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

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THE PURPOSE OF CONVENTIONS

The purpose of any Convention should be closely related to the objects of the body promoting the meetings. Members are, of course, aware that the first object of the Institution is "The promotion of the theory, science, practice and engineering of electronics." Notwithstanding the progress which has been made in the last 10 years in the study of the subject, there has been little cause to revise the definition of electronics given by the Institution in 1944 as "describing the wider uses of the radio valve and kindred devices; it is radio technique at work in new ways and in widely diverse fields."

In pursuance of its objects the Institution's post-war Conventions held in Bournemouth and in the Universities of London, Southampton and Cambridge, were devoted to: telecommunications, electronic instrumentation in nucleonics, valve technology and manufacture, radio communication and broadcasting, radar and radio aids to navigation, television engineering, and audio frequency engineering.

Increasing interest in electronics, apart from communication and acoustic devices, well justified the decision to devote the whole of the 1954 Convention to the industrial application of electronics. Over 500 delegates attended, many of whom were resident in Christ Church for the full period. In addition to Institution members, attendance at the six sessions of the Convention included representative engineers from the aircraft, automobile, electricity supply, furniture, glass, iron and steel, oil, rubber, textile and other industries.

The 36 formal papers fulfilled a valuable purpose in showing how electronics can help in improving and increasing production in a wide range of industries. The proceedings of the Convention and a full record of the discussions will be published in the *Journal.* Every effort will be made to have the proceedings printed within the next three months.

Among the more valuable features of a residential Convention are the opportunities for engineers of many callings and nationalities to discuss their problems informally between individuals and in small groups. Official group discussions at the recent Convention included a meeting between University and technical college lecturers on training and education problems, with special reference to the future scheme of the Institution's examination work. Local Section representatives also held a meeting to discuss some of the problems which arise in planning local meetings and other activities. Concurrently with these meetings other delegates attended the programmes of technical films illustrating some of the applications of electronics to industry which had been described and discussed during the days' meetings.

Over 100 members availed themselves of the opportunity to join official visits to the Clarendon and Electrical Laboratories, the Atomic Energy Research Establishment, Morris Motors Ltd., and the Pressed Steel Company. In each visit special attention and discussion centred on the application of electronics as an aid to research and production and gave emphasis to the practical side of the main work of the Convention.

The attendance at every formal session of the Convention used the full capacity of the Lecture theatre and the Council is grateful to Dr. A. J. Croft, Administrator of the Clarendon Laboratory, and his staff, for their assistance.

Thanks are also expressed to the Dean and to the Steward of Christ Church whose help and co-operation contributed to the success of the Convention.

NOTICES

Members in the Birthday Honours List

The Council of the Institution congratulates the following members:—

Squadron Leader Raymond Harrison Stephenson, Royal Air Force (Associate Member) on his appointment as an Officer of the Military Division of the Most Excellent Order of the British Empire. Sqdn. Ldr. Stephenson joined the Institution as an Associate in 1947 and was transferred to Associate Membership in 1949. During the war he was engaged on flying duties as a pilot and he has subsequently served in the Signals Branch.

Mr. Rex Henry John Cary (Associate Member) on his appointment as a Member of the Civil Division of the Most Excellent Order of the British Empire. Mr. Cary is a Senior Experimental Officer at the Radar Research Establishment of the Ministry of Supply at Malvern, and has been mainly concerned with aerial design. He was elected an Associate Member in 1953.

Election of General Council 1954/5

The August issue of the *Journal* will contain formal notice of the 29th Annual General Meeting of the Institution. The notice will include the nominations made by the General Council of members for the following appointments:—

President,

Vice-Presidents,

Six ordinary members of Council,

three of whom must be Members and three Associate Members.

Corporate members of the Institution are invited to nominate a member or members for election. Such nominations must be supported by not less than 10 corporate members and must be submitted in writing to the Secretary of the Institution, together with the written consent of such person or persons to accept office if elected.

Membership and Examinations Regulations

The new edition of the Membership and Examinations Regulations has just been published and copies may be obtained on application to the Institution offices. These incorporate the new graduateship examination syllabus (effective from November 1956) as well as giving the usual details of the requirements for membership, exempting qualifications and other general information. Reference is made in the Regulations to "Model Questions" based on the new syllabus, and an announcement about the availability of these will be made in the *Journal* in due course.

1954 Radio Show

Sir Miles Thomas, Chairman of the British Overseas Airways Corporation, is to open the National Radio Show at Earls Court, London, on August 25th. The exhibition remains open until September 4th and there will be a preview for overseas visitors and other special guests on August 24th.

This year's Technical Training stand will take a different form from that at previous Shows. It will include a small cinema showing training films and part of the stand will be devoted to the work of the Radio Trades Examination Board, on which, of course, the Institution is represented.

The exhibition will, for the first time, include a demonstration by the B.B.C. of outside television broadcasts as well as studio broadcasts on sound and television. Television programmes from seven different sources—six of them within the exhibition—will be seen continuously on the screens of several hundred domestic receivers. Cameras used will include the small industrial types and the "roving eye" which is a self-contained camera and transmitting unit, making it free of cable connections.

French Radio and Television Exhibition

The seventeenth Exhibition organized by the Federation Nationale des Syndicats des Industries Radioélectriques and Electroniques will take place from October 2nd to the 12th, 1954, at the Musée des Travaux Publics, Place d'Iéna, Paris 16. As in the case of the National Radio Show at Earls Court, there are to be television studios within the exhibition and television sets of all kinds will be simultaneously operating in a separate hall. A particular feature at the Exhibition will be programme relays from eight different European countries.

Information regarding the Exhibition may be obtained from: S.N.I.R., 23 Rue de Lubeck, Paris 16.

THE ECONOMIC USE OF DIGITAL COMPUTERS*

by

R. K. Livesley, M.A.(Cantab.), Ph.D.†

A paper presented on July 8th, 1954, at the Industrial Electronics Convention in Oxford

SUMMARY

The paper considers the factors which determine the economic use of an automatic digital computer for scientific and engineering problems. The two types of problem (a) involving a small amount of repetition work, (b) involving an indefinite amount of repetition work, are dealt with, and the necessity for treating the problem by the correct technique is stressed.

The author advocates the greater use of automatic computers as an economic method of solving many scientific and engineering problems rather than limiting their use to the solution of problems which would not have been solved by any other means.

Recommendations are made for the use of standard programmes which are adaptable to a variety of problems, and the necessity of avoiding the human computer is stressed.

1. Introduction

This paper examines some of the factors which may determine the success or failure of a computing project carried out on an automatic digital machine. It is concerned only with calculations which arise in scientific and technical engineering work, and does not cover statistical or commercial problems. The conclusions drawn are based largely on the author's experience of the Manchester University computer‡, which has now been in service for close on three years. During this period the Manchester computer has carried out many different types of calculation, and has been used by representatives of many outside organizations, as well as by research workers from various departments within the University.

Like other large-scale computers, the Manchester computer required a considerable period of preparation before it was ready to solve practical problems. During the first year of its working life the laboratory staff spent much of their time in developing a library of sub-routines for standard mathematical operations, and in finding out the best way of organizing the machine for various types of calculation. Many of the problems solved were of course of practical importance, but the main effort was directed towards exploring the possibilities of the new machine. Most of this initial exploration was carried out by mathematicians interested in computing for its own sake, and motivated by scientific curiosity rather than by a desire for numerical results.

Gradually, however, the machine came to be used by University and other research workers interested solely in obtaining solutions to their own particular problems. These in turn were followed by industrial users intent not only on results but also on obtaining them with the greatest speed and economy. It is interesting to note that this pattern of development occurs repeatedly in engineering work. The technical problems of building and operating a new machine are always followed by the economic problems of using it to the best advantage.

It is not extravagant to claim that during the last three years the potentialities of the Manchester computer have been almost completely explored. Like other large-scale machines of similar age, its future now lies in its success in solving practical problems, most of which must come either from industry, or from those government and industrial

* Manuscript received May 24th, 1954. (Paper No. 269.)

† Computing Machine Laboratory, University of Manchester.

U.D.C. No. 518.5.003.

‡ D. B. G. Edwards, "The Manchester University high-speed digital computer." *J.Brit.I.R.E.* 14, June 1954, p. 269.

research organizations capable of sponsoring computing projects.

Some of the problems which have been solved on digital computers have been so large that the calculations could not have been done in any other way. These problems, however, are rare, and it would be difficult to run a large machine efficiently if it were restricted to work of this type. The commercial success of an electronic machine depends also on its ability to solve the relatively simple problems of every-day occurrence more quickly and cheaply than could otherwise be done. In this more humble type of computing we must judge success or failure not only by the correctness of the answers obtained, but also by the amount of time and money spent in obtaining them. It becomes important not only to solve a problem, but to find the "best" way of solving it. The remainder of this paper is concerned with this aspect of computing work.

2. Types of Problem

From the computing point of view the numerical problems which arise in engineering drawing offices and research laboratories must be divided into two distinct groups.

2.1 Problems Involving a Finite Amount of Repetition Work

The most important feature of this type of problem is that the amount of work required is known beforehand. An electronic computer programme made up for such a calculation will become redundant when the computation has been completed, and must therefore pay for its creation during a relatively short working life. The amount of repetition involved may of course vary considerably, and this will usually decide whether the digital computer is the "best" instrument to carry out the work.

Nearly all "research" problems belong to this category. The end-product of the calculation is always a table of numbers, which may represent the solutions of a family of differential equations, the values of a mathematical function, or the data required for a given problem in engineering design. Such a problem might be the tabulation of "type" solutions covering all practical parameter values of a particular engineering product. This kind of work is well suited to a digital computer, but is only practicable when the number of independent parameters is small.

2.2 Problems Involving an Indefinite Amount of Repetition Work

Most engineering calculations, however, relate to certain stereotyped problems which recur at frequent intervals, and which will, as far as can be seen, continue to require solution for many years to come. This type of work is particularly prevalent in engineering firms doing contract work, whose products, whether steam turbines or shell roofs, must be designed individually to meet particular specifications.

Such calculations usually take the form of an analysis of a series of trial designs, to see if they satisfy certain conditions, that is to say, a standard form of calculation is applied to various sets of initial data. The large number of parameters involved in most designs usually renders it impracticable to use the "type" solution method mentioned above, so that there is often no alternative to analysing each new design as it is evolved. The ease with which such trial analysis can be carried out determines the extent to which the final product approaches the best possible design. One problem of this type common in civil engineering practice is the design of steel frameworks for buildings and bridges. Here the aim is to find the lightest and cheapest frame which will support the applied loads with safety. As long as steel-framed structures continue to be built, designers will have to carry out stress-analysis calculations, repeating essentially similar numerical work with different sets of data.

It is in this type of problem that the digital computer may find its most fruitful field of application. A "standard" programme converts the computer into a special-purpose machine for carrying out a certain kind of calculation, so that each individual problem can be solved as easily as a mechanical part is made on an automatic lathe.

3. Factors in the Design of Standard Programmes

Finding the "best" way of solving a given problem on a digital machine involves balancing several opposing factors. We may list these as follows:—

(i) Mathematical and numerical accuracy.

(ii) Ease of data preparation and convenience of output.

(iii) Time spent on mathematical research.
(iv) Time spent on programming and programme testing.
(v) Machine running time and cost.
(vi) Generality of application (in "standard" programmes).

The relevance of these factors will of course vary considerably according to whether the problem belongs to group 2.1 or 2.2.

The standard programme, as we have seen, is concerned with numerical calculations which arise quite frequently, and which are possible, though laborious, to do by hand. They are therefore relatively simple problems for a digital computer, taking only a few minutes of machine time. A digital machine is usually from 200 to 500 times as fast as a human computer, so that a routine calculation which normally takes 100 hours on a desk machine may take less than 15 minutes when done automatically. Since most routine computations in industry take much less than 100 hours, one may conclude that machine running time is usually of minor importance in the design of standard programmes.

It is clear that if such a programme is to be used repeatedly on many different problems, time spent on mathematical research and programme design is a worth-while capital investment. The programmer is not usually restricted by problems of computer running time, and can devote most of his energies to making his programme as general as possible. It is better to have one programme covering all problems of a certain type than a slightly faster one which can only be applied to a few special cases.

The idea of the standard programme is really an extension of the simpler concept of the library sub-routine, which has a similar claim to permanent value. Many of the general principles of good design apply to both. A programme for a group 2.1 problem is usually operated by its creator, and, like other research apparatus, does not have to stand the wear and tear of continual use. A standard programme, however, is essentially a production tool, which may be used by many different operators. It must therefore be made "foolproof" both as regards operation and data preparation, and difficulties must be foreseen, even if they can only arise in certain rare cases.

It is most important that the programme should be designed to minimize human error. Such errors are all too common, and are often more difficult to detect than in hand computing work. They may occur in three different places, namely :—

(*a*) During preparation of the initial data.
(*b*) During the operation of the programme.
(*c*) During the interpretation of the results.

Errors during data preparation may be minimized by arranging the programme so that the machine takes in data in the form in which it is naturally presented by the user. Small preliminary calculations, involving scaling, evaluation of coefficients, etc., are sufficiently simple to invite careless treatment, with the result that the machine may get supplied with the wrong data. For this reason it is foolish to programme the difficult parts of a calculation and neglect the easier ones. There is, however, another reason why it is good policy to feed the basic parameters of a problem directly into the machine. The first part of many calculations consists of evaluating various coefficients from the initial information. These coefficients are usually far more numerous than the original data, so that if they are calculated by hand outside the machine, many more quantities will eventually have to be prepared for input. Whether input is by punched cards or paper tape, the smaller the volume of material the less will be the chance of mistakes. For similar reasons, the programme should print out the final answers rather than leave the last few steps to the human computer.

Machine errors during the operation of standard programmes are rare, since the machine time used is usually small. If errors are suspected, it is often better to repeat the calculation as a test for consistency than to inflate the programme by numerous checking sequences. It is hardly necessary to say that standard programmes should never invite human error by requiring extensive manipulation of the machine controls. Several standard programmes have already been developed for the Manchester computer*, and these are available to practising engineers with problems to solve. It has been found in practice that they

* R. K. Livesley. "The utilization of electronic digital computers in engineering practice," *Engineering*, 176, p. 351.

can be run by relatively unskilled operators, and one programme for structural analysis* has been used commercially on several occasions.

The standard programme has been compared with a special purpose machine tool for production-line work. Just as a machine tool is re-designed in the light of operating experience, so we may expect standard programmes to be streamlined and extended as they are used by practising engineers.

4. Digital Computers and Mathematical Methods

There are many problems, of course, for which a digital computer is not the best choice, and others where only one mathematical method is available. In many of the remainder, however, several alternative approaches are possible, and the success of a programme may easily depend on the correct mathematical technique being used. We have seen that two important factors in solving problems on a digital machine are ease of programming and generality of application, while actual calculating time is relatively unimportant. If we also remember that machines cannot make judgments based on intuition and experience, it is hardly surprising that many techniques designed for desk machines are unsuitable for electronic computers; the human computer, of course, is mainly concerned with minimizing calculating time, and draws extensively on intuition and experience to do this. As a result of this, automatic machines, although incapable of creative thought, are yet stimulating mathematicians to produce methods of analysis more suited to their needs.

These methods are usually characterized by formal simplicity, and often represent a return to the techniques of classical mathematics. The intuitive and short-cut methods of the human computer are extremely difficult to translate into programmes for general application, and even when this can be done, it may take an automatic machine as long to decide whether to take a short-cut as to do the calculation in full. A statement of the original physical problem in logical mathematical terms, however, may produce a scheme of analysis possessing form and symmetry much more suited to a digital computer programme. Thus it is often easier to programme the exact classical solution of a problem than the human computer's approximation.

The advantage of classical mathematics is enhanced by the existence of standard library routines. The programmer who formulates his problem correctly will often find that most of his programme is already available, since his calculation will consist of standard mathematical processes for which routines already exist. A less logical approach, on the other hand, might derive very little assistance from these routines. This factor is very apparent when the problem under consideration is a linear one, as such problems may always be stated in matrix terms. Digital computers are extremely suitable for matrix arithmetic, and library routines for all the standard operations will normally be available. In many cases the programmer need do little more than compose routines for setting up the initial data in matrix form. Although a matrix method is not always the fastest way of solving a problem, it usually possesses great generality, and this is often more important than speed.

The difference in the two approaches is particularly marked in engineering problems, where mathematical analysis is often developed solely for subsequent numerical calculations. The more often a problem has been solved on a desk machine, the more certain it is that the methods developed need re-examining before translation into a computer programme. One of the best examples of this may be found in the well-known mathematical technique of "relaxation," and the comparable methods of moment-distribution in structural analysis. Both these techniques were developed because classical methods of formulating linear problems led to large sets of simultaneous algebraic equations, the solution of which was tedious by hand. Indeed, many of the methods developed for elastic structural analysis are really devices for avoiding the formal solution of large sets of linear equations. It is rather strange to find that with a digital computer there is a marked tendency to try and reduce a problem to this form.

* T. M. Charlton and R. K. Livesley, "The analysis of rigid-jointed plane frameworks," *Engineering*, 177, p. 239.

The use of a digital computer encourages the formulation of a problem in its fundamental terms. This usually means that the basic concepts are kept in their simple form, instead of new and more complex concepts being introduced to simplify the numerical work at the expense of clarity of thought. Thus it is hoped that the mathematical analysis developed as a prelude to a computer programme may throw fresh light on the real nature of a problem. In the same way it is expected that the possibility of using a computer to obtain exact solutions will stimulate fresh theoretical work on problems at present treated empirically.

5. The Human Problem

The development of the digital computer has led to the appearance of a new type of specialist, the "programmer." The solution of a problem for which a standard programme exists requires only a competent machine operator, but the preparation of a new programme requires considerably more. The speed of an electronic comnuter amplifies rather than conceals human inefficiency, so that an automatic machine sets a high price on human competence. This problem has been discussed in a recent paper by R. A. Brooker*.

When a new problem is programmed for a digital computer, the programmer must possess three kinds of knowledge :—

(*a*) A knowledge of the fundamentals of the problem.

(*b*) A knowledge of the potentialities of the machine to be used for the calculation (and ability to programme for it).

(*c*) Sufficient mathematical knowledge to formulate the problem so as to make the greatest possible use of these potentialities.

Now it is clear that in general no one person will possess all these types of knowledge. Usually the engineer who first encounters the problem has only knowledge of type (*a*), while the programmer only possesses types (*b*) and (*c*). At first sight it would appear easier for the programmer to learn the engineer's problem than for the engineer to learn to programme. It is true that for any particular problem the first course will probably produce results more quickly, but as a long-term policy it has several drawbacks.

Firstly, the engineer often finds it difficult to formulate a problem in its basic mathematical terms. He is apt to present the programmer with the scheme of calculation which he has himself used on a desk machine, and be suspicious of any new mathematical methods. Further, it is often very difficult for the programmer to find out all the implied assumptions, many of which the practical engineer may regard as quite obvious, and therefore not worth mentioning.

Secondly, the engineer will remain ignorant as to how his problem was solved, and must rely on the specialist programmer for all his information. He may remain unaware that a digital computer could easily solve several more of his problems, and he will be completely unable to build an automatic machine into the rest of his organization. At the moment a digital computer is all to often called in as a last resort when all other methods have failed. The more economic approach is to consider using a digital machine at the start of a problem, and to allow this to direct the course of any mathematical analysis which may be required.

To get industrial designers and technical management to think of the digital computer first rather than last will require a considerable amount of education. This education does not only imply that some engineers should learn to use digital machines. Such engineers also need a suitable mathematical education, based more firmly on the fundamental mathematical techniques. It would not be surprising if this in itself did not have a beneficial effect on engineering progress as a whole.

* R. A. Brooker, "Application of digital computing techniques to physics," *British Journal of Applied Physics*, 4, p. 321.

APPLICANTS FOR MEMBERSHIP

New proposals were considered by the Membership Committee at a meeting held on June 22nd, 1954, as follows: 11 proposals for direct election to Graduateship or higher grade of membership and 21 proposals for transfer to Graduateship or higher grade of membership. In addition, 54 applications for Studentship registration were considered.

The following are the names of those who have been properly proposed and appear qualified. In accordance with a resolution of Council and in the absence of any objections being lodged, these elections will be confirmed 14 days from the date of the circulation of this list. Any objections received will be submitted to the next meeting of the Council with whom the final decision rests.

Transfer from Associate Member to Member

ELDRED, Eustace Macdonald. *London, S.W.1.*

Direct Election to Associate Member

CORREA, William Raymond. *Calcutta.*
EWEN, Alexander Bruce. *London, N.W.2.*
McLACHLAN, Kenneth Roy. *Southampton.*
VINYCOMB, Reginald Knox, B.Sc. *Lightwater, Surrey.*

Transfer from Graduate to Associate Member

BARKER, Peter. *London, S.W.5.*
HALSALL, James Richard. *Welwyn, Herts.*
RAMAN, Capt. Subrahmanya. *Deolali, Bombay State.*

Transfer from Student to Associate Member

PORAT, Dan Israel. *Rehovoth, Israel.*

Direct Election to Associate

DAVID, Thekekara Pylunny. *Insein, Burma.*

Transfer from Student to Associate

WOODFORD, Paul Ivor Keith. *Trieste Force.*

Direct Election to Graduate

DANCE, Philip Ernest. *Bristol.*
MILLBURN, John Richard. *Aylesbury.*

Transfer from Student to Graduate

BETTERIDGE, John Edward. *Stoneleigh, Surrey.*
BRIDGEMAN, James Neville, M.S. *Croydon, Surrey.*
CORDUKES, George William. *Scarborough.*
KAR, Bibhuti Bhusan. *Orissa.*
NAYAR, Vattekkat Krishnan Kutty. *Deolali, Bombay State.*
ROBINSON, Gordon Stanley. *Ashford, Middlesex.*
SHAHZAD, Iqbal Hasan. *London, W.4.*
SWAMINATHAN, Mayaram S., B.Sc. *Madras.*
WAHAB, Abdul. *Karachi.*
YOUNG, Lester Harold. *Belize, British Honduras.**

Studentship Registrations

BAHL, Prem Parkash, B.Sc. *Jodhpur, India.*
BHAT, Manohar Kashinath. *Bombay.*
BLACKMORE, Kenneth John. *Torquay.*
BONNER, John Stafford. *West Hartlepool.*

CATER, Capt. Edward Alfred, Pakistan Army. *Catterick Camp, Yorkshire.*
CHAUHAN, Om Prakash. *Jabalpur.*
CHHABRA, Yog Raj, B.Sc.(Hons.). *New Delhi.**
CHRISTENSEN, Svend Aage. *London, W.2.*
CROLE-REES, David George, B.A.(Hons.). *London, W.C.1.*

DARSHAN LAL, B.A. *Dehra Dun.*
DHALL, Raj Kumar. *New Delhi.*
DUNN, Alan George. *Hull.*

FREEMAN, Kenneth George, B.Sc. *Wrexham.*

GIDDENS, George Keith. *Hounslow, Middlesex.*
GURDIAL SINGH. *Kuala Lumpur, Malaya.*

HALTOVSKY, Efraim David. *Jerusalem.*
HATTANGADI, Vasant Annaji, B.Sc. *Dharwar, India.*

JEFFS, John Edwin Donald. *Chorlton-cum-Hardy, Lancashire.*

KALANZI, Augustine Peter. *Kampala, Uganda.*
KARTAR SINGH. *Mhow, India.*
KASINATHAN, T. S. *Bangalore.*
KHOSLA, Avtar N. *Kanpur, India.*
KOCIKOWSKI, Stefan. *Wellingborough, Northants.*
KRISHNAMURTHY, G., B.A. *Madras.*
KRISHNASWAMY RAO, M. S. *Bangalore, India.*

LEIGH, Ethnan Hector. *London, W.2.*

MATHEWS, Abraham. *Agra, India.*
MELISSEN, Johannes Martinus. *Breda, Netherlands.*
MENON, K. P. V. *Madras.*
MENZIES, Duncan Alexander John. *Newton Mearns, Renfrewshire*
MERRY, John Alfred Valentine. *Bishopbriggs, Glasgow.*
MONTEIRO, Alfred Peter. *Bombay.*
MOUNTFORD, Keith Patrick. *Bournemouth.*
MYAGERI, Shivaling, M.Sc. *Welwyn Garden City, Hertfordshire.*

NICE, Lt. Richard Keith, R. Signals. *Catterick Camp, Yorkshire.*

OLSEN, George Henry, B.Sc. *Newcastle upon Tyne.*
OM KUMAR. *Kanpur, India.*

PERERA, R. P. K. Saranasena. *Kotte, Ceylon.*
PRABHAKAR, B. S., B.Sc.(Hons.). *Bangalore.*

RAJAGOPALAN, R., B.Sc.(Hons.). *Trichinopoly.*
RAMARAO, Varada. *Bangalore.*
RASHID AHMAD. *Lahore.*
RAY, Asoke Kumar, M.Sc. *Calcutta.*
ROBINS, Robin Noel. *Nelson, New Zealand.*
ROY, Biman Bihari. *Bangalore.*

SAMBASIVAN, Krishnamurthy. *Hyderabad.*
SAMPURAN SINGH. *Delhi.*
SANGHOI, Chunilal V. *Bombay.*
SANKARAN S., M.A., B.Sc. *New Delhi.*
SATISH CHANDER SHARMA. *Coimbatore, South India.*
SHANNON, John Daniel. *Edinburgh.*

TYAGI, Mahavir Datta, B.Sc., M.Sc. *Tambaram, Madras.*

VISWANATHAN, G. S., B.Sc. *Ahmedabad.*

* Reinstatement.

APPLICATIONS OF A HIGH-SPEED ELECTRONIC COMPUTER TO A BUSINESS-ACCOUNTING PROBLEM*

by

A. St. Johnston, B.Sc. and S. L. H. Clarke, B.A. †

A paper presented on July 8th, 1954, at the Industrial Electronics Convention in Oxford

SUMMARY

The use of a high-speed electronic computer is described in two systems of equipment for carrying out invoicing, customers' accounts, stock control and wages computation for an organisation having 30,000 customers and 2,000 employees. The first system gives the more complete solution to the problems, using equipment which is not yet fully developed. The paper goes on to describe how the problems can be solved by a system using equipment commercially available at the present time.

1. Introduction

Electronic computing installations fall broadly into three classifications as follows:—

MATHEMATICAL

BUSINESS ACCOUNTING   CONTROL

Both analogue and digital computers may be used, the mathematical application being the first in both cases. Analogue equipment is usually highly specialized, in that the problem is solved by simulation of physical reality reduced to the simplest mathematical equivalent. Such equipment often solves the mathematical equations in real time (t, the independent variable) and so is readily extendable to control applications. This type of operation is at present, apart from commercial flight-simulators, confined almost entirely to classified projects where the process is far from industrial. The operation is nevertheless one of control—the line between mathematical and control being narrow and depending really on whether non-computing equipment is included in the simulation loop. The business-accounting field would not seem ever to offer much scope for the analogue machine.

The digital computer is at present only just ceasing to be confined solely to the mathematical field. In this case it is the business-accounting field rather than the control field which is giving applications. Some control applications have been demonstrated but these are, as usual, confined to classified projects.

The differences between the three fields of application as far as digital machines are concerned may be characterized as shown in Table 1.

The process-control characteristics are somewhat nebulously defined, as applications in this field will differ widely and no study of general requirements has been made.

The figures quoted for mathematical machines are typical only in that machines having such characteristics are adequate for many applications, although a user will use an available machine up to the limit of its capacity whatever that may be, and will then consider any machine with lesser capabilities as being useless.

The business field will almost certainly see, in the course of time, the greatest application of digital equipment. It is therefore the most interesting one to speculate upon at the present state of the computing art.

2. Business Accounting

A certain amount of confusion exists, and indeed definition is difficult, as to where the function of input/output ends and storage begins. The heart of a business problem such as invoicing or payroll computation, generally consists in processing large amounts of original information in the light of a comparatively small amount of new data, giving out some new data essentially in printed form (for mere men to read) and also altering small portions of the original data.

* Manuscript received 21st May, 1954. (Paper No. 270.)

† Elliott Brothers (London) Ltd., Boreham Wood, Hertfordshire.

U.D.C. No. 518.5:621.389:657.

It is in this last requirement that the difficulty comes with available equipment. Basic data that require no alteration can be stored almost as conveniently on punched cards, punched tape or magnetic tape, but only magnetic tape allows portions of the basic data to be readily altered. To use punched cards as basic data storage allows a business system to be operated satisfactorily, as LEO* is showing, but there is—if nothing else—a waste of paper in having to repunch a fresh card at every operation. It would appear that the magnetic tape method of solution is the most elegant, and although it is not yet possible with equipment at present commercially available in this country, we have considered a possible system in some detail.

3. Invoicing

To illustrate the use of the Elliott 402 type computer† with such ancillary equipment in a business-accounting application, consider an organization marketing a limited variety of articles in constant demand throughout the country. Such an organization may have about 50 depots for the distribution of its goods. Each depot will carry stocks to last a month or six weeks, and salesmen will call on wholesalers and retailers and make a daily report to Head Office.

In such an organisation there are two major accounting problems which an automatic machine must solve. The first is invoicing, and the second is wages. There are other possible applications such as raw material, stock-control and purchasing, but discussion is confined to the two problems mentioned above.

The invoicing problem is assumed to cover the whole course of an order, from the receipt of the salesman's report to the recording of payment by the customer. Thus a more detailed description of the accounting system followed by this firm is necessary before discussing the application of a digital computer.

It will be assumed that there are about 80 salesmen who cover territories which may spread into the regions of two or more depots although in general, this will not be the case. The salesmen will visit, in all, about 30,000 customers and may send in up to 1,000 orders per day. From these orders, invoices are raised if the stocks of the depots can supply the demand, and if the customer's accounts do not prove to be "in the red." Each charge for goods ordered will vary acording to the customer's discount grading which depends on the volume of his trade.

From the totals of the invoices going to any one depot in a day, the amount of goods needed for replacement of stock can be found and sent off accordingly with the invoices for distribution by the depot.

Also from the invoices, the accounts of the customers will be maintained up-to-date so that when payment is made it can be seen whether an extra discount for prompt payment has been earned. Thus, once the invoice has been raised bearing the name and address of the customer, the items of the order and their cost, together with the date, all the accounting

* T. R. Thompson "Application of Electronic Computers to Clerical Work." Brit. I.R.E. 1954

† A brief description of this machine is given in the Convention paper. (To be published.) Appendix.

Table 1

Digital Machine Characteristics
(order of magnitude only)

	Storage Capacity	Input		Output	Programmes
Mathematical	10^5 bits	Single channel	Digital 250 bits/sec.	Digital 10 charac./sec.	Complex
Business	10^7 bits	Several channels	Digital 1000 bits/sec.	Digital 100 charac./sec.	"Simple"
Process-Control	10^4 bits	Multi channel	Analogue	Multichannel analogue	Simple

information is present and the possibility of supplying the order has been checked.

For the application of a digital computer to this task we must first assimilate the data contained in the salesmen's reports. This may be achieved through the medium of punched paper tape which can be read at high speeds photo-electrically. In order to sub-divide the orders into groups pertaining to single depots, where a salesman's territory spreads into more than one depot, two tapes will be prepared. These tapes are sorted as they are punched, or as they come in over teleprinter lines into group numerical order.

The next requirement, in order to use the information contained on the paper tape, is some form of storage in which to hold the depot stock positions, the customers' accounts and also the records of the salesmen. This storage will be a magnetic film, since access to any one part of the store will only be required for a short period of time once a day.

The third requirement is for a line-at-a-time printer to carry out the printing of the invoices, which is capable of working at a speed of 2 lines a second or more, and the last requirement is for a computor programme of instructions to do all this. Fig. 1 is a block diagram of the computer system in this example.

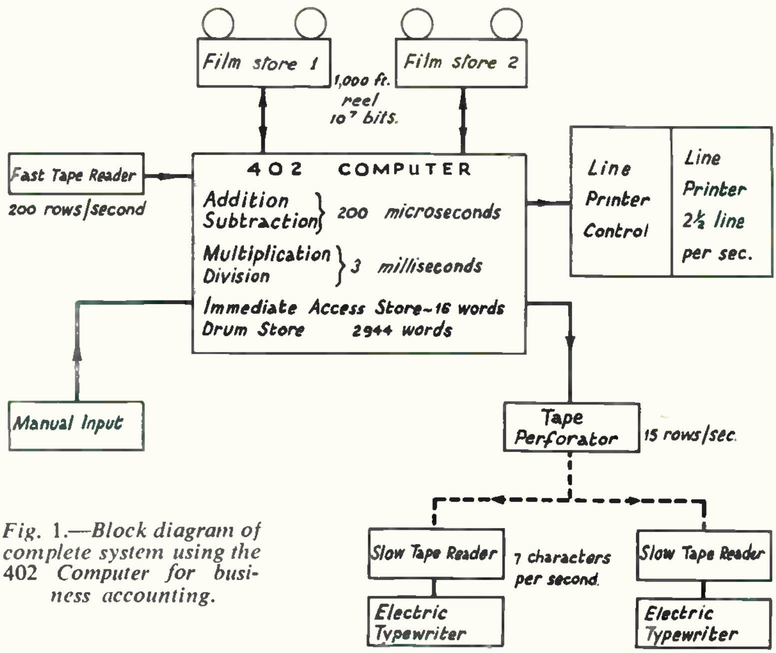


Fig. 1.—Block diagram of complete system using the 402 Computer for business accounting.

Although the organization of the data on the magnetic film will, in fact, be dictated by the programme, explanation will be made simpler by discussing this organization first. Since it is not a practicable proposition to insert pieces of film into a reel at will (as odd sheets of paper can be put into a file) it is unfortunately necessary to leave the maximum amount of space for each customer although he may at present be selling only one line. (It is possible that he may sell more in future.) Thus for each and every customer the space for the data listed in Table 2 must be allowed, assuming the firm to be selling 20 lines.

Table 2

Storage requirement for each customer

0	Serial No.	5 Alpha-numeric digits
1	Name and address	70 " " "
2	2 Invoices with date and No.	116 Decimal digits
3	Invoiced totals for 4 months including date and No.	74 " "
4	Payment totals for 4 months including date	54 " "
5	Balance to date	7 " "
6	Balance 4 months ago	7 " "
7	%age of turnover	8 " "
8	Discount rating	1 " "
	Total (in binary digits)	approximately 1,500

On 35-mm magnetic film, each customer might require about 1½in. of film for his records, which compares quite favourably with the use of microfilm. This means that about 8,000 customers could be catered for by one 1,000ft. reel of film, so that four reels would be necessary in this example. A second magnetic film would be used to store the data relevant to the salesmen and depots, together with data concerned with the analysis of sales.

A block diagram (Fig. 2) shows the six main items in the invoice accounting together with their connections with information in the store. The invoice accounting will then proceed on the following system. The subdivisions of each stage may in fact be carried out simultaneously by interleaving the orders in the programme.

3.1 *Invoice Programming*

Stage 1

1 (*a*) The paper tapes from the salesmen are sorted into depot numerical order, joined together, and placed in the reader.

1 (*b*) The first customer film is put on reader No. 1.

1 (*c*) The film containing salesmen's and depot data is put on reader No. 2.

Stage 2

2 (*a*) The film on reader No 2. will also carry the computer programme for invoicing, which is read on to the magnetic drum store for rapid access during operation.

2 (*b*) The date is read in from the head of the paper tape.

Stage 3

3 (*a*) The first two characters are read from

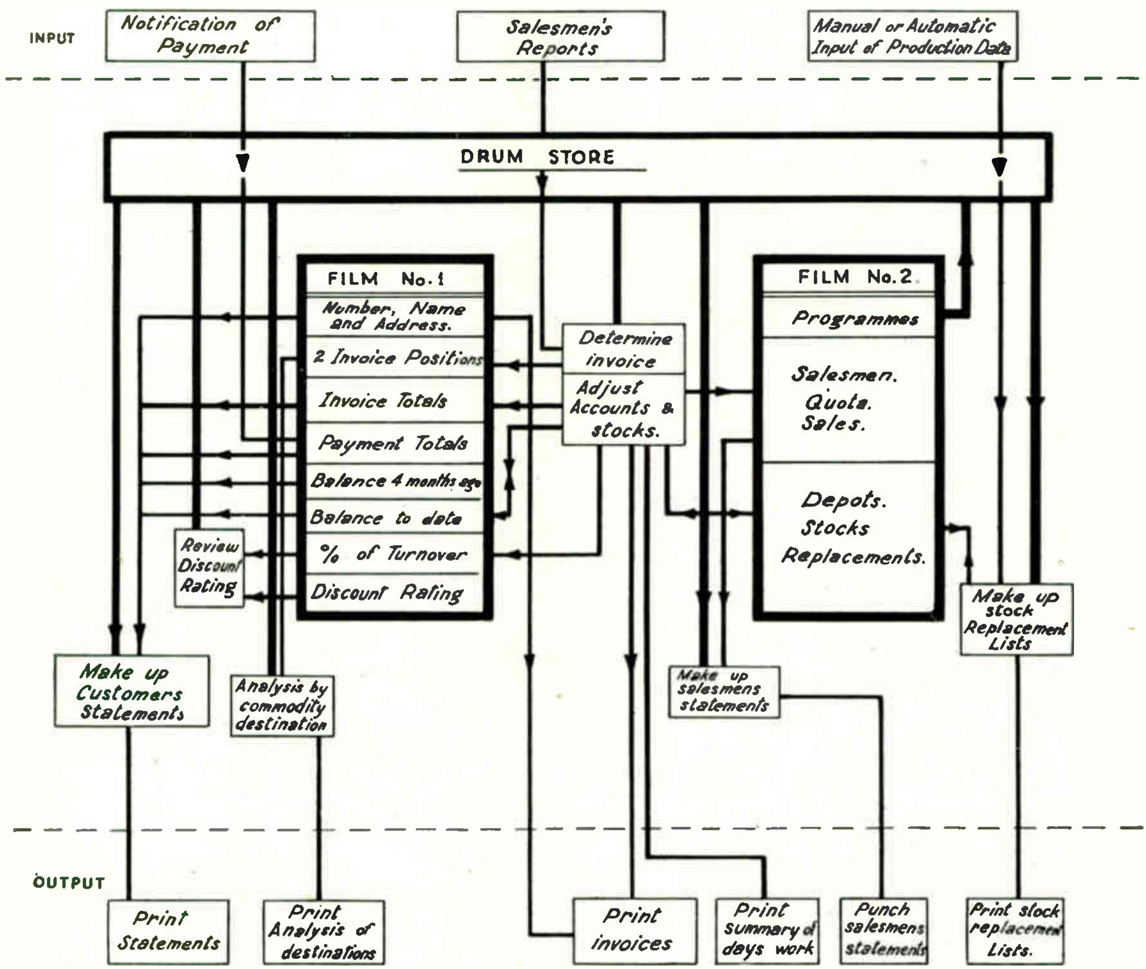


Fig. 2.—Block diagram to show the connections between invoicing programmes and separate parts of store.

the paper tape which gives the number of the first salesman.

3 (*b*) Film reader No. 1 locates the information pertaining to the first salesman's customers, while film reader No. 2 looks for the relevant depot information.

The customers' information will be located by the serial number which heads the information. The first two alpha-numeric digits designate the salesman, and will be the same for every customer in a block. The middle digit denotes the class of customer, and the last two are merely a code combination. Thus the customer with the number:—GK/Y/32, will be visited by Mr. Jones (GK), is a retailer in a small town (Y) and has the code combination 32.

3 (*c*) The present stock positions at this depot are transferred to the magnetic drum so that adjustment may be made by each incoming order.

Stage 4

4 (*a*) The first customer's order is read in from the paper tape. This will consist of fifty characters, the first three of which will specify the customer.

4 (*b*) Film reader No. 1 will search for the customer, and then the instructions given below will be carried out.

Stage 5

5 (*a*) Read out the whole of the data relevant to the customer and check that he does not owe the firm too much money.

5 (*b*) Allocate a number to the invoice and print this number and the date.

5 (*c*) Consult the depot stock position to see whether the order can be met. If the demand cannot be met on one particular line, that item of the order is transferred to the "second invoice" position in the customer's information. In this case there will be separate runs on subsequent days before the days orders are dealt with to clear up outstanding orders in this "second invoice" position. Adjust the depot stock positions when orders are satisfied.

5 (*d*) Print the name and address of the customer on the invoice.

5 (*e*) Read the customer's discount number. price each item accordingly, and find the total price.

5 (*f*) Modify the totals of each line at each price and also keep a running count of the totals of each line sold by the salesman, and for the depot.

5 (*g*) Adjust the balance to date in the account section and fill in the new line of the account.

5 (*h*) Adjust the percentage of turnover.

5 (*i*) Start printing out the lines of the invoice.

Stage 6

6 (*a*) Write the adjusted information back on the film.

6 (*b*) Continue printing out.

Stage 7

7 (*a*) Read back the information just written to check that it has been written correctly.

7 (*b*) Finish printing the invoice.

7 (*c*) Test to see if this was the last customer on a salesman's tape. If it was not the process goes back to Stage 4. If it was the end of a tape the process goes to Stage 8.

It will be noticed that in order to carry out the necessary transfers to and from the magnetic film, three traverses in the operating direction are necessary. This requires five traverses altogether to deal with one customer. There must be time to print out 25 lines on each invoice so that a time of 12 seconds may be assumed in which to do the five traverses of the film. In practice these traverses would take about 1 second each, of which all but about 1/10 second is used for stopping and starting the film mechanism. Thus it will be seen that no elaborate starting and stopping mechanisms will be needed to minimise the time taken in film transfers.

Stage 8

8 (*a*) Read the data referring to the salesman concerned from Film reader No. 2 and adjust it with the totals obtained in *5* (*f*).

8 (*b*) Check these totals against the quota and prepare a statement to be punched out on the perforator, which will later be fed to a typewriter.

Stage 9

9 (*a*) Write the modified data on film No. 2.

9 (*b*) Start punching out the salesman's statement.

Stage 10

10 (*a*) Read back the information just written on film No. 2 in order to check that it has been written correctly.

10 (*b*) Finish punching out the statement.

Stage 11

Test for the last tape of a depot. If it is not the last tape, return to Stage 3, and if it is the last tape, proceed to Stage 12.

Stage 12

Compute the amount of goods needed to maintain the stock level at the depot and enter this sum on film No. 2.

Stage 13

Test to see if this is the last depot. If it is not, all the locations in the drum store which kept depot totals must be cleared, and the process again returns to Stage 3, having suitably indicated a change of customer film if necessary. If it is the last depot all the invoices have now been printed.

Stage 14

A running total will have been kept of the replacements necessary to maintain the depot stocks, and the total of each commodity is checked against the factory production, which is inserted manually to the machine, to see whether the whole demand can be met. If the demand can be met, the necessary despatch notes to depots can be printed straight away. If the production cannot meet the demand a decision of policy is entailed, which must be included in the programme. The machine could either find the percentage of the required quantity which can be supplied and allocate that percentage to each depot, or if management ordered, certain depots could be delivered with full replacements and others cut more drastically. When these amendments had been carried out the despatch notes could be printed.

Stage 15

The last routine operation on the machine is to print out the summaries of the day's business. This comprises the totals of each commodity at each discount level, the total volume of the whole, and also the total amount of goods to be despatched to depots.

3.2 *Statements and Analyses*

The other two major items in this accounting system are only required at less frequent intervals. The printing of statements will be either on demand, in the case of a query, or at the end of four months when the account is committed to a file to be kept for the statutory length of time. This will only necessitate a search in film No. 1 for the customer requiring a statement and printing out the Invoice totals and payments in date order together with the two balances.

An analysis of commodity destination will be required about once a week and will consist of a run through the customer films keeping running totals of all goods invoiced to various classes of customer (e.g. a retailer in a small town). At the end of each depot these totals will be printed out and then summarized at the end of the four films. The designation of a customer to a class is made in his serial number.

This last problem, which in itself is perhaps the most straightforward of all, points the way to further development in accounting work. This paper has so far described the application of a digital computer in accounting to clerical work only. With the advance of the use of linear programming it may well be possible to programme the machine to utilize the results of the analysis of commodity destination to plan further production and stock distribution and so lighten the executive load.

4. Payroll

Methods of payroll calculation have been discussed elsewhere* from the point where the wage has already been calculated, and what remains is to make tax and other deductions. The system which has been described for invoicing can be used to process the information direct from the time clock through to the production of the payroll. We will consider here only the problem of producing a figure for the gross wage of each worker, since the method used would, from that point, be basically similar to those already described.

As in the case of the invoicing problem, the programme will be dependent on the organization of the information for each worker which is stored on a magnetic film. Table 3 shows the information which must be stored to enable the complete calculation to be performed. In the organization of workers the shift system may be extremely complex, varying from department to department in the length of the cycle, and from man to man in detail. Since this is the case it is best to

* B. V. Bowden (Ed.) "Faster than Thought," Chapter 22, page 246. (Pitman, London, 1954).

store the full details of each man's shift times, together with the hours worked in the week under consideration. The latter is in order to facilitate the labour costing which will follow the payroll calculation. A record of earnings for the last complete shift cycle is useful for calculation of sick pay. We have assumed a total of four deductions which will be for such things as Pensions, Hospital Savings, etc., but there could be more, or less with little effect on the problem as a whole.

Table 3

Storage for each worker (Decimal digits)

	1-week shift cycle	2-week shift cycle	4-week shift cycle
(*a*) Name	15	15	15
(*b*) Number	5	5	5
(*c*) Shift Schedule	42	84	168
(*d*) Clock Hours	42	42	42
(*e*) Past record	6	12	24
(*f*) Tax to date	6	6	6
(*g*) Gross pay to date	6	6	6
(*h*) Tax Code	3	3	3
(*i*) Nat. Insurance Code	1	1	1
(*j*) Effective rate	3	3	3
(*k*) Allowances, Code No. (Fire, Supervision, etc.)	1	1	1
(*l*) Deductions (Savings, Hospitals, etc.)	16	16	16
	146	194	290

Since the problem is carried out departmentally, it is not necessary to allocate storage space for a 4-week schedule in a department where only 1-week cycles operate, although space for a 2-week schedule would be allowed, throughout a department where both 1 and 2-week cycles operated. Thus, taking a 2-week schedule as the average for 2,000 workers we have a total storage requirement of 388,000 decimal digits or 1,552,000 binary digits which can be stored on just over 125 feet of film. Thus only one reel of film will be necessary for this application and will hold the programme as well as workers' information.

4.1 *Payroll Programme*

This means that the programme will follow the pattern described below:

Stage 1

Workers " clock on " either with conventional cards or some other device such as keys or press-buttons. The worker's number and the time are either punched directly on to paper tape which must be sorted by the machine into the correct sequence, or with comparatively little extra equipment, the sorting can be carried out automatically, tape being punched only at the end of the day.

Stage 2

Each day the sorted " clock " information is entered in the worker's information on the magnetic film.

Stage 3

3 (*a*) At the end of the week a tape is fed into the machine carrying the amounts of authorized overtime worked by each worker, together with bonuses earned (in time units).

3 (*b*) The first worker's information is found on the film and the hours worked checked against the schedule. Overtime arising from this check is then compared with the approved overtime. The clock hours are also checked to ascertain whether a bonus for good timekeeping has been earned.

Stage 4

Working time, overtime and bonus time are summed to give the wage when multiplied by the effective rate which has the allowances added to it to give the gross wage.

Stage 5

The tax and deduction calculations are performed and the payslip printed out on the line printer. At the same time the current line for the workman's individual tax record is punched on paper tape together with specified control functions. The tape containing this tax information is then fed to one of the slow tape-readers which is attached to an electric typewriter having ledger feed, so that the relevant cards may be put in one after another and the new line printed at the press of a button. In fact, it might be possible to devise a paper handling system to carry out this process automatically.

Stage 6

As this calculation has been proceeding an analysis of coins and totals for departments have been accumulating. These results are now printed out together with the total amounts payable to tax authorities, National Insurance, Pension Funds, etc.

The actual payroll being complete, the task of labour-costing is begun by presenting the machine with a tape prepared from the men's work tickets. These will allocate certain hours to specific expense numbers, so that when the programme is run, the number of hours the worker is supposed to have worked can be checked against his "clock" information, and the accounts of different expense numbers can be made up and printed out.

Many concerns have a large number of their men on piece-work and the foregoing method would not apply for their problems. However, if the labour-costing and payroll problems are considered as one large problem with the allowed overtime being punched on the same tape as the work ticket information, the production of a total time for multiplication by the effective rate becomes a simple matter in the case of the piece worker. Thus with the addition of a time-worker/piece-worker designation, men of both categories can be coped with in the same programme.

5. A System using Available Equipment

The equipment which has just been described cannot exist at the present time, since a sufficiently reliable magnetic film store is not yet available. Such a store is under development and an installation of this type might be possible in the not too distant future. It is, however, quite possible to utilise the high-speed processing of data, of which a machine like the 402 computer is capable, using equipment which can be obtained in this country. The method used is, in fact, somewhat bulky but is nevertheless considered to be an improvement on present day methods. This system was devised by Mr. E. W. Workman.

In order to give some idea of how the system will work, we will consider now its application to a wages problem. In this case there are a large number of men who spend some time on piece-work and the remainder on time-work, so that the labour costing will be done at the same time as the payroll calculation.

The bulk storage for the equipment would have to be on punched cards which would be converted to punched tape since the production model of the computer has punched-tape input. Each worker would have several cards, each of which would bear his clock number and a check combination. The first would hold only that information which would change from week to week, in this case tax and gross wage to date. A new card would be raised by the equipment each week to replace this one. The second card would carry the details of all standard deductions, including Tax Code and National Insurance, together with time-work and piece-work rates. This card would only vary infrequently (and so could be used for a considerable length of time). A third card would hold information regarding any special deductions or allowances. Only a small proportion of workers would have such a card. The fourth and subsequent cards would be raised each week from the work tickets of the men. These cards might be dispensed with and a tape punched directly from the work tickets. It is however, considered to be more reliable that the work-tickets should in fact be cards already gang-punched with the identifying information which can be written on by the foreman, and punched directly, with an automatic conversion to paper tape.

The cards of all four types are collated and converted to punched tape. Two tapes will be made, the first consisting of information unchanged since the last week. Cards, one, two, and three can be prepared before the work-tickets come in. The second tape would contain all work-ticket information. These two tapes could then be read into the machine and processed in the manner described in the first example (Section 4.1). The output would all be by punched tape which would contain three distinct sections designated by control combinations. The first section would contain all that had to be printed on the payroll, which would be converted to a card for tabulation. The second section would contain only the information for the new "card one" of the input, which would then be converted into that card. The last section would contain the information for the new line on the Individual Tax Record.

In actual fact the information in this last section is contained in the first section so that it is unnecessary to punch it twice. Then the

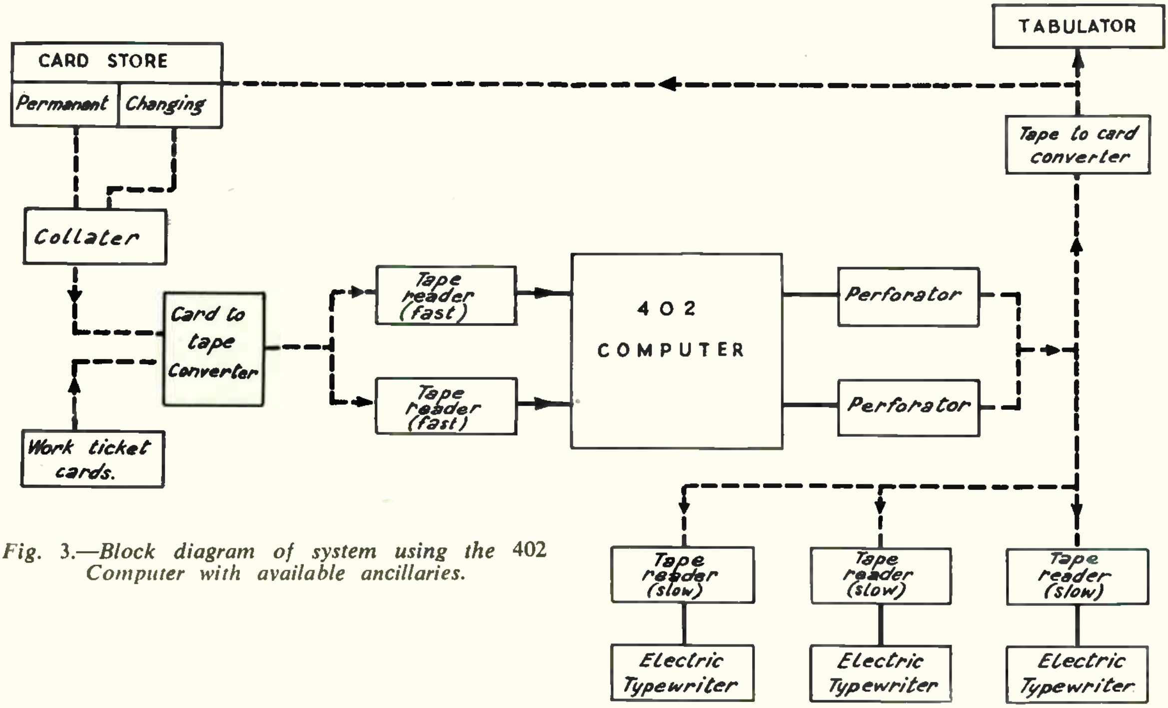


Fig. 3.—Block diagram of system using the 402 *Computer with available ancillaries.*

control combinations will designate which characters are to be typed on the Tax Record card.

The speed-limiting factor in this system would be the output perforator, so that the proposed system would have two perforators. The actual perforation of a result would take approximately twice the time needed for calculation so that an interleaved system would be used whereby, at any time, the computor would be doing the calculations of one man's wage, have just started punching another man's output on one perforator, and be just finishing a third man's output on the other perforator. Fig. 3 shows a block diagram of such a system.

As each department was completed the summaries of coins, total wages and expense accounts would be punched, with a final summary when the complete payroll had been produced.

6. Conclusions

This type of system would be rendered inefficient by the introduction of magnetic-tape storage of proven reliability. This is already in commercial use in the United States of America,* and under development in this country, and so the introduction of an interim system, which may soon be superseded by another one more fully automatic, might be undesirable. This is not necessarily entirely on account of equipment cost, but because the drastic alteration of any clerical organisation causes inevitable temporary disruption and inefficiency, so that it is seldom economical to introduce any system which is liable to be short-lived.

It is for this reason that we have considered the magnetic storage method in considerably more detail, although it may be some time before such a system can be introduced commercially. However, companies considering the introduction of any form of automatic system are well advised to study the changes necessary in their existing organization, well in advance of the availability of such equipment.

* L. D. Stevens. "Engineering organization input and output for the IBM 701 electronic data-processing machine"—Joint A.I.E.E.-I.R.E.-A.C.M. Computer Conference, December 1952, pp.81-85 (published March 1953).

D

7. Appendix: The Elliott 402 Computer

The Elliott 402 computer is a high-speed digital machine capable of solving a very wide range of problems arising in the scientific and engineering fields. It consists basically of about 200 plug-in units which combine to form a versatile computer straightforward to use and yet affording considerable scope for ingenuity on the part of the programmer. These units together with stabilized power supplies, magnetic store, cooling and other ancillary equipment are housed in seven cabinets which also contain the punched tape input reader. An electric typewriter for the printing of results is also provided.

Numbers in the machine are the equivalent of nine decimal places in length and the store capacity is about 3,000 such numbers. This means that, in the case of the solution of simultaneous linear equations, for example, up to about 50 equations can be solved by utilizing the internal store of the machine.

In addition to the usual arithmetical operations such as addition, subtraction and multiplication, the machine also has a built-in divider which makes the process of division as fast as that of multiplication. Another instruction provides a "count and test" facility, automatically adding 1 every time the instruction is obeyed and at the same time testing the count so that control is transferred to another part of the programme when a predetermined number of operations has been completed.

The speed of the machine, which is indicated by the fact that multiplication and division take place in 3 milliseconds, is achieved with the use of only 550 valves and a power consumption of only 6kVA at 415V.

Its overall dimensions (13′ x 2′ x 7′ or 3·9 x 0·6 x 2·1 metres) make it eminently suitable for installation in a comparatively small room.

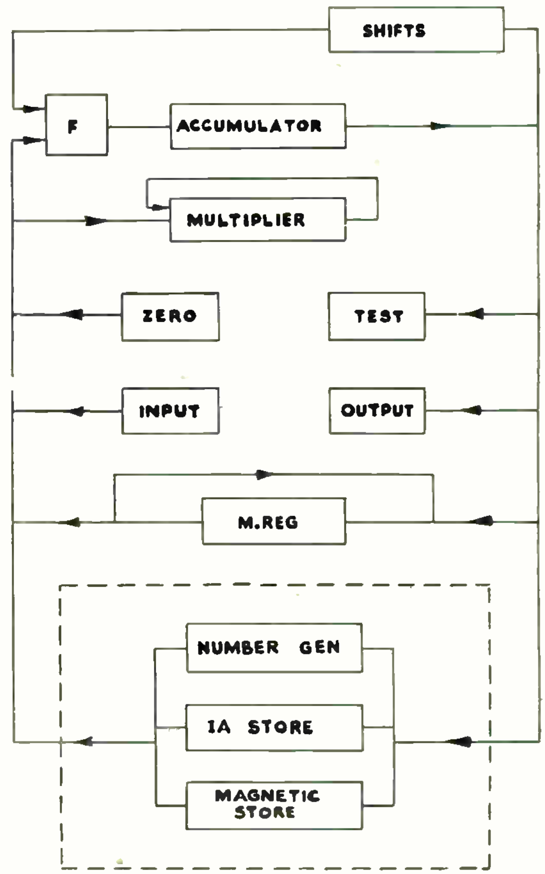


Fig. 4.—Block diagram of the Elliott 402 Computer.

IMPROVEMENTS IN ULTRASONIC FLAW DETECTION*

by

G. Bradfield, B.Sc.†

A paper presented on July 9th, 1954, at the Industrial Electronics Convention in Oxford

SUMMARY

The paper describes improvements in pulse systems of ultrasonic flaw detection in three fields: (1) A mode changer (to change longitudinal waves to shear waves) which is made of heavy material in the form of a laminated assembly which gives better efficiency and better discrimination than the usual device. (2) Damping, loading and circuitry for piezo-electric crystals to give improved discrimination and to reduce the adverse effects of rough surfaces. Additional monitoring means are described which assess and display the extent of the adverse effects of the rough surfaces. (3) Devices enabling beams of mechanical waves to be steered from chosen sites to search for flaws.

1. Introduction

The particular aspects of improvements in ultrasonic flaw detection which have been made at the National Physical Laboratory during the past four years are:—

(*a*) The use of barium titanate as a piezo-electric element in place of quartz.

(*b*) The use of heavy low-velocity mode changer wedges.

(*c*) The application of mechanical and electrical damping to the transducers to improve discrimination.

(*d*) The provision of steerable beam systems both mechanically and electronically operated.

The first item has already been discussed in some detail at the International Electro-Acoustics Congress at Delft last year[1] and also at the National Physical Laboratory Symposium on Ultrasonic Flaw Detection[2] in 1951, so discussion will be limited here to the last three items.

This activity represents a relatively small part of fundamental work carried out at N.P.L. on generating, launching and propagating mechanical waves in solids at frequencies up to 20 Mc/s or higher but it is noteworthy because it shows that this fundamental work produces, even on a short-term basis, quite valuable contributions to industrial techniques.

* Manuscript received June 16th, 1954. (Paper No. 271.)

† Communication from the National Physical Laboratory, Teddington, Middlesex.

U.D.C. No. 534.23: 620.179.

The techniques used in ultrasonic flaw detection are very similar to those employed in radar and because the latter techniques are well known, it may be found helpful to trace this similarity in more detail later.

2. Propagation of Waves in Solids

The propagation of mechanical waves in solids, which is the basis of ultrasonic flaw detection, is more complicated than that of radio waves. For the latter, Maxwell's equations can take the form

$$-\frac{1}{\varepsilon}\nabla\times\nabla\times\mathbf{D}=\mu\frac{\partial^2\mathbf{D}}{\partial t^2}\qquad\ldots\ldots\ldots(1)$$

where $\mathbf{D}$ is the electrical displacement vector

ε is the permittivity

and μ is the permeability of a non-conducting propagation medium

while from Hooke's law and Newton's law of motion the equation for mechanical waves becomes:—

$$\left(\frac{1}{\beta}+\frac{4}{3s}\right)\nabla.\nabla.\mathbf{u}-\frac{1}{s}\nabla\times\nabla\times\mathbf{u}=\rho\frac{\partial^2\mathbf{u}}{\partial t^2}\qquad\ldots(2)$$

where $\mathbf{u}$ is the particle displacement

ρ is the density

β is the compressibility

and s is the modulus of compliance (reciprocal of modulus of rigidity).

Equation (1) corresponds to a wave of velocity $(1/\varepsilon\mu)^{\frac{1}{2}}$ and, in simple cases,[3,4] (2) separates out into two independent equations, one in

$\nabla \cdot \mathbf{u}$ with velocity of propagation $\left(\frac{1}{\beta\rho} + \frac{4}{3s\rho}\right)^{\frac{1}{2}}$ and the second in $|\nabla \times \mathbf{u}|$ with velocity of propagation $(1/s\rho)^{\frac{1}{2}}$. Although the former, known as an irrotational, or longitudinal or compression wave, has no counterpart as an electromagnetic wave, the latter is formally identical: it can be termed a rotational wave though often called a "distortional" "shear" or "shake" wave.

Fig. 1.
Model of solid medium.

By taking density as analogous to permeability, i.e. to inductance, compliance as analogous to capacitance, and stress and strain as analogous to voltage and charge respectively, a mechanical medium can be represented by an iterative network as in Fig. 1 where $\bar{s}$ takes either of the two values $1/(1/\beta + 4/3s)$ or s. However, it is possible to represent the ability of the medium to support two independent waves simultaneously if the iterative network of Fig. 2 is used, a representation which may be termed a

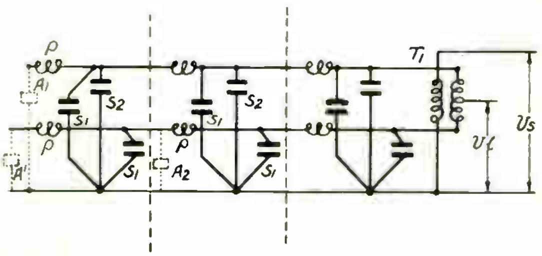


Fig. 2.—*Model of solid modified to permit propagation of waves of two different velocities.*

two-dimensional iterative network. The two velocities are now $(\rho s_1)^{-\frac{1}{2}}$ and $[\rho(s_1 + 2s_2)]^{-\frac{1}{2}}$ respectively. This network is also valid when the waves encounter a junction with another medium at say A_1. If this encounter takes place at both A_1 and A' the waves are reflected and transmitted still independently. This represents normal incidence of the mechanical wave on an interface between two solid media. If, however, the encounter occurs at A_1 and A_2 then the balanced operation is upset and one of the waves besides being partly reflected and partly transmitted at the junction, will also be partly

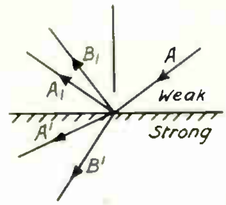


Fig. 3.
Waves at an interface between two solids.

changed to a second wave in the parallel network and originate waves there travelling both forward and backward. This phenomenon represents precisely what occurs when a mechanical wave encounters an interface between two solids at oblique incidence, although there an additional complication of the directions of propagation exists as in Fig. 3; thus four waves A_1, B_1, A' and B' are generated at an interface encountered obliquely by, for example, an irrotational wave A, A_1 being the reflected irrotational, A' the transmitted irrotational wave and B_1, B' the rotational waves.

3. The Mode Changer Made of Heavy Material

The situation can be particularized for the mode changer, e.g. of the perspex type, used in ultrasonic flaw detection as at Fig. 4. Fig. 5

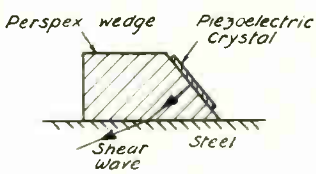


Fig. 4.
The perspex mode changer.

(calculated from Knott's equations[6]) shows the resulting splitting of the waves at a perspex-steel interface for an incident irrotational wave represented by an ordinate value of unity. The ordinate represents the product of intensity and cos α, β or β' respectively.

It will be noted in Fig. 5 that, even at the peak intensity for the shear wave transformation, which occurred at an angle of incidence of 30 deg. to 35 deg., only about one-fifth of the input energy is usefully employed. This is largely due to the impedance mismatch of 8 : 1 between the characteristic impedance of the perspex (irrotational wave) and of the steel (rotational or shear wave). Much better results can be achieved by reducing this mismatch. Since the desired beam directions largely govern the velocities they cannot be changed much;

thus the density of the mode-changer material must be increased without altering the velocity a great deal. The fundamental work which has been carried out at N.P.L. on propagation in anisotropic materials has revealed one solution

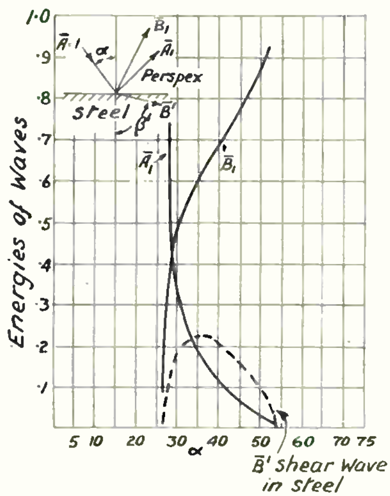


Fig. 5.—Energies of waves with perspex mode changer on mild steel.

which has worked very well. This is the laminated wedge,[7] shown in Figs. 6*a* and 6*b*, which is made up of layers of metal cemented together with a non-metallic bonding medium often of the epoxy resin type. Numerous forms of this device have been made. In that of Fig. 6*b*, a steel-araldite sandwich had a velocity as low as 2,500 m/sec. Space only permits of the mention

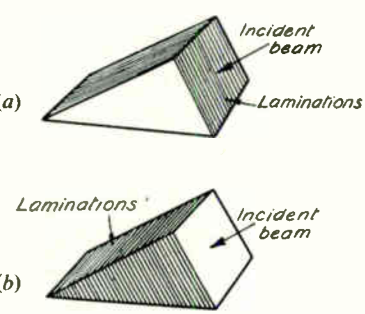


Fig. 6. Laminated mode changers.

of one other, a silver/araldite assembly as in Fig. 6*a* containing 78 per cent of silver by volume which had a velocity in the direction shown of 2,650 m/sec, i.e. almost exactly the same as perspex, but had a density of 7·9, which was 6·7 times greater than that of the latter. This wedge was very successful.

It is of interest to point out that these anisotropic materials in general support three waves in any direction and a model in a two-dimensional network exhibiting this behaviour is illustrated in Fig. 7. However, it will be realized that the medium shown in Fig. 6*b* would be represented, not by a network with uniformly distributed constants, but by a form analogous to a loaded telephone line. As is well known, this exhibits dispersion, and propagation is only possible when the wave encounters more than π structure elements per wavelength. No rigorous theory of propagation exists for the case of Fig. 6*a*, but the limitations in coarseness of structure in relation to the wavelength used has been found in practice to be rather similar to that for Fig. 6*b*, and when propagating any wave in it, the combined thickness of a metal and a cement lamination should be less than half the wavelength of the shorter shear wave.

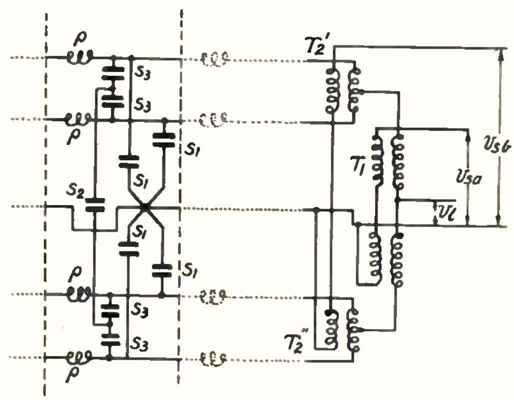
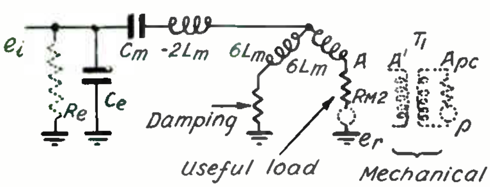


Fig. 7.—Model of solid modified to permit propagation of waves of three different velocities.

It should be noted that not only is there a great advantage in improved matching at the steel-mode changer interface, but it is equally advantageous to have a heavier medium than perspex to match to the barium titanate element, for the characteristic impedance of the latter (i.e. about 3×10^6 c.g.s units) is over nine times greater than that of perspex. Experience has confirmed that the combination of a barium titanate "crystal" with a heavy laminated medium of low velocity yields a mode changer of exceptional sensitivity.

4. The Importance of Matching the Transducer to the Medium

Besides the obvious one of gain in power, there are two other aspects of matching of great importance in ultrasonic flaw detection; one is the indication and reduction of the effect of surface roughness and the other is discrimination, i.e. the ability to distinguish between two singularities very near together, one perhaps much bigger than the other. Consider first



Approximate values:—
Re 1500Ω; Ce 2000 pF; Cm 180 pF; Lm 23μH; Damping (Rm1) 160Ω; Rm2 150–350Ω.

Fig. 8.—Equivalent circuit of piezo-electric transducer with both faces loaded.

Fig. 8 representing the equivalent circuit of a 20-mm dia. 2½ Mc/s barium titanate disc loaded on both sides (Compare Ref. 1, Fig. 9f). This approximation is sufficiently accurate for the present purpose. R_{M1} is zero with an air-backed transducer, but as mechanical damping is added to the back face, R_{M1} increases. While R_{M1} remains less than about $3/2\omega C_m$, the damping or decrement of the system increases, the band-width also increases and accordingly the

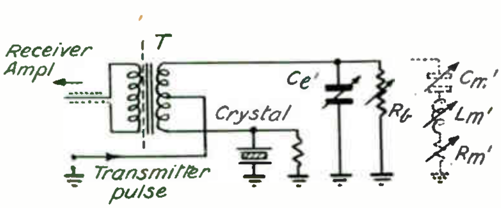


Fig. 9.—Anti-paralysis common transmit-receive circuit.

discrimination improves. The improvement obtained in the reduction of the paralysis period is very marked when the transducer is used as a common transmit-receive device. This paralysis is very troublesome for it veils the echoes from flaws near the surface. A balanced bridge circuit is customarily used as in Fig. 9 to reduce this difficulty as far as possible; the balanced circuit shown is satisfactory for general work, but improved results are obtained by the addition of extra balancing elements as shown on the right-hand side of that figure. (See Ref. 2, Fig. 5, page 9.)

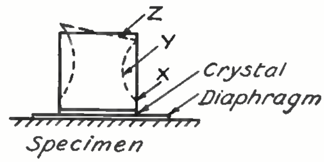


Fig. 10. Practical forms of "crystal" backings.

The physical form taken by this heavy damping material is shown in Fig. 10, which illustrates the assembly on a typical 20-mm dia. 2½ Mc/s disc. One material used very successfully is made up of Marko resin loaded with tungsten powder and has a density of 7 and characteristic impedance about 10^6 c.g.s. units, but carbonyl iron powder can also be used instead of tungsten with not too serious a loss of performance. To avoid specular reflection from the end it can be sloped slightly as at Z; a neck as at Y also helps. It is possible to grade the density, so achieving good matching at X, where it is required, but a higher attenuation further back. It has been found advantageous to introduce fibres for increasing the attenuation. Care must be taken not to include particles or air bubbles large enough to give serious scatter to the radiation, for this increases the background or "clutter." This problem is analogous to that of permanent echoes in radar equipments.

The excellent results achieved in this way have already been reported.[1, 2, 8 etc.] In an investigation carried out a year ago using devices of this sort, it was found to be possible to distinguish tiny cracks like incipient fatigue cracks even at the root of threads in bolts.[9]

5. The Effect of Rough Surfaces

When the piezo-electric element is provided with a backing of the type described above, the shape of the wave launched in a specimen does not differ very greatly whether the surface of the specimen is rough or smooth. One serious consequence, however, of using rough surfaces is the very grave reduction of the intensity of the wave launched into the specimen. This reduction may amount to 10 or even 30 db. Not only is the echo worsened by the lower transmitted intensity, but additional attenuation of the wave occurs before it returns to the receiver crystal. Now that a great deal of experience has been obtained on the reliable and successful use of ultrasonic flaw detection in industrial inspection, there has grown up a great desire, for instance, on the part of insurance companies, that the use of such a form of test should be mandatory, for example, for boiler inspection. Clearly the enormous effect of surface conditions is an obstacle of very great importance, for it is easy enough to show no flaw if the surface is so bad that no waves go into the specimen. The writer and his colleagues have attempted to devise means to reduce this danger and although their proposals will not entirely remove it, it is thought that

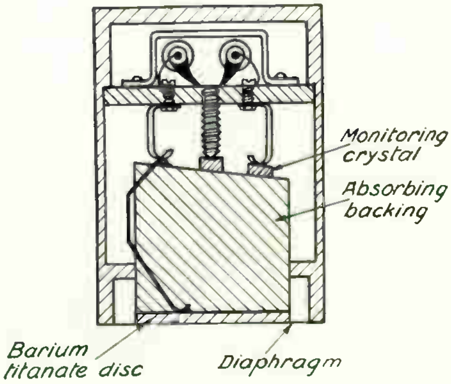


Fig. 11.—Probe with monitoring "crystal."

they merit serious consideration. Fig. 11 shows one form of a device for this purpose. Here a barium titanate disc is mounted on a diaphragm with an absorptive backing provided with an additional monitoring crystal. Mr. Woodroffe and the writer have recently carried out an investigation,[10] using such a device at the National Physical Laboratory. Fig. 12*a* represents the results of testing on a rough surface and Fig. 12*b* of testing on a smooth surface, and the device is so arranged that an additional picture can be shown on the cathode-ray tube just above the main trace. This consists of a steady echo from a delay line side-by-side with the signal received on the monitoring crystal of Fig. 11. In the case of the rough surface (Fig. 12*a*) this signal is appreciably greater than the standard delay line signal. For the smooth surface (Fig. 12*b*) it is seen that the flaw signal is increased owing to the smooth surface permitting greater energy to enter the specimen. This is achieved, however, at the expense of energy reaching the monitoring crystal which therefore falls to its normal value as shown. It is proposed that the two parts

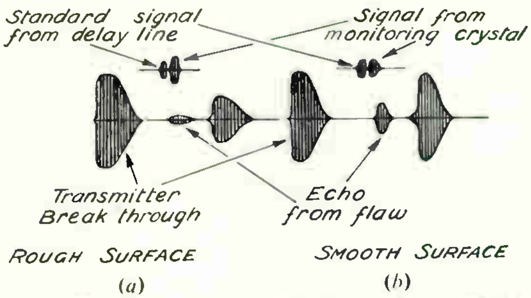


Fig. 12.—Cathode-ray tube indications when monitoring crystal is used.

of the trace should be photographed simultaneously and this would indicate whether or not a seriously poor contact occurred during the test. It is possible to provide a similar monitoring means for the mode-changer type of testing device as shown in Fig. 13.[10]

6. Steerable Beams

The writer has already discussed the use of steerable beams of a type in which the crystal is mounted on a bolster resting on the specimen under test in such a way that the crystal can be inclined while still radiating a beam into the specimen. In this way a beam can be directed to search for flaws, and such devices have indeed been successfully demonstrated.[1, 2, 8] It is likely that the best final solution is an instrument combining mechanical and electronic beam steering.

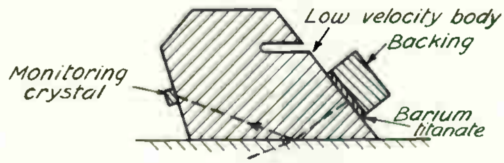


Fig. 13.—Modification of probe with monitoring "crystal" for mode changer operation.

Mechanically steered beams[12] suffer from the disadvantage, as in radar, of being relatively slow in operation and although this disadvantage can be made less serious by the use of persistent screens for the cathode-ray tube indicator as in radar, it is very much to be preferred if a series of beam positions can be selected extremely rapidly and can be displayed substantially simultaneously on the cathode-ray tube.

The advantages of such steerable beam devices for ultrasonic flaw detection are threefold:—

(1) Increased speed of search would result from simultaneously viewing several beam positions.

(2) Search would often be possible from a limited number of prepared surfaces thus saving labour in machining surfaces.

(3) Flaws sometimes occur at such attitudes that, using a common transmit-receive technique, only a certain inclination of the beam will reveal them. Such flaws would readily be seen if the beam angle were easily variable.

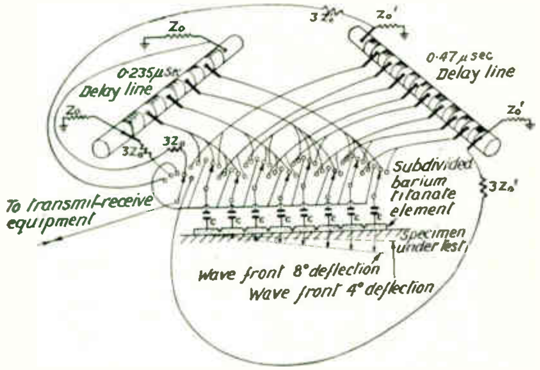


Fig. 14.—Steerable beam device operated electronically. A potential divider (not shown) is used at the central beam position.

One device which has been used successfully at the National Physical Laboratory for this purpose is illustrated in Fig. 14.[13] Here a grooved barium titanate "crystal," fitted with an absorptive backing (not shown), is connected so that its sections form part of the capacitative elements of a delay line and a short 2½ Mc/s wavetrain is fed to one end of the line. The result is that the right-hand radiation starts before the left-hand radiation from the "crystal" elements and the wave front is inclined at alternative angles of 4 deg. or 8 deg. according to which delay line is used. By feeding the delay lines at their alternative ends the tilt of the beam can take place in the opposite direction. In this way a total of five beam positions can readily be obtained with simple apparatus. Using a compact rotating switch these indications can be obtained in such rapid succession that they are effectively shown simultaneously on a cathode-ray tube either as a B-scope presentation or as a P.P.I. presentation. It may be mentioned that care has to be taken that the loss by radiation shall not attenuate the pulse in the delay line too rapidly, as it moves along; this can be achieved by the interpolation of capacitors C in series with the barium titanate sections.

7. Acknowledgments

The work described herein forms part of the research programme of the National Physical Laboratory and is published by permission of the Director. The computations for Fig. 5 are due to Mr. M. J. P. Musgrave of this laboratory. The construction of the devices described is largely the work of Messrs. E. P. H. Woodroffe, R. F. Pulfer and E. C. Pyatt.

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STATISTICAL COMPUTERS AS APPLIED TO INDUSTRIAL CONTROL*

by

P. Huggins (*Associate Member*)†

A paper presented on July 8th, 1954, at the Industrial Electronics Convention in Oxford

SUMMARY

The need and use of statistical methods for quality control of a continuous industrial process is discussed and some examples of quality control based on statistical techniques, but employing a "human" controller described. The advantages and disadvantages of automatizing such control from the engineering, economic and social points of view are considered. The prime functions of a statistical controller are discussed. An outline of some of the circuit techniques employed is given and two practical examples are quoted—one in the bakery industry and one in cable manufacture—of the application of automatic statistical control, with histograms, etc., showing improvements effected by the apparatus.

1. Introduction

A characteristic feature of modern industry is the "continuous process": liquids by the gallon: powders by the ton; articles by the million . . . mass production in fact, and mass production implies a *sameness* of the things manufactured.

However, it is axiomatic that no two particles of any substance are absolutely identical and so no two manufactured articles can really be the *same*, as they are in themselves, constructed from inequalities. Nevertheless, because man and his machines are endeavouring to make a uniform composite product, a fair degree of sameness does exist and the concept of a mean uniformity is acceptable.

2. Concept of Statistical Uniformity

If a number of discrete samples of a continuous production line were to be examined over a period of time, these samples would invariably show a variation about the norm—often represented by a histogram such as is shown in Fig. 1.

Extended to the limit, this histogram becomes the curve (the statisticians "normal" curve) shown in Fig. 2. This is the Gaussian distribution curve, having the form $\exp(-x^2)$ that repeatedly occurs in physical problems.

Not all production distribution curves are Gaussian, although the majority are near Gaussian and definitely symmetrical. Asymmetrical, irregular distribution curves usually indicate a lack of proper control of the production process. The ubiquity of the Gaussian curve in connection with mass production is not so surprising as it may seem at first, when it is realized that the convolution of two Gaussian

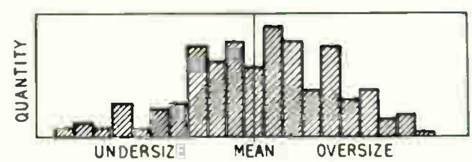

Fig. 1.—Typical histograms.

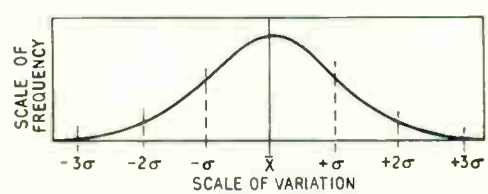

Fig. 2.—Gaussian distribution curve, derived from Fig. 1.

distribution curves results in a further Gaussian curve. The Gaussian character of the distribution curves can in consequence, be attributed to the following main factors:

(a) Randomness in material used.
(b) Randomness in machines used;
(c) The "human element."

If (*a*) and (*b*) are nominally uniform, they too will have Gaussian or near Gaussian characteristics. Experiment on "human error"

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also shows that the physiological make-up of man is such that he too normally straddles his target in a Gaussian manner; so we may assume that any "operator controlled" part of the process (i.e., "c") will also have statistical variation.

3. Use of Statistics for Quality Control

Mathematically, the Gaussian curve has two significant variables; the arithmetic mean ($\overline{X}$), which is the sum of the observations divided by their number; and the standard deviation (σ) which is the square root of the mean of the squares of the deviations of all the observations. Deviation may be defined as the difference between an observation and the mean of all the observations.

The statistical uniformity of the normal curve gives the manufacturers a most valuable tool. For instance, it is obviously not necessary to test every article manufactured on the line. Statistical theory will provide the manufacturers with the optimum number of samples that need be drawn from a consignment, or per hour, to provide data that his product is being kept within its normal limits.

Again, knowing the mean and standard variation enables the manufacturer to forecast the frequency of individual units that will be found within any desired range of the scale of measurement. For the normal curve, the percentage of observations lying within the standard deviation criteria are as shown in Fig. 3. The implications of such data can be of invaluable economic importance.

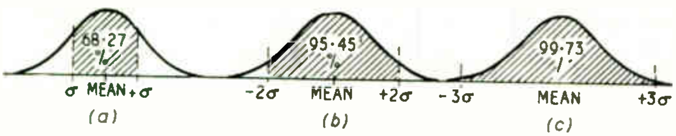

Fig. 3.—Distribution curves representing a hypothetical product falling into three tolerance ranges with a reject remainder of 0·27%.

As a hypothetical example, the curves of Fig. 3 might represent a process batch of resistors, where (a), (b), and (c) are the proportion at different tolerances, with a reject remainder of 0·27 per cent.

4. The Human Controller

In many production lines a skilled or semi-skilled operator will be found making "corrections" at some point in the process. The operator alters the speed of a motor, the ratio of a gear box, the size of a moulding cavity, or some similar physical variable. Now in some cases, this operator may be performing a function that could well be carried out by a mechanical, or electro-mechanical servo system of fairly simple conception—but most production engineers are fully alive to the potentialities of the more usual servos: the presence of the measuring, thinking human indicates that a straightforward first or second degree servo may not suffice.

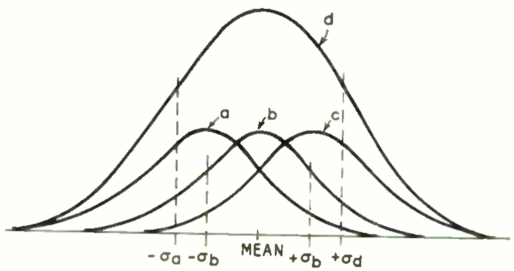

Fig. 4.—Series of distribution curves illustrating variation with time.

a—1st hour's production.
b—2nd hour's production.
c—3rd hour's production.
d—Total production a+b+c.

The fact that the operator is able to contribute towards increasing the uniformity of the product indicates the presence of some changes of a *periodic* nature (say due to temperature, humidity, etc.), as well as the purely random phenomena. This is akin to the electronic parallel of a small signal in the presence of Gaussian noise. So the distribution curve, although normal in character, is subject to variations in its intrinsic parameters and might, if uncorrected, appear from hour to hour as shown in Fig. 4. The net resultant of the three-hours' run is the production batch shown as curve (d)—far less satisfactory than if an operator had, from time to time made corrections, holding the production to within the limits of, say, curve (b).

An examination of the functions performed by the operator usually reveals that in some way he, or she, is intuitively appreciating the shape of the statistical curve, mentally locating its mean, and making compensatory corrections if the mean is straying from the optimum. This is done by taking periodic samples (or sometimes by observing a continuous measurement figure) and then carrying out empirical corrections when necessary. That there may be a time-lag between measuring and correcting, that for physical reasons there are a number of articles already completed between the measuring device and to correction point, and that occasional obviously incorrect articles may be manufactured due to machine faults, all add to the operator's problems.

5. Automatization

It is tempting to automatize the mental process of the operator—and to do his thinking and correcting for him. A robot computer-controller would indubitably perform the necessary calculations with relentless zeal and accuracy. But if such a computer is to be used, it must, in effect, possess the diverse powers of judgment vested in the operator. This is feasible, since the man's judgment is in itself based on logic.

Apparatus of the type of the well-known "computing engine" is not of course, a suitable practical solution to this problem, nor are the "business machine" computers which are primarily designed for large scale accountancy and the like. If the robot is to be an asset to industrial management, it must be engineered on lines that are functionally and economically acceptable.

Functionally it must perform in essence, the measuring, thinking and correcting process analogous to the human operator. The crux of the design lies in the appreciation of the essential factors that affect the distribution curve; how to obtain information on these factors, how to assimilate and digest such information, and how to make the necessary compensation. An engineering compromise must be made between omnipercipience and reliability: the simplest possible designs compatible with the results desired. This, unfortunately, means that the human controller (who obviously has powers of judgment outside the scope of his automatic counterpart) is superior in moments of unforeseen crises—a disadvantage that is more than offset by the long term alertness of the automatic plant.

The economics of installing a statistical controller vary from industry to industry but, in the main, it is possible to roughly predict the percentage of material that will be saved: this is usually the primary financial consideration. Saving of man hours, possible increased rate of production (the human counter-part, where it exists, is sometimes a bottle-neck) and the general benefits accrued from working to tighter limits, must also be taken into account.

If the problem can be reduced to a controller of reasonable proportions (say not more than 50 valves on the present day techniques), the user may expect a reliable service from the apparatus—provided it is manufactured on "industrial" lines. The actual electronic circuits used with the controller proper must of course, be designed with this point in mind. Components conservatively rated, uncritical circuitry that has been well tried and tested, absence of moving parts wherever possible, "failure to safety" techniques employed wherever they can be incorporated without greatly adding to the complexity of the design, all contribute towards trouble-free running.

6. The Functions of a Statistical Controller

Very careful, and sometimes extensive study of the production process and its "human controller" (if existent) must precede the design of the controller. It is upon this empirical data, and advice obtained from experts within that industry, that the conceptional ideas are based.

The preliminary investigation should disclose or decide the following:

1. How information of the production process is best obtainable (i.e., the means of measurement, transduction, etc.).
2. The pros and cons of continuous input information versus "statistical sampling" or discrete input.
3. What statistical parameters need be extracted from the input data to provide information of the trend.
4. How information of the trend should be stored.
5. How information of the trend should be "forgotten" if the trend does not persist.
6. How random subsidiary trends should be avoided as irrelevant information.
7. How the purely Gaussian "noise" of the systems shall be rejected.
8. The nature of the controlling mechanism and how it is to be operated.

9. The dynamics of the feed-back loop of the system as a whole.
10. What variables must be provided to cater for such contingencies as variations in size or grade, or limits, etc., for differing production runs.
11. What additional refinements can usefully be added to the system without undue complications.

7. The Basic Principles of the Statistical Controller

We desire to obtain information (for control purposes) of the trend of certain statistical data. As previously stated, Gaussian or near-Gaussian curves are completely expressed in terms of the parameters $\bar{X}$ and σ. Whilst field experience at this stage is somewhat limited, within those limits it has been found that the σ for any *particular installation* remains reasonably constant, the periodic variation occurs in $\bar{X}$ only (along the lines indicated in Fig. 4).

This leads to two convenient simplifications. Firstly, the basis of sensing the trend can be in terms of $\bar{X}$ only and secondly, the correction can be an arbitrary step function in terms of $\bar{X}$ only. The following hypothetical case gives an insight to the design approach:—

Suppose a preliminary investigation reveals that the short term statistical variation is the normal curve " a " whose standard deviation is $\pm\sigma_a$. However, it is found that throughout the day there is a periodic drift of the type already discussed (illustrated by Fig. 4), thus degrading the production limits.

Suppose then, for simplicity of analysis, curve " a," whilst maintaining its law, takes up a new position about a mean located at $+\sigma_a$ (see Fig. 5). As we are considering a classical case, the percentages shown in Fig. 3 apply and we can state the following assumptions :—In the case of curve " a," approximately 6 in 20 of the statistically sampled data lie outside the observation limits $\pm\sigma_a$. On an average, 3 in 10 lie outside $+\sigma_a$ and 3 in 10 lie outside $-\sigma_a$.

In the case of curve " b," 6 in 20 observations lie between the limits $\pm\sigma_b$ and 1 in 20 lie between $\pm 2\sigma_b$. On an average therefore, 5 in 10 will lie outside $+\sigma_a$ and only 1 in 20 will lie outside $-\sigma_a$.

If now we have a 3-state sensing device that gives information as to whether the individual statistical sample is " +ve error," " no error " or " −ve error," the arbitrary limits of error being say $\pm\sigma_a$, then when conditions are those outlined by curve " a," we should expect the mean of the statistical samples to be " no error "; and on the average not more than 3 in 10 will be outside either $+\sigma_a$ or $-\sigma_a$ If, therefore, we have a computer that resolves the algebraic sum of the errors, such a device would, on an average, read zero (" no error ") although the computer would make excursions either side of zero.

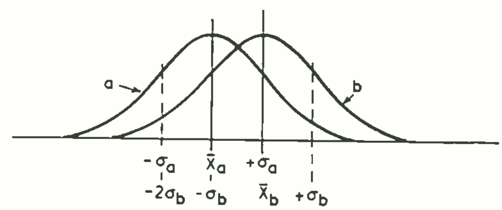

Fig. 5.—Standard deviation curves.

Suppose now, the computer is preset to make a compensating correction when the algebraic sum of the errors is $\pm$ 7 errors. The probability of the net resolution of the errors ever reaching $\pm$ 7 is negligible and so a condition of stability exists as long as curve " a " persists.

On the other hand, if production conditions were to suddenly become those outlined by curve " b," one could expect on an average that the actuation figure of $\pm$ 7 would be reached in 14 consecutive samples (assuming the computer was at zero when the change took place). This in turn can be made to instigate the necessary correction step to bring conditions back to curve " a."

Summarizing then, we see that the statistical computer, in its broad outline, takes the form of sampled information fed into a discriminating system that classifies it into " +ve error," " no error " or " −ve error " (quantizing). A storage unit retains information as to the net number of such errors that have occurred since the last correction was made. When the net total of such errors reaches a preselected figure, an appropriate correction (in both magnitude and sense) is made.

8. The Computer Variables

In general these are variables only in as far as the computer is concerned, being preset for an optimum performance on site. However, where several sizes of articles can be produced by the same plant, it may be necessary to have a range of settings for different production runs.

8.1. *Set Limits*

These determine what constitutes an error. For the hypothetical case outlined, the limits were made equal to the standard deviation σ. This is, in point of fact, quite a practical figure for many applications. These arbitrary limits represent a compromise between the sensitivity of the control system and the stability of the feedback system as a whole.

8.2. *The Sampling Ratio*

This is the repetition ratio at which information is sampled. In some cases it is both practicable and desirable (where the feedback loop has a short time constant) to inspect every article to obtain maximum benefit of the controller. In other cases, this might be impossible for mechanical reasons, or more likely, be unsuitably frequent for a slow periodic drift. Whenever possible, the sampling repetition is either number dependent or length dependent rather than time dependent, as this renders the system impervious to changes in production rate.

8.3. *The Error Selector*

This provides a control (preset or manual) to select the number of errors that must obtrude before corrective action takes place (i.e., 7 in the case discussed previously). The actual number chosen will depend on the circumstances, but usually lies between ± 5 and ± 10. Less than 5 would rather tend to lead to unwarranted corrections on the normal probability of the distribution curve.

8.4. *The Correction Degree*

The magnitude of the step correction is determined by this variable which is usually set up to bring the physical dimensions back to, or slightly beyond, the statistical mean ($\bar{X}$). It is not usually necessary to complicate the computer by making the correction a function of the rate of change of the error, provided "back-lash" compensation is incorporated.

8.5. *Back-Lash Compensation*

There is invariably a certain amount of back-lash in the mechanical apparatus that carries out the corrective process. A preset control is usually provided to take up this back-lash when succeeding corrections are of the opposite sense. As the plant wears this setting can be adjusted accordingly.

8.6. *Muting*

One of the facets of the control problem is that a number of already produced articles lie between the sensing device and the correction point. There are usually physical production reasons for this. It is therefore desirable to mute the computer for an adequate period after correction. This ensures that subsequent information analysed is, in fact, information upon which *the correction has been made*. Thus, the computer usually recommences at zero and considers the *corrected* production. However, in some cases it is advantageous to examine the articles already produced, and to bias the computer slightly according to their history. This will expedite correction in case of an unidirectional trend and tend to stabilize when the trend is contradictory.

8.7. "*Forgetting*"

The controller must not, of course, be biased by trends that start and do not persist, nor must it be at the mercy of one or two isolated production freaks. This contingency is catered for by providing the information storage with a limited memory. In some cases, this power of "forgetting" the information is a function of time, in others a function of number of samples observed.

9. Block Schematic of Statistical Controller

The general functions can be correlated roughly as shown in the block schematic (Fig. 6).

M is the mechanical device that physically measures the articles produced. This measurement is transformed into electrical energy by an appropriate transducer. The e.m.f. from the transducer is fed into the sampling selector which duly filters out unwanted information, noise, etc., and amplifies the selected statistically sampled information. This in turn is interpreted into "positive error," "no error" or "negative error" signals in the deviation classifier. Recorders, production counters, reject mechanisms (for gross errors) and similar refinements, can be conveniently operated from these units.

The statistical analyser stores this information (albeit not indefinitely), and initiates the appropriate correction timer as and when required. The operating time of these timers determines the amount of correction performed

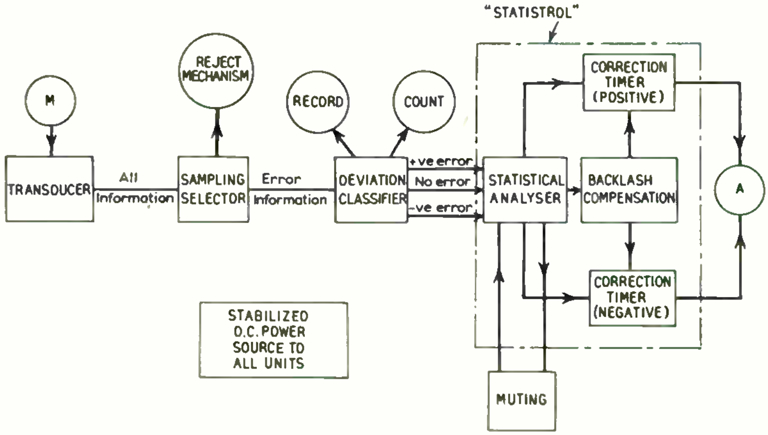

Fig. 6.—Block schematic of statistical controller.

by the mechanical actuator A (reversible motor, or gear box, etc.), and is also influenced by the modifying action of the back-lash compensator. The muting circuit is initiated when a correction takes place, and disconnects or paralyses the statistical analyser until the corrected articles are themselves being sampled.

10. Circuit Techniques

Much of the circuit design is of a fairly conventional nature—the application of such techniques being special only as far as considerable thought should be given to the use of non-critical circuitry, the effects of component failure, the provision of dynamic indicators, etc.

10.1. *Indicators*

These play an important part in the successful monitoring of the controller by semi-skilled personnel. Static indicator lights that show that power is available on each sub-chassis, fuse indicators that locate a blown fuse, valve heater failure alarm systems, all contribute to the customer's confidence that the more likely forms of breakdown will neither pass unnoticed nor be irremediable.

Dynamic indicators, that are visually active during the normal operation of the system, are both reassuring to the user and a quick diagnostic aid to the maintenance man. Whether such indication be the flashing of lights, the striking of gas filled tubes, the movement of dekatrons, or the motion of relays, solenoids, etc., their normal rhythm of operation will usually be sufficiently noticeable to alert the staff to a functional failure.

10.2. *Transducers*

These vary widely with the application. Of the two examples mentioned in this paper, one is an optical transducer and one a capacitance system.

10.3. *Sampling Selector*

If the sampling ratio is 1 : 1 this unit becomes virtually an amplifier having suitable filtering to attenuate all possible unwanted interference, noise, etc., so that clear-cut error information on the samples is made available to the deviation classifier. For 1 : 2 sampling ratio, a two-state flip-flop, and for a 1 : 3, a three-state flip-flop, would be included for division purposes. For smaller ratios a dekatron tube, or even a time base, can be employed. For continuous processes marker pulses derived from the mechanical system ensure a convenient method of "sampling" the process at fixed intervals irrespective of the production rate.

A production refinement that can in certain circumstances (e.g., the case of underweight foodstuffs), be of paramount importance, is the physical rejection of all samples that are outside certain limits. This mechanical feature may be actuated from the sampling selector, after the amplifier, but before the sampling takes place.

10.4. *Deviation Classifier*

This unit simply quantizes the error information into three distinct levels—"positive error," "no error" and "negative error." Wherever possible, the use of d.c. amplifiers is avoided, and this unit usually comprises an arrangement of gas filled trigger tubes which, in turn, actuate coupling valves into the statistical analyser. By making the input signals comparatively large, the small variations in firing potential of, say, small thyratrons, become relatively insignificant.

Some manufacturers keep records of the production runs and other statistical data. Pen recorders, counters, meters, etc., can be conveniently operated from this unit as both the quantized and the unquantized information is available.

11. The " Statistrol " *

That part of the controller that carries out the analysis and actuates the correction in the manner hereinafter described is commercially known as the " Statistrol " and is covered by certain patents.

11.1. *The Statistical Analyser*

This unit is, as it were, the heart of the " Statistrol " system. The function of the circuit is to resolve the quantized errors into approximately the algebraic sum of the errors: it retains in storage the net sense of the errors. However, such information should not be stored indefinitely, there being a decay of stored information, usually with time. Three simplified versions of some of the techniques employed are described as follows:

11.1.1. Capacitor storage with relay drive

In this system, the drive from the deviation classifier takes the form of two relays (see Fig. 7). Upon receiving a " positive error " signal RL1 operates, and for a " negative error " RL2 operates. The " no error " condition is represented by neither relay operating. Consider the state of the circuit at rest (as drawn) and assuming no input information (capacitor C2 uncharged). C1 will be charged to +300V and C3 will be charged to −300V. It will be noted that C1 = C3 and C2 is some 24 times larger. If, say, RL1 operates, then the +300V charge from C1 is carried over to reservoir capacitor C2 raising the potential difference to $+12\frac{1}{2}$V. A further cycling of RL1 will raise this potential to $+24\frac{1}{2}$V and so on. On the other hand, if RL1 operates and raises the voltage to $12\frac{1}{2}$V and then a negative error actuates RL2, the potential across C2 will drop to $-\frac{1}{2}$V. Thus, the potential difference across the reservoir capacitor represents, in magnitude and sense, the resultant of the errors. This potential is converted into usable power by the cathode-follower valve-voltmeter system shown. It can be used both for display meter M and/or as a source of triggering e.m.f. for the correction timers. Since the input to the reservoir capacitor is stepped rather than exponential, the changes of e.m.f. derived from the cathode follower can be readily resolved into the requisite steps to instigate the compensation after a preselected number of errors obtrude.

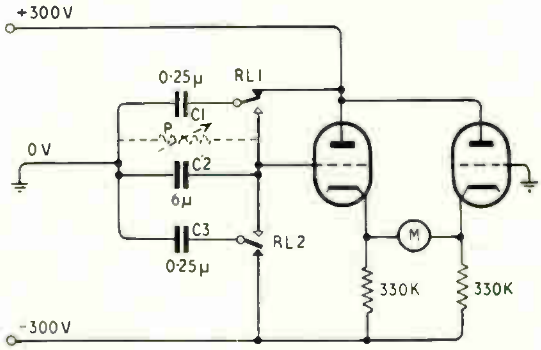

Fig. 7.—Capacitor storage with relay drive.

A further item in the circuit is the potentiometer P. This high value component provides the " forgetting " feature of the system, the information stored decaying exponentially with time.

Capacitor storage with relay actuation is the simplest form of computer—it is not, of course, digital in its accuracy, but it serves well where the time constant of the feedback loop is reasonably short and the sampling rate is compatible with relay operation.

11.1.2. Capacitor storage with valve drive

This system is a modified version of the relay operated circuit, the relays being replaced by hard valves. It is intended for use where the sampling repetition rate is too high for relay operation. The normal condition of the circuit (Fig. 8) is that V1 and V4 are conducting: V2 and V3 are cut off. Under this condition therefore, C1 and C3 are charged, but in the opposite polarity. If now, error information arrives (from a flip-flop) in the form of a square wave, in such a manner that V1 is cut off and V2 made conductive, then the charge in C1 is transferred to C2. Thus V1 and V2 virtually form

* Registered trade mark.

the change-over relay RL1 of the previous system—and the general subsequent action is similar. Likewise V3 and V4 are virtually relay RL2 and will charge C2 with voltage steps of the opposite polarity. Thus, centre-zero milliammeter M

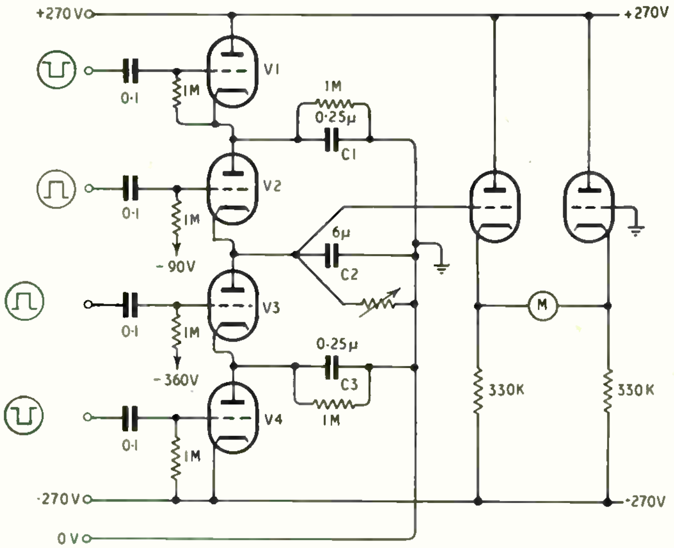

Fig. 8.—Capacitor storage with valve drive.

monitors the errors and the cathode followers can be used to drive d.c. level actuator circuits for initiating the necessary correction when the preselected voltage level is reached.

11.1.3. Dekatron storage with valve drive

In this circuit (Fig. 10) the 10-cathode dekatron is used as an 18-position storage device. This is possible by utilizing the bi-directional properties of the two-guider type dekatron.

A negative square wave pulse at input No. 1 will drive the dekatron clockwise; a negative square wave pulse at input No. 2 will drive it anti-clockwise. The rectifier combination is designed to select the appropriate quasi-integrating networks for either clockwise or anti-clockwise rotation: and at the same time, block off any interaction between circuits.

By connecting two 9-way selector switches (ganged) to the ten cathodes in the complementary manner shown, it is possible to utilize all cathode positions (other than the zero cathode) twice: once for clockwise and once for anti-clockwise rotation. This is effected by using cathodes 1 and 9 to sense whether the glow has departed from the zero position in clockwise or anti-clockwise direction. Signals from cathodes 1 and 9 are fed to an Eccles-Jordan flip-flop (V2 and V3) via two buffer amplifiers (shown schematically). Thus, the two stable states of the flip-flop mirror the prevailing sense of the error.

The voltages developed across the anode load resistors of V2 and V3 are used to bias valves V4 and V5 respectively. Thus, if V3 is conducting and V2 non-conducting, V5 will be heavily biased in such a manner that no signal can penetrate to the negative correction timer and V4 will be lightly biased so that when the dekatron ignites on cathode 4, its voltage will cause V4 to conduct, thereby initiating the postive correction timer. If error is of opposite sense the roles of V2 and V3 are reversed, and those of V4 and V5 are also reversed; it will be the fourth cathode in the anti-clockwise direction only that can trigger the negative correction timer.

This circuit system provides digital accuracy for algebraic summation to ± 9. By using 12-way dekatrons this can be extended to ± 11.

Fig. 9.—Rotary pulse generator.

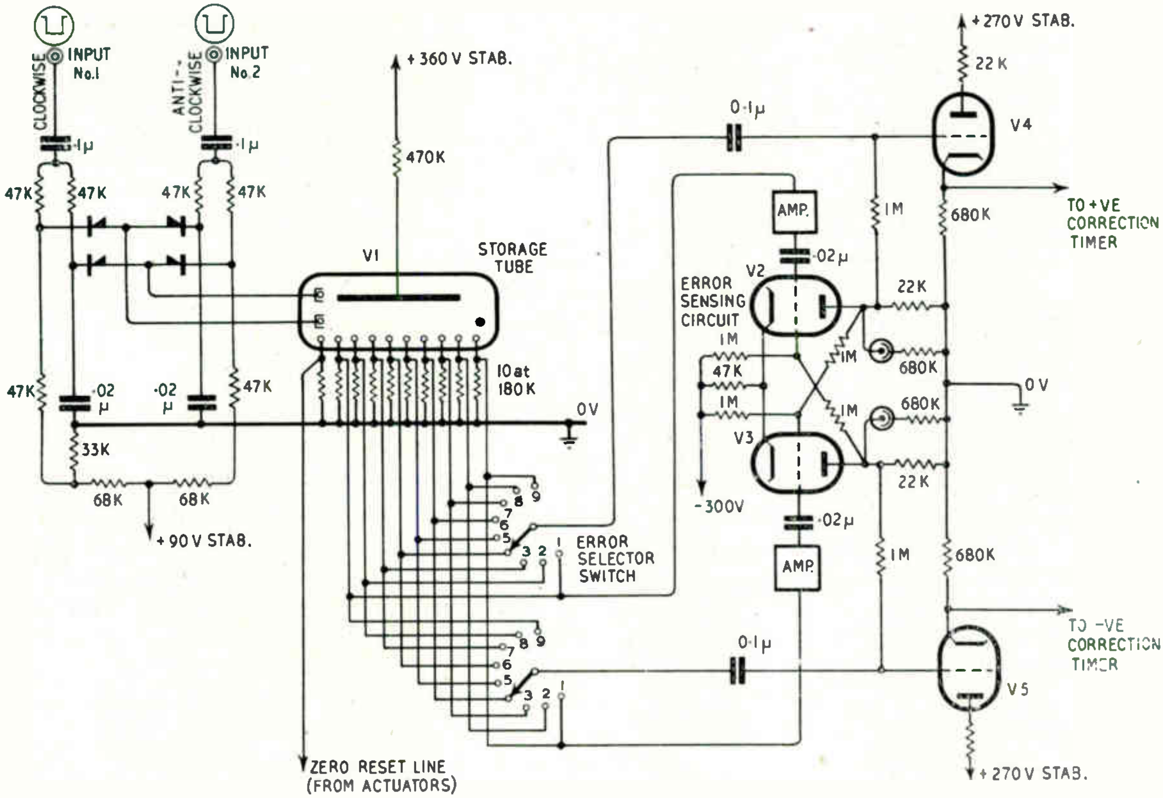

Fig. 10.—Dekatron storage with valve drive.

Although omitted for clarity on the circuit, the "forgetting" feature is also incorporated. It is obtained by means of a simple time base (or other pulse source) which, in turn, trigger feeds artificial signals through the input line. The choice of whether the signal is routed to input No. 1 or input No. 2 is determined by the flip-flop V2-V3 in such a manner that the sense of the "time base manufactured" signal is opposite to that of the prevailing error.

11.2. *Correction Timers*

These are of conventional pattern—their design being entirely dependent upon the actuators used, repetition rate, etc.

11.2.1. Backlash Compensation

The operating time of the correction timers is artificially increased if there is a change of sense in the correction. This can be effected by increasing the R in the CR network of the timer, or by voltage change on the CR network. The former method requires a system of relays to switch in the additional R; the latter method uses a two-state flip-flop to temporarily change the potential on the timing network, when the correction reverses.

11.2.2. Muting

The muting circuit is either a timer or an impulse counter, depending upon the application. Where the rate of production is near enough constant, a timer is used, as the timing circuit can be very simple, no great accuracy being required. If, on the other hand, the production rate is variable, the muting is carried out by a conventional counter circuit (usually two dekatrons in cascade) driven from a rotary pulse generator (Fig. 9) geared to the production process.

12. Plastic Extrusion of Electrical Cable Sheathing (Fig. 11)

In the established production methods which have been practised for past decades in this country and abroad, a large extrusion machine is used into which the plastic material, mostly in chip form is poured. The extrusion machine functions on the same principle as the domestic mincing machine except that it is much larger. There is a large diameter horizontal shaft with a screw thread lying in a closely fitting cylindrical barrel, occupying the main body of the machine. This screw shaft is driven by a motor through a gearbox at a few revolutions per minute and has a central hole right along its entire length allowing the unsheathed metal wire to pass through it from a spool at the rear of the machine and to emerge sheathed in plastic material at the nozzle. At the rear of the machine there is a hopper-like entry to the grooved screw into which chips of unplasticated raw material are fed. This is usually done by hand with a scoop, or by some semi-automatic device, which requires adjusting by an operator.

The raw material moves along the screw and is propelled within the barrel into the head where plasticization of the material takes place under considerable pressure and temperature rise. The plastic material is forced into the nozzle on the head which carries the die through which the material emerges as a soft tube-like sheathing over the metal wire. The soft sheathing has now to be cooled by drawing the wire and its sheathing through cooling water until at least the outer skin is hard enough to be handled without deformation. The towing of the wire is done at a distant point by a variable-speed capstan, where the sheathing is cool and hard.

12.1. *Automatic Control of Diameter*

Due to the nature of the plastic material the extruded hot soft sheathing expands immediately on emerging from the die. The final external diameter of sheathed electric wire is very important and must be held to close limits, particularly if it is intended to be incorporated in a multi-core cable. Therefore, if scrap is to

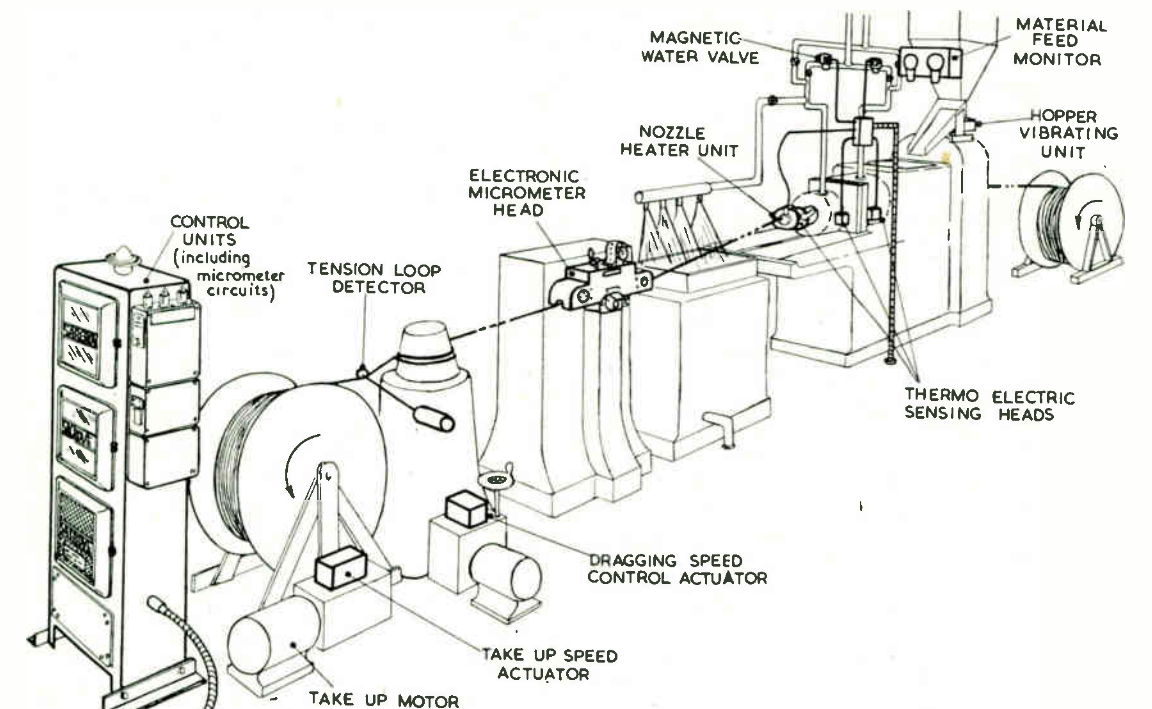

Fig. 11.—Automatic control of cable sheathing diameter.
(Illustration by courtesy of the Editor of *Electronic Engineering*)

be avoided, the rate of expansion of the sheath after leaving the die is of vital importance. On analysing the problem it is found that apart from the elastic coefficient of the particular material, the final diameter is a function of:

1. The speed of the feed screw;
2. The head of material in the intake hopper;
3. The temperature of the compression chamber in the head;
4. The temperature of the die or dies;
5. The velocity of the towing capstan;
6. The peripheral speed of the take up spool or drum.

If the speed of the towing capstan is changed while the extrusion rate remains constant the sheath diameter will be correspondingly altered. Usually this can be corrected by manual adjustment of the variable speed gear box driving the towing capstan after the operator has used a "go" and "no go" gauge to test the diameter of the sheathing. Obviously this procedure is not very satisfactory over long periods of production and continuous indication of diameter to a much greater accuracy is required if a constant diameter is to be maintained.

12.2. *Transducer*

Clearly then, the first problem is to design a suitable transducer to give continuous information monitoring the final diameter. Many of the pros and cons of various methods of approach to this problem are practical rather than electronic and eventually an instrument was designed and produced by the author's firm, based on development work carried out by the National Physical Laboratory in conjunction with Messrs. W. T. Henley's Telegraph Works Co. Ltd. Basically, the sensing element is a small, light, durable stylus that rests on the cable periphery. This stylus forms part of a crystal oscillator circuit. The oscillator frequency is varied by movements of the stylus. An f.m. discriminator system resolves the stylus variations into d.c. voltage changes which are displayed on a centre zero meter calibrating in thousandths of an inch (0·005 in. f.s.d.). The output from such a transducer system is shown in Fig. 12.

12.3. *The Controller System*

The micrometering is carried out sufficiently far down the cable line to ensure that the diameter is in fact the final diameter required, and this point may be at a considerable distance from the extruder nozzle. For example, Fig. 12 represents one length of cable equal to the distance between the micrometer sensing head and the nozzle. In one practical case, on a large cable, this distance is 108 feet. Since the extrusion rate is 360 yards per hour, the micrometering is being carried out *six minutes* after the extruding. It will be appreciated therefore that discontinuous measurement with a hand micrometer or gauge is both cumbersome and subject to errors, and the decision, as to whether and what correction to make, is a difficult one for a human operator.

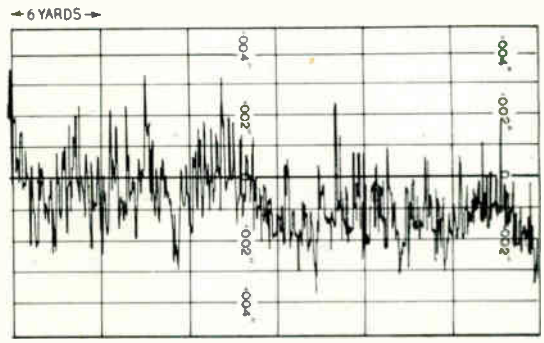

Fig. 12.—Chart record of output from transducer system in cable diameter control apparatus.

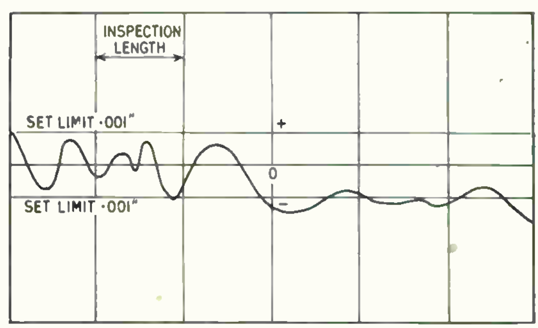

Fig. 13.—Information from Fig. 12, as integrated in controller-computer.

By integrating the information in the "Statistrol" controller-computer, the trend of the errors becomes more apparent as shown in Fig. 13. However, the decision as to whether the trend is sufficiently harmful to warrant a correction is often a subtle one, bearing in mind that there are statistical variations anyway. This particular cable length has a fairly obvious trend: usually much longer case histories are being studied by the computer. As an alternative to the "Statistrol," the design of a simple delayed servo system that would operate satisfactorily for any speed up to say, 30,000 yards per hour for varying tank lengths and differing limits, would present a number of difficulties; and would qualitatively not be as satisfactory.

Therefore, the statistical method outlined in this paper is applied in the following manner: A rotary pulse generator (Fig. 10) gives pulses that are a function of the haul-off velocity. This generator is geared through a variable speed drive so that the interval (in terms of cable length) between marker pulses is adjustable. The case in point shows these as being at 6-yard intervals. If any error beyond the "set limits" shows through the preliminary integration (i.e., Fig. 13), such error is quantized by the statistical analyser as one error per 6 yard length (even though there are two, for example, in the final section) and computed accordingly. Thus, in the length of cable shown, if the "set limits" of the deviation classifier are operating at 0·001 in., there will be a computational total of -5 errors in this length of cable, since the negative "set limits" axis is exceeded in five of the six inspection lengths. If the "error selector" control of the statistical analyser were set to operate at 5 then a step correction, equivalent to $+0{\cdot}001$ in. would be made during the last inspection length. However, there are 108 feet of cable *already manufactured* in the production line, so the computer is muted for the succeeding 108 feet (the muting also being a function of the rotary pulse generator signals). Meanwhile the computer is re-zeroed and ready to consider the corrected cable when the muting is terminated.

It must be emphasized that, for simplicity, a fairly elementary compensatory decision has been shown: in practice, the change of trend is usually more involved and spread over a much longer period. The combination of the statistical approach and the continuous measurement makes for a better qualitative control system than hand micrometering and manual speed control of the haul-off mechanism.

13. Weight Control of Dough for Large-Scale Bakery

One of the problems encountered in mass producing loaves of bread is that of guaranteeing that the final article is not underweight. In the case of bread making, the weight of the final loaf can be assessed as a direct function of the mass of the initial doughpiece.

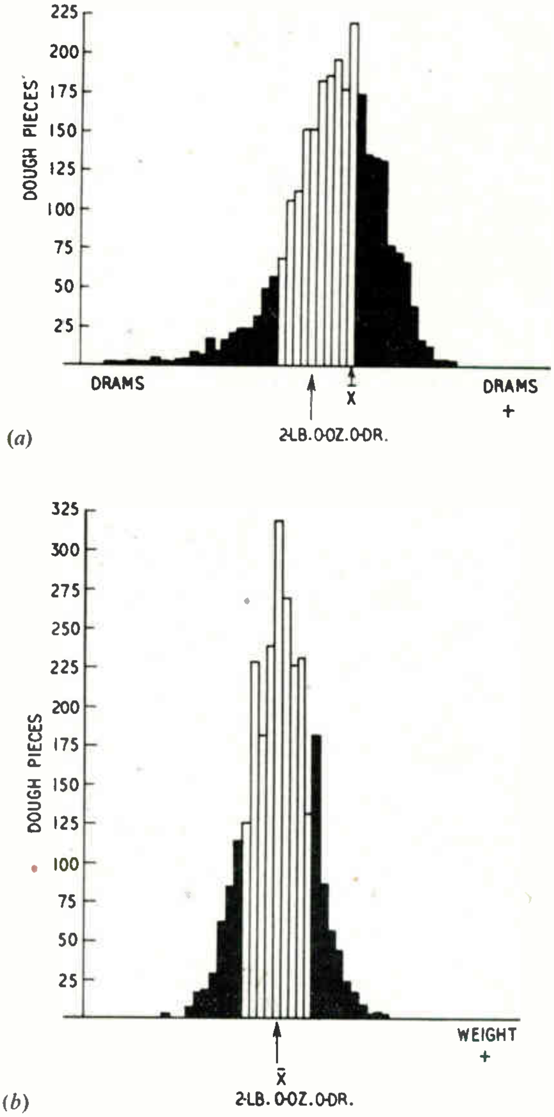

Fig. 14.—Histograms of weight of loaves (a) uncontrolled; (b) controlled.

The mass of the doughpiece is controlled by a cavity moulding device (the " dough divider ") which is fed from large vat-like pans in which the dough is allowed to age and " grow." These pans hold sufficient dough to make, say 500 loaves. During the hours that the dough grows, the action of the yeast is such that the density of dough tends to vary in stratas being greater on the top (where a virtual crust forms), less under the crust (where the gas collects), and progressively greater down the pan. Thus, as well as the normal statistical variations, there are periodic variations due to a shifting of parameter $\bar{X}$, the mean mass of the dough. Since the dough divider is operating at the rate of about 50 doughballs per minute, there is a continuous recycling of the periodic phenomena every 10 minutes.

The manufacturing bakeries, endeavouring to balance the size of the product between the minimum allowable by law and an uneconomically heavy loaf, tend to make the mean weight $\bar{X}$ greater than would be necessary on purely statistical grounds were $\bar{X}$ a constant factor. A man test-weighs occasional samples and makes manual corrections as and when he 14a. It will be observed that the mean of the deems necessary, with the results shown in Fig. histogram is in fact, heavier than the centre of the acceptable range of limits (2lb $\pm$ 4 drams). There is thus considerable wastage of dough and no guarantee that some of the bread will be exceedingly underweight. This is aggravated by the fact that the stratification of the dough density in the pans causes the loaves to be either heavy or light in *batches*, and so a shop may get a delivery of, say, 50 loaves—all lightweight.

To solve this problem, the author's firm made a controller embodying a high-speed weighing mechanism, optical transducer, and statistical computer that controlled the size of the moulding cavity. Every doughpiece was weighed, its error quantized into " light," " heavy," " very light " or " very heavy," and computed accordingly. In addition to the statistical control, mechanical rejection of all " very heavy " and " very light " doughpieces was incorporated: these doughpieces were made available for remoulding in the dough divider. The result of such a control system can be studied from Fig. 14b—a comparable run to Fig. 14a. It will be noted that the ratio of correct to incorrect doughpieces is much better, and that the mean $\bar{X}$ now corresponds with the desired weight. This means that there is an actual saving of dough. Whilst there are still underweight loaves, the occurrence of exceedingly light loaves has been avoided by the reject mechanism.

14. Acknowledgments

The author wishes to thank the Directors of Sargrove Electronics Ltd., for kind permission to publish this paper and in particular, Mr. J. A. Sargrove, Technical Director, for his help, advice and co-operation.

A CONTINUOUS MONITOR OF MICROWAVE RECEIVER NOISE-FACTOR*

by

R. D. Holland (*Associate Member*) and N. A. Godel, B.Sc.(Eng).†

SUMMARY

A practical method is described for continuously monitoring the noise-factor of a microwave receiver without impairing its operational use. A very small modulated noise signal is introduced into the receiver, a sample of the i.f. output detected and the noise voltages in a narrow band about the modulation frequency selected and amplified. This composite signal is then applied to a coherent detector followed by a low-pass filter, whose output is shown on a meter calibrated to read the noise-factor of the receiving system. Details are given of a developed design intended for use with an S-band radar set, and capable of indicating a deterioration of 1·0 db in receiver noise-factor.

1. Introduction

The sensitivity of a receiver is closely related to its noise-factor, N_r, which may be expressed as:

$$N_r = \frac{S_i}{N_i} \bigg/ \frac{S_o}{N_o}$$

where S_i and N_i are respectively the available signal and noise powers at the receiver input, and S_o and N_o the available signal and noise powers at the output. This factor is clearly of prime importance in a radar system where it is required to detect signals having amplitudes comparable with the noise level.

A deterioration in receiver sensitivity is very common in service and frequently passes unnoticed. Anything but a complete failure may not be revealed for a long time, therefore, unless frequent or continuous information about receiver performance can be obtained. This is provided by the method described, which enables the noise-factor of the complete receiving channel to be displayed or recorded continuously.

The additional equipment required is not excessive compared with that needed for methods giving less information, particularly where several receivers are used. In the latter case some modification of the conception of "continuous" monitoring is involved since simultaneous measurements cannot be made with a single monitor unit. The noise-factor is measured whilst the receiver is being used operationally, unlike most other methods, which require the receiver to be taken out of service. If desired, the increase in receiver noise-factor due to the added noise signal can be kept below 0·1 db, for an initial noise-factor of 8 db, although an increase of 0·25 db enables a more accurate indication of noise-factor to be obtained.

Such a monitor used with an a.f.c. indicator and a meter to show transmitted power constitutes the basis of a comprehensive monitor of radar performance. The disadvantages of echo boxes, namely their frequency dependence and the difficulty of maintaining a constant-Q under practical conditions, are avoided.

2. General Principles

The technique used by R. H. Dicke to measure thermal radiation at microwave frequencies[1] has been adapted to monitor receiver noise-factor, as suggested by L. A. Moxon.[2]

A block diagram of the arrangement is given in Fig. 1. The output from a broad-band noise source is modulated at an audio frequency (80 c/s in the present case), and introduced into the waveguide feeding the receiver as a signal whose mean power at the modulation peaks is some 11 db below the thermal noise power present. A sample of the receiver i.f. output is detected, a meter being provided to give a reading proportional to the mean rectified noise voltage. The signal/noise ratio is improved by selecting a narrow band from the video-frequency spectrum centred on the 80-c/s signal. The signal and

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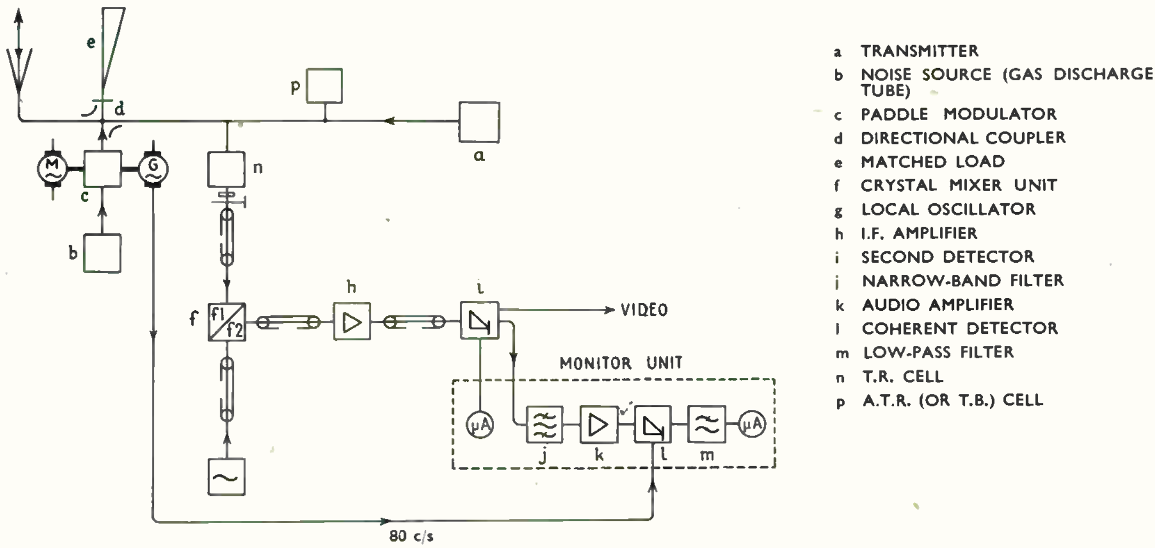

Fig. 1.—Block diagram of noise-factor monitoring system.

noise components in this narrow band are amplified and applied to a coherent detector fed from an 80-c/s a.c. source in phase with the modulation of the signal. A low-pass filter following the coherent detector reduces the effective noise bandwidth, with consequent further increase in sensitivity. A second meter is provided to measure the level of the output signal, the reading on this meter being subject to small random fluctuations due to the residual noise components present in the output from the low-pass filter.

It is shown in Appendix 1 that the signal/noise voltage ratio at the output meter varies inversely as the receiver noise-factor, provided all other parameters remain constant, i.e.,

$$\frac{V_s}{V_n} \propto \frac{1}{N_r}$$

Thus if V_n is kept constant

$$V_s \propto \frac{1}{N_r}$$

and the output meter can be calibrated to read noise-factor directly. Since V_n is proportional to the noise level at the i.f. detector its constancy is ensured by setting the detector current to a predetermined value, for which purpose a gain control is provided. For the meter calibration to hold, the gain of the post-detector circuits must remain constant. A change in their bandwidth only affects the extent of the random fluctuations of meter reading.

These random fluctuations limit the accuracy of measurement. The expected order of fluctuation has been evaluated in Appendix 1, and the observed values are in reasonably good agreement. The output signal/noise ratio can be improved by using a greater injected signal, but the consequent degradation in receiver noise-factor sets an upper limit to the input level that can be tolerated. The relationship between injected signal level and degradation of noise-factor is derived in Appendix 2, and the results for different initial noise-factors have been calculated and are shown graphically in Fig. 2. Other considerations affecting accuracy are discussed later.

The method can be modified to suit individual requirements. For example, the radar may be one which is out of use during intervals sufficiently close to one another for noise-factor checks made at such times to be nearly as valuable as continuous observation. A larger injected signal can then be used, with simplification in the monitoring circuits, and smaller fluctuation in the output meter reading. The technique may also be adapted for other forms of monitoring and test equipment, e.g. a crystal-testing set has been described.[3]

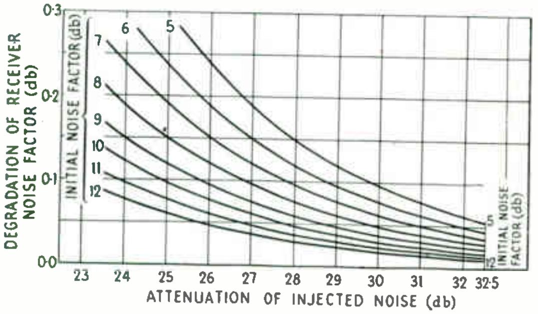

Fig. 2.—Graph showing degradation of noise-factor.

The factors influencing the design of the component parts of a practical receiver noise-factor monitor are now considered.

3. Modulated Noise Source

A 30-mm (mercury pressure) argon-filled discharge tube (type CV1881) is used as a source of broad-band noise energy.[4, 5] The output from this tube is substantially constant at a power level about 15·5 db above thermal noise at 290°K. The tube is mounted perpendicular to the E-vector and to the direction of propagation in standard WG10 waveguide. The tube mount is matched to give a voltage standing-wave ratio better than 0·95 : 1. The problem of initiating the gas-discharge by remote switching has been solved by the development of the circuit shown in Fig. 3. This arrangement avoids high transient potentials on relay contacts, and also repeats the operating sequence if the tube fails to strike initially.

During early experiments the tube was keyed on and off by a shunt valve driven from a stable master oscillator, but this method of modulation was found to generate radio-frequency "ringing" currents in the connecting cables, repeated at the keying frequency. The leakage into the receiver at i.f., and the very low amplitude of the wanted signal, make it difficult to eliminate these spurious signals even with the greatest practicable screening and filtering.

A mechanical device is used therefore, consisting of a thin rectangular "paddle" or vane rotated in the waveguide to modulate the injected noise energy at a frequency twice that of the speed of rotation. The vane is supported in ball-races, its axis of rotation being parallel to the wider dimension of the waveguide, as shown in Fig. 4. The "power-transmission *v.* angle-of-vane" law for this modulator is roughly sinusoidal, as shown in Fig. 5. The modulation of the noise-source does not follow this law exactly, due to the changing impedance presented to the generator by the revolving paddle. Two further advantages accrue from the use of a mechanical modulator. Firstly, the gas-discharge tube can be run continuously, with a much longer life. Secondly, the need for a unit containing a modulating valve mounted close to the tube, in order to minimize the effect of cable capacitances on the ignition spike, is avoided.

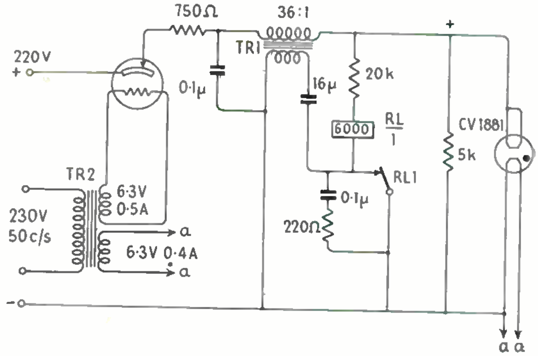

Fig. 3.—Circuit for igniting noise-tube.

The modulation frequency should be chosen to avoid interference from the radar pulse repetition frequency, power-supply hum frequencies, and any other regularly recurring signals in the receiver, e.g. from an aerial scanning system, which might bear a constant phase relationship to the injected modulation for short periods of time and thereby give rise to fluctuations in the output meter. Also, too high a frequency will result in undue wear in the rotating parts, whilst too low a frequency will introduce difficulties in the design of the selective audio-frequency circuits. The equipment described uses a frequency of 80 c/s.

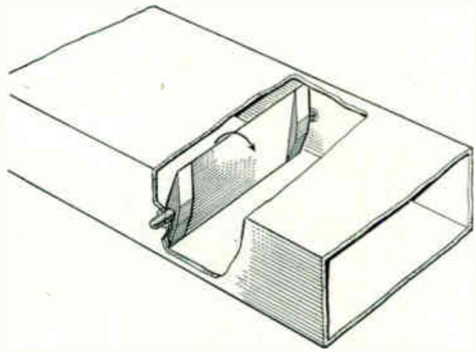

Fig. 4.—Cross-section of paddle modulator.

The rotating paddle is therefore driven at 40 r.p.s. The limits to which this shaft speed must be held depend upon the bandwidth of the selective amplifier and are discussed later. In the equipment with which the described monitor is used a power supply of highly stable frequency is available, and a fractional horse-power synchronous motor is used, with the benefits of reliability and long life characteristic of these machines.

A reference waveform, required for the coherent detector, is obtained from a small alternator, delivering 20 V r.m.s. at 80 c/s, which is coupled to the shaft driving the paddle modulator. Provision is made to rotate the outer casing of the machine to obtain the desired phase relationship at the coherent detector. It is preferable to generate the waveform in this way, as there are no commutating devices to produce the "ringing" effect mentioned earlier.

4. Coupling to Radar Receiver

The monitor may be made to check a complete receiving channel by continuously radiating the modulated noise signal, at a suitable level, into the aerial system of the set. Where this is not practicable (e.g. due to change of gain of the aerial with variation of the feed position) the noise signal may be coupled into the waveguide run between the aerial and T.R. system. The noise-factor of a number of receivers associated with one equipment may be measured consecutively, using one monitor only. Preferably, the same amount of noise energy is injected into each receiving channel, the calibration of the output meter then holds for all channels, the total noise output powers from each receiver being effectively equalized by use of the monitor's own gain control.

This technique is adopted in the monitor described. The modulated noise is fed to several broadband directive couplers in series, each connecting to a separate receiving channel. These couplers are of the crossed waveguide single-hole type[6] and with normal manufacturing tolerances all have the same attenuation within 0·1 db. The nominal attenuation is 26·5 db*; in addition there is a 10-db directivity.

The noise signal then passes through the T.R. system, crystal mixer and receiver i.f. amplifier. It is important to sample the i.f. signal at a point in the amplifier which gives a noise output linear with respect to the normal noise input.

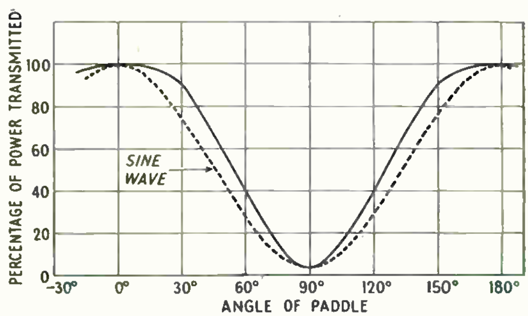

Fig. 5.—Graph showing power/angle law for paddle-modulator.

5. Monitor Circuits

The circuits which treat the output taken from the receiver and measure the noise-factor, are contained in a small unit which may be located with the receiver or at a central monitoring position.

A circuit diagram is given in Fig. 6. In the arrangement shown, a further linear stage of i.f. amplification is used, partly to ensure that the following detector operates on a linear portion of its characteristic and partly to allow the unit to work with receivers having widely different gains. A manual gain control enables the amplification to be adjusted. An automatic gain control could be applied at this point if desired, with some increase in circuit complexity. A diode

*The factors determining the attenuation required are stated in Appendix 2.

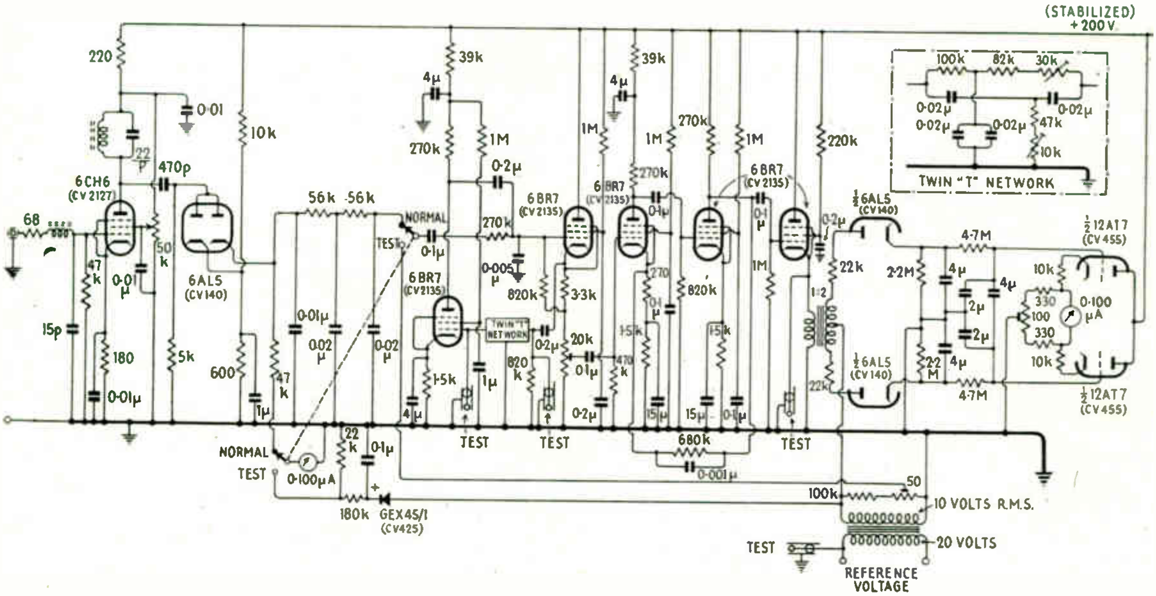

Fig. 6.—Diagram of monitor circuits.

detector feeds a meter giving a reading proportional to the mean amplitude of the noise. The reading is kept constant by adjusting the gain control. A second diode acts as a limiter, conducting only on signals exceeding the peak noise level. The system is then not upset by the presence of permanent echoes or other large signals and is unaffected by random impulsive type interference. The output from the detector is connected by a simple low-pass network to a narrow band circuit. This is basically a cathode-follower, with negative feedback applied through a "Twin-T" filter and single amplifying stage. Since the filter is tuned to 80 c/s there is no feedback at the modulation frequency and the circuit operates as a normal cathode follower for the signal.

This arrangement is adopted for stability, as a change of gain in the feedback amplifier will leave the overall gain at 80 c/s substantially unaffected. Such a change would alter the Q-factor, resulting in a slight alteration in the noise bandwidth, which would be unimportant since there is a further bandwidth contraction later in the circuit. The gain used provides a Q of about 12, passing the signal and noise components in a band approximately 7 c/s wide. The object of the selective network is to reduce the noise voltages to a level where subsequent amplification can be accomplished without overloading small valves.

If the shaft speed of the paddle modulator varies, resulting in a change of modulation frequency, the response of the selective network introduces changes in amplitude and phase in the signal output. Phase change is important since a phase-sensitive 80-c/s detector is used. With a Q of 12 the shaft speed should be maintained to within $\pm 0{\cdot}35$ per cent. for a 1 per cent. decrease in signal output voltage (see Fig. 7). If this cannot be achieved readily, the Q-factor should be reduced, or no selective network employed. The following stages would then require valves capable of handling much larger peak noise voltages.

To raise the 80-c/s signal to a suitable level for detection and observation, a two-stage amplifier with cathode-follower output is used.

The gain is stabilized by feedback. The combined signal and noise components are applied to a coherent detector[7] fed with the sinusoidal reference voltage from the paddle-shaft alternator. A resistance-capacitance filter with a time-constant of about 90 seconds confines the random noise fluctuations within acceptable limits without making the time required to register a change in noise-factor impracticably long. Fig. 8 shows a graph of output meter reading against measured noise-factor, with a superimposed theoretical curve.

It is very important to keep the gain (and phase-shift) of the circuits between the i.f. detector and the output meter constant. Good quality components, the use of feedback circuits and cathode-followers, and a stabilized h.t. supply are recommended. A pre-set control enables the gain of the amplifier to be adjusted initially and when required; the output meter may therefore be pre-calibrated. The gain of the amplifier at 80 c/s and its phase-shift (nominally zero) may be checked when desired, by use of a "test" switch which re-connects the i.f. detector meter in the unit to read the amplitude of the sinusoidal reference voltage and which feeds an attenuated sample of this voltage into the amplifier. The attenuation is pre-set to give identical readings in the two meters in the unit. Any change in gain or phase-shift is then readily detectable.

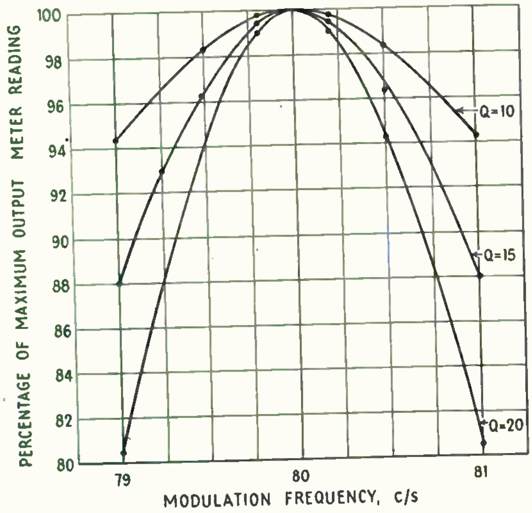

Fig. 7.—Graph of output-voltage v. *modulation-frequency.*

Connecting points are provided for a cathode-ray oscilloscope, to facilitate tuning of the "Twin-T" network, and to allow the output and reference waveforms to be observed.

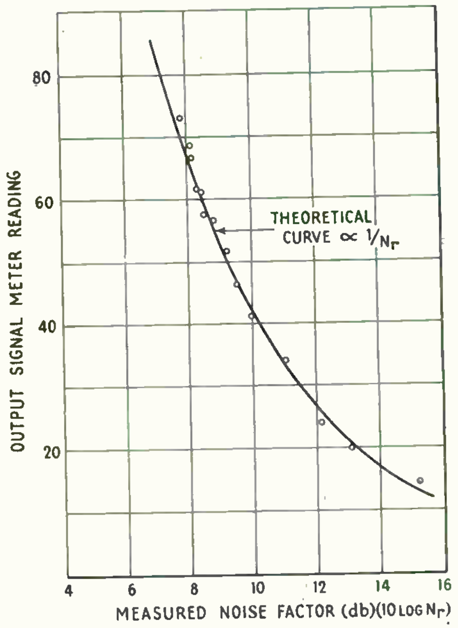

Fig. 8.—Graph of output meter reading v. *noise-factor.*

6. Performance

The ultimate accuracy of the monitor is limited by random noise fluctuations whose peak values correspond to about $\pm 0{\cdot}25$ db in the measurement of noise-factor (for an initial noise-factor of 8 db), as shown in Appendix 1. The degree of accuracy is further decreased in practice by variations in:

(*a*) h.t. and heater voltages,

(*b*) valve characteristics and component values with time and temperature,

(*c*) output from the noise-tube (to this may be added differences in coupling attenuation where several receiving channels are monitored),

(*d*) modulator shaft-speed.

Whilst the effects of valve and component replacements are largely minimized by the circuit design, any resultant change of gain can be eliminated by readjustment of the pre-set control.

For the particular monitor described, which has a shaft-speed held to ±0·1 per cent. and which does not suffer large temperature changes, the maximum error due to the factors (*a*) to (*d*) is estimated to be ±0·7 db (in noise-factor reading), giving a total possible error of the order of ±1·0 db in the noise-factor indication. Experience shows that the probable error is less than half of this maximum value, and a change in noise-factor of 1 db is readily detected in receivers having noise-factors better than 12 db.

7. Conclusion

Only laboratory models of the monitor have been constructed as yet, but their performance under working conditions shows that, when used in conjunction with an indicator of correct local-oscillator frequency, a comprehensive check of receiver performance is possible.

8. Acknowledgments

The authors acknowledge the helpful discussions they have had with Messrs. A. G. D. Watson, L. A. Moxon, J. R. Thomas and T. H. Beech, and the great assistance received from Mr. P. Andrews in the development of the microwave components.

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10. Appendix 1

(*a*) Determination of output signal/noise ratio and law of "noise-factor" meter

With no injected noise, the available noise power referred to the crystal-mixer output is given by

$$P_o = (N_{if} + t - 1)\,kTB \qquad \ldots\ldots\ldots\ldots(1)$$

where N_{if} = noise-factor of the i.f. amplifier following the mixer

t = noise-temperature ratio of the mixer

k = Boltzmann's constant = $1{\cdot}38 \times 10^{-23}$ Joules/°K

T = temperature (°K)

B = equivalent noise bandwidth in c/s.

An additional available noise power $nkTB$ is injected into the input of the receiving system, n being a known factor. At the mixer output this is equivalent to an additional power $p_o = nkTB/L$, where L represents the conversion loss of the mixer and any transmission and mismatch losses. The ratio of added power to existing power is

$$\frac{p_o}{P_o} = \frac{n}{L}\,(N_{if} + t - 1) = \frac{n}{N_r} \qquad \ldots\ldots(2)$$

where $N_r = L(N_{if} + t - 1)$ and is defined as the noise-factor of the receiving system.

Now suppose that the injected noise power is modulated sinusoidally so that the minimum available noise power at the mixer output is P_o and the maximum noise power is $P_o + p_o$. P_o and p_o represent the average values of the noise taken over a time interval t which is very long compared with the time-constant of the i.f. amplifier and short compared with the modulation period. The average noise power then varies with time at the modulation frequency, that is

$$P(t) = P_o + \left(\frac{p_o}{2}\right) + \left(\frac{p_o}{2}\right) \sin \omega t \quad \ldots\ldots (3)$$

where ω is the angular frequency of modulation.

If $p_o \ll P_o$

$$P(t) \simeq P_o + \left(\frac{p_o}{2}\right) \sin \omega t$$

$$= P_o \left[1 + \left(\frac{p_o}{2P_o}\right) \sin \omega t\right] \quad \ldots\ldots\ldots (4)$$

The corresponding r.m.s. voltage at the output of the (linear) i.f. amplifier may be expressed as

$$E(t) \simeq E_o \left[1 + \left(\frac{p_o}{4P_o}\right) \sin \omega t\right] \quad \ldots\ldots\ldots (5)$$

$$= E_o(1 + m \sin \omega t) \quad \ldots\ldots\ldots\ldots\ldots (6)$$

if $p_o/4P_o$ is regarded as equivalent to a modulation index (m). From (2):

$$m = \frac{n}{4N_r} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Consider now an i.f. detector defined by the relationship

$I(t) = aV(t)$ when $V(t) > 0$

$I(t) = 0$ when $V(t) \leqslant 0$

where $V(t)$ is the instantaneous noise voltage.

The mean rectified noise current at the output when $m = 0$ is given (approximately) by

$$I_{dc} = a\left(\frac{P_1 B_1}{2\pi}\right)^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

and the r.m.s. noise fluctuation current (approximately) by

$$I_n = \left(\frac{a}{2}\right)\left(\frac{P_1 B_1}{2\pi}\right)^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots\ldots (9)$$

where P_1 is the input noise power per c/s bandwidth, and B_1 is the equivalent noise bandwidth of the i.f. amplifier. As m is very small, these quantities will not be significantly changed in the presence of the signal. The r.m.s. signal current is

$$I_s = \left[\frac{m^2}{2}\right]^{\frac{1}{2}} I_{dc} = \left[\frac{m^2 a^2}{2}\right]^{\frac{1}{2}} \left[\frac{P_1 B_1}{2\pi}\right]^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots\ldots (10)$$

and the signal/noise ratio at the output of the detector is therefore

$$\frac{I_s}{I_n} = m(2)^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

The i.f. detector is followed by a narrow-band filter, coherent detector, and low-pass filter. If the equivalent noise bandwidths of the narrow-band filter and low-pass filter are respectively B_2 and B_3 (c/s), the signal/noise ratio at the input to the coherent detector will be

$$S_1 = m(2)^{\frac{1}{2}}\left(\frac{B_1}{2B_2}\right)^{\frac{1}{2}} = m\left(\frac{B_1}{B_2}\right)^{\frac{1}{2}} \quad \ldots (12)$$

and at the output of the low-pass filter

$$S = S_1 \cos\phi \left(\frac{B_2}{B_3}\right)^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots\ldots (13)$$

where ϕ is the phase-difference between the signal and coherent oscillation, in this case zero. Thus the ratio of direct signal current to r.m.s. noise current in the output meter is

$$S = m\left(\frac{B_1}{B_3}\right)^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

The bandwidth of the low-pass filter, considered as a simple R-C network, is related to its time-constant T_0 by

$$\frac{B_3}{2\pi} = \left(\frac{1}{2\pi}\right)\int_0^\infty \frac{d\omega}{[1 + (\omega CR)^2]}$$

$$= \frac{1}{4CR} = \frac{1}{4T_0} \quad \ldots\ldots\ldots\ldots\ldots (15)$$

and $m = \dfrac{n}{4N_r}$ (eqn. 7). Hence

$$S = \left(\frac{n}{4N_r}\right)(4B_1 T_0)^{\frac{1}{2}} = \left(\frac{n}{2N_r}\right)(B_1 T_0)^{\frac{1}{2}}$$

$$= \frac{V_s}{V_n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

It follows that if the amplitude V_n of the noise output from the low-pass filter is kept constant (e.g. by maintaining a constant noise amplitude from the i.f. detector) and n, B_1 and T_0 remain unchanged, the signal output V_s will be inversely proportional to N_r, and the output meter may be calibrated to read the noise-factor of the system directly.

(b) Effect of Output Signal/Noise Ratio on Accuracy of Meter Reading

In (a) the ratio of steady signal voltage to r.m.s. fluctuation voltage has been calculated. The meter will follow the fluctuation noise envelope, which has maximum values conforming to the amplitude probability distribution of the noise. The probability of the peak amplitude exceeding three times the r.m.s. value of the waveform is rather low, and this limit may be conveniently adopted in considering the practical case. The ratio of peak noise voltage to direct signal voltage will then be

$$\frac{\Delta V_s}{V_s} = \frac{3}{S} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(17)$$

As $N_r \propto 1/V_s$, the fluctuation is given in terms of noise-factor reading by ΔN_r where

$$\Delta N_r = N_r\left[-\left(\pm\frac{\Delta V_s}{V_s}\right)+\left(\pm\frac{\Delta V_s}{V_s}\right)^2 -\left(\pm\frac{\Delta V_s}{V_s}\right)^3+\ldots\right]\ldots\ldots\ldots(18)$$

If $\Delta V_s/V_s \leqslant 1/10$ the third and higher order terms may be neglected.

(c) Application to a Practical System

Consider a receiving system where $N_r = 6{\cdot}31$ (i.e., 8 db*), $n = 0{\cdot}127$ (noise-source 18·5 db* above kT, coupling attenuation 26·5 db, and a factor of 0·8 for imperfect modulation due to incomplete cut-off of energy and the modulation waveform not being truly sinusoidal), $B_1 = 6 \times 10^5$ c/s, $T_0 = 60$ sec. Then

*These figures include allowances for image channel reception.

$$S = \left(\frac{n}{2N_r}\right)(B_1 T_0)^{\frac{1}{2}} = 60{\cdot}4$$

$$\frac{\Delta V_s}{V_s} = \frac{3}{S} = 0{\cdot}05$$

$$\Delta N_r = N_r\left[-\left(\pm\frac{\Delta V_s}{V_s}\right)+\left(\pm\frac{\Delta V_s}{V_s}\right)^2\right] = \begin{matrix}+0{\cdot}33\\ -0{\cdot}30\end{matrix}$$

The noise-factor reading will, therefore, rarely exceed the limits 6·01 and 6·64 (7·79 db and 8·22 db). The corresponding limits for N_r = 12 db would be about 11·5 db and 12·6 db.

Figure 9 shows a typical tape record of the fluctuations of the "noise-factor" meter. In this case, the coupling attenuation was 29 db, the noise-factor of the receiving channel 7·4 db, and the factor $(B_1\ T_0)^{\frac{1}{2}} = 7350$, giving a theoretical signal/noise ratio of 48. During the recording the gain of the receiver varied within small limits, as is shown by the continuous line (at the left-hand side of the chart) which is a plot of i.f. detector current. The indicated signal/noise ratio of 31 is therefore lower than would be obtained if the gain control were adjusted to keep the amplitude of the i.f. detector current constant. It is probable, also, that "gain variation noise" is present at the modulation frequency, and the calculated signal/noise ratio does not take this into account. Allowing for these factors the agreement between the predicted and observed values is considered to be reasonably good.

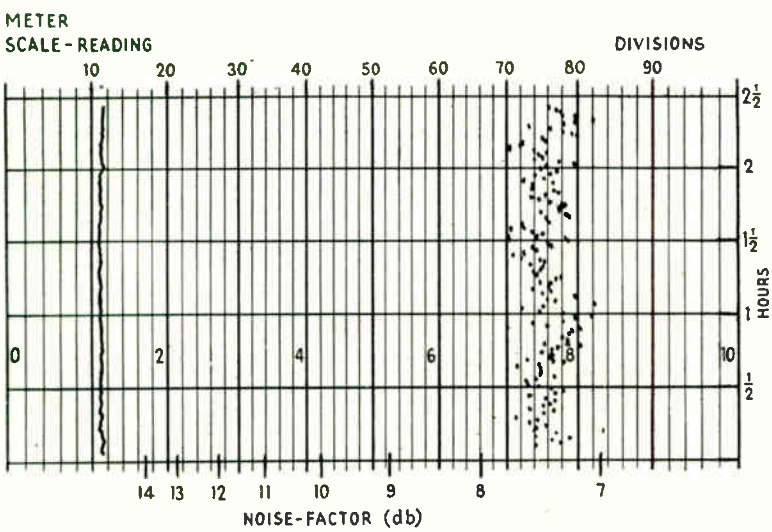

Fig. 9.—Record of output-meter reading.

Made with receiver of noise-factor 7·4 db, using CV1881 noise-tube and coupling attenuation of 29 db.

Mean of 140 readings at minute intervals is 75·8 divs. (= 7·4 db). Standard deviation = 2·45 div. Signal/noise ratio = 31. Peak deviations +6·7, —5·8 divs., corresponding to noise-factor range 7·0 to 7·75 db.

12. Appendix 2: Relationship Between Level of Injected Noise and Degradation of Noise-Factor

Using the same notation as in Appendix 1, the available noise-power, referred to the crystal-mixer output, is

$$P_o = (N_{if} + t - 1)\, kTB = N_r \frac{kTB}{L}$$

when there is no injected noise. If an additional available noise-power of $nkTB$ is introduced, the output power becomes

$$P_o' = \left[N_{if} + t - 1 + \left(\frac{n}{L}\right)\right] kTB = N_r' \frac{kTB}{L}$$

N_r' being the new noise-factor. Therefore,

$$\frac{N_r'}{N_r} = \frac{\left[\left(N_{if} + t - 1 + \left(\frac{n}{L}\right)\right]\right.}{(N_{if} + t - 1)} = 1 + \left(\frac{n}{N_r}\right)$$

and

$$n = N_r' - N_r.$$

If g is the factor by which the power level of the noise-source exceeds kT, and α is the coupling attenuation, $n = g/\alpha$. The minimum attenuation required to avoid increasing the noise-factor by more than N_r'/N_r is thus given by

$$\alpha = \frac{g}{(N_r' - N_r)}$$

The modulation of the injected noise has been neglected in the calculation since the maximum degradation is generally the important factor in radar systems using low pulse densities.

In a practical system, with N_r of 10 (= 10 db), N_r' of 10·23 (= 10·1 db) and g of 70·8 (= 18·5 db), all these values allowing for acceptance of the full image spectrum,

$$\alpha = \frac{70{\cdot}8}{0{\cdot}23} = 308 = (24{\cdot}9 \text{ db})$$

Figure 2 shows the degradation of noise-factor due to the additional noise for initial noise-factors from 5 db to 12 db. The values of attenuation shown are for a noise source 15·5 db above kT and assume that the image spectrum is not suppressed.

13. Appendix 3: Note on the Operation of the Ignition Circuit for the Discharge Tube

The discharge tube is ignited automatically when its supplies are switched-on. Fig. 3 shows the circuit arrangement.

To prevent the application of h.t. before the filament warms up, a thermal delay-switch is inserted in the h.t. supply line and fed from the same transformer as the tube filament. When the delay-switch closes, a relay is energized through its own contacts, which are normally closed. The opening of the relay contacts leaves a large capacitor in the circuit and the relay remains energized whilst this is charging. When the charging current has fallen sufficiently, the contacts close again and the capacitor discharges through the primary winding of a step-up transformer. The secondary winding is connected in series with the d.c. feed to the tube, and its polarity is such that a positive transient voltage (of about 3 kV) is applied to the anode of the tube. The magnetic conditions in the transformer are determined by a standing current flowing in the secondary winding, to enable a rapid build-up of current to occur in the tube when it starts conducting. The potential across the lit tube is only 60 V which is insufficient to operate the relay circuit. If, however, the tube should fail to ignite, the operating sequence will repeat.

INTERNATIONAL TELEVISION

One of the most important steps toward international television was the exchange of programmes between eight European countries—Britain, France, Germany, Italy, Holland, Denmark, Belgium and Switzerland—which took place during the period June 6th to July 4th, 1954.

The project was made possible as a result of previous exchanges between Great Britain and the Continent of Europe which started in 1950. In 1952* programmes from Paris were produced jointly by the British Broadcasting Corporation and Radiodiffusion-Télévision Française; in 1953† the Coronation ceremony was successfully relayed from Britain to France, Belgium, Holland and Germany.

In July, 1953, a meeting of the executives of the various television services took place in London when it was decided that an exchange of television programmes should be created within the scope of the Television Programme Commission of the European Broadcasting Union.

An outstanding problem was the different television standards used in the various countries. The United Kingdom uses a 405-line system and France has an 819-line system as well as using (in Paris only) a 441-line system. Denmark, Germany, Switzerland and Italy have 625-line systems. Standards converters of the type first developed and used by the B.B.C. and R.T.F. in 1952 were used so that networks operating on different standards could be connected together. One converter at Dover accepted either 819- or 625-line signals and converted them to 405 lines; in Paris, converters accepted 405- or 625-line signals and changed them to 819 and to 441 lines; at Breda, in Holland, there was a further converter accepting 819- or 405-line signals and producing signals of 625 lines.

In the 1954 European exchange at least six languages were used and this difficulty was solved by providing independent commentators at the scene of the originating programme, thus providing the speech accompaniment appropriate to the various countries in which reception took place.

It was essential that the television signals originating in each country should conform to rigid technical specifications of such details as synchronizing wave-forms and the types of distortion likely to arise during transmission over the very long connecting links. Pre-programme tests started one hour before each programme, followed by a standardized introduction. In order to facilitate the smooth running of the whole operation, a co-ordination centre was set up in Lille. This centre was in direct touch by telephone with a National Control centre in each of the participating countries.

On the Continent alone it was estimated that more than £1m of British-made apparatus was involved, including transmitters, cameras and studio equipment. The network stretched over 6,000 kilometres through some 80 relay stations feeding 44 transmitters. This provided a service for a total population of about 90 million in the most densely populated parts of the countries concerned.

These details show that problems of diffusing a television programme among European countries are greater than those involved in the nation-wide networks of the United States of America. There the television system complies with a uniform standard throughout, the language is the same everywhere and the relay links, whether line or radio, are under the control of one organization.

Eight of the West European countries operating television services now have permanent connections with neighbouring states. Belgium, which operates two television services, one in French, the other in Flemish, is permanently linked with France so that French programmes can be relayed for the benefit of French-speaking viewers, and with the Netherlands so that Dutch programmes can be relayed for the Flemish-speaking viewers. These links are two-way so that the appropriate Belgian programmes can be rebroadcast in France or in Holland. Similarly there are now permanent links between Switzerland, Italy and Germany. Temporary links have been established between Lopik in the Netherlands and Cologne in Germany, between Hamburg and Copenhagen, and between the United Kingdom and France.

Whilst no definite arrangements have yet been published on the 1955 European Television Exchange programmes, the British Broadcasting Corporation favours any further development toward international television. The Director-General, Sir Ian Jacob has stated that ". . . the interchange of television programmes in Europe is likely to go forward with increasing impetus. Further afield the conveyance of television programmes from country to country has of necessity to be on film, though no one knows what the future may bring."

G. D. C.

* *J.Brit.I.R.E.*, 12, July 1952, p. 370.
† *J.Brit.I.R.E.*, 13, May 1953, p. 288.