

Zmanjšana pretočnost krmilnega ventila, da ali ne ? Reduced Flow of Control Valves, yes or no ?

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V prispevku je analizirana pomembnost prave izbire pretočnosti krmilnega ventila in so pojasnjeni negativni učinki neprimerne izbire valvula na poslabšanje njegove značilnice. Prispevek prikazuje vpliv omejitve giba ali izstopnega prereza valvula. Prikazani so načini zmanjšanja pretočnosti valvula. Obravnavane so različne statične pretočne značilnice valvulov in vpliv omejitve pretočnosti. V sklepih so podane možnosti, kako se izogniti problemu. © 1998 Strojniški vestnik. Vse pravice pridržane.
(Ključne besede: razmerja krmilna, značilnice valvulov, značilnice statične, značilnice poligonalne)

The paper analyses the importance of choosing the optimal flow through the control valve and the negative impact that an improper selection of the valve may have on the valve characteristics. The effect of the limitation of the valve travel or its output cross-section is described. Some methods of reducing the valve flow are shown. Various static flow characteristics, including the effect of the reduced flow, are also discussed. In the conclusions, possible practical solutions are proposed. © 1998 Journal of Mechanical Engineering. All rights reserved.

(Keywords: control ratio, valve characteristics, static characteristics, polygonal characteristics)

0 UVOD

Pri razvoju in izbiri krmilnih valvul se velikokrat pojavlja vprašanje, kako doseči manjše pretočne zmogljivosti valvul pri isti priključni dimenzijski. Pri tem je treba upoštevati nekaj dejstev. Vsak uporabnik želi, da bo njegov krmilni valvul deloval dolgo in brezhibno tudi v najtežjih obratovalnih razmerah. S tem se želi znebiti nepotrebnih stroškov in zagotoviti stalno delovno pripravljenost krmilnega sistema. Pri izbiri valvula pa se lahko pojavijo velike napake zaradi predimenzioniranja. Zaradi želje po varnosti se pogosto izbere prevelik valvul. S tem se lahko naredi dvojna škoda, in sicer:

- zmanjša se krmilno razmerje in
- valvul deluje samo v delu svoje pretočne značilnice, kar lahko pomeni, da je pri pretiranem predimenzioniranju lahko valvul izbran tako, da so najmanjši zahtevani krmiljeni pretoki že v področju notranje prepustnosti valvula.

V ta namen v prispevku poskušamo prikazati dva načina zmanjšanja imenske pretočnosti:

- valvul z uporabo dušilnih elementov v valvulu in
- valvul z zmanjševanjem giba valvula.

Oba načina zmanjšanja lahko obravnavamo kot isto dejstvo, poleg tega pa opisujemo njun vpliv na lastnosti valvula.

Če zmogljivost valvula zmanjšamo iz večje pretočnosti na manjšo pretočnost z reducirnimi elementi v valvulu, naredimo več poslabšav značilnice valvula, kakor izboljšav. Težavi, ki se pojavitata, sta zmanjšanje krmilnega razmerja, kar neposredno vpliva

0 INTRODUCTION

When developing and choosing the right control valves, the question is often raised how to reduce the valve flow without changing the valve size. When dealing with this issue, several facts have to be considered. Namely, every user would like his control valves to have a long life and to operate faultlessly, no matter how demanding operating conditions are. This is a prerequisite for avoidance of unnecessary costs and an assurance that the system is always ready to operate. Several major mistakes can result from the valve oversizing. It is quite common that a too large valve is chosen because the designer wants to be on the "safe side". The consequent loss is double:

- the control ratio is reduced and
- the valve operates only within the limits of its own flow characteristics. This means that if the valve is considerably oversized, the smallest required control flow can already be within the domain of the valves internal seat leakage.

The target of our paper is to show two different ways of the nominal flow reduction:

- valve reduction by using a reducing element and
- valve reduction by using travel limitation.

Both approaches use the same measures. Their impact on valve characteristics is given below.

If the valve capacity is reduced from its larger to its lower flow by using an adequate reducing element, there is more damage than good made to the valve characteristics. In such case we are faced with a two-fold problem; the valve control ratio is reduced and the valve characteristics are deformed. It should herewith be noted that the reduced control

na delovanje sistema, kadar želimo vzdrževati zelo majhne pretoke, in popačenje značilnice [1] in [2]. Kljub pravi izbiri pretočnosti je področje majhnih pretokov v tem primeru zelo nestabilno.

1 RAZLIČNI NAČINI ZMANJŠEVANJA NAJVEČJE PRETOČNOSTI k_{vs}

V primeru, da v ventil vstavimo reducirne elemente, omejimo največji pretok skozi ventil. Krmilno razmerje je definirano kot:

$$R = \frac{k_{vs}}{k_{vo}} \quad (1)$$

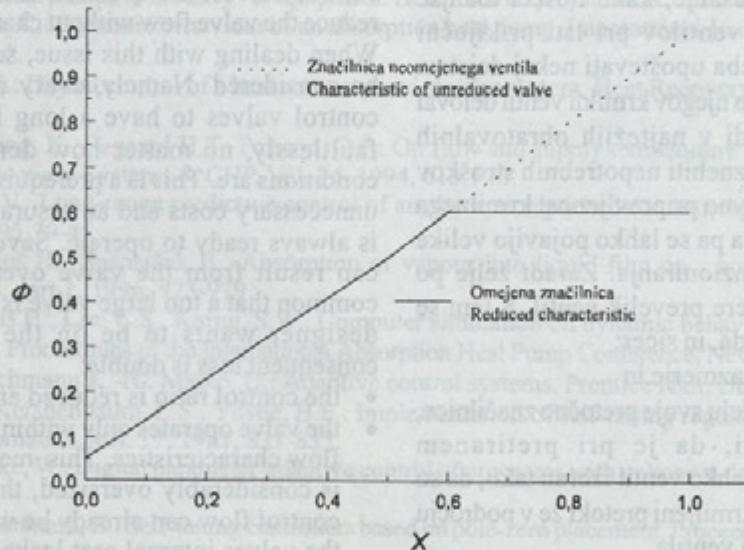
kjer so: R - krmilno razmerje, k_{vs} - imenska pretočnost popolnoma odprtrega ventila pri tlachenem padcu 0,1 MPa skozi ventil in k_{vo} - najmanjši pretok, ki lahko teče skozi ventil in ni nestabilen [3] do [5].

Zmanjšanje imenske pretočnosti po enačbi (1) pomeni zmanjšanje števca, kar pomeni zmanjšanje krmilnega razmerja. Zmanjšanje imenske pretočnosti je prikazano na sliki 1. Vodoravna črta pomeni prepustnost reducirnega elementa. Reducirni elementi so različnih oblik od ostrorobe zaslone, Venturijeve šobe, več lukenj razporejenih po obodu do drugih izvedenih reducirnih elementov (slika 2). Razlika je le v šumnosti ventila in ne v krmilnem razmerju.

ratio has a direct impact on the system operation when low flow is demanded, [1] in [2]. Even though the inherent flow is selected appropriately correct, the flow in the low flow area is very unstable.

1 VARIOUS METHODS OF REDUCING THE MAXIMUM FLOW k_{vs}

Insertion of a reducing element in the valve reduces the maximum flow. The control ratio is calculated according to:



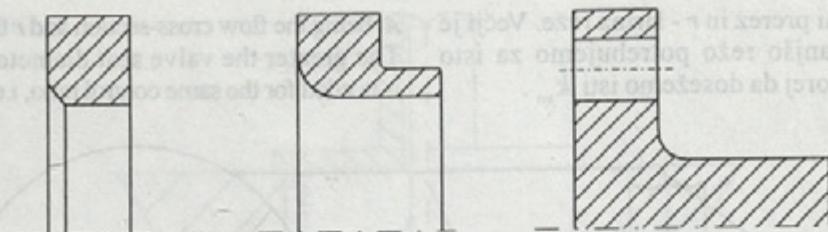
Sl.1. Popačenje pretočne značilnice ventila zaradi vgraditve reducirnega elementa

(Φ je relativna pretočnost in X je relativni gib ventila)

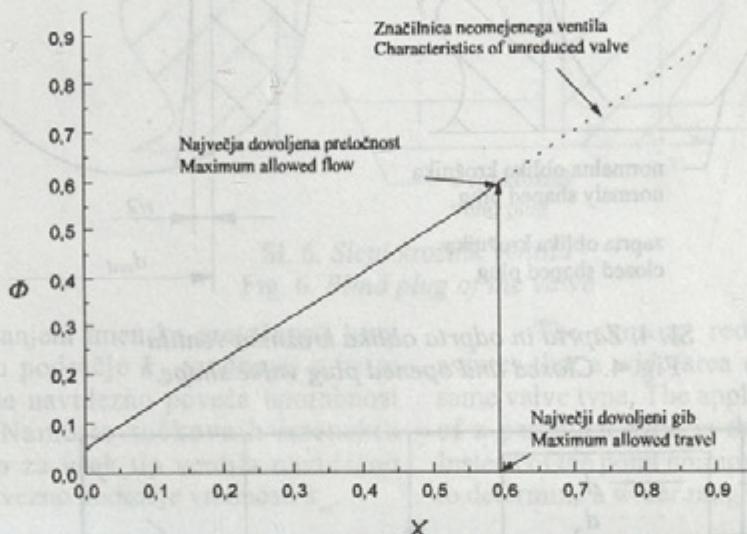
Fig. 1. Deformation of the flow characteristics due to the installation of the reducing element
(Φ is the inherent relative flow and X is the relative travel of the valve)

Druga možnost omejevanja imenske pretočnosti (ta je nehote najpogostejsa) je z omejevanjem giba krmilnega ventila. V tem primeru ventila ne odpremo do polnega giba in zato ne dosežemo imenske pretočnosti. Če upoštevamo enačbo (1) vidimo, da so razmere popolnoma enake kakor pri zgornjem primeru; krmilno razmerje se namreč zmanjša. Razmere so prikazane na sliki 3.

The second possibility of reducing the nominal k_{vs} value (undoubtedly the most common one) is the limitation of the valve travel. In this case, the valve is not opened to its maximum travel, thus assuring reduction of its nominal flow. If we take a closer look at equation (1), we can see that the conditions are the same as in the example above where the control ratio is reduced. See Fig. 3 for valve characteristics.



Sl. 2. Različne oblike reducirnih elementov
Fig. 2. Different types of reducing elements



Sl. 3. Omejevanje pretočnosti ventila z omejevanjem giba
Fig. 3. Valve flow reduction using the travel limitation

Tretjo možnost izvedemo s posebnimi oblikami krožnika ventila. V ta namen rabijo ventili, ki imajo razmerje sedeža ventila, podano z enačbo (2), enako za pretočno omejen in neomejen ventil:

$$f = \frac{d_{sed}}{DN} \quad (2)$$

kjer sta: d_{sed} - premer sedeža in DN - imenski premer vstopne odprtine v ventil. Vendar uporabimo zaprto obliko krožnika in s tem ventilom dosežemo majhno imensko pretočnost. Oblika krožnika je prikazana na sliki 4, oblika značilnice pa je enaka predpisani po standardu. V tem primeru je začetna najmanjša pretočnost k_{vo} velika zaradi velikega pretočnega prereza, ki ostane kljub majhni razlike v dimenziji med krožnikom in sedežem. Odvisnost najmanjšega začetnega pretočnega prereza ventila od širine reže in premera sedeža ventila je prikazana na sliki 5. Na sliki vidimo, da se z večanjem premera sedeža hitro zvečuje pretočni prerez. Zato je pomembna izbira razmerja sedeža. Manjši je premer sedeža, ki še omogoča doseganje imenske pretočnosti, boljše je krmilno razmerje. S slike 5 in enačbe (3) vidimo, da se pretočni prerez ventila povečuje kvadratično z večanjem širine reže:

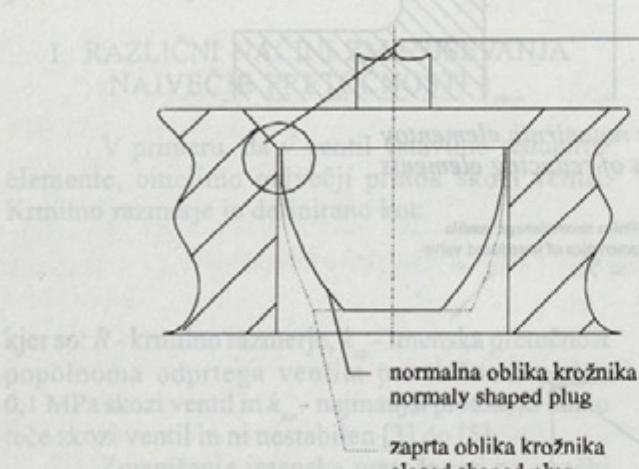
$$A = \frac{\pi}{4} r (2f \cdot DN - r) \quad (3)$$

The third option is the use of a specially shaped valve plug. For this purpose valves are needed whose seat ratio, equation (2), are the same for the flow reduced and unreduced valves:

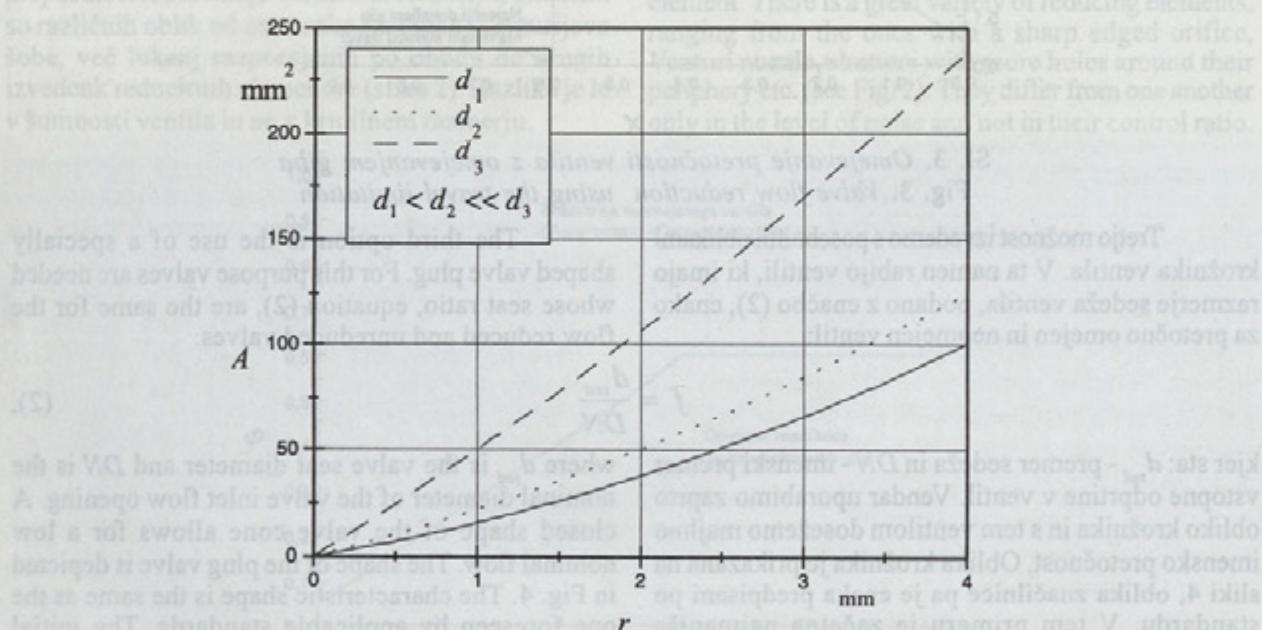
where d_{sed} is the valve seat diameter and DN is the nominal diameter of the valve inlet flow opening. A closed shape of the valve cone allows for a low nominal flow. The shape of the plug valve is depicted in Fig. 4. The characteristic shape is the same as the one foreseen by applicable standards. The initial minimum flow is here considerable due to the large cross-section of the slot which remains unchanged in spite of the small difference between the valve seat and the plug valve dimensions. The relation between the slot and the valve seat diameter is shown in Fig. 5. Fig. 5 shows that the bigger the opening the bigger the flow cross-section. This finding proves the importance of the valve seat ratio. If the valve seat is larger, a smaller width slot is needed for the same control ratio. When the width slot increases, the flow cross-section is quadratically:

kjer sta: A - pretočni prerez in r - širina reže. Večji je premer sedeža, manjšo režo potrebujemo za isto krmilno razmerje, torej da dosežemo isti k_{vo} .

A being the flow cross-section and r the width of the slot. The greater the valve seat diameter, the smaller slot is needed for the same control ratio, i.e. for the same k_{vo} .



Sl. 4. Zaprta in odprta oblika krožnika ventila
Fig. 4. Closed and opened plug valve shape

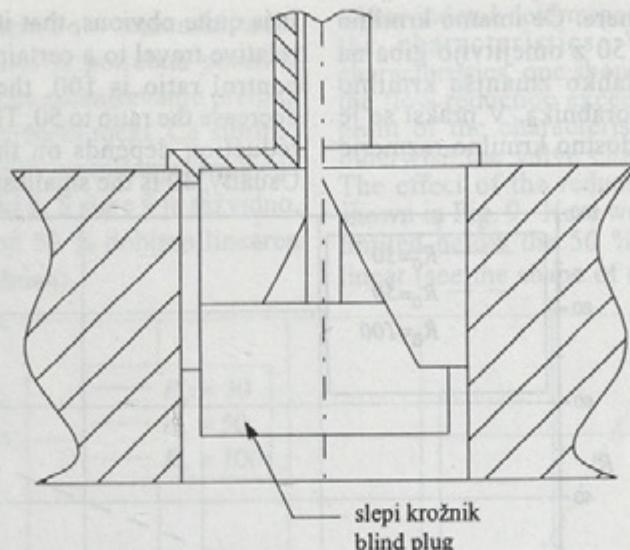


Sl. 5. Vpliv premera sedeža ventila (d_s) in širine reže (r) na velikost pretočnega prereza (A) pri enakem imenskem premeru DN 15

Fig. 5. Effect of the valve seat diameter (d_s) and width slot (r) on the flow cross-section (A) at the same DN 15

Ventilu z utornim krožnikom je mogoče omejiti imenski pretok na poseben način z dodatnim "slepim krožnikom". V utornem krožniku je še en slepi krožnik, ki skrbi za zmanjšanje pretočnosti. Prikazan je na sliki 6. Z dviganjem in spuščanjem tega slepega krožnika omejimo največji pretočni prerez, torej dobimo značilnico, prikazano na sliki 1. Tako zmanjšamo največji pretok in "nastavimo" imensko pretočnost. Rezultat rešitve je slabše krmilno razmerje in izbrana imenska pretočnost.

When using the slot plug valve, it is possible to reduce the flow with an additional so called "blind plug valve". In the slot plug valve, there is one more plug of the blind type. It reduces the flow (Fig. 6). By lifting and lowering the blind plug valve it is possible to limit the maximum flow cross-section. In this way the maximum flow is reduced and the nominal flow is enabled. The characteristics is the one shown in Fig. 1. This solution yields a less favourable control ratio and the chosen nominal flow.



Sl. 6. Slepki krožnik ventila
Fig. 6. Blind plug of the valve

Z zmanjšanjem imenske pretočnosti torej pokrijemo široko področje k_{vs} vrednosti z istim ventilom. Tako se navidezno poveča uporabnost istega ventila. Namesto točkovnih imenskih pretočnosti lahko za vsak tip ventila navidezno prikažemo neko zvezno področje vrednosti k_{vs} .

2 VPLIV ZMANJŠANJA GIBA VENTILA NA KRMILNO RAZMERJE

Začetno krmilno razmerje definirajmo kot:

$$R_o = \frac{k_{vs}}{k_{vo}} \quad (4)$$

ter linearno pretočno značilnico ventila, [5]:

$$\Phi = \frac{1}{R_o} + \left(1 - \frac{1}{R_o}\right)X \quad (5),$$

pri čemer sta:

in

where

$$\Phi = \frac{k_{vs}}{k_{vo}} \quad (6)$$

and

$$X = \frac{h}{h_{max}} \quad (7).$$

Z obrazci (4) do (7) lahko izračunamo novo krmilno razmerje:

$$R' = 1 + (R_o - 1)X \quad (8).$$

Ko zmanjšujemo pretok, izračunamo relativni gib X iz obrazca (5) in ga vstavimo v enačbo (8). Tako dobimo ustrezno zmanjšano krmilno razmerje. Možna zmanjšana krmilna razmerja za različna začetna krmilna razmerja in relativne gibe so prikazana na sliki 7, s katere se vidi, da je primerno

When reducing the flow, relative travel X is calculated using formula (5) and then its value is entered in the above equation (8). An adequately reduced control ratio is thus obtained. The possible reductions of control ratios for various initial control ratios and corresponding travels are shown in Fig. 7.

The sum up, reducing the nominal flow assures that a wide area of k_{vs} is covered with the same valve type. The application scope of the valve of a particular type is thus apparently increased.

Instead of the point nominal flow values it is possible to determine a wider range of k_{vs} for any valve type.

2 EFFECT OF TRAVEL LIMITATION ON CONTROL RATIO

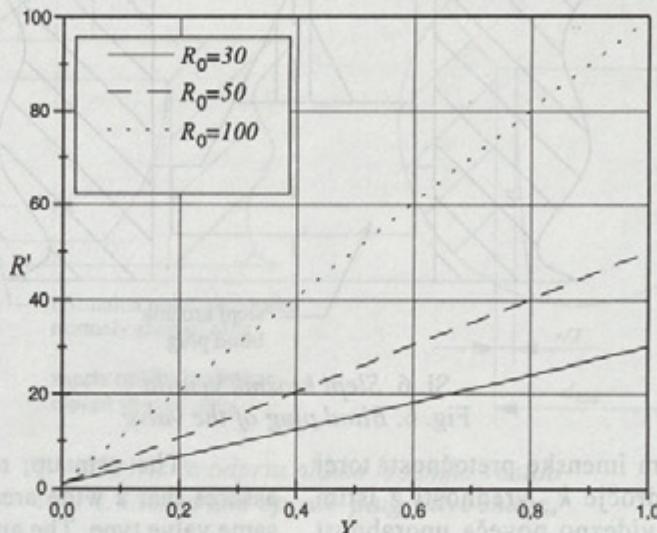
The initial control ratio is defined as:

and the linear characteristics of the valve as [5]:

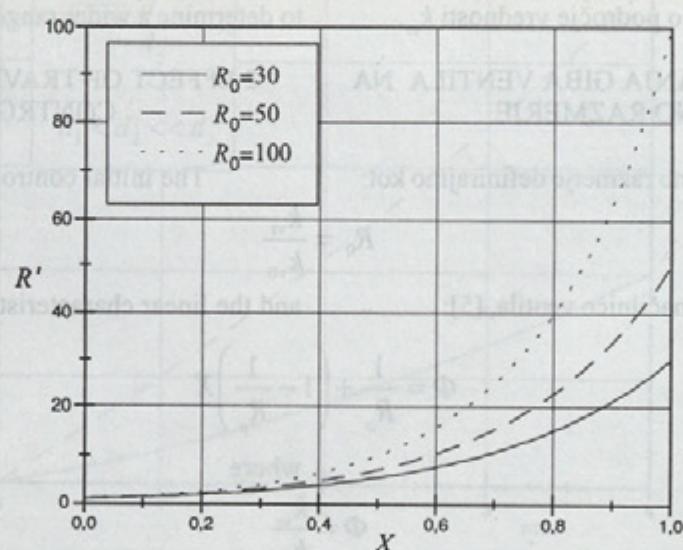
Using the formulae from (4) to (7), it is possible to calculate the new control ratio:

omejevati gib le do neke mere. Če imamo krmilno razmerje 100, se zniža na 50 z omejitvijo giba na 0,5. Mera, do katere se lahko zmanjša krmilno razmerje, je odvisna od uporabnika. V praksi se je uveljavilo najmanjše še zadostno krmilno razmerje okoli 30.

It is quite obvious, that it is reasonable to limit the relative travel to a certain degree only. If the initial control ratio is 100, the travel limitation of 0,5 decrease the ratio to 50. The level of the control ratio reduction depends on the user's practical needs. Usually, 30 is the smallest permissible control ratio.



Sl. 7. Zmanjšanje krmilnega razmerja za ventil z linearno značilnico
Fig. 7. Control ratio reduction for the valve with linear characteristics



Sl. 8. Zmanjšanje krmilnega razmerja za ventil s sorazmerno značilnico
Fig. 8. Control ratio reduction for the valve proportional characteristics

Za sorazmerni ventil je slika podobna. Novo krmilno razmerje:

je prikazano na sliki 8.

In še za nestandardno poligonsko značilnico ventila, [1]:

$$R' = R_0 \max \left[\frac{\Phi_k - \frac{1}{R_0}}{X_k} X + \frac{1}{R_0}; \frac{1 - \Phi_k}{1 - X_k} (X - 1) + 1 \right] \quad (10)$$

The result is similar for the proportional valve. The new control ratio is

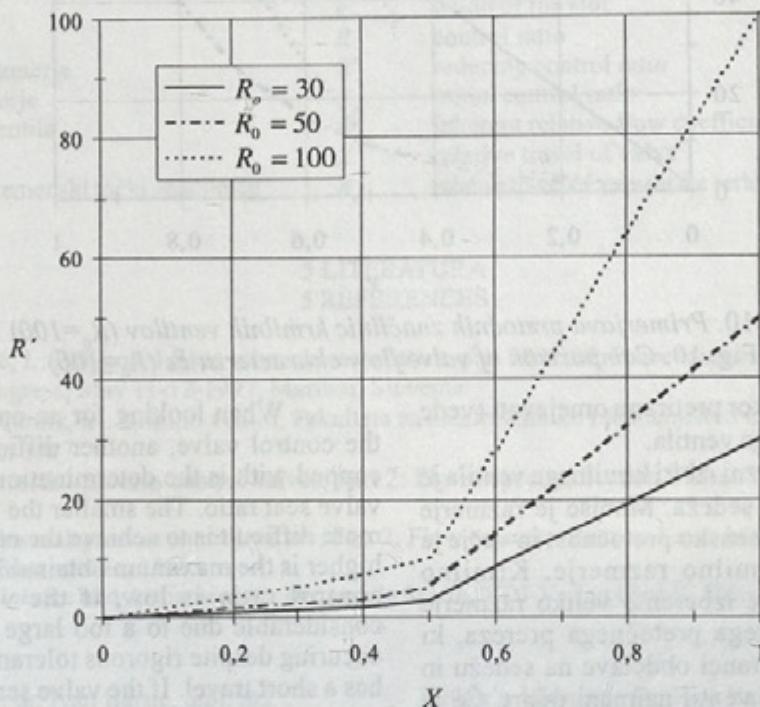
$$R' = R_o^x \quad (9)$$

as shown in Fig. 8.

The control ratio for the non-standard polygonal characteristic, [1] is:

kjer indeks k označuje razmere v temenski točki značilnice. Pri tej značilnici je potrebna posebna pozornost. Izogniti se je treba zmanjševanju pretoka pod vrednost pretoka v temenski točki. Če storimo slednje, je ventil linearen. Vpliv zmanjšanja krmilnega razmerja je prikazan na sliki 9. Slike 9 je razvidno, da z zmanjšanjem giba pod 50 % dobimo linearen ventil (kar je lastnost značilnice).

where index k determines conditions in the vertex of the characteristics. When using the above characteristics, one should be very careful. Namely, the flow reduction exceeding the flow at the vertex point of the characteristics should be avoided as otherwise the valve characteristic becomes linear. The effect of the reduction on the control ratio is shown in Fig. 9. Here we can see that if the travel is limited below the 50 % limit, the valve becomes linear (see the shape of the characteristic).



Sl. 9. Zmanjšanje krmilnega razmerja za ventil s poligonsko značilnico (Φ_k in $X_k = 0,5$)

Fig. 9. Reduced control ratio for the polygonal characteristic of valve (Φ_k and $X_k = 0,5$)

3 SKLEPI

Iz prispevka je vidno dvoje pomembnih dejstev:

- ne izbirajmo prevelikih imenskih pretočnosti ventilov in
- izdelovalci ventilov morajo zagotoviti velika krmilna razmerja, da lahko ventil kljub predimenzioniranju dobro deluje.

Pretok krmilnega ventila naj ne bi nikakor omejevali z reducirnimi elementi, saj je to tako, kakor bi zmanjšali uporabni gib. Krmilno razmerje ventilov se zelo hitro zmanjša z zmanjševanjem giba. Na sliki 10 so primerjane vse obravnavane značilnice ventilov. Najmanjši vpliv na krmilno razmerje je pri linearni značilnici ventila, največji pa pri sorazmerni. Iz zgornjega izhaja pomembna ugotovitev, da je poligonska značilnica zelo primerno nadomestilo za sorazmerno značilnico ventila.

Krmilno razmerje ventilov se zelo hitro znižuje z zmanjševanjem giba (kar je enako kakor z omejevanjem največjega pretoka). Bolje je izbrati manjši imenski premer ventila in s tem bolj ustrezno

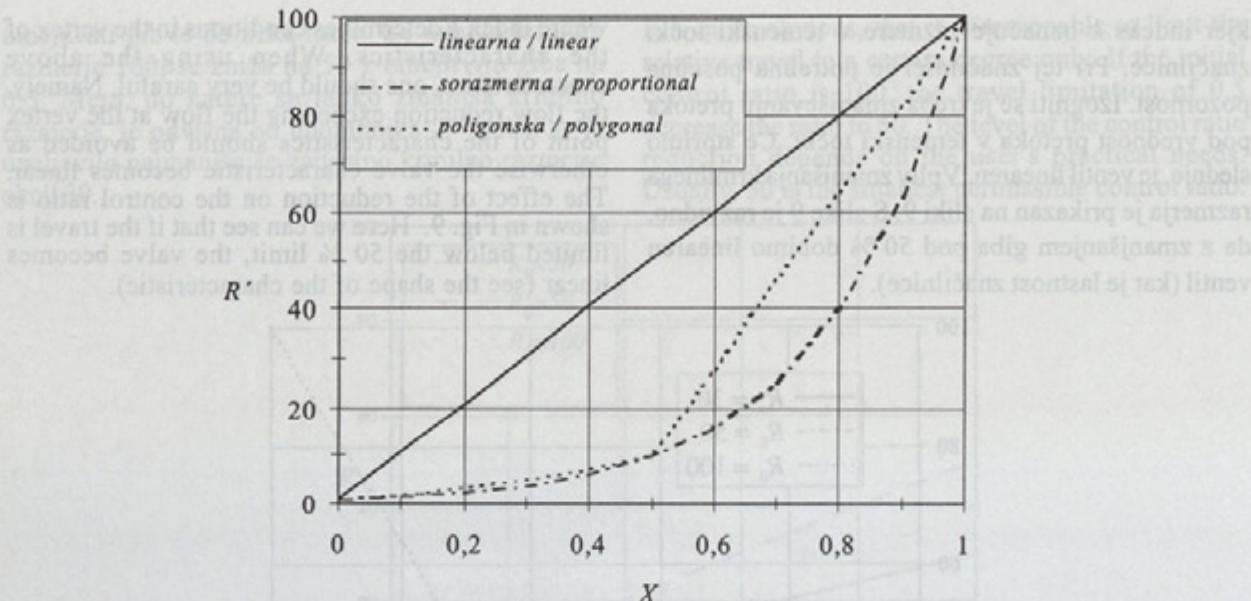
3 CONCLUSIONS

The paper reveals two important facts:

- it is not advisable to select valves with too large k_{vv} values, and
- valve manufacturers should produce valves with large control ratios, enabling good operation despite oversizing.

Valves should not be with reducing elements as this means the same as limiting the travel. The control ratio decreases rapidly when the travel is limited. Figure 10 compares the discussed characteristics. The effect of the control ratio is the smallest at the linear characteristics and the largest at the proportional characteristics. Following the above, the polygonal characteristics is a very good substitute for the proportional characteristics of valve.

The control ratio decreases rapidly with the travel limitation (which is the same as reducing the maximum flow). It is better to choose a smaller valve nominal diameter and consequently a more appropriate nominal flow than to limit the travel excessively (deliberately or undeliberately).



Sl. 10. Primerjava pretočnih značilnic krmilnih ventilov ($R_0=100$)

Fig. 10. Comparison of valve flow characteristics ($R_0=100$)

imensko pretočnost, kakor pretirano omejevati (vede ali nevede) gib krmilnega ventila.

Težava pri ustreznih izbirkah krmilnega ventila je tudi razmerje velikosti sedeža. Manjše je razmerje sedeža, teže je doseči imensko pretočnost in večje je možno doseglijivo krmilno razmerje. Krmilno razmerje bo majhno, če izberemo veliko razmerje sedeža zaradi prevelikega pretočnega prereza, ki nastane kljub ostri toleranci obdelave na sedežu in krožniku ventila, ko je ventil najmanj odprt. Če je razmerje velikosti sedeža ventila veliko, zlahka dosežemo imensko pretočnost z zelo kratkim gibom, vendar je zato krmilno razmerje majhno.

Za najboljšo rešitev omejitve imenske pretočnosti pri nekem imenskem premeru ventila lahko poskrbi izdelovalec z vgraditvijo različnih premerov sedežev v isti okrov in tako poskrbi za širši spekter vrednosti k_v oziroma imenskih pretočnosti. To je edina celostna rešitev problema. Druga možnost je izbrati ventil z večjim krmilnim razmerjem od ustreznega in ugotoviti, ali se kljub zmanjšanju imenskega pretoka še doseže najmanjšje zahtevano krmilno razmerje.

When looking for an optimum selection of the control valve, another difficulty that has to be coped with is the determination of the appropriate valve seat ratio. The smaller the valve seat ratio, the more difficult is to achieve the nominal flow and the higher is the maximum obtainable control ratio. The control ratio is low, if the valve seat ratio is considerable due to a too large flow cross-section occurring despite rigorous tolerances when the valve has a short travel. If the valve seat ratio is large, it is very easy to achieve the nominal flow with a very short travel. Notwithstanding, in such case the control ratio is to be low.

The best solution regarding the reduction of the nominal flow at a particular nominal valve cross-section would be the manufacturer's installation of valve seats with different diameters in the same housing thus assuring a broader range of k_v value nominal flows. This is the only integral solution of the discussed problem. The second option is to choose a valve with a quite high control ratio upon what it has to be established if the nominal required control ratio is still achievable inspite of the reduction of the nominal flow.

4 OZNAČBE

4 SYMBOLS

pretočni prez	A	effective flow area
premer sedeža ventila	d_{sed}	seat diameter of valve
imenski premer ventila	D_N	nominal size of valve
razmerje sedeža ventila	f	seat ratio of valve
gib ventila	h	travel of valve
imenska pretočnost ventila	k_n	nominal flow coefficient
najmanjša pretočnost	k_m	minimal flow coefficient
širina reže	r	width of the slot
krmilno razmerje	R	control ratio
reducirano krmilno razmerje	R'	reducing control ratio
začetno krmilno razmerje	R_i	initial control ratio
relativna pretočnost ventila	Φ	inherent relative flow coefficient of valve
relativni gib ventila	X	relative travel of valve
relativni gib ventila v temenski točki značilnice	X_k	relative travel of valve at the vertex point of the characteristics

5 LITERATURA

5 REFERENCES

- [1] Bobič, M., Bajšić, I.: Polygonal flow valve characteristics, p.p. 303/309, Proceedings of the Second SITHOK-2 International Congress, May 11-12-1997, Maribor, Slovenia
- [2] Đonlagić, D., Tovornik, B.: Krmilni ventili, Fakulteta za elektrotehniko računalništvo in informatiko, Univerza v Mariboru, Maribor 1997
- [3] IEC 534-2-4: Industrial-process control valves, Part 2: Flow capacity, Section Three: Test Procedures, First edition, 1983
- [4] IEC 534-2-4: Industrial-process control valves, Part 2: Flow capacity, Section Four: Inherent flow characteristics and rangeability, First edition, 1989
- [5] F. Piwinger: Stellgeräte und Armaturen für strömende Stoffe, VDI-Verlag GmbH, Düsseldorf, 1971

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