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**THE DEUCE COMPUTER AS AN AID TO
RAILWAY TRACTION DESIGN AND OPERATION**

The ENGLISH ELECTRIC Company Limited



The Central Computing Bureau of The English Electric Company at Kidsgrove, Stoke-on-Trent. Some of the many applications of the DEUCE computers here are described in the accompanying article.

The DEUCE Computer as an Aid to Railway Traction Design and Operation

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THE ENGLISH ELECTRIC COMPANY is one of the few companies in the world which manufacture both railway traction equipment and digital computers. As a result, since 1955 the Company has used its DEUCE computers to assist in the design and assessment of performance of electric and diesel-electric locomotives, and has also offered a computer service for railways at home and overseas.

The great advantage of the digital computer is its universal nature. After completing a payroll for a factory, for example, it can immediately be used for some atomic power or aircraft engineering calculation, then for a calculation in traction machine design, and then perhaps for some production engineering problem.

Before the DEUCE computer (Fig. 1) was built in 1955 a few members of The English Electric Company's Nelson Research Laboratories worked on the A.C.E. Pilot model computer at the

National Physical Laboratory at Teddington. This machine, as its name implied, was a pilot model for the large A.C.E. computer which recently came into use at the N.P.L. It was built specifically for testing electronic techniques to be used in the construction of the A.C.E., but although it was no more than a collection of experimental units it functioned as a remarkably fine computer. It was so successful, in fact, that it was developed further and the engineered version of the Pilot model became the DEUCE. The Company's use of the Pilot model was largely related to work in the aviation field, but one or two other applications such as the critical speeds of rotating machinery were programmed, and also the first train performance programme for railway traction was written.

A digital computer can perform the following functions.

- (a) Accept information consisting of numbers or instructions.

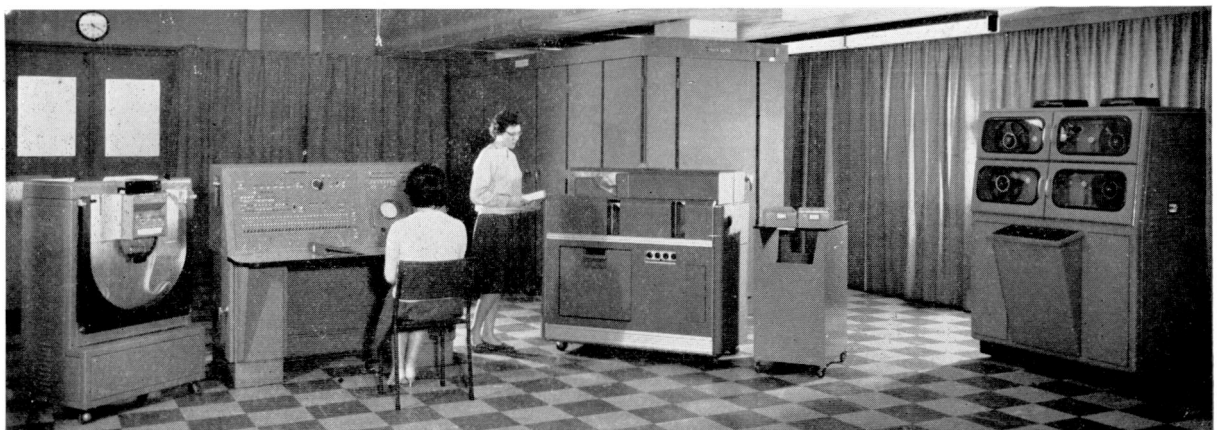


Fig. 1.—DEUCE Computer

- (b) Store these numbers and instructions.
- (c) Obey these instructions in a predetermined order.
- (d) Transfer numbers or instructions from one part of the store to another.
- (e) Perform certain arithmetical operations. Most machines can add, subtract, multiply and divide at very high speeds.
- (f) Perform certain logical operations. The most important of these is the function of discrimination. At a certain stage of its operations the machine will follow one of two courses of action depending upon whether, for example, some given number is positive or negative. Another form of discrimination is a test of whether a number is zero or non-zero. By means of these facilities the computer can repeat a certain sequence of steps a given number of times and then go on to perform a different sequence.
- (g) Print or punch out information on cards or tape.

The DEUCE reads data on punched cards or punched paper tape. It has three levels of storage, a high-speed store consisting of mercury-filled delay lines which will hold the equivalent of 626 nine-digit decimal numbers, a magnetic drum which can store 8,192 numbers, and magnetic tape units with effectively unlimited storage.

The arithmetic speeds of DEUCE are 2 milliseconds for multiplying or dividing two nine-digit decimal numbers, and 64 microseconds for adding or subtracting two such numbers. Output of information is again on punched cards or paper tape and is then printed out on conventional tabulators or typewriters.

One of the first programmes to be written for the DEUCE, after it was installed at the Nelson Research Laboratories in Stafford in 1955, was a programme for calculating speeds, times, energy consumption and motor heating of a d.c. electric locomotive. This was a development of the A.C.E. Pilot model programme designed to the requirements of the Company's Traction Department. Since then the application of the DEUCE to railway problems has increased considerably, both within and without the Company, and the purpose of this article is to give a survey of this work and of likely future developments. These applications fall naturally into two groups, applications relating to traction design and those relating to the operation of railways, and for this reason this article has been divided into two parts. Part I, on traction design work, describes work carried out on the DEUCE for the design departments of The English Electric Company. Part II describes work performed for British Railways by the Data Processing and Control Systems Division, in conjunction with railway staff.

PART I. RAILWAY TRACTION DESIGN

TRAIN PERFORMANCE CALCULATIONS

Object of Calculations

The object of these calculations is to enable the manufacturer to produce a locomotive of minimum cost and maximum reliability for the performance of a specified duty, and to give the railway authorities particulars of this performance.

In order to be able to make an accurate prediction of the performance of a locomotive having known characteristics, hauling a train of a given weight over a specified route, it is necessary to simulate the actual running conditions very closely and it is primarily essential to establish that the train will

cover the specified distance in the required time. Dependents of these fundamental quantities are speeds to be attained, tractive efforts required and energy (or fuel) consumed.

In order to select motive power which is correctly matched to the specified duty it is necessary to know the load duty-cycle and to establish that the machines concerned are suitably rated. They must not overheat or be overstressed.

In the first instance it is necessary to perform the calculation for an 'all out' run, to establish the r.m.s. current and the minimum time in which the selected locomotives can perform the specified duty, obeying all speed restrictions. In this

connection it has been found that the r.m.s. current of the traction motors over the section of the route which constitutes the most severe period of duty gives a close guide to motor temperatures attained in service, which must be within acceptable limits.

It is further often necessary to calculate the 'all out' fuel consumption in order to establish the size of the fuel tanks under the most severe operating conditions possible, or the 'normal run' energy consumption in order to calculate the capacity of substations and to establish operating costs.

The 'normal run' time should have a margin of from 5% to 10% 'make up' time in hand over the 'all out' run in order to produce a realistic timetable, where a train can make up time lost due to unforeseen signal checks or temporary speed restrictions caused by permanent-way defects.

Presentation of Results

The best way of presenting all these performance particulars is by means of curves relating distance with time and with the other dependent variables such as speed, line current, energy (or fuel) consumption and a function of the power losses in the traction motors, from which the r.m.s. current for any particularly arduous section of the route can readily be established.

Input Data

The essential information required for these calculations includes particulars of the locomotive, the train and the track.

The Locomotive

Characteristic curves relating tractive effort and current with speed on all economical running notches are required, together with particulars such as average line volts, motor groupings, field strengths with corresponding motor resistance values, diesel-engine fuel rates at various loads and engine speeds, locomotive weight, resistance to motion, etc.

The Train

As for the locomotive, a curve relating resistance to motion with speed and the total train weight are required.

The Track

A profile indicating length and values of all gradients, curves and speed restrictions is required, together with location of stations at which the train must stop, stopping time, and location of points at which passing time is required.

Storage of Input Data

All curves such as the locomotive characteristics and the train resistance curves are stored on the magnetic drum of the DEUCE in the form of a sufficient number of ordinates to enable the computer to interpolate linearly with acceptable accuracy for intermediate points. The relevant section is brought down into the high-speed store when required for computation. All other parameters such as train weight, braking rate, acceleration factor, integration interval, coasting constant, multiplication factors depending on units used, etc. concerning the locomotive performance are stored in the high-speed store, where they are readily accessible for computation. All information concerning the topography of the route is stored on the magnetic drum and brought down into the high-speed store, section by section, as and when it is required for computation.

Method of Calculation

This consists basically of calculating repeatedly the time taken and hence the distance travelled by a train which is being accelerated uniformly by a constant force through a small increment in speed, and progressively totalling these increments of time and distance.

The relationship between these quantities is given by Newton's first and second laws of motion, which may be expressed as :

$$\text{Force} = \text{Mass} \times \text{Acceleration}$$

From this, the fundamental linear differential equations

$$\delta t = \delta v \cdot F/P \dots \dots \dots (1)$$

$$\text{and } \delta s = \delta t \cdot \bar{v} \dots \dots \dots (2)$$

are derived, suitably expanded to take account of various factors, and integrated for successive steps in speed.

δt = time increment over the step δv
 δv = speed increment
 F = force required to accelerate a given mass at a constant rate
 P = specific net accelerating tractive effort or pull at \bar{v}
 δs = distance increment over the step δv
 \bar{v} = average speed over the step δv

B = rigid wheelbase
 r = radius of curve

The factors to be taken into consideration before these equations can be solved are outlined below. It will be seen that the 'Force' is the net tractive effort of the locomotive available for acceleration at any given speed and position along the route after deduction of all resistance to motion, and the 'Mass' is the total weight of the train plus locomotive.

The other part is termed 'train resistance', which is dependent on speed and consists of mechanical and air resistance to the motion of the train. Normally, separate train resistance curves for the locomotive and for the train are provided, and the appropriate values read from these curves are stored.

Usually, the train resistance curve can be represented in the form of a quadratic equation :

$$R = a + bv + cv^2 \dots\dots\dots (5)$$

where R is the total resistance to motion of the train and/or locomotive

v is the train speed and a , b and c are constants.

Resistance to Motion

This is divided into two parts. One part is a function of the track, comprising gradient and curve resistance, and these values are independent of speed, varying discretely along the track.

Normally, the first term ' a ' comprises journal friction, track resistance, rolling resistance, etc. and may be termed 'mechanical resistance', ' bv ' consists mostly of flange resistance, and ' cv^2 ' is the air resistance term.

Grade resistance is caused by the force of gravity acting on a train negotiating a gradient, and may be expressed as

$$R_g = g(M + m) \sin \alpha \dots\dots\dots (3)$$

where R_g = resistance to motion caused by gradient, which may be positive or negative

g = gravitational constant

M = weight of locomotive

m = weight of trailing load

$\sin \alpha$ = gradient, 1 in n

Various methods for calculating these quantities have been evolved, given the necessary particulars of the construction of the locomotive and train. Also many curves have been produced as a result of extensive dynamometer-car tests carried out by the railways.

Rotary Inertia

The force required to produce a linear acceleration of 1 m.p.h.p.s. on a mass of 1 ton

$$= \frac{2,240 \times 5,280}{32.2 \times 3,600} = 102.03 \text{ lb} \dots\dots (6)$$

Curve resistance is caused by friction at the wheel flanges and depends on the radius of the curve, the track gauge and the rigid wheelbase. It can generally be expressed empirically in the form

$$R_c = \frac{K \sqrt{(G^2 + B^2)}}{r} \dots\dots\dots (4)$$

where R_c = resistance to motion caused by curve

K = a constant depending on units used

G = track gauge

This figure has to be increased by from 6% to 10% to allow for the energy stored by rotating parts on a moving train, such as wheels and axles, and traction motor armatures and gears. Correction factors normally used in this connection are 6% for heavy locomotive hauled freight trains, 8% for locomotive hauled passenger trains and 10% for multiple unit trains. The figures used for the force required to accelerate 1 ton of train weight through 1 m.p.h.p.s. are normally taken as 108, 110 and 112 lb respectively.

The Differential Equations of Motion

Taking these various factors into account, the differential equations (1) to be solved during normal full-power running conditions of the locomotive and train can be expressed more fully than in 'Method of Calculation' on page 5, as under:—

$$\delta t = \frac{\delta v (1 + \gamma) (M + m)}{T - (R_l + R_t + R_g + R_c)} \dots\dots\dots (7)$$

where γ = factor to take account of rotary inertia

T = tractive effort at the locomotive wheel treads

R_l = resistance to motion of the locomotive

R_t = resistance to motion of the train (wagons and/or coaches).

The value of δt thus derived may now be used in the equation (2) for its solution.

Energy or Fuel Consumption

To calculate the energy or fuel consumption of the locomotive the curve which specifies the relationships between the rate of energy or fuel consumption and speed (or tractive effort) is used to solve the equation

$$E = \int_0^t e. dt \dots\dots\dots (8)$$

where E = energy or fuel consumption at t
 dt = time increment

e = rate of energy or fuel consumption.

In the case of a d.c. equipment a curve of motor current against speed is provided. From this the line current can be established, as it is a multiple of motor current, the multiplying factor depending on the traction motor connections. The motors may be grouped in series, series parallel, or parallel, and the speed range over which each grouping obtains is specified.

The calculation of energy consumption then is:—

$$E = \int_0^t I_l V_l dt \dots\dots\dots (9)$$

where I_l = line current

V_l = nominal line voltage.

Traction Motor Temperature

To calculate the r.m.s. motor current referred

to under 'Object of Calculations' on page 4, the following relationship has to be evaluated :—

$$I_{rms} = \sqrt{\frac{\int_{t_1}^{t_2} I_m^2 dt}{\int_{t_1}^{t_2} dt}} \dots\dots\dots (10)$$

where I_{rms} = root mean square motor current

t_1 = time at start of required time interval

t_2 = time at end of required time interval

I_m = motor current at nominal line volts, per motor.

Normally, only $\Sigma I_m^2 dt$ is calculated progressively. This is a function of the electrical power losses in the traction motor. It is then easy to establish the r.m.s. motor current over any required arduous section of the route, or over the whole run.

Generally, it can be said that provided the r.m.s. current does not exceed 100% to 110% of the continuous rating of the traction motors on an 'all out' run, depending on the amount of ventilation provided, then the motors will not be damaged in service due to overheating.

Coasting Constant

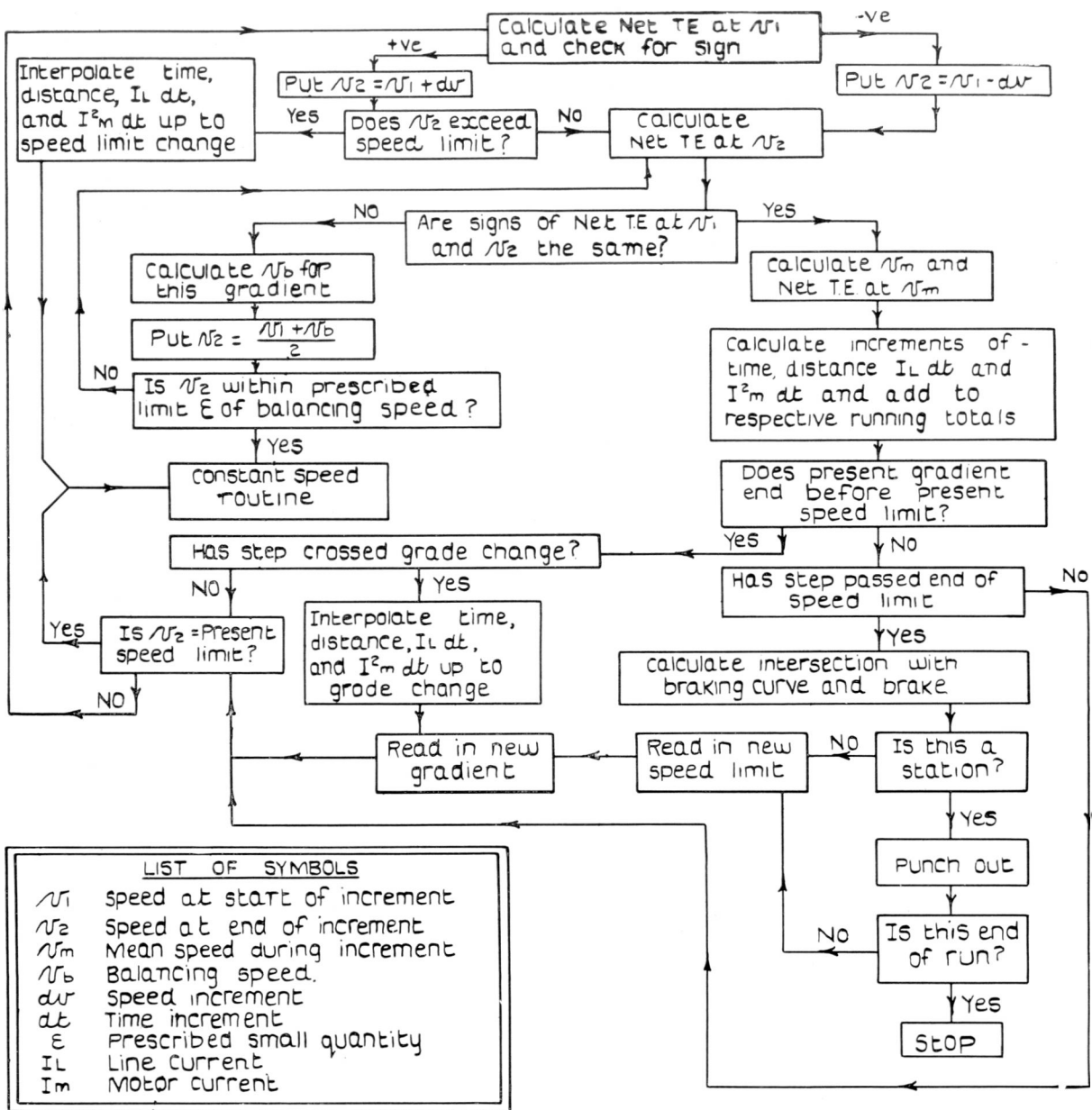
During coasting the kinetic energy of the train is opposed not only by the resistance to motion which obtains during acceleration but also by the friction and windage of the motors and gearing which have to be driven by the kinetic energy of the train. To allow for this force, a coasting constant of about 2 lb/ton (of the weight of the locomotive only) has to be added to the existing resistance to motion at the position and speed under consideration.

Braking

It is assumed that the train decelerates at a constant rate during a brake application and that the driver will (and can) achieve this by suitably adjusting the braking force.

Units

The programme will work with either British or metric units, which can be selected by means of a suitable marker.



T. E. = Tractive effort

Fig. 2.—Block schematic diagram for traction performance calculation programme

Logical Complications

The main difficulties encountered when performing these calculations at selected increments in speed consist of the necessity (1) to perform an interpolation at the end of each gradient, and (2) to reduce the size of the otherwise uniform increments in speed, when approaching balancing speed.

Other complications are caused by the need to establish at the end of each step that (1) the end of the gradient has not been passed, (2) the present speed limit has not been exceeded and (3) the point in distance has not been passed at which it is necessary to commence braking down to a lower subsequent speed limit.

The solution of some of these difficulties is illustrated in greatly simplified form in the block schematic diagram shown in Fig. 2. A completely detailed block schematic diagram would occupy many sheets and would be very difficult to follow. For example, the block labelled 'constant speed routine' is in itself a logically very complicated section, requiring several block schematic diagrams to describe fully all the tests which have to be made at the end of each step, and to show the various exits from it which lead back into other parts of the programme.

For the reader of this article it will be easier to follow a description of some of the logical operations required in the train performance calculation. It is however well to realise that the art of programming lies in the construction of a logically complex block diagram, quite apart from the ability to write a sequence of instructions in the form which is acceptable by the computer, or the need to have a sound knowledge of mathematics.

Constant Acceleration

When starting from rest and accelerating up to the speed at which the free-running curve or natural characteristic of the motors is reached, there are a number of discontinuities in the locomotive tractive-effort/speed characteristic, due to the driver notching up his controller. This results firstly in cutting out steps of the starting resistances, which are provided to ensure nearly uniform and reasonably smooth acceleration in order to avoid damage to the drawgear and discomfort to the passengers. Thus the voltage on the motors is gradually increased, thereby increasing the speed for a given current and tractive effort. Initially, the motors may be connected in series, and finally in parallel, the resistances being re-inserted when the motor grouping is changed and again being cut out step by step until the full-field parallel characteristic is reached at nominal line voltage. In order to attain greater speed the traction motor field may now be weakened, causing a drop in tractive effort for a given mean starting current.

Each speed range over which approximately constant starting acceleration is maintained can therefore be calculated as one step, provided that

no gradient change occurs during this step and that no speed limit is exceeded.

The time elapsed, distance travelled, energy or fuel consumed, etc. for that increment in speed can then be evaluated, and these contributions are then added to the respective running totals to date and stored.

Free Running on Full Power

When the train is operating in the speed range covered by the natural characteristic of the traction motors and is not running at constant speed, its motion is calculated by using small increments in speed of say 4 m.p.h. in the step by step integration of the differential equations of motion described under 'Method of Calculation' on page 5. At the end of each step, as before under 'Constant Acceleration', tests have to be made to ensure that in the distance covered by that step (1) no gradient change has occurred, (2) the present speed limit has not been exceeded, and (3) the point in distance at which it is necessary to commence braking down to a lower subsequent speed limit has not been passed.

Constant-speed Running

When the train is running at constant speed, either as a result of reaching a balancing speed or because it is running through a speed restriction, where it has power in hand, then the required information such as time, distance, energy or fuel consumption, etc. can be evaluated up to the end of the present gradient in one step, provided again that the point in distance at which it is necessary to commence braking to a subsequent lower speed limit is not passed. If it has been passed, then a test is made at the end of the gradient to see whether the train will be running at the speed limit during the next gradient. If it is, a test is made to see if the tractive effort on the next gradient is greater than the total resistance to motion. If it is, the train can continue to run at constant speed, and the constant-speed running cycle is repeated.

Operation on Part Load

To calculate the energy consumption or r.m.s. current during constant-speed running through

speed restrictions on part load with d.c. electric motive power, the proportion of time on the adjacent notches above and below the tractive effort required to balance at this speed is first computed. The currents corresponding to the tractive efforts on these notches are then multiplied by these times respectively and added to the running total. This is equivalent to the driver notching up and down between these notches in such a way as to keep his speed within a small margin above and below the speed restriction alternately.

In the case of diesel-electric, diesel-mechanical or a.c. electric locomotives a different method is used for calculating fuel (or energy) consumption and motor heating, when operating at constant speed on part load. For the first two, the programme interpolates linearly between the family of fuel/tractive-effort curves produced by the appropriate locomotive construction programme. For the third the motor current is established by the 'locating' method used by the diesel-electric locomotive characteristics construction programme described on page 12.

Speed Restrictions

The whole of the route is continuously covered by speed restrictions as laid down by the Civil Engineer. These consist of an overall maximum permissible speed for the track, with reduced speeds in curves, over bridges, through junctions, stations, etc., as necessary for safety. At stations where it is required to stop the train, the speed restriction value is put equal to zero. During the process of reading-in these speed restrictions the computer calculates the point in distance on the previous higher speed limit at which it is necessary to start braking at the specified rate in order to reach the new lower speed limit at its commencement. This point is stored, since it is the earliest point in distance at which it may be necessary to start braking. Whenever a change in speed restriction occurs, this is also made to correspond to the end of a gradient. If in fact no change occurs at this point, then the unchanged gradient is split here into two sections.

As already mentioned, a test is made at the end of each step in the calculation to check whether the point in distance has been reached at which it is

necessary to brake to the next speed restriction. If not, then the next step is calculated. If, however, the point in distance has been passed at which braking must start if running at the present speed limit, in order to reduce speed by the required amount on reaching the new lower speed limit, then the computer forms the braking function to this new limit and calculates the distance and speed at the point of intersection of the braking curve and a straight line between the beginning and end points of the last integration. The values at the end of the last step of integration are then replaced by the values at the beginning of this step. Then time, energy consumed, etc. are calculated, assuming a straight line between these values of speed and distance and those at the calculated intersection. These contributions are then added to the corresponding running totals.

In addition to the speed limits imposed by local conditions of the track, there is also always the maximum permissible speed of the train. This is usually governed by the maximum safe speed of the traction motor armatures. This speed limit is read in as a single value, and the programme always takes the current speed limit as the lower of the track and the train speed limits.

Output Results

Depending on requirements the output from the train performance calculation can be produced in various forms, either on punched cards or tabulated on sheets of paper, or in the form of a graph. Some details of these forms of output are of interest and are given below. Graphical output is described under 'Curve Plotting Programme' on page 15.

Punched Card Output

The output can be given either in binary form, for use with the graph plotting programme, or in decimals, for subsequent tabulation.

Values of distance, speed, time, line current, energy or fuel consumption, and a function of the power losses in the traction motors, are punched out at selected intervals.

This frequency can be chosen by the use of a suitable marker, and can be (1) at every step in

the calculation, for use with the graph plotting programme, (2) at the end of every gradient, where much detail is desirable but graphs are not required, (3) only at stations at which the train stops, and (4) at specified points.

Whichever form of output is chosen, the programme always punches out at stops.

To cater for cases where motor heating and energy or fuel consumption are not required, that is, when only the information required for the compilation of a timetable is needed, a separate programme is used which calculates only the relationship between distance, time and speed. This programme is of course much faster on the DEUCE due to the reduced amount of calculation at each step.

Tabulation of Output

For the convenience of reading the results produced by the computer, the result cards are fed into a tabulator which reads decimally punched cards, one at a time, at a rate of 150 cards per minute, and types the results in suitable columns on a roll of paper of the required width.

SUPPLEMENTARY PROGRAMMES

To assist in producing the input data in a suitable form for use with the train performance calculation programmes, and also to produce the output in alternative forms, a number of supplementary programmes have been and are being written. Details of some of these are given in the following sections.

Gradient Profile Preparation Programme

The function of this programme is (1) to calculate the combined resistance to motion produced by the presence of gradients and curves, (2) to perform grade averaging when required, and (3) to punch out the results in binary code in a form suitable for use with the train performance calculation programmes.

Input Data Preparation

The values of gradient, curvature and speed limit shown on the gradient profile of a railway track are logged with corresponding values of

distance at the beginning and end of each incident, and are arranged in continuously increasing order of distance from the start of the journey. This tabular information is then punched decimally on to cards.

Now that computers can calculate the train performance, the most tedious and time-consuming task which remains is usually the measuring and logging of the data shown graphically on the gradient profile. It would be of enormous assistance to manufacturers if the railway authorities who have not already done so would enter on their profiles all distance values at which gradients, curves and speed restrictions start and finish, and if the gradient profile were drawn to a specified vertical scale, indicating the height above a suitable datum at each grade change. Whichever method is used for the performance calculations, the track data is always initially required in tabular form in order to combine the resistance to motion caused by both gradients where appropriate. The authors take this opportunity of appealing to all railway civil engineers to assist by preparing profiles in the form suggested. This will enable manufacturers to give a far better service whenever train performance particulars are required.

Grade Averaging

When a gradient profile consists of many short gradients of, for example, less than 0.1 mile in length, it may be desirable for the purpose of train performance calculations to reduce the number of gradients by replacing a number of adjacent gradients of similar slope by one equivalent gradient. This programme reads-in the cards containing the track data described above and averages groups of adjacent gradients to any prescribed degree of accuracy.

The programme has been arranged to work with either metric or British units, and gradients can be defined by 1 in n , or as a percentage or by height above a given datum. Curve resistance can be added if required, either as a given value or calculated from a formula of the type, resistance = constant/radius. The maximum permissible height error acceptable in grade averaging has to be specified. The machine reads-in a group of gradients and replaces the first two by an



Fig. 3.—The 3,300 h.p. 'English Electric' Deltic locomotive

equivalent one. A comparison is then made between the height of the intersection of the two original gradients and the corresponding point of the equivalent gradient. If the difference is greater than the maximum permissible error, the machine stores the original gradients and examines the next two gradients. If this difference is less than the maximum permissible error, the machine calculates the equivalent to the first three gradients and compares heights at intersections and so on.

The programme is arranged so that no grade averaging is performed for the first quarter mile beyond a station, as this might have considerable effect on train performance calculations.

Diesel-electric Locomotive Characteristics Construction Programme

This programme produces a family of fuel-rate/tractive-effort curves for a given set of speeds, suitable for use with the appropriate train performance calculation programme (see 'Operation on Part Load' on page 9).

Input Data

The input data consist of :—

1. The traction motor speed/current and tractive-effort/current curves for all field strengths.
2. The locomotive speed/tractive-effort curves with unloading point loci.
3. A generator output/fuel-rate curve.
4. The traction motor resistance for all field strengths.
5. A given vector of tractive efforts at suitably selected intervals.
6. A given vector of speeds at say 10 m.p.h. intervals.

For the purpose of illustration, the graphical input data and the results of the calculation are given for the 3,300 h.p. 'English Electric' Deltic locomotive shown in Fig. 3. The relevant characteristics of this locomotive are reproduced in Figs. 4, 5, 6 and 7.

Method of Calculation

The programme selects the speeds in turn from the given vector of speeds, and for each value of tractive effort in the vector of given tractive efforts it calculates the fuel rate.

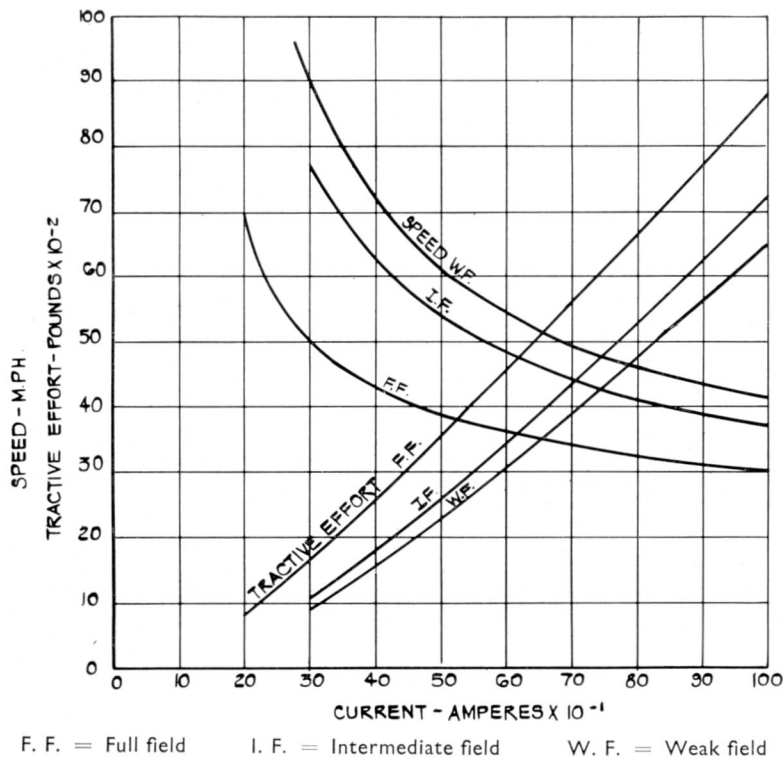


Fig. 4.—Traction motor characteristics

Given a speed v_a and a tractive effort T_a , it locates the point (v_a, T_a) in the plane illustrated in Fig. 5. In other words, it determines the field on which the locomotive would be working, namely full field, one of the intermediate field connections, or weak field. Any point outside C2 is ignored.

Having decided on the field, the programme looks up the motor current I_m on the corresponding traction motor tractive-effort/current curve, Fig. 4.

$$\text{Then } I_g = K I_m \dots \dots \dots (11)$$

where I_g = main generator current

K = number of strings of motors in parallel.

The programme then looks up the speed v_n at current I_m for the nominal voltage E_n for which

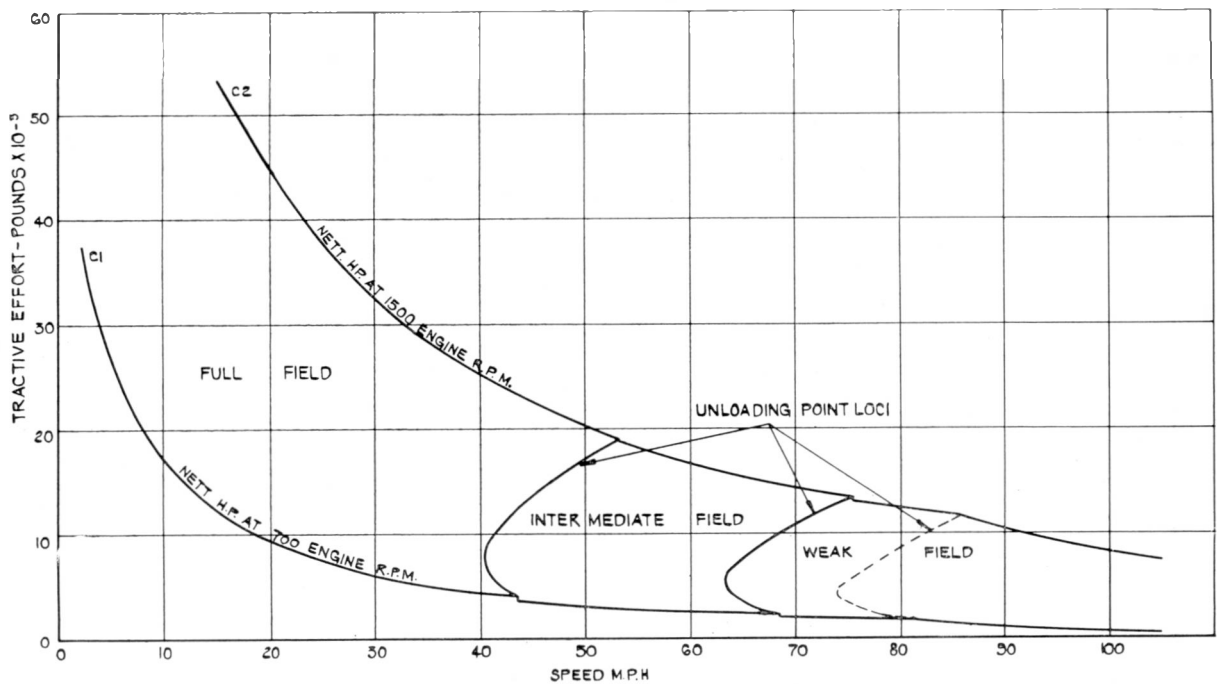


Fig. 5.—Performance characteristics of 106 ton 3,300 h.p. Deltic Co-Co diesel-electric locomotive

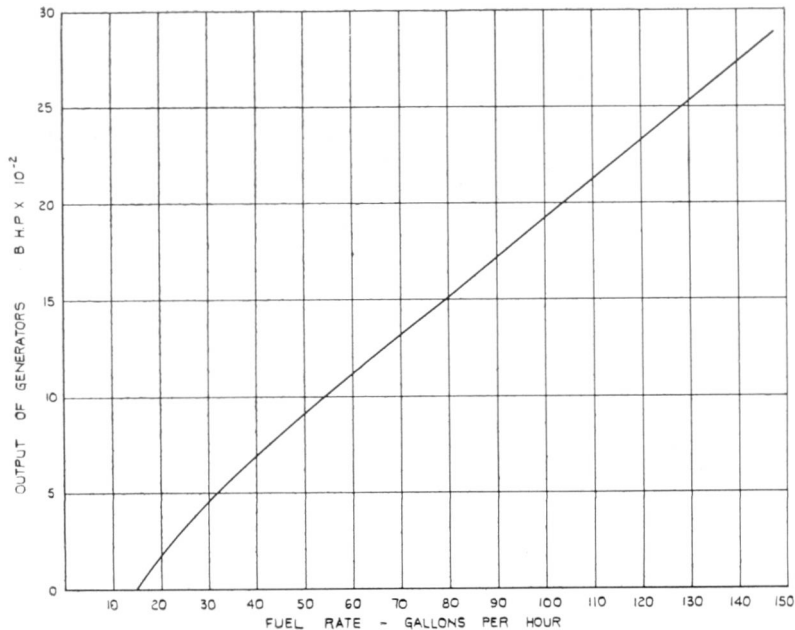
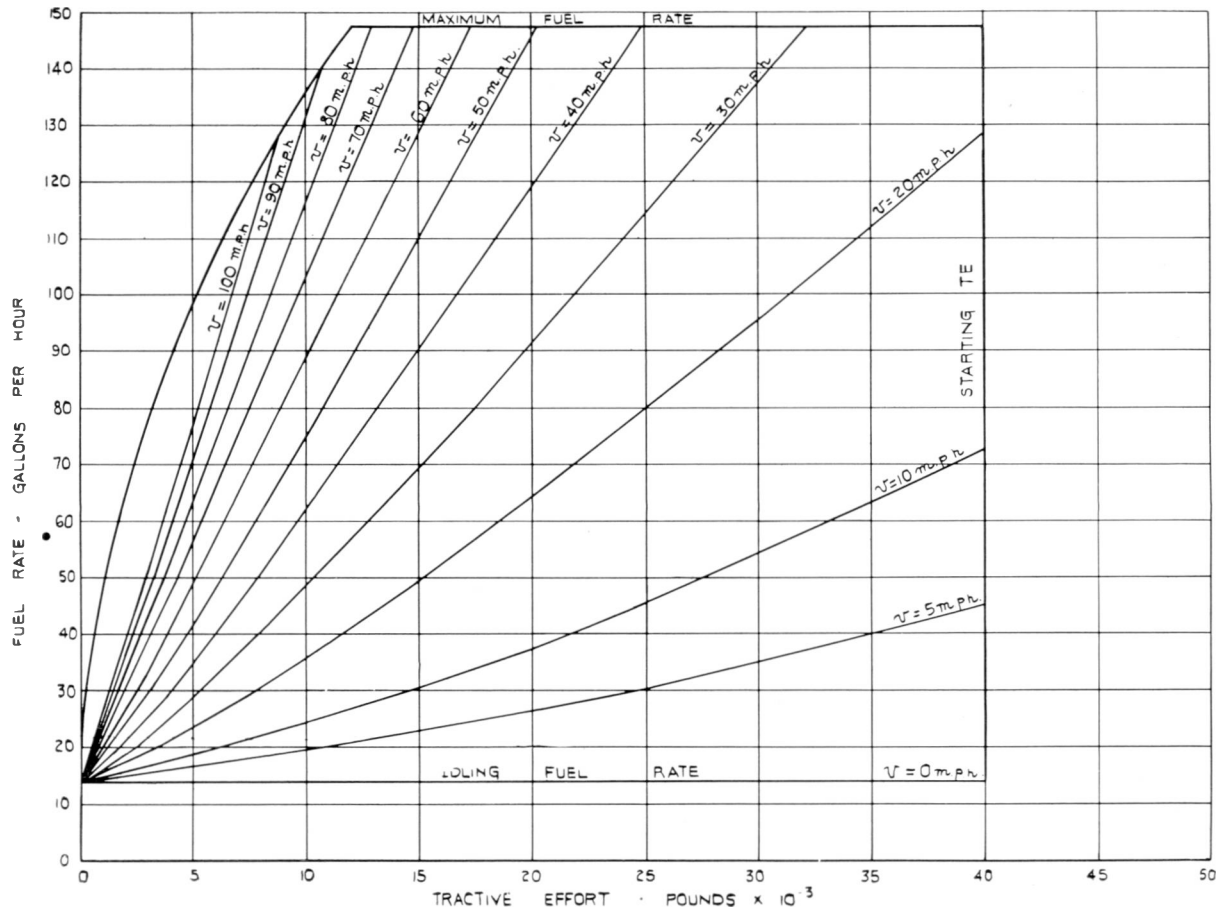


Fig. 6.—Fuel rate characteristic of 3,300 h.p. Deltic diesel-electric locomotive, incorporating auxiliary load fuel consumption

Fig. 7.—Fuel-consumption/tractive-effort curves of 3,300 h.p. Deltic diesel-electric locomotive at various locomotive speeds



the motor characteristic is drawn. The back e.m.f. of the motor E_{nb} for the nominal voltage E_n is then obtained from the relation

$$E_{nb} = E_n - (B + I_n R_f) \dots\dots\dots (12)$$

where B = brush drop

R_f = motor resistance for the particular field.

Then E_a , the actual motor voltage, is calculated from the formula

$$E_a = \frac{E_{nb} \cdot v_a}{v_n} + (B + I_m R_f) \dots\dots\dots (13)$$

The generator voltage E_g is obtained from the relation

$$E_g = N \cdot E_a \dots\dots\dots (14)$$

where N is the number of motors in series per string.

The generator output P_g is then derived from the expression

$$P_g = \frac{I_g E_g}{746} \dots\dots\dots (15)$$

and finally, the fuel rate is looked up on the generator-output/fuel-rate curve, giving the fuel rate F at the point (v_a, T_a) . This curve is shown in Fig. 6 and takes into account the auxiliary load.

The process is repeated for all values of tractive effort in a given vector of speeds, and this is then repeated for the next value of speed and so on. The fuel-rate/tractive-effort curves are produced for the same values of tractive effort at each speed, except that more and more of the later values will be ignored. For this reason, the input values of T must be 'bunched' near the beginning of the range in order to obtain a reasonable number of points for the curves at the high-speed end.

Results

The output of this programme consists of the calculated values of the family of fuel-rate/tractive-effort curves at the required speeds, punched on cards in binary code, in suitable form for use as input data for the main train performance calculation programme, and as illustrated in Fig. 7.

A.C. Locomotive Characteristics Construction Programme

This programme is at present being compiled and when completed it will produce a family of energy-consumption/tractive-effort curves at a range of selected speeds, say 10 m.p.h. intervals, and punch out the calculated values in binary code in a form suitable for use with the train performance calculation programme. The losses in all the electrical equipment, such as transformer, rectifiers, traction motors, chokes and diverts, are taken into account so that the train performance programme will calculate the energy consumption of the locomotive at the pantograph, worked back from the tractive effort requirements at the wheel tread.

Curve-plotting Programme

In order to provide an alternative output directly from the DEUCE in graphical form, of results produced by the train performance programme, a curve-plotting programme has been written which produces a continuous trace of speed, time, energy consumption, etc. (as ordinates y) on a distance basis (as abscissae x).

Input Data

The input to this programme consists of the appropriate binary gradient and speed limit data cards as used in conjunction with the train performance calculation programme, together with the output from the latter, punched out in binary form at every step in the calculation.

Operating Principle

Four electronic channels are provided, each of which can produce a voltage proportional to the size of an eight-digit binary number. Consequently, the size of any number can be represented by a voltage having a theoretical discrimination of one part in 256 in y , and four such numbers can be stored per 32 binary digit word. This degree of accuracy is well in excess of the nominal accuracy of the recorder.

These four analogue voltages are applied simultaneously to four channels of a 14 channel Duddell oscillograph type of recorder. In this instrument each galvanometer movement rotates a small

mirror, which has one degree of freedom, so scanning the light from a point source across the bromide chart paper.

If, therefore, successive values of y_1 , y_2 , y_3 and y_4 are calculated at very small uniform increments of x , and the appropriate analogue voltages are applied to four of the reflecting galvanometers at very small uniform increments of time, then four apparently smooth and continuous curves will be drawn on the chart paper if this is synchronised to move at a uniform speed. The result will be a correctly scaled graph of the four values of y , plotted against x .

Required Calculation

To use this equipment for plotting the results from the train performance calculation programme it is therefore necessary to calculate the values of all parameters to be plotted at very small uniform intervals of distance, say at increments of 1/100th of a mile.

The programme uses linear interpolation for the calculation of intermediate values of all quantities except train speed, for which a quadratic interpolation is performed in order to produce a correctly formed curve during acceleration and braking.

The values calculated are stored on the drum and are subsequently brought down for plotting at 20 millisecond intervals. If the chart paper is moved at $\frac{1}{2}$ inch per second, the resulting scale will be 1 inch per mile.

A run exceeding approximately 30 miles has to be plotted in sections of about this distance, as otherwise the storage capacity of the magnetic drum will be exceeded.

Graphical Output

The output consists of curves plotted on a 'distance' basis. For each plotting section of the route the programme produces either one or two charts, depending on whether the input data is from a timetabling run or from a comprehensive run. On each chart four curves are plotted simultaneously.

The four curves of the first group are plotted in either case and comprise :—

1. A correctly scaled gradient profile.
2. A speed limit envelope.
3. A continuous trace of train speed on the same ordinates as 2.
4. A saw-tooth trace of time.

The four curves of the second group are plotted only in the case of a comprehensive run. They are plotted to the same distance scale as the first group and comprise :—

1. A saw-tooth trace of energy consumption.
2. Spare. May be used as a continuous trace of actual traction-motor temperature eventually.
3. A continuous trace of line current.
4. A saw-tooth trace of a function of the power losses in the traction motors.

Fig. 8 shows typical output from this equipment for the Deltic locomotive running over a section of the route from London (Kings Cross) to Newcastle.

Speed of Calculation

The speed of calculation varies greatly and depends largely on the number of incidents of grade, curve and speed-limit changes per mile of track, the frequency of station stops, the frequency at which it is required to punch out the data, and the amount of data to be calculated, i.e. whether it is a timetable or a comprehensive run. The limits for the train performance calculation programme vary from the equivalent of about 600 to 6,000 m.p.h.

As an example, on a recent calculation for an express run from London (Liverpool Street) to Norwich with one stop at Ipswich, the actual performance calculation for the 114.96 miles was completed in 73 seconds, equivalent to 5,669 m.p.h. To this should be added the gradient profile preparation time on the computer, which was 90 seconds in each direction, including reading and punching time. As this was a timetable run there was no locomotive characteristic preparation time. The reading of the necessary locomotive and track data for the main programme took 30 seconds, excluding the 60 seconds required for reading-in the programme itself. The time required for punching the output data is included

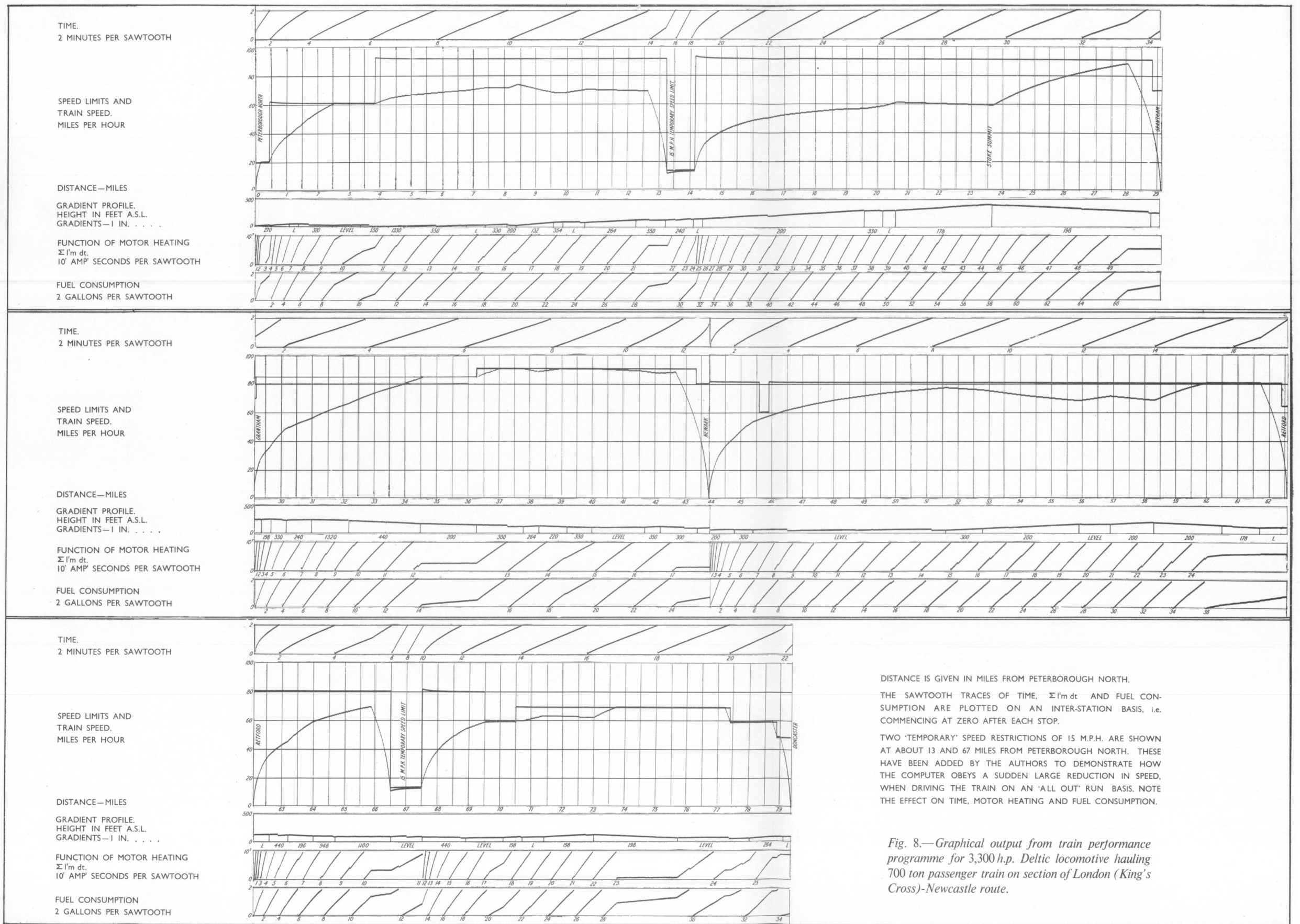


Fig. 8.—Graphical output from train performance programme for 3,300 h.p. Deltic locomotive hauling 700 ton passenger train on section of London (King's Cross)-Newcastle route.

in the 73 seconds calculating time. Once the programme is read in, it can be used for any number of train performance runs and was in fact on this occasion used for four consecutive runs. The total time on the DEUCE for this one run is therefore 73 + 90 + 30 + say 15 seconds, or 208 seconds. On this basis the average speed in terms of total machine time is 1,989 m.p.h.

The actual speed of plotting graphs is 1,800 m.p.h. if points are calculated at 1/100th mile intervals. However, if reading and calculating times of the curve-plotting programme are added to the plotting time, then the speed of operation in terms of time on the machine is about 300 m.p.h. The time taken to translate track and locomotive data into a form suitable for calculation either by hand or on an analogue or digital computer is usually the same for all three methods.

TRACTION MACHINE DESIGN CALCULATIONS

The calculations described in the preceding paragraphs are concerned with the expected performance of a specific design of locomotive.

Many calculations are involved in the design of motors, rectifiers, transformers and control gear for a locomotive, and some of these calculations produce the basic data used in the performance calculations.

Most of the problems concerned, in common with many other design office problems, have a common feature in that much of the data used is in the form of empirically determined curves, and the results are also required in the form of curves for inclusion in tenders. A typical calculation by hand would involve an engineer in looking up a series of points on a curve, or family of curves, performing some calculations on the values so obtained, and then looking up the results on another series of curves and so on, the final results being another set of curves. Some of these problems occur regularly in traction machine design, such as the determination of the motor characteristic curves shown in Fig. 4. Others occur less frequently, such as the calculation of regenerative braking curves. In all these types

of problem the General Interpretive Programme (Ref. 1) has been used, since it is easier to use than the normal machine code and is particularly suited for operations in parallel. Although this interpretative scheme was originally used for matrix calculations, a number of programme sections have been written for the scheme which make it suitable for design office calculations of this type. These relate to the storage of and interpolation between families of curves.

Regenerative braking calculations may only be required once or twice a year but it may take an engineer two or three weeks to do them, and on each occasion he will have to spend some time studying the method of calculation. Now that there is a programme available he has only to follow the rules for preparing data for the programme, and the computer will do the rest. The method of calculation is of interest in showing the type of design office calculation which can be carried out using the interpretative scheme.

The starting point of the calculation, obtained either from test results or design data, is the

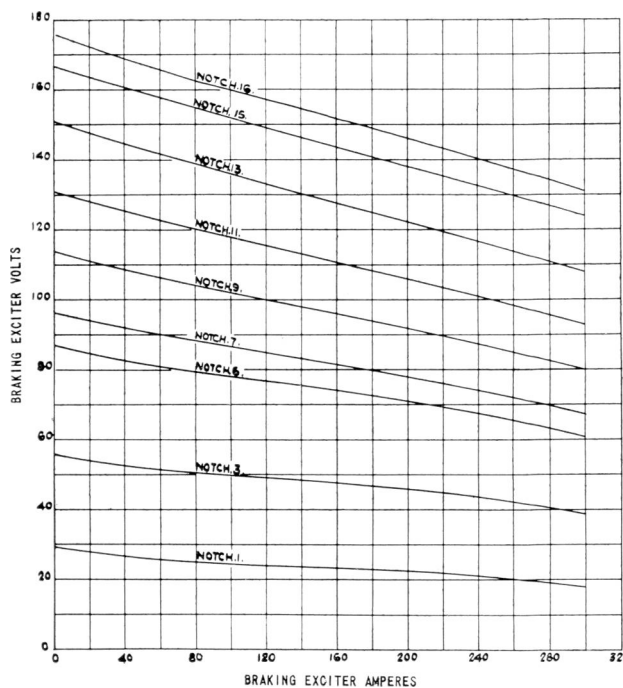


Fig. 9.—Volt/ampere output characteristics of a regenerative braking exciter

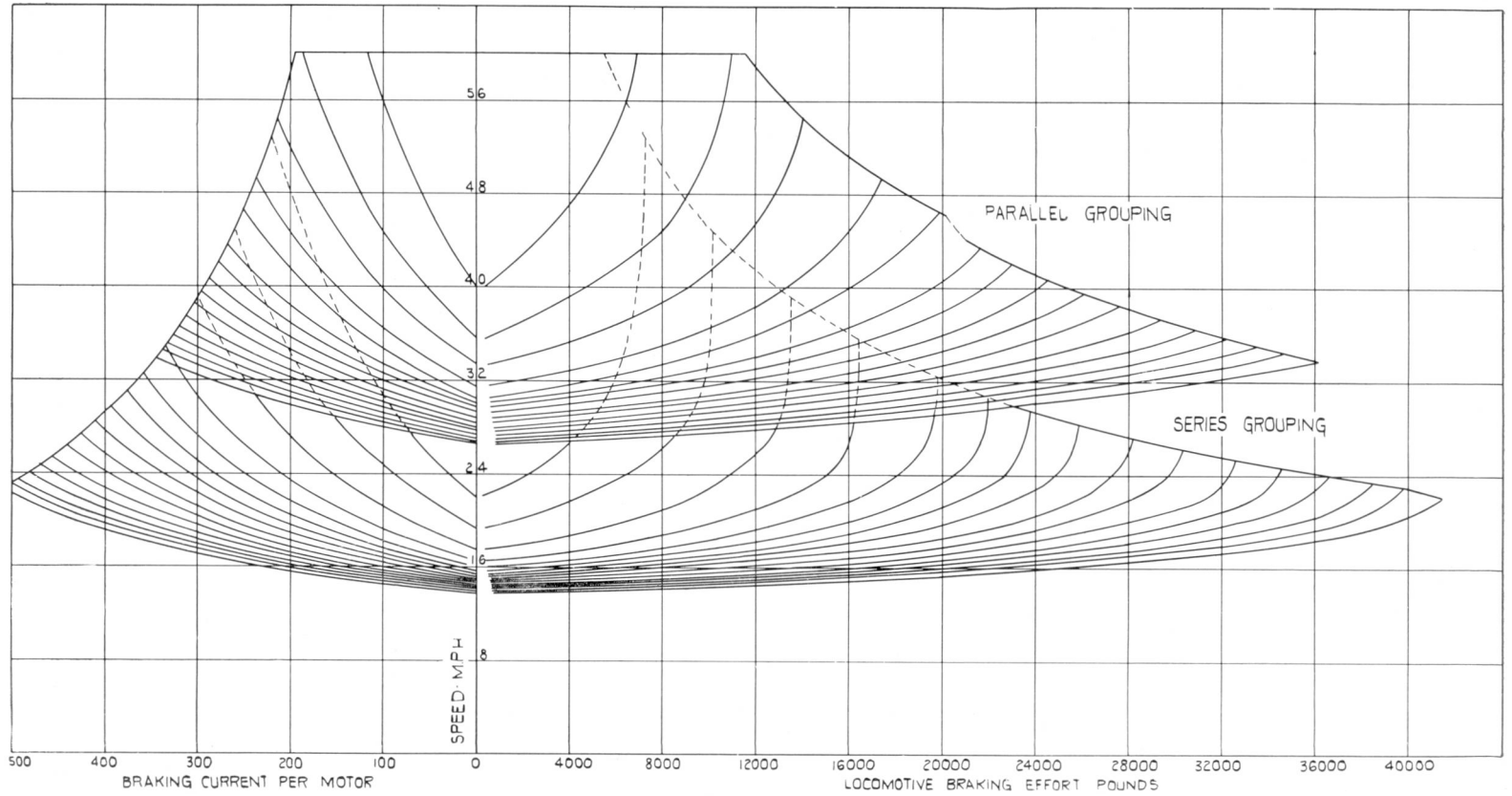


Fig. 10.—Regenerative braking characteristics

volt/ampere output characteristics of the regenerative braking exciter for different values of generator and field current, an example of which is given in Fig. 9.

In the programme each volt/ampere characteristic curve is dealt with in turn and the values of traction motor field current corresponding to definite values of traction motor armature current are obtained by calculating the intersections of the characteristic curve with the family of straight lines whose equations are of the form

$$V_g = I_f(R_s + M_t R_f + R_e) + I_{tm} R_s$$

where V_g = output voltage of a generator

I_f = traction motor field current

R_s = stabilising resistance

M_t = number of traction motors in series

R_f = traction motor field resistance

R_e = resistance of cabling in exciter output circuit

I_{tm} = traction motor armature current
(the chosen values for which the calculation is performed).

The appropriate traction motor field current for given values of armature current can therefore be determined for each curve of the braking exciter output characteristic. Once the values of these two quantities are known the motor flux can be looked up on the saturation curve and the generated e.m.f. calculated. From this the motor and locomotive speed can be calculated and the mechanical work performed by the locomotive determined.

The braking effort is then given by

$$\text{Braking effort} = \frac{\text{Mechanical Input} \times K_{te}}{\text{Speed}}$$

where K_{te} is a constant depending on the units used.

The combined characteristic, traction motor armature current, speed and braking effort, is then plotted as shown in Fig. 10.

PART II. RAILWAY OPERATION

SPEED TIMING CALCULATIONS FOR RAILWAYS

As has been seen in the preceding sections one of the train performance programmes is designed to produce speeds and times of trains only, and has been used by a number of railways to compute point to point running times for new types of motive power. These times then form the data on which new timetables are based.

One unusual application has arisen in connection with the use of diesel-electric locomotives on a region of British Railways. Although, under the modernisation plan, British Railways are replacing all unfitted wagons by wagons fitted with vacuum brakes, the interim period must be considered when some wagons are fitted and others are not. When a freight train consists of unfitted wagons the braking effort is produced by the locomotive alone. The diesel-electric locomotives now coming

into service on British Railways are usually more powerful than the steam locomotives which they replace, but have a smaller braking effort because of their smaller weight. Although this is unimportant when passenger trains are hauled, it may mean that on down gradients the speed of a diesel-hauled unfitted freight train may be lower than for a corresponding steam train, since they must both be able to stop within a prescribed distance in order to obey signalling regulations. The questions which the DEUCE computer was used to answer were :—

1. What are the point to point running times for a certain diesel-electric locomotive hauling a certain load over a certain route?
2. What is the maximum load of unfitted wagons that the diesel-electric locomotive can haul in order to meet the timings of the existing steam service?

British Railways have seconded men, experienced in timetabling and operating practice, to computing centres where they can study this problem and prepare the necessary programmes. One of the teams is at present working at the Kidsgrove computing centre of The English Electric Company, and here programmers of the Company's Data Processing and Control Systems Division advise them on programming methods to use in their work.

The basic problem in this study is to calculate the path of a special train through an existing timetable, and to determine the consequential alterations to other trains. By the word 'path' is meant the arrival, the departure, and passing times of the train at each signal box, and the lines on which the train runs, i.e. fast, slow or goods line. The alterations to other trains in the timetable will clearly depend on the importance of the special train. If it is of the lowest possible priority then no alterations to other trains will be necessary, but if it is very important, for example, a crack express train, then it may be necessary to alter the timings of a large number of trains, depending on the time at which the special train runs. When the Coronation Scot was introduced into service before the war, 150 trains had to be re-timed in order to give it the clear path required.

The information required to prepare a timetable is :—

1. The point to point running times for different types of train, which can be obtained from the speed/timing calculations described in previous sections.
2. The current working timetable, which may be in the form of a table of figures similar to the public timetable but containing much more operating information, or it may be in the form of a graph with time plotted horizontally and distance plotted vertically. An example of a graphical timetable is shown in Fig. 12.
3. The layout of the railway track itself, showing the connection between various lines, the position of signals and signal boxes, and the location of platforms and sidings.

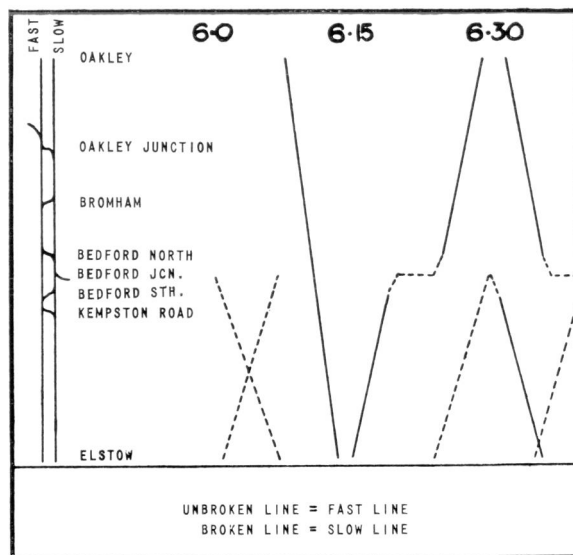


Fig. 12.—Graphical working timetable

4. A list of 'headway distances': these are the distances between successive trains which must exist if the following train is to proceed at all, and the corresponding distance which must exist if the following train is to travel at maximum speed.
5. The times at which signal boxes are open. Many signal boxes are continuously open, but some are only open for certain days of the week and certain hours of the day, and may only control certain lines. When a signal box is closed, the length of line which it normally controls is then controlled by an adjacent signal box.
6. The details of the special train, i.e. the class of train, the days on which it is to run, the stations at which it will stop and the route to be taken.

Although some of this information is used in numerical form, the layout of the track is only available in the form of a map or plan, and the working timetable used by a timetabling clerk is usually in graphical form. To use a digital computer to compile timetables, one of the first steps to be taken is to decide upon a method of storing all this information in numerical form. The working timetable can clearly be stored in a similar

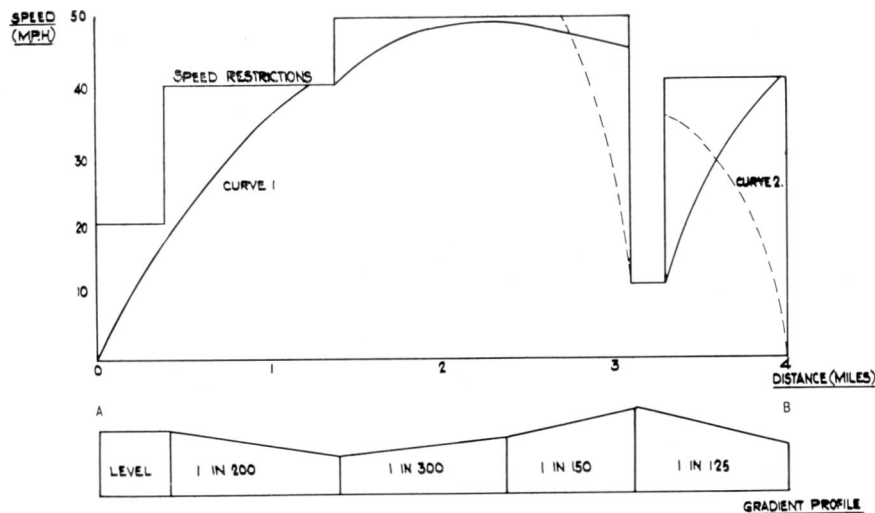


Fig. 11.—Speed/distance curves for unfitted freight trains

In both cases the train had to be able to stop within 1,000 yards at any point of the route.

In order to solve these problems a programme was written to calculate the maximum permissible speed which a train could maintain on a gradient if it were to stop within 1,000 yards. This in effect produced a curve of maximum permissible speed, called train restrictions, against percentage gradient. The results of this programme were then read into the computer, together with the gradient profile of the track and the track speed restrictions and positions of stations. The machine then selected the lower of track and train restriction for each gradient and punched out gradients and speed restrictions in suitable form for use with the main train performance programme.

The assumption in the train performance programme that the train brakes at a constant rate of m.p.h./sec² is not accurate when unfitted trains are concerned, since gradients will affect the braking rate considerably and it will thus vary from point to point along the track. To overcome this difficulty two calculations were performed. If the train was travelling from A to B the programme was used with an assumed large constant braking rate, giving Curve 1 in Fig. 11. A similar calculation was then performed in the opposite direction, in which the tractive effort of the locomotive was replaced by the braking force, and the resistance assisted the (backwards) motion of the train. This gives Curve 2 in Fig. 11.

Using the notation under 'The Differential Equations of Motion' on page 7, the equation for this calculation is

$$\delta t = \frac{\delta v (1 + \gamma) (M + m)}{F + R_l + R_r - R_g + R_c}$$

where F is the braking force and, like the tractive effort, can be a function of speed.

Both the forward and backward curves were then plotted, using the curve plotting programme, and the combined curve was produced by superimposing one on the other.

TIMETABLING

The preparation of a railway timetable is an operation which requires very little calculation, a great deal of clear logical thought, and considerable knowledge of railway operation. Since a railway must work to a clearly defined set of rules, and since these rules are effectively embodied in a timetable, it is theoretically possible to use a computer to construct a timetable. For this to be practicable it must be known whether a computer would be economically justified, and whether certain decisions relating to the priorities of trains can be included in a programme—for example, if two express trains were due to be on the same line, at a junction, at the same time, which should have priority? In order to test the practicability of using computers for this work,

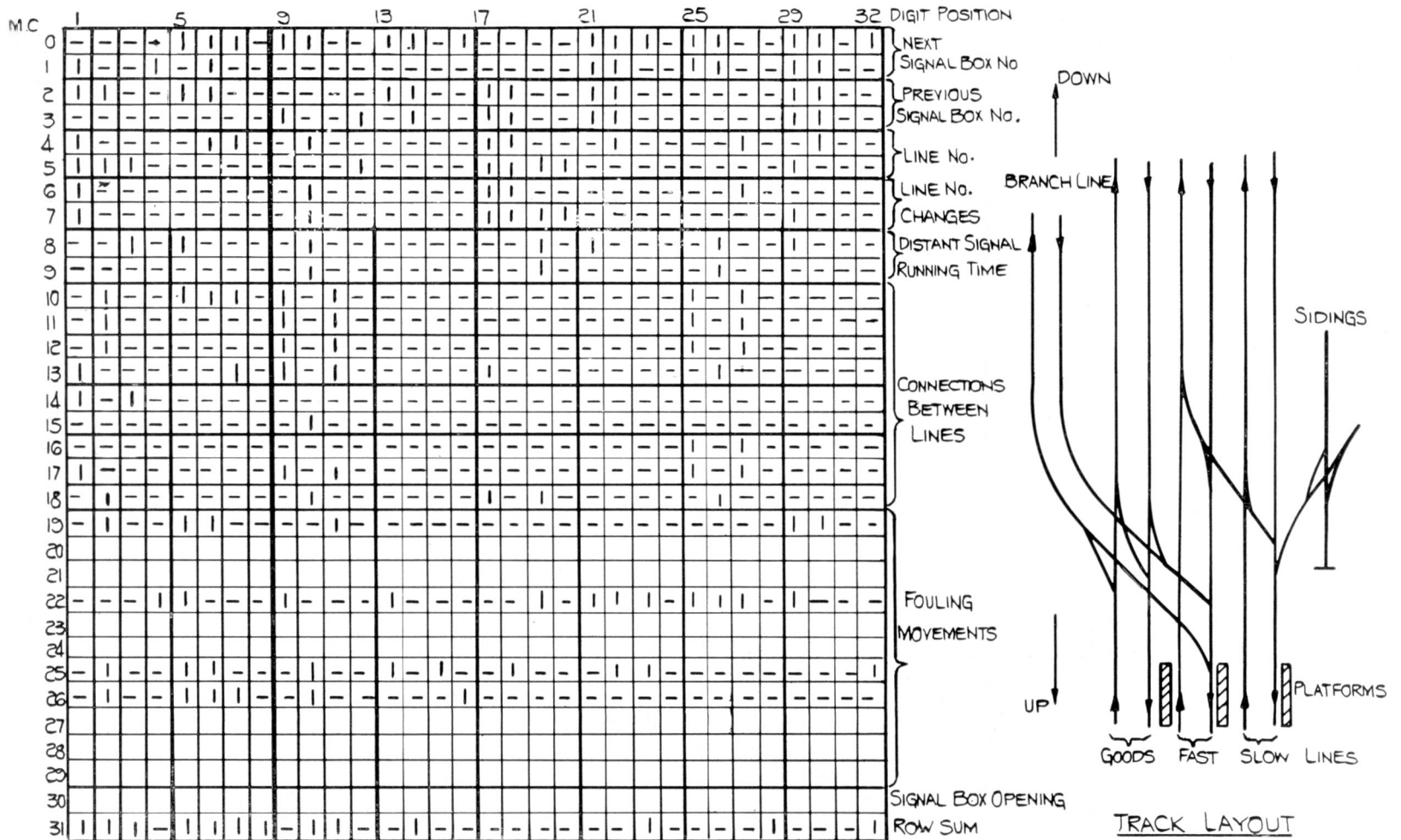


Fig. 13.—Representation of track layout by a pattern of binary digits

form to that in which it is printed, but the track layout is a more difficult proposition. Much thought was given to this problem before the DEUCE timetable programme could be started. A method was devised whereby the connections between various lines controlled by a signal box could be expressed as a series of binary digits, and additional information could also be provided showing the various conflicting train movements which exist, this being particularly important at a junction. An example of the type of information which has to be stored and the corresponding binary storage pattern is shown in Fig. 13.

To describe all the effort put into the study of timetabling on an electronic computer by the staff of the London Midland Region of British Railways would in itself require a lengthy article, and there is only space here to outline the method of the programme and a few of the interesting problems that have arisen during this study.

The path of a train as shown on a graphical timetable may be imagined as a piece of wire, the shape of which is determined by the point to point timings of the train and its stopping times at stations. The problem of calculating the timings for a special train amounts to positioning the piece of wire on the graphical timetable so as to meet the special-train conditions. For example, the train may be required to leave one of the terminal stations, or arrive at the other terminal, between certain times, and it is necessary to ensure that there is sufficient headway between the special train and the preceding and following trains for them all to travel at maximum possible speed. If it is not possible to position the wire of the required shape to meet these conditions, then either the wire must be bent or the paths of the other trains must be bent so that the special-train conditions are met ; which paths are bent, and by how much, depends on the relative priority of the trains.

The first step in the programme is to calculate the shape of the piece of wire for the special train, and the next step is to find the lines on which the train will run. The programme tries to keep the train on the fastest possible line as it travels from section to section. When the train arrives at a station at which it is to stop, the computer will

check whether there is a platform on this line. In many cases there will not be a platform on the fast line, and the computer then looks back along the line to find the point at which the train could transfer from the fast line to the slow line, a point which may occur several miles before the station. The next step of the programme is to check whether the running of the special train will cause any delays to other trains. If it does then the computer examines if these delays can be avoided by running the special train on different lines to those which have just been established in the previous section of the programme. If this is not possible then additional time must be added to the timings of the special train, or the timings of some of the trains in the timetable must be altered, and here the question of priorities must be dealt with. When a path has been found for a special train, the timings of this train and any consequent alterations to other trains are inserted into a copy of the working timetable so that when another special train is to be timed, account is taken of the addition and alterations.

Although the programme is made to calculate the path of a special train through an existing timetable, it may be used for many other purposes. A repeated application of this programme will enable a complete new timetable to be written ; also, since special care has been taken in it to see that all signalling rules are obeyed, it is possible to simulate all railway traffic movements other than shunting. In other words, it will be possible to ' play ' trains on a computer and test such things as the best locations of signals and signal boxes in a modernisation scheme, or the value of introducing a new flyover junction.

Apart from the method of storing the track data, the most interesting computing aspect is the use of magnetic tape to store all the basic information. For the purposes of the programme a railway system is split up into a series of timing districts, each consisting of a stretch of main line, usually about 40 miles, and a few miles of every branch line that leads off it. Although the magnetic drum of the DEUCE can store over a quarter of a million binary digits of information, this is not sufficient to store the programme, the working timetable, the track layouts and all the other necessary data for a timing district. As a

result the working timetable has been split into 48 half-hour periods, each period being stored as a block of information on magnetic tape, and transferred to the magnetic drum when required. The selection of half an hour as the unit of time into which the working timetable should be divided, as determined by storage considerations, enables the programme to deal with 16 trains passing any signal box in any half hour, which seems the maximum traffic density likely to be encountered on most sections of British Railways main lines. Where the traffic is much denser, for example on the Southern Region suburban lines, the timetable could be stored by dividing it into quarter-hour periods, whereas in sections of lighter traffic an hourly period could be used.

Although there is much to be done before the study is complete, it seems likely that it will not be long before an electronic computer is used for the compilation of timetables.

THE DISTRIBUTION OF EMPTY WAGONS

One of the mathematical techniques which have been developed in parallel with the development of electronic computers is linear programming.

In mathematical terms, linear programming may be described as the maximisation or the minimisation of a linear function of a set of variables, each of which may be subject to a series of constraints. It has become an invaluable tool for the operational research worker, and has been applied to many problems which not very long ago were regarded as only soluble by the application of a mixture of intuition, judgement and experience. Many books and papers have been written on the subject, and one of these (Ref. 2) contains many descriptive examples of the practical applications of linear programming. One of the best known applications is known as the diet problem. In its simplest form the problem may be stated as, 'A housewife wishes to purchase food for her family for which the total calorific value is not less than a certain amount and for which the total cost is a minimum, given the costs and calorific values of the available foods.' Clearly, although a solution or a number of optimum solutions may be found for this problem, there is no guarantee either that the resulting diet will contain the right proportion of vitamins or that it will be appetising, since no mention was made in the specification of the problem of either of these requirements. This illustrates one of the features of many practical

Destinations	Sources											Surpluses	
	Masborough	Sheffield	Staveley	Westhouses	Kirkby	Nottingham	Leicester	Wigston	Chaddesden	Burton	Saltley		
Toton	40	35	28	15	18	8	25	29	9	16	46	*M	1203
Wellingborough	99	94	87	74	72	58	34	30	63	61	71	*M	117
Kentish Town	163	158	151	138	136	122	98	94	128	125	135	*M	296
Cheshire Lines	73	67	85	83	81	94	109	114	79	90	120	*M	1954
Gowhole	37	31	49	47	45	58	73	78	43	54	84	*M	119
Rowsley	47	42	35	22	24	37	51	55	22	33	63	*M	106
Gloucester	138	138	126	113	116	104	92	87	93	82	52	*M	220
Deficits	308	86	112	106	220	76	107	184	407	148	297	1964	Excess of surpluses over deficits

*M = Very large number.

Fig. 14.—Matrix of mileages between sources and destinations

		Masborough	Sheffield	Staveley	Westhouses	Kirkby	Nottingham	Leicester	Wigston	Chaddesden	Burton	Saltley	'EXCESS'
<i>Surpluses</i>		308	86	112	106	220	76	107	184	407	148	297	1964
Toton	1203	24	25	0	0	$-x$	0	$+x$	0	0	0	0	
				101	106	114	76	107	67	407	148	77	
Wellingborough	117	82	83	58	58	53	49	8	6	53	44	24	
									117				
Kentish Town	296	90	91	66	66	61	57	16	8	62	52	52	
													296
Cheshire Lines	1954	0	$+11$	0	0	-11	11	6	29	27	28	13	17
		189	86	11									1668
Gowhole	119	0	-11	0	0	$+11$	11	6	29	27	28	13	17
		119											
Rowsley	106	25	26	1	1	$+x$	0	$-x$	23	20	20	7	11
						106							
Gloucester	220	116	122	92	92	92	122	61	52	78	60	0	
												220	

Fig. 15.—Final solution and partial-cost matrix

applications of linear programming, that the solution may not meet all the requirements and some adjustments may be necessary to meet various conditions.

A particular type of linear programming problem is known as the transportation problem, which can be generally stated as determining the method of movements of a particular product from S places (known as sources) where the product is available to D places (known as destinations) where the product is required, in such a way that the movement costs are a minimum, given the movement costs of one unit of the product between all sources and all destinations. In Fig. 14 is shown the movement costs in the form of a matrix, the cost matrix, bordered by the availabilities at the sources and the requirements at the destinations, for a hypothetical problem. The solution to the problem, which is also set out in matrix form (Fig. 15), shows the number of products going

from S to D in the optimum solution, and, in addition, shows what is known as the partial costs. These latter figures are used for finding the extra cost which may be incurred by making a variation in the optimum pattern in order to meet some other condition. In the hypothetical example in Fig. 14, if it is wished to vary the optimum pattern by moving x wagons from Rowsley to Westhouses instead of from Rowsley to Kirkby, the extra cost in wagon-miles is given by multiplying the change in the number of wagons moved by the partial cost as given by the left-hand figure in each rectangle of Fig. 15. Thus the increase in movement costs is $x \times 0 - x \times 0 + x \times 1 - x \times 0 = x$ wagon miles.

There are various methods which can be used by a skilled person for solving the transportation problem by hand, but where no such skilled staff are available, or the problem is too large for hand computation, an electronic computer is an

invaluable aid. An example has been given recently (Ref. 3) of one of the Area Gas Boards who claim to have saved £45,000 in a year in their transport costs for coal and coke conveyed to and from gasworks, by using a computer for preparing the optimum movement pattern.

The user of transport is in a much better position to benefit from these techniques than is the transport operator, since the user is only concerned with the movement of goods from one place to another whilst the operator is faced with the problem of moving both empty and loaded vehicles. On the railways there are further complications in the fact that although requirements at stations will be in the form of wagons, the unit of movement is a train.

In order to discover the practicability of using linear programming techniques to improve the distribution of wagons, The English Electric Company recently carried out an exercise in conjunction with The London Midland Region of British Railways to examine the regular flow of empty mineral wagons from stations to collieries within an operating district. The majority of wagons supplied to collieries are sent on booked trains, and only variations from the average demand are met by running special trains, or by cancelling some of the booked trains. The information provided for this exercise was the average weekly demand for wagons for each colliery, the average weekly availability of mineral wagons at stations in the district, and the distances between the stations and the collieries. Wherever a route between a station and a colliery was regarded as impracticable the corresponding distance was replaced by a very large number. In the application of the transportation programme to this example the computer, which found the wagon movements to give minimum wagon mileage, ignored these impracticable routes because of the artificially large distances shown in the cost matrix. The result of the computer calculation was not a practical one from a railway operating point of view since the solution was in the form of numbers of wagons to be moved from stations to collieries and not in numbers of trains. Without any further calculation, however, it had one immediate value; the computer solution gave the minimum number of wagon-miles for which the average weekly

demand of collieries could be met. By comparing this figure with that of wagon-miles for the existing booked services it is possible to see if there is likely to be a potential improvement. In this exercise the difference between these two figures was about 25% of the existing wagon mileage, so that it seemed likely that a practical improvement in the services could be made.

A programmer of The English Electric Company in conjunction with a Freight Rolling Stock Inspector of British Railways then used the partial cost matrix to manipulate the solution into a practical operating pattern of train movements, while departing as little as possible from the optimum computer solution. This solution was still not necessarily a practical one since it only took into account the movement of empty wagons and did not deal with the loaded coal trains which would be hauled by the same engines. This section of the work was studied by British Railways operating staff, and the outcome of the entire exercise was that the planned movement of empty and loaded coal wagons was subsequently carried out with 12% less trains than had run before. Similar exercises will be carried out in other districts, and members of The English Electric Company's programming staff at Kidsgrove are now studying the possibilities of using the computer to carry out the further stages of this work.

FUTURE DEVELOPMENTS

Future developments in the use of digital computers for traction design and operating problems are likely to be related to the interconnections between the various types of problem already discussed. For example, the linear programming problem will lead to new train services which can be timetabled using the timetabling programme. The traction performance programme in conjunction with timetabling details will be used to calculate substation loadings when electrification schemes are planned. Both the main operating problems described lead naturally to the consideration of using computers for scheduling locomotives, rolling stock and train crews for the services laid down in the timetable.

On the design side it may be worthwhile using computers for adding refinements to existing

train performance calculations, e.g. calculating the actual temperature of a traction motor for a given duty, or the energy restored to the line during regenerative braking, or the effect on motor temperature of either regenerative or rheostatic braking. In addition there are numerous small calculations such as concern weight transfer, train resistance, resistance notching and balancing-speed/trailing-load curves for various gradients, which occur regularly in a traction office and which would be worth programming if there was a computer close at hand.

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REFERENCES

1. ROBINSON, C. *DEUCE interpretative programmes*. The Computer Journal (1959), Vol. 1, p. 172.
2. VADJA, S. *Studies in linear programming*. Pitman.
3. WRAGGE MORLEY, D. *British Computing Services*. The Business Computer Symposium, p. 20.

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