16 Apr 1992

A Heat Balance Program for a Nuclear Power Plant

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ABSTRACT

In a coal fired power plant, the steam leaving the boiler can reach 1000 °F and 3000 psia; this state is superheated considerably. On the other hand, a nuclear power plant is not capable of reaching such conditions without compromising reactor safety and integrity. Therefore, the steam leaving the reactor might only be a few degrees superheated, and hence the steam leaving each turbine will be wet. Since wet steam will erode turbine blades very quickly, devices must be placed between turbines to separate the steam into saturated vapor and saturated liquid. The steam is routed through the next turbine and the water is added elsewhere in the system (usually a feedwater heater, FH). This device is called a moisture separator, and my task was to add the FORTRAN code necessary to accurately model a moisture separator into an existing heat balance program.

INTRODUCTION

Background and Theory

Kam W. Li and A. Paul Priddy authored a heat balance program called AHBP [1], Advanced Heat Balance Program. Upon analyzing the program for a couple of weeks, the structure of the program became clear and the scope of the project was evident: there should not be too much code needed to add, in relation to the overall program.

The following figure gives a simplified schematic of a moisture separator (MS):

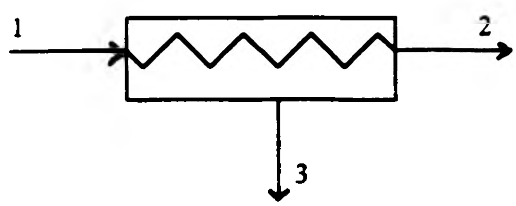

Figure 1. Simplified schematic of a MS.

State 1 is the steam entering the MS, state 2 is the saturated vapor exiting the MS, and state 3 is the saturated liquid leaving the MS. As with any component in a power plant, there is a pressure drop (DP) across the MS, so the temperature should be different leaving the MS. This temperature is the same as the saturation temperature at the decreased pressure. Moreover, since the steam leaving the MS has a quality of around 1.0, the conditions (enthalpy, entropy, and specific volume) at that point are equal to the conditions at point g on figure 2. Likewise, the conditions at point 3 are the same as point f on the same figure. This project required the addition of two Ms's. 1 between the HP and IP turbine, and one between the IP and LP turbine. The water is routed to a FH.

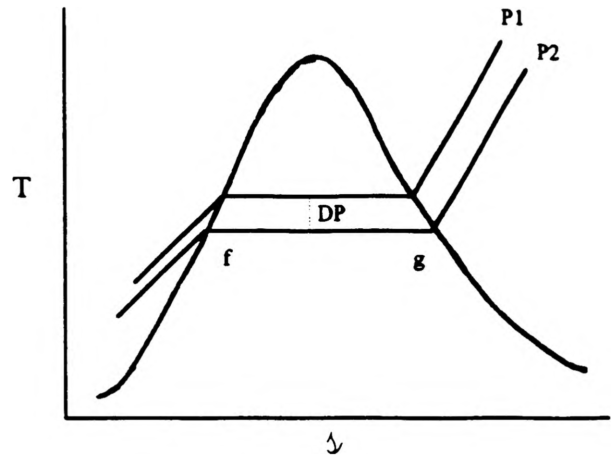

Figure 2. A simplified temperature-entropy diagram with a DP of P1-P2 for the MS.

PROGRAMMING ASSUMPTIONS

As with any generalized heat balance program, there must be some assumptions made which will limit the scope and degrees of freedom given to the user to model a particular solution. The assumptions made in the development of the MS code are:

- In fig. 2, P1 is the inlet pressure, and P2 is the outlet pressure
- The outlet temperature is, of course, the saturation temperature at P2, T2
- Point f has a quality of 0.0, and point g has a quality of 1.0
- There is no heat addition or work done on the MS control volume
- The water leaving the MS (point f) is routed to a FH, not the condenser
- The pressure of the extraction steam going to a FH is less than the pressure of the water leaving the MS going to the same FH
- There are only two MS's and they are found between the HP & IP turbines and the IP & LP turbines

Assumptions 1 and 2 are just simple applications of thermodynamic laws; however the third assumption is not. This assumption is based on the principle of an MS, and how it operates. The purpose of the MS is to separate the steam from the water, and to route the steam back into the turbine system, hence many MS's are coupled with a reheater. Additionally, this program is not concerned with how the separation is occurring but rather, what the final result is (i.e. a "black box" approach). Any heat added to the MS is neglected, and no work is assumed. For the sake of simplicity and without compromising educational value, this is a valid assumption as this code is not intended to be used as an official heat balance program for a commercial power plant.

The assumption that the water is routed only to a FH is a good assumption, also. However, in many nuclear power plants, this water is first sent to a drain cooler pump. Again, simplicity and ease of use demands that this assumption be used. The next assumption is based on the fact that, going into the MS, steam at one pressure and water at another will not mix well. There might be some form of "backwashing" into the line of lower pressure, so the water is assumed to be "flashed" to a lower pressure to match the incoming steam. Doing so changes the thermodynamic properties of the water, but simplicity and ease of use is still conserved. The reason why the water pressure is lowered is that flashing of the steam is physically harder and presents more problems than trying to flash the water. These problems and limitations are not addressed in this paper as they are of little consequence to the overall problem. Again, there must be some limitations in the program, and this was chosen to be one of them.

Finally, the program is assuming that there are only two MS's in the system, and that they fall between the HP and LP turbines and the IP and LP turbines. However, most nuclear power plants have more than two; usually four. Only two were used because educational value is not compromised and that ease of use and simplicity demanded it. If more than two MS's were used, then there would be lines routed to FH's and much more room for user input data errors. To alleviate any problems like this, only two MS's are needed. A simplified sample schematic of a steam-turbine system is shown below in fig. 3.

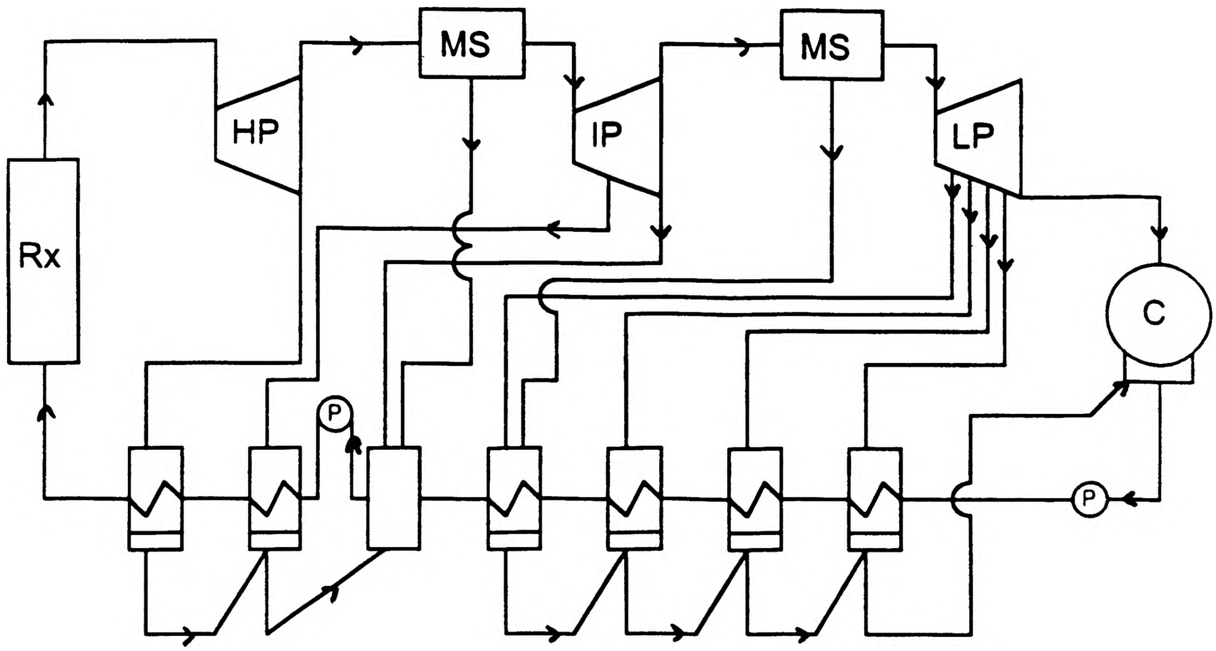

Figure 3. A sample steam-turbine system

FORTRAN CODE ADDITION

Preliminary

Since the general code is much too long, and the added code is more complex than this paper is meant to be, the actual code will not be included here. However, the process by which the code was generated will be explained. The heat balance code is separated into 11 sections. Since the program is so long, it was not feasible to search the entire code line by line for relevant parts. In response to this, all of the variables that were defined in the program were examined. In this list, the variables that looked relevant were highlighted. Using a text editor, a search throughout the entire document was performed on all of the variables. Reading the code around the points that the searches stopped at, and noting any relevant lines, the parts of the code that needed to be changed were quickly found. Upon later checking the entire program, it was concluded that these points were indeed the only places where code needed to be added. In short, the added code encompasses the following ideas:

- Changing of input data to include input for the Ms's
- Changing of read input data line in code to include MS variables
- Changing of turbine steam outlet/inlet conditions
- Changing of mass flow rate calculations
- Changing of the output data

Each of the changes necessary are described below.

The input data was the easiest, by far, to change. There was a small problem with the format specifiers, though, but the changes were:

- Delete the reheater outlet temperature
- Add two more variables detailing where the outlet water from each MS goes (i.e. which heater)
- Add the pressure drop over the MS

Where appropriate, a read line was added to the code to read in the new values for the new variables.

As can be seen from fig. 3, the inlet conditions for the IP and the LP turbines may change. Depending on whether or not the steam is saturated coming out of the HP or LP turbine will determine if a MS is needed. If a MS is not needed, then obviously the outlet conditions of one turbine will be the same as the inlet conditions for the next turbine. However, if the steam is in the saturated state, then the conditions will change making the outlet for one turbine different from the inlet of the next turbine.

First, a pressure drop is encountered in the MS. Assuming that the steam and water is going to leave the MS at the same spot, they should be at the same pressure. Since both the steam and the water is saturated, it follows that they should also be at the same temperature. It can also be concluded that the steam outlet conditions of the MS are the same as the inlet conditions of the next turbine. Additionally, referring back to fig. 2, the steam conditions are evaluated at point g, and the water conditions are evaluated at point f. Also, the conditions are evaluated at the outlet pressure, not the inlet. It is assumed that there is no heating of the steam during the process of separating the moisture from the steam.

Next, from the second law of thermodynamics [2], the energy balance around the MS (referring back to fig. 1) is:

$$W_{rev} = \sum m_i\left(h_i + \frac{V_i}{2} + gZ_i\right) - \sum m_e\left(h_e + \frac{V_e^2}{2} + gZ_e\right) \qquad (1)$$

Assuming $W_{rev} = 0$, $V_i = V_e$, and $Z_i = Z_e$, eq.1 can be rewritten as

$$m_1h_1 - m_2h_2 - m_3h_3 = 0 \qquad (2)$$

$$m_3 = m_1 - m_2 \qquad (3)$$

$$m_1h_1 - m_2h_2 - (m_1 - m_2)h_3 = 0 \qquad (4)$$

Reducing eq. 4 yields

$$m_2 = m_1\frac{h_3 - h_1}{h_3 - h_2} \qquad (5)$$

Equation four was used in the mass flow rate calculation around the MS. Now knowing m_2,and m_1, m_3 can be found using eq. 3. If a MS is used, then the mass flow rate entering the turbine is the same as m_2. If a MS is not used, then the outlet mass flow rate from one turbine is the same as the inlet mass flow rate for the next turbine. Eq. 5 was entered into the program in the appropriate place, and other minor changes that needed to be made were done so. Additionally, the same methodology was used for the mass flow rates around the FH's.

To change the output, all mentions of a reheater were changed to read the corresponding value for the appropriate MS. For example, the output that originally read "Reheater outlet temp." was changed to read "First MS outlet temp." All output was done for both MS's, and they are distinguished by either "first" or "second," as the previous example shows.

After the output was changed, all of the modifications that were thought to have been needed were made. With the exception of making a few changes to some equations for partial load case, the program was finished.

CONCLUSION

The code for the MS, along with all of the required equations, has been tested, and they seem to be correct. In addition, the installation of the various parts of the code is still being performed. The final program, with the required MS's, should be ready by the time that the next group of students require the program for a design project.

NOMENCLATURE

Throughout this paper, the following abbreviations are used:

- "MS" stands for "moisture separator"
- "FH" stands for "feedwater heater"
- "point f" refers to the point on the steam dome with a pressure, P, and quality 0.0
- "point g" refers to the point on the steam dome with a pressure, P, and quality 1.0
- "water" is the saturated liquid which will be put back into a FH
- "steam" is the saturated vapor which will be put back into the next turbine in the series
- "HP" is the high pressure turbine
- "IP" is the intermediate pressure turbine
- "LP" is the low pressure turbine

ACKNOWLEDGMENTS

I would like to thank the following people for their valued help:

- Dr. Edwards, my advisor on this project, for his help and patience with me
- Dr. Mueller for his valued comments on the subject
- The graduate office for their involvement in promoting undergraduate research

REFERENCES

1. Li, K.W. and Priddy, A.P., "Advanced Heat Balance Program."
2. Van Wylen, G.J., Fundamentals of Classical Thermodynamics, 3rd Edition, SI version, John Wiley and Sons, Inc., 1985, pg. 258.