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WEAR MODELING IN SLURRY PIPELINES

MODELIRANJE HABANJA CEVOVODA ZA TRANSPORT HIDROMEŠAVINE

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Abstract: *Internal wear in slurry piping is of a great interest for users. There are two aspects of problems concern users: technical-a slurry pipeline is only as leakproof as it must worn-out; economical-a slurry pipelines only brings a profit as long as it continues to carry the load without leaking. As might be expected, the main concern of slurry pipelines users is to ensure the durability of such pipes and to predict the woking life.*

Where is the worn-out point is being forecast by common sense expirience, empirical determination in laboratories and by theoretical predictions.The problem is wery complex and a model proposed here, is a little contribution for it solving.

Key words: *modelling, wear, slurry, pipe, prediction.*

Apstrakt: *Unutrašnje habanje cevovoda, za transport hidromešavine, od posebnog je interesa za korisnika. Dva su aspekta ovog problema značjna za korisnika: tehnički-cevovod za transport hidromešavine je ili hermetičan ili pohaban-vodopropusan.; ekonomski- cevovod za transport hidromešavine donosi profit sve dok obezbeđuje transport bez curenja. Kao što se može očekivati glavna pažnja korisnika sistema, za transport hidromešavine, je usmerena na pouzdanost cevi i predviđanje radnog veka.*

Gde je tačka kraja radnog veka je posao predviđanja zasnovan na: empirijskim, eksperimentalnim i teorijskim razmatranjima. Posao je vrlo složen i model, predložen u ovom članku, je samo mali doprinos rešavanju ovog problema.

Ključne reči: *modeliranje. habanje, hidromešavina, cev, predviđanje.*

1 INTRODUCTION

The term erosion wear explain a loss of material under an impact of solid particles to the wall of pipe, [1], [2]. Wear mechanisms are stochastics processes and, to explain its by stochastic analysis we must to investigate a lot of influental factors.

There are two aproaches for solving this problem:

1 UVOD

Pod pojmom eroziono habanje podrazumeva se gubitak materijala pod dejstvom čestica čvrstog na zid cevi [1], [2]. Eroziono habanje je stohastički proces i može biti objašnjeno modelom koji zahteva istraživanje brojnih uticajnih veličina.

Dva su pristupa za rešavanje ovog problema:

- Loss of mass definitions, on the pilot or industrial plants;
- A theoretical analyisis, experiments in laboratories associated with a computer simulation of wear.

First access take a long time, it is expensive and the results can be only applied to the same conditions of the transport.

Computer simulation faster and cheaper gives a results acceptable for users. Modelling of the wear process, based to the experiments in laboratories, to the theory of erosion wear, to the theory of statistics and probability, must to involve the major and most common interaction between the: particles of solids, material of the pipe wall and slurry flow.

Some of the influental factors can be described as a frequency functions:

- $Y_1(d_s)$- characteristics of solids
- $Y_2(H_M)$- characteristics of material of which the pipe is made;
- $Y_3(c)$- characteristics of slurry flow.

A linear function, which describe a loss of mass:

$$E(t) = kf(I) \qquad (1)$$

where are: k-constant

$f(I)$- wear rate depends from the probable values $\Phi(Y_1, Y_2, Y_3)$, is a median of a family of function $f(I)$, Figure 1.

A model, proposed here, have to be simple, useable for computer application and it must to give a correct answer.

- Definisanje gubitka mase na pilot ili industrijskim postrojenjima;
- Teorijska analiza, eksperimenti u laboratorijama koji su praćeni kompjuterskom simulacijom habanja

Prvi pristup zahteva mnogo vremena radovi su skupi, a dobijeni rezultati mogu biti primenjeni samo za iste uslove transporta..

Kompjuterska simulacija brže i jevtinije daje rezultate prihvatljive za korisnika. Model procesa habanja zasnovan na eksperimentima u laboratorijama, teoriji erozionog habanja, teoriji statistike i verovatnoće, mora da uključi glavne i najčešće interakcije između: čestica čvrstog, materijala zida cevi i toka hidromešavine.

Neke od ovih uticajnih veličina mogu biti opisane funkcijom gustine raspodele:

- $Y_1(d_č)$, - karakteristika transportovanog materijala;
- $Y_2(H_M)$, - karakteristika materijala radnih elemenata;
- $Y_3(c)$, - karakteristika protoka.

Linearna funkcija, koja opisuje gubitak mase u vremenu:

$$E(t) = kf(I) \qquad (1)$$

gde su: k-konstanta;

$f(I)$- intenzivnost habanja koja zavisi od $\Phi(Y_1, Y_2, Y_3)$, je medijana familije funkcija $f(I)$, Slika 1.

Model, predložen ovde, mora da bude prost, prihvatljiv za primenu na računaru i mora da da korektne rezultate.

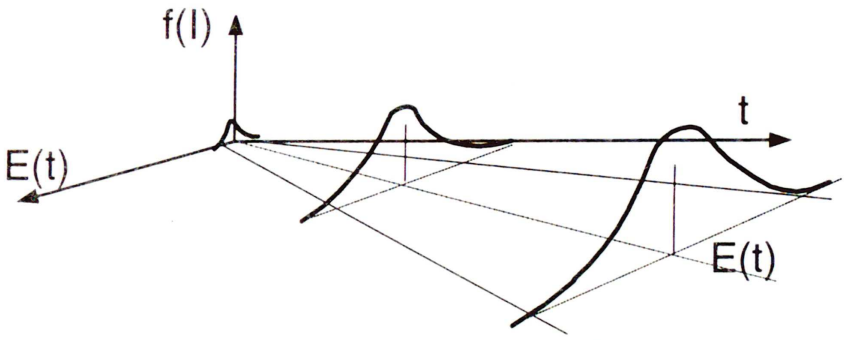


Figure 1 A posible realisation of E(t)
Slika 1 Moguće realizacije E(t)

2 CHARACTERISTICS OF SOLIDS $Y_1(d_č)$

Wear rate varies from the many influental factors: particle size, density, hardness of solids, particle shape, etc. Altrough along the lenght of the pipelines wear varies with the solid deformation this complex phenomenon will not be considered in this model.

Particle size of solid influent on the character of: slurry flow, particle - pipe wall contact, energy of impct, etc.

The particles can be regulary dispersed throughout the fluid, its may be concetrated or settle on the bottom of the pipe. The critical sedimetation velocity is a boundary between the settle and flow of solids.

For model, proposed here, a heterogeneous flow of slurry (slime) is analysed. In this case wear by impact is a dominant and energy of impact depends from the particle size $E \sim d_č^3$.

Particle size, defined in a laboratories, has a probable character and can be described as a frequency function $N_1(d_č)$ with a mean value $M_1(d_č) = \overline{d}_č$ and dispersion $D_1(d_č) = \sigma^2$ as a mean characteristics.

Dansity (ρ_a), hardness of solid (H_a) are connected with a mineralogical composition of rocks.

Mineral composition of rocks is a very changeable factor and hardness of particles must be described as a probable value $N_1(H_a)$.

A deviation of particle shape, from the ideal shape (sphere), is described through the coefficient K_1. For grind material $K_1 = 1$.
A mathematical model, which describe a characteristics of solid is:

$$Y_1(d_č) = K_1 \rho_a^{\frac{3}{2}} d_č^3 \qquad (2)$$

If the main influental factors $(d_č, \rho_a\ H_a)$ are probable values therefore a function $Y_1(d_č)$ is a frequency function, Figure 2, with a mean $M(Y_1) = \overline{Y}_1$ and a dispersion $D(Y_1) = \sigma^2$ as a main characteristics.

2 KARAKTERISTIKE ČVRSTOG MATERIJALA, $Y_1(d_č)$

Intezivnost habanja zavisi od mnogih uticajnih faktora: krupnoće čestica, tvrdoće čestica, pblika čestica, itd. Mada se, duž transportnog cevovoda, habanje menja sa deformacijom čvrstih čestica, ovaj složeni fenomen neće biti razmatran u ovom modelu.

Krupnoća čestica čvrstog utiče na karakter: toka hidromešavine, kontakta čestica-zid cevi, energije udara, itd.

Čestice mogu biti ravnomerno raspoređene u hidromešavini, mogu biti sa povećanom koncetracijom ili vučene po dnu cevi. Kritična brzina taloženja je granica između nataloženih i lebdećih čestica.

Za model, predložen ovde, analizira se heterogeno kretanje hidromešavine (flotacijska jalovina). U ovom slučaju habanje udarom je dominirajuće a energija udara zavisi od krupnoće čestica $E \sim d_č^3$.

Krupnoća čestica, definisana u laboratoriji, je verovatnosnog karaktera i može biti opisana funkcijom gustine raspodele $N_1(d_č)$ sa srednjom vrednošću $M_1(d_č) = \overline{d}_č$ i disperzijom $D_1(d_č) = \sigma^2$

Gustina (ρ_a), tvrdoća čvrstog (H_a) su zavisne od mineraloškog sastava stenskog materijala.

Mineraloški sastav stenskog materijala je vrlo promenjiva veličina pa gustina (tvrdoća) čestica može biti opisana kao verovatnosna vrednost $N_1(\rho_a)$.

Deformacija oblika čestica od idealnog oblika (lopta) se opisuje koeficijentom K_1. Za mleveni materijal $K_1 = 1$.

Matematički model, koji opisuje karakteristika čvrstog je:

$$Y_1(d_č) = K_1 \rho_a^{\frac{3}{2}} d_č^3 \qquad (2)$$

Ako su uticajne veličine $(d_č, \rho_a\ H_a)$ verovatnosne vrednosti onda je funkcija $Y_1(d_č)$ funkcija gustine raspodele, Slika 2, sa srednjom $M(Y_1) = \overline{Y}_1$ i disperzijom $D(Y_1) = \sigma^2$ kao glavnim karakteristikama.

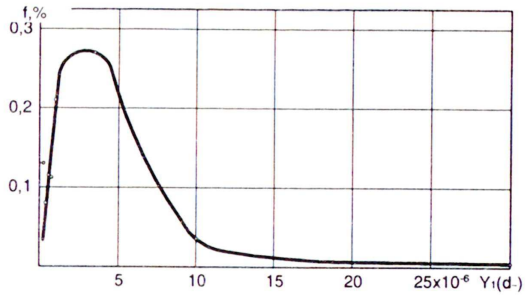


Figure 2 Function $Y_1(d_č)$
slika 2 Funkcija $Y_1(d_č)$

3 CHARACTERISTICS OF PIPES MATERIAL $Y_2(H_M)$

Dispite the fact that the materilals are nowdays technically very advanced, problems are still encountered where cost-intesive plant components break down as a result of premature wear.

A complexity of the particles-wall contact, stress due to shear, operating stress, corosion, cavitation, etc., made that the term „*wear resistance*" is a very dificult to define.

Wear resistance depends from the: density, chemical composition, hardness, elastic modulus, etc. [1].

For this model hardness of material [2] (metal), will be take as a main characteristics of wear resistance:

$$Y_2(H_M) = \left(\frac{1}{H_M}\right)^{\frac{3}{2}} \qquad (3)$$

Dependence $Y_2(H_M)$ is an probable value with a mean $E(Y_2) = \overline{Y}_2$ and dispersion $D(Y_2) = \sigma^2$ as a main characteristics, Figure 3.

3 KARAKTERISTIKE MATERIJALA CEVI, $Y_2(H_M)$

Uprkos činjenici da su materijali danas veoma razvijeni, problemi koji su povezani sa velikom potrošnjom, skupih delova postrojenja, zbog habanja su još uvek prisutni.

Složenost kontakta čestica-zid cevi, napon smicanja, značajna eksploataciona opterećenja, korozija, kavitacija, itd. čine da je pojam «*otpornost na habanje*» *vrlo* teško definisati.

Otpornost na habanje zavisi od: gustine, hemijskog sastava, modula elastičnosti, tvrdoće, itd. [1].

Za ovaj model tvrdoća materijala [2] (metal), je uzeta kao glavna karakteristika otpornosti na habanje:

$$Y_2(H_M) = \left(\frac{1}{H_M}\right)^{\frac{3}{2}} \qquad (3)$$

Zavisnost $Y_2(H_M)$ je slučajna veličina sa srednjom $E(Y_2) = \overline{Y}_2$ i disperzijom $D(Y_2) = \sigma^2$ kao glavnim pokazeteljima, slika 3.

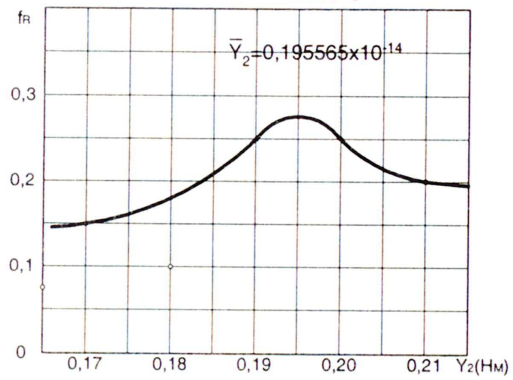


Figure 3 Function $Y_2(H_M)$
slika 5 Funkcija $Y_2(H_M)$

4 CHARACTERISTICS OF SLURRY FLOW $Y_3(c_M)$

Wear mechanisms are stochastic processes and to explain them by stochastic analysis we must first investigate the motion in the vicinity of the pipe's internal surface and then a model of impact.

For model, proposed here, we consider an influence of:

- Tangential c_T and normal c_N component of the velocity c;
- Impact angle $tg\beta_1 = \frac{c_T}{c_N}$;
- Concentration, particles reflection.

At the velocity c close to the sedimentation velocity c_s, a component c_N $[c_N=(0,1\text{-}0,2)c]$ of velocity c is a Gauss distribution[6]:

$$N(c) = 2140e^{-\frac{c_N^2}{0,02}} \qquad (4)$$

With a mean value $N(c_N)=\bar{c}_N$ .and dispersion $D(c_N)=\sigma^2$.

Impact angle of particles has a specific influence to the erosion wear of metal or unmetal materials. Wear of metalic material grow up to the impact angle of 20°, Fig. 4. Microcuttings is a dominant process of destruction. Wear of: plastics, ceramics, etc. is the most intesive under an imact angle of ~90°, Fig.4. Tear and crater formation are a dominant process of the destruction..

Impact angle is a changeable value g(α) and it depends from the slurry velocity c. Impact angle decrease with a slurry velocity increasing. For c $c \approx c_{kr}$ impact angle is 12° but for $c \approx 3c_{kr}$ this angle is 3°. In this model, a coefficient $K_2 = tg\beta_1 = \frac{c_T}{c_N} = const$. expresses an influence of impact angle to the wear process.

For heterogeneous flow of slurry dependence:

$$Y_3(c) = K_2 c_N^2 \qquad (5)$$

describe an influence of slurry flow characteristics to the wear process. The curve, Figure, is a median of the probability density of functions $Y_3(c)$.

3 KARAKTERISTIKE TOKA HIDROMEŠAVINE, $Y_3(c_M)$

Eroziono habanje je stohastički process i da bi smoga objasnili stohastičkom analizom mi moramo da znamo kretanje hidromešavine u blizini zida cevi kao i model udara čestice o zid cevi.

Za model, predložen ovde, razmatramo uticaj:

- Tangencijalne c_T i normalne c_N komponente brzine c;
- Ugla udara čestice $tg\beta_1 = \frac{c_T}{c_N}$;
- Koncetracije i refleksije čestica.

Pri brzinama bliskim kritičnoj brzini, komponenta c_N $[c_N=(0,1\text{-}0,2)c]$ brzine c je Gausova raspodela [6].

$$N(c) = 2140e^{-\frac{c_N^2}{0,02}} \qquad (4)$$

Sa srednjom vrednošću $N(c_N)=\bar{c}_N$. i disperzijom $D(c_N)=\sigma^2$.

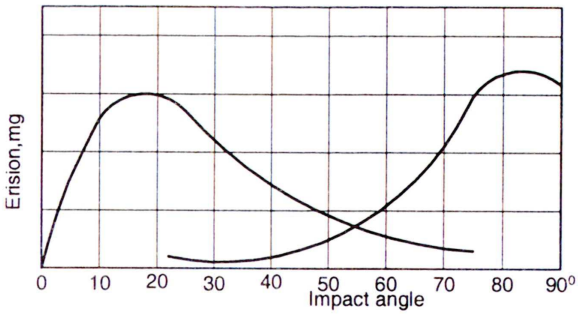
Ugao udara ima specifičan uticaj na eroziono habanje metaličnih i nemetaličnih materijala. Habanje metaličnih materijala brzo raste pri uglu udara do 20°, Sl. 4. Mikrorezanje je dominirajući proces razaranja,. Habanje: keramike, plastike, itd. je najintezivnije pri uglu udara od ~90°, Sl. 4. Otkidanje i formiranje kratera, su dominirajući načini razaranja.

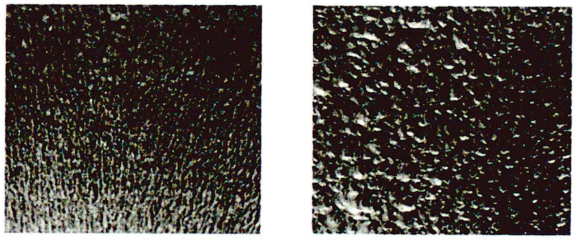
Ugao udara je promenjiva vrednost g(α) i zavisi od promene brzine hidromešavine c. Ugao opada sa porastom brzine toka. Za $c \approx c_{kr}$ ovaj ugao je 12° da bi pri $c \approx 3c_{kr}$ ovaj ugao bio 3°. U predloženi modela koeficijent: $K_2 = tg\beta_1 = \frac{c_T}{c_N} = const$. definiše uticaj ugla udara na habanje.

Za heterogeni tok hidromešavine zavisnost:

$$Y_3(c) = aK_2 c_N^2 \qquad (5)$$

opisuje uticaj karakteristika toka hidromešavine na process habanja. Kriva, slika 5, je medijana funkcija gustine raspodele $Y_3(c)$.





~20° ~90°

Figure 4 Wear of still plate [2]
sika 4 Habanja čelične pločice [2].

4. EROSION WEAR MODELLING

Algoritam, based on the model of wear by impact of one particle [5] is:

$$V = K_1 \left[d_č^3 c_N^2 \left(\frac{\rho_a}{H_M} \right)^{\frac{3}{2}} \right] \qquad (6)$$

A number of the impact which bring to the destuction of the materila is defined by:

$$n_c = \left(\frac{3\pi\sigma_0\theta}{4K_o f} \sqrt{\frac{r}{h}} \right)^t \qquad (7)$$

where are: σ_o-stress failing of material, MPa;

$\theta = \frac{1-\mu^2}{E_M}$ -elastic constant, MPa^{-1};

$K_o = 3$ - constant;

f - friction coefficient;

$\frac{r}{h} = \frac{2H_M}{\sigma_č}$ - condition of transition to the microcutting;

$\sigma_č$ - stress failing of solid, MPa;

t - coefficient of fricion fatigue.

Wear rate, a relation between the mass of the worn material to the mass of the material which wear:

4. MODELIRANJE HABANJA

Algoritam je baziran na modelu habanja udarom jedinične čestice [5]:

$$V = K_1 \left[d_č^3 c_N^2 \left(\frac{\rho_a}{H_M} \right)^{\frac{3}{2}} \right] \qquad (6)$$

Broj ciklusa udara koji dovodi do razaranja materijala se definiše izrazom [6]:

$$n_c = \left(\frac{3\pi\sigma_č\theta}{4K_o f} \sqrt{\frac{r}{h}} \right)^t \qquad (7)$$

gde su: σ_o-napon granici kidanja, MPa;

$\theta = \frac{1-\mu^2}{E_M}$ -elastična konst.,MPa^{-1};

$K_o = 3$ - konstanta;

f - koeficijent trenja;

$\frac{r}{h} = \frac{2H_M}{\sigma_č}$ - uslov prelaska na mikrorezanje;

$\sigma_č$ - napon razaranja čvrstog, MPa;

t - koeficijent frikcionog zamora.

Intezivnost habanja, definisana kao odnos mase pohabanog materijala i mase materijala koji haba:

$$I = \frac{a\rho_M V}{nC_z \rho_č V_o} \quad (8)$$

is a probable function, Fig 6.

$$I = \frac{a\rho_M V}{nC_z \rho_č V_o} \quad (8)$$

je funkcija verovatnoće, slika 6.

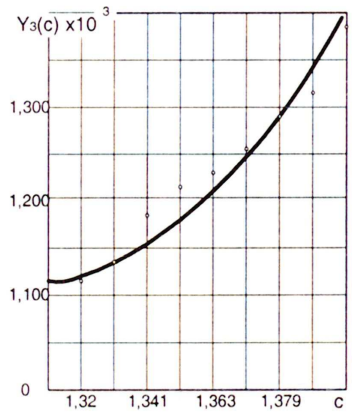


Figure 5 Curve $Y_3(c)$
slika 5 Kriva $Y_3(c)$

A coefficient *"a"*:

$$a = \frac{0,4}{0,4 + C_z^{\frac{3}{2}}} \quad (9)$$

express an influence of the particles reflection to the wear process. A corrective factor:

$$C_z = C_{zo} e^{-\frac{ch}{\varepsilon}} \quad (10)$$

$0<h<D$, for $h=0$ $C_z=C_{zo}$.

for solids distribution have to be a part of equation (8).

Koeficijent „a“:

$$a = \frac{0,4}{0,4 + C_z^{\frac{3}{2}}} \quad (9)$$

definiše uticaj refleksija čestica na proces habanja. Korektivni faktor:

$$C_z = C_{zo} e^{-\frac{ch}{\varepsilon}} \quad (10)$$

$0<h<D$, for $h=0$ $C_z=C_{zo}$.

za neravnomernu distribuciju čvrstog mora da bude deo jednačine (8).

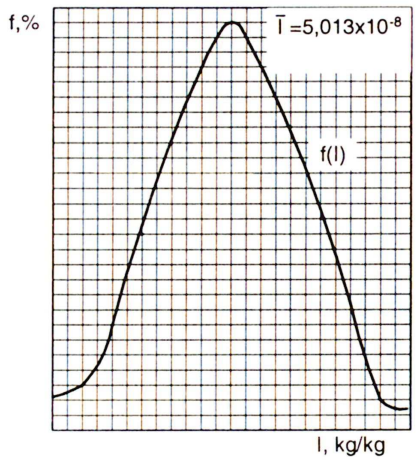


Figure 6 Wear rate, frequency function
slika 6 Intezivnost habanja, gustina raspodele

5. CONCLUSION

This model is based on the assumptions that the main influental factors have a probable character. The reasons for this are.

- Numerious of solid characteristics: particle size, mineralogical composition, hardness, desity, etc. are changeable values;
- The results of the measurement of the characteristics of the solids and pipe's material have a wide limits of trusts.
- It is a very dificult to define a main characteristics of slurry flow because of turbulent character.

A model, proposed here, gives a results usable for practice, reduce a time and a costs of investigations.

This model, by some adaptation, can be applied for wear rate definition for: valves, elbow, pumps parts, etc.

5. ZAKLJUČAK

Pri formiranju predloženog modela autor je prihvatio nedeterministički karakter većeg broja uticajnih veličina. Razloga za ovaj pristup ima više:

- Brojne karakteristike, čvrstog krupnoća, mineraloški sastav, tvrdoća, gustina, itd. su veoma promenjive vrednosti;
- Rezultati merenja, izvršena na opitnim uzorcima materijala cevi: tvrdoća, gustina modul elastičnosti, itd, imaju široku granicu poverenja;
- Vrlo je teško definisati karakteristike toka zbog njegovog turbulentnog karaktera.

Model, predložen ovde, daje rezulte koji su prihvatljivi za praksu, smanjuje vreme i troškove istraživanja.

Model se, uz neka prilagođavanja može uspešno koristiti za definisanje habanja: ventila, kolena, delova pumpe, itd.

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