The combined valve design improvement and analysis of the regulatory characteristics

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Abstract— **The combined valve is used as an executive element in regulation circuits for temperature regulation in installations for district heating systems, cooling, air conditioning, preparation of domestic hot water, etc. This paper presents the construction and characteristics of the combined valve used in hot water heating systems, as well as a proposal to design improvement. The results of testing the regulatory characteristics of the improved combined valve are also presented. Based on the obtained results, it can be concluded that the improved combined valve has regulatory characteristics equal to and better than those declared and that its overall quality corresponds to valves of the same type from other world manufacturers. Monitoring the operation of the combined valve during exploitation should confirm the steps taken to design improvement.**

Keywords- District heating systems, combined valve, regulatory characteristics, design improvement

I. INTRODUCTION

In district heating systems, the regulatory valve has the role of releasing a certain amount of heat that is extracted from the district heating system by controlling the fluid flow through the heating substation, depending on the building's heat needs. The method of designing the automatic control system is particularly important for the reliable behavior of the system during exploitation, as well as the creation of conditions for energy saving [1].

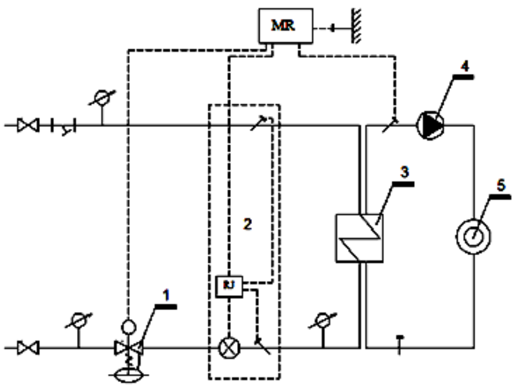

Figure 1. Scheme of the heat transfer station with indirect connection of the installation for district heating system

Regulation of heat energy delivery is qualitative-quantitative and is carried out by sliding the temperature of the water in the supply line of the hot water network when the temperature of the outside air changes and the flow rate changes [3]. The sliding of the water temperature in the supply water of the hot water network is carried out in the heating plant.

The change of flow is done in the heat transfer station and for this a combination valve is used as an executive element. Limiting the maximum flow is also done by the combined valve. The microprocessor regulator is used to regulate the temperature of the water in the supply line of the installation for district heating as a function of the change in the temperature of the outside air. The heat meter measures the total heat energy delivered to consumers [4].

II. APPLICATION AND IMPROVED CONSTRUCTION OF THE COMBINED VALVE

The combined valve is used as an executive element in regulation circuits for temperature regulation in installations for district heating systems, cooling, air conditioning, preparation of domestic hot water, etc. The combined valve presents the executive element in two regulatory circuits:

1. The regulation circuit for water temperature regulation in the supply line of the installation for district heating and flow limitation and

2. The regulating circuit for temperature regulation and flow limitation (PTV).

The combined valve consists of two control valves: a control valve with electric drive (RV) for temperature regulation and a differential pressure regulator (RDP) for flow limitation, which are connected in series. Both control valves are placed in one housing and represent a whole combined valve presented on Figure 2 [5].

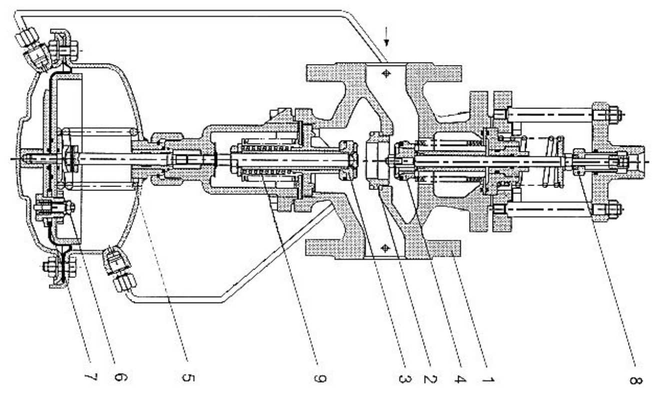

Figure 2. Cross section of a combined valve: 1. Valve housing, 2. Valve seat, 3,4. Valve mushroom, 5. Actuator housing, 6. Overpressure protection, 7. Moving diaphragm, 8. Adjusting nut, 9. Balance spring

The differential pressure regulator maintains a constant differential pressure value at RV (Δp_{rv}) and provides mechanical flow limitation. The most common values of the differential pressure on the RV, which is kept constant, are 0.2 or 0.5 bar. The total pressure drop of the combined valve is equal to the sum of the pressure drops on the control valve with electric drive and the differential pressure regulator.

When the differential pressure in the TPS increases (Δp_{ps}), the flow also increases. Due to the increase in flow, the differential pressure on the RV also increases. Then the RDP is closed, the flow in the TPS is reduced to the set limit value, and the differential pressure on the RV is reduced to the declared value (0.2 or 0.5 bar). In this way, the function of mechanical flow limitation is realized.

The temperature regulation function is achieved by opening and closing the RV valve, i.e., by increasing or decreasing the flow of the heat carrier (boiling or hot water produced in the heating plant). The flow in the TPS increases up to the set limit value. When the flow reaches the set limit value, then the combined valve works as a flow limiter. The limit flow is set based on the flow measurement registered on the heat meter or by using the diagram of the flow change in the RV stroke change function.

The working fluid that should flow through the combined valve is circulating water. Water quality is defined according to VDI 2035 [6]. The purpose of this guideline is to avoid damage due to scale formation when heating water in water heating systems.

Factors that influence the formation of deposits are water quality, supplementing the system with an additional amount of water, wall temperatures on the surfaces where heat transfer takes place, and working conditions. As the temperature rises, so does the risk of deposits forming.

Problems in the exploitation of combined valves occur in district heating systems in certain areas, which manifest as leakage on the upper part of the valve, after a short time of valve operation. Visible corrosion was observed on the upper assemblies, even on the brass parts, and deposits were also observed [7].

By analyzing the quality of the brass from which the parts on the old assembly were produced, it was concluded that the brass that was used during machining was of poor quality, which led to the occurrence of dezincification of brass, which is the selective removal of zinc from brass alloys, leaving a porous residue rich in metallic copper with poor mechanical strength. Dezincification can be prevented by appropriate material selection. It is recommended to use brass with at least 85% copper. It is important to ensure a clean surface, by maintaining adequate flow and periodic cleaning of the surface. In addition, appropriate water treatment is required to prevent deposition of corrosion products, biological contamination or sludge that leads to surface damage.

In order to solve this problem, brass CW602N, which is a standard alloy resistant to dezincification, was adopted as the material for making parts of the combined valve [6].

When creating a new construction of a combined valve, the task is to eliminate defects with the regulatory characteristics of the valve and to maintain the maximum declared flow for that valve. Special attention in design improvement was paid to the sealing elements and the valve housing material and design.

Analysis of the cross-section of the upper assembly concluded that the brass part can only come into contact with water if its sealing elements are not functioning. For this reason, the arrangement of seals in the upper valve assembly has been improved. It is especially necessary to adopt seals that are declared for high temperatures, and at the same time for circulating hot water. The recommended material for making these seals is ethylene propylene monomer (EPDM) material intended for high temperatures. Additional sealing rings are made of Teflon (PTFE), which is a non-elastomeric material that has the function of a static and dynamic secondary seal. It is usually produced in such a way that it is allowed to stretch no more than 10% of the initial size of the outer diameter of the ring, which conditions the use of split rings for smaller diameters.

The lower assembly of the combination valve is sensitive to the accumulation of impurities, which is why the valve can remain stuck in one position and lead to flow disturbances. For this reason, during the improvement, another wiper made of EPDM was added, so that there are two wipers in the differential pressure regulator, which, in addition to having the role of a seal, also clean the shaft in both directions while it moves axially [8].

III. Methodology of Testing the Regulatory Characteristics of the Improved Combined Valve

The test station for testing the regulatory characteristics of the improved combined valve consists of an open feed tank, a pump unit, a flow measurement section, a test line and a group for pressure regulation as presented on Figure 3.

Pumps (2) collect water from the feed tank (1) and push it into the installation. The water first passes through the flow measurement section (3). Using one of the flow meters, the flow of water going into the test line (4) is measured. One flow meter has a nominal diameter of DN100, and the other has a nominal diameter of DN40. The maximum flow of water through the installation is ≈ 150m^3/h, and the minimum flow is ≈ 2m^3/h. The minimum flow in the installation can be lower than 2m^3/h for a short time. The flow of cold water is realized by means of three pumps with electric motor drive which are connected in parallel.

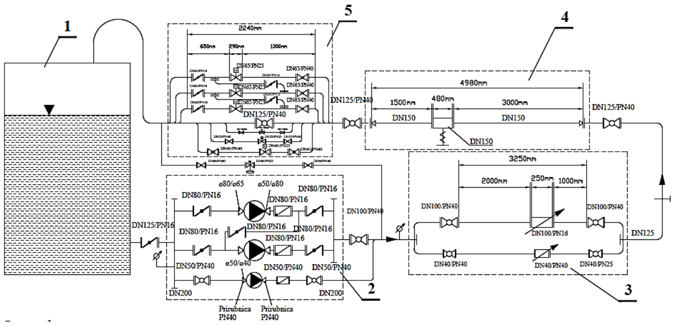

Figure 3. Scheme of the test station: 1. Feed tank, 2. Pump unit, 3. Flow measurement group, 4. Test line, 5. Pressure regulation group

The test line consists of upstream and downstream piping with a nominal diameter equal to the nominal diameter of the control valve being tested. The tested valve is mounted between the upstream and downstream pipelines. The length of the upstream pipeline is at least 20 diameters of the control valve (Lu_{min}=20 DN). The length of the downstream pipeline is at least 10 diameters of the tested valve (Li_{min}=10 DN). The pipelines of the test line are connected to the test installation using flanges.

Water from the test line goes to the group for pressure regulation. The pressure regulation group consists of 4 parallel-connected regulation valves with electric motor drive. Three valves have a nominal diameter of DN65, and the fourth valve has a nominal diameter of DN40. Regulating valves are used to regulate the differential pressure that needs to be provided in front of and behind the tested valve. The regulation valves enable the adjustment of the differential pressure on the test valve in the range from Δp_{min}=5 mVs to Δp_{max}=70 mVS when the flow rate changes from 2 to 150 m^3/h. With the sequential connection of two pumps of higher capacity and three regulating valves DN65, it is possible to set the maximum differential pressure on the test valve from Δp_{max}≈120 – 160 mVS when the flow rate changes from 20 to 70 m^3/h.

The collector on the pressure side of the circulation pumps is connected to the water distributor at the outlet of the pressure regulation group by a short connection with a nominal diameter of DN65. The short connection serves to regulate the pressure at the entrance to the test line.

On the test line and around the tested sample, there are measuring points where the following measurements are performed: flow measurement (Q), inlet pressure measurement (p_1), outlet pressure measurement (p_3), differential pressure measurement on the control valve (Δp_{1-2}), measuring the differential pressure on the differential pressure regulator (Δp_{1-3}), stroke of the regulating valve (h). During the measurement, it is necessary to record the following data: frequency of pump operation and water temperature.

The described measurements were used to determine the following regulatory characteristics:

1. Flow coefficient of the regulating valve;
2. Nominal flow coefficient of the control valve
3. Flow coefficient of differential pressure regulator;
4. Nominal flow coefficient of the differential pressure regulator;
5. Relative flow coefficient i
6. Flow characteristics.

IV. RESULTS AND DISCUSSION

The listed measured regulatory characteristics are measured for relative strokes in the range of 10% to 100%. Based on the measured values, the differential pressure RDP (Δp_{2-3}) and flow coefficients for RV and RDP were calculated. The flow coefficient and relative flow coefficient were determined using the formulas:

$$K_v = \frac{V}{\sqrt{\Delta p}} \qquad \Phi = \frac{k_v}{k_{vs}} \qquad (1)$$

Where: K_v [m^3/h] - flow coefficient, V [m^3/h] - flow, Δp [bar] - differential pressure.

The mean values of RV and K_v flow (V_{sr}), RV flow coefficient (k_v) and relative RV flow coefficient (Φ) as a function of relative stroke change in the range from 11% to 100% are shown in Table 1 [9].

TABLE I. MEASUREMENT RESULTS OF FLOW VALUES, FLOW COEFFICIENT AND RELATIVE FLOW COEFFICIENT IN THE RANGE FROM 11% TO 100%

h [%]	V_{sr} [m^3/h]	K_v [m^3/h]	Φ_{iz} [/]
11.1	0.81	1.46	0.0925
22.2	0.93	1.67	0.1060
33.3	1.06	1.94	0.1232
44.4	1.27	2.37	0.1502
55.6	1.75	3.40	0.2152
66.7	2.45	4.95	0.3133
77.8	3.92	8.06	0.5104
88.9	5.69	11.75	0.7445
100.0	7.59	15.78	1.0000

The diagram of the flow characteristic and the ideal natural flow characteristic of the RV in the range of relative stroke change in the range of 11% to 100% are shown on Figure 4. The flow characteristic shows a very good match with the equal percentage ideal natural characteristic. A slight deviation exists in the range of relative stroke change from 11% to 40%.

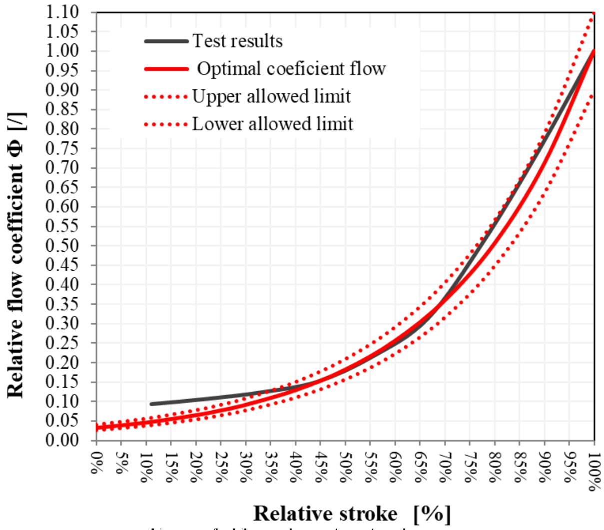

Figure 4. Flow characteristic diagram

Based on the obtained results, it can be concluded that the nominal coefficient of flow RV is K_{vs}= 16 m^3/h and is equal to the declared value (mean value K_v=15.8 m^3/h for h=100%, nominal flow coefficient RDP is K_{vs} = 16 m^3/h and is higher than the declared value of 12.5 m^3/h (K_v=15.54 m^3/h for h=100 % and $\Delta p_{1\text{-}3}$=0.47 bar, that the deviation of the measured flow is in the range of -3.4% to +3.1%.

Figures 5 and 6 show the flow rate change diagrams when the differential pressure K_v changes ($\Delta p_{1\text{-}3}$) for relative strokes in the range from 11% to 100%.

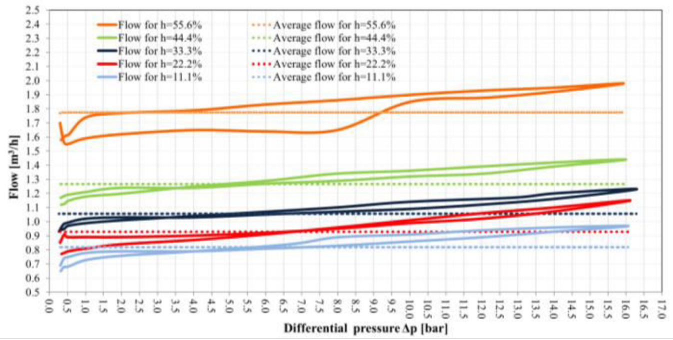

Figure 5. Flow diagram for h=11.1% do 55.6%

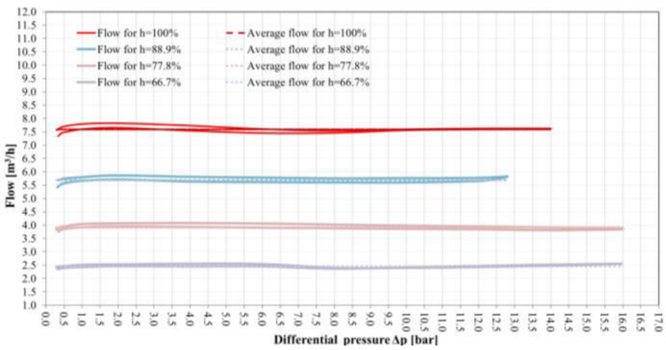

Figure 6. Flow diagram for h=66.7% do h=100%

The maximum flow of the combined valve is higher than declared, while the minimum flow is lower than declared. The flow characteristic is the same percentage and corresponds to the declared one.

The deviation of the maximum flow is within the permitted limits for h=100%, and the same applies to the measured flows on other relative strokes.

The flow is constant for all values of the relative stroke in the differential pressure range of the combined valve from 0.47 bar to 16 bar.

The mean value of differential pressure $\Delta p_{1\text{-}2}$ = 0.232 bar is approximately equal to the declared value.

The rated stroke of the RV is equal to the declared value.

V. CONCLUSION

Rapid, sudden and large changes in PTV demand that PTV temperature regulation equipment meet high technical requirements. That is why it is extremely important that designers of installations for the preparation of PTV, when choosing regulation equipment, adhere to the requirements and recommendations of the manufacturers.

Constructional improvements in the sealing of the combination valve enable the prevention of leakage on the seals, which leads to an increase in operational safety and an increase in service life. Monitoring the operation of the combined valve during exploitation should confirm the steps taken to improve sealing.

Based on the obtained results, it can be concluded that the improved combined valve has regulatory characteristics equal to and better than those declared and that its overall quality corresponds to valves of the same type from other world manufacturers.

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