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ACOUSTICAL OSCILLATIONS IN BOILING WATER REACTOR SYSTEMS

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Summary

A method is presented for the evaluation of the steam production rate to tank pressure transfer function of boiling water reactors. The derived transfer function illustrates the resonant character of the acoustical oscillations observed in boiling water systems (1) as well as the dependence of the resonance characteristics on reactor operating conditions.

The reactor system is shown in Fig. 1. Acoustical phenomena develop in the volumes V_1, V_2, and the pipe ℓ associated with the steam mixture through propagation of pressure waves. These phenomena are best visualized in terms of electrical parameters by using electrical analogies as suggested by Olson (2) and summarized in Table I. More precisely, the volumes V_1, V_2 are equivalent to capacitors C_1, C_2 and the steam pipe ℓ is equivalent to an inductor L in series with a resistor R. The values of the parameters are related to the thermodynamic properties of the steam mixture and the geometry of the system (see Table I). The steam production rate to pressure perturbation transfer function (acoustical transfer function) is the impedance of the network shown in Fig. 2. The overall reactor system block diagram is shown in Fig. 3.

The analysis of this system shows that for large boiling water reactors (C_1 and C_2 large) being operated at steam qualities as large as 0.1 (L large) the resonant frequency of the acoustical transfer function is of the order of 1 cps.

Table I

Analogies between lumped, linear electrical and acoustical systems

ELECTRICAL SYSTEM			ACOUSTICAL SYSTEM			
Parameter	Symbol	Definition	Parameter	Symbol	Definition	Practical Formula
Voltage	u		Pressure	P		
Current	i		Volume Current	U	vA	
Charge	q		Volume Displacement	X	ΔV	
Resistance	R	u/i	Incremental Flow Resistance	R	dP/dU	$k_1 U \ell \rho_o / d^5$
Capacitance	C	q/u	Acoustical Capacitance	C	X/P	$V\rho_o\ dV/dP$
Inductance	L	$u/\frac{di}{dt}$	Acoustical Inductance	L	$P/\frac{dU}{dt}$	$\ell \rho_o / A$

v — velocity of two phase mixture

ρ_o — average density of two phase mixture

k_1 — empirical constant ($\sim 2.7 \times 10^{-2}$ cgs units)

A — cross section of steam pipe

ℓ — length of steam pipe

V — steam volume

d — I.D. steam pipe

dV/dP — function of steam quality and pressure evaluated from steam tables for adiabatic, constant entropy processes

The damping is small (R small) and results in a large amplitude peaking. The resonant frequency decreases with increasing power. For certain conditions acoustical oscillations may be beyond the tolerable level.

Application of the method to the Dresden reactor gives good agreement between the theoretical predictions and the experimental results derived during the stability tests of Dresden (1).

References:

1. E. S. Beckjord, "Dresden Reactor Stability Tests", To be published.

2. H. F. Olson, "Dynamical Analogies", 2nd Ed., Van Nostrand, Princeton, New Jersey, 1958.

List of Figures

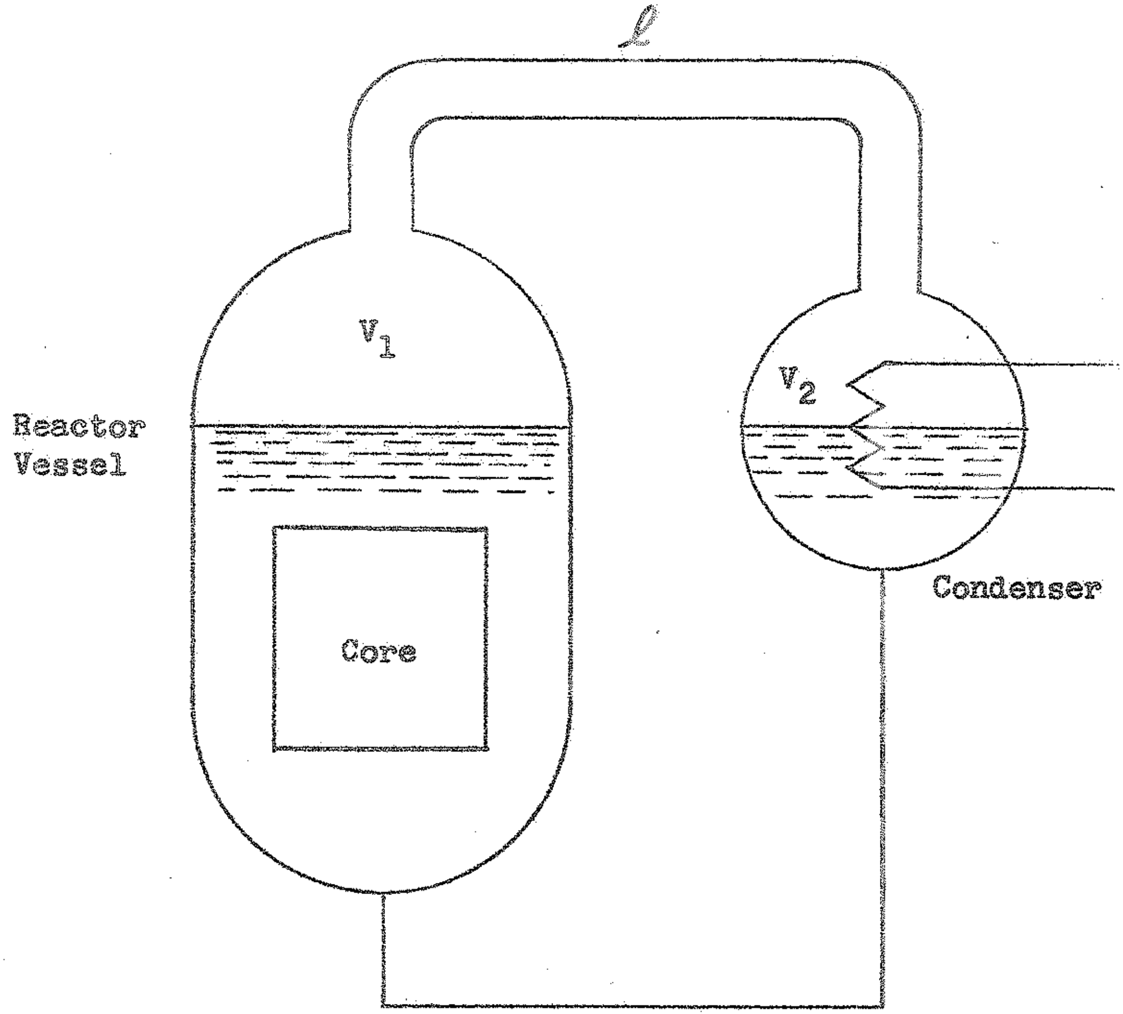


Figure 1

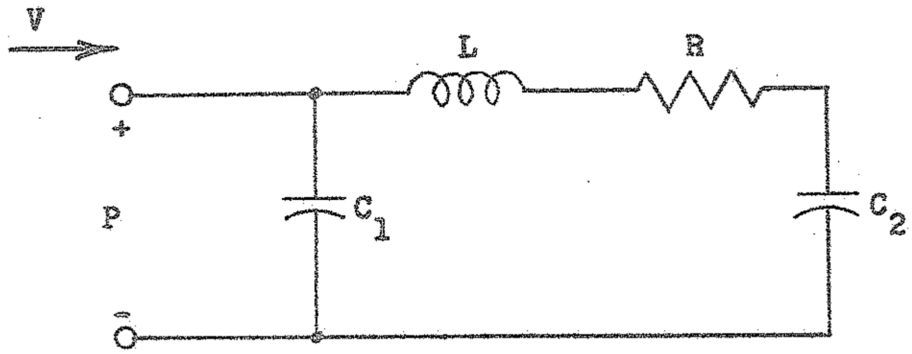
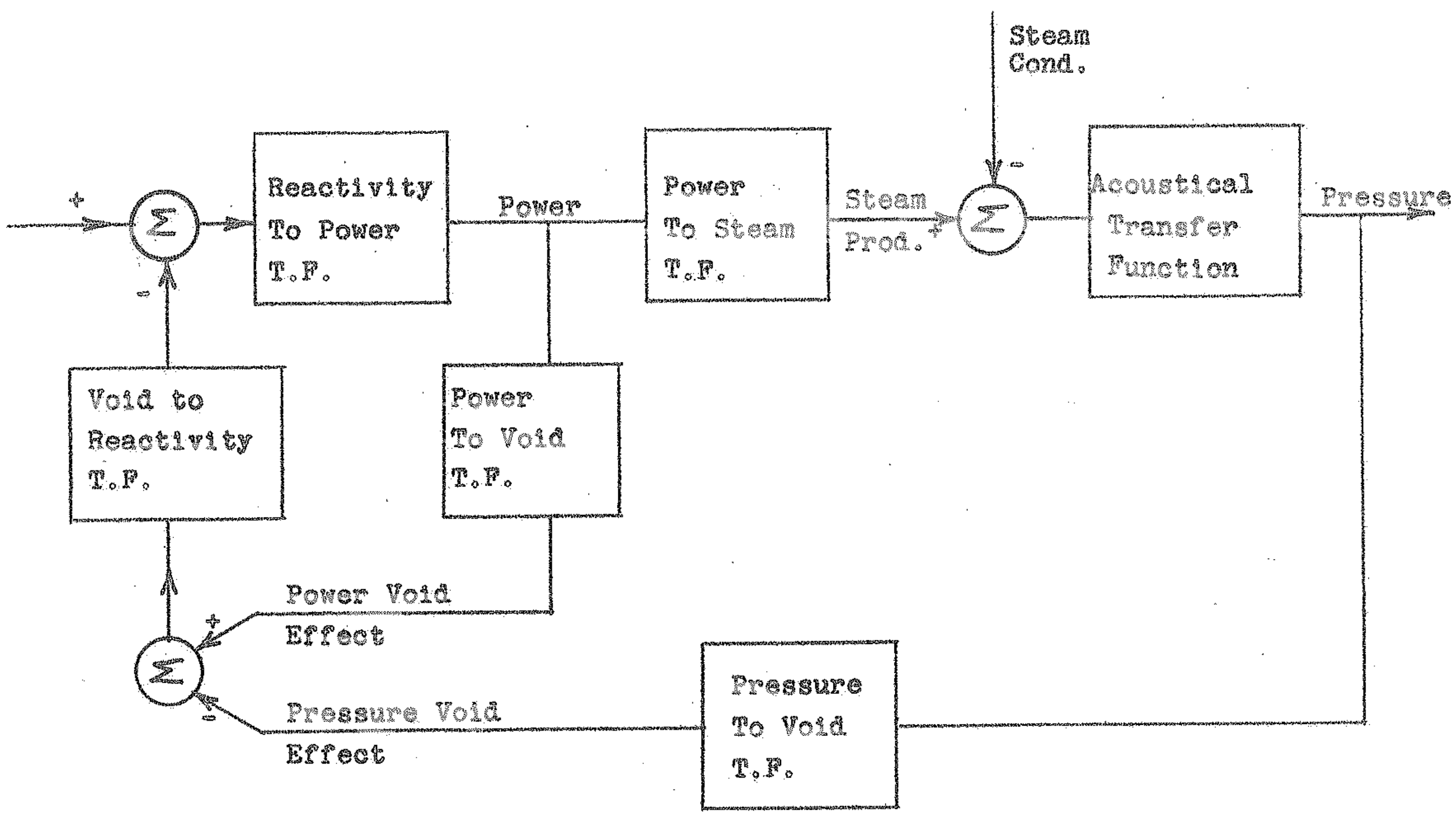


Figure 2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-
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Reactivity
To Power
T.F.
Power
Power
To Steam
T.F.
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Prod.
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Σ
Acoustical
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Function
Pressure
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To Void
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Power Void
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Figure 3