Application of EXCEL Univariate Solution Function in Thermal Calculation

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Abstract. The univariate solution solves the problem of solving the independent variable when the dependent variable result is known. According to "ASME PTC6-1996 Turbine Performance Test Procedures", the method of applying EXCEL univariate solution function is proposed, which can be used for thermal calculation without programming. This method can be easily applied to steam turbine performance test calculation and system correction calculation.

1. Introduction
With the increasing level of office automation, Excel is widely used in engineering calculations as a powerful, well-structured and easy-to-use tabular data integrated management and analysis system. In particular, Excel has a large number of powerful and easy-to-use formulas and functions; it has the functions of drawing and regression data statistics, as well as macro and self-embedded VBA functions, etc., which is very convenient for testers to call physical parameters and compile thermal calculations program [1].

As we all know, in the thermal calculation, there are a large number of iterative operations, especially for the low-pressure cylinder exhaust expansion end point and the system correction calculation; it is necessary to cyclically reference a certain variable. In fact, Excel does not support the direct "cyclic reference" function, which brings a lot of inconvenience to our calculations.

Through the in-depth study of the Excel function, it is found that the powerful Excel provides a variety of data tools that can avoid "circular reference" and implement iterative operations, among which there is "univariate solution". In this paper, the specific application of the univariate solution in each stage of thermal calculation is introduced. Excel univariate solution can not only solve simple explicit equations, but also solve complex implicit equations. What we usually encounter in thermal calculations is explicit equations [2-3].

2. Univariate solution
The "Univariate Solver" tool is the most convenient equation solving tool. It can adjust the value of "variable cell" to make the "target cell" reach a specific value, and the final value of "variable cell" is the solution of the equation. The solution accuracy is the absolute deviation of the target value from the calculated value of the "target cell" (to meet the calculation requirements), and the number of iterations can be set in the "Recalculate Card" in the "Tools" menu "Options" command. The
numerical algorithm principle of the "univariate solving" tool is not explained in Excel, but its solution method can be used to determine the string cutting method and start the algorithm in a certain step.

2.1. Function loading
Due to the different software versions, the page setting of the single variable solution is not the same but the usage is the same. The open version of the 2003 version of the "Tools - Single Variable Solver" 2007 version of the "data - hypothesis analysis - single variable solution" 2010 version of the open mode bit is consistent with the 2007 version.

The Custom Ribbon is a new addition to the Excel 2010 release that allows users to add Excel's own commands to an existing tab or to a new tab to specify a location.

1) Place the mouse anywhere in the function area, right-click the pop-up menu and select “Customize Functional Area”.

2) In the pop-up custom ribbon menu, the right side is the tab contained in the current ribbon, the included command group, and the commands in it. You can view by tab category:
   ① Main tab is the tab that you can usually see;
   ② Tool tabs are contextual tabs that appear in specific situations, such as the Design and Format tabs in the Chart tool, which appear when the chart is selected.

3) Click the "New Tab" button below the right tab list box, then a new tab and a new group will appear in the list. Once selected, click on the "Rename" button alignment below to rename.

4) Use the "Up" and "Down" buttons on the right side of the tab list box to adjust the order of the tabs and command groups.

5) Select the newly created group, select the command you want to add in the command list on the left, and click the “Add” button in the middle to add the command to the custom group.

6) Use the "up" and "down" commands to adjust the order of the added commands.

7) Using the drop-down options above the command list box, you can quickly find the desired command by selecting a different category.

2.2. Simple example of univariate solution
A simple example is used to illustrate the univariate solution. For example, the main steam temperature should be the average of the four thermometers in the field. The temperature of the first three measuring points is already known. How many is the fourth measurement point that makes the average value exactly 535? We can create a table as shown.

Where the formula in unit E2 is "=(B2+B3+B4+B5)/4".

The specific steps for solving with a single variable are as follows:
1) Select the target cell that contains the formula for which you want to generate a specific value. For example, click cell E2.

2) Excel 2000/2003 selects the "Univariate Solve" command in the "Tools" menu; Excel 2007/2010 selects "Data" - "Assumption Analysis" - "Univariate Solver", the "single variable" will appear as shown Solve the dialog box. At this point, the cell you just selected is in the Target Cell box.

3) Enter the desired solution in the "Target value" box. For example, type "535".

4) Enter "$B5$" or "B5" in the "Variable Cell" box.

5) Click the "OK" button and the "Univariate Solving Status" dialog box appears as shown. In this example, the result 533.93 is displayed in cell B5. To keep this value, click the OK button in the Single Variable Solving Status dialog.

By default, the Univariate Solve command stops the calculation when it performs 100 solves with a specified target value within 0.001. If you do not need such high precision, you can select the "Options" command in the "Tools" menu and click "Recalculate" to modify the values in the "Maximum Times" and "Maximum Errors" boxes.
2.3. Univariate solution for the main feed water flow

In the calculation of heat balance and flow balance, the thermodynamic equation can usually be expressed as a multivariate linear equation system. The method of solving the simultaneous equation is time consuming, especially if there are multiple high pressure heaters and a large number of test points involved in the calculation. An alternative approach is to use an iterative solution. In the Excel function, we can use the built-in function functions such as univariate solution, plan solving function and matrix solution to perform iterative calculation of the thermal equation. Take the univariate solution as an example: This method requires a rough initial flow rate of the final feedwater (in the case of a 135 MW unit, 400,000 kg/h can be filled in the table first). It is not necessary to accurately determine the initial value, because even if there is a large error, the error will be reduced within a sufficient accuracy range in the subsequent iteration [4].

With this calculation method, when the calculation step is listed in the table, the extraction flow rates of the high-pressure heaters and the deaerator of each stage are determined one by one from the assumed feed water flow rate according to the extraction pressure from high to low. These flows are then flow balanced to resolve the condensate flow into the deaerator. In the target cell, the difference between the condensed water flow test value and the calculated value is set to zero, and the variable cell is assumed to be the main feed water flow. Excel will automatically iterate until the target value is zero. See Table 1:

| Item                                           | Parameter       |
|------------------------------------------------|-----------------|
| Condensate flow test value (t.h⁻¹)             | 331290          |
| Main feed water flow assumption (t.h⁻¹)        | 401939          |
| #1High plus steam flow calculation value (t.h⁻¹)| 20328           |
| #2High plus steam flow calculation value (t.h⁻¹)| 40457           |
| Deaerator inlet flow calculation value (t.h⁻¹)  | 9864            |
| Condensate flow calculation (t.h⁻¹)             | 331290          |
| Condensate flow deviation (t.h⁻¹)              | 0.00            |

Although the univariate solution can easily implement iterative calculations, it is worth noting that when any of the calculation parameters involved in the univariate solution changes, it needs to be manually recalculated. We can easily judge whether the value of the target cell tends to zero.

2.4. Univariate solution for low pressure cylinder expansion line end point enthalpy

The iterative calculation of the turbine expansion end point enthalpy is similar to the iterative calculation of the feed water flow in 2.1 cases. First, assume the enthalpy of the expansion end point...
enthalpy, and calculate the corresponding iteration amount by energy balance and flow balance. The target cell is written with the "expansion end point enthalpy calculated value - expansion end point enthalpy assumed value", so that its target value is zero. Due to space limitations, the calculation of the final stage of the low-pressure cylinder extraction is not listed. See Table 3[5]:

Table 2. Low pressure cylinder expansion line end point enthalpy solution process.

| Item                                           | Parameter |
|------------------------------------------------|-----------|
| Assumed value of the expansion end point enthalpy (kJ.kg⁻¹) | 2346.6    |
| Useful energy threshold enthalpy (kJ.kg⁻¹)            | 2377.6    |
| Exhaust specific volume corresponds to ELEP (m³.kg⁻¹)  | 26.2      |
| Single cylinder volume flow (m³.s⁻¹)                  | 994.2     |
| Residual loss (kJ.kg⁻¹)                              | 30.9      |
| Calculated value of the expansion end point enthalpy (kJ.kg⁻¹) | 2346.7    |
| Expansion end point enthalpy deviation (kJ.kg⁻¹)      | 0.0       |

2.5. Determination of the re-heat steam enthalpy after system correction
For reheat steam turbines, there are two calculations for the reheat steam enthalpy corrected in ASMEPTC6-1996: (1) The reheat steam temperature and enthalpy correction value can be obtained by interpolation or extrapolation from the test expansion process line according to the new pressure value at the reheat shut-off valve; (2) The corrected reheat enthalpy can be read from the new expansion line. This new expansion line is based on the new reheat pressure at the reheat shutoff valve, the test reheat temperature, and the efficiency of the test turbine. For the second calculation method, it can be solved sequentially according to the conventional calculation steps. For the first method, the univariate solution can be obtained by correcting the hot steam pressure, the efficiency of the test cylinder, and the test end point parameters of the low pressure cylinder. The corrected extraction enthalpy values at other levels can be similarly solved, and will not be described here.

3. Conclusion

3.1. In Office Excel, the value of the referenced cell is continuously adjusted according to the target value provided, and the value of the variable is determined until the target value of the required formula is reached.

3.2. Using the Excel single-variable solving 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 it is convenient to adjust the calculation process and view the results.

References
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