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Contributions of Correlations of the Cavitational Erosion Parameter 1/*MDPR* with the Functional Parameters of Laboratory Station

The paper establishes two relations for the correlation of the value 1/MDPR with the running parameters of the vibratory apparatuses (vibrations amplitude A, frequency of the vibrations f and specimen diameter d). The starting point of our improvement were the relations given by Steller [1]. *In the present contribution the values of the coefficients α, β, γ are significantly modified taking into account a great number of the correlated results obtained in the laboratories of Gdansk and Michigan but also at the Hydraulic Machinery Laboratory of Timisoara (LMHT). As a standard, the Michigan vibratory facility* (f = 20 kHz, A = 25,4 μm, d = 14,3 mm) *was chosen. Depending on the numerical values of the three exponents, their significance is thoroughly interpreted.*

Keywords: *erosion, cavitation, parameter, device, exponent*

1. INTRODUCTION

Materials destruction by cavitational erosion is a complex process depending upon the hydrodynamics of the process and on the factors that determine the materials nature. The hydrodynamic nature of the process also depends on the type of the industrial machine and on the laboratory station, respectively. So, for the vibrator devices – as are the magnetostiction oscillator T1 and the piezoceramics T2, in the Laboratory of Hydraulic Machines from Timişoara (LMHT) – the parameters that influence the hydrodynamics of cavitation are: the amplitude and frequency of vibration; temperature; liquid nature; the diameter of the sample and acoustical power [2], [3], [4], [5].

The material characteristic parameters with a powerful influence on the physical-mechanical character of the cavitational erosion are [2], [3], [6]: flowing limit $R_{p0,2}$; the ultimate resistance of the material R_m; the longitudinal module of elasticity E; the elongation A_5; hardness; the breaking resistance *KCU*, the final resilience *UR* ($UR = R_\mathrm{m}/(2E)$)- non-standard measure; analytically determined by field measurement [2], [3]).

The correlation of the parameters characteristic to the hydrodynamics of cavitation with those that determine the parameters of the material can lead to a general equation which can model the material destruction through cavitation. This objective could not be achieved until today, because of the complexity of the phenomenon and of the diversity of the factors involved. These are the reasons why the scale effect is a problem which has been solved step by step.

One of the directions followed (in solving the scale effect) but unsolved till now is the correlation between the parameter 1/*MDPR* of cavitational erosion with the functional parameters of the installation and of the laboratory station, respectively.

In the paper this problem is thoroughly analysed taking into account the experimental results obtained with the devices T1 and T2, from LMHT, by establishing a relation that enables us to transfer the results from one apparatus to another. Also, the relations are used for transferring the results to the vibratory device from Michigan, considered by the ASTM [1] as a standard.

2. THE CORRELATION RELATION

2.1. The shape of the relation

Steller made the simplifying hypothesis that the medium depth penetration rate (*MDPR*) depends mostly on: the amplitude of oscillation of the vibrator station (A); the frequency of oscillation (f) and of the diameter of the eroded area (d) [7]. In this situation he considers that for cavitational destruction of the same material tested by *MDPR* (mean depth penetration rate, in mm/hours), in the case of using different vibrator device, there is the following relation:

$$\frac{MDPR_1}{MDPR_2} = \left[\frac{A_1}{A_2}\right]^{\alpha} \cdot \left[\frac{f_1}{f_2}\right]^{\beta} \cdot \left[\frac{d_1}{d_2}\right]^{\gamma}. \qquad (1)$$

MDPR can be obtained by dividing the volume of the eroded material to the eroded area (considered as having the diameter d) and to the total testing time; it represents the degree of destruction (the 1/*MDPR* parameter can be considered as the cavitational resistance).

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The values of the exponents α, β and γ depend on the type of the material [8]:

- for stainless steel 316 SS: $\alpha = 1{,}2$; $\beta = 0{,}58$; $\gamma = -0{,}17$;
- for 270 Ni: $\alpha = 1{,}55$, $\beta = 0{,}83$, $\gamma = -0{,}53$;
- for 6061-T651Al: $\alpha = 1{,}72$, $\beta = 1{,}06$, $\gamma = -0{,}14$.

The values of the exponents α, β and γ are the expression of the capacity of the material to absorb the energy developed during the implosions and is determined by the parameters A, f, d.

The indicator MDPR shows the advantage of the unique quantitative parameter; but it has the following disadvantages: it takes into account only the lost volume of material at the end of testing instead of the evolution in time of the material losses; it is difficult to apply to the industrial cavitation where the total eroded volume is difficult to determine; it is an indicator with dimensions, mm/hours; the cavitation wear is rather non-uniform in the area of the circle, having the diameter d [2]. Following the mentioned disadvantages in the correlation of various materials, there will be some distortions.

2.2. Determination of the values of the exponents α, β, γ, for the devices in LMHT

Using the results obtained by:

- Bordeasu [2] for 5 steels, 2 bronzes and a naval brass tested in the vibrator device T1 and 11 steels, 2 bronzes and a naval brass tested in the vibrator device T2, respectively;
- Sisak, Kuzman and Potencz [2] for 7 steels tested on the vibrator device T1;

and using programs for statistical processing the fraction $(MDPR)_{T2}/(MDPR)_{T1}$ with the ratio $(A^{\alpha} \cdot f^{\beta} \cdot d^{\gamma})_{T2}/(A^{\alpha} \cdot f^{\beta} \cdot d^{\gamma})_{T1}$ according to the relation:

$$\frac{(MDPR)_{T2}}{(MDPR)_{T1}} = \frac{\left(A^{\alpha} \cdot f^{\beta} \cdot d^{\gamma}\right)_{T2}}{\left(A^{\alpha} \cdot f^{\beta} \cdot d^{\beta}\right)_{T1}}, \qquad (2)$$

and the following values were obtained:

$$\alpha = 4{,}32, \ \beta = 1{,}01, \ \gamma = -1{,}25, \qquad (3)$$

after the Steller's model with a negative coefficient γ and

$$\alpha = 4{,}45, \ \beta = 1{,}01, \ \gamma = 0{,}15, \qquad (4)$$

a new shape with a positive coefficient γ.

In the relation (2) the diameter d is the average value of the circular cavitational corroded mark, measured on two perpendicularly directions (for the device T1, magnetostriction oscillator, $d = 9{,}8\,\text{mm}$; and for the device T2, piezoelectric crystal vibrator, $d = 11{,}5\,\text{mm}$).

The values of the exponents α, β and γ are an expression of the role of the parameters A, f and d at the energy transfer towards the material during the cavitational attack. The positive values show that these parameters ensure the enhancing of the energy transferred towards the material, the negative values show the dissipation of this energy. This aspect is the reason why the case has been searched with all exponents having positive values.

Transposing the results from the vibrator device T2 to the vibrator device T1, Table 1, by the relations:

$$\left(\frac{1}{MDPR}\right)_{T2-T1} = \\ = \frac{(A^{4,32} \cdot f^{0,96} \cdot d^{-1,25})_{T2}}{(A^{4,32} \cdot f^{0,96} \cdot d^{-1,25})_{T1}} \cdot \left(\frac{1}{\text{MDPR}}\right)_{T2} \qquad (5)$$

and

$$\left(\frac{1}{\text{MDPR}}\right)_{T2-T1} = \\ = \frac{(A^{4,45} \cdot f^{1,01} \cdot d^{-0,15})_{T2}}{(A^{4,45} \cdot f^{1,01} \cdot d^{-0,15})_{T1}} \cdot \left(\frac{1}{\text{MDPR}}\right)_{T2}, \qquad (6)$$

respectively, one ascertains that the differences between the values obtained with both relations are reduced.

In the tables 1a to 1e the transposing of the experimental results from the vibrator device T2 to the vibrator device T1 are given. The marks To7* and T09* mean: stainless steel T07-CuMoMnNiCr 165-Nb and stainless steel T09-CuMoMnNiCr 185-Ti.

Analysing the data in Table 1a to 1e, one ascertains that the device T1 has a destructive intensity two times higher than that of the device T2. Also, when ordering the materials following the parameter 1/*MDPR* calculated for T1 and those obtained by extrapolation with the relations (5) and (6), some changes of places between materials having close resistance can be seen: stainless steel III-RNR, T09CuMoMnNiCr 185-Ti and CuNiAl III-RNR, on one hand, and on the other hand.carbon steel I RNR, CuNiAl I-RNR and 40Cr10, respectively. But these changes of places do not modify the class of cavitational erosion resistance of those materials.

Table 1a

No. crt.	Materials	$\frac{1}{MDPR}$ [hours/mm]	
		T1	**T2**
1	OLC 15	48	93,3
2	Ol370-3k	16,2	22,97
3	33MoCr11	58,8	118,52
4	**40Cr10**	**31**	**61,96**
5	18M0CrNi13	66,1	111,14
6	**Carbon I -RNR**	**28,03**	**52,89**
7	D-32	14,22	24,81
8	**Stainless steel III-RNR**	**76**	**149,55**
9	T07*	83	178,52
10	**T09***	**79,5**	**148,77**
11	20Cr130	39,7	94,89
12	**CuNiAl III-RNR**	**76,3**	**166,07**
13	**CuNiAl I-RNR**	**38,2**	**53,5**
14	Naval Brass	16,4	36,66

Table 1b

No. crt.	Materials	$\dfrac{\left(\frac{1}{MDPR}\right)_{\mathrm{T1}}}{\left(\frac{1}{MDPR}\right)_{\mathrm{T2}}}$
1	OLC 15	0,51
2	Ol370-3k	0,70
3	33MoCr11	0,49
4	**40Cr10**	0,5
5	18M0CrNi13	0,59
6	**Carbon I -RNR**	0,53
7	D-32	0,57
8	**Stainless steel III-RNR**	0,50
9	T07*	0,46
10	**T09***	0,53
11	20Cr130	0,41
12	**CuNiAl III-RNR**	0,46
13	**CuNiAl I-RNR**	0,71
14	Naval Brass	0,44

Table 1c

No. crt.	Materials	$\left(\frac{1}{MDPR}\right)_{T1-T2}$ [hours/mm] (rel.5)
1	OLC 15	48,6
2	Ol370-3k	12
3	33MoCr11	61,7
4	**40Cr10**	**32,3**
5	18M0CrNi13	57,9
6	**Carbon I -RNR**	**27,5**
7	D-32	12,9
8	**Stainless steelIII-RNR**	**77,9**
9	T07*	92,9
10	**T09***	**77,4**
11	20Cr130	49,4
12	**CuNiAl III-RNR**	**86,5**
13	**CuNiAl I-RNR**	**27,9**
14	Naval Brass	19,1

Table 1d

No. crt.	Materials	$\left(\frac{1}{MDPR}\right)_{\mathrm{T1-T2}}$ [hours/mm] (rel.6)
1	OLC 15	48,7
2	Ol370-3k	19
3	33MoCr11	61,8
4	**40Cr10**	**32,3**
5	18M0CrNi13	58,1
6	**Carbon I -RNR**	**27,6**
7	D-32	12,9
8	**Stainless steel III-RNR**	**78**
9	T07*	93,2
10	**T09***	**77,6**
11	20Cr130	49,5
12	**CuNiAl III-RNR**	**86,7**
13	**CuNiAl I-RNR**	**26,9**
14	Naval Brass	19,1

Table 1e

No. crt.	Materials	Cavitation Resistance [2]
1	OLC 15	Very good
2	Ol370-3k	Low
3	33MoCr11	Excellent
4	**40Cr10**	**Good**
5	18M0CrNi13	Very good
6	**Carbon I -RNR**	**Good**
7	D-32	Low
8	**Stainless steel III-RNR**	**Excellent**
9	T07*	Excellent
10	**T09***	Excellent
11	20Cr130	Very good
12	**CuNiAl III-RNR**	Excellent
13	**CuNiAl I-RNR**	**Good**
14	Naval Brass	Low

2.3. Correlation of the results from various laboratories

For the cross examination of the degree of generality of relations (5) and (6), there will be considered a standard apparatus and the results, obtained in various devices other than T1 and T2 will be used.

As a standard apparatus we consider the vibrator device with piezoelectric crystals from Michigan ($f = 20\,\mathrm{kHz}$, $A = 25{,}4\,\mu\mathrm{m}$, $d = 14{,}3\,\mathrm{mm}$) [9]. As results we shall use those obtained by Garcia [9] for 6 steels tested in the device from Michigan and those obtained by Steller [7] for two steels tested in the vibrator device from Gdansk ($f = 8{,}1\,\mathrm{kHz}$, $A = 50\,\mu\mathrm{m}$, $d = 12{,}5\,\mathrm{mm}$), Table 2.

For transposing all of the results read at the standard device, the relations (5) and (6) take the shape (7) and (8). In Table 3 the values are shown, as obtained with the new relations. From this table we can see that the differences between the values transposed with the relations (7) and (8) are not meaningful.

$$\left(\frac{1}{MDPR}\right)_{i-M} = \frac{(A^{4,32}\cdot f^{0,96}\cdot d^{-1,25})_i}{(A^{4,32}\cdot f^{0,96}\cdot d^{-1,25})_M}\cdot\left(\frac{1}{MDPR}\right)_i, \qquad (7)$$

respectively

$$\left(\frac{1}{MDPR}\right)_{i-M} = \frac{(A^{4,45}\cdot f^{1,01}\cdot d^{0,15})_i}{(A^{4,45}\cdot f^{1,01}\cdot d^{0,15})_M}\cdot\left(\frac{1}{MDPR}\right)_i. \qquad (8)$$

Here M – is the standard device from Michigan, $i = \mathrm{T1}, \mathrm{T2}, \mathrm{G}$ – means the vibrator devices from LMHT and Gdansk (used by Steller [1]).

Table 2

Materials	$\frac{1}{MDPR}$ [hours/mm]	REFERENCES
Carbon steel	171,17	3
304 SS	393,7	3
316 SS	437,44	3
Mo-1/2 Ti	237,44	3
Cb-IZr	269,54	3
Cb-IZr(A)	218,72	3
OLC45	41,66	7
Mild steel	26,3	7

Table 3

Crt. Nr.	Materials	$\left(\frac{1}{MDPR}\right)_{i-M}$ [hours/min] relation (7)	$\left(\frac{1}{MDPR}\right)_{i-M}$ [hours/min] relation (8)
1	OLC 15 (T1)	256,8	256,3
2	33MoCr11 (T1)	314,6	313,9
3	18M0CrNi13 (T1)	353,7	352,9
4	Stainless steel III-RNR (T1)	406,6	405,8
5	T07-CuMoMnNiCr 165-Nb (T1)	444,1	443,1
6	T09-CuMoMnNiCr 185-Ti (T1)	425,4	424,4
7	OLC 15 (T2)	259,9	260
8	33MoCr11 (T2)	330,1	330,2
9	18M0CrNi13 (T2)	309,6	309,7
10	Stainless steel III-RNR (T2)	416,5	416,5
11	T07-CuMoMnNiCr 165-Nb (T2)	497,2	497,2
12	T09-CuMoMnNiCr 185-Ti (T2)	414,4	414,5
13	304 SS	393,7	393,7
14	316SS	437,44	437,44
15	Mo-1/2 Ti	437,44	437,44
16	Cb-I Zr	269,54	269,54
17	Cb-I Zr(A)	218,72	218,72
18	Carbon steel	171,17	171,17
19	OLC 45	243,8	210,7
20	Mild steel	386	333,7

The data from Table 3 show that the relations (7) and (8) can serve, in this form, for the comparison and ordination of the materials, respectively, following their cavitational erosion resistance. Also, these relations can be used for comparing the tested materials in vibrator devices with different operational parameters but in the same testing conditions the parameters and temperature of liquid medium.

3. CONCLUSIONS

1. The relation of Steller has been studied more attentively at a number of 22 materials, 14 tested on vibrator devices T1 and T2, from the LMHT, enabling the generalisation of the values of the exponents α, β and γ.
2. As a standard vibrator device, the Michigan one, has been admitted (recognised by ASTM from USA [11]) and the relations (7) and (8) have been built, which helped the transposing, at the standard device, of the parameter $1/MDPR$ calculated for the steels tested in the devices from Gdansk and Timişoara.
3. The relations (7) and (8) (by the new values of the exponents α, β and γ.) have a greater degree of generalisation than relation (1) established by Steller. Also, relations (7) and (8) can serve for the comparison and ordination of materials, respectively, following their resistance factors to cavitational erosion. This comparison is also possible for the materials tested in identical conditions, in a vibrator device with different operational parameters.

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