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Ojačanje krmilnega ventila s poligonsko pretočno značilnico

Gain of a Control Valve with Polygonal Flow Characteristics

Ivan Bajsić - Miha Bobič

Namen prispevka je prikazati pretočno značilnico, ki ima dobre lastnosti dveh standardnih značilnic krmilnih ventilov. Pretočne značilnice so primerjane glede na njihovo ojačanje. Izdelana je primerjava med vsemi tremi pretočnimi značilnicami in različnimi možnostmi izbire temena poligonske pretočne značilnice. Izračunane vrednosti so eksperimentalno ovrednotene. Dinamične lastnosti pretočnih značilnic so prikazane s simuliranjem prenosne funkcije sklenjene krmilne zanke. Matematični model, uporabljen za simuliranje prehodne funkcije na skočno motnjo, je izbran iz literature [5] in načrtuje prehodno funkcijo prvega reda.

(Ključne besede: značilnice pretočne statične, značilnice statične poligonalne, ventili krmilni, ojačitve ventilov)

The aim of the paper is to show the flow characteristics which have the advantages of two standard characteristics of the control valves. The flow characteristics were compared in terms of their gain. During the evaluation all three flow characteristics were compared as well as the possibility of choosing the vertex point of the polygonal characteristics. The results were evaluated using experimental methods. Dynamic characteristics were displayed by the means of the closed-loop response simulation. A mathematical model for the simulation of transfer function has been chosen from the literature [5] and anticipates the response of the first order lag.

(Keywords: static flow characteristics, polygonal characteristics, control valve, valve gain)

0 UVOD

Velika težava pri krmilnih sistemih s prenosnikom toplote je uporaba krmilnih ventilov s sorazmerno statično pretočno značilnico, saj izvedba te značilnice, v nasprotju z linearno, terja zelo dolge gibe ventilov. To pomeni daljše izvajalne čase in zato počasnejši odgovor sistema. Teže je tudi doseči večje krmilno razmerje. Zaradi tega se je pri teh sistemih pojavilo prizadevanje po uporabi krmilnih ventilov z linearno statično pretočno značilnico. Problem nastane pri krmiljenju manjših pretokov tekočin zaradi izredno velikega ojačenja te značilnice pri majhnih gibih. Ker je ojačenje na izvršilnem členu zelo veliko, je zato tudi ojačenje vsega sistema veliko. Sistem postane nestabilen, zato se pojavijo nihanja pri krmiljeni veličini npr. temperaturi. Problem še ne bi bil tako velik, če se ne bi s temi nihanji pojavila nihanja v pretoku tekočin, kar pomeni nenehno odpiranje in zapiranje ventila ter pogona. To jima zmanjša dobo trajanja, saj je doba trajanja teh naprav odvisna od števila gibov in ne toliko od staranja materiala.

0 INTRODUCTION

The greatest problem with heat-exchanger control systems is the use of control valves with proportional static-flow characteristics, because they require very long spindle travels, when compared to valves with linear-flow characteristics. This causes longer execution times and therefore a slower system response. It is also harder to reach a larger control ratio. As a result of these problems, there was a tendency to use valves with linear-fluid-flow characteristics in such systems. Problems occur when controlling the small flows, due to a very large gain during the initial part of the valve's travel. Large valve gain results in a large gain of the whole control loop, and the system becomes unstable because of large system gain which causes the control values i.e. the temperature to oscillate. The problem is made worse because the fluid flow starts to oscillate too, which results in frequent opening and closing of the valve and actuator. The expected useful life of the valve is therefore reduced, because the service life does not depend much on the materials' ageing, but on the number of working cycles.

Za rešitev tega problema, izvedbe nespremenljivega ojačenja ventila v celotnem gibu krmilnega ventila, ali vsaj nižje ojačenje pri manjših gibih, ob hkratnem kratkem gibu ter velikem krmilnem razmerju, je bila uporabljena poligonska pretočna značilnica ventila.

The solution to this problem - a valve with constant gain through the whole valve travel or at least lower gain by smaller travels, while keeping short travels and a large control ratio - is the use of polygonal valve characteristics.

1 MATEMATIČNI MODEL

1 MATHEMATICAL MODEL

Najprej je treba poznati ojačenje ventila [3]. Tega definiramo kot odvod prostorninskega toka tekočine po relativnem gibu:

First, we have to determine the valve gain [3]. This is defined as the differential between volume fluid flow and relative travel:

$$K_v = \frac{dq}{dX} \qquad (1).$$

Zapis pove, za koliko se bo spremenil pretok ob spremembi giba ventila. V našem primeru lahko vzamemo relativne vrednosti. Ob upoštevanju linearne pretočne značilnice [4]:

It shows the change of flow when the valve travel is being changed. Our example allows for relative values. Considering the linear-flow characteristics, [4]:

$$\Phi = \left(1-\frac{1}{R}\right)X + \frac{1}{R} \qquad (2)$$

in sorazmerne pretočne značilnice [4]:

and the proportional-flow characteristics, [4]:

$$\Phi = \frac{1}{R}e^{X\ln R} \qquad (3),$$

dobimo za linearno pretočno značilnico, z upoštevanjem mere linearnosti a, ojačenje krmilnega ventila:

the linear-flow characteristics have the following control valve gain with respect to authority a:

$$K_v = a\left\{a + (1-a)\left[\left(1-\frac{1}{R}\right)X + \frac{1}{R}\right]^2\right\}^{-\frac{3}{2}}\left(1-\frac{1}{R}\right) \qquad (4)$$

za sorazmerno pretočno značilnico pa:

and for the proportional flow characteristics:

$$K_v = a\left\{a + (1-a)\left[\frac{1}{R}e^{X\ln R}\right]^2\right\}^{-\frac{3}{2}}\frac{\ln R}{R}e^{X\ln R} \qquad (5).$$

Oba poteka ojačenj za nespremenljivo krmilno razmerje R = 50 in tri različne mere linearnosti (a = 1, a = 0,5 in a = 0,1) sta prikazana na sliki 1. Slika prikazuje povečanje ojačenja pri manjšem gibu in pri linearni pretočni značilnici. Čim manjša je mera linearnosti, tem večje je ojačenje pri manjšem gibu.

Iz omenjenega izhaja zamisel o značilnici, ki bi bila v svojem spodnjem gibu podobna sorazmerni pretočni značilnici, v zgornjem pa linearni. Zato je nujno potreben prelom značilnice, oziroma pretočna značilnica mora imeti dve različni strmini. Teoretično bi lahko prelom, tj. točko temena, določili iz presečišča ojačenja linearne in sorazmerne pretočne značilnice z iskanjem ničel v enačbi:

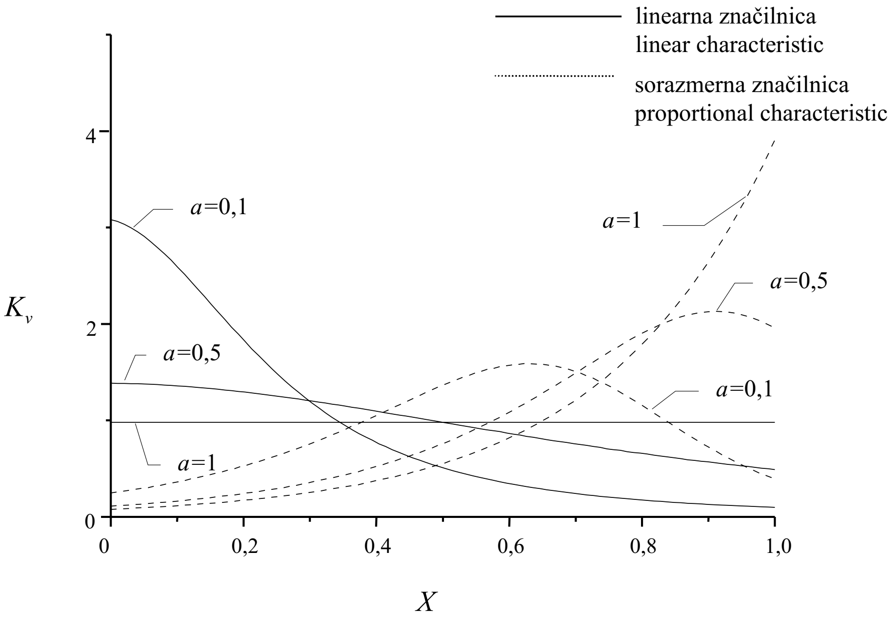
Both the gain characteristics calculated on the basis of the constant control ratio R = 50 and the three different authority (a = 1, a = 0.5 and a = 0.1) are shown in Fig. 1. There you can see the gain growth with the small travel of the linear-flow characteristics. A smaller authority results in a larger gain at the beginning of the valve's travel.

The above mentioned leads to the possibility of flow characteristics which would be proportional in the lower and linear in the upper part of the travel. Therefore, it is necessary to determine the break point of the characteristics i.e. the flow characteristics should have two different gradients. Theoretically the break point - the vertex point of the flow characteristics - could be determined by calculating the intersection point of the linear- and proportional-gain characteristics by finding the zeros of the equation:

$$0 = \left\{a + (1-a)\left[\left(1-\frac{1}{R}\right)X + \frac{1}{R}\right]^2\right\}^{-\frac{3}{2}}\left(1-\frac{1}{R}\right) - \left\{a + (1-a)\left[\frac{1}{R}e^{X\ln R}\right]^2\right\}^{-\frac{3}{2}}\frac{\ln R}{R}e^{X\ln R}; a \neq 0 \qquad (6).$$

Ničle so predstavljene za različna krmilna razmerja in mere linearnosti v preglednici 1 ter slikah 2 in 3.

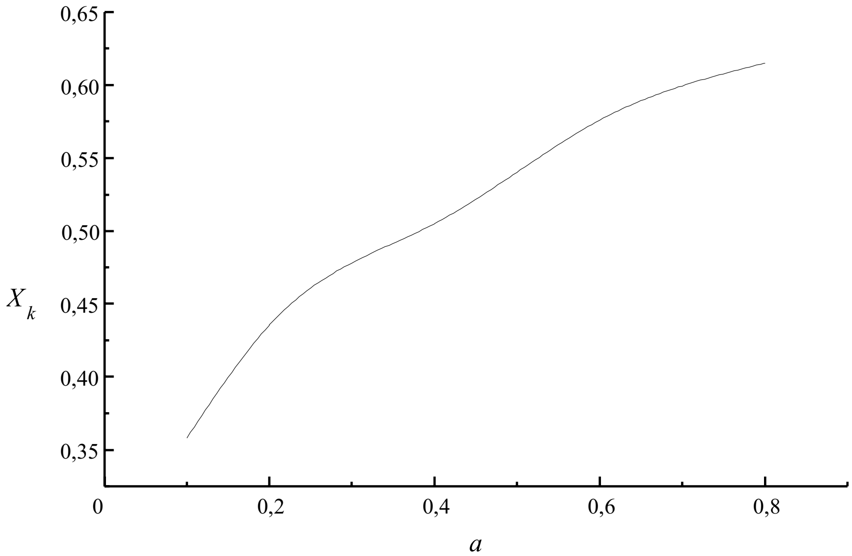
Zeros calculated on the basis of different control ratios and different authority are shown in table 1 as well as Fig. 2 and 3.



Sl. 1. *Ojačenje sorazmerne in linearne pretočne značilnice K_v v odvisnosti od relativnega giba ventila X*
Fig.1. *Gain of proportional and linear-flow characteristics K_v with respect to the relative valve travel X*

Preglednica 1. *Točke temena poligonske pretočne značilnice*
Table 1. *Vertex points of the polygonal-flow characteristics*

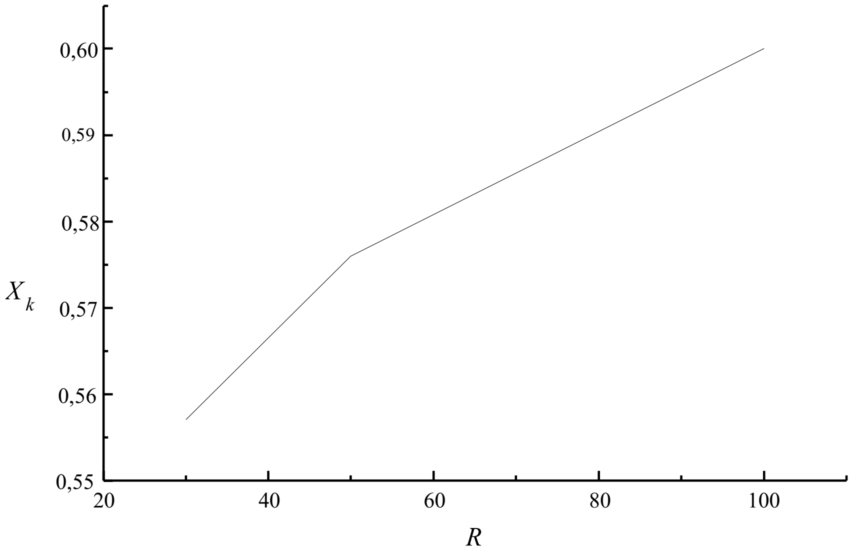
R \ a	1	0,8	0,6	0,4	0,2	0,1
100	1	0,636	0,6	0,545	0,467	0,39
50	1	0,615	0,576	0,505	0,4355	0,358
30	1	0,597	0,557	0,503	0,414	0,335



Sl. 2. *Točke temena X_k poligonske pretočne značilnice, značilnice za različne mere linearnosti a in krmilno razmerje R=50*
Fig. 2. *Vertex points X_k of the linear-flow characteristics at different authorities a and the control ratio of R=50*

Za mero linearnosti a = 1 je povsem primerna linearna pretočna značilnica, kar pomeni, da je najbolj primeren izbor temena v točki X_k = 1.

The linear flow characteristic fits perfectly for authority a = 1, which means that the vertex point of X_k = 1 is the most appropriate.



Sl. 3. *Točke temena X_k značilnice za različna krmilna razmerja R in mero linearnosti a = 0,6*

Fig. 3. *Vertex points X_k of the characteristics at different control ratios R and authority a=0.6*

S slike 2 je razvidno, da se gib v točki temena povečuje skoraj linearno z naraščajočo mero linearnosti.

Tudi slika 3 prikazuje povečevanje giba v točki temena s povečanim krmilnim razmerjem. Določitev temenske točke po tem načinu imenujmo 1. metoda. V praksi pa sta se uveljavili dve drugačni merili za določevanje točke temena poligonske pretočne značilnice [1]:

– 2. metoda → merilo nespremenljivega krmilnega razmerja,
– 3. metoda → merilo nespremenljivega ojačenja.

Potek poligonske pretočne značilnice lahko zapišemo z naslednjo enačbo [1]:

As shown in Fig. 2 the travel at the vertex point becomes almost linear with the growing authority.

Fig. 3 also shows the increase of the travel in the vertex point when the control ratio grows. Determination of the vertex point using the above calculation is called the 1st method. Two other ways of determining the vertex point of the polygonal flow characteristics were proved in praxis, [1]:

– 2nd method → on the basis of a constant control ratio,
– 3rd method → on the basis of constant gain.

Polygonal-flow characteristics can be determined using the following equation, [1]:

$$\Phi = \max\left\{ \frac{\Phi_k - \frac{1}{R}}{X_k} X + \frac{1}{R}; \frac{1-\Phi_k}{1-X_k}\left(X-1\right)+1 \right\} \tag{7}$$

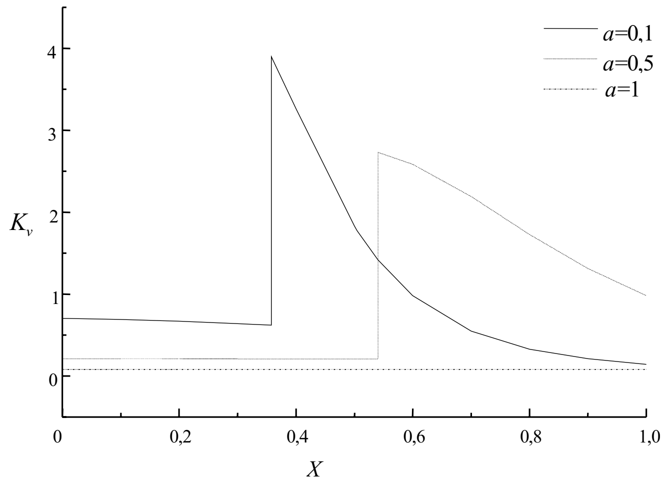
Če zgornjo enačbo vstavimo v enačbo (1), dobimo ojačenje poligonske pretočne značilnice:

The above equation in formula (1) can be used to calculate the gain of the polygonal-flow characteristics:

$$K_v = \begin{cases} a\left\{a+\left(1-a\right)\left[\dfrac{\Phi_k - \frac{1}{R}}{X_k} X + \dfrac{1}{R}\right]^2\right\}^{-\frac{3}{2}} \dfrac{\Phi_k - \frac{1}{R}}{X_k}; & X < X_k \\ a\left\{a+\left(1-a\right)\left[\dfrac{1-\Phi_k}{1-X_k}\left(X-1\right)+1\right]^2\right\}^{-\frac{3}{2}} \dfrac{1-\Phi_k}{1-X_k}; & X > X_k \end{cases} \tag{8}$$

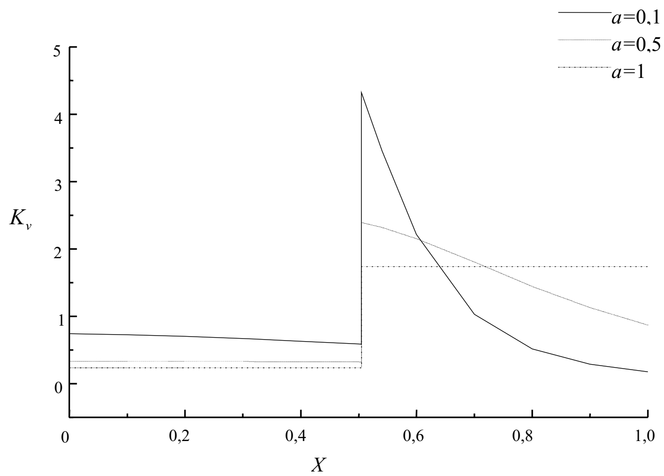
Ker krivulja, ki popisuje pretočno značilnico, ni zvezna, dobimo dve enačbi, ki opisujeta ojačenje poligonske pretočne značilnice. Ojačenje za vse tri metode določanja točke temena je mogoče prikazati na slikah 4, 5 in 6. Pri tem upoštevamo krmilno razmerje R = 50 in mere linearnosti a = 1, a = 0,5 in a = 0,1.

Because the curve derived from the flow characteristics is not continuous, we get two equations which describe the gain of the polygonal flow characteristics. The gain, calculated on the basis of all three methods, is shown in Fig. 4, 5 and 6. All calculations use the control ratio of R = 50 and authority a = 1, a = 0.5 and a = 0.1.



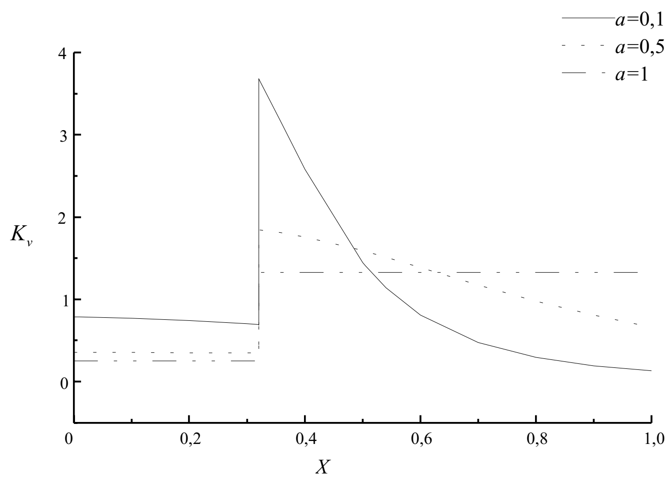
Sl. 4. *Ojačenje poligonske pretočne značilnice K_v s točko temena izračunano iz presečišča med ojačenjem linearne in sorazmerne pretočne značilnice pri* $\Phi_k = 0{,}1$ *(1. metoda)*

Fig. 4. *Gain of the polygonal-flow characteristics K_v with vertex point is calculated using the intersection point between the gain of linear and proportional flow characteristics at* $\Phi_k = 0{,}1$ *(1[st] method)*



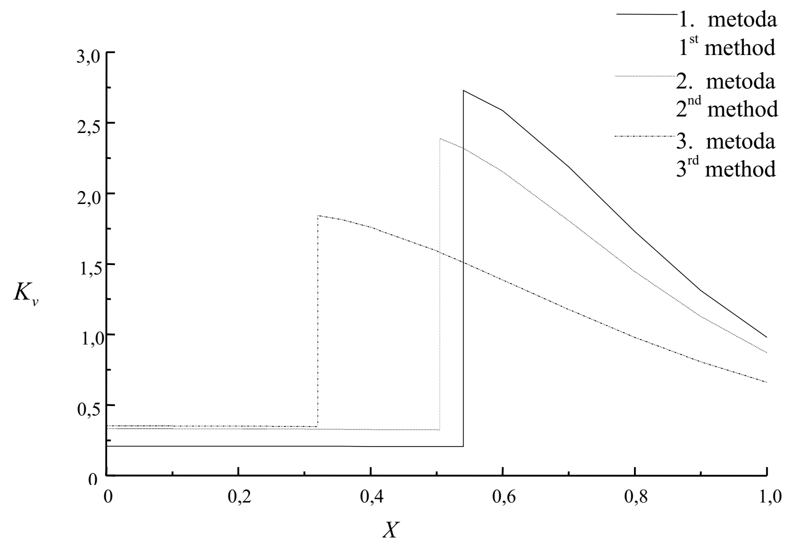
Sl. 5. *Ojačenje poligonske pretočne značilnice K_v s točko temena po metodi nespremenljivega krmilnega razmerja (2. metoda)*

Fig. 5. *Gain of polygonal-flow characteristics K_v with vertex point using the method of constant control ratio (2[nd] method)*



Sl. 6. *Ojačenje poligonske pretočne značilnice K_v s točko temena po metodi nespremenljivega ojačenja* $\Phi_k = 0{,}1$ *(3. metoda)*

Fig. 6. *Gain of polygonal-flow characteristics K_v with vertex point using the method of constant gain* $\Phi_k = 0{,}1$ *(3[rd] method)*



Sl. 7. *Primerjava ojačenja poligonske pretočne značilnice K_v za različne točke temena pretočne značilnice, izračunane po treh različnih metodah*

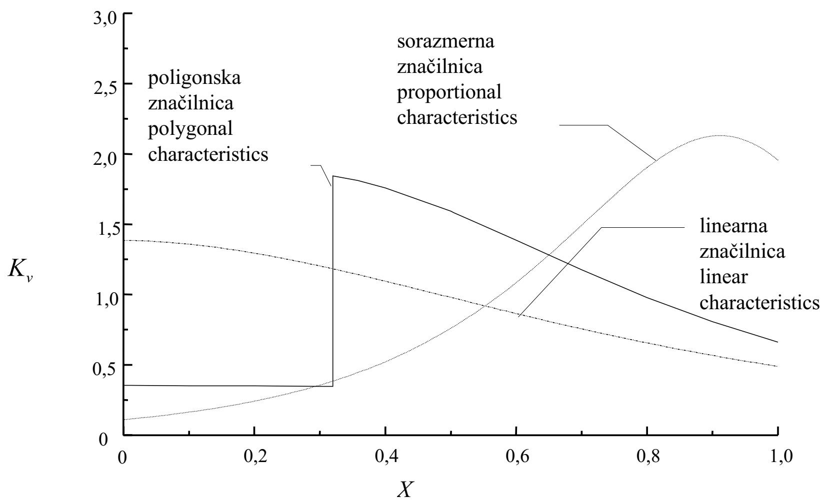
Fig. 7. *Comparison of polygonal-flow characteristics gain K_v for different vertex points calculated by three different methods*

Vse tri slike kažejo na nezveznost pretočne značilnice, ki je v točki temena. Ojačenje je za majhne gibe ventila skoraj nespremenljivo, medtem ko se po prehodu čez temensko točko pretočne značilnice močno poveča. Primerjava med vsemi tremi metodami za R=50 in a=0,5 je prikazana na sliki 7.

Usmeritev pretočnih značilnic je vseh treh primerih enaka. Opazna je precejšnja nezveznost v točki temena. Za nadaljnje primerjave bo vzeta značilnica, izračunana po metodi 3, kajti ta da najmanjšo razliko med obema ojačenjema. Primerjava ojačenja poligonske, linearne in sorazmerne pretočne značilnice je prikazana na sliki 8.

All three diagrams show that the curve is not continuous in the vertex point. Gain is almost constant for the small travels, while it increases strongly after the vertex point of the flow characteristics has been passed. The comparison of all three methods at R = 50 and a = 0.5 is shown in Fig. 7.

All three flow characteristics have the same trend. Characteristics show discrete behaviour evident in the vertex point. The characteristics calculated by the 3rd method will be used for a further comparison because it has the smallest difference between both gains. The comparison of the gain between polygonal, linear and proportional flow characteristics is shown in Fig. 8.



Sl. 8. *Primerjava med ojačenji K_v linearne, sorazmerne in poligonske pretočne značilnice krmilnega ventila za krmilno razmerje R = 50 in mero linearnosti a = 0,5*

Fig. 8. *The comparison of gain K_v between linear, polygonal and proportional flow characteristics of a control valve at control ratio R = 50 and authority a = 0.5*

Slika 8 prikazuje, da je poligonska pretočna značilnica izravnava med linearno in sorazmerno pretočno značilnico.

Fig. 8 shows that the polygonal-flow characteristic is actually a compromise between the linear- and proportional-flow characteristic.

2 EKSPERIMENTALNO OVREDNOTENJE

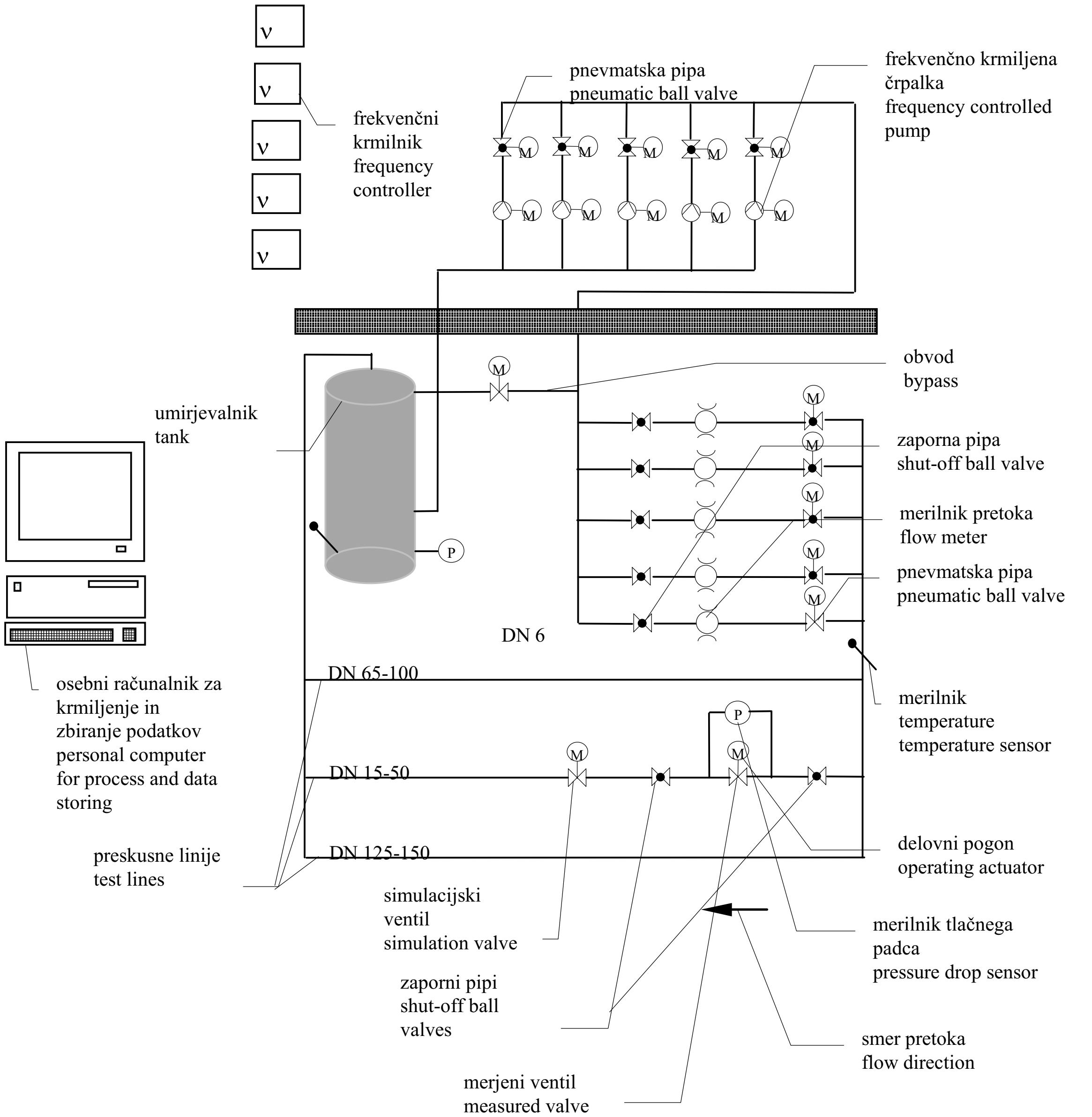
2 EXPERIMENTAL EVALUATION

Matematično modelirana ojačenja so bila eksperimentalno ovrednotena na vseh treh primerih značilnic. Namen meritve je bil eksperimentalno ovrednotenje računskih rezultatov. Zaradi tehničnih težav pri dinamičnih meritvah smo se omejili le na statične meritve ojačenj ventilov.

Uporabljeno je bilo preskuševališče, prikazano na sliki 9. To omogoča hkratne meritve in shranjevanje giba ventila, pretoka kapljevine in tlačnih padcev na ventilu.

Mathematical models of all three models were experimentally evaluated. The aim of the measurement was to experimentally evaluate calculated results. Due to technical problems when performing dynamic measurements, the evaluation was limited to static measurements of valves' gains.

The test rig in Fig. 9 was used. It allows the user to simultaneously measure and store valve travel, fluid flow and pressure drop on the valve.



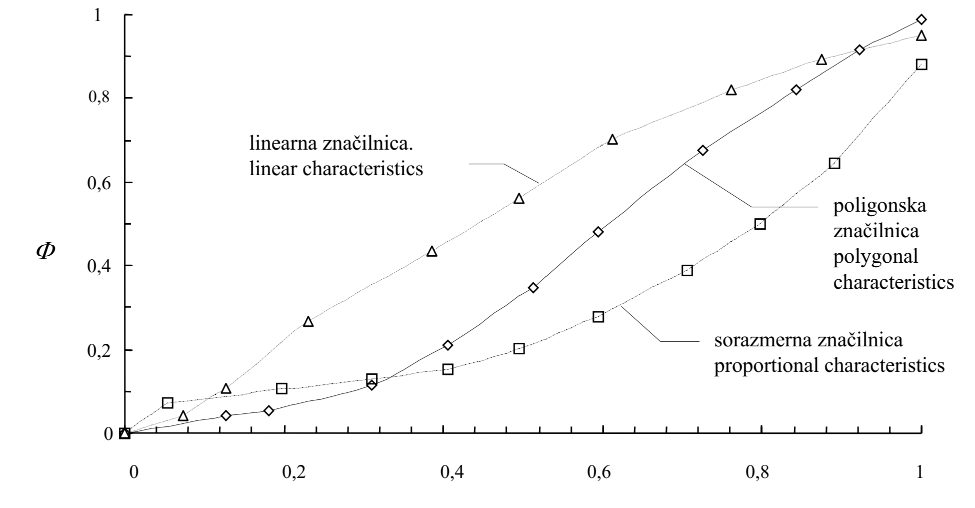
Sl. 9. *Merilno preskuševališče*
Fig. 9. *Test rig*

Za meritev so bili uporabljeni ventili z naslednjimi pretočnimi značilnicami:
- linearna pretočna značilnica,
- sorazmerna pretočna značilnica,
- poligonska pretočna značilnica.

Izmerjene statične pretočne značilnice so prikazane na sliki 10.

Valves with the following flow characteristics were measured:
– linear- flow characteristic,
– proportional-flow characteristic,
– polygonal-flow characteristic;

For static-flow characteristics see Fig. 10.



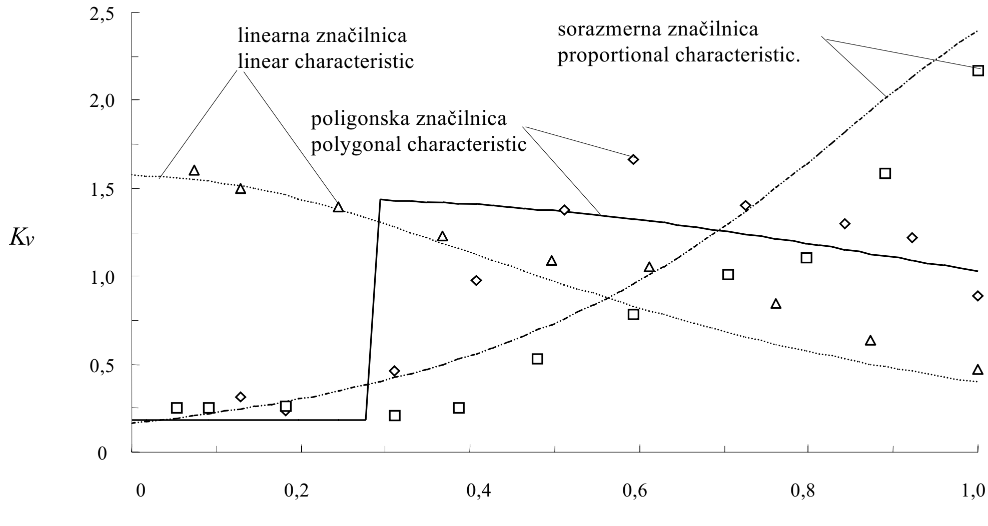
Sl. 10. *Statične pretočne značilnice obravnavanih ventilov*
Fig. 10. *Static-flow characteristics of tested valves*

Razmere v okolici so bile standardne, uporabljena tekočina za merjenje je bila voda. Temperatura tekočine je bila enaka temperaturi okolice (segrevanje zaradi črpalk je bilo zanemarljivo).

Meritev je potekala takole. Ventil je bil odprt za določen gib. V tej točki smo merili pretoke ter padce tlaka pretočnega sistema in ventila. Iz strmine med dvema sosednjima točkama je bilo izračunano ojačenje ventila.

The tests took place under standard environmental conditions; water was used as the flow medium. The temperature of the flow medium was the same as the ambient temperature (heating caused by the pumps was negligible).

The measurement was performed as follows. The valve was opened until it reached a pre-set position. At this point, flow and pressure drops of the valves and system were measured accordingly. A gradient of two adjacent points was used to calculate the valve gain.



Sl. 11. *Rezultati meritev ojačenj K_v različnih statičnih pretočnih značilnic ventilov*
Fig. 11. *Gain measurements K_v of different static-control-valve flow characteristics*

Rezultati meritve so prikazani na sliki 11. Z nje je razvidno, da obstajajo določeni odstopki med izmerjenimi in izračunanimi rezultati. Do tega pride zaradi tega, ker strmina merjene pretočne značilnice ni povsem enaka nagibu teoretične pretočne značilnice. Smer zviševanja in zniževanja vrednosti krivulj je enaka teoretičnim za vse primere. V primeru poligonske pretočne značilnice preskok ni tako izrazito nezvezen zaradi njene realnosti, ki je tudi v točki temena zvezna.

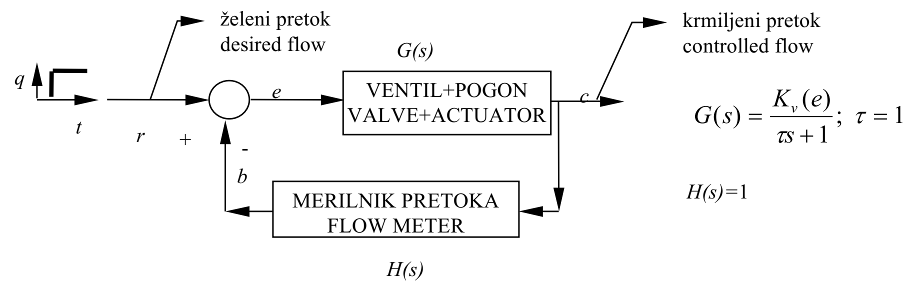
Measurement results are shown in Fig. 11. There is an evident difference between the measurements and the calculated results. The reason for this is because the slope of the measured-flow characteristics is not precisely the same as the slope of the theoretical flow characteristic. The growing and declining trends of the measured characteristic equals the theoretical models in all cases. The point where the polygonal-flow characteristic is discontinuous is not so steep, because we are dealing with a real curve, which is continuous through the whole range.

3 DINAMIČNI ODZIV

3 DYNAMIC RESPONSE

Dinamični odziv smo preskusili v zaprti krmilni zanki. Prenosna funkcija ventila in pogona je dobro znana, npr. iz literature [5]. Zamišljeni sistem je prikazan na sliki 12. Ob skočnem vzbujanju (od 0 % do 100 % pretoka tekočine) ventila in pogona lahko primerjamo, katera pretočna značilnica nima nihajoče prenosne funkcije.

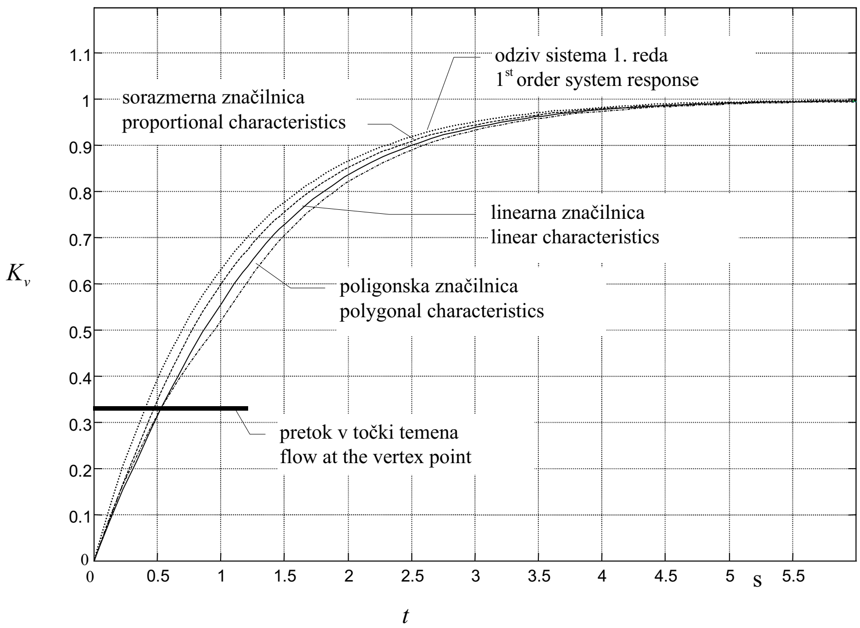
The dynamic response was tested in a closed control loop. The transfer function of the valve and actuator is well known from the literature, [5] . The hypothetical system is described in Fig. 12. Using the step exciting (from 0 % to 100 % of medium flow) of the valve and actuator it is possible to determine which flow characteristic does not have an oscillatory response.



Sl. 12. *Sistem za preverjanje dinamičnega obnašanja pretočnih značilnic*
Fig. 12. *Testing system for dynamic response of flow characteristics*

Primerjava med odgovori vseh treh značilnic je prikazana na sliki 13.

The comparison of responses of all three characteristics, see Fig. 13.



Sl. 13. *Simuliranje odziva na skočni vstopni signal v zaprti zanki za različne pretočne značilnice v odvisnosti od časa t*
Fig. 13. *Simulation of the flow characteristics response on step disturbance in a closed loop dependent on time t*

Simuliran odgovor na skočno motnjo dobimo s simuliranjem na računalniškem paketu Mathlab Simulink ([6] in [7]). Pri tem domnevamo, da se izvršni člen obnaša kot sistem prvega reda [5]:

The simulation was performed by means of the Mathlab Simulink computer programme, [6] and [7]. The procedure works under the assumption that the executive element behaves like the 1st order system lag [5]:

$$G_S = \frac{K_v}{\tau s + 1} \qquad (9).$$

Prenosna funkcija merilnika pretoka v povratni zanki je:

Transfer function of the flow meter in the feed-back loop:

$$H = 1 \qquad (10).$$

Torej je prenosna funkcija sistema:

The transfer function of the whole system:

$$G_S = \frac{G}{1+GH} = \frac{\frac{K_v}{1+K_v}}{\frac{\tau}{1+K_v}s+1} \qquad (11).$$

Z uporabo obratne Laplaceove transformacije dobimo za enotski koračni vhodni signal krmiljeni pretok tekočine:

Using the inverse Laplace transformation and input as the unit step, controlled flow is as follows:

$$c = \frac{K_v}{1+K_v}\left(1 - e^{-\frac{t(1+K_v)}{\tau}}\right)r;\; r = 1 \qquad (12).$$

Če primerjamo odgovor sistema (prikazan na sliki 12) med tremi različnimi pretočnimi značilnicami na skočno motnjo, vidimo, da so odgovori zelo podobni odgovoru sistema prvega reda, vendar dajo manjše vrednosti. Iz tega izhaja, da nelinearnosti v točki temena niso kritične. Simuliranje je normirano na relativni gib in pretok, ker lahko tako pokažemo relativne medsebojne odvisnosti.

The comparison of system responses on step input disturbance (see Fig. 12) for all three characteristics shows that the responses are very similar to the 1st order responses but give smaller values. The conclusion can be made that the nonlinearity in the vertex point is not critical. The simulation is calculated on the basis of relative travel and flow, to be able to demonstrate relative interdependence.

4 SKLEP

Prikazane so tri značilnice in njihova ojačenja. Ta smo primerjali tako statično kakor dinamično. Poleg tega pa so omenjene tudi tri različne metode določevanja točke temena poligonske pretočne značilnice.

Če pogledamo 1. metodo za določevanje točke temena značilnice, vidimo, da bi se ta morala spreminjati za vsako krmilno razmerje in mero linearnosti. To je zaradi spreminjanja točke temena s spreminjanjem mere linearnosti nepraktično. To pa zato, ker so krmilni ventili vgrajeni v različne sisteme, medtem ko spremembe točke temena zaradi krmilnega razmerja niso kritične, saj krmilno razmerje določi izdelovalec ventila. Iz primerjave med vsemi tremi metodami vidimo, da tretja metoda daje najmanjšo razliko med ojačenjema v točki temena, najmanjše ojačenje pri majhnih gibih pa dobimo po 1. metodi. 2. metoda je nekje vmes. Ojačenje pri majhnih gibih je vedno majhno in skoraj nespremenljivo, kar je zelo ugodno za krmiljenje manjših prostorninskih pretokov tekočin.

4 CONCLUSION

Three characteristics and their gain were compared from the static as well as the dynamic point of view. In addition, the article describes three different methods of determining the vertex point of the polygonal-flow characteristic.

If we take a closer look at the 1st method used for calculation of the flow characteristics, vertex point, we can see that the latter should be changed for every control ratio and authority. The change of vertex point caused by the control ratio is not decisive, because the valve producer determines the control ratio. On the other hand, the change of authority leads to problems, because control valves are designed to be mounted in different systems. The comparison of all three methods shows that the 3rd method has the smallest gain difference at the vertex point, while the smallest gain at the low travels is an attribute of the 1st method. The 2nd method is somewhere in between. Gain at low travels is always small and almost constant, being favourable for the control of lower volume flows.

Naš namen je bilo doseči čim manjše ojačenje pri majhnih gibih in čim krajši gib ventila, idealno pa je nespremenljivo ojačenje pretočne značilnice za vse gibe ventila. Na splošno najbolj zadosti tem potrebam poligonska pretočna značilnica, saj zagotavlja gib, ki je krajši od sorazmerne pretočne značilnice. Po drugi strani ima daljši gib od linearne pretočne značilnice, a dobimo manjše ojačenje vsaj do 30 odstotkov giba od linearne pretočne značilnice, vendar je ta hkrati večji od ojačenja sorazmerne pretočne značilnice. Pri večjih gibih pa imamo večje ojačenje (kar je ugodno za hitrejše odgovore krmilnega sistema) od linearne pretočne značilnice, a spet manjše kakor pri sorazmerni pretočni značilnici. Vendarle je poligonska pretočna značilnica nekaj vmes in torej primerna za uporabo skupaj s prenosniki toplote. Zelo velik problem je nezveznost pretočne značilnice, ki se še toliko bolj kaže v ojačenju pretočne značilnice. Pomembno je, da je prehod iz enega nagiba v drugi pri poligonski pretočni značilnici čimbolj gladek. Vprašanje, kakšnega reda mora biti krivulja, ki povezuje oba dela poligonske pretočne značilnice, da bo ta ohranila svoje lastnosti, je zanimivo za nadaljnje raziskave. Dejstvo je, da je potreben zvezni prehod med strminama, kar je tudi edino mogoče v praksi izdelati.

Eksperimentalna analiza je pokazala ujemanje med izračunanimi in dejansko izmerjenimi ojačenji pretočnih značilnic. Problem je v tem, da se računske in izmerjene pretočne značilnice popolnoma ne ujemajo in zato nismo dobili popolnoma enakih rezultatov. To je še posebej očitno pri poligonski pretočni značilnici, katere nezveznost ni opazna iz meritve. Poligonska pretočna značilnica je praktično vedno zvezna v točki temena. Izmerjene in simulirane vrednosti kažejo enake strmine, iz česar lahko sklepamo o verodostojnosti matematičnih modelov.

Iz simuliranega dinamičnega odgovora značilnice vidimo, da je odgovor podoben odgovoru prehoda prvega reda, kar je očitno iz reda vzbujane funkcije. Ojačenje se spreminja z gibom, kar pomeni, da je pomembno ojačenje pri majhnih gibih. Vsi trije odgovori so stabilni, prenihanja ni. Pri prehodu čez točko temena ne pride do nihanj pri poligonski pretočni značilnici kljub nezveznosti v ojačenju.

Poligonska pretočna značilnica je ustrezen nadomestek za sorazmerno v sistemih, kjer potrebujemo poleg visokega krmilnega razmerja še hiter odziv (to je kratek gib). Ta značilnica je primerna za cenejše sisteme, saj ni prava sorazmerna pretočna značilnica.

Our aim was to reach the smallest possible gain at low travels while keeping the valve travel short. The ideal solution would be a constant gain over the whole range of the valve's travel. In general, a polygonal-flow characteristic fulfils most of these requirements. It has a shorter travel than a proportional-flow characteristic and despite having longer travel than a linear-flow characteristic, it features a smaller gain for at least 30 % of the travel, it still has a larger gain than a proportional-flow characteristic. Higher gain occurs at larger travels, (which enable faster response of the control system) as with the linear-flow characteristic, but again slower than the proportional flow characteristic. Nevertheless, the polygonal-flow characteristic is a good choice and therefore suitable for use together with heat exchangers. A huge problem is the discontinuous form of the flow characteristic, which becomes even more evident at the valve gain. It is important to make the passage between different slopes as smooth as possible. The question about which order of the curve connecting both parts of the flow characteristic to maintain its properties is an interesting one for another research project. The fact is that the transition has only to be continuous, which is only feasible in real conditions.

Experimental analysis proved the accordance between the calculated and measured gains of the flow characteristics. The only problem is that the calculated and measured flow characteristics do not fit completely, thus giving a slight discrepancy to the results. It is quite obvious from the polygonal-flow characteristic, whose discontinuity is not evident from measurement. Measured and simulated curves have the same slopes, which lead us to believe in the credibility of the mathematical models.

Simulation of the dynamic response reveals that the response is similar to the response of the 1st order, which can be seen from the order of the exciting function. Gain changes along with travel, which means that gain is important at the lower part of the travel. All three responses are stable and without oscillations. Polygonal-flow characteristics show no oscillations even when passing through the vertex point, where the gain is supposed to be discontinuous.

The polygonal-flow characteristic is a suitable replacement for the proportional characteristic in systems where a high control ratio as well as a fast response (short travel) is required. This flow characteristic is ideal for cheaper systems, being a pseudo-proportional flow characteristic.

5 OZNAČBE
5 DESIGNATION

mera linearnosti	a	authority
merjeni pretok tekočine	b	measured flow of the liquid
krmiljeni pretok tekočine	c	controlled flow of the liquid
napaka krmiljenja	e	control error
prenosna funkcija ventila	$G(s)$	valve transfer function
prenosna funkcija sistema	G_s	system transfer function
prenosna funkcija merilnika pretoka	$H(s)$	flow meter transfer function
ojačenje krmilnega ventila	K_v	control valve gain
referenčni pretok	r	reference flow
krmilno razmerje	R	control ratio
prostorninski pretok tekočine	q	volume flow rate of the liquid
čas	t	time
relativni gib	X	relative travel of the valve
relativni gib v točki temena	X_k	relative travel at the vertex point of the characteristic
relativna pretočnost	Φ	inherent flow
relativna pretočnost v točki temena	Φ_k	inherent flow at the vertex point of the characteristic
časovna konstanta	τ	time constant

6 LITERATURA
6 REFERENCES

[1] Bobič, M., I. Bajsić (1997) Poligonska pretočna značilnica ventila. Zbornik mednarodnega kongresa SITHOK-2, Maj 11-12-1997, Maribor, Slovenija.
[2] Bajsić, I., M. Bobič (1998) Reducirana pretočnost krmilnega ventila, da ali ne ?, Strojniški vestnik, letnik 44, št. 7/8.
[3] Đonlagić, D., B. Tovornik (1997) Krmilni ventili. Fakulteta za elektrotehniko, računalništvo in informatiko, Univerza v Mariboru, Maribor.
[4] CEI/IEC 534: Industrial-process control valves (skupaj 8 delov)
[5] Smith, C. A., A. B. Corripio (1997) Principles and practice of automatic process control; Second edition, John Wiley & Sons, Inc., New York.
[6] Mathlab™ (1993) The MathWorks, Inc.
[7] Simulink™ dynamic system simulation software (1993) The MathWorks, Inc.

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