This issue of the Newsletter might well be called the Hideo* Mori (Dynamic Analysis and Control Lab., MIT, Cambridge, Mass.) number because we are indebted to him for the minutes of the January and March meetings of the Eastern Simulation Council, which constitute Pieces in this month's Newsletter. Discussion at these meetings centered around resolvers and the simulation of nuclear reactors.

Information Without Theory is al-

so indebted to Hideo's notes, since it is concerned with discussions of the Eastern Simulation Council's study groups.

**Eastern Simulation Council**


**Canadian Simulation Council**

F. W. Prudden, Analog Computation and Simulation Group, Mechanical Engineering Div., National Research Council, Ottawa, Canada; Chairman, Steering Committee.

**Central Simulation Council**

Bruce Estes, Department 659, McDonnell Aircraft Corp., St. Louis, Missouri; Chairman, Steering Committee.

**Western Simulation Council**


**Southeastern Simulation Council**

M. David Prince, Federal Telecommunication Laboratory, Atlanta, Ga.; Chairman, Steering Committee.

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**Pieces**

**EASTERN S/C MEETING OF 28 JANUARY ON "RESOLVERS"**

About 75 people representing 40 different groups attended the thirteenth Eastern Simulation Council meeting at the Applied Physics Laboratory of Johns Hopkins University (Silver Spring, Maryland) on 28 January 1957. Their subject was "Resolvers."

Dr. James Follin (JHU/APL) welcomed those attending the meeting and recalled that the organizational meeting of the Eastern Simulation Council was held at Johns Hopkins two years ago.

*The fact that it was written by Hideo and changed by us does by no means justify anyone's saying that the writeup is Hideo us!

**Loveman on Definitions and Evaluations**

Bernie Loveman (Reeves Instrument Corp., New York, N. Y.) began the technical discussion. His presentation* was divided into three parts: definitions and evaluation of resolver performance; a description of some new resolvers that Reeves is building; remarks on electronic resolvers. Bernie described a resolver as a black box capable of operating in either of two modes: polar or rec-

*Like Gaul

In the former the value of the two components of a vector are the inputs, e.g., \( y = A \sin \theta \) and \( x = A \cos \theta \), and the outputs are the vector \( A \) and the angle \( \theta \). When operating in the rectangular mode there may be three inputs \( A, B, \) and \( \theta \) and two outputs, usually \( A \cos \theta + B \sin \theta \) and \( -A \sin \theta + B \cos \theta \).

Bernie said the factors required to evaluate performance of resolvers are static accuracy, dynamic accuracy, noise, and life.

Three factors determine the static accuracy of servo resolvers: resolver conformity, linearity of the followup potentiometer, and gear ratio between followup and resolver. When giving percent error, the manufacturer should specify whether the error is divided by the peak-to-peak voltage or the zero-to-peak voltage. Spot checks on a resolver do not give a good indication of its quality. The output of a sine-cosine potentiometer should be recorded on a plotting board to reveal any errors in conformity which might not be found by point checks. An alternative procedure would be to compare \( A \sin \theta \) with \( B \sin \theta \) with \( A = B = 100 \) volts.

The error in positioning the follow-
up potentiometer with respect to the resolver can be much greater than the conformity error. With $\pm 100$ and $-100$ volts across the followup potentiometer, this error in percent is given by

$$E = \left( \frac{200}{57.3} \right) (\lambda g)$$

where $\lambda$ is the followup potentiometer linearity in percent, and $g$ is the gear ratio in degrees per volt. For example, with an 0.025% potentiometer and 2° per volt gear ratio, the position error at the resolver will be 0.17%. On the other hand, if the gear ratio were increased to, say, 20° per volt, then the error would be 1.7%.

The dynamic accuracy of a resolver servo is usually given by amplitude and phase curves. From the user’s point of view, a better method would be to present error data as a function of frequency, Bernie said.

Specifications on noise should include both the rms value and data on the peak-to-peak noise.

Finally, the life of the resolver was defined as the period of time for which it remains within specifications, not the total time before you throw it away. Experience at Project Cyclone indicates that the average life of sine-cosine potentiometers, with a maximum velocity of 30 rpm, is one year, after which the sine-cosine cards must be removed and cleaned.

Because life, accuracy, and resolution (there is no granularity) are much better for induction resolvers than for sine-cosine potentiometers, Reeves developed an induction resolver system for use in the Wright Air Development Center computing facility. The schematic diagram Fig. 1 indicates how Reeves has handled the problem of accurate modulation and demodulation. The input modulators produce square waves proportional to the inputs. A peak-to-peak phase-sensitive detector is used in the output, and a special centerband chopper circuit samples the center of the square waves. The purpose of feedback networks in the detection circuit is to smooth the output and improve the dynamic accuracy.

Using a 400-cycle square-wave carrier, Bernie quotes the static error (including modulator, demodulator, and resolver) as 0.08% of the zero to peak voltage. The dynamic error, with respect to either A or B input, is about 0.5% at 10 cycles.

Bernie then turned to the controversial topic of electronic resolvers. As one of the key elements of an electronic resolver is an electronic multiplier, usually of the time-division type, and as Bernie expressed the opinion that dynamic accuracy of today’s time-division multipliers is not even one order of magnitude better than the accuracy of a high-quality servo he feels that the performance of electronic resolvers leaves something to be desired.

In answer to a question about the design of special filters, Bernie agreed that phase shift could be reduced, as in the RCA multiplier (see RCA Review December 1955, pp. 618-633), but only at the expense of an amplitude rise of 8 to 10 db at some higher frequencies. This may be permissible for special-purpose computers, but for general use in solving a set of simultaneous differential equations there will be closed loops in which these multipliers will produce oscillations.

**Merritt on Varying Loop Gain**

Nelson Merritt (Mid-Century Instrument Corp., New York, N. Y.) brought out the problem of varying loop gain when a servo resolver is used in the polar mode. If we consider a servo which uses the $-x \sin \theta + y \cos \theta$ output of a resolver as an error signal, then the servo will

*For details of Bernie’s opinion of electronic time-division multipliers, see last month’s Newsletter.
position the shaft $\theta$ so that $\theta = \tan^{-1} \frac{y}{x}$. If other factors are constant, such a servo becomes unstable for large values of $xy$ or insensitive for small ones. Fortunately the other output of the resolver, $x \cos \theta + y \sin \theta$, can be used to control the loop gain to counteract the effect of this variation. Merritt's scheme for automatic gain control is shown in Fig. 2. The dc voltage corresponding to $x \cos \theta + y \sin \theta$ is applied to the grid of a sharp cutoff pentode, which in turn changes the cathode bias of a push-pull stage of the servo amplifier, which is used to drive the $\theta$ input of the resolver.

**Weyrick on Vector Resolution at Goodyear**

The next speaker, R. C. Weyrick (Goodyear Aircraft Corp., Akron, Ohio), described recent developments at Goodyear for use in vector resolution: their dc servo, their electronic resolver, and a quadrant switch used to extend the usefulness of their servo resolver.

The Goodyear A14 computer has transistorized dc servos which contain sine-cosine potentiometers. These have a 3-dB peak at 46 cps and are down 3 db at 76 cps with a 2-volt-peak input. The acceleration limit is in excess of 100,000 volts/sec^2 and velocity limit is 5500 volts/sec. A stabilized dc amplifier is used for most of the loop gain, and there is an output stage with 4 transistors in a symmetrical circuit, two transistors for positive signals and two negative. Automatic gain control is also available so that the resolver can be used in the polar mode.

The Goodyear electronic resolver is a precision diode function-generator which uses a dither voltage to round out the break points. Five silicon diodes serve to approximate the trigonometric function which yields a static error of 0.2% of full scale. There is a 2° phase shift at 100 cps and a 3° shift at 300 cps.

**Bernie Loveman** pointed out that multipliers are necessary if a rectangular mode of operation is required from this electronic resolver.

The quadrant switch consists of electronic integrators, precision-amplitude comparators, and switching circuits. One of its functions is to extend the angular range of the resolver to a full ±180°, not normally possible because of limits in feedback potentiometers.

Static accuracy of 0.25% and dynamic accuracy of 1% at 180° per second can be expected using this switch. The switching circuits not only reverse the servo when 180° is reached, but also switch polarities so that it appears to be continuous. The largest inaccuracy occurs when this takes place.

**Carbon-Film Pots** are used in both linear and sine-cosine potentiometers. Also available is a mode of operation which allows use of a rate input to the servo.

**Wadlin on Electronic Resolver**

Milo Wadlin (Radio Corporation of America) next described the electronic resolver shown in Fig. 3. Because of their experience at Typhoon, RCA decided to build an all-electronic computer. The electronic resolver uses the $x$ and $y$ inputs to give $\cos \theta$ and $\sin \theta$, where $\theta$ is $\tan^{-1} y/x$. The unit requires two master multipliers and four slave multipliers. The amplifier with the 0.002-mfd feedback capacitor is not an integrator but a high-gain amplifier with only sufficient capacitive feedback to keep the circuit stable.

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**MEETING OF EASTERN S/C OF 22 MARCH ON "SIMULATION OF NUCLEAR REACTORS"**

The fourteenth Eastern Simulation Council meeting took place at the American Machine and Foundry plant in Greenwich, Connecticut, on March 22nd and was attended by about 65 persons representing 31 groups. Subject of the meeting was "Simulation of Nuclear-Reactor Systems."

**McPhee on AMF Reactor Simulator**

Al Groner welcomed the group and introduced John McPhee (AMF) who described an attachment built by American Machine and Foundry for their general-purpose analog computer to simulate kinetic behavior of the reactor itself, or the fission process. The equations simulated are

\[ \frac{dC_i}{dt} = - \beta K_{ett} N_i - \frac{C_i}{\tau_i} \]

There are seven simultaneous differential equations, and the method of simulation has been worked out so that only two basic computing amplifiers are necessary. Fig. 4 is a block diagram of the equations, and Fig. 5 is a functional diagram of the AMF reactor simulator showing how the equations can be solved using only two amplifiers. The delayed neutron feedback groups $\Sigma \beta_i$ can be simulated by RC networks because the gains $\beta$ are small, ranging from 0.0025 to 0.00025. The variable $N$ is neutron power or neutron concentration, the variable $S$ is the source, $N$ can be greater than $S$ by as much as $10^9$. The source $S$ is not the input to the system; the system is parametrically forced and the vari-

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able $K_{\text{eff}}$ can be considered as the input.

A nuclear-reactor system is a closed-loop positive-feedback system with a loop gain close to one, so that to increase the power level $N$ one has only to make $K_{\text{eff}}$ greater than 1 for a short period of time. $K_{\text{eff}}$ is the multiplication factor of the reactor and is the ratio of the number of neutrons born in a finite time. $K_{\text{eff}}$ is the ratio of the number of neutrons born to the number of neutrons absorbed in fission, plus those lost in other absorbing processes, plus those that leak out of the pile. If $K_{\text{eff}}$ is greater than 1 the reactor is in a supercritical condition, while if $K_{\text{eff}}$ is less than 1 it is subcritical.

There are potentiometers whereby each value of $\beta_i$ can be adjusted. Capacitors are not adjustable because for all practical purposes the decay time constants for different fuels are the same. There are provisions for initial conditions and also for simulating some problems of circulating-fuel reactors. The capacitor for $I^+$ is a plug-in unit so that it can be changed for various reactors. The simulator does not have any provisions for taking care of dead time, which prevents it from simulating certain types of circulating-fuel reactors.

**Mariani on L&N Reactor Simulator**

Following John's talk Mr. C. Mariani, Jr. (Leeds & Northrup Co., Philadelphia, Penna.) discussed a nuclear-reactor simulator for educational use. Although the best all-around facility for laboratory instruction might be a critical reactor assembly, the high initial cost and subsequent operating expenses, and the tendency for critical reactors to be monopolar by research projects sometimes make this impractical. Besides, any useful assemblage of fissionable material capable of going critical, even at low power levels, constitutes a hazard in the hands of inexperienced student experimenters.

The reactor simulator described by Mr. Mariani is to be used for the study of reactor kinetics, evaluation of reactor control systems, and for reactor operator training. The L&N simulator provides a vivid graphic demonstration of reactor kinetics, as well as demonstrating the nature of discontinuous servo control as applied to nuclear reactors. It also makes visual training in reactor operation both dramatic and effective.

The simulator assembly consists of an instrument panel, control console, and a reactor core mockup (non-radioactive*) equipped with two safety rods operated from one drive unit, and one control rod with its own drive unit.

On the instrument panel are:

1. A Log N recorder, calibrated 0.0001 to 300% power
2. A period recorder, minus 30 to infinity to plus 30 seconds
3. A linear power level recorder, zero to 150% power
4. A log count rate recorder, zero to 10,000 cps
5. PAT*** servo-units—discontinuous relay output, with proportional, reset, and rate functions
6. Analog computer

On the operating console are various auxiliaries: switches, indicators, and signal lights. These allow the student to operate the simulated plant like an actual reactor.

On the console are:

1. The safety rod raise-lower switch and position indicator
2. The control rod raise-lower switch and position indicator
3. The safety and control rod position signal lights
4. The scram button*
5. A receptacle for remote instructor operation of the control rod.

A computer similar to that described by McPhee is used in the simulator. The simulator has been designed with flexibility in mind:

1. By changing the value of the plug-in feedback capacitor, a variety of thermal reactors can be simulated.
2. Various fuels can be simulated by changing the potentiometer setting, which varies the fraction of each of the delayed neutron groups. The contribution of each of these groups can be eliminated with a switch.
3. Control and safety rod worths can be changed with plug-in resistors. $\Delta K$ of the control rod is variable from 12% to 10%, while each safety rod can be varied between $\frac{1}{2}$% and 5%.
4. Various step-function changes in reactivity in both positive and negative directions can be introduced by operating switches on the computer panel. Plug-in resistors allow the magnitude of changes to be varied between $\frac{1}{4}$% and 7% of control rod worth.

The simulator can be operated in both open- and closed-loop condition.

1. Open Loop—Reactor kinetics can be studied by inserting step-function changes in reactivity of various amounts and observing period and neutron level response. This can be extended for different safety- and

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*Handiest gadget we've heard of yet. Is there a portable model for home and office?
mod worths, and further expanded for different mean life times. Ramp function changes also can be introduced by withdrawing the safety or control rods. By changing rod mod, various rates of ramp reactivity changes can be made. Dynamic reactor behavior can be observed by noting period and neutron level response, which can be read directly from the recorders. Other parameters can be changed to increase the range of experiments performed.

2. Closed Loop—In this mode responses of the control system can be studied easily.

**Barnes on Power-Plant Simulation**

John Barnes (General Electric Knolls Atomic Power Laboratory) spoke on the simulation of a liquid-cooled reactor power plant, and explained some fundamental principles of water-moderated reactors. As shown in Fig. 6, the reactor is the source of heat for the primary water which is circulated through a heat exchanger. Heat from the primary loop is thus passed to the secondary loop, where steam is made. The steam goes through a throttle valve into a turbine, and condensed steam from the turbine is pumped back into the boiler.

John described the simulation of each of the blocks shown in Fig. 7. The reactor is a one-delay group approximated by a 10-second time constant. The RC combination around the high-gain amplifier is such that if a positive potential is on the grid, the output N goes negative, and if a negative potential is on the grid the output goes positive. If the grid is zero, the output will be constant. ΔK is the reactivity which is considered to be the driving function for the reactor. The source need not be considered since we may assume that the reactor has been started. Reactivity is changed by adjusting the control rod. This reactor model is good for ΔK = $1.00$, plus or minus perhaps 30 cents.

Called upon to explain the business of dollars and cents, John said to assume that the delayed group $\Sigma \beta_i$ is equal to about 0.0073, i.e. approximately 0.7 of 1 percent of all of the neutrons are coming from delayed emitters. This indicates the influence of the delayed neutrons as compared with the prompt ones. If $K$ is the multiplication factor of the assembly, i.e. on the average, the number of neutrons being made in one generation as compared with the past generation, then $\Delta K$ can be normalized by dividing by $\beta_i$ to give $\Delta K$. Now if $\Delta K$ is made equal to 1, the reactor will be critical on prompt neutrons alone. So prompt critical is plus $1.00$.

The one-group representation of the reactor will not hold for very large values of $\Delta K$ because then the prompt neutron lifetime is important. But for much less than prompt critical this is a fine representation.

Consider again the case where 73 out of every 10,000 neutrons were coming from delayed emitters. If reactivity is increased by pulling a control rod so that 73 more neutrons are obtained from the prompt emitters, then the reactor does not have to wait for the delayed neutrons and the neutron concentration increases at a tremendous rate. Now if these 73 neutrons could be taken out, then the reactor could be kept at a steady-state level. In most power reactors the coolant and the moderator are the same thing, which is usually pressurized water. The moderation that a neutron experiences depends on how many hydrogen atoms it bumps into. But as the water in the reactor is heated, the hydrogen atoms get farther apart so that the neutrons experience less moderation and are therefore less favorable for fission. This inherent negative feedback results in the negative temperature coefficient of reactivity of the coolant, which in turn makes it possible to hold a desired temperature very accurately.

In the simulation of the temperatures $\theta_c, \theta_m$, and $\theta_l$ (temperatures of the reactor fuel, the primary coolant, and the steam respectively), Barnes used the same general formula which states that the rate of change of temperature times the heat capacity is equal to the heat input minus the heat loss. In the case of the reactor fuel temperature, the heat input is proportional to the neutron concentration $N$. Heat is lost to the primary coolant and the amount lost is equal to a heat transfer coefficient times the temperature difference between the fuel and the coolant.

The heat lost by the fuel is added to the primary coolant.

In the secondary loop the heat loss...
due to the turbine load is proportional to the weight rate of steam flow through a throttle valve opening.

If the steam pressure is proportional to its temperature, then the equations for the system can be completed.

Information (Without Theory)

We were interested to learn from Hideo Morii's notes that the Eastern Simulation Council's study groups seem to be thriving.

Harold Skramstad's group on Combined Analog-Digital Simulation has discussed the current work at National Bureau of Standards to connect their analog facility with the digital computer SEAC to simulate sampled-data systems. They have also considered:
1. The work at Convair and Ramo-Woolridge, and plans at Holloman Air Force Base, for combining large-scale analog and digital computers for simulating complex missile systems.
2. Relative computing speeds and accuracies of analog and digital computers.
3. The types of calculation which should be done analog-wise, and those which should be done digitally.
4. Advantages and disadvantages of a combined facility as compared with each type alone.

Dr. Morris Rubinoff's (Univ. of Penna., Philadelphia) group on Fundamentals of Simulation has considered definitions and interpretations, and as usual the human element enters in. Who determines whether a simulation is a good enough approximation to the system being simulated? To what extent does the path between the system and its representation enter into the definition of simulation? The direct path might be via analog or digital computer with output on a continuous recorder or as a tabulation of data, while the indirect path might be a solution in general or a closed analytic form followed by evaluation of particular cases.

The group on Future Trends in Simulation (Frank Richmond, The Glenn Martin Co., Baltimore, Md., Chairman) discussed the limitation of non-linear elements and the need for more realistic and uniform specifications in their January meeting. This is particularly important since the introduction of analog computers into industry for use in oil refineries, power distribution systems, process control, etc. In March Frank's group outlined their field of interest as follows:

I. Equipment and arrangements
   A. New and expanded fields of simulation
   1. Combined analogue-digital simulation
   2. Components

II. Application
   A. Simulation of a logic system
   B. Dynamics and simulation for business controls

In January the study group on Dead Time Simulation (Bernie Loveman, Chairman) reviewed work on abstracts of papers on simulation of dead time in order to compile a bibliography. This included use of linear approximations to dead time and the definition of a best or optimum network. This study group thus terminated work on their subject. In its place a new study group on Evaluation of Analog Computer Performance (also chaired by Bernie) plans to discuss performance factors and testing procedures for components of dc electronic analog computer systems. The effect of component errors on the solution of problems will not be discussed, since that subject falls in the realm of error analysis. Performance factors to be considered are static accuracies, dynamic accuracies, noise, life, and repeatability. Also linear elements such as amplifiers, potentiometers, resistors, and capacitors will be reviewed.

He Went That-A-Way!

Our friend and Chairman Emeritus of the Western S/C, Norm Irvine, is now Senior Dynamics Engineer with the Poma, California, division of Convair.

Computer Events

Fourth Annual Symposium on Computers and Data Processing
Dates: 29 and 30 August 1957

Central Simulation Council
Date: 16 September 1957
Place: Boeing Airplane Company, Wichita, Kansas
Subject: "Hardware Tie-Ins"
For information write Harry Cordes, Boeing

Symposium on Analog and Digital Computation and System Dynamics
Dates: 19-20 November 1957
Place: Wright Air Development Center, Wright-Patterson Air Force Base, Ohio
There will be one combined session on topics of interest to all groups, followed by separate meetings on digital computation, analog computation, and system dynamics. For information write A. C. Robinson, Aeronautical Research Laboratory, WCRHY, Wright Air Development Center.

International Simulation Council
Dates: 9-12 December 1957
Place: Washington, D. C.
This will be held in conjunction with the Eastern Joint Computer Conference. For information write Dr. Harold Skramstad, National Bureau of Standards, Washington 25, D. C.