produced force on a charge as F = qv, and proceed erroneously to write this equation in dimensional terms, thus:

$$[F] = [qLT^{-1}]$$

hence
$$[qLT^{-1}] = \left[\frac{q^2}{\varepsilon_0 L^2}\right]$$

and, cancelling a q, as we did an M earlier, the dimensions of ε_0 are at once calculable as $[\varepsilon_0] = [qL^{-3}T]$ which is surely as acceptable as $[G] = [M^{-1}L^3T^{-2}]$. Ultimately a dimensional discrepancy between F = qv and $F = \frac{q^2}{\varepsilon_0 d^2}$ would appear as a

**Some modernists assert that the dimension ε_0 is known: "Farads/m", they declare. That's great until someone asks them what a Farad is and they have to say "Well—er—an epsilon-metre". Such an approach is to say the least, trivial.

*Professor of Electrical Engineering, Imperial College, London.

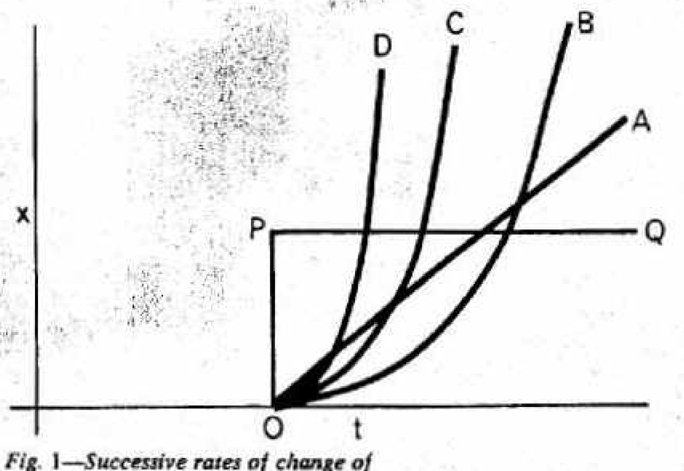

Fig. 1—Successive rates of change of displacement with time.

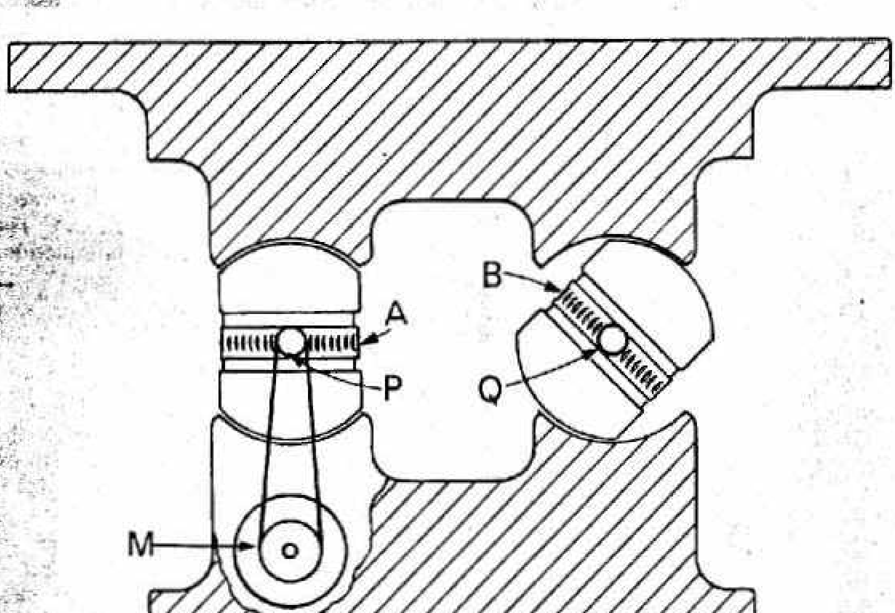

Fig. 2—Wallace's first machine demonstrating an inertial circuit.

velocity, LT^{-1}, and experimentally it would turn out to have a value of 3×10^8 m/s!

The problem is not a new one. Professor E. G. Cullwick wrote a splendid book in the 1930s[1] in which appears this wonderful paragraph on the subject of dimensional analysis:

"How confusing it must be for him (the student) if he is not told at once what this fourth physical concept is. If he is introduced to electric charges, magnetic poles, electric and magnetic fields as though they were all equal in the possession of physical reality, little wonder that they become in his mind all equal in mystery. And if he is then told, in dimensional formulae, that none of these is to be linked with mass, length and time in the quaternion of primary concepts, but that he must use *either* the 'permittivity' *or* the 'permeability' of free space, the race is indeed for the swift and the battle for the strong."

This is not an example of the "bad old days" of teaching in e.m. and e.s. units. I can well imagine the teaching profession reading this article up to this point and demanding (in modern language) what was demanded in Biblical times: "Give us a sign". Then a sign you shall have.

Gravitational waves

Quarks, gluons, neurons, up, down, beauty and charm are not only respectable terms in modern physics: a fundamental physicist is "old-fashioned" without them. From considerations involving non-solid nuclei it emerges that the more fundamental bits can have spin momenta, corresponding of course to the spin of electrons. If therefore certain substances have an unbalance of spin in the nucleus, comparable to that in the electrons in the outer shell of certain elements such as iron, might these not give rise to a phenomenon comparable to ferro-magnetism and might that not be seen to be an inertio/gravitational phenomenon, involving perhaps such concepts as gravitational waves?

My knowledge of such matters is sparse, but the message of one Henry Wallace, US research physicist, is crystal clear. In 1968 Wallace filed a Patent Specification on the subject of "Method and apparatus for generating a secondary gravitational force field", and he completed it in December 1971[2]. Space permits me only to summarise his key experiments, but before doing so I will quote verbatim a few phrases from his spec. that are strikingly similar to those I myself used in a Royal Institution discourse in November 1974 and in the Christmas Lectures which were televised at the end of that same year:

". . . whereby the rotational motion of said one member about the axis perpendicular to the plane of the other said member results in the dual interaction of the angular momentum property of said one member with inertial space . . .".

and then:

"This field is not electromagnetic in nature; being by theoretical prediction related to the gravitational coupling of relatively moving bodies."

This implies however the similarity with electromagnetic coupling of relatively moving charges.

"For purposes of the present invention the field generated by the relative motion of materials characterised by a half integral spin value† is referred to as a 'kinemassic force field'."

(lovely choice of words!)

"The kinemassic force field finds theoretical support in the laws of physics, being substantiated by the generalised theory of relativity."

(which, of course, is non-Newtonian.)

Magnetic field is similarly generated, being as it is associated with inductance and with a voltage $L\frac{di}{dt} = L\frac{d^2q}{dt^2}$ which can only be theoretically predicted by the use of general relativity on electrons with a relative acceleration. Indeed, our inventor proceeds to say:

". . . it should be helpful to an understanding of the present invention if consideration is first given to certain defining characteristics thereof, many of which bear an analogous relationship to electromagnetic field theory . . . The second significant property of the kinemassic field relates the field strength to the nature of the material in the field. This property may be thought of as the kinemassic permeability . . ."

(I used the words "inertial permeability" in the Christmas Lectures, having no knowledge of Wallace's work at that time.) He takes the analogy a step further:

"This latter feature gives rise to a further analogy to electromagnetic field theory in

1. "The fundamentals of electro-magnetism" (Cambridge University Press, first edition 1939).

2. US Patent No. 3,626,605.

†A nuclear spin corresponding to the out-of-balance electron spin in the outer shell of a ferromagnetic substance.

that the interaction of adjacent spin nuclei field dipole moments gives rise to another domain-like structure."

He speaks of "kinemassic field flux lines"††, of "a mass circuit" (my "inertial circuit"), of "mass flow" and of the fact that steel has a "high relative reluctance to the kinemassic field". Brass it appears is a far better conductor and mercury the best he has found to date.

Now to his apparatus: basically his first machine consisted of two precessable gyro rotors A and B (Fig. 2). Each rotor was mounted for rotation in an armature-like structure with brass pole-pieces. The pole-pieces were joined by bridges so that each whole armature could be precessed in bearings P, Q respectively. The axes of precession are thus perpendicular to the plane of the diagram. The wheels were spun by air jets acting on pelton buckets and the air could be turned off to leave the gyros running free for the experiment proper, so that the jets were in no danger of imparting side forces. The inertial circuit was closed by means of brass yokes as shown and the clearance between armatures and yokes was 0.0005 inches. The degree of detail given in the spec. is such as to leave no doubt that this was no "pie-in-the-sky" idea that was never tried. The engineering in his test machines was of the highest quality.

When rotor A was force-precessed about P by means of the motor M and belt drive, rotor B precessed in sympathy about axis Q.

In his second experiment his apparatus was as shown in section in Fig. 3. The shaping of the yoke was such as to give a constant effective path area. R is an annular tube full of mercury, held in place by a number of wires such as S, each of which carried a strain gauge, so that the mercury annulus could be weighed continually. When the rotor was force-precessed the mercury lost weight. The inventor attributes the cause to the fact that the spin field oscillates (like an a.c.-generated flux) within the yoke. He claimed to be able to pass through total weightlessness of the mercury ring and to a subsequent loss of weight of the entire apparatus as the precession rate was increased (presumably a saturation phenomenon within the yoke proper, for he speaks of "a 'bowing out' or spreading of the gravitational flux lines within the immediate proximity of the apparatus . . .").

Now the only thing that divides us is that Wallace chooses to "explain" the mechanism by gravitational waves and as a result assumes that reaction with the planet's gravitational field is essential (unless I have misunderstood the text, for he did begin with the generalisation of interaction between angular momentum and inertial space, and I would have expected propulsion in any direction to have been possible). Yet he concludes only that the inertial circuit merely acts as a "screen" against Earth-generated gravitational waves. It is a strange document to say the least,

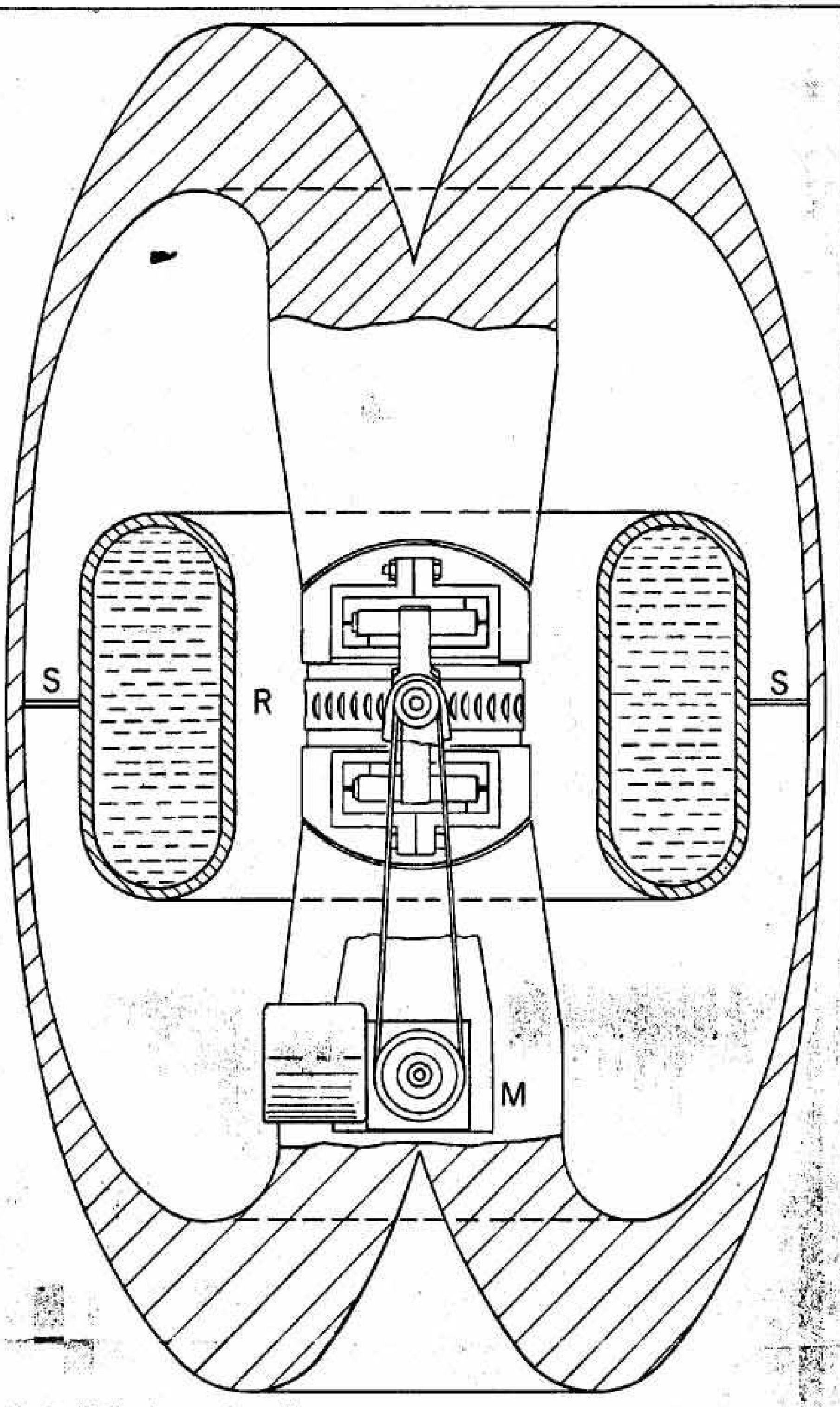

Fig. 3—Wallace's second machine.

especially as I have failed to find any follow-up material. But the theory has a dual with electromagnetism that cannot readily be dismissed and as I have long continued to demonstrate, both in these series of articles and elsewhere, I do not *understand* electromagnetism. But who among us does?

"What's that Isaac, you were thinking of spinning yourself? No, don't do that, we could use your help right now, as you were!"

††These are normal to the direction of spin, as is angular momentum when considered as a field vector.

Roll Isaac, roll—Part I

Before the letters start arriving, we apologise for some errors that appeared in Professor Laithwaite's last article (*Electrical Review*, 16 February). On page 38, the expression for tangential acceleration should have read $r\frac{d\theta}{dt} = r\,\theta$. And on page 41 equation (8) should have been

$$MgR = (I_Z W_Z)\,\Omega_Y + \left(\frac{I_X I_Y}{I_Z W_Y}\right)\dot{\Omega}_Y,$$

where M represents mass, not angular momentum as on page 39. Lastly in the footnote marked ††, $\frac{dq}{dt}$ and $\frac{I_Y}{I_Z \omega_Z}$ were incorrectly printed as $\frac{dg}{dt}$ and $\frac{I_Y}{I_Z W_Z}$

We hope for better luck in this week's article; though amongst the errors that have been corrected one is perhaps worthy of repetition. In the footnote marked †, our printers had profoundly coined the phrase "A nuclear sin".