Finite Analysis of Extraction Flows on Heat Rate

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HEAT RATE DEVIATION METHOD

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TURBINE CYCLE HEAT RATE FROM TEST

- COMPLETE HEAT BALANCE FOR THE TEST
- DEVIATION CALCULATION

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HEAT RATE DEVIATIONS

$$HR = f\,(w_i,\ h_i)$$

$$HR = HR_o + \Delta HR = f_o + \Delta f$$

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DEVIATION APPROACH

- BASELINE HEAT RATE CALCULATION – YOU DO IT ONCE
- TEST HEAT RATE – DETERMINE Δf
  - DIFFERENTIAL

$$dHR = df = \frac{\partial f}{\partial w_1} dw_1 + \ldots \frac{\partial f}{\partial h_1} dh_1 + \ldots$$

  - APPROXIMATE, FINITE FORM

$$\Delta HR = \Delta f = \Delta f_{w1} + \ldots \Delta f_{h1} + \ldots$$

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EVALUATE DEVIATION FUNCTION

- SUMMARIZE CYCLE POINTS THAT CAN IMPACT HEAT RATE THROUGH
  - HEAT TO CYCLE
  - TURBINE POWER

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POINTS HAVING HEAT RATE IMPACT

- SUPERHEAT SPRAY
- REHEAT SPRAY
- BOILER EXTRACTIONS
- HP TURBINE EXTRACTIONS
- REHEAT TURBINE EXTRACTIONS
- CONDENSER HOTWELL ADDITIONS
- FEEDWATER LINE EXTRACTIONS
- FEEDWATER LINE ADDITIONS

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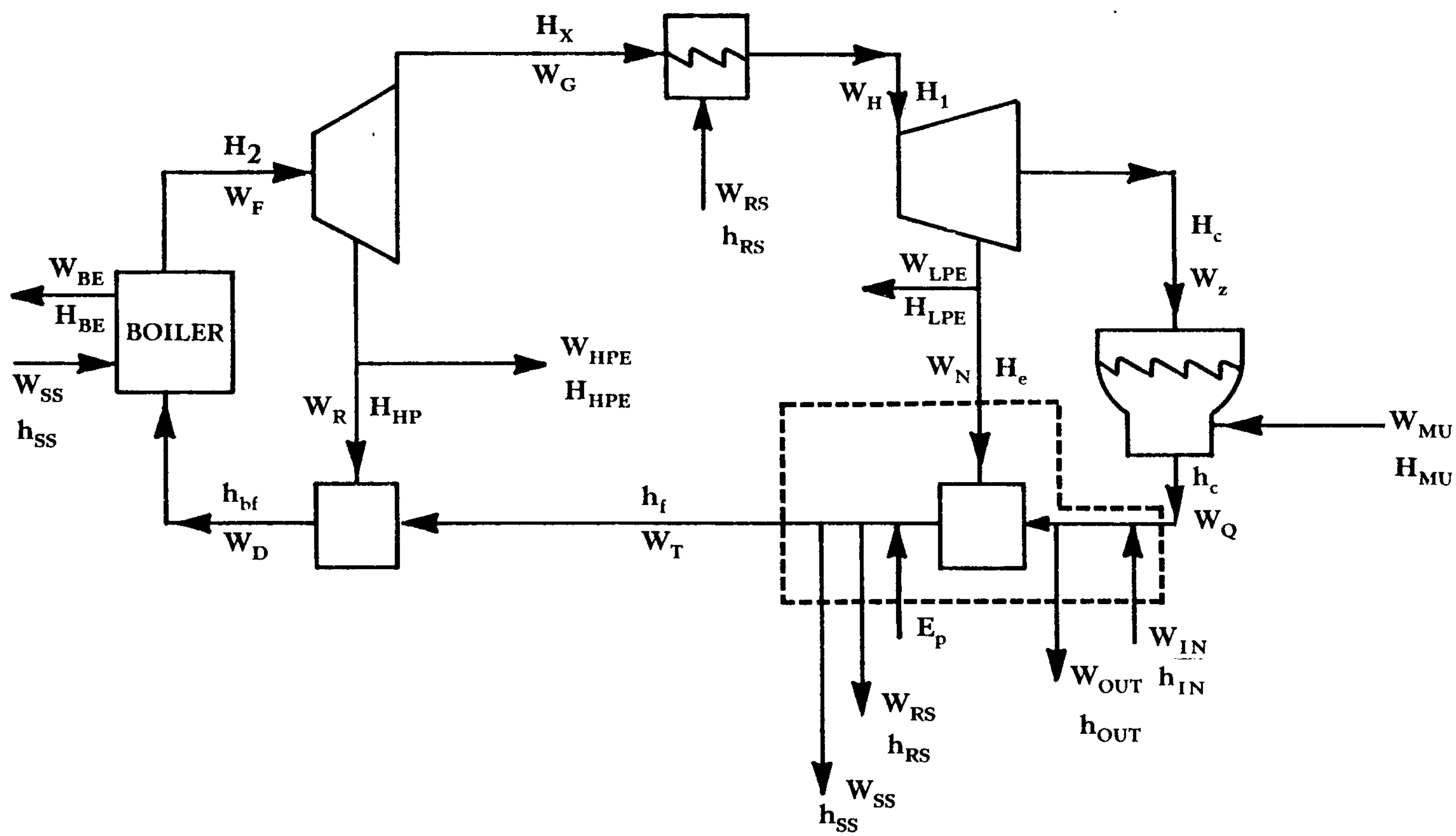

SALISBURY'S DIAGRAM REVISED TO SHOW EXTRACTIONS
FIGURE 2

HEAT RATE DEFINITION

$$HR = \frac{\text{Heat Added}}{\text{Power Generated}}$$

$$HR = \frac{F\,(H_z - h_{bf}) + H(H_1 - H_x) + SS\,(h_{bf} - h_{ss}) + RS(H_x - h_{RS}) + BE\,(H_{BE} - h_{bf})}{LOAD}$$

CONSTRAIN:

LOAD

ENTHALPIES

$$\Delta HR = \frac{1}{LOAD}\,[\,\Delta\ \text{Numerator}\,]$$

CONSIDER SUPERHEAT SPRAY FLOW EFFECT

$$\frac{\partial HR}{\partial SS} \; dSS = \frac{1}{LOAD} \left[(H_Z - h_{bf}) \frac{\partial F}{\partial ss} \; dSS + (h_{bf} - h_{ss}) \frac{\partial SS}{\partial SS} \; dSS \right]$$

$$\Delta HR_{ss} = \frac{1}{LOAD} \left[(H_z - h_{bf}) \, \Delta F + (h_{bf} - h_{ss}) \, \Delta SS \right]$$

RELATE ΔF to ΔSS

$$F = D - BE + SS$$

$$D = T + R$$

$$T = Q + IN - OUT + N - RS - SS$$

$$R\,(H_{HP} - h_{bf}) = T\,(h_{bf} - h_f)$$

$$\%\,\Delta HR_{ss} = \frac{\Delta HRss}{HR} * 100 = \left[\frac{(H_z - h_{bf})\,\Delta F + (h_{bf} - h_{ss})\,\Delta SS}{LOAD}\right]\frac{100}{HR}$$

WHERE

$$\Delta f = -\Delta SS\left[\frac{h_{bf} - h_f}{H_{HP - h_{bf}}}\right]$$

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SUMMARY

$$\text{HEAT RATE} = \text{HEAT RATE}_{\text{BASE}} + \Sigma \; \Delta \, \text{HEAT RATES}$$

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2. J. Kenneth Salisbury, "A New Performance Criterion for Steam-Turbine Regenerative Cycles", Journal of Engineering for Power, October 1959, pp. 389-402.

3. J. Kenneth Salisbury, "Power Plant Performance Monitoring", Transactions of ASME, October 1961.

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NOMENCLATURE

H_2 - enthalpy of steam entering HP (Btu/lb)

H_1 - enthalpy of steam entering LP (Btu/lb)

H_x - enthalpy of steam leaving HP (Btu/lb)

H_c - enthalpy of steam leaving LP (Btu/lb)

H_e - effective LP extraction enthalpy (Btu/lb)

h_c - hotwell enthalpy (Btu/lb)

h_f - enthalpy of condensate leaving top LP heater (Btu/lb)

h_{bf} - enthalpy of condensate leaving HP heater (Btu/lb)

H_{BE} - enthalpy of boiler extraction (Btu/lb)

h_{SS} - enthalpy of superheat spray (Btu/lb)

H_{HP} - effective enthalpy of HP extraction (Btu/lb)

H_{HPE} - HP miscellaneous extraction enthalpy (Btu/lb)

h_{rs} - reheat spray enthalpy (Btu/lb)

H_{LPE} - LP miscellaneous extraction enthalpy (Btu/lb)

H_{MU} - makeup enthalpy (Btu/lb)

h_{IN} - miscellaneous condensate in enthalpy (Btu/lb)

h_{OUT} - miscellaneous condensate out enthalpy (Btu/lb)

W_Z - condenser flow (lb/lb)

W_N - effective LP extraction flow (lb/lb)

W_R - effective HP extraction flow (lb/lb)

W_D - feedwater flow (lb/lb)

W_F - throttle steam flow (lb/lb)

W_G - cold reheat flow (lb/lb)

W_H - hot reheat flow (lb/lb)

W_Q - condensate flow to LP heaters (lb/lb)

W_T - condensate flow to HP heaters (lb/lb)

W_{RS} - reheat spray flow (lb/lb)

W_{SS} - superheat spray flow (lb/lb)

W_{HPE} - miscellaneous HP extraction flow (lb/lb)

W_{BE} - boiler extraction flow (lb/lb)

W_{LPE} - miscellaneous LP extraction flow (lb/lb)

W_{MU} - hotwell makeup flow (lb/lb)

W_{IN} - miscellaneous condensate in flow (lb/lb)

W_{OUT} - miscellaneous condensate out flow (lb/lb)

Z - condenser flow (lb/hr)

N - effective LP extraction flow (lb/hr)

R - effective HP extraction flow (lb/hr)

D - feedwater flow (lb/hr)

F - throttle steam flow (lb/hr)

G - cold reheat flow (lb/hr)

H - hot reheat flow (lb/hr)

Q - condensate flow to LP heaters (lb/hr)

T - condensate flow to HP heaters (lb/hr)

RS - reheat spray flow (lb/hr)

SS - superheat spray flow (lb/hr)

HPE - miscellaneous HP extractions (lb/hr)

BE - boiler extraction flow (lb/hr)

LPE - miscellaneous LP extraction flow (lb/hr)

MU - hotwell makeup flow (lb/hr)

IN - miscellaneous condensate in flow (lb/hr)

OUT - miscellaneous condensate out flow (lb/hr)

Ep - energy added by pumps (Btu/lb)

APPENDIX A

FINITE DIFFERENTIAL APPROACH TO LOSS CALCULATION

<u>Data Inputs</u> (From Heat Balances, Target Values)

H_1	Z	HPE	h_{out}
H_2	D	H_{HPE}	h
H_c	SS	LPE	PX
h_c	h_{SS}	H_{LPE}	LOAD
H_x	RS	MU	LOSS
H_{HP}	h_{rs}	IN	
h_f	BE	h_{IN}	
h_{bf}	H_{BE}	OUT	

<u>Initial Calculations</u>

$R = D\ (h_{bf} - h_f)/(H_{HP} - h_f)$

$F = D - BE + SS$

$G = F - R - HPE$

$H = G + RS$

$N = H - Z - LPE$

$Q = Z + MU$

$T = Q + IN + N - OUT - SS - RS$

$HPE + LPE + OUT + BE = MU + IN$

$W_Q = Q/Z$

$W_T = T/Z$

$W_{SS} = SS/Z$

$W_{RS} = RS/Z$

$W_{OUT} = OUT/Z$

$W_{IN} = IN/Z$

$W_D = D/Z$

$$H_e = \left[\frac{h_f - (W_Q/W_T)h_c}{1-(W_Q/W_T)}\right]$$

$$\left[\frac{1 + \dfrac{(W_{SS}/W_T)h_{SS} + (W_{RS}/W_T)h_{RS} + (W_{OUT}/W_T)h_{OUT} - (W_{IN}/W_T)h_{IN} \quad h - \dfrac{(W_D+W_{SS}+W_{RS})}{WT}}{(h_f - (W_Q/W_T)\ h_c)}}{1 + ((W_{OUT} + W_{SS} + W_{RS} - W_{IN})/(W_T - W_Q))}\right]$$

$HTRATE = [F(H_2-h_{bf})+H(H_1-H_x)+SS(h_{bf}-h_{SS})+RS(H_x-h_{rs})+BE(H_{BE}-h_{bf})]/LOAD$

$r_N = W_H(H_1-h_f)/[W_H(H_1-h_f) - H_c-h_c)]$

$r_r = [W_F(H_2-h_{bf})+W_H(H_1-H_x)+W_{SS}(h_{bf}-h_{SS})+W_{RS}(H_x-h_{rs})+W_{BE}(h_{BE}-h_{bf})]/$

$[W_F(H_2-h_{bf})+W_H(H_1-H_x)+W_{SS}(h_{bf}-h_{SS})+W_{RS}(H_x-h_{rs})+W_{BE}(H_{BE}-h_{bf})-(H_c-h_c)]$

$G_r = (r_r-1)(H_2-H_x)(H_x-h_f)/(H_1-h_f)(H_x-h_{bf})$

$C = (r_r/r_r-1)(G_r/1-G_r)$

<u>For ΔSS</u>

Assume load is constant.

$\Delta T = -\Delta SS$

$\Delta R = \Delta T(h_{bf}-h_f)/(H_{HP}-h_{bf})$

$\Delta F = \Delta R$

$$\%\Delta HR = [\Delta F(H_2 - h_{bf}) + \Delta SS(h_{bf} - h_{SS})]\ 100/(LOAD)(HTRATE)$$

For ΔRS

Assume load is constant.

$$\Delta T = -\Delta RS\ (1 - (\frac{h_f - h_c}{H_e - h_c}))(1 - (\frac{h_{bf} - h_f}{H_x - h_{bf}}))$$

$$\Delta R = \Delta T(h_{bf} - h_f)/(H_{HP} - h_{bf})$$

$$\Delta F = \Delta T + \Delta R$$

$$\Delta H = \Delta T + \Delta RS$$

$$\%\Delta HR = [\Delta F(H_2 - h_{bf}) + \Delta H(H_1 - H_x) + \Delta RS(H_x - h_{rs})]\ 100/(LOAD)(HTRATE)$$

For ΔBE

Assume load is constant.

$$\Delta T = \Delta BE/(1 - \frac{(h_{bf} - h_f)}{(H_{HP} - h_{bf})})$$

$$\Delta R = \Delta T(h_{bf} - h_f)/(H_{HP} - h_{bf})$$

$$\Delta F = \Delta T + \Delta R - \Delta BE$$

$$\%\Delta HR = [\Delta F(H_2 - h_{bf}) + \Delta BE(H_{BE}' - h_{bf})]\ 100/(LOAD+LOSS)(HTRATE)$$

For ΔHPE

Assume $\Delta F = 0$

$\Delta D = 0$

$\Delta T = 0$

$\Delta R = 0$

$\Delta H = -\Delta HPE$

$\%\Delta HR = - \left[((H_1-H_c)\ \Delta H - \Delta HPE(H_{HPE}'-H_x))/(3412.5)(LOAD+LOSS)\right]$

$[\Delta H(H_1-H_x)/(LOAD+LOSS)(HTRATE)]\ 100$

<u>For LPE</u>

Assume $\Delta F = 0$

$\Delta D = 0$

$\Delta T = 0$

$\Delta R = 0$

$\Delta H = 0$

$\Delta N = -\Delta LPE(h_f-h_c)/(H_e-h_c)$

$\%\Delta HR = [\Delta LPE(H_{LPE}'-H_c) + \Delta N(H_e-H_c)]\ 100/(3412.5)(LOAD+LOSS)$

<u>For OUT</u>

Assume $\Delta F = 0$

$\Delta D = 0$

$\Delta T = 0$

$\Delta R = 0$

$\Delta H = 0$

$$\Delta N = \Delta OUT(h_f - h_c)(1 - \frac{h_f - h_c}{H_e - h_f})/(H_e - h_c)$$

$$\%\Delta HR = [\Delta N(H_e - H_c)\ 100]/(3412.5)(LOAD+LOSS)$$

<u>For ΔIN</u>

Assume $\Delta F = 0$

$\Delta BE = Y_{BE}\ \Delta IN$

$\Delta HPE = Y_{HPE}\ \Delta IN$

$\Delta LPE = Y_{LPE}\ \Delta IN$

$\Delta OUT = Y_{OUT}\ \Delta IN$

$$\%\Delta HR = \%\Delta HR_{BE} + \%\Delta HR_{HPE} + \%\Delta HR_{LPE} + \%\Delta HR_{OUT}$$

<u>For ΔMU</u>

Assume $\Delta F = 0$

$\Delta BE = X_{BE}\ \Delta MU$

$\Delta HPE = X_{HPE}\ \Delta MU$

$$\Delta LPE = X_{LPE} \, \Delta MU$$

$$\Delta OUT = X_{OUT} \, \Delta MU$$

$$\%\Delta HR = \%\Delta HR_{BE} + \%\Delta HR_{HPE} + \%\Delta HR_{LPE} + \%\Delta HR_{OUT}$$