Applied Energy 155 (2015) 421–433

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

A proposal for a new methodology to determine inner authority of the control valve in the heating system

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HIGHLIGHTS

- A proposal of a new methodology to determine the inner authority of the control valve was presented.
- Exemplary calculations were performed for control valves using in heating and domestic hot water systems.
- The results were compared with results obtained from the alternative methodology.
- The proposed methodology returns results consistent with experimental data.

ARTICLE INFO

Article history:
Received 18 December 2014
Received in revised form 9 May 2015
Accepted 2 June 2015
Available online 24 June 2015

Keywords:
Control valve
Valve authority
Heating system
Hydraulic balancing

ABSTRACT

This paper presents and discusses a proposal for a new methodology to determine the control valve inner authority, which is one of the basic parameters deciding about the control valve regulation capacity. Experimental verification is also carried out for selected control valves using the proposed concept and the alternative analytical methodology presented in recent years by Pyrkov. A comparison of the results is presented. It is shown that the proposed methodology gives results consistent with experimental data, whereas the results obtained using previously known methods can be substantially different from them.

1. Introduction

The optimization of the operation of heating systems in residential buildings and the reduction in energy consumption are important issues frequently discussed in literature, cf. [1–11].

Control valves, including the radiator control and balancing valves, are among the most important elements of heating fittings. Despite the very high diversity in terms of design solutions, they all have to do the following tasks:

- Equalize the pressure drop from the circuit hydraulic resistance with active pressure in a given part of the system for defined conditions.
- Ensure the design flow rates of the medium, according to the results of the system thermal and hydraulic balancing process.
- Allow, if necessary, *ad hoc* (current) automatic adjustments in the settings of the radiator valves, i.e. make it possible to set the temperature in a room by quantitative changes in the thermal power of the radiator. These requirements can be satisfied by the following elements co-operating with the control valve:
  - Thermostatic heads, acting directly.
  - Electronic and electric heads.
  - Heads with thermal actuators.

The radiator control valves, in combination with the most commonly used thermostatic heads, are important elements of the heating system control process. They have to ensure and maintain the right temperature in the heated area, which is one of the basic components of thermal comfort. So that the installation can operate in a stable and smooth manner in a wide range of loads, the valves should be characterized by a sufficiently high *authority*. The value of this parameter, according to commonly accepted requirements, should be in the range from 0.3 to 0.7 [12–19].

Too low values, especially with a linear initial characteristic of the regulating element of the valve (valve plug), will involve unstable work of the thermoregulator (control valve + head), which in

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http://dx.doi.org/10.1016/j.apenergy.2015.06.014
0306-2619/

Nomenclature

a_w	inner authority of the valve, –
$a_{w,100}$	inner authority of the valve closing part fully opened, –
$a_{w,\mathrm{I},\min}$	the minimum value of the throttling element authority (for full opening) for a valve with two adjustable sections of the fluid flow, –
$a_{w,\max}$	the maximum value of the valve closing element inner authority, –
$a_{w,\min}$	the minimum value of the valve closing element inner authority, –
$a_{w,x}$	the valve closing element inner authority for a given pre-setting, –
c	equal-percentage ratio of the initial characteristic of the closing element, %
h_{100}	the position of the closing/throttling element corresponding to full opening, mm, m
h_x	the position of the closing/throttling element corresponding to a partial opening, mm, m
$k_{v,reg,100}$	the flow factor of a fully opened current-regulation element of the valve, $m^3/(h\ bar^{0,5})$, m^3/h
$k_{v,reg,x}$	the flow factor of the current-regulation element for a partial opening, corresponding to a given pre-setting, $m^3/(h\ bar^{0,5})$, m^3/h
$k_{v,x}$	the flow factor of a valve for a partial opening, corresponding to a given pre-setting, or an intermediate position of the closing element of the valve, $m^3/(h\ bar^{0,5})$, m^3/h
k_{v100}	the flow factor for a fully opened valve, $m^3/(h\ bar^{0,5})$, m^3/h
$[k_{v,x}]_{Xp}$	the flow factor of a thermostatic valve for a given pre-setting for the closing element lift corresponding to a given range of X_p, m^3/h, $m^3/(h\ bar^{0,5})$
$[k_{v100}]_{ni}$	the flow factor of a thermostatic, or a double-regulation manual valve for a given pre-setting of the throttling element and the maximum lift of the closing element, m^3/h, $m^3/(h\ bar^{0,5})$
n_i	the *i*th number of the valve pre-setting, –
$n_{\max}$	the maximum value of the valve pre-setting, –
$r_{I,i}$	hydraulic resistance of the valve throttling element for the position limited by the *i*th opening degree, corresponding to a given pre-setting, $(h^2\ bar)/m^6$, $(Pa\ s^2)/m^6$
$r_{\mathrm{I},0}$	hydraulic resistance of the valve throttling element for the minimum opening, $(h^2\ bar)/m^6$, $(Pa\ s^2)/m^6$
$r_{\mathrm{I},100}$	hydraulic resistance of the valve throttling element for its full opening, $(h^2\ bar)/m^6$, $(Pa\ s^2)/m^6$
$r_{\mathrm{II},100}$	hydraulic resistance of the valve closing element for its fully available range of movement, $(h^2\ bar)/m^6$, $(Pa\ s^2)/m^6$
r_k	hydraulic resistance of the valve body, $(h^2\ bar)/m^6$, $(Pa\ s^2)/m^6$
$r_{k+I,i}$	total hydraulic resistance of the valve body and its throttling element for a given degree of opening, corresponding to a given pre-setting, $(h^2\ bar)/m^6$, $(Pa\ s^2)/m^6$
$r_{reg,100}$	hydraulic resistance of the current-regulation element of the valve for its full opening, $(h^2\ bar)/m^6$, $(Pa\ s^2)/m^6$
$r_{reg,x}$	hydraulic resistance of the current-regulation element of the valve for a given opening degree, $(h^2\ bar)/m^6$, $(Pa\ s^2)/m^6$
r_{str}	hydraulic resistance of added pipework, $(h^2\ bar)/m^6$, $(Pa\ s^2)/m^6$
$r_{z,100}$	hydraulic resistance of the valve for a full opening of both sections of regulation, $(h^2\ bar)/m^6$, $(Pa\ s^2)/m^6$
$r_{z,x}$	hydraulic resistance of the valve for a given degree of opening of both sections of regulation, $(h^2\ bar)/m^6$, $(Pa\ s^2)/m^6$
$\Delta p_{I,i}$	pressure loss of the fluid across the valve throttling element for the position limited by the *i*th opening degree, corresponding to a given pre-setting, bar, Pa
$\Delta p_{\mathrm{I},0}$	pressure loss of the fluid across the valve throttling element for the minimum opening, bar, Pa
$\Delta p_{\mathrm{I},100}$	pressure loss of the fluid across the valve throttling element for its full opening, bar, Pa
$\Delta p_{\mathrm{II},100}$	pressure loss of the fluid across the valve closing element for its fully available range of movement, bar, Pa
Δp_k	pressure loss of the fluid across the valve body, bar, Pa
$\Delta p_{reg,100}$	pressure loss of the fluid across the fully opened part of the valve regulated on a current basis, bar, Pa
$\Delta p_{reg,x}$	pressure loss of the fluid across the valve section regulated on a current basis for a given degree of opening, bar, Pa
$\Delta p_{z,100}$	pressure loss of the fluid across a fully opened control valve, bar, Pa
$\Delta p_{z,x}$	pressure loss of the fluid across the control valve for a given degree of opening of both sections of regulation, bar, Pa
$\dot{V}_{k+\mathrm{I},i}$	the fluid resultant volume flow through the valve body and the throttling element for the *i*th pre-setting, m^3/h, m^3/s
$\dot{V}_k$	the fluid volume flow through the valve body, m^3/h, m^3/s
$\dot{V}_z$	the fluid volume flow through the valve, m^3/h, m^3/s

practice will act as a discontinuous-bilateral regulator, rather than a continuous-proportional one (see Fig. 1). This can result in:

- Unfading oscillations in the system.
- Hydraulic shocks in the system.
- Reduction in year-round efficiency of the system operation.
- Deterioration in thermal comfort parameters in heated rooms.
- Faster wear of components and equipment installed in the pipework.
- Increase in the system operating costs.

Exceeding the recommended upper value will involve financial outlays disproportionate to the achieved results because pipes will need very large diameters, thus being oversized, or the pump active pressure will have to be raised (Formulae (1)–(10)). This will mean high investment costs and – probably – increased operating costs due to:

- the large heat flux loss of large-diameter pipes, or
- the increased demand for power to drive the pump.

Moreover, in the case of thermostatic valves, it is then possible that the water mass flow through the radiator will substantially exceed the design value fixed for the nominal valve opening level [13,14,19]. Therefore, due to a number of factors, and in terms of investment and operating costs optimization in particular, the established appropriate range of the valve authority variation mentioned above should be observed. This especially concerns the radiator control valves.

As it turns out, this condition is often not satisfied in practice. The reason for that is that the commonly accepted method of