Preparations for $\delta \phi / \phi$ Transfer Function Test - MSRE

S. J. Ball
2-12-68

Recording Amplified, Biased, & Low-Pass Filtered $\phi$ & $P_{bowl}$ on Logger Fast Scan

1) Scan Pt. 2033 (DT-592) Range to be changed such that 0-10V input gives 0-100 units output.

Flux Chan +1

Existing cable from Nuclear Panel to Computer Room

2) Scan Pt. 5058 (LT-600) Range to be changed such that 0-10V input gives 0-100 units output.

Scan Seq.
S013
Pt-522

100k on upstream of 5031

Attenuator; parallel existing input (S. J. Edgar)
One-Shot Multivibrator

Open HCV - Equalize for "N" ms.

Set Pt 3P

For Max. P

10V

Increase for shorter on times

Energize relay to open equalizing valve

UCN-3889A DATA SHEET
(125 11-52)
SERVO AMP.
RM-NARC-A4

This affects tach signal input
LAG WITH 0.2 SEC. T.C.
LEAD WITH 2 SEC. T.C., GAIN OF 1.5 X NORMAL φ GAIN

10 MEG (EFFECTIVE)
100 SEC LAG
(ADDITIONAL 0.2 SEC LAG OMITTED)
TO FLUX DEMAND CALC.
"RESET AMP."
RM-NARC-A1

LEAD WITH 2 SEC. T.C., GAIN OF 1.5 X NORMAL φ GAIN

REFERENCE DWG. - AUTOMATIC ROD CONTROLLER CIRCUIT DIAGRAM
RC 13-12-53 (R4)

FIG. 2 MSRE ROD CONTROL CIRCUIT - PROPOSED MODIFICATIONS FOR 233U-FUEL LOADING SIMULATION
<table>
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<th>INS</th>
<th>LABEL</th>
<th>OPR</th>
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<td>S.B.</td>
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</table>

**Notes:**
- `STR.A` represents a store operation.
- `BUN` is a bypass operation.
- `N.R.2` is a compare operation.
- `B.ZM` is a branch operation.
- `S.H.F` is a shift function.
- `A.L.D` is an add operation with a left shift.
- `ADD` is an add operation.
- `REM` is a remainder operation.
- `STR.A` is a store operation.
- `C.L.F` is a condition label.
- `L.O.D` is a load operation.
- `M.G.M` is a multiply operation.
- `B.U.N` is a branch unconditioned.
- `O.P.E` is an output operation.
- `S.E.T` is a set operation.
- `E.X.M` is an extract operation.
- `E.L.E` is an entry operation.
- `STR.C` is a store.
- `F.E.X` is a function extract.
- `F.C.T` is a function control.
- `ADDR` is an address operation.
- `N.R.M` is a normal remainder.
- `M.F.M` is a multiply function.
- `S.B` is a subtract operation.
<table>
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MEASUREMENT OF LAGS IN THE MSRE CONTROL ROD RESPONSE

Proposed Measurement

Simulated control rod activation signals of predetermined time and duration will be sent to the control rod relays. The velocity of the control rods will be recorded as a function of time. From analysis of these data we expect to determine the lags associated with control rod startup in insertion and withdrawal and with coastdown in insertion and withdrawal.

Need for Measurement

The MSRE with $^{233}\text{U}$ loading is expected to show a livelier high frequency flux response to reactivity signals. Whether this response together with the time response of the control system creates any problems must be determined. We do not have information related to the time lags in the control system. Hence, we propose to measure them.

The lags so measured will be incorporated in an analog simulation of the system with controls.

Description of Experiment

The reactor will be in the normal operating condition at power. It is not expected that the experiments proposed here will cause any significant disturbance to the system or to any experiment being performed concurrently on the system.

The automatic control system will be disconnected at the output of the servo amplifier.* At that point we shall introduce a controlled voltage signal to operate the regulating rod drive relays.

The controlled voltage will be zero or $\pm 6.5$ volts - enough to override the relay bias in the insertion or withdrawal mode.

A $\pm 6.5$ v signal is impressed for a pre-determined and pre-programmed time. A time mark is recorded when the signal begins and when it terminates. The rod velocity,

*RC-13-12-53 R4
as given by the synchro-demodulator* is recorded during the experiment. This velocity is the fundamental output. The time between the application of the signal and the assumption of a non-zero velocity by the rod is a pure time lag. There is a further lag associated with acceleration of the rod to its final velocity. A derivative circuit will be provided to differentiate the velocity signal. This derivative will also be recorded. It is anticipated that the pure lag will be easily read from the derivative. The acceleration, too, can be obtained directly from the derivative circuit if its response is good enough. If not, the velocity record will be further analyzed off line.

When the signal is terminated a time mark is made, and, after a pure lag, we anticipate a sharp change in the derivative output indicating the beginning of deceleration. Subsequent output of the derivative and and velocity channels will be available to measure decelerations during the coast-down and braking period. No signal will be longer than 2 seconds.

For very short duration signals the startup and coast down velocities may be poorly separated in time so that analysis would be complicated.

As an additional check on the equipment we shall integrate the velocity signal and record the integrated output. This output should correspond with the rod position indicator.

We shall consider a single measurement to begin with the start of the ±6.5 v signal to the relays and to end a few seconds after the termination of that signal (when rod coast down can be expected to be complete). Hence, a single measurement may take about 5 seconds.

By an inverse of a measurement we shall mean exactly the same measurement with the direction of the rod motion reversed.

Controlling the Reactor During the Measurement

The measurement involves disconnecting the automatic control system. Hence, some remarks should be made about reactor control.
1. All measurements will be in pairs with their inverses and very little time will elapse between an inverse pair. Hence, in about 10 seconds of operation an inverse pair will have been run and the regulating rod restored to essentially the position from which it started.

2. The amount of rod traverse in any measurement will be small. The reactor will be at power and it has a large temperature coefficient. The entire disturbance of the measurement is expected to be compensated for immediately by a small temperature change. The rod is never expected to move more than two inches (0.12% δk/k).

3. The operator will stand by manual control at all times to make whatever adjustments appear to be necessary.

The above is the procedure of choice. Its great virtue is its simplicity of realization. It requires only that a servo amplifier be unplugged, some experimental circuitry on a TR-10 be plugged into its place and some output connections be made to a recorder.

An alternative procedure which has certain distinct advantages but which requires the wiring of a switch is as follows. Let all connections of output to recorder be as before. However, instead of replacing the servo amplifier with the experimental gear let us tie them both into the system through a selector switch. Now the system can be always subject to automatic and corrective control except during those isolated intervals (~5 seconds) during which measurements are made. Further, output can be collected during the automatic control periods. While this output is not essential to our purposes a limited amount of it could provide added understanding of the demands placed on the automatic control system.

Experimental Circuitry

The required circuitry is as shown in Fig. 1. The points marked (A) and (B) are tie points into the reactor circuitry and are shown in RC-13-12-53 R4. The remainder of the circuitry in Fig. 1 will be wired on a TR-10 as shown.
The timing circuitry has been separately tested, and it is found that varying potentiometer R covers most of the time range wanted with the gains indicated, the higher R, the shorter the time.

The calibration of R should be done on the spot at the experiment by use of the timing mechanisms on the recorder.

The differentiator circuit was checked out on an oscilloscope with a square wave input. The width of the derivative pulse when it had retraced its way about 90% toward the zero base was about 20 millisecond suggesting an equivalent first order lag of about 10 milliseconds in the circuit. This is easily bearable. No check was made for gain distortion.

**Equipment Required**

This measurement will require a TR-10 analog computer and an 8-channel (Sanborn) recorder.

It is desirable to have available a square wave and triangle wave generator, 10 v amplitude, and an oscilloscope.
CHECK LIST

1. Connect triangle wave, then square wave input to differentiator circuit. Observe output on scope.

2. Connect differentiator, velocity integrator, time marker, velocity tie point to recorder. Connect velocity tie point to differentiator and integrator input.

3. Check time circuit. Set for first desired time.

4. Is reactor critical and at power?

   power =

   temperature out =

5. Connect output of R 259 (RC 13-12-53 R4) to velocity tie point.

6. Check differentiator and integrator output.

   Leave TR-10 in Reset.

7. Remove synchro amplifier and connect in the point A, Fig. 1 to the regulating rod relays.


11. After no less than 5 seconds place TR-10 in Reset. Open Time Pulse switch.

12. Throw relay power supply switch to -10 v.

13. Repeat steps 9-11.

14. Place Relay power supply switch at zero.
15. Label the record.

16. Set R to next time interval.

17. Go to step 8 and repeat sequence until measurements are complete.

Initial | Date/Time
--------|--------
        |        

F. H. Clark
A Input to Regulator Rod Relays
B Output of Synchro Demodulator

Fig. 1 - Required Circuitry
Revised MSRE Dynamics Test Memo

Add to section entitled "Special Equipment and Preparations":

**Pseudo Random Flux Demand Signal Generator**

While the rod positioning device required extremely accurate timing circuits to control the rod insert and withdraw commands, the pseudo random flux demand signal is simply a d-c voltage fed into the MSRE rod controller.

A special MSRE computer program similar to the one used for the rod jogging tests will provide a single contact output signal for the PRBS tests and two contact outputs for the PRTS tests. The required circuitry is shown in Fig. 2. One extra wire (in addition to the 2-wire flux signal now installed) will need to be run from the rod control panel to the computer room.

The bit time for the PRBS and PRTS flux demand inputs will be controlled by the MSRE computer program, and can be set to any integer times the basic fast scan interval (0.25 sec).
Fig 2 CIRCUITRY REQUIRED FOR PRBS AND PRBS FLUX DEMAND DYNAMICS TESTS
NEEDE PUMP BOWL PRESSURE TRANSIENTS

\[ \frac{\Delta p}{\Delta t} \text{ rise with purge flow } = 0.15 \text{ scfm} \]

\[ (.00158 \text{ lb/m}) \]

\( \Delta p \) with Letdown Valve Closed, \( p_{\text{nominal}} = 5 \text{ psig} \)

\( = 0.45 \text{ psi/min with D.T. valves closed} \)

\( = 0.073 \text{ psi/min with D.T. tied on} \)

For PCV-522, \( C_v = 0.019 \) (à la 1963)

Calc. Letdown Flow \( \approx 0.3 \text{ scfm at } 5 \text{ psig } P_{\text{bowl}} \)

\( \rightarrow \text{ would be } -0.9 \text{ psi/min max.} \)

\( \rightarrow \text{ Use } \sum \sum \text{ or PRSS to control flow in & out } \)

\( \text{ IN = on when OUT = off etc.} \)

Flow in! FIC-516 B on manual, valve wide open

ON-OFF SOLENOID ESV-516 A1 or A2

Flow out: IF SOLENOID IN SERIES W/ PCV 522,

OPEN 522 WIDE & CONTROL SOLENOID

\( \sim 180^\circ \text{ out of phase w/ 516, maybe} \)

Adjust phase to optimize, if no solenoid,

(3-way solenoid)

Use E/P or I/P converter to drive

Valve or Controller.
Main Purpose of This Session -

Discuss the transient characteristics of the reactor - or at least our predictions of what they'll be.

Suspicious of motives & methods:
1) Best way to define clouds: impartial computer (top page)
2) Even with impeccable analytical methods
   \[ \text{Dynamics} = f(\text{model}, \text{parameters}) \] - much of work

Why Interested in Dynamic Behavior?
1) See if plant behavior will be tolerable
   a) Design & operate control system to harness it
   b) Accident studies
   c) Inherent stability, safety, control for tests & rods
2) Info from dynamic tests - e.g., separate \( \alpha_f \) & \( \alpha_G \)
3) Check on methods of predicting model, parameters;
   use info. in design of larger plants.

Outline
1. Transient Behavior
2. Dynamic Test Program
   if time → 3. Training simulators -
• INCIDENTALLY
  \rightarrow Questions, discussion, suggestions now or later

• REVIEW Dynamic Analysis Techniques à la MSRE

  1. "Time Constants"

  Eq: MSRE: Pri, see metal, salt, graphite

  \[ M C v \frac{dT}{dt} = P - hA(T - T_a) \]

  or

  \[ \frac{dT}{dt} + \frac{hA}{M C v} T = \frac{P}{M C v} + \frac{hA}{M C v} T_a \]

  \[ T_{C, i} = \frac{M C v}{hA} = 1200 \text{ sec} = 20 \text{ min} \]

  Step input in
  \[ P \rightarrow T \]

  \[ T_{i} \rightarrow \frac{1}{0.63} \rightarrow T \]

  \[ T_{C, i} = \frac{M C v}{hA} = 1200 \text{ sec} = 20 \text{ min} \]

  ANALOG

  also ratio of \( \frac{T_p}{T_{ss}} = \frac{1}{hA} = 100^\circ F/mw \)

  @ 1 mw  Say \( T_a = 400^\circ F \)  \( P = 1 mw \)  \( hA = \frac{1 mw}{800^\circ F} \)

  \[ T_{C} = 12 \times 800 = 9600 \text{ sec} = 3 \text{ hr} \]

  \[ \frac{T}{P}_{|_{96}} = 800^\circ F/mw \]

  Note problem of controlling temps. just by \( \phi \) control.
2. Linear System Frequency Response

- Sinusoidal P input → T output \( \frac{T}{P} \)
  - Low freq gain = \( \frac{1}{sA} \), T keeps up
  - \( \rightarrow \) Analog & Scope
  - Higher freq = lag & attenuation

- \( \text{FREQ. RESP.} \) Plot \( \frac{|T|}{P} \) log-log
  - \( \times \) 0
  - \(-90^\circ \) lag
  - \( \rightarrow \) \( \omega \) rad/time (log-log)

- \( \text{INTEGRATOR, Char.} \): \( \int \cos \omega t \ dt = \frac{1}{\omega} \sin \omega t \)

**METHOD**
- Get Freq. Response Solutions from DE's
  - Laplace \( s = \frac{d}{dt} = j\omega \); use digital codes.
  - Solve transient eqn's on analog or digital

---

Heat Transfer: Write ordinary DE's - Heat Rate Balance

- BUT: ordinary \( \Rightarrow \) point masses; actually PDE's.
- MODEL is important
  - Accuracy = \( f(\omega, \text{no. of "umps"}) \)
Fluid Flow

\[ \Delta V = \frac{1}{\phi} + \text{Heat } \times f \]

Plug Flow

Turbulent

Actual Case - Some TRC, Some Mixing

Advantage of FR - Can Do P.D.E.'s Exactly

Kinetics Eq'n's

Analog \( \Rightarrow \)

(\text{maybe just to middle later}) FR

\[ SK_{in} + G - H \]

\[ N = GSK_{in} - N_{in} \cdot GH \]

\[ \frac{N}{SK} = \frac{G}{1 + GH} \]

Thermal FB, \( 6H = -1 \rightarrow 0^\circ C \)
STABILITY

- Analog - 3 loops w/oscillator input - Freq Resp.
  Then close loop.
  Stability is Relative
  Peaks on F.R. Curve
  Phase Margin

METHOD of Analysis - Seek out worst (or best)
  f(Param) stability case using linear models T.H. Code
  Then plug specific case into computer for NL Soln.

MSRE FREQ RESP

1. Note Fig 16 BlockDiag → Breakdown of Thermal F.B.
2. Note "overall" $\frac{C}{N}$ → good approx $\sim 0.005$ m/sec
3. Next Slowest Stem = Graphite $\sim 3$ min TC
4. Note transient responses $\sim 10$ min - on Bd.
5. Frequency of oscillation $\sim$ where $|GH|=1$
   Stability $= f$ (how close to $-180^\circ$) GH curve.
   Note @ low powers $\frac{C}{N}$ $\sim -90^\circ$
   Also $\frac{N}{\delta K} \times \text{No.} \sim -90^\circ$ at low freq.

So $GH \rightarrow -180^\circ$ for lower powers & lower freq's where $|GH|=1$
6. Note Fig 13 (Freq Respx2No)
Dynamic Tests

1. Purpose - to Determine Parameters, Models
   Not otherwise available from static meas. (e.g. $\chi_k$ & $\chi_0$). Re-examine stability & new info. Mechanisms -> Noise

2. Methods of Analysis
   Pulse, Step, Binary Noise inputs -> Transfer Functions
   Develop tests & analysis methods (practice w/ computer models)
   Physical feasibility
   NL's, Noise, Drift, measurement accuracy
   Routines for auto. fit of data by varying parameters

   Hot slug -> Core, reactor critical in 0 power
   Components -> check thermal response of core, TC's, noting rod motion or $\phi$ -> SK
   Data logger in fast scan

4. Example - Rod Step or pulse at power
   System -> fit model response to expt'd
OTHER DYNAMIC TESTS

Zero Power Flow TRANSIENTS

Separate effects of circ. precursors & voids, w/ X-ray densitometer measurements.

2. Loop HEATERS

SS & transient effects on loop temps, nearly TC readings.

3. Trans Pulses - Pri & Sec. as noted.

4. Rod gvturbations, noise analyses for Zero pwr (i.e. no FB) kinetics eqn's.


Higher Powers --- Repeat 4

Note: Extra checks & cross checks on exp't & info.
**TRAINING SIMULATORS**

1. **Startup:** Log Power Comp. (see notes)
   
   + Reciprocal period $= \frac{dn}{dt}$
   
   + Note $\int \frac{dn}{n} dt = \int \frac{dn}{n} = \log n$

   SK [pos.]

2. **Power Level (after Critical Run)**
   
   Solve linear eq'ns., w/ thermal F.B. approx.
   
   Use Rod position for SK in
   
   Use Radiator Door Pos. & Rod AP to give
   
   radiator characteristics
Example of No for W resonance. (= Class exercise in time)

\[ \alpha_f = 0.0000485^oF^{-1} \]
\[ \alpha_g = 0.0000370^oF^{-1} \]

For low freq \( \xi = 0.000085^oF^{-1} \)

Pick \( W_{tot} = 0.005 \) rad/sec. Find No

From Fig 13
\[ \frac{N}{SK} = \frac{16000 \text{ mw}}{SK \times No} \]

From Figs. 17 & 18
\[ \frac{T}{N} = 20 + 10 = 30^oF \]

\[ 0.000085^oF^{-1} \times 16000 \frac{\text{mw}}{SK \times No} \times 30^oF \times No = 1 \]

\[ No \approx 0.02 \text{ mw} \]

See Fig 13 - OK
\[ \phi = -180^\circ \text{ where each } = -60^\circ \]
\[ G = K \times \left( \frac{1}{T^2 + 1} \right)^3 \quad (j\omega + 1) \quad (T = 1) \]
\[ \frac{V_{b}}{V_{a}} = \frac{1}{2} = 0.5 \]
\[ (5)^3 = 125 \]
\[ K = 2 \text{ for } G = 1 \]
\[ @ \omega = \sqrt{3} \text{ rad/sec } \approx \frac{1}{2} \text{ cps} \]
Proposed Outline of Talk to MSRE Operations, Engineers

Thursday, 4-1-65, 8:30--10:30 AM  WED 3-31-65  100--300 pm

A. Review of Dynamic Analysis Techniques

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B. Dynamic Models of MSRE

1. Low frequency behavior
2. Response of components
3. Overall inherent response and stability
4. Response with automatic controller

C. MSRE Dynamics Experiments

1. Purpose
2. Methods of Analysis
3. Non-Nuclear Tests
4. Nuclear Kinetics Tests
5. Noise Measurements

D. Description of Training Simulators

1. Startup
2. Power Level Operation

NOTES: 1. The talk will be continuously open to questions and discussion.
        2. A TR-10 analog computer will be used to demonstrate some points.
        3. A break is planned for about half way.
Fig. 16. HSRE as Closed-Loop Control System
Fig. 17 Frequency Response Diagram of Core Inlet Temperature as a Function of Nuclear Power.
Fig. 18 Frequency Response Diagrams of Nuclear Average Temperatures as Functions of Nuclear Power and Core Initial Temperature
Fig. 13. MSRE Frequency Response for Several Power Levels - Complete Model and Current Data.