JOURNAL OF

The British Institution of Radio Engineers

(FOUNDED IN 1925 – INCORPORATED IN 1932)

"To promote the advancement of radio, electronics and kindred subjects by the exchange of information in these branches of engineering."

Vol. XIV No. 8 AUGUST, 1954

NOTICE OF THE TWENTY-NINTH ANNUAL GENERAL MEETING

NOTICE IS HEREBY GIVEN that the TWENTY-NINTH ANNUAL GENERAL MEETING (the twenty-first since Incorporation) of the Institution will be held on WEDNESDAY, OCTOBER 27th, 1954, at 6 p.m., at the London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1.

AGENDA

1. **To confirm the Minutes of the 28th Annual General Meeting held on October 21st, 1953.** (Reported on pages 517-520 of Volume 13 of the *Journal* dated November, 1953.)

2. **To receive the Annual Report of the General Council.** (To be published in the October 1954 *Journal.*)

3. **To elect the President.**

   The Council is unanimous in recommending the election of Rear-Admiral (L) Sir Philip Clarke, K.B.E., C.B., D.S.O., as President of the Institution for the year 1954/55.

4. **To elect the Vice-Presidents of the Institution.**

   The Council unanimously recommends the re-election of Leslie H. Paddle, John L. Thompson and Professor E. E. Zepler, Ph.D., and the election of George A. Marriott, B.A.(Cantab.).

5. **To elect the General Council.**

   The retiring members of the Council are:—

   E. A. H. Bowsher (Member)
   H. E. Drew (Member)
   H. J. Leak (Member)
   Major S. R. Rickman, T.D. (Associate Member)
   Commander (L) H. W. Young, R.N. (Associate Member)

   In addition, G. Wooldridge, B.Sc. (Associate Member), retires on receiving an appointment abroad.

   Consequently, under Article 29, vacancies arise for ordinary members of Council as follows:—a maximum of four Members, a maximum of three Associate Members and one Honorary Member.

   In accordance with Article 32, the Council has nominated:—

   (*a*) Member for re-election: H. J. Leak.
   (*b*) Members for election: D. R. Chick, M.Sc., B.Sc., Captain (L) A. J. B. Naish, R.N., M.A., F. G. Diver, M.B.E.
   (*c*) Associate Members for election: F. T. Lett, Lt.-Col. J. P. A. Martindale, B.A., B.Sc., E. W. Pulsford, B.Sc.

   Any member who wishes to nominate a member or members for election must deliver such nomination in writing to the Secretary, together with the written consent of such person or persons to accept office, if elected, not later than September 14th, 1954. Each nomination must be supported by not less than 10 corporate members.

6. **To elect the Honorary Treasurer.**

   The Council unanimously recommends the re-election of Mr. G. A. Taylor (Member).

7. **To receive the Auditors' Report, Accounts and Balance Sheets for the year ended March 31st, 1954.**

   The Accounts for the General and other Funds of the Institution will be published in the October *Journal.*

8. **To appoint Auditors.**

   Council recommends the reappointment of Gladstone, Jenkins & Co., 42 Bedford Avenue, London, W.C.1.

9. **To appoint Solicitors.**

   Council recommends the reappointment of Braund & Hill, 6 Grays Inn Square, London, W.C.1.

10. **Awards to Premium and Prize Winners.**

11. **Any other business.** (*Notice of any other business must reach the Secretary* 40 *days before the meeting.*)

(*Members unable to attend the Annual General Meeting are urged to appoint a proxy.*)

The 1954 Convention Banquet

"THE INSTITUTION"

by

Air Vice-Marshal R. G. Hart, C.B., C.B.E., M.C.*

The toast proposed at the Institution Banquet in Christ Church, Oxford, on July 9th, 1954, during the Industrial Electronics Convention.

One of the purposes of any technical meeting is to promote discussion. In this way, points are made clear and some measure of agreement is obtained in solving particular problems.

What I have to say this evening, however, will hardly require discussion, for I know that there is a general desire to express every good wish for the future of the British Institution of Radio Engineers.

Although the Institution is only now in its twenty-ninth year, it has accomplished much and has seen the development of a scientific hobby into one of the country's most important industries, and into some of its most potent weapons. Indeed, in my lifetime, I have seen the birth and healthy development of a new type of professional engineer, for whose services our country has much cause to be grateful, and whose work not only extends all over the world, but will have a profound influence on our future lives.

Those of us who have seen the growth of your Institution, Mr. President, have found much to admire in your initiative, your mastering of obstacles, and your determination to justify your place in the realm of learned societies and engineering bodies. You were young and not fully developed when the war broke out—indeed, you were then but 14 years old. To men of lesser determination, that catastrophe could have been the most serious setback. I believe, however, that you, Mr. President, were one of those who were determined, at the outbreak of war, to prove your Institution's usefulness to the country, to your profession, and to your industry. I know that within my own Service we had much cause to be glad that there was a British Institution of Radio Engineers. Without your help we could not have built up quickly enough that protective Leviathan, the Radio Defence System, which gluttonously devoured 16,000 officers and a vast number of other ranks. A few of these officers were admittedly recruited from the Stock Exchange because of their ability to appreciate a situation quickly and to take prompt and profitable action, but your profession, largely through your Institution, contributed a really handsome force of able radio engineers, without whom such pillars of the financial world would have crumbled to impotent dust.

You may recollect that in 1945 Sir Victor Tait,† speaking in his capacity of Director-General of Signals of the Royal Air Force, paid a glowing tribute to the inestimable help given to the Services, and particularly to the Royal Air Force, by your Institution during the last war. Electronic devices have become essential elements in major weapons of war, and the development of such weapons in peace can be a major deterrent to an aggressor. This can only be achieved by close co-operation between electronics engineers and the Services.

I believe it has always been a cardinal point in your policy to serve the three defence Services and your industry by promoting professional association between engineers in the Services, in Government Departments and in industry. In these fields there are many common problems, not the least of which is the present-day shortage of manpower. It is so easy to pay lip-service to such a problem, but once more you have shown initiative by attempting, in this current Industrial Electronics Convention, to start lines of thought which might mitigate the manpower problem.

You have already discussed in your opening session the value of the computer as an integral part of the simulator in helping us to train aircrew. Many man-hours are thereby saved, apart from wear and tear of valuable equipment. The use of computing machinery is showing much promise in

* Director-General of Engineering, Air Ministry, London. (Address No. 11.)
U.D.C. No. 061.27 (425.7.)

† During an Address at the Twentieth Annual General Meeting. See *J.Brit.I.R.E.*, 5, October 1945, pp. 188-9.

the efficient analysis of defects: I anticipate that computers may very well replace pay accounts clerks so that an angry airman seeking an interview with the accounts clerk will, in future, find only a hard mechanical nose to punch!

I must admit that the prospect becomes a little frightening if there is much more development work on the theme of one of your authors, who is to discuss with you on Saturday "The replacement of the human operator by machines"; I have a nostalgic memory that the ability to keep an aeroplane flying was very much an individual's job, but now the computer, the radar aid, radio guidance of manned and unmanned flying machines, most ingenious devices to locate submarines and the mechanical operator have invaded the nursery in which I was reared where a sterling spark transmitter conveyed a message from the air to the ground, but the human eye had to distinguish a sometimes grubby white ground strip to learn what the battery commander or the isolated infantryman wished to tell the intrepid birdman above him!

To more serious thought—the use of sonics, X-rays, and gamma-rays are being shown in your Convention as great contributory factors towards reliability in production, and I hope we can expect them to contribute also towards detection of faults in servicing, for which the Royal Air Force will be most grateful. Reliability of aircraft and all equipment in them is of paramount importance to my Service, as I am sure you realize.

The expansion of the use of electronics beyond the simple realm of communications has been almost fantastic in my lifetime. Your art and science offer much promise in reducing the cost of production and in creating better outlets for technical ability. I am waiting to hear that electronics have entered the field of battle on which the fair sex wage a relentless struggle with Father Time.

This is the third Convention that you have held since the war. The first was wholly concerned with the art of communication and with radar, and brought us up to date, so to speak, with what had been achieved during war-time. You demonstrated the application of radar technique to safety in flying and to navigation generally, and we all recall your example of post-war possibilities in communication by sending and receiving messages from the four corners of the earth within a few minutes.

I personally liked very much the trend of your 1951 Convention, which you most appropriately tied up with the Festival of Britain. It was, I think, the first time that there had been a series of meetings on problems of nuclear instrumentation. You attacked boldly the technique and future development of valves and comparable devices and many of the papers read then are now regarded as standard reference works. At a time when Eurovision had hardly been thought of, you went on to a further session of your Convention in another University—Cambridge—to discuss the future of television. This session was notable for the number of engineers who attended from overseas countries and the original papers which you then discussed.

I must, however, comment here on the way in which the Institution is either pushed by its members, or is determined to punish its members. Most bodies seem content to hold a Convention by just having at the most half a dozen papers for discussion. In 1947, you had 14 papers; in 1951, you divided your Convention into 14 days, spread over three months, and having a total of 68 papers. Now you are in the middle of your Industrial Electronics Convention where I note from the programme that you are discussing over 40 separate and independent contributions. Indeed, such is the scope of this Convention that you have had to divide it into six separate sessions.

Such hard work reaps its reward. From the attendance at the Convention, where you are welcoming representatives from many countries overseas, it is obvious that the Institution is well respected and well justifies the recognition that it has gained at home and abroad.

Radio and electronics engineers are not only needed in the Services, in research, in the industry which provides the equipment, in all forms of broadcasting and communication, but now, in those factories which are producing equipment and goods with the aid of electronics. You surely must have a wonderful future; I am, of course, conscious of the fact that your Institution demands high standards of qualification for membership; this leads me to the ever-present problem of keeping pace in technical education with rapidly developing applications.

We have just had the satisfying experience of dining in this magnificent hall of this ancient foundation of learning, and I have had the additional thrill of sitting in the shadow of a fine portrait of Marshal of the Royal Air Force Lord

Portal. In the days when this educational establishment was founded a single qualified instructor had time to spend upwards of a month illuminating a single letter or cypher. How times have changed!

The problem of up-to-date education is now a matter of national life and death. I cannot claim to be an expert on these matters, but I have good reason to believe that the percentage of scientists and engineers trained in relation to the population in this country shows a sorry comparison with what is being done elsewhere in Europe and in America. We cannot afford to allow this situation to continue, so I would like to urge the importance of technical education, with particular reference to training in physics—the pearly gate in the citadel of education which opens on countless paths of technical endeavour. At the same time I would like to pay tribute to our national status in research on nuclear physics and low-temperature physics. Our standards are high—our technical education *must* grow.

You are an Institution of engineers and it is expected of you that you will get down to practical problems and that, in this way, you will justify your first object—the advancement of science for the benefit of mankind.

In those endeavours you have the good wishes of people from all walks of life and it is to wish you success in your Convention and, in fact, in all your work, that I am honoured to propose the Toast of the Institution, coupled with the name of your President, Mr. W. E. Miller.

The Response :—

The President, Mr. W. E. Miller, responded to the Toast and thanked Air Vice-Marshal Hart for the generous way in which he had spoken of the Institution's work.

Mr. Miller continued :—

"This Convention does show the diverse ways in which electronics is now affecting almost every other branch of science. If evidence were needed of this fact it has been provided in the tremendous attendance we have had at this Convention, not only from our own membership, but from delegates representing every other major industry.

"We must remember, however, that the scientific principles of radio were established less than 60 years ago—a point which was emphasized last night by Sir John Cockcroft when he delivered to us the Clerk Maxwell Memorial Lecture. Those of us who attended that meeting are proud of the fact that the first principles of what we call radio were discovered by a Scot—albeit in another university. Although I suppose Clerk Maxwell would to-day be regarded as a physicist, Sir John Cockcroft emphasized last night that after the work of Maxwell and then Hertz, the development of our branch of science passed from the hands of the physicist to the engineers, and a new breed of engineer—the radio engineer—was born.

"Now the advance of modern science is so rapid that the problem of securing an equally rapid translation of the results of research into industrial practice is of vital importance. The problem resolves itself into two parts, first that of making the results known, and secondly, that of applying them industrially.

"All engineering Institutions comprise bodies of men who endeavour to translate scientific principles into practical benefits. We have always been fortunate in our membership and it is proper that I should pay tribute to my predecessors in office and to those of our members who help to organize Conventions of this character. I hope they will feel that their work has been well rewarded in the enthusiastic attendance and by the kind remarks of Air Vice-Marshal Hart."

The Toast of the Guests was proposed most humorously by Rear-Admiral Sir Philip Clarke. The guests included the Dean of Christ Church and many overseas representatives.

Dr. Denis Taylor replied on behalf of the guests and especially stressed the growth of the Institution and its importance in the increasing application of electronics in industry.

During the reception and dinner, music was provided by the orchestra of the Irish Guards under the direction of their Director, Captain C. H. Jaeger, Mus.Bac.

OPTICAL TRANSDUCERS AND SOME INDUSTRIAL APPLICATIONS*

by

John A. Sargrove (*Member*)†

A paper presented during the Industrial Electronics Convention held in Oxford in July 1954

SUMMARY

After a brief survey of the principles and characteristics of photocells and electron multipliers, the advantages of various optical arrangements for different applications are considered, with particular reference to a high signal-to-noise ratio. Sharp focus light spot transducers for reflectometers and light scatter transducers for nephelometric determinations are described. Suitable transducers are referred to for particle detection in liquids, goniometric applications such as high speed weighing, line following and edge alignment equipment.

1. Introduction

An optical transducer converts visible or near visible radiant energy into electrical energy. Its electrical part is based on the photo-electric cell, of which there are many types. This aspect of the transducers will only be considered when absolutely essential to the point under discussion.

The main features dealt with are the optical considerations enabling a high signal efficiency to be obtained, i.e., a high ratio of wanted signal to unwanted background energy or high signal-to-noise ratio.

In industrial applications it is rare to be faced with the type of difficulties encountered in a television camera, or even in a sound on film photo-electric head unit, as the speed at which separate signals follow each other is comparatively slow. There is, therefore, no difficulty in using photo-electric circuits of a type which are quite unsuitable for video or audio frequencies, but which may present some other advantage particularly useful to the industrial applications in question.

Thus, for instance, the barrier layer photocell (or photo-E.M.F. cell)[1, 2, 3] will be usable in spite of its comparatively high electrical capacitance. Though the capacitance of this type of cell is of the order of 0·01μF/cm^2 and is thus inherently slower in response to change in light intensity than the photo-emissive cell, it can nonetheless be used to advantage in industrial applications where frequencies of the order of 500 c/s are rarely exceeded. In many industrial applications the rate of change in light intensity in any signal wave front is much slower, representing something like 10 c/s. At such low frequencies it is sometimes even advantageous to shunt the photocell with a 1-μF capacitor and make the input to any subsequent electronic circuit non-responsive to the 100-c/s ripple, due to 50-c/s mains feeding the light source.

Apart from its high capacitance the barrier layer photocell has the disadvantage of a low output voltage. Whilst this is, generally speaking, true, the cell gives specific output voltage of about 0·1 V at 100ft. candles, rising very little above this level with increasing illumination intensity. (The output at 10,000ft. candles is only about 0·5 volts.) On the other hand, the open-circuit voltage is quite independent of area, provided the whole cell is illuminated. With partial illumination of the cell the unilluminated area is electrically in shunt with the illuminated area, consequently the cell is no longer in an open-circuit condition as might be thought by considering the circuit.

The great advantage of this type of cell in industrial use is its low impedance when illuminated. As stated, a signal of 0·1 volts can be realized in most industrial applications. A further advantage is its very long term perman-

* Manuscript received May 31st, 1954. (Paper No. 274.)
† Sargrove Electronics Ltd., Hounslow, Middlesex.
U.D.C. No. 621: 383: 62.

ency, its rigidity, robustness, and small size, which make it invaluable in many machine applications which would be impossible to achieve by other types of glass envelope cells.

In applications where the maximum achievable light intensity is well below 100ft. candles, emissive cells have advantages as they are effectively light-sensitive relays and the output signal voltage is proportional to the supplying voltage as well as to the external load resistance. In practice, a usable output signal of, say, 0·1 V, with light levels down to about 1ft. candle, may be obtained from an emissive cell mounted in proper optical systems.

On the other hand, the very high impedance of this cell is a disadvantage. For light levels lower than 1ft. candle it is necessary to use very special optical and circuit techniques, but in general the approach is to use a multi-stage secondary-emission electron-multiplier cell. With a well-designed optical system, which should obscure all extraneous light, it is possible to operate with very low light levels, provided the multiplier cell is kept at a low temperature by water-cooling to eliminate all traces of thermionic emission. In fact, the usable light-to-darkness step signals can be so small that a distant star can be detected. This would not be an industrial condition, but is mentioned to emphasize the amazing sensitivity of the multiplier cell. There are, however, some practical cases, such as guarding long fences against intruders on dangerous industrial plant (such as explosive works, etc.), where this type of light-sensitive device might be required.

2. The Light Source

The light source must be considered almost as an integral part of the optical transducer, because in most industrial applications it is not used as a remote transmitter of energy to the receiving photocell. The light source shining into the photo-electric cell forms a complete system maintaining the "no signal" background level. If the lamp is lit by a 50-c/s supply its light output will be modulated by twice this frequency as the light output is proportional to the square of the instantaneous wattage dissipated.

At signal frequencies much lower than the filament ripple, this effect can be completely neglected. However, should the signal frequency be near to the ripple frequency, one must either adopt a direct current light source with very good smoothing or produce a much higher frequency to feed the incandescent filament.

In certain cases, this light source ripple may actually be used as a continuous carrier frequency at the photo-electric receiver to feed a tuned 100-c/s amplifier. It is easier to obtain larger gains by tuned transformer coupling without the difficulties inherent in direct-coupled amplifiers otherwise required.

To increase the light modulation depth in such cases, it is usual to insert a half-wave metal rectifier in series with the lamp filament which eliminates one half-wave of the 50-c/s current and hence the output frequency will now become actually 50 c/s but with quite appreciable dark gaps in between the remaining active half-waves of radiant energy.

3. Optical Considerations

The optical system used is one of the most important aspects of obtaining a high signal to noise ratio.

In practical cases, unfortunately, some stray light falls on the photo-electric cell. Also the quantity of active, useful light that can fall on the photo-electric cell is limited by economic considerations, as well as the upper limits of temperature which the photo-sensitive layers of a p.e.c. will stand. The step in light levels between useful light and background dark is never very large, and the optical system must be designed to make this step as large as possible.

3.1. *Long-Range Light Beams*

In cases where the light beam is, say, 100 times as long as its diameter, and which occur most frequently in industry in photo-electric guards for dangerous machinery or photo-electric burglar alarm systems, a number of conflicting factors have to be reconciled.

The first consideration is the amount of light energy which can be projected through a given optical aperture at a given light source brilliance. Clearly, the total spherical light output from a lamp filament can never be used with lenses lying on one side of a filament, but only the rather small cone of light subtended by the lens aperture on the actual incandescent filament.

Even with a concave backing mirror the output rarely reaches double this value.

In designing an optical transducer the main consideration must be to obtain the largest possible electrical change from a given change of light level. With any given load circuit attached to the photocell, the useful signal is

$$\triangle E_L = P_T K_T K_R \frac{\triangle A\, r}{l^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

and the signal/noise ratio

$$= \frac{\dfrac{P_T K_T r}{l^2} + P_O}{P_O} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where K_T is a constant of the transmitting optical system.

K_R is a constant of the receiving optical system.

P_T is the light power output of the transmitting light source.

P_O is the effective light power level at the aperture of the receiving photocell housing from any irrelevant background.

$\triangle A$ is the effective aperture of the receiver.

l is the length of path between transmitter and receiver.

and r is the effective loss ratio of the actual light level change in the optical image at the receiving light-sensitive surface, to the actual change in light level at the viewed object itself.

This factor r could be unity only in the ideal case when the image is in perfect sharp focus and at some part of its time cycle it must completely cover the optical slit mask in the receiver and there is no loss through haze in the transmission path, etc.

As none of these ideals can be completely realised, r is always smaller than unity. In designing practical systems r is one of the most difficult factors to cope with efficiently.

3.2. *The Effective Aperture of the Light Projector*

Dealing with the more obvious factors first, consider Figs. 1 a, b and c. Here P.E.C. is the photo-electric cell in a light-proof box which is assumed to have the same aperture $\triangle A$ in all three cases. Also L.P. is the light projector which is assumed, for simplicity's sake, to have one condensing lens. $\triangle A$ is always smaller than A, the full transmitted image of the light source.

3.3. *Determination of Transmitting Power: P_T*

It is obvious that with any one of these optical systems, if the effective brightness of the incandescent body increases, and provided its effective dimensions do not change, then P_T would increase. As the light source is usually an incandescent tungsten filament, the emitted radiant energy reasonably follows the laws of a so-called black body radiator. The photocell is, however, sensitive to a restricted band of spectrum frequencies which, being the only effective part of P_T is approximately proportional to the square of the watts dissipated in a given incandescent filament, a fact well known in the electric lamp industry. The remainder of P_T is lost in useless heat energy. The useful light output of any given piece of tungsten wire is, therefore, proportional to the fourth power of the voltage that can be applied to it. Hence, the over-run photoflood lamps, and the instantaneously vaporizing photographic flash bulbs are very efficient light emitters. As industrial applications require very long life light projectors, the tungsten filament must be under-run, both with a view to increasing the crystallization time, and to reduce to insignificance the vaporization of the metal and the blackening of the inside of the evacuated glass bulb.

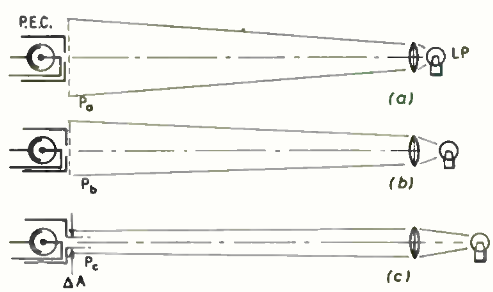


Fig. 1.—Basic features in design of long-range industrial light projectors. Though using smaller cone of light from the total spherical emission of lamp, (c) makes best use of light at p.e.c. aperture.

Normally the lamp with long-life filament runs at an abnormally low temperature of about 1,500° K at most (red-orange to yellow) certainly not the bright white light normally used in non-industrial light projectors.

It may be concluded that P_T cannot be made very large because with any given filament size the useful wattage is limited by permissible temperature for long life, and with a given temperature the wattage can only be increased by making the filament larger. This brings with it the immediate enlargement of every dimension of the projector optical system if the same shape of light beam is to be maintained. This is not the only consideration.

From Fig. 1a, assuming the filament of the L.P. twice as large as shown, and the lens twice as large, then with the same distance l between L.P. and p.e.c., the image Pa received at the plane of the p.e.c. would also be twice as large, due to the normal laws of optical projection, but as the $\triangle A$ (effective aperture) of p.e.c. must be assumed to be unaltered considering the light source only, no more light enters through the aperture than before and the photocell receives no more energy.

Thus, it is important to choose the most compact filament lamp, run it at a suitable temperature for long life and accept the resultant wattage at whatever upper limit it happens to be. Therefore the useful power of the transmitter P_T is very much limited and could almost be entirely dependent on the material and temperature of the filament. In practical cases, a lamp with the lowest voltage filament available is used to obtain the thickest piece of tungsten filament and it is hoped that the lamp designer has coiled it into a very compact and short coil. It is a pity that the industrial uses of photo-electric devices do not yet demand sufficient numbers to warrant lamp manufacturers investing in the design of a special lamp for this purpose alone. Such a lamp would probably have a rating of 1 V 10 A with one, or at most three, very tight coiled loops forming the really hot light source. The filament ends would have to be straight for a short length to permit a sensible temperature gradient before the weld at the thick support rods. The maximum temperature of the centre of the incandescent coil would probably be designed to run at around 2,000° K, the whole structure being enveloped in a bulb about 1 inch diameter, a somewhat larger size than is customary for a 10-watt lamp, to expose a larger area for the deposited vaporized metal. Krypton gas filling might also be beneficial to increase the specific cooling effect by convection cooling with the heaviest inert gas.

In practical cases it is normal to use a 6 V 6 A car headlamp bulb and to run it at about 4 V 5 A. The filament shape is quite wrong and of the 20 W dissipated, probably not more than 5 W is used to heat the part whose image ultimately falls upon the useful aperture $\triangle A$ of the photocell housing.

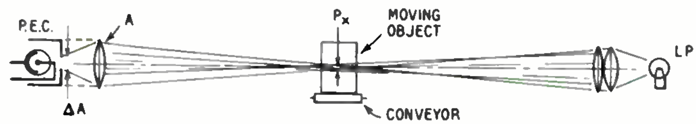


Fig. 2.—Practical advantage of use of cross-over light beam.

3.4. *Determination of K_T*

Comparing Figs. 1a, 1b and 1c, it will be noticed that these are all drawn with the same diameter lens on L.P., the same size of filament, the same length path l and the same $\triangle A$ of the p.e.c. The only difference is in the focal length of the condenser lens. Fig. 1a uses the largest cone of light emitted in a spherical

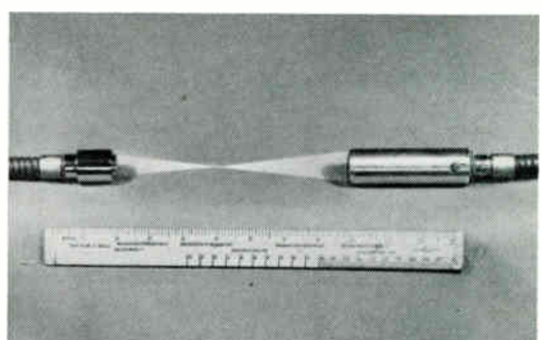


Fig. 3.—Typical industrial accessories utilizing cross-over light beams.

manner by the incandescent body, and would at first sight appear to make the most efficient use of the total emitted light; it does not really achieve this at all. This is again due to the laws of optical projection magnification. The projected image Pa is largest in this case and the fraction of the image light actually entering through the aperture $\triangle A$ is very small.

Considering Fig. 1b, and then 1c, it will be found that 1c is the most efficient, although the focal length of the lens in this case is the longest, and consequently the amount of light used is the smallest (probably not more than 3 per cent. of the total global cone). The largest fraction of the image falls on the $\triangle A$ aperture.

It is this kind of consideration that determines the magnitude of the coefficient K_T and decides the design dimensions of the light projector. Designers would prefer to use a parallel beam of light, but unfortunately this cannot be obtained in practice as a point source of light having no size does not exist.

3.5. *Aperture of Receiver*

In many practical industrial applications, such as perceiving moving objects on a conveyor (Fig. 2), it is possible to improve matters still further. In this case, an optical system is used at L.P. which will project an image of the actual incandescent light source half-way between L.P. and p.e.c. Now that the image path is $l/2$, the magnification of the projector is only half of the previous case. The image is more compact and the rays of light cross over at the object to be detected and do not form an image at the receiving photocell. A lens with similar aperture to that of L.P. may be mounted at the receiver and a fairly large fraction of the diffused image passes through $\triangle A$.

3.6. *Determination of P_0*

There is another much more important reason why a lens at the receiver is advantageous. Not only does this help to make the constant K_R larger, but also makes the receiver directionally selective and this decreases P_0 the unwanted background lighting. Without the optical system at the receiving aperture the p.e.c. views a large diffused cone of space increasing the chance of extraneous light falling on the cell. The more directional the optical system at the receiving end is made the smaller is P_0 and the greater is $\triangle E_L$ and the greater is the signal-to-noise ratio.

3.7. *Optimum length of Path*

Theoretically, if a point source of light having no dimensions was realizable and hence a really parallel light beam, the factor l in equation (1) would not be raised to the power of two. Further, if there was no absorption in air due to haze, l could be ignored entirely. In practical cases, as none of these ideals exist, and the image is always larger than the real light source, the factor l^2 is also very real and the well-known inverse square law operates. Therefore, where really long beams of light reflected perhaps from mirror to mirror in a zig-zag form to make a guard for a dangerous machine, would appear to be a desirable solution, this reduction must be borne in mind. It frequently pays to build into a system two or more light sources and a corresponding number of receivers instead of using many mirrors. Again, experience helps in deciding the best compromise. Another factor which must not be ignored in this type of argument is the reliability of the whole photo-electric amplifier system. A mirror is likely to get dirty, broken or be pushed out of its correct directional setting, but it cannot fail in the same way as an electronic system or even the entire light source. It depends very much on the actual application which solution one chooses, and no dogmatic rules can be laid down to cover all cases.

4. Reflectometer-Type Transducers

When the object to be detected cannot be made to form a shadow, the alternative is to illuminate it and view the light reflected. Thus, a further loss factor enters into our system, i.e., the coefficient of reflection.

A comparatively simple example is shown in Fig. 4a. Here, within a box having five black sides, a travelling surface is viewed which is arranged to be the sixth side of the black box. For the purpose of this example, assume that the travelling surface is itself black and the mark to be detected is white. If, in Fig. 4a, there is a p.e.c., looking at the surface directly, without the aid of an optical system, it receives any light reflected from the travelling surface. Assuming that the light source would also have no optical system (not as shown in the drawing), then the travelling surface would be illuminated

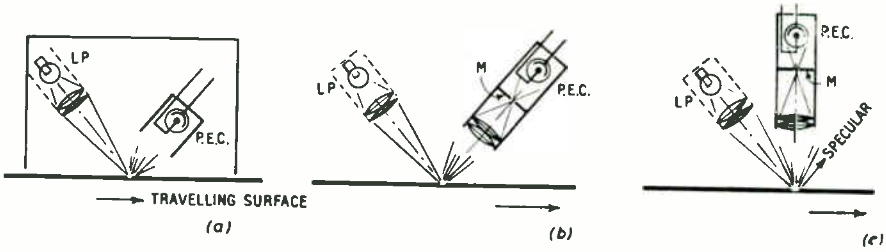


Fig. 4. — Evolution of the modern "Registec" head transducer.

generally. If it is black and matt, only a very low state of illumination will fall on the p.e.c., especially if it has a small box surrounding it, as shown, shielding it from direct light. As the white mark printed on the travelling surface enters the larger box from the left, there will be an immediate increase in diffuse light reaching the cell, which will remain more or less at the same level until the travelling white mark leaves the box again on the right. However, as the light from the lamp is diffuse the brightness on the entire travelling surface is low.

The signal to be detected, which is the increase in light level energy received by the p.e.c., is very small, though it lasts the whole time the white mark is travelling through the black box. If, on the other hand, a transmitting optical system as shown in Fig. 4a is used to focus the light on the travelling surface (which by definition was matt), the general background light level will be the same, but the active signal step when it occurs will be tremendous in comparison with the above case. While the increase in light intensity level is very great, its duration is extremely short. It should be noted, however, that the total energy over total time is the same, though in the latter case it is used efficiently to give a very large signal step both up and down, i.e., a square pulse of energy if displayed on a time base.

Figure 4b shows a more practical case used frequently in industrial applications where it is often inconvenient to use the method described above because, to act efficiently, the box must be very near to the travelling surface which may be soft or wet or gummy, etc. The arrangement shown in Fig. 4b enables the two optical systems to be far from the travelling surface. In this case, the p.e.c. lies behind a mask " M " inside a rear box behind the receiving optical system. The mask " M " must be in the plane in which the focused image of the travelling white spot produces a sharp image. The white spot is now illuminated by stray light all the time and the reflected image of the white spot travels across the mask " M " also. The p.e.c. does not receive this reflected light until the image on the mask just passes over the slot, as actually shown in Fig. 4b. In this case, the sharpness of focusing of the light source image on the travelling surface is not so critical. A slightly blurred image is in fact best, as this allows for the filament of the lamp to sag with age without the arrangement becoming seriously affected.

The receiving optical system, however, has to be very carefully focused to get the sharpest reflected image on the mask to permit the greatest light level step or contrast to occur as the image moves across the slit in the mask. The narrower this slit is, the steeper becomes the wave front and the greater the signal to background ratio.

4.1. *Lustrous or Shiny Surfaces*

It has been assumed that the surface was black and matt, but in most industrial cases this is not so. Usually, one has to deal with a white surface and a dark printed register mark and, furthermore, the surface is itself either lustrous or shiny. The shiny surface causes great difficulty, as even if it is black there is still a large proportion of light reflected from it at an angle equal, and opposite, to the angle at which the projector is pointed at the travelling surface. This is called the specular reflection. Thus even the black background would reflect much light into the p.e.c. and the factor P_0 in equation (2) would be large and thus the wanted signal step received is small.

There is a further trouble with shiny surfaces. Small creases will directionally alter the reflected light, the image wobbling across the slit in

Fig. 5.—Reflectometer-type transducer used in dentistry to compare whiteness of teeth.

mask " M." Hence the intensity of the unwanted light falling in the p.e.c. is itself being modulated by these creases and wrinkles. Some of these modulation waves, if large enough, might be detected by the p.e.c. and appear as spurious signals. For this reason, so-called " register-mark detecting units " frequently have a " threshold limiter " circuit built in which can eliminate all modulations less than the threshold voltage. The main signal itself may become obscured by such a wrinkle if it is not very much larger than the threshold, consequently except on matt surfaces the arrangements Fig. 4a and Fig. 4b are not very suitable.

A much better system is shown in Fig. 4c. Here the specular reflection from the shiny surface (either light or dark) can never reach the receiving cell. The diffused light from the printed white or dark image still sweeps across the mask " M " which has to be carefully focused to have a sharp image of the travelling surface appear on it. The background level received by the cell is low and P_0 is small and this makes $\triangle E_L$ large, even if all the other factors remain unchanged. Also wrinkles do not now affect the system to the same extent, and they would have to be exceedingly large to cause trouble. Moreover the main signal $\triangle E_L$ is larger than before, and thus the threshold voltage can be pre-set even higher in the amplifier and this will still further reduce the disturbing effect of the wrinkles and creases.

These facts, relating to the different angles at which the specular light and the diffused light are reflected from the surface, can be used industrially in, for instance, chocolate wrapping machines. In these, the metal foil for the packing can be embossed with a register mark instead of being printed in colour. The whole pattern may be embossed and deliberate dimpled wrinkles put on the surface provided there is a marked contrast between this general state and the register mark.

5. Light-Scatter-Type Transducers

There are some photo-electric applications in which the objects to be detected are very small. These occur when detecting small solid particles of matter suspended in a transparent liquid. Fig. 7a shows one approach in which a glass tube is assumed to carry the transparent liquid, with or without the solid particles, and the light beam is passed through it, generally at right angles to the flow. Obviously, the pipe need not

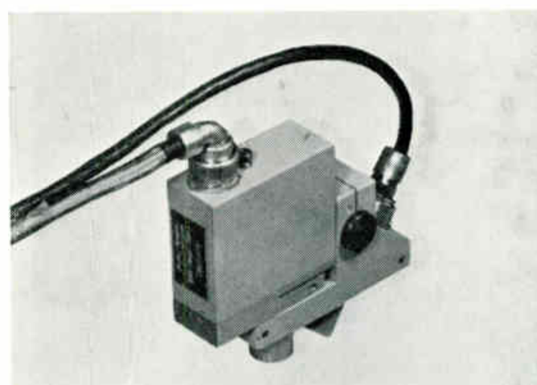


Fig. 6.—Register mark detector ("Registec") head (cf. Fig. 4c). Note simplicity of mounting and built-in amplifier.

carry a transparent liquid, it could carry a gas, as is the case in chimney stacks, where the aim is to detect smoke particles.

The solid particles will rob the photo-electric cell of a small fraction of the light that would have fallen on it had there not been any solid particles. If the concentration of these particles is a sufficiently large percentage of the whole and the photo-electric cell and light source and amplifier are all sufficiently stable, then these particles will cause a sufficiently large decrement in the light to be detectable as an electrical signal. An electronic circuit can then be used to translate the light decrement into a corresponding electrical decrement or increment, whichever is required.

In practice, this type of nephelometric system, together with most carefully designed constant-gain amplifiers, can be used to detect turbidity concentration in a transparent background fluid of 1 part in 100 down to 1 part in 10,000 solid to liquid matter. The sensitivity will be greatest at the larger concentrations.

For much lower concentrations, usually referred to as a haze in the range of 1 part in

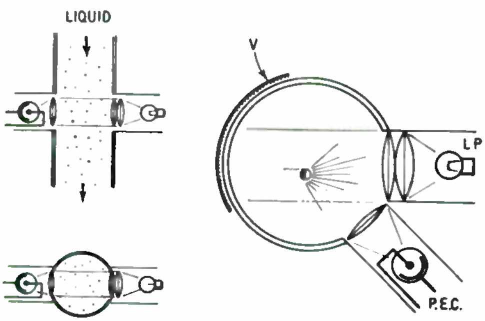
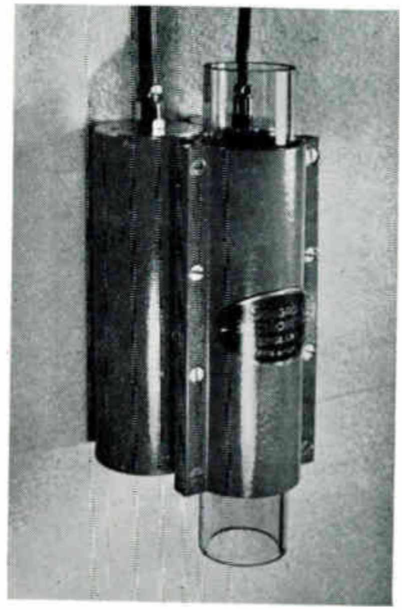


Fig. 7.—Evolution of the modern "Nephoscope" head transducer.

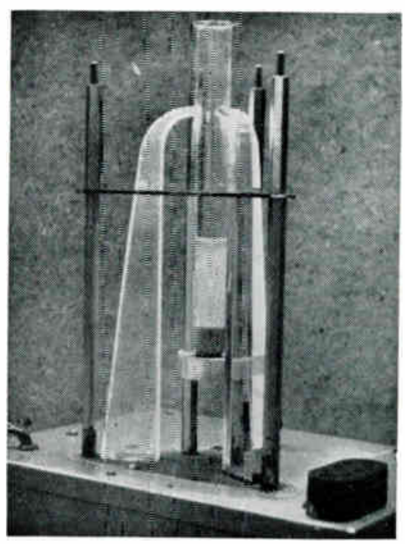
1,000 to 1 part in 100,000, then quite a different type of optical arrangement is required. Such an optical arrangement is shown in Fig. 7b. The light source LP projects a beam of light across the tube as before, but as much of the light as possible is now absorbed in black matt material marked "V." The p.e.c. looks into the tube and at the screen "V" through an optical system arranged adjacent to and at an angle to the light projector. The whole system has to be very carefully designed and built so that no shine from the glass tube is reflected into the p.e.c. but all the reflected light should go back into the light projection aperture.

If the liquid is truly transparent and clear, then the background illumination is very low and the factor P_0 very small.

Figure 7b shows one giant particle of solid matter floating through the illuminated light beam. This represents the thousands of microscopic particles in concentrations in the region of, say, 1 part in 10,000 or less. Each particle will scatter some of the light into the p.e.c. giving the increase in the factor "r." This small



(a)



(b)

Fig. 8.—(a) Light-scatter-type transducer with built-in pre-amplifier for continuous turbidity monitoring (cf. Fig. 7a). (b) Test tube turbidity "Nephoscope" for precipitation or sedimentation monitoring using light guides with scatter-type transducer.

increment in light produces a similarly small signal which can be amplified until it becomes usable. This type of scatter optical system is more efficient at low concentrations. This statement and equation (1) contain all the relevant information to design a successful Nephoscope, but there are many practical difficulties to which only long experience provides the answer. Obviously electronic stabilizers of a high order are required to compensate for any tendency of the electrical constants to alter, but the maintenance of cleanliness of the optical system is usually a practical operational difficulty. Industrial users adopt certain periodic flushing routines to keep the system clean. The designer can also help by using transparent surfaces, which should be as non-adhesive to dirt as possible.

The criterion as to which type of optical system to adopt for any given case is obviously further complicated by such factors as the colour of the particles and the colour of the liquid.

Obviously, the scatter effect referred to in connection with Fig. 7b is greatest when the particles are white and the liquid is colourless. This system is not very promising for the detection of carbon particles. For this problem, an arrangement closer to Fig. 7a is used, though somewhat altered to make the transmitted light path long. The factor $\triangle Ar/l^2$ is here made as large as possible.

By making l longer, it might appear that the signal will get smaller for any given concentrations, but this is not the case due to the statistically random distribution in particle arrangement in every unit length of l. If, in one unit length cross-sectional slice of the light path l, there is a space through which the light can pass, it is statistically much more likely that in the next slice it will be obscured. It is very unlikely that the particles would be just behind each other and form only one shadow. Thus, the greater the length, the greater the effective obscuration.

Therefore, $\triangle Ar$, the fraction of the effective aperture, is altered most by increasing l. Due to the random distribution of particles the change in $\triangle Ar$ is greater than the change in l^2 and hence the signal, which is proportional to $\triangle Ar/l^2$, becomes larger.

For turbidity concentrations which are very low, 1 part in 1,000,000 or less, the amplifiers have to be even more carefully constructed to have a very low background noise and extremely good long-term stability.

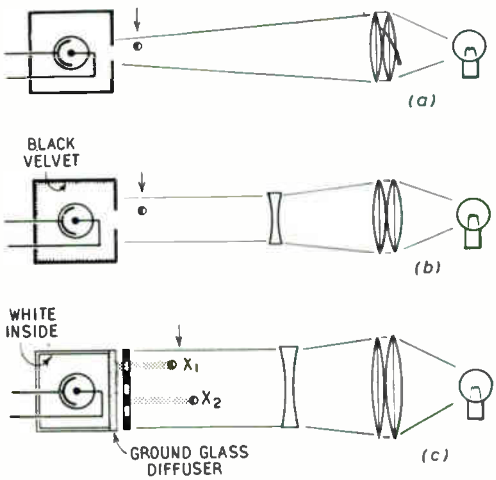


Fig. 9.—Slit optics and optical grid method of detecting small particles.

In special cases, quite good long-term results have been obtained, however, and it must be emphasized that every case has to be assessed on its own merits before design is undertaken.

6. Slit-type Transducers

Another approach to this problem of detecting only a few solid particles in a transparent liquid has been proposed[4] and this is, broadly speaking, to use an optical system similar to Fig. 7a, but to make the aperture of the photocell into a very narrow slit, as shown in Fig. 9a. The slit width is comparable to the diameter of the particles to be seen. Very little light is now seen and P_0 is almost zero but $\triangle Ar$ will be a maximum. P_0 is made even smaller by putting the p.e.c. into a box lined with light-absorbent black velvet (Fig. 9b).

For the optimum-sized particle, r is an absolute maximum and if the liquid is moving fast then its transit time across the slit is a minimum.

Therefore, as explained above in conjunction with Fig. 4a and b, the transitional signal pulse will be very short and all the signal energy, however small, concentrated into one very short pulse. Accurately parallel light is required so that the particle will make a sharp shadow, and this is diagrammatically shown in Fig. 9b by the introduction of the double concave lens, though in practice many other ways are open to the designer.

A special amplifier is used which ignores all long-term changes and amplifies only very short changes. This method has the great merit that the amplifier can be made with a.c. coupling elements and designed to sharpen pulses. P_T, the output of the lamp, does not have to be long-term constant either, as the amplifier will ignore this even if the p.e.c. does not. This system has been used for the examination of soft drinks in bottles on rotary table machines at high repetition speeds. It has also been used experimentally to detect blood corpuscles in a blood solvent passing through capillary tubes to obtain automatic blood counts.

6.1. *Multiple Slits or an Optical Grid*

Slits or a grid, coupled to an a.c. amplifier, can also be used as shown in Fig. 9c. The sequential appearance X1 and disappearance X2 of the particle to be detected produces a.c. signal pulses, which is now the relevant signal. As P_T and $\triangle Ar$ are both large, the short-term constancy of these two factors is very important. However, long-term constancy is not important due to use of the a.c. coupled amplifier and, therefore, such a system is much more tolerant to dirt adhering to the optical surfaces.

7. Goniometric Transducers

There is quite a different class of industrial applications where we are interested in the change in direction of a light beam along the light path. This change in direction can be by reflection, refraction or deflection of the axis of either the directional transmitter or the directional receiver (Fig. 10a). This arrangement is obviously useful for detecting small changes in angles of a few degrees in some part of a machine, but it is not sensitive enough for very small angles. However, the optical system can be greatly improved.

One application of this principle is photo-electric precision weighing. Fig. 10b shows a torsionally mounted mirror which can rotate slightly on its axis by an angle $\triangle\theta$. The sensi-

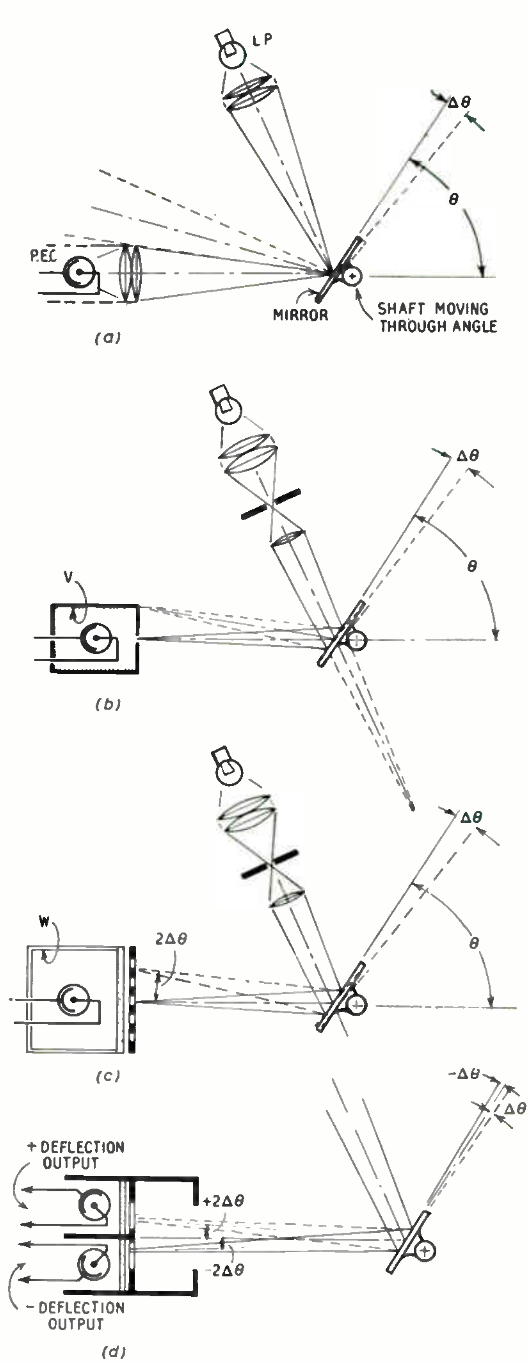


Fig. 10.—Evolution of the goniometric transducer.

tivity is increased by improving the transmitting optical system. This now has a slit mask so as to make the used fraction of the light source narrower. The fine slit approximates more closely to the ideal light source having no dimension at all. The slit projects an almost parallel beam of light and it is used as an angular lever. In Fig. 6c this design feature produces a very small end image on the series of optical slits behind which there is one photocell arranged in a dark box.

At rest, the optical system is so adjusted that the transmitter slit produces an image on one end of the black mask surface. The light is absorbed and the photo-electric cell is in darkness, and we have no deflection and no signal.

A small deflection upwards allows the light beam to illuminate the cell and provides one signal. A small further deflection and the light image now falls on the next black surface. A further angular motion allows the light to illuminate the cell a second time and so on. If some form of electronic counter is now coupled to the photocell a digital knowledge of the angular motion of the mirror is obtained. Naturally, the torsional system carrying the mirror must be perfectly clamped so that the system cannot rock, after its initial movement, as it would then produce additional counts and consequent errors.[5]

The final resolution of this system is one pulse for every black bar uncovered, but due to the optical law of rotating mirrors, the reflected angle is $2 \triangle \theta$ for every unit angle $\triangle \theta$ of the mirror.

Figure 10d shows another arrangement for weighing in which two photocells are used, each in its own black box. This system is particularly good for check weighing and sorting objects moving on a conveyor band. If the control black bar of the mask is made wide enough to allow the weighing mirror to deflect within the weight tolerance without light falling on either photocell, then the weight is within tolerance limits. If the deflection is sufficient, either in a positive or negative sense ($+\triangle\theta$ or $-\triangle\theta$), to fall on one of the cells, the electronic amplifier attached to the appropriate cells and actuators can operate selector gates which can marshal the object being weighed into appropriate channels.

A light diffuser screen is shown in front of each cell in Fig. 10d and the slits in the mask are shown quite wide. This is to permit the appropriate p.e.c. to retain the light signal even if the angular deflection of the mirror, and hence the weight deviation, greatly exceeds the exact tolerance point limit. If the slit were too narrow then the deflecting light beam would, after hitting the p.e.c., pass to the edge portion of the black mask and the signal would vanish and the electronic system might not be able to distinguish this condition from the neutral one.

Of course, with certain types of impulse-hold amplifiers this feature is not required, although it increases the reliability of the system.

7.1. *Grouped Photocell Transducers*

If the design is taken a stage further, the system illustrated in Fig. 11a is obtained. There are four separate photo-electric cells each arranged in light-tight boxes with separate slit apertures for each cell. At rest the transmitting optical system and the weighing mirror are set up to produce the image of the transmitting slit on the central black bar of the mask. This is the position in which the system is shown in Fig. 11a.

A very slight angular motion of the mirror now produces a signal in one or other of the cells adjacent to the central bar. A greater deflection of the mirror produces a signal first in one of the inner cells and then in one of the outer ones. With suitably designed electronic circuits attached to the several cells, the degree of mirror deflection can be ascertained without the possible ambiguity of the arrangement of Fig. 10c using the electronic counter. By adopting light guides made of Perspex, as shown in the drawing, the optical slits in the receiver can be arranged very close to each other and higher angular accuracies are obtainable.

7.2. "*Statistrol*"[6]

This system is particularly suitable for automatic weight control of a production process. The transducer (such as Fig. 11a) can be coupled to an electronic statistical computer. Statistical histograms are produced automatically by coupling electronic counters to each cell with appropriate muting and hold circuits.

A production process which results in objects being produced having random weight variations,

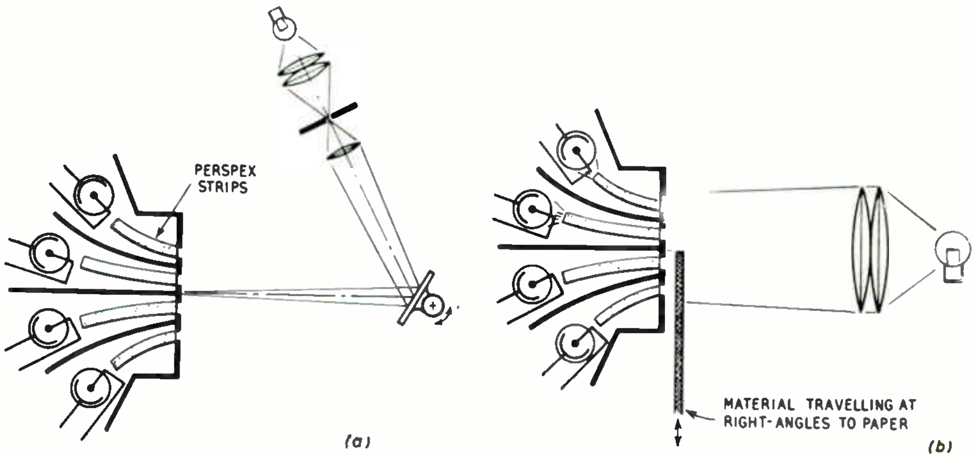


Fig. 11.—Evolution of the multi-aperture transducer.
(a) For goniometric use such as rapid weighing, (b) for rapid correction edge alignment guiders.

for example, a mechanical bread dough divider, may be controlled by varying the volume of the moulding cavity of the dough divider machine through appropriate actuators from the calculated mean weight by the statistical computer coupled to the above group of photo-electric cells.

The statistical computer in this case is designed to discern any trend in the apparently random variations and control the processing machine to compensate for this drift, before it becomes serious.[7]

8. Edge Alignment and Guiding Transducers

A four-aperture optical transducer which is very similar to the one discussed above has been evolved for guiding at high speed the edge of a sheet of paper, textile web or metal strip, etc.

Whilst there are very much simpler systems in existence they all suffer from one or more deficiencies in performance which are not present with the system shown in Fig. 11b. This, together with its specially designed electronic amplifier circuit, can deal successfully with the edge of materials which defeat the simpler arrangements.

Four photocells are used in a composite head having four slit-like apertures all close together illuminated as uniformly as possible by a short focus light source mounted rigidly close by. The edge of the material to be observed is arranged to be guided by mechanical means into a processing machine, such as a textile "stenter."

Figure 11b shows the edge of the material (which should be visualized as coming out of the drawing at right angles to the paper) in its correct position. Thus, the two upper photocells are fully illuminated while the two lower ones obtain less light through the textile fabric. The electronic circuit is designed to accept this state of affairs as a neutral one.

If, now, the material shifts slightly to obscure the inner aperture immediately above the neutral state, an edge alignment correcting mechanism is brought into play by the appropriate amplifier and the edge correction mechanism corrects the lie of the material back to neutral. The same thing happens if the edge of the material moves downwards. Now, the inner photo-electric cell becomes completely uncovered and its amplifier responds in a way to make the correcting mechanism bring the edge of the material upwards, back to the neutral state again. However, whilst this two-way correction system can be made to deal adequately with the normal kinds of bad alignment due to the shapelessness of the textile fabric, it cannot cope quickly enough with mis-alignments which occur occasionally at joints of strips of material where a sudden mis-alignment may be several inches.

In this case, either of the outer cells is also involved in addition to one or other of the inner cells whose action has already been described. The electronic circuits connected to the two outer cells are so designed that they will accelerate the correction system to a lateral correcting velocity several times the normal. It should be noted that as soon as the correction has been effective enough to leave only one of the inner cells perceiving a residual small misalignment, the correction velocity reverts to normal and the edge comes back to the neutral position slowly. This avoids over-shooting and what would be termed " hunting."

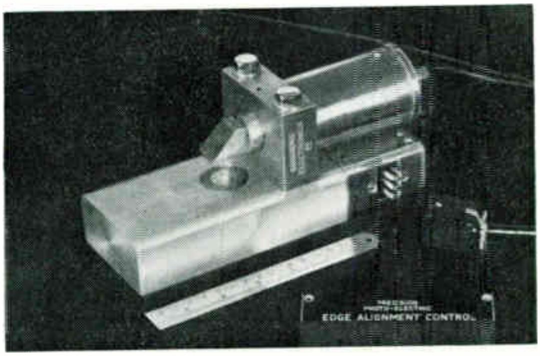


Fig. 12.—Double-photocell transducer for industrial edge alignment problems.

This type of system, with its appropriate control system, can cope with almost completely transparent textile materials as knitted nylon web, net-like materials, such as lace curtains, etc., etc., at high speed. With such materials the actual signal is only 3 per cent. of the background illumination. Automatic equipments of this type have been in industrial use satisfactorily for many years.

8.1. *Line-Following Transducers*

In some industrial problems the optical system has to follow, not the edge of the material, but a line drawn, printed or even woven into it. In these cases an optical system, such as depicted in Fig. 10d or Fig. 11b, might at first sight appear suitable. This is not the case, however, if the line to be followed moves out of the observation region too quickly to be followed by the mechanism, the line would become irretrievably lost. The alignment mechanism would search around and in most cases make the misalignment even greater than it was before the correction took place.

Clearly, such a system would be unstable and thus industrially quite unsuitable. For line following and similar applications, it is better to use the flying spot system of scanning. One such system is illustrated, purely as an example, in Fig. 14a.

An optical transmitter is arranged to produce a flying spot of brightly illuminated light in a fairly wide region where the black line on the surface of the material might be found. The high-speed rotating polygonal mirror shaft, which also carries a commutator, is so arranged that at the moment when the light beam is pointing vertically downwards to the place where the line ought to be, a slot of the commutator surface is just passing under the commutator brush. Thus, it is touching both segments, the one ahead of the slot as well as the one behind it.

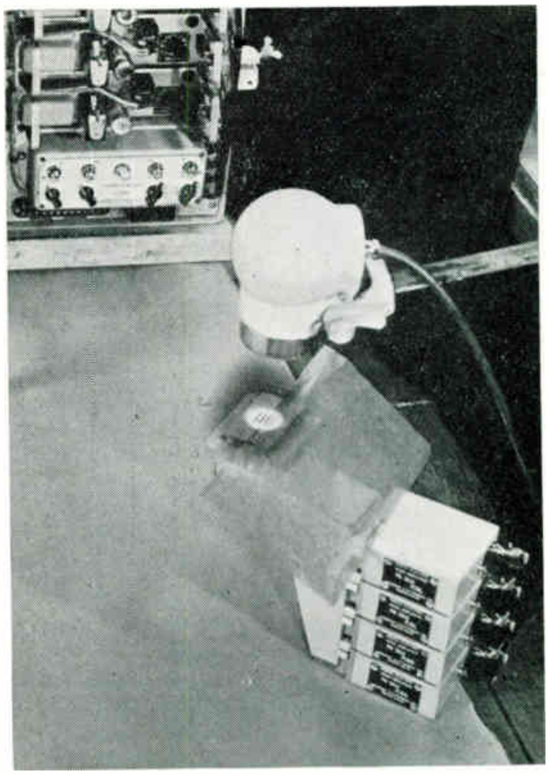


Fig. 13.—Four-aperture optical transducers and associated amplifiers for edge alignment guiders (cf. Fig. 11b).

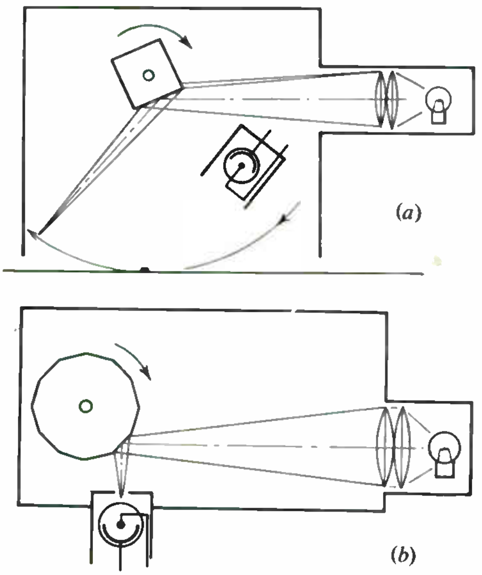


Fig. 14.—(a) Line-follower transducer, (b) rotary pulse generator head transducer.

The electronic amplifier and switching circuit has to be so designed that the line-following correcting mechanism remains mute under this condition—the correction system must only act if the commutator brush touches only one segment alone of the commutator, at the instant when the flying spot appears and thus the photo-electric cell is actually observing the black line upon the surface.

If, now, this happens on a segment in advance of its correct neutral position (Fig. 14a), then the correcting system would move the entire optical system and any machinery attached to it towards the right, until the black line is again exactly vertically under the mirror shaft.

This system can be used to guide an oxy-acetylene flame cutter mounted on pantograph arms or on a slide, and make the cutter follow the pattern on a drawing mounted on an adjacent table.

8.2. *Rotary Pulse Generating Transducers*

An optical system somewhat similar to the above is illustrated in Fig. 14b, with a mirror polygon having many facets. The number of photo-electric pulses is an exact function of the speed of rotation. The pulses obtained per second can be related to peripheral speed of some mechanism coupled to the shaft. There are very many applications of this device, and also further elaborations of the optical systems are possible. They are of use as tachometers and length-measuring systems in conjunction with high-speed production processes.

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ANALOGUE COMPUTERS IN AIRCREW TRAINING APPARATUS*

by

A. E. Cutler, B.Sc. Ph.D.†

A paper presented during the Industrial Electronics Convention held in Oxford in July 1954.

SUMMARY

After discussing the economic advantages of training on simulated equipments, some of the problems solved by the computers in flying trainers, engine trainers and track recording will be described. The relative complications of a full flight simulator computer using digital and analogue methods are considered and the analogue type found to be most suitable. The use of the building brick principle is dealt with and details of utilization, running time and percentage serviceability given. Further applications of analogue methods to training equipments are discussed.

1. Introduction

The complete instruction of aircrew in ground-based trainers has been the goal of aircraft operators and the Services for many years. The earliest attempts, quite naturally, were made with tethered and suspended aircraft, but these methods were soon abandoned in favour of a type of trainer in which the pilot, sitting at a set of controls, was provided with a small, pre-selected number of characteristic effects generated artificially. These trainers were hydraulically or pneumatically operated and instruments were not provided.

When in the late 1920's it became necessary to operate instruments such as compasses, altimeters and rate-of-climb and airspeed indicators in response to the engine throttles and the flying control settings, and to produce some sort of attitude response, the possibility of using computers began to be explored.

Roeder in 1929 formulated in general the problem which a flying training apparatus must solve, indicating the direction of transmission of data through the computer (Fig. 1), but it was not until fifteen years later, after the great stimulus given to electronics during the late war, that the problem was solved.

In the meantime the individual problems of instrumentation, track recording and radio aid simulation were tackled, great improvements being introduced by Adorian and his co-workers in the Company with which the author is associated.

Before the war and during the war years, Edwin Link developed extensively the famous Link series of trainers. These are essentially pneumatically-actuated linkage-type computers, the design being based on a suitable number of control movement/instrument reading relations with a fairly considerable degree of interlacing of the various channels. A new form of trainer based on true mathematical relations, but still pneumatic, was described in 1945.

By this time the electronic flight trainer was approaching a degree of completeness and reliability comparable with the pneumatic types. After several attempts to formulate sections of the overall problem capable of useful solution using electrical computers, notably by Dehmel, Hellings and Winstanly, the Curtiss-Wright Corporation produced in 1945 their famous 400 type trainer, the first trainer to be based throughout on the application of electronic computing methods to the simultaneous solution of the equations of flight. Using 60-c/s rate controlled servos with drag-cup tacho-generators for integration and servo operated contoured potentiometers for function generation and multiplication, the computer translated the pilot's control movements into instrument deflections in "real time".

The logical successor to this, a flight trainer in which the aerodynamic performance of a specific aircraft was matched by the trainer in all respects, was produced, also by Curtiss-Wright, for Pan-American Airways to train

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Stratocruiser crews in 1949. This device was the first true flight simulator, the first device that is, which solved the equations of flight exactly with a computer designed to specific aerodynamic data. To perfect the realism of simulation, all the crew members' stations were laid out in exact facsimile using actual aircraft equipment which had been suitably modified, and the characteristics of most minor services such as lighting, intercomm and electrical supplies were fully reproduced.

The Stratocruiser simulator was an outstanding success, speedily gaining recognition as a device which could replace training time on the actual aircraft. Pan American were soon able to announce that their training costs had been reduced by 60 per cent.

Stimulated by the success of the first simulator, a number of electronic equipment manufacturers in the U.S.A., Great Britain and Canada, many of whom had already acquired considerable experience in the flight training field by being associated with earlier trainers, began work on similar equipments, each introducing variations in basic technique. Generally speaking, the same fundamental principles of operation are used by all, and with the exception of a device planned in the U.S.A., all flight simulators use analogue computers.

In Great Britain, particularly in the civil air lines, the training value of the flight simulator as a flight and engine trainer is fully recognized, and every attempt is being made to extend its scope to cover all aspects of crew training simultaneously. The ultimate, complete simulation of all systems, is now almost within sight, only visual and acceleration effects being absent. It is thought likely that a sufficient degree of visual presentation will ultimately be possible to permit simulated landings in bad visibility, but a complete solution of the acceleration problem, particularly "black-out" effects at high vertical accelerations, does not appear possible.

Another body of opinion, largely in the U.S.A., holds that the considerable extra cost in equipment required to produce an exact likeness of the aircraft is not justified by the extra value of the training produced. A second type of trainer, based on the same principles but far less stringently designed, has therefore been created called the generalized flight trainer, which sells for roughly a third to half of the price of a complete flight simulator.

The generalized flight trainer and the flight simulator, have substantially the same basic flight and engine computers. The flight simulator has added computers to produce simulation of aircraft auxiliary systems, such as cabin pressurization, flying control hydraulic boost and autopilot.

Radio aids simulation, an important part of flying training, has developed in parallel with the flying trainers, and has now reached the stage where, in the simulators now being designed, it will be possible to fly correctly computed courses with all aids at correct points en route over all parts of the globe currently available to British aircraft.

Although these aids are equally applicable to all trainers, it is the great realism of the flight simulator which has made imperative their present accuracy of simulation. In particular, long range direction finding has been provided for many years, but has only recently been computed in such a way as to introduce the effects of earth curvature.

In the light of the pressing needs of the Services for radar, gunnery, and submarine search equipments, considerable development has been made over recent years in the simulation of these, and it can be said that no known tactical equipment at present in Service use is without a suitable simulator.

All flight simulators, with the exception of a recently announced French helicopter simulator,* are without an external view. This, of course, is a serious drawback and detracts more than any other feature from the absolute realism required. Considerable effort is being expended on this problem, and it is hoped that an apparatus will ultimately be produced which is sufficiently inexpensive to permit its use, not only in the field of flight simulation, but also in less complicated trainers, as for instance for cars, or for the periscopic guidance of submarines.

2. The Economics of Flight Training

The economic success of any synthetic aircrew trainer is dependent upon the air time which it saves compared with the cost of a flight simulator and its maintenance. The direct operating cost of modern four engine aircraft, excluding depreciation, is from £100—150 per hour varying with type, while the direct operating cost of a flight simulator is £5 per hour. Corresponding American figures are approximately

* *Flight*, 15th January, 1954.

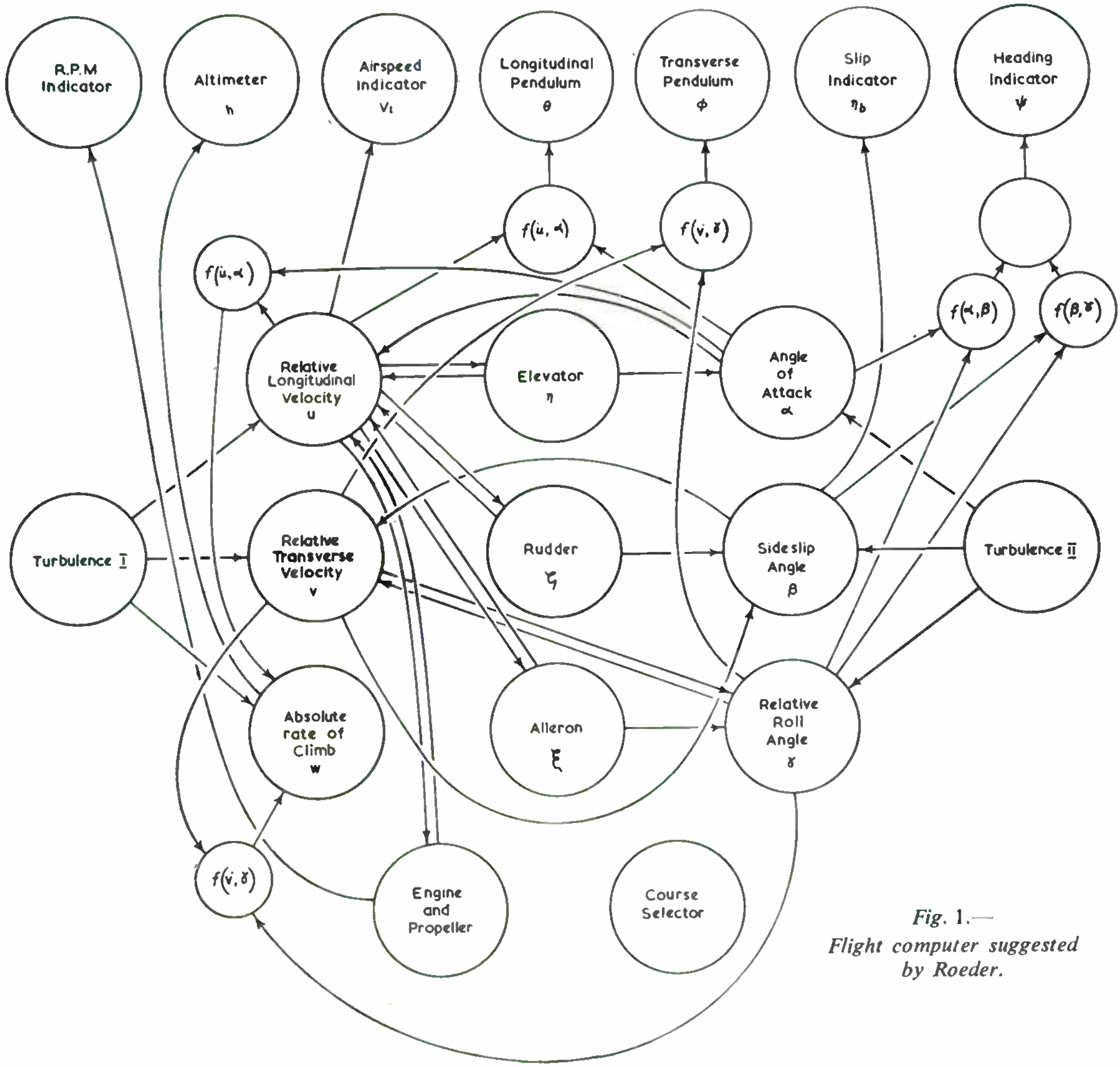

Fig. 1.—Flight computer suggested by Roeder.

400 dollars and 20 dollars per hour respectively. It is clear therefore, that once the principle of electronic crew training is accepted and a flight simulator purchased, even though several hours simulating training may be considered necessary to replace each aircraft flying hour, very considerable saving will result.

Assuming that the first line life of an aircraft is five years, a crew would require, in addition to the type conversion course of 20 hours, approximately ten, 6-hour instrument flight checks (six month checks). Current practice allows the conversion course to be split into approximately five hours flying and thirty simulator hours. This means that eighty flying hours are replaced by five flying hours and ninety simulator hours, giving a total saving per crew between £7,000 and £10,000. If the life of the aircraft is ten years, these figures are almost doubled.

There are several further factors for which no exact price can be set, which improve the position still further. Among these are:—

(*a*) The increased familiarization which may be obtained by using the simulator for far more hours than it replaces in the air.

(*b*) Crew co-ordination is improved because in the simulator it is not necessary to carry an experienced captain in one of the pilot's seats as well as a check pilot, making it possible to train and check two trainee pilots simultaneously.

(*c*) The lack of hazard in simulator training.

(*d*) The fact that pilots are progressively replaced due to termination of service, causes the time spent in conversion training to be more than quoted above. This is particularly important in the military sphere.

(*e*) Loss of revenue on the aircraft allotted to training flights.

(*f*) The possibility of sale of surplus simulator time.

The Services' approach to the problem of flying training has a slightly different character. The majority of Service aircraft are single-engined and on these it is imprudent to attempt emergency conditions, because of the low safety factor afforded by the single engine. The flight simulator can produce these conditions in complete safety, and is therefore of much greater utility for these types.

Such is the training value of simulators for these emergency procedures that current American thought favours a special type of trainer in which none of the standard performance or equipment is simulated, the only computing provided being associated with the generation of emergency conditions. These devices are naturally very much cheaper than the full flight simulator, and are not used in any way to replace flying time, but to supplement such training. Between these two types lies the generalized electronic flying trainer used largely for basic training prior to conversion to advanced aircraft. They are a valuable addition to any flying school.

The simulators in the case of bomber and passenger aircraft are equipped with track recorders which take into account the curvature of the earth and plot to a high degree of accuracy. With complete simulation of all radio and navigation aids, it is possible to fly the whole of a simulated route or mission on instruments. This adds route familiarization to the training which may be carried out on the simulator, extending its use considerably.

3. Problems Solved by the Computer

The principal problems associated with flying trainers are related to:—

(*a*) Solution of the equations of motion.

(*b*) Derivation of engine thrust, etc.

(*c*) Provision of radio facilities.

The practical form for the basic equations of flight of the aircraft may be written:—

Linear:—

$$V_T = u = \frac{X'}{m}$$

$$\dot{v} = \frac{Y'}{m} - rV_T$$

$$\dot{w} = \frac{Z'}{m} + qV_T$$

$$V_X = V_{E-W} = V_T \cos\theta \sin\psi$$

$$V_Y = V_{N-S} = V_T \cos\theta \cos\psi$$

$$V_Z = \frac{\mathrm{d}h}{\mathrm{d}t} = V_T(\sin\theta - \sin\alpha)$$

and

Rotational:—

$$\dot{p} = \frac{L}{A}\,;\ \dot{q} = \frac{M}{B}\,;\ \dot{r} = \frac{N}{C}$$

$$\phi = \int p + (q\sin\phi + r\cos\phi)\tan\theta\,.\,\mathrm{d}t$$

$$\theta = \int (q\cos\phi - r\sin\phi)\,\mathrm{d}t$$

$$\psi = \int (q\sin\phi + r\cos\phi)\sec\theta\,.\,\mathrm{d}t$$

Using conventional symbols. (See Appendix).

These relations have been set out in greater detail in a previous paper.*

These equations are not complicated in form, but the terms X', Y', Z' and L, M, N which they include are complicated expressions including the aerodynamic stability coefficients of the particular aircraft for which the simulator is designed, and their variation with airspeed, Mach number, aero-elastic distortion, and each other. X', Y' and Z' also include resolved

* G. B. Ringham and A. E. Cutler, "Flight simulators," *J. Roy. Aero. Soc.*, 58, March 1954. p. 53.

gravity components. Frequently the graphs of the stability coefficients include more than two variables and are represented in the form of "carpets".

The section of the computer which evaluates the forces and moments is called the aerodynamic computer, and the portion of the computer which translates the forces and couples by double integration into displacements and angles is called the aerobatic computer. The aerodynamic computer must be individually designed to suit the characteristics of the specific aircraft and the form in which the aerodynamic data is presented by the manufacturers of the aircraft.

Computing the forces and moments on the basis of these stability coefficients requires approximately 100 specially contoured, servo-driven potentiometer cards, and fifteen booster amplifiers. The whole of the subsequent flight computing requires approximately half these quantities.

One of the greatest problems in the construction of the flight simulator arises, particularly in new aircraft, from the difficulty in obtaining the flight tested aerodynamic data necessary for accurate simulation of the flying conditions. It is possible, of course, to design the computer using tentative data and to modify it progressively as the information is confirmed. This results in speedy delivery of the flight simulator but is naturally very expensive.

The accuracy of the overall results produced by the computer is in general of the order 2-3 per cent, but in certain cases this is improved to as accurate as ¼ per cent. In order to obtain this accuracy the potentiometer cards must be contoured to ½ per cent or better, and the gain of certain critical systems held to a similar figure, as for example, by the use of amplifiers with as much as 60db of feedback. The accuracy is further supplemented by calibration at critical points.

The total equipment for the solution of the flight equations includes twenty-five computing servomechanisms, twelve of which are integrators, and fifty 4-valve a.c. amplifiers mounted on four 6ft. racks.

Engine performance is almost entirely empirical, and therefore all the relations between variables, say fuel flow/throttle setting, r.p.m./fuel flow, including the intermediate stages where the effects of atmospheric pressure, air speed and air temperature are utilized, are non-analytic in form and require contoured potentiometer cards. Each jet engine requires approximately six servos and twelve amplifiers of several different types, the associated fuel system requiring a further six servos. A propeller-turbine engine computer is approximately twice as complicated.

By contrast with the engine systems the equipments required to simulate radio facilities are completely analytic in operation, i.e. their operation rests solely on the processes of addition, subtraction, multiplication, integration and resolution. The complexity of this computing is determined largely by the number of individual aids required to be simulated. The total number for civil use being two track recorders, large and small scale, both requiring corrections for convergence of lines of longitude, ADF systems, with three radio beacons for long range D.F. and two radio ranges, ILS system with localizers and marker beacons, DME, v.h.f. and h.f. communications and intercomm. Stations have rapidly changeable positions and identifying transmissions to simulate operations in all parts of the world. The associated position, range and bearing computers include twenty servos, and approximately seventy amplifiers.

When the auxiliary systems are included for the simulation of hydraulics, electrics, autopilot, undercarriage system, zero reader, Gyro/Magnetic compass, etc., the total equipment becomes approximately one hundred and seventy servo-type devices including seven hundred contoured potentiometers, and over three hundred electronic units, using approximately a thousand valves. The power requirement is about 10 kW. This equipment deals only with those aspects of operation which are basically computable in form. In a complete flight simulator a very considerable number of circuits must be added to make the fire warning, lighting, electrical and other auxiliary systems with their multiplicity of switches, fuses, circuit breakers, and indicator lights, operate realistically.

4. Advantages of Analogue Computers in Training Equipment

There are two types of equipment which are known by the name of flight simulator; the type with which we are already treating, and the mathematical machine which is used in testing stability, performance, etc., by the aircraft manufacturers. It has been suggested that these two functions could be combined if the computer associated with the flight simulator could be made of sufficiently flexible form to permit its use as a development tool. Unfortunately the analogue method of simulation requiring contoured potentiometer cards for all functions, is not particularly flexible, although it may be improved with some slight loss of accuracy by the use of multi-tapped linear potentiometers.

The digital method of computing does not suffer from any similar limitations, it being only necessary to modify the stored functions and orders to produce a complete change of aircraft characteristics.

The question does, therefore, arise whether it is possible to develop a computer of digital form as a development tool and later to associate it with a flight deck to become an aircrew trainer; and further whether it is possible to develop a single computer associated with two or more flight decks for different aircraft, so that by change of programme it is possible to activate one or another. The latter cannot be considered very likely as the computer manufacture takes only a fraction of the total development and manufacturing costs of a flight simulator, and it would therefore be difficult to justify the enforced idleness of one fuselage on the basis of such economy. The degree to which the former is possible is influenced very largely by the degree of approximation which is permitted in the computer. When the computer is used as a research tool it might be necessary to require it to handle thirty or more digit numbers, while for the flight computer ten digits appear adequate. Further, relations used at the design stage are to some extent idealised into analytical functions, but when the computer is associated with the aircrew trainer it is required to solve the flight and engine equations for the aircraft which it simulates, and therefore it must accommodate means for utilising the many non-analytical functions which appear in measured performance.

The difference in principle between the two methods of operating the computer would make it impossible for both aspects to be permitted without a certain amount of reorganisation.

The most serious limitation on the use of digital computers for flying trainers arises from the considerable number of computing operations required to solve the equations of operation of the various sections. It would be relatively simple to design a computer which would complete all the arithmetical operations, if necessary, in less than 1/10th sec., but a very considerable number of empirical functions are used in the system, and must be stored in the computer. There are approximately one hundred such functions, thirty of which are used in the engine computations, and therefore appear in the cycle once for each engine. The selection of a suitably inexpensive store to retain them has a considerable influence on the choice of computing speed.

In a digital computer, the time required for gaining access to these functions in store and the use of appropriate interpolation formulae is a large fraction of the desired repeat time for the full cycle of operations. For example, if we consider a computer in which the number of values stored for each non-analytical function is 32, dividing it into 31 equal parts, it is possible in general to obtain accuracy to approximately $\frac{1}{2}$ per cent by interpolating linearly the two adjacent stored values. This would require a permanent store, say of drum type, with capacity for one hundred groups of 32 ten-digit words. As the shortest possible access time is required, the highest speed available from conventional high-speed, magnetic drums would be utilized, making each digit approximately three microseconds long. If the functions are stored on the drum in locations which permit immediate access to the function when required, the programme being written on the same drum (optimum programming), the access time is reduced to one millisecond, the time required for the 32 words to pass the reading head.

In addition to the empirical functions, approximately fifteen trigonometrical functions which are also required would be most rapidly accessible in table form on the drum.

The complete computing cycle necessary for a 4-jet, high-speed aircraft including flight, engines, radio aids, cabin air and atmospheric conditions computing has been examined on the basis of the above figures.

This cycle is $\frac{1}{2}$ second using conventional multipliers, and can be reduced to roughly $\frac{1}{3}$ second by using the more expensive high-speed multipliers. Slightly more than half of the length of the computing cycle is spent looking up the tables and functions. The times taken up by interpolations are $\frac{1}{4}$ and $\frac{1}{3}$ seconds respectively. If the machine is suitably designed it would of course be possible to arrange that all the arithmetical operations are carried out simultaneously with looking up the functions, but even so the cycling time cannot be reduced below the time for the interpolations. It is clear therefore that, since 0.1 second is considered to be the most satisfactory sampling time for the digital to analogue output converters, in this application some further time reduction is required. The substantial equality of the complete cycle of arithmetical operations and interpolations means that, for a substantial reduction in the cycling time of the computer, both the times must be reduced simultaneously.

There are three possible approaches to the problem:—

(1) If the digit length is reduced to one microsecond, the computer will complete the operations in $\frac{1}{3}$ of the time.

(2) Doubling up on the arithmetic unit and increasing the store capacity will permit a double order system to be used with half the cycling time, and so on.

(3) Suitable approximations could be made to reduce both the number of arithmetic operations and the number of empirical functions.

Increasing the speed of the computer will increase the cost of components considerably, since the magnetic store would be required to pass its data into additional large capacity high-speed stores prior to utilisation in the computer, and the nickel wire delay lines which were suitable for the previous frequency would have to be replaced by mercury delay lines or c.r.t.-type, high-speed stores. The cost is also increased substantially if we consider multiplication of the arithmetic units. The last alternative offers possibly the most fruitful field for study.

Many of the functions required could be approximated with reasonable accuracy by using approximating quadratics or cubics, and a further group, being linear over the greater part of the march of their functions, need only have the values corresponding to the non-linear part in the permanent store.

In the case of functions where the curvature is not very great it may be possible to obtain satisfactory approximations using only eight weighted points. These and other simplifications of the stored information could reduce the access time for non-analytic functions to a fairly considerable extent, but only at the expense of an increase in the number of arithmetic operations. As both arithmetic operations and looking up must be simultaneously reduced, the method cannot be used unless it is associated with a considerable reduction in the number of minor effects which are taken into account, or by using a special programme which allows different arithmetic operations to be simultaneously carried out in the arithmetic unit. This would require the inclusion of a dual transfer system, again with a further substantial increase in price. Some operations, e.g. computing of gross weight, need only be computed once for every ten cycles of flight computing, and this could be built into the orders to reduce the computing time.

The present realism of flight simulators would not permit such approximations on the score of accuracy, but as approximation is a natural feature of the generalised flight trainer, the digital computer has obvious potentialities in this particular respect.

The one feature which reduces the value of a digital computer in connection with a "real time" problem is the need for input and output converters (analogue to digital, digital to analogue). It is estimated that the cost of a suitable number of photo-electric input converters (fifteen) plus ten servo and ninety meter-type output converters would increase the computer cost by more than half as much again of the cost of the basic computer, and this must be taken into account in evaluating the digital computer economically as analogue input devices are extremely simple, and in general the output units are the computing servos themselves. It is estimated that the total cost of the computer and converters, excluding the obtaining of technical information and the compiling of the programme would be substantially the same as the equivalent analogue computer. No difficulty is experienced in the analogue computer due to sampling time phenomena, although the basic accuracy is a little lower.

From the servicing point of view, the value of being able to consult on a pointer-type indicator the value of the variable represented by each computing servo must not be underestimated, as it tends considerably to reduce the "black box" bogey which would be found, initially at least, in connection with the digital computer.

5. Survey of Analogue Computing Components

There are two basic types of analogue processes:

(1) Processes relating to perfect equipments which are made up exclusively of components performing analytical processes, e.g. addition, subtraction, multiplication, division, integration, differentiation, resolution and function generation.

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(2) Processes representing the imperfections of equipment, such as limiting, backlash, and non-linearity.

5.1. *Processes relating to perfect equipments*

Addition and subtraction are most readily performed by the method of series summation, but this requires that each series signal shall be isolated from earth and tends to become difficult in a complicated computer. For this application the parallel method is preferred, the potentials being proportionally summed by applying them through selected resistors to a common, high impedance point. If the voltages are e_1, e_2, e_3 etc., and the conductances g_1, g_2, g_3, etc., assuming negligible source impedances, the voltage of the common point is given by:—

$$\frac{g_1 e_1 + g_2 e_2 + g_3 e_3 \ldots\ldots\ldots\ldots}{g_1 + g_2 + g_3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots}$$

If, as in the case of servo input or servo or feed back amplifier input, the scale of the resulting voltage is not important, these resistors become proportional to the individual degrees of relative attenuation required.

Subtraction is obtained by reversal of polarity or phase of the negative quantities.

The most accurate and stable method of multiplication is by the use of servo-driven potentiometers fed with the appropriate signal and positioned in accordance with the multiplier. This is also true for function generation, the potentiometer in this case being wound on a strip of material, the width of which is contoured in accordance with the slope of the desired function, appropriate corrections being made for loading. This type of contoured card potentiometer may be fed with a reference signal for function generation, or a varying signal voltage for simultaneous function generation and multiplication.

Contouring is not the only available method of shaping functions, although it is the most accurate. There are several methods of connection to multi-tapped potentiometers, which will yield straight line approximations of functions.

The above methods require the use of a servo mechanism, or similar device to control the potentiometer brushes.

A less complex, though less accurate system may be made which is based on the pentode multiplier and the diode function generator, and these methods are in fact used in many analogue computers for short time operation.

There are a number of circuits capable of producing specific functions over restricted ranges of operation, usually based on valve characteristics, but these are a little difficult to assimilate into a comprehensive computer.

Integration may be carried out with good accuracy by a number of methods. When the input is d.c. the charging capacitor, and its development the "Miller" integrator are capable, with careful selection of components, of good accuracy and reasonable stability.

Mechanical integrators may be based on simple motor characteristics i.e. using the fact that the d.c. motor rotates at a speed proportional to the applied voltage over a wide range of speeds, or by using a servo-type mechanism in which a d.c. generator or a.c. drag-cup tachometer is used to provide the rate feed-back voltage.

In computers requiring the greatest possible accuracy, servo-operated "potter's wheel" integrators are used, but the cost of a suitable unit is prohibitive for normal operation.

Differentiation is a simple process in d.c. analogue computers requiring only the standard R-C network, but in a.c. computers it is very difficult to produce accurately. The output of a drag-cup generator coupled to a stiff servo, slaved to the variable, will give a function which is approximate to the differential with respect to time, but is smoothed by the response of the servo and contains residual and distortion components due to the shortcomings of the generator.

Fortunately in true analogue systems differentiation is very rare and in most cases where it does occur the equation may be integrated through to eliminate it and solved in the integrated form.

Resolution in the a.c. case is obtained by applying the signals to be resolved through amplifiers to the input coils of a resolver, the output of which is connected in a servomechanism for nulling operation; the resolver shaft then indicates the direction of the resultant and the voltage on a coil at right angles to the nulling coil is proportional to the resultant.

All other proceses such as division, or the extraction of roots may be carried out by rearranging the equation as a multiplication, and using a servo to obtain a solution, or by the use of suitably contoured servo-positioned potentiometers.

5.2. *Processes representing the imperfections of equipment*

These processes are a little difficult to classify since they depend exclusively on the machine design. The most important mechanical imperfection is back-lash, and in a mechanical analogue the identical principle may be used, in fact this is true of all mechanical imperfections.

If an electrical analogue is required however, a simple alternative can usually be found.

Limiting a direct voltage which represents a variable can easily be achieved using a catching diode or any of the conventional limiters. The limiting of an a.c. waveform requires a little more care.

Non-linearity is generated as for empirical functions, and a number of trigger circuits have been used to simulate back-lash.

6. Development and Production

As with all large computing machines, considerable effort has been expended in the field of flight training devices to reduce the electronic units used in the computing to a minimum number of types, and to build the units on chassis of the same physical size. For instance, line amplifiers, buffer amplifiers, servo amplifiers, resolving amplifiers, instrument amplifiers, switching amplifiers, etc., with the range of from two to six valves, and made to fit a standard chassis, and the racks on which the equipment is mounted have standard fixings and power supplies, so the units may be inserted as required.

In order that this technique should be as effective as possible it is desirable that the number of different standard units should be kept to a minimum, with the obvious result that an amplifier, say a line amplifier is made far too versatile for most purposes to ensure that it will meet any normal requirement however stringent. In a typical case, the line amplifier has an internal gain of over 1,000 and is so designed that over a range of input impedances from 0-5 megohms with shunt capacitances up to 0.002 microfarads and load resistance from 250 ohms-1 megohm, the overall gain may be adjusted without instability using external feedback to any value greater than 0.5. This amplifier can obviously cope with any normal requirement, but is considerably more complicated than is required for say phase inversion, or when used as an isolating amplifier. For these purposes, it is therefore supplemented by a smaller amplifier the performance of which is more moderate (mounted two per chassis).

Even this amplifier is not the simplest which could be used in a number of applications, but the process of standardization quickly falls down if there are too many standards. If flight simulators are ever ordered in substantial quantities, as might occur for instance in wartime, this position would need to be revised. At the moment however, the engineers responsible for a flight simulator are required to design the computer within a few months of receiving the specific information on which the design must be based, and they therefore must have available a range of units which they can insert into the circuit with the certainty that they will obtain satisfactory results. An advantage of standardization from the operators point of view is the reduction in the number of spares which he must hold.

No long production runs of flight simulators have yet been made in this country, so that the whole concept of simulator design must be based on the principle of selling the prototype. This is further emphasised by the desirability of completing the simulator for delivery along with production aircraft and if possible a few months before. The minimum time for design, manufacture and installation of a large flight simulator is eighteen months to two years, with possible reduction of a few months for a smaller type.

7. Performance and Serviceability

The flight simulator is such an extremely good financial proposition that the operators make every effort to obtain the highest possible utilization. Both Pan American Airways and B.O.A.C. have used simulators over extended periods for between sixteen and twenty hours/day on the basis of a five-day week, giving utilization of over 3,000 hours/year. That this type of utilization is possible on a prototype speaks well for the reliability of these equipments. Considerable maintenance is required to keep these units in 100 per cent working order, and this is carried out by standby maintenance crews during the day-time, with the bulk of the work being carried out overnight and at weekends.

Pan American have quoted a figure of 0.1 per cent as their loss of training time on their Stratocruiser simulator, the B.O.A.C. figure, which is felt to be more realistic, is 2 per cent. That the B.O.A.C. figure was obtained during the first six months of operation speaks as highly for their maintenance organization as for the simulator itself.

8. Conclusion

The use of analogue methods in training equipments is not restricted to devices for air-crew training, but can be applied quite generally to all "real time" problems. It is inevitable that the modern military missile control will be far too expensive to practise in the conventional way, and simulators for this type of missile capable of indicating the path which it takes and generating suitable radar and other responses will be very desirable. This also applies to marine exercises, particularly with radar control, and the interception of enemy aircraft.

The use of short period, usually d.c. analogue computers for examination of chemical plant control and heavy industrial servo control problems is well known, although the extent to which they are applied seems far less than could be expected. For most of the problems they work on a shortened time scale.

Electro-mechanical analogue computers, which can maintain accuracy comparable with the d.c. systems over very much longer periods, must obviously be developed to permit "real time" solutions to be obtained, thereby making possible far more realistic analyses of the systems.

In the field of flying trainers, only two principal problems remain substantially unsolved, provision of visual presentation and simulated acceleration forces, and both of these are outside the field of pure computing. It is possible that satisfactory approximate representations even of these will be available within the next few years.

9. Acknowledgments

The author is indebted to the directors of Redifon Limited for permission to publish this paper and would like to thank Mr. R. A. Marvin for his valuable advice on digital computers, and all other members of the organisation, who, directly or indirectly, have made contributions to it.

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11. Appendix: Notation

m,	aircraft mass.
x, y, z,	aircraft principal axes (forward, sideways and downwards).
A, B, C,	moments of inertia about the aircraft principal axes.
X', Y', Z',	forces along the aircraft principal axes including gravitational effects.
L, M, N,	moments about the aircraft principal axes.
α,	angle of incidence or attack.
u, v, w,	velocity components along the aircraft principal axes.
V_T	true airspeed.
p, q, r,	angular velocity components about the aircraft principal axes.
ϕ, θ, ψ,	aircraft roll, pitch and heading angles.
V_X, V_Y, V_Z,	velocities along the E-W, N-S and vertical directions.
h,	altitude above sea level.

INDUSTRIAL RADIOGRAPHY AND THE LINEAR ACCELERATOR*

by

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A paper presented during the Industrial Electronics Convention held in Oxford in July 1954

SUMMARY

To obtain maximum sensitivity of flaw detection in the radiographic examination of thick specimens encountered in heavy engineering, several aspects of the X-ray equipment must be considered. The most important factors are the energy of the radiation and the size of the source, while in order to obtain reasonably short exposure times a large X-ray output is required.

The paper shows that, due to the complex process involved, the absorption of radiation at first decreases as energy is increased, but reaches a minimum and thereafter rises to some asymptotic value. The energy for minimum absorption depends on the absorbing substance, but for the materials used in engineering it will be some few MeV. Since the inherent unsharpness of the photographic image increases with energy, it can be shown that optimum results may be expected with equipment operating at an energy of the order of 4 MeV.

The development of the travelling wave linear accelerator, which is briefly described, has made possible compact equipments to operate at such an energy, and the results of investigations into the suitability of such equipments for industrial radiography are given.

1. Introduction

The use of radiography in industry is concerned largely with the examination of articles for flaws or irregularities. Various thicknesses and densities of specimen are encountered and a variety of techniques is employed to obtain optimum results for the various conditions. Many cases can be dealt with quite adequately by orthodox X-ray equipment operating at voltages up to say 250 kV and such techniques are a routine procedure in most engineering concerns. For thicker and heavier specimens, however, more penetrating radiation is required, and in many cases the gamma-radiation from radium or radio-isotopes, such as cobalt 60 or iridium 192, has been used. The energy of such radiation is in the range of 1–2 MeV but the relatively low intensities available from such sources necessitate long exposures. It is the purpose of this paper to examine how optimum results can be obtained for specimens of large thickness and to indicate the suitability of a particular form of X-ray generator for this purpose. It will be necessary to examine the variation of absorption of X-rays with energy since clearly minimum absorption is desirable in dealing with maximum thickness. Further consideration has to be given to the quality of the photographic image and here such factors as size of source, source to image distance, and energy of radiation are important. Finally, high intensity is required and this with the desirability for compact equipment can be expected to influence the design. Such considerations lead to the conclusion that a 4-MeV linear accelerator would form a very suitable generator for radiography of the thickest specimens and that adequate flaw detection could be obtained for steel or iron of thickness up to say 13 in while the X-ray output is such that relatively short exposures could be used.

2. Absorption of X-rays

2.1. *Monochromatic Beam Neglecting Secondary Radiation*

The process of absorption of X-rays in matter is complex and in practical radiography there are many factors to be considered. It is profitable, however, to consider the ideal case of the absorption of a beam of monochromatic, that is, monoenergetic radiation and to neglect the effect of secondary radiation scattered in the forward direction. This problem has been considered in

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detail by Heitler[1] and it is sufficient here to summarize the main effects.

Certain processes by which absorption or scattering may occur can be neglected as not being of importance in the energy range with which we are concerned. Thus, selective absorption due to the excitation of atoms to discrete energy levels is disregarded as it is only of importance for low energy radiation while certain other processes are considered of negligible importance or as requiring extremely high energy. There are three main processes, each of which will cause the intensity of the beam to decrease exponentially with the thickness of material traversed, and for each process an absorption coefficient (μ) may be defined. Total absorption of the beam will be determined by all three processes and there will be a resultant absorption coefficient (μ_{tot}) which is the sum of the individual coefficients. The intensity of a beam having traversed a distance, x, will then be given by :—

$$I = I_0.\exp.(-\mu_{tot}\, x)$$

where I_0 is the initial intensity.

The three processes involved are as follows :—

(*a*) *The photo-electric effect*

In this process quanta of radiation interact with the bound electrons of the absorbing material. Energy is absorbed and given to a photoelectron which is emitted at some angle to the direction of the incident quantum. As the energy of incident radiation is increased so is the energy of the photoelectrons and the direction of emission approaches nearer to that of the incident radiation. The absorption coefficient due to this process, μ_{phot}, decreases rapidly as the energy of the radiation is increased and increases rapidly for increase in the atomic number of the absorbing material.

(*b*) *Compton scattering by free electrons*

In this case energy is lost from the beam by the scattering of radiation by free electrons and it should be noted that since the energies with which we are concerned are in general high compared with the ionization energy all electrons can be considered as free. The coefficient, μ_{Compt}. varies with energy and atomic number in the same direction as does that for the photo-electric effect, but in each case more slowly.

(*c*) *The creation of pairs of positive and negative electrons*

The third process by which the intensity of a beam may be reduced occurs when the energy of the radiation is greater than twice the rest energy of an electron, and in this case a quantum of radiation can, in the field of the nucleus, interact to produce a pair of positive and negative electrons. Energy in excess of the rest energies of the particles is carried off by the particles in the form of kinetic energy. The absorption coefficient, μ_{pair}, whilst showing an increase with atomic number as did the previous coefficients, shows a marked difference in that it increases to an asymptotic value with increasing energy and is, of course, zero for energies below the critical value equal to twice the rest energy of an electron.

The three processes outlined above are not, for any given material, equally important at a particular energy and it is possible to regard one or other process as being the predominant effect in certain ranges of energy. For comparatively heavy materials and quantum energies of a few MeV the main effect is Compton scattering. For this effect the absorption co-

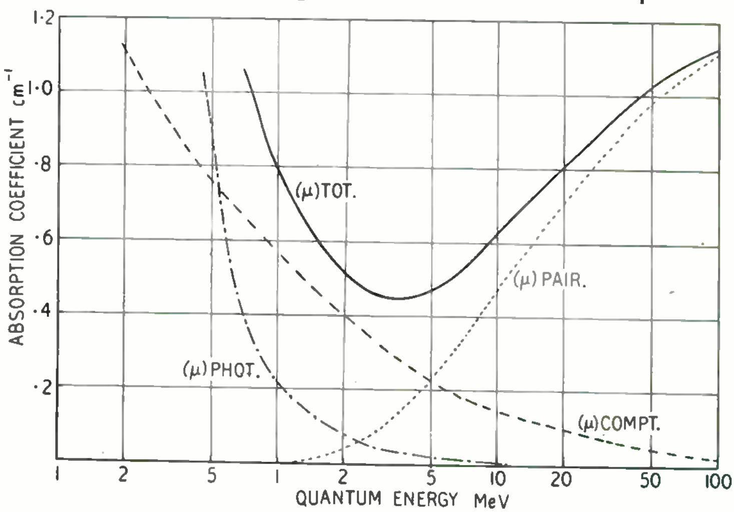

Fig. 1.—Theoretical absorption of monochromatic radiation by lead.
μ_{phot}, *absorption due to photo-electric effect.*
$\mu_{Compt.}$, *absorption due to Compton scattering.*
μ_{pair}, *absorption due to pair production.*
$\mu_{tot.}$, *total absorption coefficient.*

efficient varies linearly with the atomic number, Z, of the absorbing material being in fact proportional to NZ, the total number of electrons per cm^3. Further, since Z is roughly proportional to the atomic weight, μ is almost proportional to the density of the material and a mass absorption coefficient can be defined and this will be almost constant from one material to another. It should be emphasized that such is not the case when the other processes of absorption become important since for these the variation with Z is more complex.

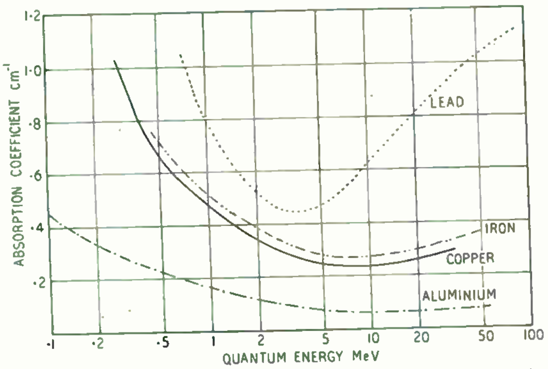

Fig. 2.—Total absorption coefficients for various materials. (Theoretical values for monochromatic radiation.)

In Fig. 1 the variation with energy of the individual and total absorption coefficients is shown for lead, while in Fig. 2 the same variation for the total absorption is shown for a variety of materials. In each case the total coefficient shows a rapid decrease for increasing energy, proceeds to a more or less broad minimum and finally increases to some asymptotic value. Both the width and value of the minimum along with the asymptotic value for very high energy are characteristic of the particular material.

2.2. *Practical Case. Effect of Spectra lDistribution and Secondary Radiation*

In practical radiography there are a number of effects which have so far not been considered. First, the X-ray beam will not be well collimated and the effects of secondary radiation may be expected to become important. In the absorption of a wide beam some of the secondary radiation from the Compton scattering will be in the forward direction. Further, both photoelectrons and pairs may have appreciable energy and these will produce further secondary radiation some of which will be in the forward direction. All such radiation will be of lower energy than the quanta of the primary beam which has led to its production, but, nevertheless, it can be seen that even in the case of a monochromatic incident beam the emergent radiation will have all energies from that of the primary beam down to zero. It is also clear that the effect of the secondary radiation is to increase the intensity of the emergent radiation to a value higher than that expected from the theoretical absorption coefficients given above.

Although monochromatic radiation may be obtained from radio-active sources the X-rays produced from the bombardment of a thick target even by a stream of monoenergetic electrons has a continuous spectral distribution. The exact calculation of such a spectrum is a matter of considerable complexity and involves very laborious numerical work.[2] The production of low energy quanta is favoured and, of course, no radiation can be produced with energy higher than that of the incident electrons. It can be shown, therefore, that if the absorption of radiation by the target itself is neglected, the spectrum would be of the form shown in Fig. 3, that is, the intensity would continuously fall with increase of quantum energy reaching zero at a value equal to that of the incident electrons. An allowance can be made for the self-filtering action of the target and when this is done the intensity for low energies is considerably reduced. In fact, the modified distribution also shown in Fig. 3 is obtained and it is now noted that the spectrum has a peak at some intermediate energy. The value at which this peak occurs will depend on the thickness of the target, moving to higher energy values for thicker targets.

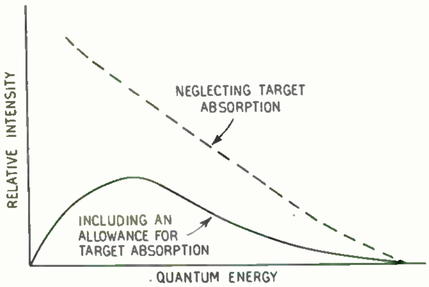

Fig. 3.—Spectral distribution of radiation from a thick target.

When, as in certain forms of X-ray generator, e.g., resonant transformer equipments, the electron beam is not monoenergetic but has a wide energy distribution the X-ray spectrum is further modified and will show an even greater amount of low energy radiation.

The absorption of such continuous spectral distributions is not, of course, quite so simple as that for the monochromatic radiation as described in Section 2.1. If, however, we consider first a distribution whose maximum energy does not exceed that which would give minimum absorption the general form of the process can readily be seen. Since low energy radiation will be more easily absorbed than that of higher energy there will, if we neglect secondary radiation, be a change towards higher energy in the spectral distribution of the emergent radiation as the thickness of the absorbing material is increased. For very large thicknesses only the highest energy radiation will penetrate and thus the energy of the emergent radiation will approximate to that of highest energy electrons producing the primary X-rays. It is thus clear that the absorption cannot be represented by a constant absorption coefficient, but requires one which decreases as the thickness of the absorbing material increases limiting at the value which would have been obtained for the highest energy component of the original radiation.

It is interesting to note that under the same conditions if the original spectral distribution continues to energies higher than that for minimum absorption these will also be preferentially absorbed. The effect will then be that the absorption coefficient will show the same gradual reduction, but the limiting value will be that for minimum absorption.

The effect of secondary radiation which must be considered in practice is that even for large thicknesses of material there is always an appreciable amount of relatively low energy emergent radiation. In consequence, although the absorption coefficient will be reduced by increased thickness of absorbing material it will rapidly reach a limiting value.

Although the processes outlined above are somewhat complex the situation for practical purposes can be relatively simple and as one criterion for assessing the merits of a particular equipment an effective absorption coefficient for thick specimens can be determined. It is sometimes found convenient to give this same information in alternative form by specifying the Half Value Layer (H.V.L.), that is the thickness of absorbing material which reduces the intensity by a factor of 2. It is clear that this quantity is given by $1/\mu . \log_e 2$, i.e., $\sim 0{\cdot}69/\mu$.

3. Production of X-rays, the Effect of Electron Energy

3.1. *Efficiency of the Process*

When a beam of high energy electrons falls upon a target there are two processes involved. Energy may be transferred directly to an atom causing ionization or excitation, this being a process of inelastic collision and the energy appears as heat in the target. Further, the particle may undergo deflection or " braking " in the field of an atom with consequent emission of radiation (" bremsstrahlung ") and it is this process which produces the desired beam of X-rays. It can be shown[1] that for conditions likely to be met in the production of high energy radiation the collision loss per unit track length varies linearly with the atomic number of the target material, Z, and logarithmically with the electron energy. The radiation loss on the other hand varies as Z^2 and directly with electron energy. It is clear, therefore, that good efficiency of X-ray production calls for high electron energy and targets of heavy material that is of high atomic number. A somewhat approximate estimate of this efficiency, that is the percentage of the electron beam power which appears as radiation, can be made (see Appendix) and typical values are given in Table 1 for a variety of target materials and electron energies.. It should be noted that this efficiency takes into account energy radiated in all directions and not only that in useful directions. When, however, the form of the X-ray beam is considered it will be seen that the desirability of a heavy target and high electron energy is confirmed.

Table 1

The Efficiency of X-ray Production for Various Target Materials and Electron Energies

Target material	Electron energy % 2 MeV	4 MeV	8 MeV	20 Me V
Aluminium	1.1	2.2	4.5	11
Copper ..	2.6	5.1	10	22
Gold ..	7.3	13.5	24	43

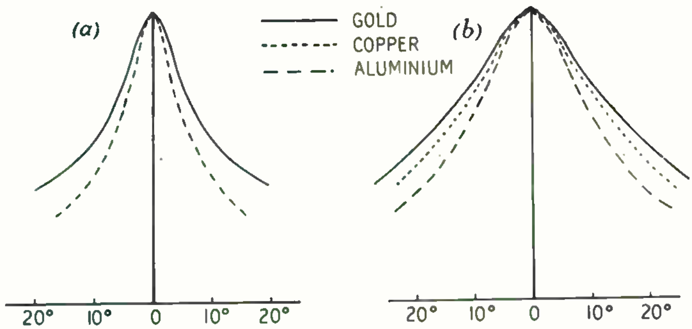

Fig. 4.—Intensity distribution of X-ray beam from various thick targets. (Intensity against angle with respect to forward direction.)
(a) For 8-MeV electrons *(b) For 4-MeV electrons*

3.2. *Form of the X-ray Beam*

X-rays produced at high energy are emitted predominantly in the forward direction, that is, in the direction in which the electron beam is travelling. This effect becomes more pronounced the higher the energy and for this reason it is usual to use transmission targets whose thickness is greater than the electron range rather than the reflection targets used at lower energies. The width of the X-ray beam, measured as say the angle between directions of intensity of half the forward or maximum value, varies inversely as the square root of the electron energy. This beam width is also a function of the target material, becoming wider for the heavier materials. Figs. 4a and 4b show the form of beam being measured for a variety of targets for electron energies of 8 MeV and 4 MeV respectively, while for lower energy similar curves have been given by Buechner, Van de Graaff *et al.*[3]

Although as stated in Section 3.1 the total quantity of X-rays produced is greater the heavier the target material, the broadening of the beam with target density leads to the rather unexpected result that the X-ray intensity in the forward direction is to a first approximation independent of the target material. Since, however, broad beams are usually desirable to give good coverage a heavy target material is still required.

In addition to a variation of intensity with angle there is also a variation of energy and radiation in the forward direction has the highest energy. This effect, however, is far less important than the intensity distribution.

3.3. *Intensity in the Forward Direction*

For practical purposes the important criterion of X-ray production is the intensity of X-rays in the forward direction for unit electron beam current and the variation of this parameter with electron energy. Buechner, Van de Graaff *et al*[3] have given values for energies up to 2 MeV and measurements have now been made in the neighbourhood of 4 MeV and 8 MeV. These later figures show that the previous measurements may be extrapolated to higher energy and the results are shown in Fig. 5.

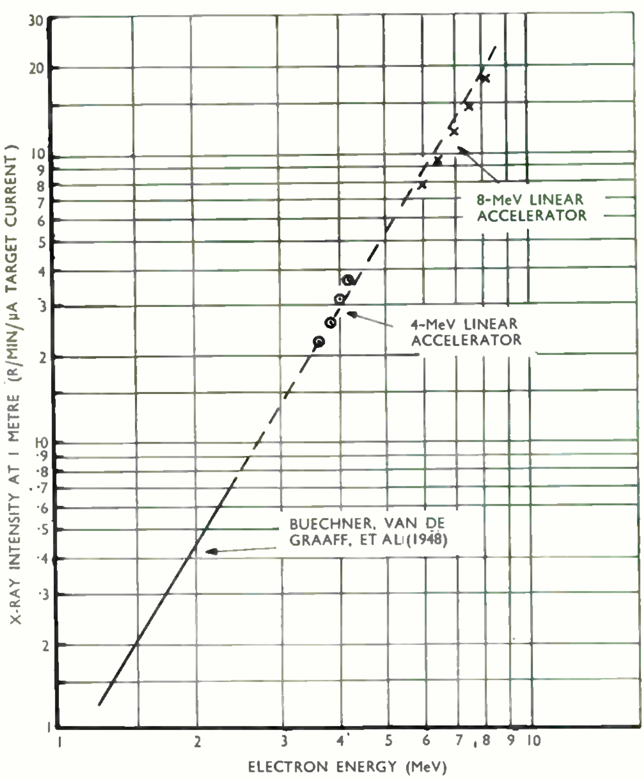

Fig. 5.—The relation between X-ray output and electron current as a function of energy. Intensity is measured in the forward direction and a thick gold target is used.
(Illustration blocks for Figs. 5 and 9 by courtesy of Metropolitan-Vickers Electrical Co. Ltd.)

4. Quality of the Radiograph

4.1. *Contrast and Latitude*

It is clear that in order to obtain maximum differentiation between different thicknesses of material it would be desirable that high contrast should be obtained ; it is equally clear that such a contrast would limit the range of over-all thickness of specimen which could be treated in one radiograph. Thus, these parameters cannot be optimized by the same conditions. They are, moreover, a function of the film and intensifying screens and a consideration of this is beyond the scope of the paper. They are, however, also affected by the energy of the radiation in that this determines the absorption coefficient. The limits which may be set will obviously depend on the actual purpose of the radiograph, but it can be said that an 8-MeV equipment can produce on a single film, a useful radiograph of a steel specimen whose thickness varies by as much as 4·5 cm while the figure for 500 kV equipment would be about 1·8 cm. In general, high energy gives greater latitude but lower contrast.

4.2. *Effect of Source Size and Film to Target Distance*

The technique of radiography is that of shadow casting and ideally, therefore, a point source is required. The effect of a finite source size is to cause any sharp change of density which would occur in the ideal radiograph to become diffuse. This effect increases with source size and, of course, sets a limit to the smallest detail which can be detected. The effect can be reduced by increasing the target to film distance since it is the angle subtended by the source which is the important parameter but this reduces the intensity of the incident radiation in accordance with the inverse square law and in many cases cannot be tolerated because of increased exposure time. The assessment of any equipment must, therefore, consider source size, and film distance in conjunction with equipment output.

4.3. *Effect of Energy on Sharpness of Image*

All processes of radiation absorption whether in the specimen or in the photographic film result in the production of secondary electrons and these after multiple scattering will have more or less random direction. Further, because of the greater absorption of electrons as compared with quanta of high energy radiation, particularly when the electron is reaching the end of its range, it is the electrons which are more likely to affect the grains of the photographic film. It is for this reason that intensifying screens are used. Thus a thin layer of metal (usually lead foil) pressed in intimate contact with the film by absorbing X-rays produces secondary electrons and gives an enhanced effect upon the film. Whilst for low energy radiation only those electrons produced at the common face of screen and film reach the film, the case of high energy radiation is somewhat different. Now electrons which are produced at some depth in the screen may have sufficient energy to reach the film and since they will have a random distribution of direction there will be a diffusing of the image. The effect although obviously depending on the particular film and screens used will increase with the energy of the primary radiation. It might be thought that the effect could be eliminated with some sacrifice in speed if screens were not used ; in fact, however, the specimen itself produces secondary electrons and the effect would still be present. Indeed, since these secondaries would now have to travel through some distance to reach the film, probably in air, a greater spread on the film might be expected. Normally, when screens are used the secondary electrons from the specimen are absorbed in the screen and do not reach the film. For high energy radiation it is desirable that the screen should be of dense material—it is then effective in absorbing electrons and only those produced at a short distance from the film are able to reach the film. Commonly lead of a few thousandths of an inch thickness is used for the screen in front of the film whilst the back screen becomes less critical for the higher energies since the number of back scattered electrons is relatively small. Nevertheless, a back screen is still useful as in addition to giving some increase in speed it shields the film from any low energy radiation scattered from the surroundings.

It can be seen that the qualitative effect of the process outlined above is that even for radiation produced at a point source the sharp line of the ideal radiograph will be diffused with consequent loss of detail. A theoretical assessment of the magnitude of the effect would be difficult but Meakin[4] and Halmshaw[5,6] have given experimental values for a wide range of energies.

They have measured the diffuseness of what would ideally have been a sharp change in density on the film and give values which range from 0.06 mm for a 250-kV equipment up to 0.56 mm. for 8-MeV. Since a film could not be regarded as critically sharp if the " unsharpness " figure was to exceed say 0.15 mm the effect becomes of importance for energies greater than about 750 keV.

4.4. *Combination of Effects*

The lack of resolution in a radiograph is obviously the resultant of both the effect due to source size (geometric unsharpness) and that caused by the secondary electrons (inherent unsharpness). The two effects are additive but the numerical value of the resultant unsharpness is subject to some doubt since although there are a number of papers on the subject[7-11] there is a lack of agreement as to the appropriate method of summation.

5. Required Features of Equipment and Assessment of its Capabilities

It is clear from the foregoing analysis that no equipment can be ideal in all respects since some of the desired features are mutually contradictory. For dealing with thick specimens, however, it can be said that equipment should operate at sufficiently high energy to give radiation approaching minimum absorption. This does not in itself mean that electron energies considerably in excess of the quantum energy for minimum absorption should not be used since in fact such energies would actually give considerable amounts of X-rays with energies appropriate for minimum absorption. High energy radiation will of necessity give low contrast and this must be tolerated if thick specimens are to be dealt with some compensation being gained in increased latitude. Small source size is required to minimize geometrical unsharpness, but since high output is essential, source size cannot be indefinitely reduced because of target cooling problems. From the designer's point of view high output is most easily obtained at high energies. Probably the most important factor is inherent unsharpness and this will set an upper limit to energy. Even this last point must be considered in conjunction with other factors since, if either target size or output conditions permit, magnified radiographs can be produced by having the specimen a considerable distance in front of the film and the effect of inherent unsharpness is reduced by a factor equal to the magnification ratio.

To summarize, an optimum equipment will have high output, small spot size and an energy decided as a compromise between the demands of minimum absorption and the inevitable inherent unsharpness associated with high energy. It seems reasonable from the data quoted above that an energy in the region of 4 MeV will, for direct radiography at any rate, be optimum.

The capabilities of any equipment is probably best specified by a statement of its energy and X-ray output in roentgen per min (r/min) measured at some specified distance, usually 1 metre, in the forward direction. Further information required by the radiographer can be given as follows :—

(*a*) The effective Half Value Layer of the radiation for say steel or some suitable material ;

(*b*) Some statement of the sensitivity for flaw detection or a statement of the percentage change in thickness of specimen which is just detectable ;

(*c*) The maximum thickness which can be dealt with before scattered radiation from the surroundings reduces sensitivity or the exposure becomes intolerably long ;

(*d*) For the radiographer who wishes to use magnification a statement of the unsharpness both inherent and geometric is required.

In addition to the factors already discussed a number of other features must be considered in the choice of an equipment. These include such matters as availability, reliability and cost and probably even more important the compactness and manœuvrability of the equipment. Since the number of types of equipment operating in the megavolt range is not large choice is limited.

6. Possible Types of Equipment

An orthodox type of X-ray equipment has an accelerating tube across which the total voltage is applied. This tube may have intermediate electrodes for field equalization but nevertheless in the limit high voltage insulation becomes a serious problem. For low energy equipments many forms of voltage generator are available, but for higher voltages only two types of generator are in common use. These are the resonant transformer[12] and the Van de Graaff generator.[13] In both cases the engineering difficulties associated with the high voltage insulation and the construction of the accelerating tube limits the energy to about 2 MeV for industrial application.

An alternative approach which avoids the high voltage difficulty is to accelerate the electrons to high energy by magnetic induction while restraining them to move in a circular orbit by means of a magnetic field. Such an equipment is the betatron[14] which can be regarded as a transformer in which the electron beam itself forms the secondary winding, each electron acquiring relatively little energy whilst performing one orbit, but eventually reaching a high energy after a very large number of such orbits. Betatrons operating at energies of 20 to 30 MeV have been used for radiography both in America and in Europe. Since such equipments are very restricted in the current they can accelerate the only method to obtain reasonable X-ray output is to operate at relatively high energies with the consequent disadvantage of a narrow X-ray beam and considerable inherent unsharpness. It should be noted, however, that the betraton has one very great advantage in that the cross-section of the electron beam is very small and therefore an extremely small source size can be obtained leading to very small geometrical unsharpness. This leads to the suitability of the equipment for the production of magnified radiographs and within the limits of its output this may well be the chief application of the equipment. Recently a betatron[15] operating at 20 MeV has been developed by the author's organization and is installed at the Christie Hospital, Manchester, where it will be used for X-ray therapy. With this equipment an unfiltered output in excess of 100 r/min at 1 m has been obtained and the suitability for industrial radiography of a similar equipment is at present being investigated.

The post-war development of the travelling wave linear accelerator has provided another method of avoiding the high voltage problem while still supplying a beam of high energy electrons which may be used for X-ray production. Many papers have dealt with the design and performance[16-23] of linear accelerators whilst others have described complete installations intended for X-ray therapy.[24, 25] The present paper will, therefore, only give a brief account of the operation of the linear accelerator and will deal chiefly with those features of its performance and construction which indicate its application to industrial radiography.

7. Operation and Performance of the Linear Accelerator

In a linear accelerator electrons are maintained continuously in a radio-frequency field travelling along with the electron and having a

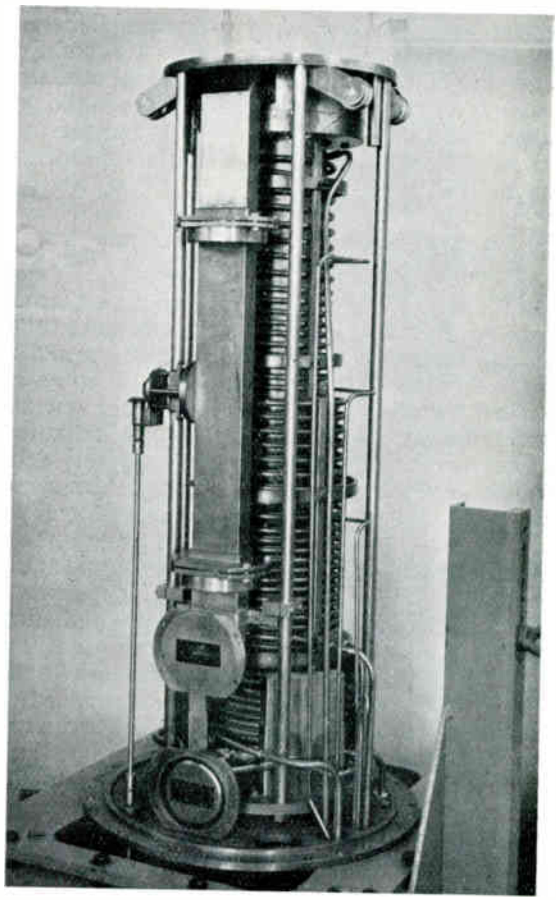

Fig. 6.—The accelerator unit of a 4-MeV equipment.

velocity equal or nearly equal to that of the electron. The fields propagated inside a hollow metallic tube in the E_0 waveguide mode provide an axial field of the correct form for the acceleration of particles. As is well known, however, the phase velocity of such a wave in the normal smooth-walled guide is always greater than that of light and, therefore, the condition of nearly equal velocities cannot be met. This difficulty can be resolved since a process analogous to the inductive loading of a transmission line is possible. Thus the introduction of metallic discs or irises into a smooth-walled guide modifies the phase velocity and makes it possible to arrange that the wave and the electrons travel at the same speed. Two of the more important dimensions of the "corrugated guide" which is formed are the radius of the central iris hole (a) and that of the guide itself (b). By variation of these, usually expressed in relation to the free space wavelength (λ) of the radio frequency power, the wave velocity and accelerating field are controlled. It can be arranged that at the input end of such a guide the wave velocity is say 0·4 times the velocity of light, so that an electron beam may be injected with a velocity equal to that of the wave and yet a relatively low voltage (40 to 50 kV) is sufficient for the operation of the electron gun. By progressive variation of a and b along the length of such a guide the wave velocity can be increased towards light velocity, and the electrons collected by the wave will be accelerated. At energies greater than about 1 MeV an electron has a velocity only slightly less than that of light, and thereafter it acquires energy from the wave by increase of mass rather than by increase in velocity; thus, in the later stages of acceleration the wave velocity needs only slight variation or may even be kept constant.

By an action rather similar to that which occurs in a klystron valve, electrons while travelling at velocities appreciably below that of light in the early stages of the accelerator are collected into discrete bunches about particular phases of the wave. The first stage of an accelerator is, therefore, often referred to as the "buncher."

In a guide as described above there is, in addition to the axial accelerating field, a radial electric field and a circumferential magnetic field, the resultant effect of which under normal conditions tends to disperse the beam of electrons. This effect may, however, be compensated by the focusing action of a steady axial magnetic field provided by solenoids surrounding the accelerator.

The attainment of high energies in relatively short lengths of accelerator involves accelerating fields in the corrugated waveguide of the order of 30 to 40 kV/cm, and this can only be obtained if the radio power flux is of the order of some megawatts. Such considerations enforce pulse operation of the equipment, and since the free space wavelength may conveniently be 10 cm operation becomes similar to that of pulsed radar equipment. In fact, the energizing of an accelerator from a pulsed magnetron and modulator can be regarded as standard microwave engineering as is much of the associated equipment shown in the partly cross-sectioned view of a typical accelerator given in Fig. 8. In this particular equipment, a 4-MeV unit, the accelerator waveguide along with the end feed

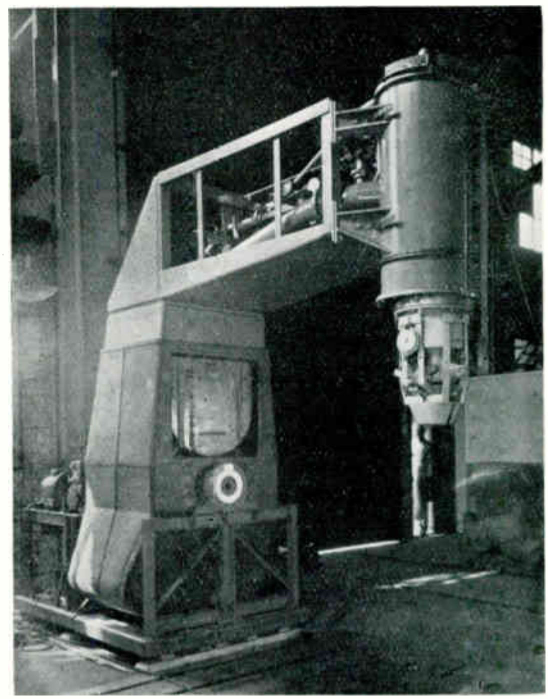

Fig. 7.—A 4-MeV linear accelerator under construction. The accelerator guide and focusing coils are contained in the cylindrical vacuum chamber, to which the X-ray head is attached; waveguide components and the magnetron are in the top member of the framework, and pumping equipment and driving mechanisms occupy the remainder.

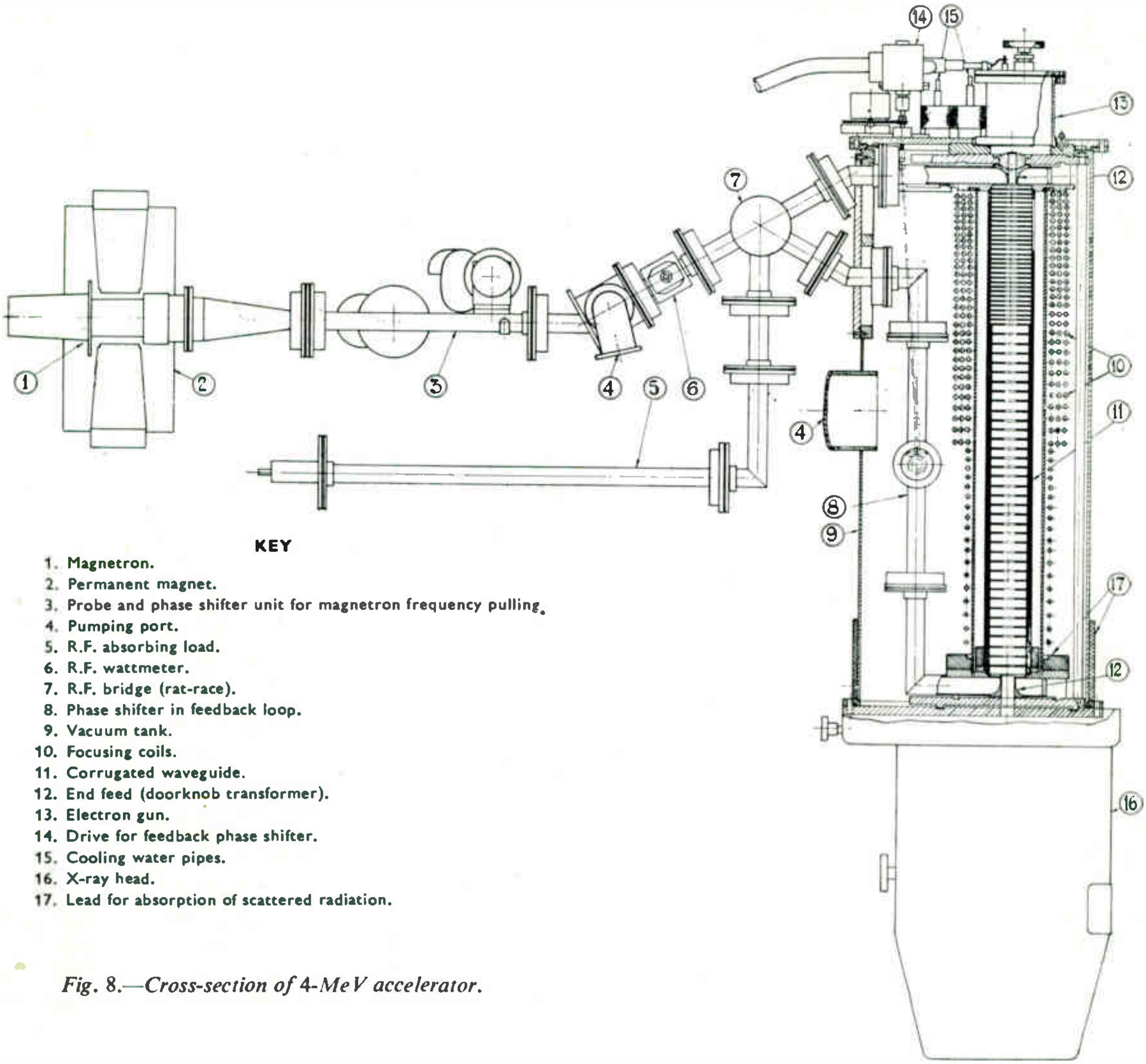

Fig. 8.—Cross-section of 4-MeV accelerator.

transformers, focusing coils and certain waveguide components are mounted as a single assembly on a plate. This unit, of which a picture is given in Fig. 6, slides as a whole into a cylindrical vacuum tank. Such equipments have so far been used for X-ray therapy and the ability to move the equipment in order to direct the beam in the required direction on to the patient is all important. In the case of this 4-MeV machine the accelerator mounted in its vacuum tank and coupled to a rather complex diaphragm and shielding unit termed the X-ray head is mounted on a rotatable framework as shown in Fig. 7. The movement of this supporting equipment enables the accelerator to be swung around the patient with the beam directed radially inwards.

Turning to the performance of such equipment, the author's organization has been concerned with two particular designs of linear accelerator. The first of these was an 8-MeV equipment and was in fact the first linear accelerator for X-ray therapy ever made, and it is now in service at Hammersmith Hospital.

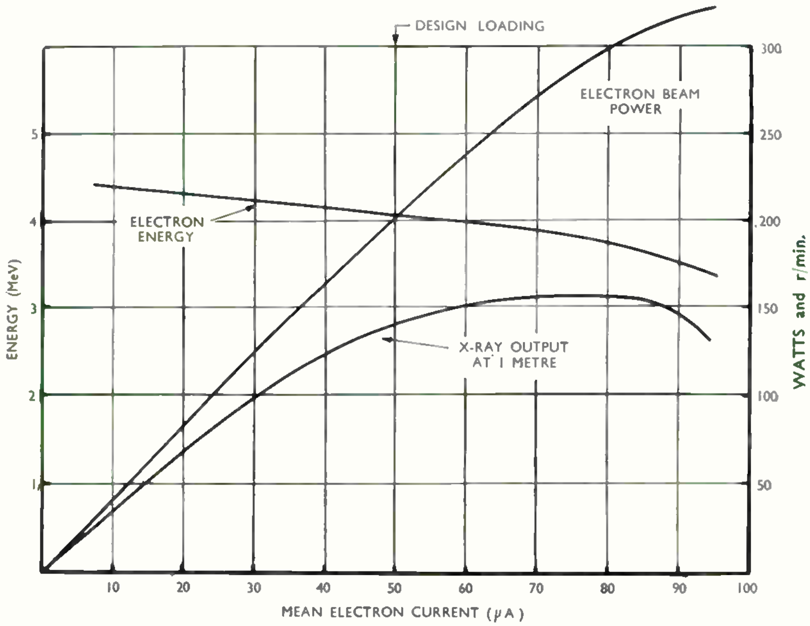

Fig. 9.—The performance of the 4-MeV linear accelerator at 200 pulses per sec. recurrence. (Recurrence rate may be increased to 500 p.p.s. to give proportional increase in output)

This equipment had an accelerator guide 3 m in length, could produce a mean current of up to 40 μA and X-ray outputs of 600 r/min at 1 m when the clinical facilities of the X-ray head were dispensed with. The second type is the 4-MeV equipment described and illustrated above. Of these a number are being made for hospitals both in this country and abroad and the first equipment has been installed in the Christie Hospital, Manchester. The accelerator guide in this equipment is only 1 m long and the performance may best be specified by the curves of Fig. 9.

In both the equipments mentioned above the r.f. power source is a 2 MW magnetron operating at a pulse length of 2 μsec and recurrence rates up to 500 p.p.s., thus having a maximum mean power output of 2 kW. In order to increase the peak power flux in the accelerator guide to a value approaching 4 MW use is made of a system of r.f. power feedback first suggested by Harvie and Mullett.[26] The arrangement is in some respects similar to that of the " back to back " test for motors and generators in which large circulating powers are obtained whilst the primary power source has only to supply the losses. The arrangements of the feedback loop can be seen in the cross-section of Fig. 8. Residual power from the output end of the corrugated waveguide is recombined, in suitably adjusted phase relationship, with the incoming power from the source thus giving increased power flux in the accelerator. A bridge ratio of unity has been used and it can be shown that when conditions are such that the losses round the whole of the feedback loop are 3 db the power build-up ratio will be 2, that is, the power flux in the accelerator is twice that from the source and under steady state conditions no power flows into the absorbing load attached to the fourth arm of the bridge. The waveguide bridge may take any of the various mathematically identical arrangements such as " magic tees "[27, 28] or " rat-races."[29] In this particular case a rat-race was used for the convenience of the waveguide arrangement.

From Fig. 9 it can be seen that by operating at the design conditions and at 500 p.p.s., a 4-MeV beam of electrons can be obtained at a mean power of 500 watts (125 μA) thus representing a power conversion efficiency of r.f. to electron beam of 25 per cent. This is a very conservative value since Fig. 9 also shows that by increasing the loading of this same machine an efficiency of 40 per cent. can be obtained at the expense of a slight loss of energy. Further, Saxon[22] has shown that accelerators of even higher efficiency can easily be designed. It is interesting, however, using this value of 25 per cent. and the information of Fig. 5, to assess the X-ray output that could be obtained from accelerators designed for other energies although employing the same power source. These results are given in Table 2 and emphasize the preference for relatively high energies when large X-ray outputs are required.

Table 2

X-ray Output of Linear Accelerators Designed for Various Energies

Mean input power 2 kW ; accelerator power efficiency 25 per cent.

Electron energy MeV	X-ray output at 1 m r/min
1	35
2	112
4	375
6	760
8	1,250
10	1,800

The definition of the source size in a linear accelerator is perhaps a little difficult since the radial distribution of the beam current is to a first approximation Gaussian. A rough estimation of the distribution can be obtained by the effect of the electron beam on photographic paper. A better specification can be made by stating the diameter within which half of the total current can be found. On this basis a figure of 3 mm has been obtained for the 8-MeV equipment, whilst for the 4-MeV machine the value is only slightly higher. In the latter equipment electron collimation is also used and a shield of lead and aluminium ensures that electrons outside a 6-mm diameter circle are prevented from reaching the target.

8. Radiography with the Linear Accelerator

8.1. *Experiments with the 8-MeV Equipment*

Although the 8-MeV equipment was designed primarily for X-ray therapy it was found possible during the development programme to perform a limited number of experiments to assess the suitability of such high energy radiation for industrial radiography.

Experiments with an unshielded target mounted straight on the end of the accelerator soon showed the necessity for some form of collimation to reduce the general scatter which occurred in the somewhat confined conditions of the laboratory. Later work utilized the rather elaborate X-ray head which had been provided for clinical operation. This, whilst being excellent in cutting down scatter, considerably restricted the output of the machine and, in fact, gave a maximum output of about 300 r/min at 1 m. It did, however, provide a uniform beam since an aluminium flattening filter is included to give uniform intensity over a beam 15 deg. wide and so cover a circle 26 cm diameter at 1 m distance.

With this equipment flaw sensitivity was found to be 0·38 per cent., that is a 0·03. in deep groove was visible in 7·8 in of steel. The half value layer in steel was about 1·14 in corresponding to an absorption coefficient of $0{\cdot}24\,\text{cm}^{-1}$. Corresponding to this absorption a latitude of 1·87 in was found, in particular a 1 per cent. groove was visible throughout a wedge-shaped specimen whose thickness varied from 1·63 to 3·5 in. Inherent unsharpness was measured as 0·56 mm. The maximum thickness which could be dealt with was not fully investigated and in fact, no specimens over 8 in. were used. As regards exposure times a basic figure of about 8 seconds can be quoted for a 5-in sample at 1 m when the equipment is operated at full output. In practice it might be found desirable with this equipment to work at rather larger distances, say 2 m so that geometric unsharpness can be made small compared with the inherent, and in this case, exposure times will be quadrupled giving 32 seconds for 5 in. whilst for other thicknesses times can be calculated from the known half value layer.

8.2. *Experiments with the 4-MeV Equipment*

The assessment of the results obtained with the 4-MeV machine are not yet complete, they do, however, confirm the expected performance. In view of the difficulties encountered due to scatter in earlier experiments all measurements were made using an improvised collimator of lead and concrete bricks.

X-ray output after the fitting of a beam flattening filter so as to give uniform intensity over a 31-cm diameter circle at 1 m is 200 r/min.

Flaw sensitivity has been found to fall from a figure of 0·4 per cent. at 4 in thickness to about 0·3 per cent. at 13 in. This may be compared with an optimum of 0·5 per cent. for the radiation from cobalt 60 when thickness is 4 in to 5 in. Measurements with an open field indicate a half value layer of 1·0 in (absorption coefficient 0·27 cm^{-1}) and this will give a latitude not greatly different from that for the 8-MeV equipment. Inherent unsharpness has been determined as 0·42 mm showing good agreement with the value expected by interpolation between measurements performed at other energies. A rough guide to exposure times (assuming an average film speed) can be taken as 1 min for a 7-in thick specimen at 1 m and this time must be doubled for each additional inch of thickness. A practical limit of thickness might be reasonably set at 13 in and for this it can be seen that an exposure of about 1 hour is required. If, however, the fastest available films were used and some reduction in density of the image tolerated it would be possible to deal with specimens up to say 15-in thickness.

9. Industrial Application of the 4-MeV Equipment

The earlier parts of this paper have made a case for the use of equipment operating at approximately 4 MeV and experimental findings have confirmed the desirability of this energy. It remains to consider the adaptability of the 4-MeV linear accelerator for industrial use.

The 4-MeV accelerator unit is only 1 m long and a suitable movable mounting system has already been devised for the application of this unit for clinical purposes. This arrangement as it stands is perhaps too elaborate for industrial use and, in fact, many of the clinical facilities could be dispensed with. In particular the X-ray head would obviously be replaced by a much simpler unit. Further the movements provided are not exactly those required in industry. It is clear that particular applications may make their individual demands on the mounting arrangements, but since the accelerator unit along with the associated waveguide components could easily be mounted in a comparatively small tank the meeting of these needs would be a matter of straightforward engineering. A typical construction might well take the form of an overhead travelling gantry after the fashion of a travelling crane. This would give lateral freedom in two directions whilst the accelerator could be so suspended as to be movable in the vertical plane, rotatable about a vertical axis and tiltable in the vertical plane. Some restriction on the amount of travel would have to be applied but all practical requirements could be met. Ancillary equipment such as the pulser unit for energizing the magnetron might well be mounted on the gantry and controls could either be on the gantry or for reasons of protection might well be remote from the equipment. The accelerator units are at present continuously evacuated by means of oil diffusion pumps and at first this may be thought to cause difficulties with the mounting arrangements. Whilst the solution of this problem will be affected by the needs of any particular design it should be noted that this problem has been dealt with in the 4-MeV clinical equipment by mounting the oil diffusion pump inside the movable framework. Although as a long-term development it might be possible to construct sealed-off accelerators thus removing the necessity for pumps it must be remembered that continuously-evacuated equipment is very reliable in operation and makes the replacement of filaments an extremely simple matter.

As regards future developments it would seem possible either by further study of electron injection or the action of the accelerating field that the diameter of the electron beam as it leaves the accelerator could be reduced. Should this not be possible some form of focusing after acceleration may solve the same problem and thus reduce the geometric unsharpness which is at present rather larger than is desired. In those cases where this unsharpness is at present the limiting feature it would obviously be possible at the expense of a fall in output to use further electron collimation and by this means a source size of very small dimensions could be obtained. A further possibility is that since the electron beam can easily be extracted from a linear accelerator it could be passed along an evacuated tube of quite small diameter before striking the target. This would enable the target to be introduced into relatively confined spaces. An extension of this same idea by adding a rotatable magnet so as to deflect the electron beam on to an annular target would make possible the radiography of circumferential welds in large cylindrical tanks or pipes in one operation.

10. Conclusion

A case has been made for X-ray equipment operating at an energy of about 4-MeV as the optimum arrangement for the radiography of the heavy and thick specimens found in heavy engineering. It has been shown that a linear accelerator is the almost ideal solution to this problem and that a particular equipment can deal with specimens up to 13-in thickness with very adequate flaw detection and resolution.

11. Acknowledgments

The author has been considerably assisted, particularly in connection with Sections 4 and 8, by access to the unpublished work of R. Meakin and R. Halmshaw of the Armament Research Establishment. For this and their measurements with both accelerators he is greatly indebted. The assistance of the author's colleagues, G. Saxon and M. C. Crowley-Milling, is also acknowledged. The author also expresses thanks to Dr. Willis Jackson, F.R.S., M.I.E.E., Director of Research and Education, and to Mr. B. G. Churcher, M.Sc., M.I.E.E., Manager of the Research Department, Metropolitan-Vickers Electrical Co., Ltd., for permission to publish this paper.

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13. Appendix: Efficiency of the production of X-Rays

Expressions for the loss of energy per unit length of track by an energetic particle in penetrating matter have been given for various conditions by Heitler.[1] He has shown that two processes are involved as discussed in Section 3 and for energies sufficiently high that the particle can be considered relativistic the following expressions are derived :—

$$\left(-\frac{\mathrm{d}E}{\mathrm{d}x}\right)_{\mathrm{coll}} = NZ\,\varphi_o\,\mu^{\frac{3}{4}}\log . \frac{E^3}{2\mu\ I^2\ Z^2} \quad \ldots .(1)$$

$$\left(-\frac{\mathrm{d}E}{\mathrm{d}x}\right)_{\mathrm{rad}} = 4\,\frac{NZ^2\,r_o{}^2}{137}\,E\left(\log\frac{2E}{\mu}-\frac{1}{3}\right) \quad (2)$$

The total loss per unit distance is, of course, given by the sum of these expressions. It can be then be seen that by integration of the loss due to radiation and comparing this with the total loss over the whole track length, the efficiency of X-ray production can be determined. Since, however, energy and distance will vary together it is more convenient to turn the integral into a form which is integrated with respect to energy and the limits of integration will be the initial particle energy and its rest energy.

A little simple rearrangement leads to the expression for the efficiency of X-ray production (η) as follows :—

$$\eta = \frac{1}{E_0 - 1} \int_1^{E_0} \frac{aE\,(\log 2E - \frac{1}{3})}{aE\,(\log 2E - \frac{1}{3}) + b \log \frac{E^3}{d}} \,.\, \mathrm{d}E \quad (3)$$

In this expression E is the total energy of the particle, that is, it is the sum of the rest energy (μ) and the kinetic energy. It is measured in units of m_0c^2, the rest energy of the electron and so the limits of integration are unity and E_0 the initial value of E.

The values of the constants a, b and d are given below in terms of atomic constants, it being noted that μ has become unity since the particles are electrons.

$$a = 4 \,.\, \frac{NZ^2\, r_0^{\,2}}{137}$$

$$b = NZ\, \varphi_0$$

$$d = 2I^2\, Z^2$$

where N is the number of atoms or molecules per cm³ of absorbing material

Z is the nuclear charge of the absorbing material, i.e., the atomic number

IZ is an average ionization energy of the atom and I has been experimentally determined as 13·5 electron volts but must, of course, be expressed in terms of $m_0c^2 = 511$ keV

φ_0 is given by $\dfrac{8\pi\ r_0^{\,2}}{3}$

and r_0 is the classical radius of the electron $2{\cdot}80 \times 10^{-13}$ cm.

Alternatively values for a, b and d can be found in terms of other quantities, thus :—

$$a = 1{\cdot}38 \times 10^{-3} \,.\, \frac{Z^2\, \rho}{A}$$

$$b = 0{\cdot}397 \frac{\rho Z}{A}$$

$$d = 1{\cdot}4 \times 10^{-9} \,.\, Z^2$$

where Z has the same significance as above, ρ is the density in gm/cm³ and A is the atomic weight of the material.

It should be noted that the evaluation of efficiency by means of expression (3) assumes that the electron remains relativistic throughout the whole of its path. This is obviously incorrect since it is finally brought to rest. Nevertheless, the expression can be expected to give quite a close approximation since it is only when the electron has lost most of its energy that it ceases to be relativistic and, therefore, though the expressions for rate of energy loss may be in error there is so little energy left to lose that they can cause only a slight error to the efficiency.

The integral of expression (3) has been computed for various values of the constants and limits of integration thus providing the data for Table 2. The error mentioned above means that these values will be rather too high, particularly for the lower energies but the discrepancy will decrease as energy is increased.

A further error should be considered at high energies in that expression (2) completely neglects the screening effect of the outer electrons. In consequence $\left(\dfrac{\mathrm{d}E}{\mathrm{d}x}\right)_{\mathrm{rad}}$ given by (2) continues to increase with energy whereas in fact it should approach an asymptotic value which is a function of the material. The discrepancy only becomes appreciable at energies greater than say 10 MeV and is greater for heavy materials. In consequence, efficiencies calculated from expression (3) will also be somewhat high even for high energies.

It is possible to avoid the errors mentioned above and Heitler does, in fact, give more exact expressions for energy loss under non-relativistic conditions and also to allow for screening. The use of these would, however, considerably increase the difficulty of computation and expression (3) is sufficient to show the general variation of efficiency with energy and target material.

NOTICES

Obituaries

The Council of the Institution has expressed its sympathy with the relatives of the following members:

Wilson Finding (Member), who died on May 30th last at the age of 61, was first elected an Associate Member in 1934 and transferred to Member in 1937.

Following service in the 1914-18 war with the Wireless Section of the Royal Engineers, he joined the Department of Posts and Telegraphs of the Sudan Government as Wireless Inspector, being concerned with the erection and maintenance of permanent stations. From 1926 to 1928 he was associated with the British Broadcasting Corporation, as a maintenance engineer, and in 1928 joined the Anglo-Persian Oil Co., Ltd. (subsequently the Anglo-Iranian Oil Co., Ltd.) as radio engineer. In 1931 Mr. Finding was promoted to Superintendent of Communications, being in charge of all the company's electrical communications in Iran and Iraq, and retired from this position in 1944.

Raymond Laurence Clark (Associate Member), who died early in July last after a long illness, at the age of 37, was elected in February 1952. He was at that time with the Telegraph Condenser Co. Mr. Clark served in the Royal Air Force during the war, first as a technical instructor in radio and electrical subjects and later on flying duties as a pilot. On being invalided out of the Service in 1943 he joined Standard Telephones and Cables, Ltd., as a development engineer, being principally concerned with communications projects.

International Scientific Radio Union

The eleventh meeting of the General Assembly of the International Scientific Radio Union (U.R.S.I.) is being held during the period August 23rd to September 2nd in The Hague. Reports are being submitted by the various international delegations reviewing advances made in the fields of research covered by the work of the union. Members of the British delegation, nominated by a committee under the auspices of the Royal Society, will speak on such topics as radio propagation, radio astronomy and measurements and standardization.

Proposals for radio observations during the international geophysical year, 1957-58, will be considered by the General Assembly.

University of Southampton Electronics Diploma

The University of Southampton Electronics Diploma has recently been awarded to seven R.A.F. officers. These successes are particularly noteworthy, as two of the officers obtained First Class Honours diplomas. Only nine First Class Honours Diplomas have been granted since the Diploma was established eight years ago.

One of the successful officers is Flt.-Lt. A. J. B. Clements, an Associate Member of the Institution, who was elected in January 1951.

Institution Meetings in London

Meetings during the coming session, 1954-55, will be held, as in previous years, at the London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, W.C.1, commencing at 6.30 p.m. Arrangements are as follows:—

Wednesday, Sept. 29th: "Computing Circuits in Flight Simulators," by A. E. Cutler, B.Sc., Ph.D.

Wednesday, Oct. 27th: Annual General Meeting followed by the Presidential Address.

Other meetings during the session will be held on the following dates (all Wednesdays): November 24th, December 29th, January 26th, February 23rd, March 30th, April 27th, May 18th.

The details of the programme, as well as the programmes of the six local sections in the British Isles, will be circulated to members during September, and will, in addition, be announced regularly in the *Journal*.

Out-of-Print *Journals*

The Institution has received urgent requests for copies of the January 1953 *Journal*. Members who are prepared to release their copies of this issue are invited to return them to the Institution at a charge of 5s. per copy, post free. Copies must be clean and in good condition as they are required for binding.

Bound Volumes

Enquiries are still being received for bound volumes of the Institution's *Journals* prior to 1946. In order to save correspondence it would be appreciated if members will note that the Institution cannot comply with any order for *Journals* prior to 1946 as these are now out of print and there are no stocks of bound volumes.

INSTRUMENTS FOR RADIATION PROTECTION *

by

R. B. Stephens†

A paper presented during the Industrial Electronics Convention held in Oxford in July 1954

SUMMARY

The paper discusses the general requirements and the design principles of these instruments, emphasis being placed on such features as reliability, ease of handling and simplicity of control. The influence of these features on the design of a hand and foot monitor and a Civil Defence contamination meter is then considered. Mention is made of the various types of circuits employed.

1. Introduction

The years since the passing of the Atomic Energy Act, 1946, and the subsequent growth of the Atomic Energy Research Establishment and Atomic Energy Factories have seen a great expansion in the industrial use of radioactive isotopes. Many examples can be quoted of the successful application of isotope techniques to the solution of problems which had hitherto proved difficult.[1] One example which immediately comes to mind is the use of gamma-emitting isotopes for radiography of castings, forgings and welds where often the technique may offer advantages over normal X-ray methods.[2]

In medicine, tracer techniques have given to the doctor a powerful new tool in such applications as the location of tumours and the study of body metabolism.[3]

Other fruitful fields have been measurement of wear, for example in the cylinders of engines or in the refractory linings of furnaces and the detection of leaks in pipes.[4]

Thickness gauges using isotopes are now widely used for the control or measurement of material thickness, for example in steel strip mills[19] and in paper manufacture.[20]

These are but a few of the well-established uses of isotopes. New applications are continually being discovered, often in the most unexpected directions.

For example, investigations are now being made into the possibility of sterilizing food by subjecting it to intense gamma radiation[5] and only recently it was found possible to improve the characteristics of transistors by irradiating them with neutrons in an atomic pile.[6]

Again, the electrical and mechanical properties of materials are often radically changed by bombardment with high energy particles and much research is being devoted to this question.[7]

In such an expanding field there are many outlets not only for the equipment directly related to the application of the isotope, but also in connection with the necessary maintenance and testing facilities and for the very important aspect of control of the health hazards which may arise. It is with instruments of the latter type that this paper is concerned.

2. Health Hazards and Health Monitoring Instruments

The health hazard is due to the damage caused to the body cells when energy absorption takes place as the result of the passage of ionizing rays.[8] The extent of the damage will depend upon the nature of the radiation, intensity of the radiation and the time of the exposure.

The danger from alpha-emitting substances arises only when they have been ingested by the body because alpha particles are unable to penetrate the skin to any appreciable depth.

Radium, for example, being in the same group as calcium, strontium and barium, finds its way to the bone marrow where long-lasting ionization destroys the red and white corpuscles at their source.

The range of beta rays is considerably greater than that of alpha particles, but is usually insufficient to penetrate more than a few millimetres of the skin, where the maximum effect is therefore produced. The effects of excessive

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exposure to beta rays are skin burning, dermatitis, dryness and cracking of the nails and skin, and in extreme cases skin cancer may result. Ingestion of beta-active material would again lead to internal tissue damage.

The skin effects of gamma rays are similar to those of beta rays but since their penetration is great, biological changes similar to those produced by alpha particles accompany the skin effects. In addition, intense gamma radiation may cause sterility.

It is also known that gamma radiation may have deleterious genetic effects so that in the course of generations the characteristics of the human race may be adversely affected if appreciable numbers of people become subject to excessive radiation.

At this point it is worth mentioning briefly how the nature of the radiation influences the design of the detector and mode of use of the instrument.

Thus for alpha radiation the range is so small that the detector must be brought to within a few millimetres of the source. Any material, such as an aluminium light-tight window (for a scintillation counter), interposed between the source and detector must be extremely thin. In a typical case aluminium only 0·00003 in. thick might be used.

For beta rays it is still necessary to bring the detector up to the source but in this case obstructions, if any, can be somewhat thicker, equivalent perhaps to a few milligrams per square centimetre of material.

The penetrating gamma radiation can be detected at a distance so that it is unnecessary to bring the instrument right up to the source.

It is incumbent upon employers to ensure that their personnel are not exposed to such hazards and this obligation was given legal force in the Radioactive Substances Act, 1948.[9] Under the terms of the Act, an advisory committee was set up to advise the appropriate Ministers on matters arising from the provisions of the Act. In the near future the Committee will recommend the specific measures which employers will be required to take. The recommendations will undoubtedly focus attention on the necessity for the provision of radiation monitoring instruments and it is therefore pertinent to discuss their requirements in the light of experience of health monitoring problems.

One can classify health instruments as follows:—[10]

(*a*) Personal monitors for measurement of the cumulative radiation of each individual worker.
(*b*) Survey meters for obtaining detailed information about radiation intensities in different parts of the work-place.
(*c*) Contamination monitors for detecting deposited contamination.
(*d*) Personnel monitors for checking for contamination on the body of those working with the radioactive substances.
(*e*) Radiac instruments—a class of health monitoring instruments specially designed for Civil Defence work.

Although these instruments have widely different functions and detailed design, there are certain features which are common to them all. These are as follows :

2.1. *Reliability*

In recent years much emphasis has been laid on the need for increasing the reliability of electronic equipment. Very often this has been in connection with equipment whose breakdown would cause irritation or economic loss to the user. It must be stressed that in the case of health monitoring equipment there is an even more compelling reason for ensuring absolute reliability in that the safety or even the life of the user may depend upon its correct operation.

Some simple and perhaps fairly obvious rules may be stated for ensuring maximum reliability. These are:—

(*a*) Circuit design should be independent of valve characteristics.
(*b*) Components whose stability critically influences the operation of the instrument should be avoided as far as possible and those which remain must be chosen with great care.
(*c*) Component selection should be based on recognized standards such as those of the Interservices Components Technical Committee or the Radio Industry Council.
(*d*) Materials and finishes should be to similar standards.
(*e*) The heat dissipation per unit area should be kept to a minimum. In this connection, the use of cold cathode valves or transistors offers many advantages.

(*f*) The prototype equipment should be subject to adequate testing over the range of climatic conditions for which it has been designed. Where this is impossible, it is surprising how many weak points in prototype equipment can be revealed by continuous (i.e., 24 hours per day) unattended operation under normal conditions for periods as short as, say, three or four hundred hours.

2.2. *Simplicity of Handling*

Health monitoring equipment is used by people of widely differing intelligence levels, often with little or no knowledge of electronics. It should therefore require a minimum amount of skill for its operation. This implies simplicity of controls and clear indication of the quantity being measured. For example, the complication of a range-changing switch can sometimes be avoided by the use of a logarithmic scale. Again, direct reading instruments are preferable to null methods requiring a manual balancing operation.

2.3. *Ease of Decontamination*

Over a period the apparatus may become contaminated with radioactive material and itself constitute a health hazard. This activity may also result in incorrect indications. The instrument should be designed to make decontamination easy. This implies smooth contours and the absence of inaccessible holes, recesses and crevices in which small particles may lodge, and the use of paints which do not retain dust.

2.4. *Safe Failing*

The most careful design cannot eliminate every possibility of failure and the designer must therefore bear in mind the form of indication which would be given by the apparatus when a component failure does occur.

In any design it is usually possible to point out a few components as being more likely to fail than most others. The designer should then try to arrange for the meter indication to increase with such failure so that the operator does not unwittingly expose himself to excessive radiation.

To illustrate some of the points enumerated it is proposed to describe some of the features of two equipments which have been developed in collaboration with the Atomic Energy Research Establishment, Harwell.

The first of these instruments is a personnel monitor for checking for contamination picked up on the person. The instrument is known as a Hand and Foot Monitor.

The second instrument is a Civil Defence contamination meter intended for checking of personnel, clothing or working areas for health hazard and also for monitoring of liquid samples (e.g. checking of water supplies).

3. The Hand and Foot Monitor

This apparatus is used wherever there is routine handling of radioactive substances and consequently a danger of ingestion of active material picked up on the hands or clothing. The Hand and Foot Monitor is used by all personnel exposed to such a hazard:

(*a*) to check for alpha, beta and gamma contamination on the hands;

(*b*) to check that the clothing is free from contamination with the aid of alpha and beta-gamma probes;

(*c*) to check the level of gamma activity on the feet.

A general view of the apparatus is shown in Figs. 1a and 1b, and the simplicity and clean lines are immediately apparent. It is noteworthy that there is not a single control knob accessible to the user, a fact which has presented many an interesting design problem in such a complex equipment.

3.1. *Detectors*

A suitable type of alpha counter for monitoring the large area of the hands is the air proportional counter,[11] of which four have been used, one for each side of the left and right hands.

The proportional counter was chosen in preference to the scintillation counter because of the difficulty of designing the latter to cover uniformly the large area (about 8 in. x 5 in.) At the time no large cathode area photomultiplier tubes were available and, in any case, the design of a robust light-tight window thin enough to allow the passage of alpha particles was very difficult.

The proportional counter itself presented many problems. The output pulses are only a few millivolts in amplitude and spurious counting due to minute insulation breakdowns and microphony can easily occur. The working voltage is 2·5 kV and great care had to be taken with the design of the e.h.t. circuit,

Fig. 1.—Hand and Foot Monitor, (a) front and (b) rear views.

counter and all high voltage insulation to prevent these. Notwithstanding these difficulties it has proved possible to produce reliable and simply constructed counters on an industrial scale.

The A.E.R.E. tolerance level for alpha contamination is 600 disintegrations per minute per hand and with a counting efficiency of about 25 per cent., approximately 150 counts/min. may be expected.

Geiger-Müller counter tubes[12] are used for detecting beta and gamma rays. They have the merits of simplicity, high sensitivity and produce large pulses requiring little subsequent amplification.

Four thin-walled counters are arranged, one on either side of each hand, to scan from the fingertips to the wrists. About 200 counts/min. may be expected at tolerance level. Due to the poor geometry, the counting efficiency is only about 4 per cent.

The gamma activity of the feet is measured with two further Geiger-Müller counters with an active length of about ten inches and a diameter of 1¼ inches. The tolerance level is 500,000 disintegrations/min. per foot and again, due to the poor geometry, only about 900 counts/min. are recorded.

In each of the beta-gamma measurements mentioned, the background counts would at most be about 25 per cent. of the tolerance level.

For the alpha clothing probe, a scintillation counter[13, 14] has been chosen on the grounds of compactness. For beta-gamma monitoring of the clothes another G.M. tube is used. These two counters are attached to flexible leads which feed the pulses to a common amplifier and ratemeter circuit. Removal of the appropriate probe from its hook automatically connects its output to the amplifier.

Associated with each of the detecting systems is an amplifier for bringing up the pulse level to that necessary for operation of the indicating circuits (about 5 volts). In the case of the Geiger-Müller and scintillation counters the amplification is small and obtained from a single valve. The pulses from the proportional counter average only about 1 mV in size and a high-gain amplifier is required.[15] Two plug-in amplifiers are used, one for each pair of counters (left and right hands). They have a bandwidth of a few hundreds of kilocycles and a low frequency cut-off at about 10 kc/s to minimize the effect of microphony in the input valve and the proportional counters. Negative feedback has been used on all the amplifiers to minimize the errors due to ageing of valves.

3.2. *Operational Sequences*

The operational sequence of events for alpha hand contamination illustrates the automatic nature of the equipment. The user pushes his hands through two vertical slots until the tips of the fingers of both hands make contact with micro-switches at the rear of the unit. When *both* switches have been closed, relay circuits complete the circuit of a motor which then presses the alpha counters on to the front and back of the hands. When the counters are in the correct position the motor is switched off and, after a short delay, a fifteen second count begins and a "Test now on" warning is illuminated. During this period the counts are registered as successive increases in the reading of the top left and right hand meters (Fig. 1a). The end of the fifteen second testing period is indicated by the extinction of the warning indicator. The final readings on the meter give a measure of the alpha contamination of the hands. Once the hands are removed, the meter readings are cancelled and the motor opens the counters in readiness for another count.

A similar sequence occurs when the hands are checked for beta-gamma contamination in the horizontal openings. The activity is indicated on the same two meters.

At the same time gamma contamination of the feet is indicated on the centre meter. The sequences are entirely automatic and only commence when the hands are correctly positioned.

Should the count for either hand exceed the tolerance dose or should the hands be removed before the end of the count a loud alarm bell sounds. The contaminated worker then returns for decontamination and is tested afresh.

3.3. *Circuit Techniques*

Each meter is controlled by a circuit similar to that shown in Fig. 2.

The double triode V1 operates as a "flip flop"[16] producing a positive pulse of standard amplitude and width for any input large enough to overcome the bias. The pulses are integrated in the Miller integrator circuit[16] of V2 in which capacitor C, connected between the anode and grid, is the integrating capacitor. The anode current of V2 is then a linear measure of the total number of pulses received.

It will be noted that the first pair of valves are operating as a switch and the integration performed by the second valve is sensibly independent of valve characteristics (Sect. 2.1).

For the probes, a counting-rate meter with a logarithmic scale covering two decades has been used. The indicating meter can be seen in the centre of the panel from which the probes are suspended. The logarithmic scale is particularly useful in this application as the activity on the clothing will probably occur in spots, giving rise to large peaks on the counting ratemeter as the probe is moved about.

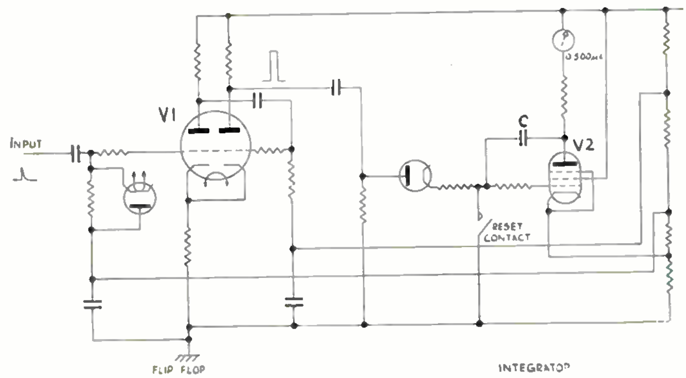


Fig. 2.—Hand and foot monitor counting circuit.

The h.t. and e.h.t. supplies employ conventional valve stabilizers. The h.t. supply is at the bottom of the rack and contains positive and negative supplies for all the electronic circuits. The e.h.t. supply is above it and contains two stabilizers, one giving approximately 1,200 volts for operation of the G.M. counters and the scintillation counter and one giving approximately 2,500V for operation of the alpha hand counters.

Some of the mechanical features of the apparatus can be seen from Fig. 1b. For ease of servicing each of the electronic units is mounted on sliding arms so that they can be withdrawn from the front of the apparatus. Interconnections between the units are made by plug and socket connections. A system of interlocks ensures that the high voltage supplies are disconnected from any unit which has been withdrawn. All nameplates are detachable for easy decontamination.

Maximum reliability has been obtained by using as far as possible only type approved components. For example, the mains transformers are of the oil-immersed C-core type and the majority of capacitors and resistors are to be found listed in the Interservice Technical Committee's Handbook. In the mechanical design the components have been well spaced to give maximum freedom of air circulation and the h.t. and e.h.t. clearances are generous.

4. The Civil Defence Contamination Meter

The second instrument is a Civil Defence contamination meter designed to measure the intensity of beta and gamma radiation in the region of tolerance level and also the beta contamination of liquids. It is a counting rate instrument indicating the rate of arrival of pulses from a Geiger-Müller counter. The instrument has a logarithmic scale calibrated over the range 0·1 to 10 millirontgens/hour (for gamma radiation) corresponding to about 3-330 counts per sec. for the particular counter used.

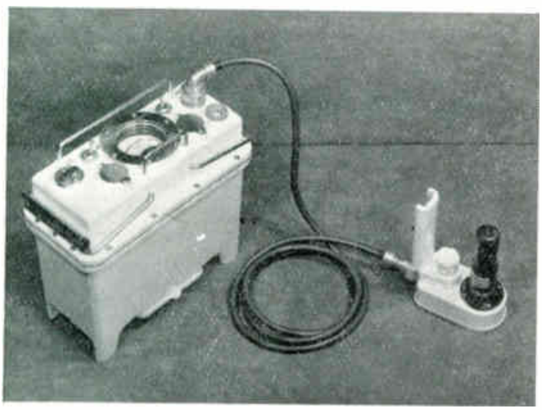


Fig. 3.—*The Civil Defence Contamination Monitor.*

For beta monitoring, a liquid counter is used and in this case tables or a radiac slide rule is used to interpret the meter reading. A general view of the monitor is shown in Fig. 3. On the right is the probe containing the Geiger-Müller counter and the counting valve. On the left is the main unit which contains the major portion of the circuit, the controls and the indicating meter. Just visible is the lid at the bottom of the indicating unit which gives access to the compartment in which the power supply unit is housed.

The instrument may be operated from any one of three types of self-contained power unit and is stabilized against effects due to changes of supply voltage. Cold cathode valves are used throughout so as to give long battery life and good reliability.

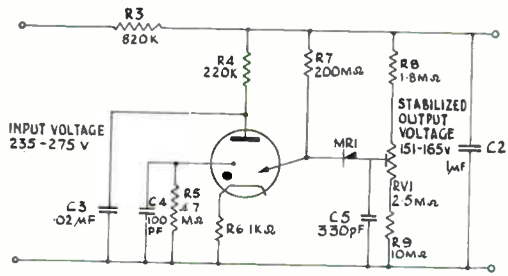


Fig. 4.—*H.T. stabilizer using cold cathode valve.*

The power unit supplies d.c. within the limits 235-400V at a current of about 200 μA for the operation of the remainder of the circuit. To make the instrument independent of failure of power supply as far as possible, three alternative types of power supply are available, namely,

(i) A mains-operated unit having a small transformer and metal rectifier, suitable for supply voltages from 100V to 250V and frequencies from 40 to 60 c/s.

(ii) A miniature 300V h.t. battery made up of two 150V units connected in series. The battery is usable until its terminal voltage falls to 235V. The working life is several hundred hours. The miniature layer batteries have the disadvantage of short shelf life especially when stored under adverse conditions of temperature and humidity. Accordingly, a second type of battery unit is available, namely:

(iii) A vibrator unit employing a special low driving power vibrator operated from a 6V battery. The working life of the battery is about fifty hours. In this case the battery will have a long shelf life.

The d.c. from the power unit feeds the following circuits:

(*a*) A stabilizing circuit which provides the h.t. for the counting rate circuit.

(*b*) A stabilizing circuit which provides e.h.t. for the G.M. counter.

These stabilizers have been provided so that the accuracy of the Monitor may be maintained as the battery voltage falls with life or as the mains supply voltage fluctuates.

4.1. *Counting Rate Circuit H.T. Stabilizer*

The function of this circuit is to stabilize the d.c. from the power unit at a level in the range 150-165V, the actual voltage being preset on test according to the requirements of the counting rate valve. The stabilizer employs a single cold cathode valve connected as a relaxation oscillator. It has been found that the mean current drawn by such a circuit varies steeply with small variations in the voltage fed to the trigger electrode[17] (see Figs. 4 and 5), i.e., it can behave like an amplifier. In this way the cold cathode valve circuit is used as the parallel amplifier valve in the well-known series-parallel type of stabilizer. The series element is a resistor.

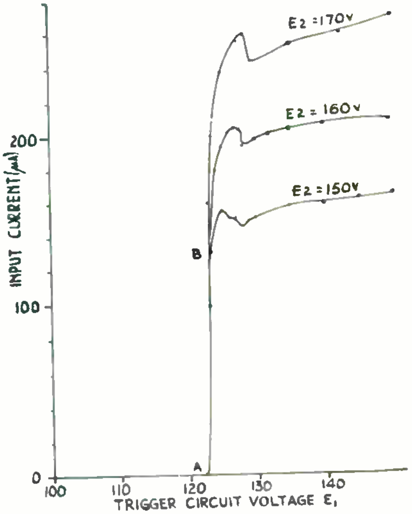


Fig. 5.—Variation of oscillator current with trigger voltage.

The circuit of this stabilizer is shown in Fig. 4. The stability is such that a change of input voltage to the circuit from 300 to 230V or a change in load current from 0-50 μA does not change the output voltage by more than ± 1 per cent.

The cold cathode valve is a tetrode, CV 2255 which was specially designed for use in the monitor.

4.2. *H.T. Generator and Stabilizer for the Geiger Counter*

The Geiger counter may require a maximum voltage of 420V for operation. This voltage must be well stabilized for the following reasons:

(*a*) To avoid the necessity for adjustment of the Geiger counter voltage with temperature. This follows because the threshold voltage and length of the plateau change with temperature. Hence the "useful" counter plateau common to the family of curves representing the plateaux over the working temperature range $-50°C$ to $+50°C$ is quite short.

(*b*) To minimize the effect of the finite slope of the counter plateau.

This voltage is provided by a two-valve circuit (Fig. 6). The first valve functions as a relaxation oscillator providing a saw-tooth wave which is fed to a voltage trebling circuit using miniature selenium rectifiers.[18] The output of this circuit, about 800 volts, is fed to a cold cathode stabilizer of the type previously mentioned, stabilizing the voltage at the required value.

The cold cathode valve in this case is a tetrode, CV 2236 which again was specially designed for use in this instrument. Its principle features are its large anode/cathode hold-off voltage and the stability of the striking and maintaining potential. The stabilization is such that the stabilized voltage changes by not more than about 1 per cent. for a 15 per cent. change of input. The circuit is capable of supplying a current of 5-10 μA.

Provision is made for adjusting the G.M. counter voltage exactly to its correct value by returning the cathode of the tube to an adjustable potentiometer connected across the 150V stabilized supply. This is a preset control and would normally require adjustment only when the Counter is changed.

4.3. *Geiger Counter*

This is a self-quenching halogen counter having the following electrical characteristics:

Maximum threshold voltage
370V

Minimum plateau length
100V

Slope of plateau
0·1 per cent. per volt

Temperature co-efficient of starting voltage
0·3V per °C.

These counters were specially developed for this instrument and represented a great improvement on the alcohol quenched counters. Their principal advantages over the latter are their very long life ($> 10^{10}$ counts) and their excellent temperature characteristics. The counters are very robust and may be dropped without damage.

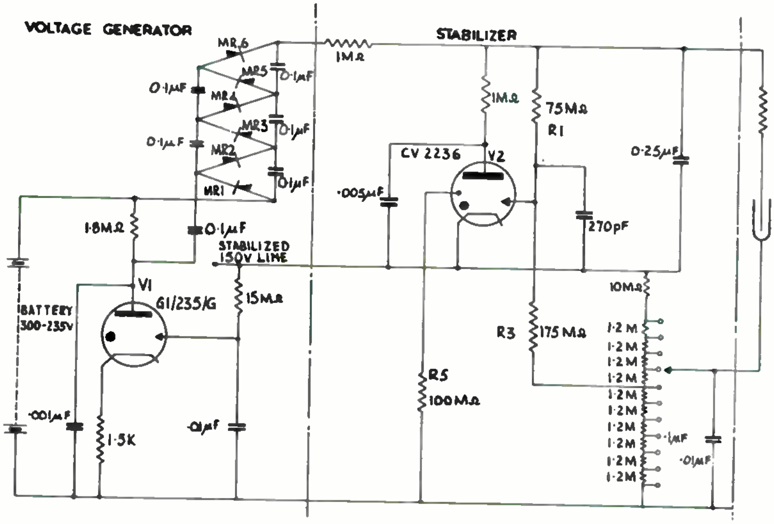


Fig. 6.—Stabilized e.h.t. supply for G.M. counter.

4.4. *Counting Rate Circuit*

The pulses from the G.M. tube are fed to a counting rate circuit (Fig. 7) using a cold cathode valve in which the current varies with the rate of arrival of the pulses. The circuit is so arranged that an approximately logarithmic scale is obtained (Fig. 8). Apart from avoiding the necessity for range changing, a further advantage is that an indication from the meter is obtained on normal background, although full-scale deflection corresponds roughly to tolerance level for gamma rays.

The principle of the counting rate circuit is illustrated in Fig. 7. Here the supply voltage to a cold cathode valve V1 is normally insufficient to break down the anode cathode gap. Neglecting for the moment the circuit R2 C2 MR1 if a positive pulse of sufficient amplitude is applied to the grid, the main anode cathode gap will break down and the capacitor C1 will rapidly acquire a charge. V1 anode potential then falls below the level necessary to maintain the glow discharge within the valve, which thereupon ceases to conduct. The charge on C1 then leaks away through R1. If a succession of pulses are fed to the grid, the mean current flowing through the valve will produce a deflection of the meter M in the anode circuit. The "tank" capacitor CT and resistor RT provide a long time constant for the meter so that the current pulses are smoothed out.

The charge per input pulse will be independent of the frequency of the input pulses. However, as the frequency increases, the interval between pulses becomes too short to allow C1 completely to discharge through R1, so that the charge per pulse becomes less. The mean current is then no longer proportional to the frequency.

A plot of mean current as a function of frequency gives a curve of the shape shown in Fig. 7b (Curve 1).

The effect of increasing the time constant C1 R1 is to move the curve to the left on the frequency scale (Curve 2). Each of these curves covers only one decade of counting rate. It is desirable to cover at least two decades and to achieve this the mean currents taken by two such time constant circuits C1.R1, C2.R2, of which C2.R2 is the lower, are added by the circuit to give Curve 3. To prevent the circuits interacting they are isolated from each other by a metal rectifier. Since C1.R1 is the shorter time constant, the rectifier will cut off immediately the valve is extinguished so that as far as the discharge of the capacitor is concerned, the two circuits are independent.

The valve used for the actual monitor circuit was another CV2255 and was specially designed for this application to give high sensitivity and fast operation.

4.5. *Mechanical Design and Temperature Effects*

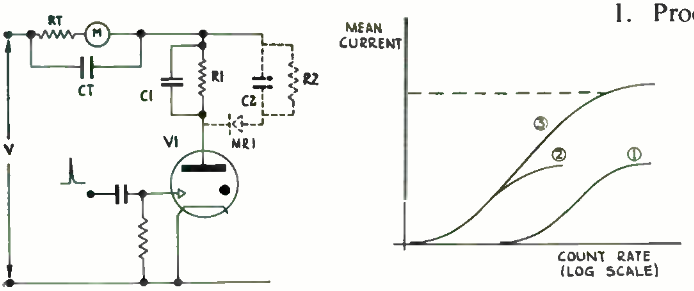
The mechanical design of the instrument is such as to conform to the rigorous requirements of the British Services. Both probe and main units are hermetically sealed and the electrical components themselves are tropically rated. The power unit is a hermetically sealed unit and may be interchanged without destroying the main seal of the instrument. On test the equipment has successfully withstood prolonged operation and storage at temperatures ranging from $-50°C$ to $+50°C$ and relatively humidity of 95 per cent. It also continued to function when immersed for one hour in five feet of water.

Some idea of the robustness of the Monitor may be gained from the fact that it was still functioning correctly after ten drops on to a concrete floor from heights ranging from one to five feet.

Figure 9 shows the layout of the top panel on which only two controls are normally used. The ON-OFF switch is on the left and the battery test switch on the right. The control under the Cover A is for adjusting the G.M. tube voltage and is only used when the tube is replaced. That under Cover B is for taking up the large differences in power unit voltage which can occur with the different types of unit. It is used in conjunction with the battery test switch. Normally the user is required to operate only the ON-OFF switch and the battery test switch.

5. Conclusions

Although the two instruments which have been described are completely different in application and conception, the same principles underly the design of both. They are simple to



(a) (b)

Fig. 7.—(a) Schematic counting rate circuit using cold cathode valve, (b) Mean current count rate for various time constants in counting rate circuit.

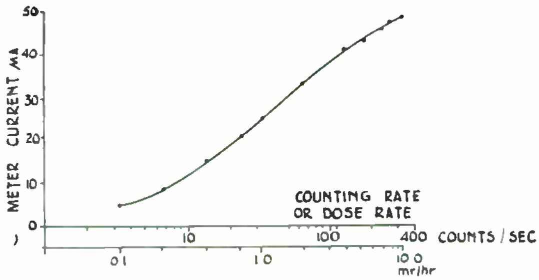


Fig. 8.—Calibration curve for Civil Defence contamination meter.

use and the operator cannot be under any misapprehension as to the meaning of the indication. On the Hand and Foot Monitor he reads his contamination in terms of fractions of the tolerable amount. On the Civil Defence Monitor green, amber and red zones on the meter scale tell their own story.

The circuits have been designed so that the calibration is maintained under adverse conditions of supply voltage and, as far as possible, to be independent of valve characteristics. The engineering of the complete equipments has been carried out completely in accordance with the standards of the Ministry of Supply. The net result has been the production of reliable equipments whose accuracy can be relied upon over long periods of time and a wide range of climatic conditions.

6. Acknowledgements

The author is indebted to the management of Messrs. Philips Electrical Ltd., for permission to publish this paper.

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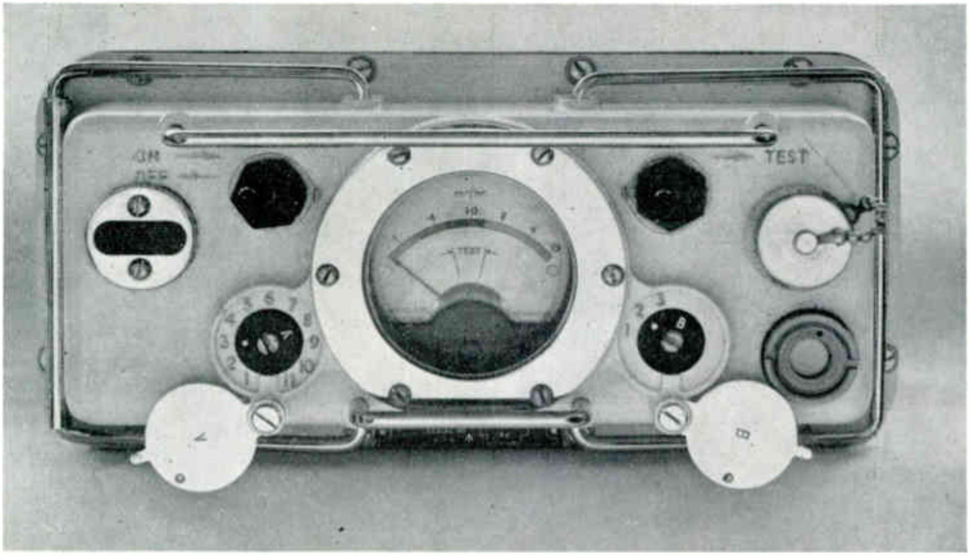

Fig. 9.—Top panel of Civil Defence contamination meter.

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GRADUATESHIP EXAMINATION—MAY 1954

FIRST PASS LIST

This list contains the results of all candidates in the British Isles and those of the oversea candidates which were available on July 23rd.

Eligible for Transfer or Election to Graduateship or Higher Grade of Membership

(These candidates have passed the entire examination, or, having previously been exempt from part of the examination, have now passed in the remaining subjects)

BARTLETT, Haroun Bey. (S) *Malvern Wells, Worcestershire.*
BISHOP, John. (S) *Birmingham.*
BOTTOMLEY, Frederick Walter. *Liverpool.*
BROWNING, Robert (S) *Wells, Somerset.*

CHUI, Toni Yim. (S) *Kowloon.*
COX, John Edward. (S) *Liverpool.*

DICKINSON, Philip. (S) *Manchester.*

GRAY, Bertram Charles. *London, S.E.17.*

HOPKINS, William Thomas. *London, S.E.9.*

JOHARI, Maharaj Bahadur. (S) *Delhi.*

LONGMAN, Charles Robert. (S) *Ickenham, Middlesex.*

MURRAY, Patrick Joseph. *Dublin.*

OLISA, Peter Enebeli. *Bristol.*
OSBORNE, John. (S) *Ilford, Essex.*

PASFIELD, Arthur Edmund. (S) *London, S.E.24.*

RICHARDS, James Henry Clayton. *Ruislip, Middlesex.*
ROSS, William Anderson. (S) *Chelmsford, Essex.*

SAWANT, Vasant Narayan. (S) *Coventry.*
SAYAL, Bhaddar Sain. *London, N.W.9.*
SHANNON, John Daniel. (S) *Edinburgh.*
SHORT, Thomas. (S) *Dublin.*
SIMPSON, Raymond Frank. *Karachi.*

TOWERS, Thomas Dundas. (S) *Kuching, Borneo.*

The following Candidates passed the Part or Parts indicated against their names

ALLEN, George Edward Elphick. (S) *Southend-on-Sea, Essex.* (I).
ARDITTI, Joseph. (S) *Tel-Aviv.* (II).

BALDWIN, John Richard. (S) *Harrogate.* (II).
BENNETT, Wilfred Dennis. (S) *Stockport, Cheshire.* (IIIa).
BOWN, Geoffrey Charles Stanley. (S) *Penarth, Glamorgan.* (I, II).
BRAUN, Simon. (S) *Haifa, Israel.* (II).
BUGEJA, Alban Anton. (S) *London, N.19.* (I).
BUNTING, Derek Henry Stanley. (S) *Nairobi.* (II).

CLARKE, Leonard Roy. (S) *Cheltenham.* (IIIa).
CLEARY, Alan. (S) *Manchester.* (I, IIIa).
COLLINS, Gerald. (S) *Exeter.* (II).
CONROY, Richard Peter. (S) *Stillorgan, Eire.* (II, IIIa).
CORDEIRO, Joseph Rufino. (S) *Nairobi.* (II).

DAS, Girdebi Kanta. (S) *Surbiton, Surrey.* (II).
DOUGLAS, Walter Harry. (S) *Victoria.* (II).

ELLIOTT, Alan Tilbury. (S) *Ilford, Essex.* (I).

FLOREK, Casimirus. (S) *London, S.E.6.* (IIIa).
FLOYD, John Thomas. (S) *Hemel Hempstead.* (I).

GABOR, Peter Reuven. (S) *Ramat Gan, Israel.* (I).
GILVARY, David Francis. (S) *Co. Wicklow, Eire.* (IV).
GITTINS, Leonard. (S) *Wolverton, Buck.* (IIIa).
GUNN, Douglas Arnold. (S) *Dublin.* (II).

HAJISTATHI, Pavlos P. (S) *London, N.7.* (I).
HANDS, Raymond Kenneth. (S). *Blyth, Northumberland.* (IV).
HEDLEY, Thomas William. *Pinner, Middlesex.* (IIIa).
HEWITT, Patrick John. (S) *Lichfield, Staffordshire.* (II).
HURST, Sydney. *Blackpool.* (II).
HUTSON, Geoffrey Henry. *Birchington, Kent.* (IV).

INDER, James Haviland. (S) *Waimauku, New Zealand.* (I).

JARVIS, John Walter. (S) *Stevenage, Herts.* (I, II, IIIb).
JHA, Chandra Shekhar. (S) *Edinburgh.* (IIIb).

JORDAN, Francis Joseph Patrick. (S) *Dublin.* (I, II, IIIa).

KAPLAN Zeev. (S) *Givaatayim, Israel.* (IIIa).
KIRKMAN, Charles Neville. (S) *Toronto.* (IV).
KLOTZER, Levy. *Ramat Gan, Israel.* (II).

LEE, Frank Frogbrook. (S) *St. Albans.* (II).
LONGLAND, David Arthur. (S) *Northampton.* (II, IV).

MAHLAB, Ezra Salim. (S) *Jerusalem.* (I, II).
MARSHALL, Laurel Everleigh. (S) *London, W.9.* (IIIa).
MEYER, Christoffel Hendrik. *The Hague.* (IIIa).
MILES, Ronald Boyce. (S) *Harrow, Middlesex.* (IIIa, IV)
MORDEKHAI, Ephraim Hay. (S) *Ramat Gan, Israel.* (IIIb).
MURPHY, Edward Colman. (S) *Blackrock, Co. Dublin.* (I).

OAKES, Mervyn Brian. (S). *Bristol.* (I).

PATANKAR, Atmaram Anant. (S) *Codsall, Staffordshire.* (IIIb).
PIDDINGTON, Vivian Henry. *Ashford, Middlesex.* (I, II, IIIa, IIIb)

RANGARAJAN, K. S. (S) *Salem, India.* (IIIb).
REICH, Paul Aharon. (S) *Doar Zwai, Israel.* (I).
RIDGWELL, Dennis. (S) *Slough.* (I).
ROW, Edward Francis. (S) *Chessington, Surrey.* (IIIb).

SCOULDING, William George. *Hornchurch, Essex.* (IIIa).
SEALE, Edward Gilbert. (S) *Dublin.* (I).
SPENCER, Godfrey Stanley Gibson. (S) *Orpington, Kent.* (I).
SPROSTON, Norman. (S) *Crewe.* (II).
STOCK, Peter Anthony. (S) *New Malden, Surrey.* (II).

THORP, Ian Robert Gardner. (S) *Maidenhead.* (I).

VINNELL, Lionel Frederick. (S) *Wells, Somerset.* (IIIb, IV).

WARIN, John William. (S) *Lydd, Kent.* (IIIa).
WHITE, William Michael Patrick. (S) *B.A.O.R.* (I).

ZIELINSKI, Stefan. (S) *Reading.* (II).

(S) denotes a Registered Student

The second pass list, giving the results of the remainder of the successful oversea candidates, will be published in the September issue of the *Journal*.

# of current interest . . . .

Higher Technological Education

The Parliamentary and Scientific Committee has recently issued a memorandum on higher technological education.

Among the many recommendations, the Committee asks for further Government action in support of the development of better facilities for higher technological education in this country. In the case of universities, the memorandum expresses the hope that the Government will continue to support the financial requirements. It also recommended the abandonment of the Barlow Committee dictum that the number of arts students should be increased with the number of science students. The Committee urges universities to widen their conditions of admission to post-graduate work to accept some of those whose "graduate" standing has been achieved otherwise than by means of a University degree.

In the cases of Colleges of Technology, the Committee recommends that a few colleges should be granted a Royal Charter with financial independence as in the case of universities. In the opinion of the Committee there are about 20 technical colleges in this country capable of fulfilling the necessary requirements. The chartered colleges should provide a number of highly qualified technologists by full-time courses, "sandwich" courses, part-time day and evening classes, from a suggested entrance level of Ordinary National Certificate.

The memorandum finally calls for a greater co-operation between industry and the universities and technical colleges, for industry should recognize the value of university research work and the universities should not be too rigid in their regulations governing the acceptance of sponsored research work.

There is also scope for increased use of teaching staffs as consultants in industry and for suitably qualified industrial engineers undertaking part-time or temporary whole-time lecturing. Industry should also provide grants for post-graduate students either for their own employees or for particular types of research work.

The Institution is represented on the Parliamentary and Scientific Committee but this memorandum was prepared by a sub-committee consisting entirely of Members of Parliament who are also members of the committee.

Courses in Higher Technology

This year's bulletin of "Special Courses in Higher Technology" has just been published. Some of the subjects which are available during the coming months include:—

Automatic control
Design and circuitry (for automatic digital computers)
Crystal valves and transistors
Advanced, applied and biological electronics
Microwave theory and technique
Pulse techniques
Servomechanisms
Vacuum technology
Wave mechanics

The majority of courses are for Graduates or holders of the Higher National Certificate and upwards, and course fees range from £1. Copies of the bulletin may be obtained from: The Secretary, Regional Advisory Council, Tavistock House South, Tavistock Square, London, W.C.1, price 1s. 6d.

V.H.F. Stations for Sound Broadcasting

The Postmaster-General recently announced the first stage of the B.B.C.'s scheme for sound broadcasting on very high frequencies using frequency modulation. It will comprise the following nine stations, each carrying the Home, Light and Third Programmes within the band 88-95 Mc/s.

	Effective radiated power kW
Wrotham (Kent)	120
Pontop Pike (near Newcastle)	60
Divis (Northern Ireland)	60
Meldrum (near Aberdeen)	60
Norwich	120
South Devon	60
Sutton Coldfield	120
West Wales	60
Holme Moss	120

The network of stations will make it possible to receive the three programmes free from interference in many areas where reception on medium wavelengths is spoiled by interference and fading, especially after dark during the winter months.

At Wrotham there are already two transmitters, which have been carrying an experimental service since 1950.* A third transmitter will be installed and the station will be brought into regular service in May 1955. The other eight stations will be completed during the following 18 months; they will be at the same sites as television stations and the same masts will be used as for the television transmissions.

*See *J.Brit.I.R.E.*, 11, February 1951, p. 72.