Running a hydronic balancing simulator in Microsoft Excel

Rularea unui simulator de echilibrare hidrică în Microsoft Excel

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Abstract. *Providing the required indoor comfort at minimal operating costs is the main objective of every HVAC system. However, despite the fact that in theory, each design effort promises to deliver the design flow at each heating or cooling unit, in reality this is not happening too often. The role of balancing is to obtain the design flow at each terminal unit, by installing some specialized valves and applying a coherent procedure of setting and adjustment. This paper presents a simple hydronic balancing simulator, implemented in a Microsoft Excel spreadsheet. The model uses static STAD balancing valves, provided by the Swedish manufacturer Tour Andersson. The main purpose of the simulator is to obtain a learning tool for students or young engineers, allowing them to observe and understand the circuits interactions when running balancing procedures.*

Key words: hydronic balancing, simulator, Excel, balancing valves, Tour Andersson

1. Introduction

Providing the required indoor comfort at minimal operating costs is the main objective of every HVAC system. However, despite the fact that in theory, each design effort promises to deliver the design flow at each heating or cooling unit, in reality this is not happening too often. If no balancing measures are taken, the circuits situated closer to the pump will be usually favoured, by having overflows, at the expense of other circuits that will experience underflows. The purpose of balancing is to obtain the design flow at each terminal unit, by installing some specialized valves and applying a coherent procedure of setting and adjustment: while these balancing valves are chosen and preset at design time, an on-site adjustment is always necessary.

Therefore, the balancing procedure is extremely important and needs to be carefully carried out.

This paper presents a simple hydronic balancing simulator, implemented in a Microsoft Excel spreadsheet. The model uses static STAD balancing valves, provided by the Swedish manufacturer Tour Andersson. This choice was natural, since our Hydraulics Laboratory is fitted with such valves and we use them for many years.

The idea of making software hydronic simulators is not new. Usually, balancing valve producers have such tools for training and design purposes. But these proprietary software is either not freely available or it is limited to the producers' specific valves ([1], [2]). Therefore, our goal was to create an in-house simple simulator that would become a valuable learning tool for students or young engineers, allowing them to observe and understand the circuits interactions when running balancing procedures.

2. Basic hydronic balancing theory

According to [3], one balancing valve positioned near each terminal unit is sufficient to create the correct distribution of flows in the system. But when the flow is adjusted in one valve, pressure drops also change in pipes, valves and accessories, thus modifying the differential pressure across other balancing valves. These interactions among circuits are unavoidable, therefore without having a coherent balancing procedure, there is a danger to never obtain the required flows, even after a long series of tedious and repeated maneuvers and corrections. To avoid this danger, it is required to divide the plant into modules. A module contains several terminal units connected in parallel (each having its own balancing valve), controlled by a common balancing valve (Figure 1).
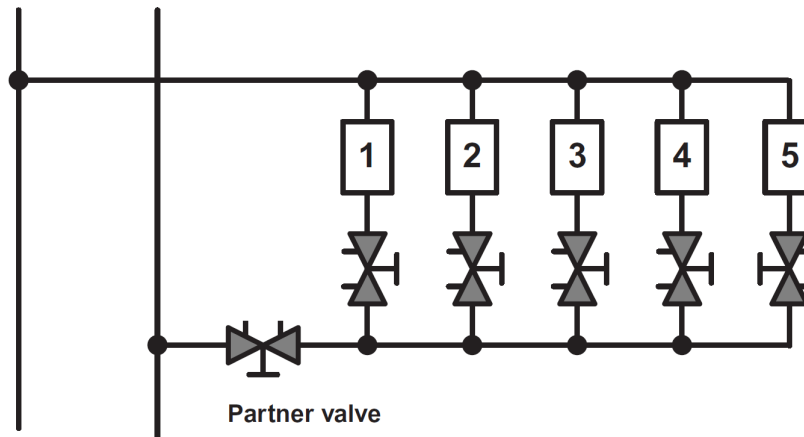

Fig. 1. A module example with conventional valve naming [3]

This common valve is named partner valve and its role is to balance all units of a module against each other, by compensating the disturbances created by each flow adjustment [3]. This is possible because the so-called law of proportionality applies: an external disturbance affects the flows in all terminal units in the same proportion.

Therefore, adjustments will start from the circuit furthest away from the partner valve (called reference valve, e.g. valve no. 5 in Figure 1). Then terminal 4 will be

adjusted, disturbing terminal 5, until 4 and 5 are balanced with each other in the same flow ratio (usually >1). Thus, 4 and 5 will respond in the same proportion when an external disturbance to them will arise. So, when terminal 3 will be adjusted, it will disturb 4 and 5 to the same extent, yet that adjustment must allow a common flow ratio for all the valves 3, 4 and 5. It means that these valves are balanced with each other. The procedure continues until the entire module is balanced at a certain flow ratio. In the end, the overflow will be compensated (for the entire module) from the partner valve.

3. Using Microsoft Excel as a framework for the hydronic simulator

In order to simulate the previously described procedure, we needed to choose some balancing valves for the model and a software framework to implement the equations. The choice for the balancing valves was rather easy, as we worked for many years in our Hydraulics Laboratory with static STAD valves, provided by the Swedish manufacturer Tour Andersson. These STAD valves are characterized by the Kv factor/coefficient, which increases with the valve opening (Table 1).

Table 1

Kv values for PN-25 STAD valves [4]

Turns	DN 10	DN 15	DN 20	DN 25	DN 32	DN 40	DN 50
0.5	-	0.136	0.533	0.599	1.19	1.89	2.62
1	0.091	0.226	0.781	1.03	2.09	3.40	4.10
1.5	0.134	0.347	1.22	2.13	3.36	4.74	6.76
2	0.264	0.618	1.95	3.64	5.22	6.25	11.4
2.5	0.461	0.931	2.71	5.26	7.77	9.16	15.8
3	0.799	1.46	3.71	6.65	9.82	12.8	21.5
3.5	1.22	2.07	4.51	7.79	11.9	16.2	27.0
4	1.36	2.56	5.39	8.59	14.2	19.3	32.3

The Kv factor depends on the differential pressure and flow, as shown in Eq. 1:

$$Kv = 0.01 \frac{q}{\sqrt{\Delta p}} \quad [\text{-}] \qquad (1)$$

where:
Kv   - flow factor [-],
Q   - flow [l/h],
Δp   - differential pressure [kPa]

The software framework chosen for implementing the simulator was an Excel spreadsheet, because it offers both an easy graphical interface and a nice programming environment for writing the equations.

The prototype of the simulator had to be simple. At this stage it has only one module with four terminal units (Figure 2). In order to simplify the graphical interface, only the return pipes were represented, because traditionally the STAD valves are placed there. Each terminal unit is characterized by a design flow and a pressure drop

(yellow cells). Pump parameters are known and also pressure drops on the riser are known (yellow cells). For simplicity, we assumed that horizontal pipes have negligible head losses. Each STAD is clearly visible as a small image, accompanied by a SpinButton showing its setting (with a precision of one hundredth of a turn). Underneath each valve, its differential pressure is shown (Figure 2). Also, each STAD can be quickly shut off using a CheckButton, allowing us to simulate a zero-flow situation.
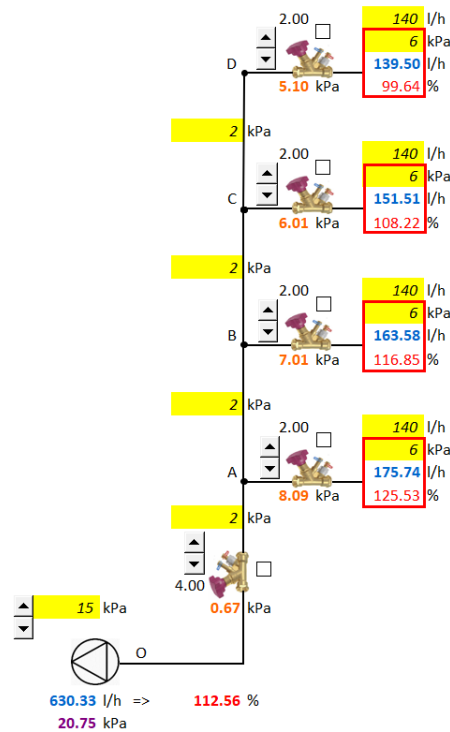

Fig. 2. The hydronic simulator interface during an exercice

The valve opening had to be related to its Kv, therefore a function Kv=f(turns) was implemented for each STAD valve of the module. This function was written in the VBA programming language (Visual Basic for Applications), using a linear interpolation algorithm based on the values from Table 1. For simplicity, only DN 15 STAD valves were used.

Then, classical hydraulics equations were written (such as flow conservation in each node and Bernoulli's equation) following a special approach given by [5] and taking into account each series and parallel configuration. It should be noted that the novelty of this approach consists of thinking that every element of the module has a Kv, not only the valves, but also the pipes and the terminal units.

As *modus operandi*, the simulator is mouse-driven: by (left) clicking on the SpinButton of a balancing valve, the number of turns is modified, this changes Kv, then the flow and differential pressure are modified, with influence on all other circuits...

This dynamic interactivity is the major advantage of the simulator. In real-life hydronic circuits, several expensive measurement tools (e.g. TA Scope) would be necessary to observe and understand the phenomenon.

4. Working with the hydronic simulator – applying the proportional method

In a specific dataset configuration used as an exercise, the aim of running the simulator is to obtain the design flow on each terminal unit, by adjusting each balancing valve opening position with the mouse. The recommended precision for obtaining the flows by Tour Andersson is ±10%.

In this example, we started with all the balancing valves with a presetting of 2 turns (Figure 2), i.e. the middle opening, and we applied the proportional method for balancing the module. This presetting of 2 turns may also be considered as a rule of thumb for all the valves of a module in order to ensure enough differential pressure (3kPa for the TA Scope instrument in real-life measurements). Anyway, our simulator makes the calculations even if the pressure drop in the balancing valves is under that threshold of 3 kPa. But if we want to simulate exactly the real-world measuring device and also to optimize our module, we need to impose 3 kPa at design flow on the most unfavoured circuit and find the corresponding valve setting.

But let's assume first that we are not interested in any optimization. The target of the exercice is to obtain 140 l/h in each terminal unit. The partner valve is fully open (4 turns).

The most unfavoured circuit is no. 4, because it gives the smallest flow ratio - lambda (99.64%). So we adjust the balancing valve no. 3 until its flow ratio is the same as for the valve no. 4. The common flow ratio will be very close to 101%. This gives a setting of 1.83 for the valve no. 3. Now, these two valves are balanced to one another and will react in the same proportion to external disturbances. Then, valve no. 2 will be adjusted in order to obtain the same flow ratio as valves no. 3 and 4. The common flow ratio for these three valves will be very close to 102.5%. This gives a setting of 1.71 for the valve no. 2. Finally, valve no. 1 will be adjusted in order to obtain the same flow ratio as the other three valves. The common flow ratio for all four valves will be very close to 104.3%. This gives a setting of 1.63 for the valve no. 1. In the end, in order to obtain the design flow for each valve (i.e. to bring the flow ratio close to 1), the overflow will be taken away from the module by closing the partner valve to a new position, 2.74 (Figure 3a).

The balancing procedure succeeded to obtain the desired flows, but the solution is not optimized, because the index valve (no. 4) has too much differential pressure (anything above 3 kPa is considered a waste of energy).

In the next stage, we can try to optimize the solution, by imposing 140 l/h and 3 kPa on the valve situated on the most unfavoured circuit, i.e. the circuit no. 4. The setting of the valve no. 4 is determined by using some Tour Andersson specialized software (HyTools or HySelect) or a nomograph. Since HyTools is freely available on the Android platform and it is very easy to use on a smartphone, we definitely

recommend it. So, from HyTools we found that the setting for the valve no. 4 must be 2.33 (instead of 2.00 - the initial guessed/customary non-optimized presetting).

Repeating the whole proportional procedure again for the rest of the valves, we obtained the optimized solution for the entire module, all flows being very close to 140 l/h and the index valve having a differential pressure of about 3 kPa. Not exactly 3kPa, but close enough, due to precision issues generated by the linear interpolation assumption.

If we compare the two solutions, it can be noticed that for the optimized method, each balancing valve is more opened (having less pressure losses), while the partner valve is more closed than in the non-optimized method (Figure 3b).

For the optimized solution, the partner valve is closed to 2.37 turns and its differential pressure, 4.84 kPa, actually reveals the excess pressure at the pump. Thus, the pumping costs can be minimized, i.e. the pump can operate at a lower head [3].
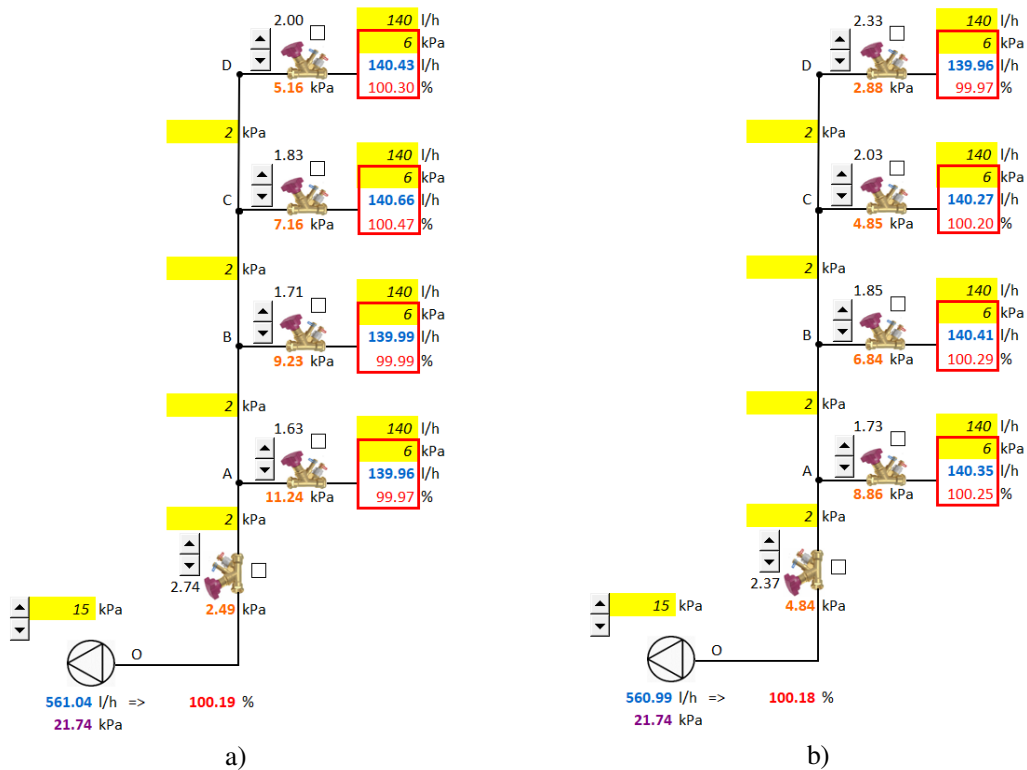

Fig. 3. The module is finally balanced: a) non-optimally b) optimally

5. Conclusions

For the moment, our hydronic simulator has only one module with four circuits, but it gives the expected results and fulfills its purpose. We are using it as a learning tool for students and young engineers, in their quest to observe and understand the circuits interactions when running balancing procedures. It is a project under development and it will be certainly improved in the future: we expect to have 4

connected modules with a total number of 16 terminal units, using different types of valves, different terminal units with different design flows and different pressure losses.

References

[1] *** Hydronics Design Studio, https://www.hydronicpros.com/downloads/index.php?id=21, accessed October 2022

[2] *** Belimo Hydronic Simulator, https://www.belimo.com/us/en_US/support-am/sizing-and-selection-tools/sizing-selection-tools.html#belimo-hydronic-simulator, accessed October 2022

[3] *R. Petitjean*, „Total hydronic balancing: a handbook for design and troubleshooting of hydronic HVAC systems", Tour & Andersson Hydronics AB, Ljung, Sweden, 1994

[4] *** STAD_PN25_EN_low.pdf, https://www.imi-hydronic.com/product/stad-pn-25, accessed October 2022

[5] *P. Fridmann*, „Equilibrage thermohydraulique des installations de chauffage", Les éditions parisiennes (EDIPA), Paris, 1989