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# MODELING OF WEAR DISTRIBUTION BETWEEN TRIBOELEMENTS OF DIRECT AND INVERSE STRUCTURES OF TRIBOSYSTEMS

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*The paper presents mathematical expressions to determine the weighting coefficient of the wear rate increase of triboelements of inverse structures of tribosystems compared with direct structures which are necessary to apply for modeling the wear distribution between triboelements in tribosystems in the design phase of new machines.*

**The topicality of the issue.** According to the classification, presented in the work [1], the variety of the tribosystems that the machine constructions and mechanisms consist of is divided into direct and inverse. The tribosystem consists of such structures where the movable element is made of harder material than the immovable one and it also has larger friction area than the immovable element. On changing the layout of the materials on its hardness in the tribosystem or the frictional area values of movable and immovable triboelements, the wear rate value is supposed to change which is important to take into account on forecasting the resource in the design phase of the new machines.

**The analysis of the published works devoted to the current issue.** Basing on G. Tsigler's work [2], the authors of the works [3 – 5] have developed the methodical approach in modeling the distribution of dissipation work rate between triboelements in the tribosystem. It is concluded in the mentioned above works that, having the same stress intensity in the materials of the triboelements on the single factual contact spot, the speed of deformation significantly differs as physical-mechanical properties of the triboelements' materials differ.

The ultimate expression for calculating the dissipation work rate, including the deformed volume of the surface layer on friction, has been obtained in the works [6, 7]. Using the parameter, the dissipation work rate, it is possible to define the "capacity" of the triboelements in the tribosystem. In the works mentioned above [3-7], the functional connection is shown between wear, losses on friction of the tribosystems and the dissipation work speed in the tribosystem.

The further development of the given approach is presented in the works

[8, 9] where the mathematical expressions have been obtained for modeling the wear rate and the friction coefficient. However, these expressions are true only for direct structures of tribosystems.

**The purpose of the research** in the present work is to define the weighting coefficients G which are necessary to be used in the formulas for calculating the wear rate of movable and immovable triboelements in the inverse structures of the tribosystems.

**The methodical approach in the research process.** Make mathematical modeling of wear rate by the formulas of the works [8, 9] and experimental check of the modeling results of different structures of the tribosystems.

Modeling and experimental researches were made for the tribosystem "ring-ring" with coefficient of relative overlap 0,5, therefore the friction area was $F_{тр}$ = 0,00015 *м*$^2$. The roughness of friction surfaces of both triboelements: $Ra$ = 0,2 *mkm;* $S_m$ = 0,4 *mm*. The lubricating medium is motor oil М-10$Г_2$: $E_y$ = 3,209·10$^{14}$ *J/m*$^3$, the sliding speed $v$ = 0,5 *m/s.* In the course of the research the load changed $N$ = 400…1200 *H.*

**The results of the research.** Figure 1 – 3 present the results of the mathematical modeling (full lines) and the results of the experimental researches (dotted lines) for the combination of the materials and friction areas which match the structure of the direct tribosystem.

On combining the same materials of the movable and immovable triboelements, for example, steel 40X + steel 40X (HRC = 56), the wear rate in both triboelements is the same that is shown with a single full line for modeling and a dotted line for the experiment in Figure 1. The modeling error was not more than 14 %.

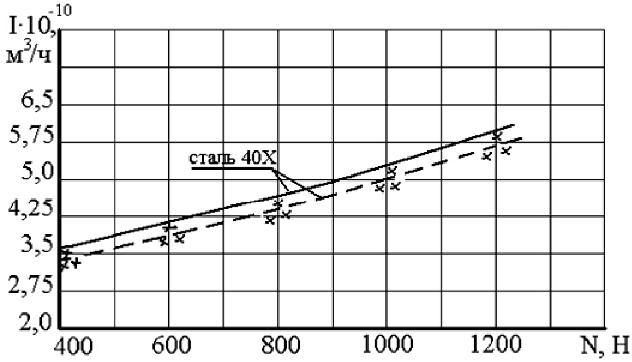


Fig 1. The functions of wear rate of the movable 40X and immovable steel 40X triboelements of the direct tribosystem:
________ calculation; _ _ _ _ _ experiment

Using a softer material, grey iron GI (HB = 285), as an immovable triboelement and steel 40X (HRC = 56) as a movable one, the distribution of wear rate values have changed, Figure 2. The immovable triboelement has 1,42 times more wear rate in comparison with the movable one.

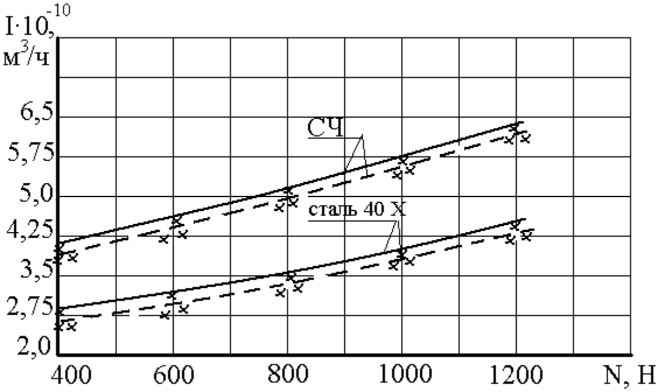


Fig 2. The function of wear rate of the movable steel 40X and immovable grey iron triboelements of the direct tribosystem:
________ calculation; _ _ _ _ _ experiment

On further increase of the differences between the hardness of movable and immovable triboelements the difference in the wear rate increases. The results of modeling and experimental researches for the tribosystem are presented in the Figure 3: the immovable triboelement "Бр. АЖ 9-4" (HB 110) and the movable triboelement steel 40X (HRC56).

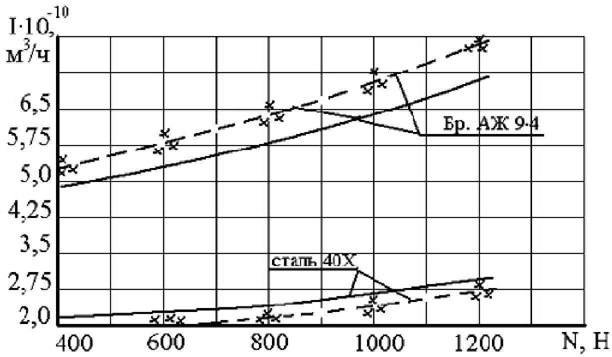


Fig 3. The function of wear rate of the movable steel 40X and immovable "Бр. АЖ 9-4" triboelements of the direct tribosystem:
________ calculation; _ _ _ _ _ experiment

The present research may be the basis for the conclusion that the difference in hardness between movable and immovable triboelements is the function of their wear rate.

The functions of wear rate for the inverse structures of the tribosystems were obtained experimentally: inverse tribosystem on materials (ITM); inverse tribosystem on geometry (ITG) and inverse tribosystem on materials and geometry at the same time (ITMG).

The inverse tribosystem on materials, in contrast to the direct one, has less hard material as a movable triboelement than the immovable one and the place of the friction areas is the same like in the direct tribosystem. The place of friction areas of the inverse tribosystem on geometry, comparing with the direct tribosystem, is changed and the place of materials in hardness responds the direct tribosystem.

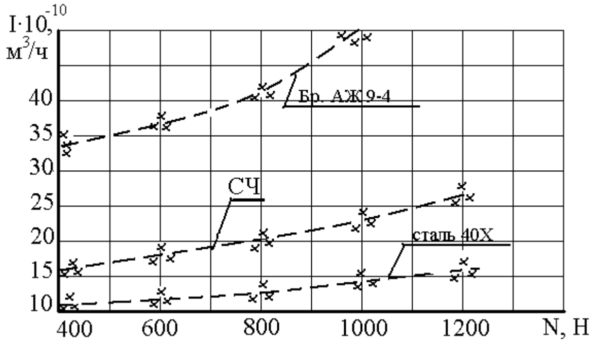


Fig.4. Experimental functions of wear rate of movable and immovable triboelements of the inverse tribosystem on material and inverse tribosystem on geometry.

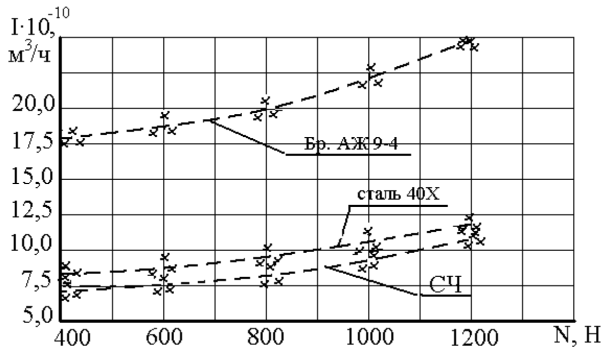


Fig.5. Experimental functions of wear rate of movable (“СЧ” and “Бр. АЖ 9-4”) and immovable “сталь 40Х” (steel 40X) triboelements of the inverse tribosystem on materials and geometry at the same time.

The functions of wear rate of ITM and ITG have turned out to be the same and they are presented in Figure 4. The wear rate of the triboelement made of steel 40X has increased 2,85 times compared with the direct tribosystem, made of grey iron – 8,53 times and of “Бр. АЖ 9-4” (Bronze Aluminum Iron 9-4) – 8,3 times that also confirms the fact that there is functional relation between the difference in hardness between the materials of movable and immovable triboelements.

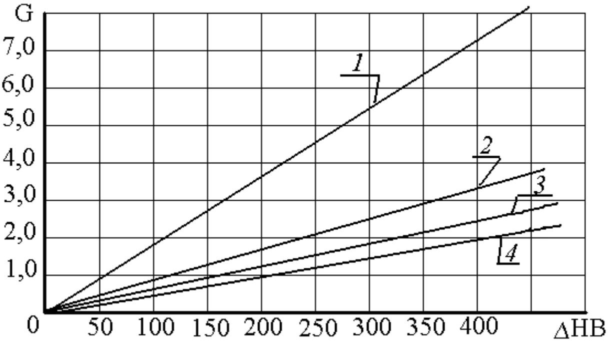


Fig 6. The functions of the weighting coefficients from the difference in hardness between movable and immovable triboelements:
1, 3 – *ITM (ITG)*; 2, 4 – *ITMG*

The functions of wear rate for ITMG where, comparing with the direct tribosystem, the place of materials and the fiction areas are changed at the same time, are presented in Figure 5. The analysis of wear rate enables to consider that, comparing with the direct tribosystem, the triboelement of steel 40X has 2,1 times more wear speed, the one of grey iron – 1,78 times and of “Бр. АЖ 9-4” (Bronze Aluminum Iron 9-4 ) – 3,56 times.

It should be noted that the values of friction coefficients of the direct and inverse tribosystems are not changeable.

The performed experimental research of the direct and inverse structures of the tribosystems has made it possible to get the functions of the weighting coefficients G for movable and immovable triboelements. The weighting coefficient G considers how many times the wear rate of the triboelements of the inverse tribosystems increases compared with the direct ones. The obtained functions are presented in Figure 6 and consider the difference in hardness on *HB* scale between the materials of the triboelements, Δ*HB*.

By means of the method of least squares, the regression equations for the functions (1 – 4) in Figure 6 were obtained.

The function (1) specifies the weighting coefficient value of the triboelement for ITM and ITG, made of softer material comparing with the other contacting material in the tribosystem. For ITM – it is a movable triboelement with bigger area. For ITG it is an immovable triboelement also with bigger friction area. The calculation of such coefficient is made by formula:

$$G^{м}_{ITM(ITG)} = 18{,}44 \cdot 10^{-3} \Delta HB \tag{1}$$

where $\Delta HB$ is the difference in hardness of the materials in the tribosystem on *HB* scale.

The function (2), Figure 6, specifies the changes of the weighting coefficient for a softer, a movable triboelement ITMG:

$$G^{м}_{ITMG} = 7{,}91 \cdot 10^{-3} \Delta HB \tag{2}$$

The function (3) specifies the weighting coefficient value for the triboelements ITM and ITG, made of harder material in the tribosystem. For ITM it is an immovable triboelement and for ITG it is a movable triboelement with less friction area.

$$G^{T}_{ITM(ITG)} = 6{,}33 \cdot 10^{-3} \Delta HB \tag{3}$$

The function (4) specifies the changes of the weighting coefficient for a hard, an immovable triboelement ITMG:

$$G^{T}_{ITMG} = 4{,}66 \cdot 10^{-3} \Delta HB \tag{4}$$

Using the obtained expressions for determining the weighting coefficients (1) – (4) and the expressions for the calculation the wear rate of the movable triboelement and immovable triboelement which are given in the works [8, 9] it is possible to get the formulas to calculate the wear rate of the triboelements of the inverse tribosystems.

For the calculation the wear rate of the movable (softer) triboelement ITM with bigger friction area:

$$I_{п\,ITM} = G^{м}_{ITM(ITG)} \left[ 6 \cdot 10^{-10} \exp\left( 0{,}795 \cdot 10^{16} \cdot \frac{1}{E_у} \sqrt{\frac{\pi}{(\delta_п \cdot \delta_н)}} \cdot W_{TP} \right) \right] \frac{W_н}{W_{TP}}, \ \frac{м^3}{ч}, \tag{5}$$

for the calculation the wear rate of immovable (harder) triboelement ITM with less friction area:

$$I_{н\,ITM} = G^{T}_{ITM(ITG)} \left[ 6 \cdot 10^{-10} \exp\left( 0{,}795 \cdot 10^{16} \cdot \frac{1}{E_у} \sqrt{\frac{\pi}{(\delta_п \cdot \delta_н)}} \cdot W_{TP} \right) \right] \frac{W_п}{W_{TP}}, \ \frac{м^3}{ч}. \tag{6}$$

For the calculation the wear rate of the movable (harder) triboelement ITG with less friction area:

$$I_{п\,ITG} = G^{T}_{ITM(ITG)} \left[ 6 \cdot 10^{-10} \exp\left( 0{,}795 \cdot 10^{16} \cdot \frac{1}{E_у} \sqrt{\frac{\pi}{(\delta_п \cdot \delta_н)}} \cdot W_{TP} \right) \right] \frac{W_п}{W_{TP}}, \ \frac{м^3}{ч}, \tag{7}$$

for the calculation the wear rate of the immovable (softer) triboelement ITG with bigger friction area:

$$I_{н\,ITG} = G^{м}_{ITM(ITG)}\left[6\cdot10^{-10}\exp\left(0{,}795\cdot10^{16}\cdot\frac{1}{E_у}\sqrt{\frac{\pi}{\left(\delta_п\cdot\delta_н\right)}}\cdot W_{TP}\right)\right]\frac{W_н}{W_{TP}},\ \frac{м^3}{ч}. \qquad (8)$$

For the calculation the wear rate of the movable (softer) triboelement ITMG with less friction area:

$$I_{п\,ITMG} = G^{м}_{ITMG}\left[6\cdot10^{-10}\exp\left(0{,}795\cdot10^{16}\cdot\frac{1}{E_у}\sqrt{\frac{\pi}{\left(\delta_п\cdot\delta_н\right)}}\cdot W_{TP}\right)\right]\frac{W_н}{W_{TP}},\ \frac{м^3}{ч}, \qquad (9)$$

for the calculation the wear rate of the immovable (harder) triboelement ITMG with bigger friction area:

$$I_{н\,ITMG} = G^{T}_{ITMG}\left[6\cdot10^{-10}\exp\left(0{,}795\cdot10^{16}\cdot\frac{1}{E_у}\sqrt{\frac{\pi}{\left(\delta_п\cdot\delta_н\right)}}\cdot W_{TP}\right)\right]\frac{W_п}{W_{TP}},\ \frac{м^3}{ч} \qquad (10)$$

The wear rate of the inverse tribosystem on the materials is defined as the sum of the wear rate of the movable and immovable triboelements:

$$I_{ITM} = I_{п\,ITM} + I_{н\,ITM}. \qquad (11)$$

The wear rate of the inverse tribosystem on geometry:

$$I_{ITG} = I_{п\,ITG} + I_{н\,ITG}. \qquad (12)$$

The wear rate of the inverse tribosystem on the materials and geometry at the same time:

$$I_{ITMG} = I_{п\,ITMG} + I_{н\,ITMG}. \qquad (13)$$

For the confirmation of the modeling accuracy the calculation was made from the obtained formulas (5) – (10) for the conditions of the experiment which is presented in the Figure 1-5.

The experimental researches of the direct and inverse structures of the tribosystems and the results of modeling from the formulas (5) – (10) confirmed the adequacy of the obtained formulas, the modeling error is not more than 12,5%.

As a result of the made researches the expressions (1) – (4) were obtained which make it possible to calculate the weighting coefficients of wear rate increase of movable and immovable triboelements of the inverse structures of the tribosystems.

## Conclusions

For modeling the wear distribution between triboelements in the tribosystems in the design phase of the new machines, the mathematical expressions were obtained to define the weighting coefficient values for the wear rate increase of inverse structures' triboelements of the tribosystems compared with the direct structures of tribosystems. The experimental accuracy check of modeling the wear rate in movable and immovable triboelements of inverse structures is made, the modeling error is not more than 12,5%.

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**Анотація**

## МОДЕЛЮВАННЯ РОЗПОДІЛУ ЗНОСУ МІЖ ТРІБОЕЛЕМЕНТАМИ ПРЯМИХ І ЗВОРОТНИХ КОНСТРУКЦІЙ ТРІБОСИСТЕМ

**Войтов В.А., д.т.н., проф., Захарченко М.Б., аспірант**

*В роботі отримані математичні вирази для визначення значень вагових коефіцієнтів збільшення швидкості зношування у трібоелементів зворотних конструкцій трібосистем в порівнянні з прямими конструкціями, які необхідно застосовувати для моделювання розподілу зносу між трібоелементами в трібосистемах на етапі проектування нових машин.*

**Аннотация**

## МОДЕЛИРОВАНИЕ РАСПРЕДЕЛЕНИЯ ИЗНОСА МЕЖДУ ТРИБОЭЛЕМЕНТАМИ ПРЯМЫХ И ОБРАТНЫХ КОНСТРУКЦИЙ ТРИБОСИСТЕМ

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*В работе получены математические выражения для определения значений весовых коэффициентов увеличения скорости изнашивания у трибоэлементов обратных конструкций трибосистем по сравнению с прямыми конструкциями, которые необходимо применять для моделирования распределения износа между трибоэлементами в трибосистемах на этапе проектирования новых машин.*