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EXPERIMENTAL INTERPRETATION OF A CRITERION OF NONLINEAR STABILITY

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The purpose of this paper is to illustrate how a sufficient criterion for nonlinear asymptotic stability, derived in reference (1), can be interpreted by means of small amplitude perturbation tests. A special form of the criterion is:

$$\mathrm{Re}\left[\frac{W(j\omega)}{1 + aP_1W(j\omega)F(j\omega)}\right]\left[1 + \frac{b}{W(j\omega)}\right] > 0 \qquad (1)$$

where $W(s)$ is the zero power reactor transfer function, $F(s)$ is the reactivity feedback transfer function, P_1 is the operating power level and a and b are arbitrary positive constants. The constant a is greater than unity and it is a measure of the range of operating power levels, $0 \div aP_1$, over which the reactor is guaranteed to be nonlinearly, asymptotically stable.

The first bracket in (1) represents the reactor transfer function, $H_a(s)$, at power aP_1. If the phase of the second bracket is denoted by $\psi_b(\omega)$ then for $\omega > 0$, $0^\circ < \psi_b(\omega) < 90^\circ$, and the meaning of (1) is:

$$\phi_{2b}(\omega) = -90^\circ - \psi_b(\omega) < \arg H_a(j\omega) < 90^\circ - \psi_b(\omega) = \phi_{1b}(\omega) \quad ; \omega > 0 \quad (2)$$

The zero power transfer function can be measured by small amplitude tests. Hence, the phases $\phi_{1b}(\omega)$ and $\phi_{2b}(\omega)$ can be readily evaluated for $0 < b < \infty$. The reactor transfer function at several power levels can also be measured by small amplitude tests. The phases of these transfer functions at power are superimposed on a plot of $\phi_{1b}(\omega)$ and $\phi_{2b}(\omega)$. The maximum nonlinearly, asymptotically stable operating power level, $a_m P_1$, is found by extrapolation and so that requirement (2) is satisfied. That pair of curves $\phi_{1b}(\omega)$ and $\phi_{2b}(\omega)$, i.e. that value of b, is selected which results in the largest maximum power.

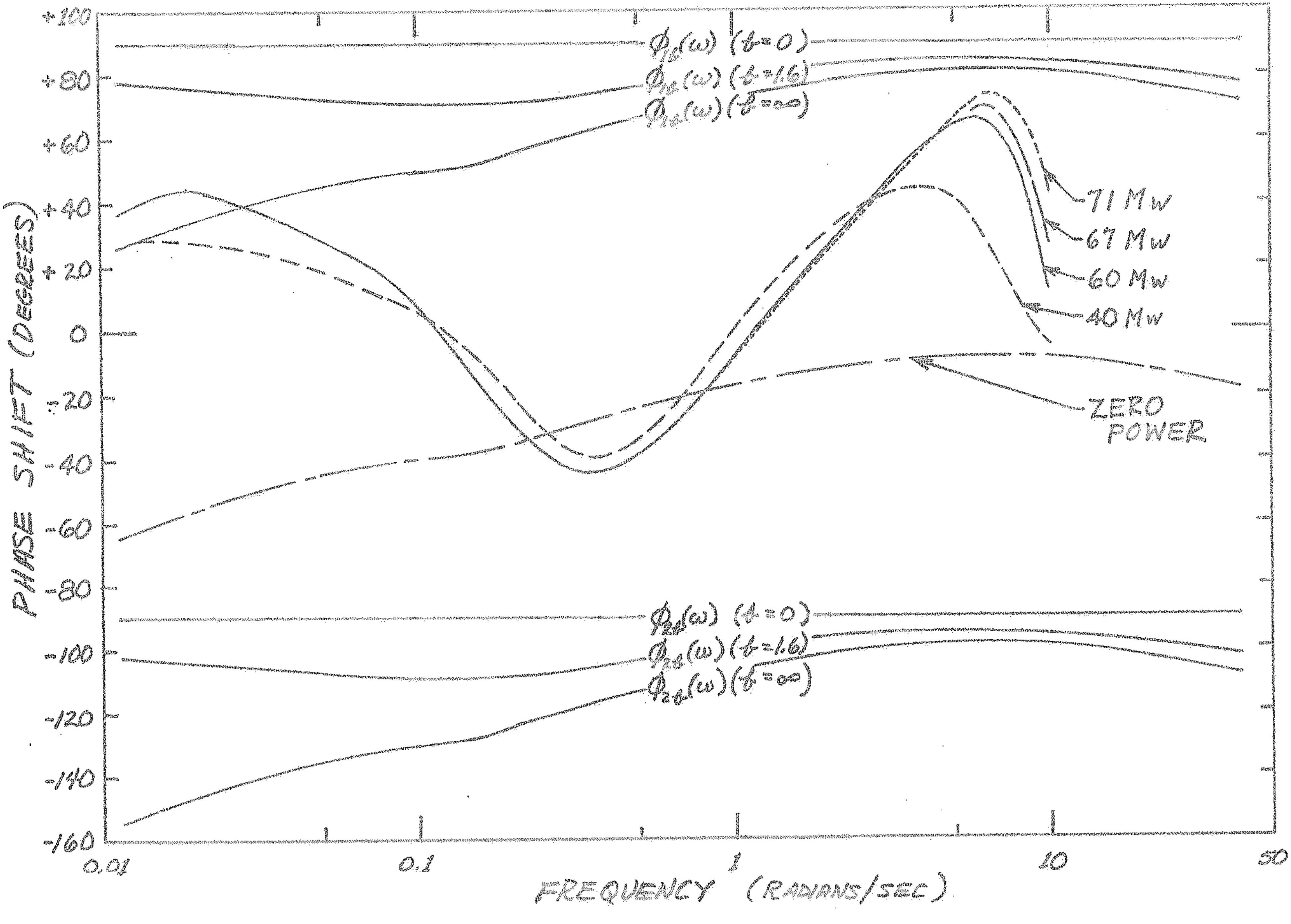
This procedure has been applied to the published data on EBWR.[2] Figs. (1) and (2) illustrate the results. Specifically, from the phase shapes (Fig. 1) it is seen that the best choice for b is zero and that the most crucial portion of the phase curves is around the resonance at 6 rad/sec. Hence, power versus phase at this resonance is plotted in Fig. (2) and extrapolated to 90°. Depending on how the data are extrapolated $a_m P_1 \approx 98$ or 108 MW.

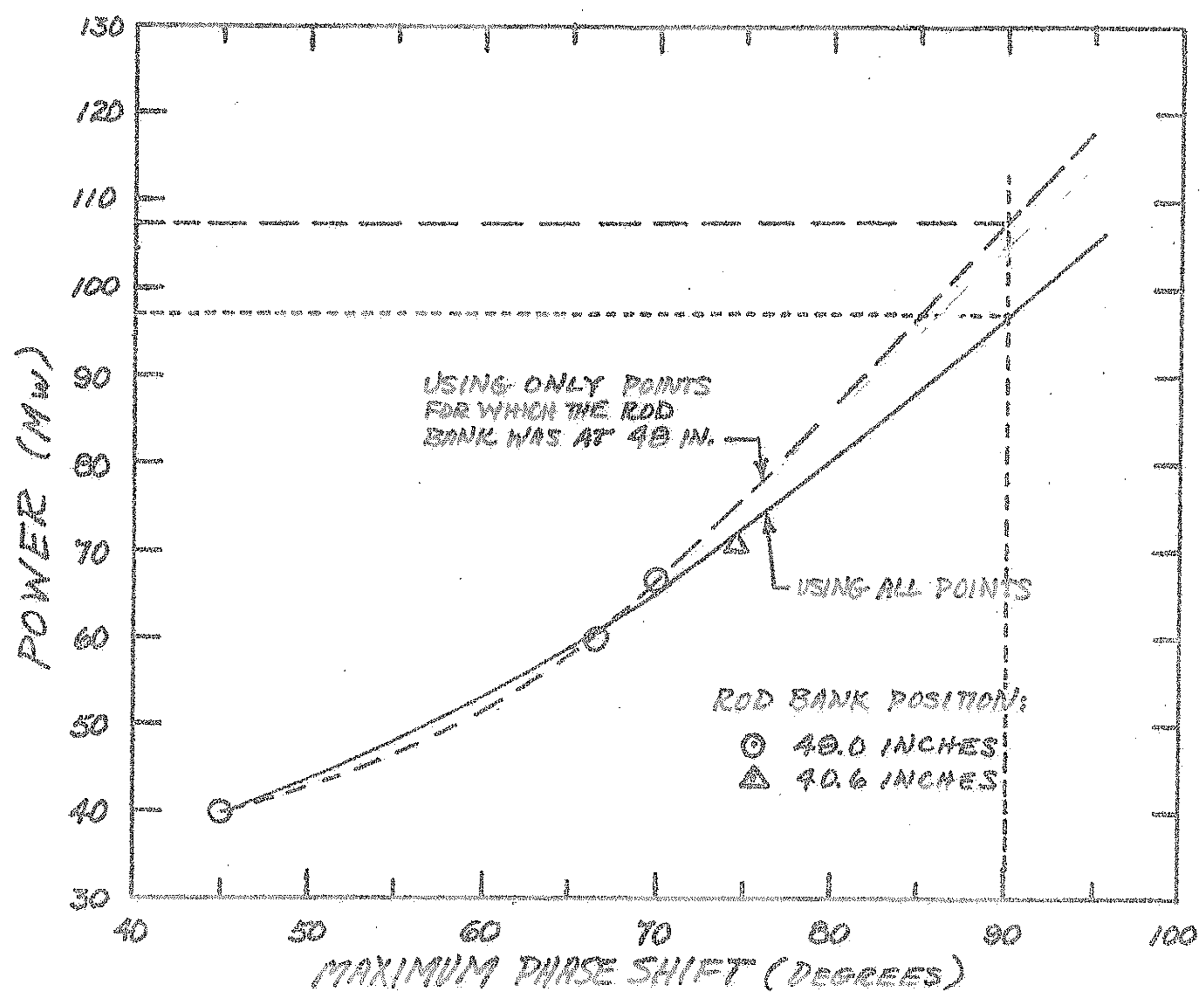
REFERENCES

1. Gyftopoulos, E.P., Some Applications of Mathematical Methods to Nuclear Engineering at MIT, Proceedings of Symposium on Neutron Dynamics and Control, Univ. of Arizona, April (1965).

2. Lipinski, W.C., A. Hirsch, C. Hsu and G. Popper, "EBWR Reactor Transfer Function Measurements", ANL 6703, 268-286 (1964).

LIST OF FIGURES


PHASE SHIFT (DEGREES)
+100
+80
+60
+40
+20
0
-20
-40
-60
-80
-100
-120
-140
-160
0.01
0.1
1
10
50
FREQUENCY (RADIANS/SEC)
(f = 0)
(f = 1.6)
(f = ∞)
71 Mw
67 Mw
60 Mw
40 Mw
ZERO POWER
(f = 0)
(f = 1.6)
(f = ∞)



130
120
110
100
90
80
70
60
50
40
30
POWER (MW)
40
50
60
70
80
90
100
MAXIMUM PHASE SHIFT (DEGREES)
USING ONLY POINTS
FOR WHICH THE ROD
BANK WAS AT 49 IN.
USING ALL POINTS
ROD BANK POSITION:
49.0 INCHES
40.6 INCHES