SOME ENGINEERING PROBLEMS REQUIRING AUTOMATIC COMPUTATION

E. L. Harder
Westinghouse Electric Corp.

For the larger computational problems in the Westinghouse Electric Corporation, analog and digital computing both play an important role. Starting in the middle twenties, the D-C Calculating Board, an analog computer, was in use for solving many power system network problems. However, the desk calculator, a digital computer, was being used for network solutions requiring complex numbers, particularly on a-c railway electrifications for which the D-C board was unsuitable. In 1929 the A-C Network Calculator[1] was developed and has handled most of the steady state a-c network calculations since that time.

Thus for engineering calculations there has been a period of over 20 years in which analog computers have been extensively developed and utilized to the practical exclusion of digital computation for our large calculation problems. Following the A-C Network Calculator, came two devices, the Electrical[2] and Mechanical[3] Transients Analyzers, then the Servo Analyzer[4], and in 1948 the Anacom, a general purpose electric analog computer.[5]

It is only with the extensive developments of the last few years that digital computing is beginning to play an important part again in our larger computational problems in engineering and research. Of course, in accounting inventory, stock control and many other factory operations, the analog computer plays no part and these have been handled entirely by digital computer, or business machine.

I would like to discuss a few of the engineering problems of general interest, some analog and some digital, requiring automatic computation.

Blade Design - Of the problems now being handled by digital computer blade design is perhaps most interesting and important. The problem is simular to that of an airplane wing design in that the designer must calculate the modes of vibration and natural frequencies in order to determine the stresses and to space the natural frequencies away from exciting frequencies. In terms of mechanics it is the problem of a beam in bending, a tapered beam. Because of the twist a force in one direction causes displacement in another direction. It is a problem in coupled bending.

If this beam is subdivided into say 10 sections, or 10 smaller beams, each treated as having appropriate elastic coefficients and as having its mass concentrated at its center of gravity, 8 equations can be written for the dependent variables at one section in terms of the preceding at a fixed frequency. The digital solution consists of calculating through the blade by these iteration equations and determining the moment by which the system fails to close at that frequency. By making calculations for a sufficient number of frequencies a curve of closing moment is obtained whose zeros are natural frequencies. The mode shapes are then readily obtained, the four lower modes being sufficient for the largest blades currently being designed.

The time for this operation averages about a week per blade design, on the IBM 602A compared with about 1-1/2 years by longhand calculation - by a somewhat different technique.

The analog of the blade is also available and the time is of the order of one day. However, for a general study with orderly changes from blade to blade as many as 48 blades have been studied in a week by analog computer. Subsequent digital spot checks have shown the results to be correct within 1 or 2%.

Other digital problems of a similar type are disc vibration, the combination discs and blades, blades with lashing wires and tension effects due to centrifugal forces, the multiple span critical speed problem, and the flexible foundation problem.

Steam piping stresses and strut problems involve systems of linear algebraic equations, for example 18 for 2 boilers piped to two turbines, and 6 additional for each added fixed point. These are beind coded for the CPC.

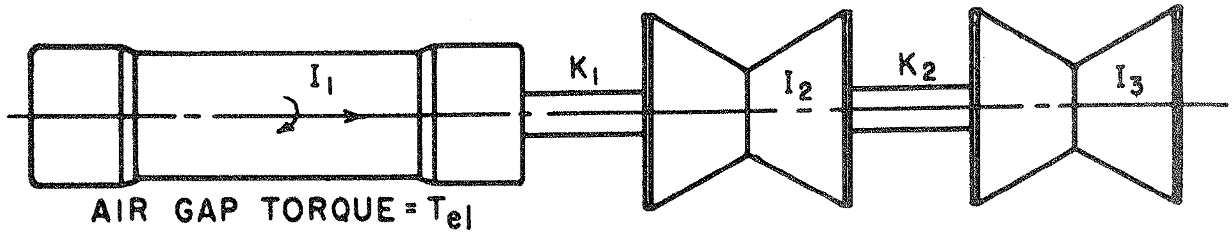
Design optimizing problems of steam and gas turbines and compressors require coding the complete thermodynamic calculation for machine handling so that the empirical factors can be altered to obtain the optimum.

In a number of basic research problems such as the study of gas flame models or fuel droplet evaporation, the digital computer makes possible solutions for cases that would require many lifetimes by longhand calculation.

These are simply typical of some 28 digital problems in various states in our analytical section at the present time.

Transient Torques[6] - Fig. 1 illustrates the main stress calculation for a turbine generator shaft and couplings. The worst stresses occur for a line-to-line fault on the generator. The equation of the mechanical system of rotor inertia and elastic shafts is 4th order for a 2 shaft system, increasing by 2 orders for each added shaft.

The forcing function torque applied at the generator air gap due to the short circuit currents is a composite wave having several exponentially



MECHANICAL SYSTEM

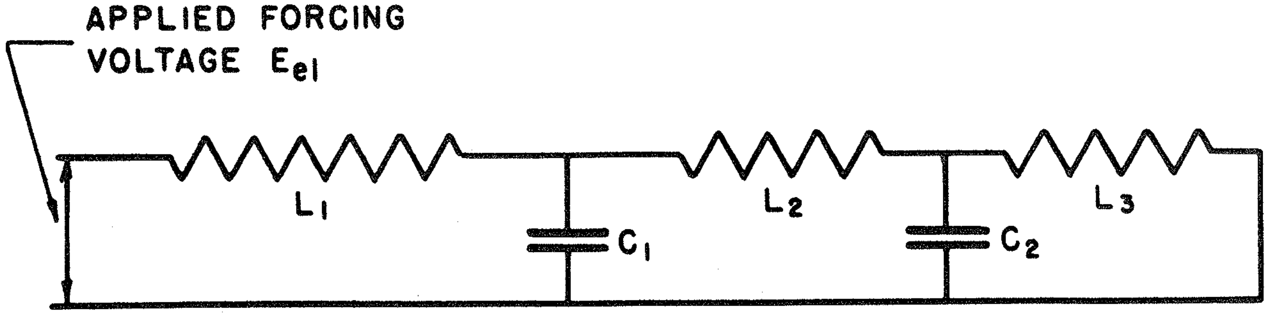


FIG. 1 MASS-INDUCTANCE ANALOGY CIRCUIT

decaying sinusoidal terms. The analog solution requires less than a day overall. The electric circuit analog uses inductors proportional to the machine inertias and susceptances proportional to shaft spring constants. The computer generates the forcing function as a voltage and applies it to this analog. The shaft torques are measured as voltages across the respective capacitors, as shown in Fig. 1.

This reduces a 2 to 3 weeks job to a single day in a critical period before the forgings can be ordered. However with ship drives, having up to 15 or 16 interconnected masses, the job would be practically impossible without the computer. This is typical of some 40 mechanical problems solved on the Anacom in the last few years.

FIG. 2

ROLL EQUATION ϕ = ANGLE OF ROLL

$$\left(1 + p\frac{I_x}{-C_{l\dot\phi}}\right)\phi = -\left(\frac{C_{l\dot\psi}}{C_{l\dot\phi}}\psi + \frac{C_{l\beta}}{pC_{l\dot\phi}}\beta + \frac{C_{l\delta}}{pC_{l\dot\phi}}\delta\right)$$

YAW EQUATION ψ = ANGLE OF YAW

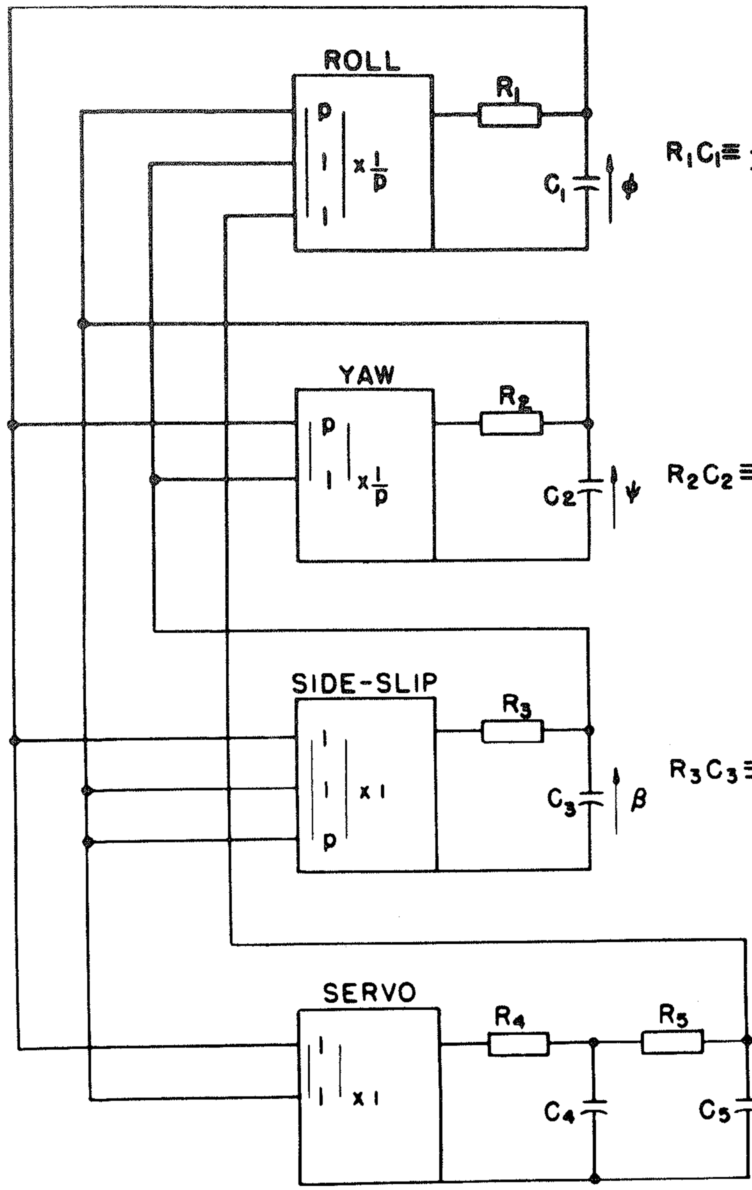
$$\left(1 + p\frac{I_z}{-C_{n\dot\psi}}\right)\psi = -\left(\frac{C_{n\phi}}{C_{n\dot\psi}}\phi + \frac{C_{n\beta}}{pC_{n\dot\psi}}\beta\right)$$

SIDE SLIP EQUATION β = ANGLE OF SIDE SLIP

$$\left(1 + p\frac{2b\mu}{VC_{Y\beta}}\right)\beta = -\left[\frac{C_L\phi}{C_{Y\beta}} - \left(\frac{2b\mu}{VC_{Y\beta}} - \frac{C_L\tan\gamma}{C_{Y\beta}}\right)\psi\right]$$

SERVO EQUATION δ = DEFLECTION OF AILERON

$$(1+pT_4)(1+pT_5)\,\delta = -(K_\phi\phi + K_\psi\psi)$$



$R_1C_1 \equiv \frac{I_x}{-C_{l\dot{\phi}}}$

$R_2C_2 \equiv \frac{I_z}{-C_{n\dot{\psi}}}$

$R_3C_3 \equiv \frac{2b\mu}{VC_{Y\beta}}$

$R_4C_4 \equiv T_4$ $\quad$ $R_4C_5 \equiv T_5$

FIG. 3

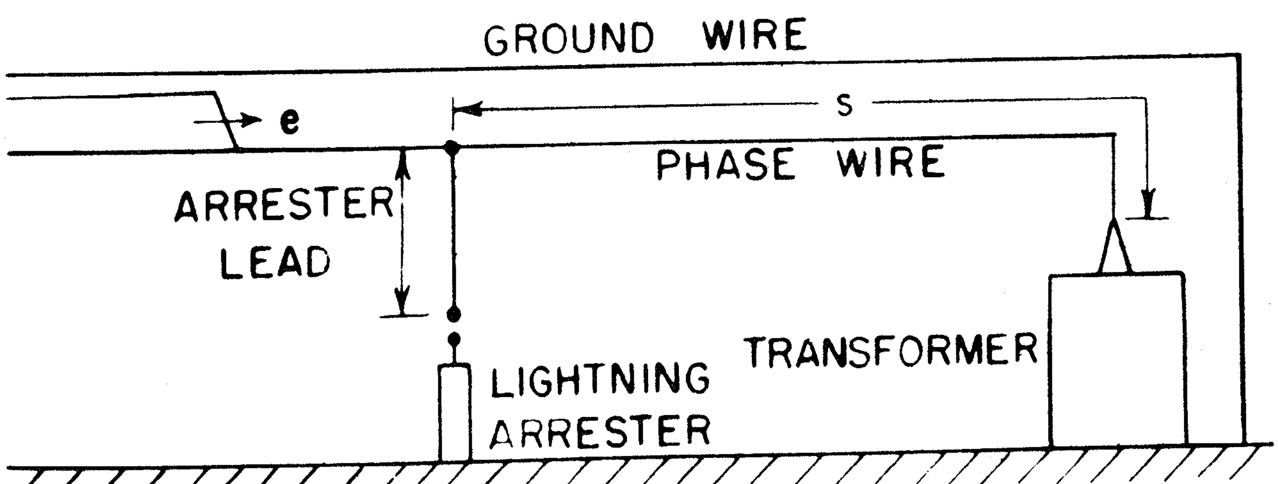


FIG. 4

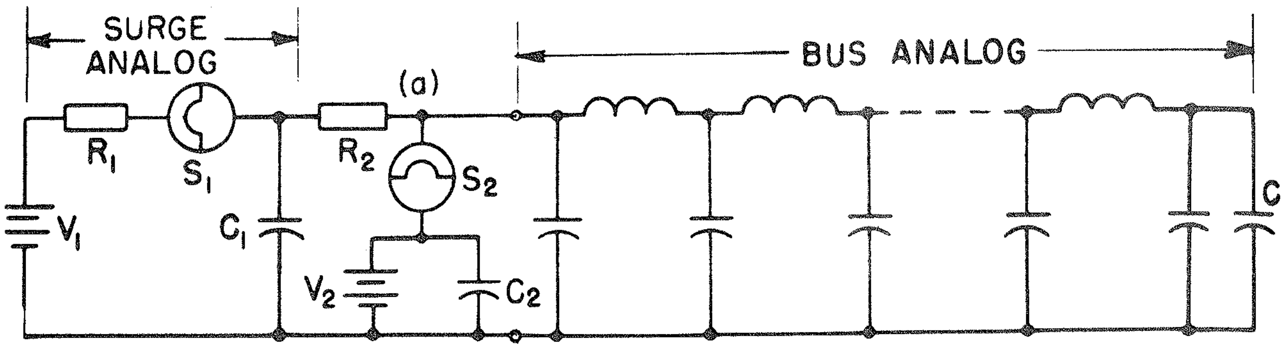


FIG. 5

We may note here a basic difference between analog and digital computing. In analog work it is only necessary to know the equations and to find an electric circuit that has the same equations. It is not necessary to know how to solve the equations. The computer solves them. With the digital computer it is necessary to know how to solve the equations by basic arithmetic processes and to code the problem for solution in this way.

Regulating Systems[7] - Fig. 2 illustrates the equations of a hi-speed airplane with auto-pilot and is typical of a regulating system to be solved by analog computer. The variables are Roll, Yaw, Sideslip and Aileron deflection.

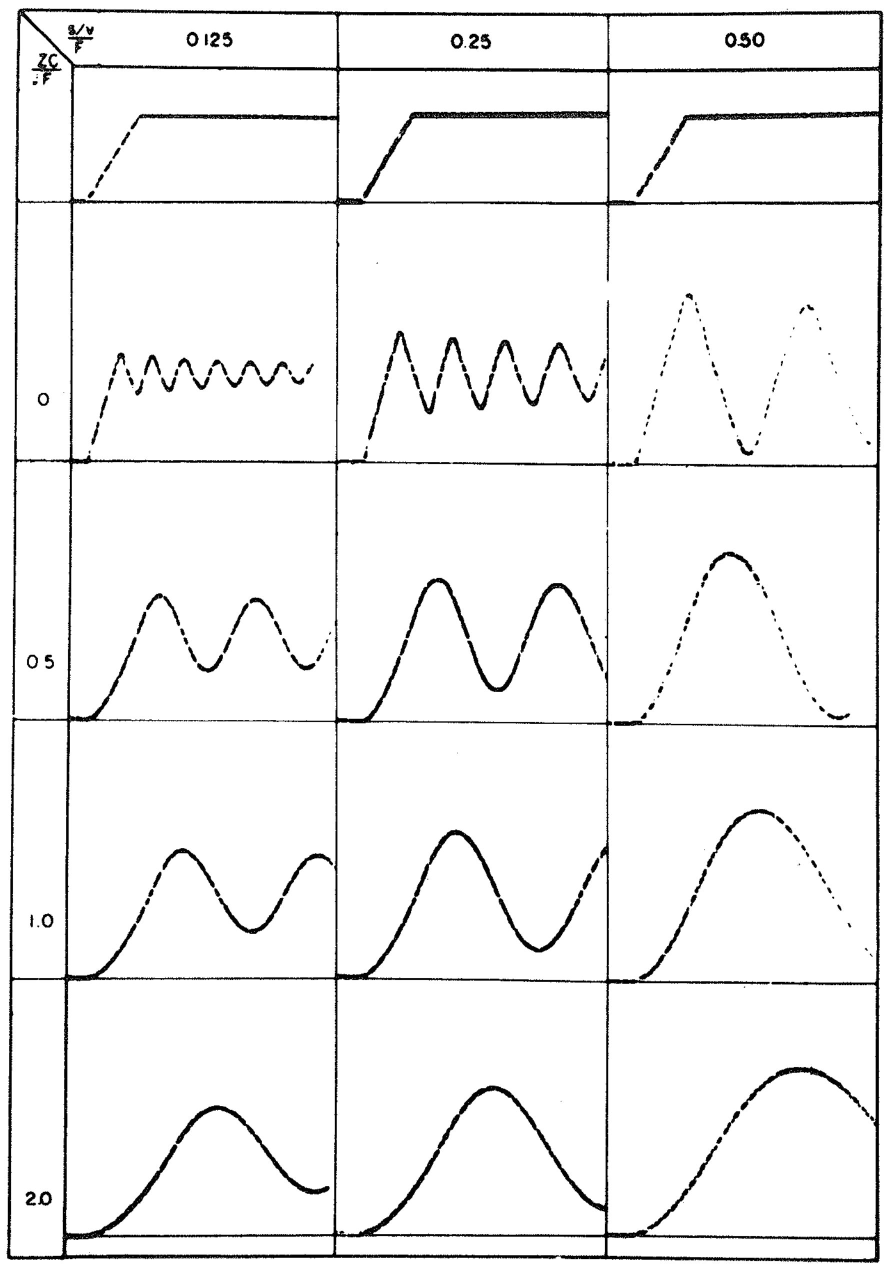


FIG. 6

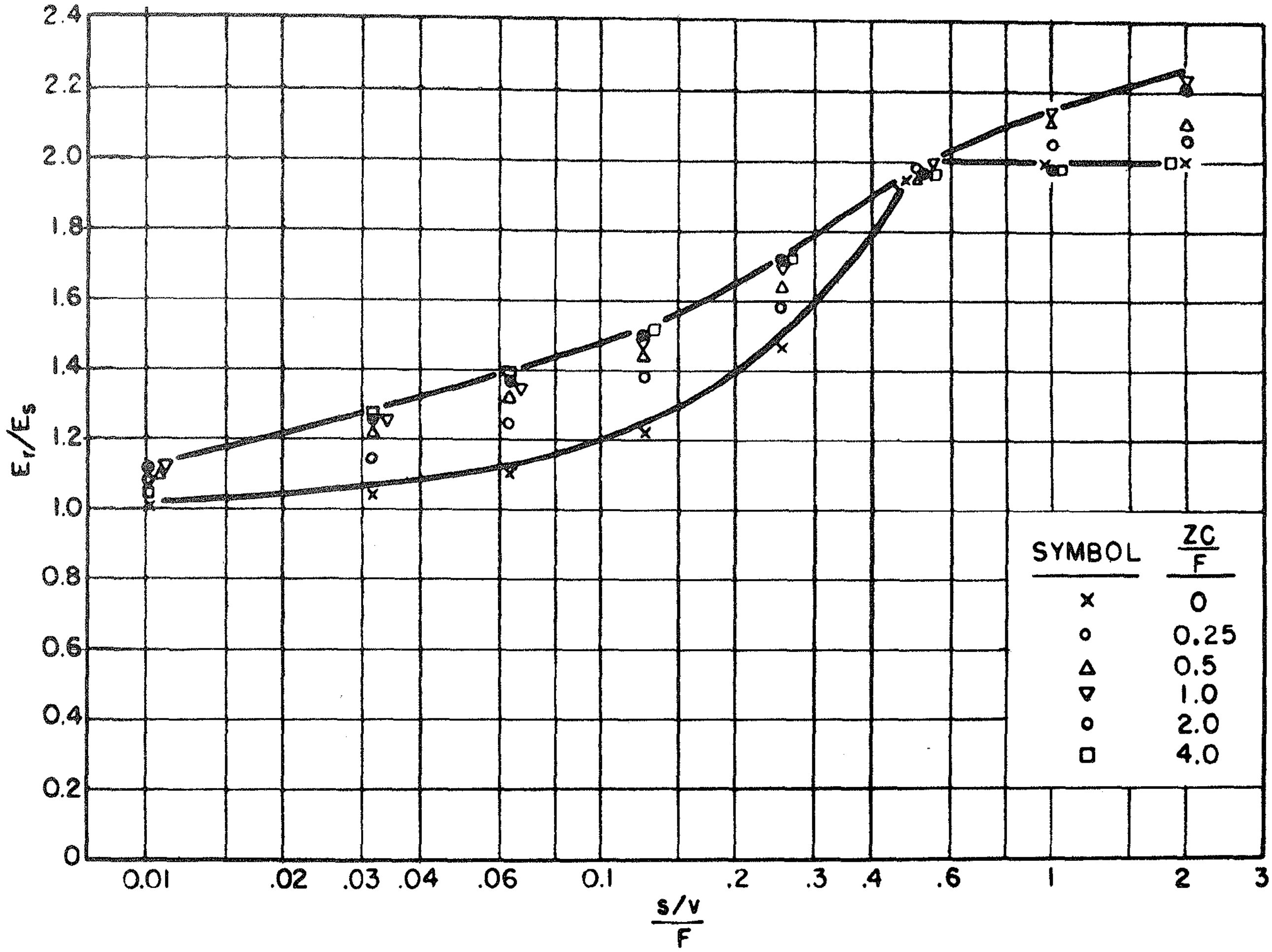


FIG. 7

The roll equation is arranged with all the forces* causing roll on the right and the inertia and friction terms on the left. The other two axes and the servo are treated likewise.

Fig. 3 shows the direct analog of this free body acted on by various forces. The inputs to the 4 amplifiers are the forces. The outputs equal the RC circuit voltages which are proportioned to the viscous friction and inertia terms, in roll, yaw, etc. The capacitor voltages on the right are the variables. This circuit has the same equation as the airplane, with every parameter of the plane and autopilot represented discretely, and easily adjusted to study the effect on performance.

The symbols in the amplifiers indicate the nature of the inputs and feedback. For example the roll equation can be read directly from the analog. The forces, that is the derivative of yaw, plus side slip, plus aileron position, all integrated, equals the inertia and friction forces, etc. The regulating system is studied by varying the servo parameters which the designer will be able to control, to determine the best values. A human operator can be introduced, if the computer is operated on natural time base, to study his reactions.

This is typical of some 40 regulating and servo problems solved on the Anacom during the last two years covering autopilots, torpedoes, jet engine controls, generator voltage regulators, steel mill drives, paper mill drives, wind tunnels, valve controls, aircraft regulators and others.

Lightning[8] (Fig. 4) - A lightning arrester is located at some distance from a transformer and the problem is to determine if it will protect the transformer. The variables are the magnitude and shape of the incoming surge, the arrester characteristics, the length of line and the transformer characteristics.

This is a problem in partial differential equations, and the analog, Fig. 5, shows the line represented in pi sections corresponding to the partial difference equations. The surge is generated by a surge analog, the arrester represented by an arrester analog and the transformer by its analog which is a capacitor at this frequency.

Fig. 6, shows the voltage solutions at the transformer as functions distance and transformer size. In Fig. 7 this data is summarized and the ratio of transformer voltage to arrester voltage plotted against dimensionless spacing for various transformer sizes (also dimensionless).

*Actually integrals of forces.

In Fig. 8, this data has been interpreted into a proposed industry standard showing the permissible distance between arrester and transformer, as a function of the system voltage, the incoming line construction (wood or steel), the type of arrester and its rating. It is a typical general study.

This is typical of some 25 problems of lightning and switching transients on power systems solved on the Anacom during the last few years.

In addition there has been about an equal number of electrical problems involving carrier current, series capacitors, corona, transformer saturation, cyclotron supplies, etc.

In other fields there have been handled on the Anacom quite a few problems in heat flow and oil and gas flow, as well as some purely mathematical problems. While the three problems illustrated were linear (except for the lightning arrester characteristic.) a considerable part of the Anacom problems are non-linear.

This completes a very brief picture of some of the types of analog and digital computer problems of current interest in the research, design, and application of electrical equipment. Some of you will see the Anacom equipment later this afternoon.

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Table II. Suggested maximum distance transformer to arrester-lead tap · full transformer insulation.

System Voltage	Line Construction	Arrester	Maximum distance - feet: 100 Percent Arrester	80 Percent Arrester
34.5	wood	Station type	22	52
69	wood		22	66
	steel		32	82
115	wood		31	107
	steel		44	133
138	wood		33	94
	steel		46	126
161	wood		39	84
	steel		52	122
230	steel		58	187
34.5	wood	Line Type	*	18
69	wood			19
	steel			29

* Arresters should be mounted adjacent to, and preferably on transformer.