Fraser Duncan.

SOME USES OF DEUCE IN MECHANICAL ENGINEERING.

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English Electric has been active in the computer field from the very earliest development of these machines in this country; the Mark I DEUCE was in fact developed from the ACE Pilot model built at Teddington just after the war in association with the National Physical Laboratory. Since then, apart from many installations for other firms, English Electric has established and operated nine DEUCE'S in its own divisions, and DEUCE calculations are a standard procedure in the design of our products. The complete stressing of the Canberra and Lightning aircraft, control characteristics of nuclear reactors, and design and analysis of many types of electrical machine, are cases in point.

A very large accumulation of experience in the use and operation of electronic computers has been gained over these years, and a library of programmes unequalled in variety and versatility, has been built up.

Our DEUCE computing service now makes this experience available to all. Many concerns who do not wish to buy a computer make use of our services to relieve their technical staff of the mental drudgery associated with much day to day design work.

Just a brief outline will be given here of some examples of the way in which DEUCE has been used to solve problems in Mechanical Engineering which it would be impracticable to attack by other means. This theme is illustrated by examples drawn from our experience with this type of problem.

There are several levels of DEUCE programming, since in addition to the basic instruction code of the computer, a number of schemes have been devised for minimising programming effort, and for simplifying the task of programming. Foremost among these schemes is the DEUCE alphacode.

It frequently happens that engineers and scientists wish to make use of the facilities offered by DEUCE, but do not wish to prepare a normal programme themselves, and that no experienced programmer is available to assist them. It is also common for a particular calculation to be needed only once or twice, and in such cases the time taken in preparing and testing an orthodox programme might be out of all proportion to the time spent in actual computation. Alphacode meets these situations. It provides a method of writing instructions for DEUCE in a simple and quick way, in plain English; the method can be learnt in a short time, and used at once. Using Alphacode, an engineer can learn in a few hours how to write complicated programmes, without the necessity of spending time acquiring the more sophisticated techniques of the programmer. In our experience, cutting out the "middleman" between the engineer and the computer has proved invaluable in terms of time served and the avoidance of misunderstanding. Alphacode is somewhat slower in operation than an orthodox DEUCE programme, but the computer can if necessary be made to convert from Alphacode into the fast order code.

As a very simple example of the use of Alphacode, consider a shaft of radius r, rotating in dry bearings with angular velocity $2\pi N$. Suppose we apply an alternating displacement $e \sin 2\pi nt$ to the shaft in the direction of its axis. Then it is easily shown that the average value of the frictional couple resisting rotation is reduced by a factor

$$r \sin \left[\tan^{-1} \frac{\mu}{\left(1 + \frac{n^2 e^2}{2N^2 r^2}\right)^{\frac{1}{2}}} \right]$$

To evaluate this expression using Alphacode we would merely write down instructions of the form:

$n^2 = n \times n$

$e^2 = e \times e$

$n^2e^2 = n^2 \times e^2$

$N^2 = N \times N$

$r^2 = r \times r$

$N^2r^2 = N^2 \times r^2$

$2N^2r^2 = 2 \times (N^2r^2)$

$A = n^2e^2 \div 2N^2r^2$

$B = 1 + A$

$C = \sqrt{B}$

$D = \mu \div C$

$E = \tan^{-1} D$

$F = \sin E$

$G = r \times F$

Print out G.

Fairly typical of the more complex problems we have treated in this way is the stress analysis of a thin conical frustum (in this case a water-wheel generator thrust-bearing support). The frustum has flanges on both ends and is loaded through the flanges. The analytic solution is expressed in terms of Bessel functions of imaginary argument, and is of considerable complication. It took however only a few hours to programme by Alphacode. Using a computer-optimised version of the Alphacode programme, a complete solution of stresses and displacements at any point of the cone can be obtained in less than a minute.

Other applications of Alphacode have included the design of a suitable arrangement of cams to control a cutting tool for manufacture of water-turbine impeller blades; the compilation of steam tables by statistical analysis of new test results; calculations of the moment of area of turbine blades; elastic/plastic stresses in thick-walled cylinders under internal pressure; Kinematic characteristics of complex linkage mechanisms; analysis of piston displacement and indicator diagrams; and many others.

A second programming scheme of considerable importance in the solution of mathematical and engineering problems is that dealing with the manipulation of matrices. Matrix operations are ideally suited to digital computers, and the DEUCE scheme, which enables the programmer to link together in any desired order a number of matrix calculations, finds many practical applications in mechanics. The programming involved is little, being just enough to link together the standard programmes which perform the individual matrix operations. DEUCE has a comprehensive library of matrix programmes, and any problem which can be formulated in terms of matrices (and linear equations) can be quickly and easily solved.

Matrix calculus and linear algebra techniques are particularly suited to structural problems and are used both for stressing of simple two dimensional building frameworks and for the complex problems encountered by our Aircraft division, such as calculations of stressed skin aircraft structures. Less obviously perhaps, a great many vibration problems can be solved using matrix concepts: an example being the determination of natural frequencies in torsion of a multi-mass system on a single shaft, or a system of geared shafts. We have also been able to apply similar techniques to the isolation of machine vibration, the response of machine frames to impulsive excitation, and so on.

Yet another simplified programming scheme will be briefly mentioned. Many calculations in mechanical engineering can be set out in tabular form, and the repetitive calculations involved are very tedious to perform by hand. In order to ease this burden, a programme has been made in which simple coded instructions can be made to operate on whole columns of numbers at a time. This is very useful, for example, for finding values of a formula at intervals of a variable for the purpose of plotting a curve.

So much for easy-code schemes. Regarding programmes which will be required frequently over a long period of time, it is desirable that they should be as fast and efficient as possible. This type of programme might he used many times weekly over a number of years, and great care taken both in programming and the mathematical preparation preceding it, is well rewarded.

A description will be given of a few of these programmes and of particular cases in which they have been used.

SECOND ORDER PARTIAL DIFFERENTIAL EQUATIONS.

This programme obtains numerical solutions to many types of second order elliptic partial differential equations, including those of Laplace or Poisson. An accelerated relaxation process is used (the extrapolated Leibmann method) and very large meshes (over 5,000 points) can be used.

By way of an example, it is well known that the problem of torsion of a prismatical bar can be reduced to the solution of a Poisson equation with the stress function ψ zero on the boundary. For sections of arbitrary shape, the partial differential equation programme can be used to evaluate ψ , from which shear stress distribution can be plotted and the torsion constant found.

Many other applications of this very flexible programme can be found - we have used it for calculation of heat flow in diesel engine pistons, for finding pressure distribution and lubricant flow in bearings, etc.

Programmes are also of course available for solving ordinary simultaneous differential equations by a variety of methods. No engineer will be at a loss to think of many uses for these routines.

THERMAL STRESSES IN PIPING SYSTEMS.

One of the major problems in the design of pipelines for high temperatures and pressures is the difficulty of performing the intricate calculations necessary to forecast the elastic strength under thermal expansion. It is clear that, under all temperature conditions likely to be encountered, the piping must have sufficient inherent self-springing to ensure that no part is critically stressed.

Studies of this sort require the calculation of the forces produced in a tubular framework when thermal displacements are imposed at points of the frame: a basic problem of structural engineering, complicated however by the necessity of inclusion of curved frame components, and of members which commonly lie skew to one another. A further consideration is the distortion to ovality of curved tubes under loading, a phenomenon which has the effect of increasing the flexibility.

A comprehensive set of programmes has been made to tackle this problem: it is possible, using very simple data regarding dimensions, spatial position and so on, automatically to calculate and print out stresses and displacements at all points of the pipe system.

These programmes are a good example of the way in which computers can solve problems which could not be contemplated by manual methods. The effects, for instance, of partial flexible constraints along a complex three dimensional multi-anchor configuration containing re-entrant loops of pipe, can be analysed by routine procedures on DEUCE. Such calculations would take many months using a desk machine. Further, exhaustive checks can be made at every stage of the computer calculation with little extra effort - very great care would need to be taken in a hand computation to achieve the same confidence in the final result.

These piping calculations also underline the desirability of having a very fast optimised programme for problems which occur frequently - over nine hundred different pipe systems have been analysed to date.

The dual problem of determining stresses in rigid frameworks with applied loads, is another type of calculation of obvious importance, and similar programmes have been written to deal with day to day work in this field.

As a final example, let us consider the calculation of

CRITICAL SPEEDS.

A very important consideration in the design of rotating shafts is the necessity of ensuring that the whirling speeds are sufficiently removed from the running speed. This resonance condition, set up by small amounts of unbalance in the shaft, is a problem of fundamental importance in the design of large rotors, where the stored energy is very high.

The DEUCE programme for this work has a wide range of application, from very small single rotor machines on two bearings (or a single cantilever bearing) to very large shaft systems on many bearings. The discussion here, however, will be restricted to its application in turbo-alternator design.

A large turbo-generator would normally essentially consist of an alternator rotor driven by three or more turbines. The critical speed of the complete set must be found both at running temperature and at room temperature: the first calculation gives whirling speeds encountered in normal running and shut down conditions, the second finds an upper limit to the values of critical speeds attained on starting from cold. In addition, critical speeds of individual shafts need to be computed in the design stage, as do those of the coupled turbines without alternator - these conditions refer to the separate testing of turbine assembly and alternator, during manufacture.

A further calculation gives static deflection curves for the complete machine, with bearing heights adjusted to ensure parallelism of each pair of adjacent couplings, and an alignment diagram is prepared to facilitate erection on site. Use is also made of relative amplitude curves, computed at critical speeds, to decide how individual shafts need to be modified to avoid undesirable vibration.

The method of calculation follows that of Myklestad-Holzer. The rotors are divided into a number of dicrete sections, and the length and diameters of each section are specified, together with temperatures, types of couplings and bearings, bearing heights, and so on. Mass, and influence coefficients are computed for each section, a trial value of speed is chosen and, working section by section along the shafting using the known boundary conditions at one end, equations in terms of the unknown conditions at that end are found. If the trial speed is a critical, these equations must be consistent with the terminal conditions at the other end, and zero energy input.

Corrections for lateral shear and gyroscopic inertia are automatically applied and provision is also available for introducing bearing flexibilities where these can be calculated or experimentally determined. The relative amplitude and static deflection curves, giving shear force, bending moment, slope and displacement at the end of each section, are also automatically produced by the computer.

Enquiries about these or any other applications of DEUCE will be welcomed by the Managers of our two Computing Bureaux whose addresses are given on the front sheet.