Application of EXCEL Solver Function in Solving Steam Turbine Thermal Equations

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Abstract. Linear programming solver solves the optimal result of the formula in the target cell on the worksheet based on the constraints or limits of the values of some cells. According to "ASME PTC6-1996 Turbine Performance Test Procedures", EXCEL Linear programming solver function is applied to the calculation of the thermal equations of steam turbines; this method can be easily applied to steam turbine performance test calculation and system correction calculation.

1. Introduction
Compared to previous thermal calculation software programming, Excel removes the barriers of ordinary thermal testers to computer language. We can see that the spreadsheet form of Excel has the same hand-calculated book structure form as the table form used in manual calculation. The tabular interface form also eliminates the need to program data graphical interfaces in computer language. Moreover, the specific calculation process is straightforward and easy for other testers to read and change. In the actual calculation, the user can also use the relative reference and absolute reference function of Excel to flexibly realize the thermal performance of multiple working conditions. Therefore, Excel is an effective tool for general technicians other than programmers to understand and master the thermal calculation of steam turbines more quickly [1].

However, in the use of Excel for thermal calculations, we also began to find some shortcomings of Excel: for example, the spreadsheet can be difficult to loop or iterate over, and can't jump freely and multiple programs like other programming languages structure, etc.

Linear programming solver is an optimization program that maximizes, minimizes, or determines the value of a "target cell" by changing the value of one or several "variable cells" while satisfying certain "constraints". Through the in-depth study of the Excel function, it is found that the Solver function can avoid the "cyclic reference" and realize the iterative operation for solving the thermodynamic equations. Through examples, the specific application of the "Solution" function in thermal calculation is given.

2. Linear programming solver function
Linear programming solver is part of a set of commands, sometimes called hypothesis analysis tools. With Solver, you can find the optimal value for a formula in a cell on a worksheet. Solver adjusts the
values in a set of cells that are directly or indirectly associated with a formula in the target cell, and ultimately finds the desired result in the target cell formula. Solver finds the desired result from the target cell formula by adjusting the values in the specified changeable cells. During the creation of the model, you can apply constraints to the variable cell values in the Solver model, and the constraints can reference other cells that affect the target cell formula.

2.1. Function loading
If the Solver command or Analysis group is not available, you need to load the Solver add-in.

In the EXCEL2003 version, you can load the macro by clicking [Tools] - [Macro] - [Add Macro] and loading [Prototype Add-ons].

In the EXCEL2007 version, you can load the Solver macro by clicking the Office button, the EXCEL option - Add-ons - Go to the EXCEL add-in, and then load the [Solution Add-In].

In the EXCEL2010 version, open the "Add Options" dialog box by clicking the "File" tab, click the "Add-ons" tab on the left, and click the "Go" button on the right to open the "Add-Ins" dialog box. Select the Solver Add-Ins check box and click the OK button to bring up the Analysis option group on the Data tab of the toolbar with the Solver button.

![Add-ins dialog box](image)

Figure 1. Solver function loading.

After loading the macro, you can use EXCEL's Solver function to solve the problem.

2.2. Linear programming solver for thermal equations
When using solver to calculate the thermodynamic equation, firstly, the heat and flow multivariate homogeneous equations for each heater are listed on the manuscript paper [2-3]. Then, the left term of each equation in the thermodynamic linear equations is filled into the cells one by one [4]. Since it is a multivariate homogeneous system of equations, the right term is zero, so the constraint values of the solution are also zero. Using solver to calculate the thermodynamic equations, it is not necessary to perform the shifting of the equations in advance for the univariate solution [5-6]. The equation structure is clear (in Tools - Options - View - Window Options - Select Display Formula) to find
errors and modifications. However, Solver is similar to the univariate solution, and requires human intervention when the parameters involved change. It can also be judged by whether the constraint cell number is zero or not.

Taking a 135MW unit as an example, the relevant settings of solver are briefly introduced as follows:

1. In the Set Target box, enter a cell reference or name for the target cell, and the target cell must contain a formula. Set the target cell "Maximum", "Minimum" as needed, or type the determined value in the box.

2. In the Variable Cell box, enter a name or reference to a range of cells. Non-adjacent references are separated by commas. Variable cells must be directly or indirectly related to the target cell [7-8].

3. In the Constraint box, add a constraint: Select or enter a reference, select a constraint, and click Add to append the constraint.

4. Click “Solution” to get the result. You can choose “Retain Solution Solver” or “Restore Initial Value”, as shown in Table 1.

| Item | Parameter | Annotation |
|------|-----------|------------|
| Measuring condensate flow (t.h⁻¹) | 331290 | This is the constraint part of Solver. In the cell, enter the heat balance equation and the flow balance equation item by item, and the constraint values are all zero. |
| #1 heater heat balance equation | 0 | |
| #2 heater heat balance equation | 0 | |
| Deaerator heat balance equation | 0 | |
| Deaerator flow balance equation | 0 | |
| #1 heater inlet steam flow (t.h⁻¹) | 20328 | This is the variable cell part of Solver for placing each unknown variable. |
| #2 heater inlet steam flow (t.h⁻¹) | 40457 | |
| Deaerator inlet flow (t.h⁻¹) | 9864 | |
| Main feed water flow (t.h⁻¹) | 401939 | |

Figure 2. Thermal equations
3. Conclusion

3.1. Linear programming solver is to determine the optimal result of the formula in the target cell on the worksheet according to the constraints or limits of the values of some cells.

3.2. Using the Excel Solver tool, the iterative process of thermal calculation can be easily realized. The calculation process is clear at a glance, easy to learn and use, and convenient to adjust the calculation process and view the results.

3.3. In practical applications, EXCEL still has many skills and functions, such as matrix function, trend prediction function, etc., which deserves further application and development in thermal calculation.

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