

COMPARATIVE TRIBOLOGICAL BEHAVIOURS OF HARD AND SELF-LUBRICATING COATINGS DEPOSITED ON HEAT TREATED STEELS

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ABSTRACT

The purpose of this study is to investigate comparative tribological behaviours of PVD hard coatings (TiN, TiAlN, TiCN and ZrN) and self-lubricating coatings (MoS₂, PTFE and WS₂) deposited on heat treated steels.

The sliding tests with boundary or dry sleading were carried out using block on disc testing rig, varying the levels of contact loading and sliding speed.

Obtained results for the friction coefficient and resistance to wear provide the possibility of comparative analysis of tribological effects of the tested coatings. Though the testing of coating does not give the same characteristics in the variable conditions of contact (normal loading and sliding velocity), it can be concluded that the applied surface treatments can significantly contribute to tribological improvement of tested steels.

KEYWORDS: Coatings, Modification of contact surfaces, Friction coefficient

1. INTRODUCTION

Taking into account that tribological losses, direct and indirect, in summary amount significantly erode national economies, and that they represent the retarding factor in development of technique in the world, the question of their lowering is very actual. Realization of that goal is directly related to improvement of tribological levels of technical systems, what, considering the nature of tribological phenomena, assumes, before all, improvements of tribological properties of tribo-mechanical systems contact layers. Due to that, from the total volume of tribological investigations, today in the world, about 40 % is related to the area of materials [1/.

Since the quality tribological materials are, at the same time, expensive and scarce, and the tribological processes are located only in the thin surface layers, clearly the production of the critical triboelements integrally of the same material represents reality that should be overcome. The promising structure of triboelement along the cross section must be of the composite form, i.e., surface layer of high tribological quality on the lower quality base.

From that aspect, the area of contact surfaces modification, whether considering tribological coatings or changes of base material properties in the surface layer, is estimated as the area of great potentials.

In this paper are presented some results of tribometric investigations of surfaces modified by different procedures, that are being performed within the corresponding project financially supported by the Ministry for Science and Technology of Republic of Serbia.

The established disagreement of effects from the aspect friction and the aspect of wear, requires necessity for existence of two criteria: frictional characteristics and wear resistance, where to these criteria one can assign different weights, or can seek the optimum solution from the aspect of both. Even when considering only the wear resistance, the necessary criterion is not uniquely determined.

However, the tribological aspect is not sufficient alone in solving the concrete tribological problem. Namely, in decision making about optimality of certain types of surface layers modification,



the economical aspect is also unavoidable. Based on the developed input/output model, in which the input vector contains all costs of direct, indirect and past labor, the output vector contains reliability, working life and prices of the technical system, it is possible to determine the efficiency of the applied procedures of surface modifications.

2. EXPERIMENTAL PROCEDURE

2.1. Tribometric conditions

Investigations are of the model type and they were performed on the computer supported tribometer. The contact pair geometry in this, due to a series of conveniences known in the world of tribometry, corresponds to one of possible combinations of the pin on disk or disk on disk type, [Figure 1](#).

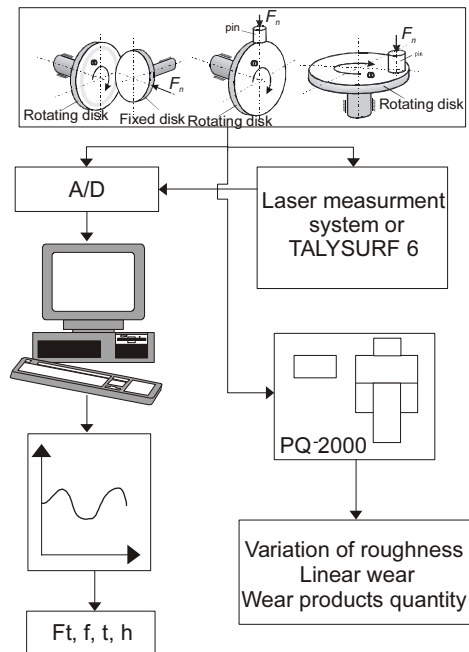


Figure 1: Measurement setup.

In investigations, as the element whose contact surface modification is expected, is used the fixed element of the contact pair, which is, due to very small degree of covering exposed to significantly greater tribological loads. The types of modifications (PVD coatings, hard lubricants coatings and ion implantation) and base materials (substrate) are shown in [Table 1](#). The investigated PVD coatings were applied to the front, previously ground surfaces of elements made of construction steels, at temperatures lower than 400 °C. The applied procedures of deposition resulted in lower decrease of base material hardness (because of exposure to elevated temperatures of the PVD processes) and in unchanged level of the surface roughness with respect to the initial conditions.

As the moving element of the contact pair, in all investigations, were used disks of diameter of 82 mm, and thickness of 8 mm, made of chromium-nickel steel 15CrNi6, in the cemented state, with the hardness 60 HRC. Contact surfaces of disks were machined by grinding under the same conditions ($R_a = 0.2 \mu\text{m}$).

Table 1: Types of modifications and base materials

Type of modification	Modified layer	Base material
PVD Coatings	TiN ion plating TiN arc TiAlN TiCN ZrN	15CrNi6 cemented 16MnCr5 cemented 25CrMo4 bettered C35 bettered SAE 52100
Hard Lubricants	Based on: MoS ₂ PTFE WS ₂	
Ion Implantation	Ti+C Ta+C	

Series of repeated investigations were conducted in the conditions of sliding friction with the limiting lubrication, or without any lubrication, with varying the levels of the contact loading and sliding speed within the wide ranges.

3. RESULTS AND DISCUSSION

3.1 Tribological effects of modification

Tribological effects of contact surface modification can be practically considered from the aspect of several fundamental questions, like: general influence of modification on the wear and friction resistance, influence of the type and modality of modification on tribological effects, possibility of substitution of the higher quality construction materials with the lower quality ones, at the expense of application of the adequate modification procedures, choice of tribological and also economical criteria for choice of the modification type, etc.

When considering the possibility of improvement of the wear resistance by application of the contact surfaces modification procedures, the most superior results were obtained with the hard coatings. This is related both to domain of the initial and stationary wear.

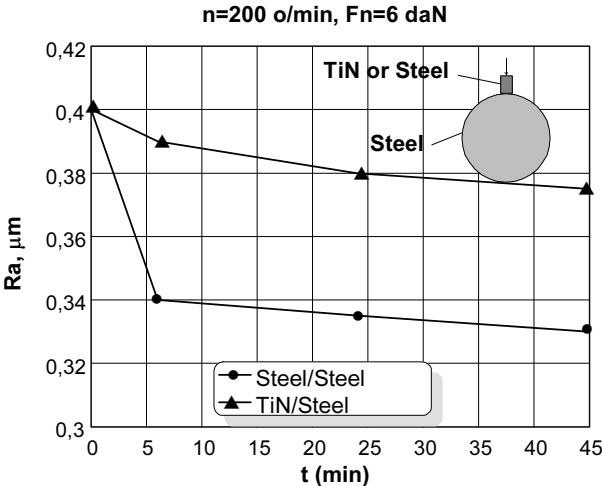


Figure 2: Roughness variation during the running-in period.

Effect of the TiN coating on the initial wear, during which the process of running-in is going on, is illustrated in [Figure 2](#), by application of the roughness parameter R_a . It can be observed that the TiN coating application significantly contributes to lowering the wear intensity, and also the wear level, namely the level of changing of the initial topography of the contact surface due to running-in process. This is very important considering that the initial wear, in tribomechanic systems, can significantly change the constructionally set, and technologically provided conditions of contact surfaces leaning against each other (specially tolerances), what determines the quality and reliability of their functioning.

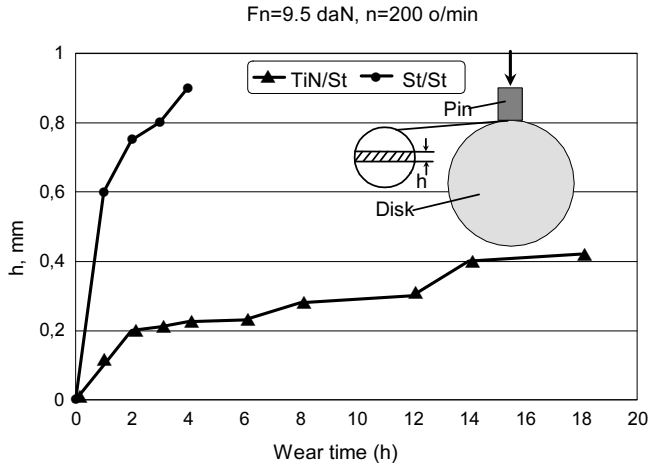


Figure 3: Wear curves of modified and unmodified surfaces.

From the standpoint of technical systems maintenance, it is specially important to improve the working life of the critical elements of tribomechanic systems. Practically those are elements that are operating in conditions of the Hertz contact, and with the very low degree of covering. Just for contact conditions like those, tribometrically obtained results show very positive effects of application of the hard tribological coatings (like the PVD TiN coating is), what is illustrated in [Figure 3](#).

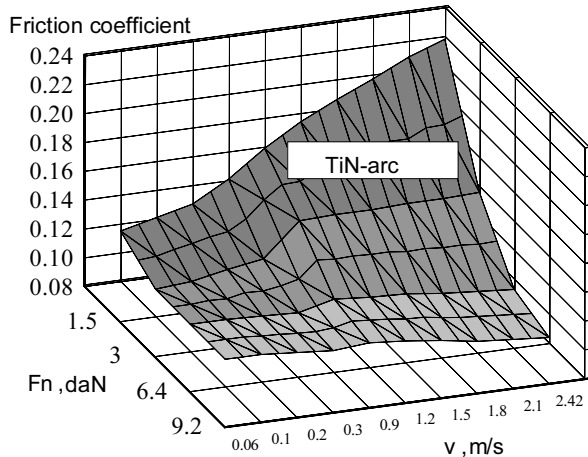


Figure 4: Friction coefficient as a function of normal load and sliding speed.

However, more complex consideration of tribological effects (especially frictional), of different types of contact surfaces modifications, imposes necessity of taking into account the fact that tribological characteristics of the modified surface do not represent its immanent property, but that they are only result of tribological interaction under certain contact conditions. Thus one can notice from [Figure 4](#) that the TiN coating friction coefficient presents the function of the contact load (F_N) and the sliding speed (v).

With increase of contact loading the friction coefficient is decreasing, what is especially expressed for the large sliding speeds. The influence of the sliding speed is smaller and it is not unique. Such an influence can be expressed, with the high correlation degree, by the correlative dependence of the type:

$$f = C_v^x \cdot F_N^y \quad (1)$$

The tribological effects also represent the function of contact realization conditions ([Figure 5](#)). It can be seen that at low sliding speed there is no positive effects of the TiN coating on the lowering the friction energy. However, with strictening of the contact conditions regime, the positive effects of the TiN coating become prominent.

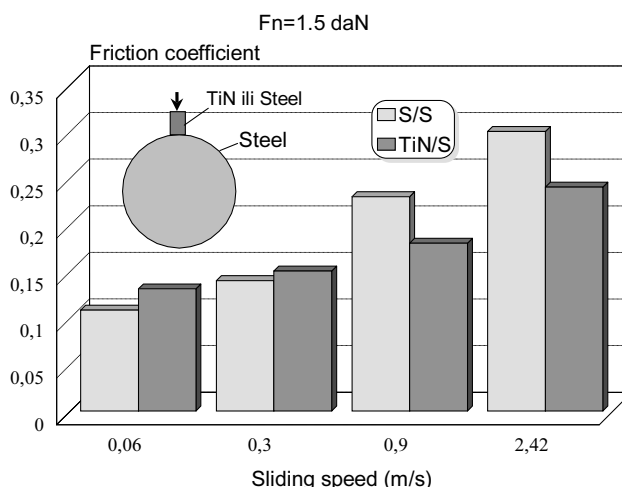


Figure 5: Friction coefficient for the modified and unmodified surfaces.

Obtained results of investigations of different types of contact surfaces modifications can be used for comparison of their tribological effects, what creates the basis for choosing the optimal solutions for particular contact conditions. Those comparisons are possible both for effects of different modalities of one particular type of modification, and for essentially different types of modifications.

In that sense, the illustrative are comparative results of tribological parameters of different coatings ([Figure 6](#)), that are previously listed in the table. From the whole series of results obtained for different combinations of the contact conditions parameters, on these diagrams are shown results that are considered as typical, and by that also sufficient for comparison of tribological properties of investigated coatings.

From the relative ratios of the friction coefficients it can be seen that the best tribological properties has the ZrN coating, and the worst the TiCN coating, that was used as the reference for comparison. The friction coefficients of the other three coatings are within relatively narrow

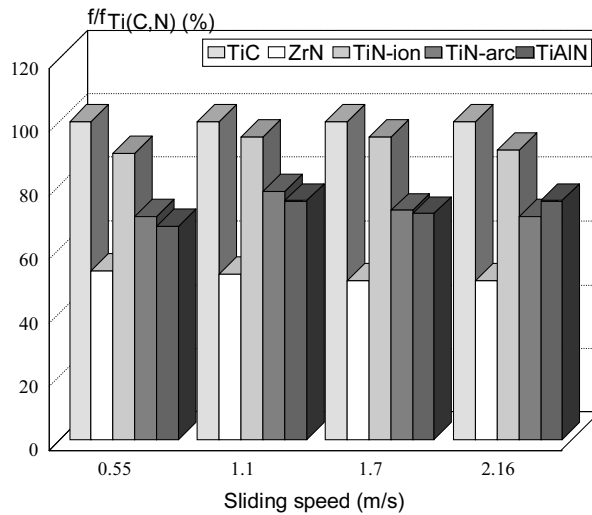


Figure 6: Influence of the PVD coating in the friction coefficient.

range. The largest differences of frictional characteristics were established in the area of small contact loads, while with the increase of the contact loads and the sliding speed the differences decrease. The high average level of differences undoubtedly points to the fact that by choice of the modification type one can significantly influence the frictional behavior of the modified surface. In that, the friction effects are the function of the conditions under which the sliding is occurring.

The development of the wear process on the tested specimens was monitored as the growing of the wear belt width on the nominally linear contact (for coatings until the moment of their complete destruction). The established relationships are presented by the percentage amounts of the corresponding wear coefficients for the friction conditions with the limiting lubrication (Figure 7) and without lubrication (Figure 8).

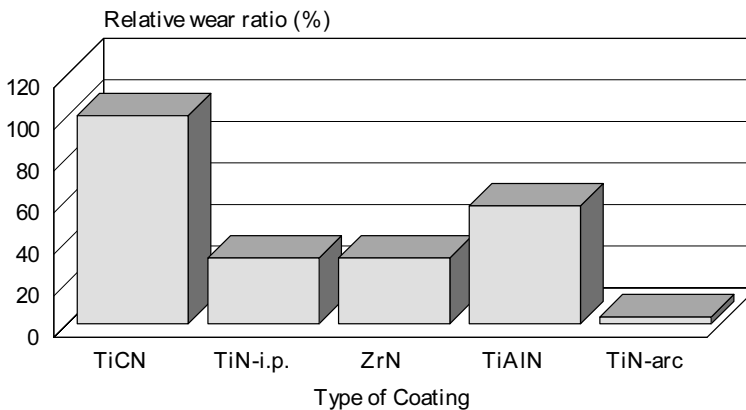


Figure 7: Influence of the PVD coating on the wear ratio in conditions of friction with lubrication

Thus, based on results like these, it is obvious that the PVD coatings strongly improve the wear resistance of the base material, but also that different coatings, or even that same coating ob-

tained by different PVD procedure, have different contributions to that improvement. Simultaneously, it is obvious that the position of particular coatings on the rating lists, based on the friction coefficient, and based on the wear coefficient, is not unique. Thus, for instance, the ZrN coating has the best frictional properties, and, at the same time, the lowest wear resistance.

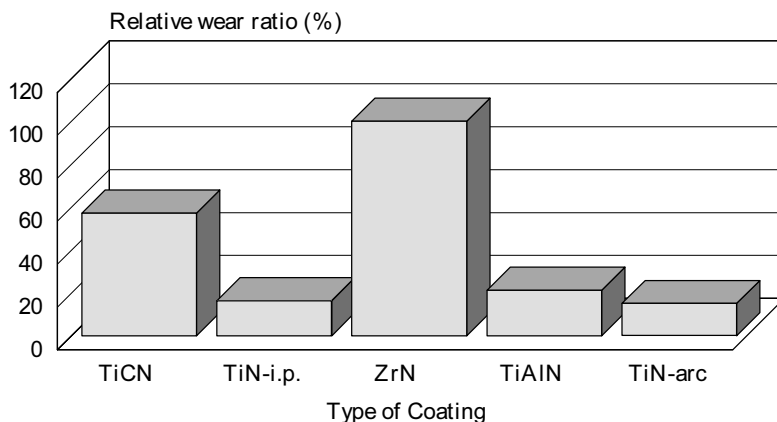


Figure 8: Influence of the PVD coating on the wear ratio in conditions of friction without lubrication

Examples of results, presented in Figures 9 and 10, show how different types of modifications of contact surfaces, influence the improvement of their tribological properties from the aspect of friction and the aspect of wear. As in the previous example, ranking based on these two criteria gives even completely opposite pictures about their contributions.

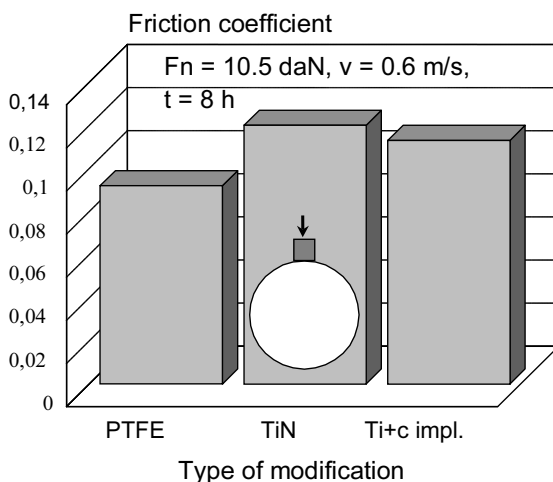


Figure 9: Influence of type of modification on friction coefficient.

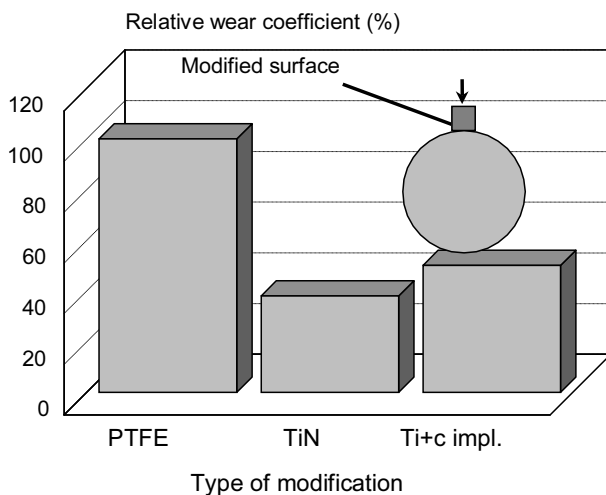


Figure 10: Influence of type of modification on wear ratio.

3.2 Choice of tribological criteria for evaluation of the modifications effects

The presented disagreement of effects from the aspect friction and the aspect of wear, requires necessity for existence of two criteria:

- frictional characteristics and
- wear resistance,

where to these criteria one can assign different weights, or can seek the optimum solution from the aspect of both.

Even when considering only the wear resistance, the necessary criterion is not uniquely determined.

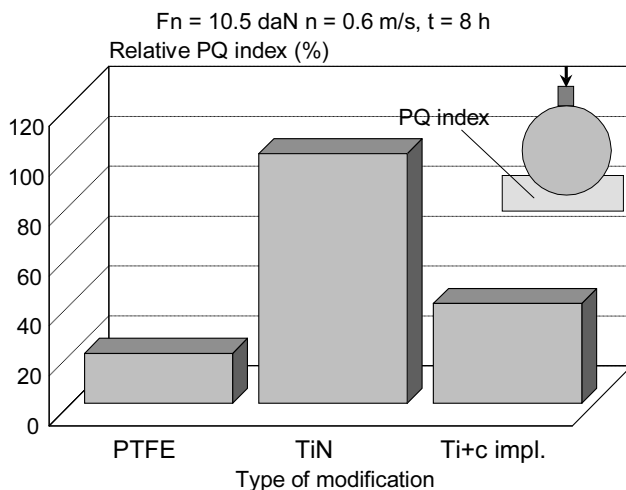


Figure 11: Influence of type of modification on PQ index.

Namely, the up to now approach had a wear resistance, as a criterion for evaluation of the modified surfaces, but only of one element in the contact pair, and that was, understandably, the pin, which is tribologically highly jeopardized, considering the contact geometry (namely the degree of coverage). If one keeps in mind wear effects of the whole contact pair, then the picture can look completely different. Thus, in [Figure 11](#), are shown comparative results of total wear of the contact pair, expressed by the PQ index, for the compared modification procedures. The PQ index represents the measure of the wear products concentration in the lubricating oil, that are the result of wear of both elements in the contact pair. The rating list, from the aspect of summary wear, looks completely opposite, with respect to one that comes out from the presentation in [Figure 10](#). Thus, the smallest total wear corresponds to contact pair in which one of elements has the surface modified by the hard lubricant coating.

So, one of the most important questions is the question of criteria for evaluation of tribological effects of modification, where the criterion has to come out from the nature of the problem that is being solved. Thus, in tribomechanical systems, that are, by their structure characterized by existence of elements with small coverage degree, namely tribologically extremely jeopardized elements, the tribological problem is being solved by improvement of the wear resistance of those particular elements. Less interesting is the question of total wear, since the wear of other, noncritical elements, does not endanger the functioning of the system. And vice versa, in structures that are characterized by uniform tribological jeopardy of contact elements, i.e., where there is no expressed critical element, interesting is the question of decreasing the total wear.

3.3 Tribo-economic criterion for evaluation of modification effects

The solution of certain tribological problem assumes the more complex approach than just choice of tribologically most superior version of surface modification. Namely, in decision making about optimality of particular types of contact surfaces modifications, the economical aspect is inevitable. Based on the developed input/output model, in which the input vector contains all costs of direct, indirect and past labor, the output vector contains reliability, working life and prices of the technical system, it is possible to determine the efficiency of the applied procedures of surface modifications. Thus, in [Figure 12](#) are shown relations between efficiencies modified and unmodified elements for the three mentioned types of modifications.

It can be seen that the curves, as functions of number of pieces per series, are above 1. At the same time, the curve that corresponds to implanted surface is far below 1. That means that tri-

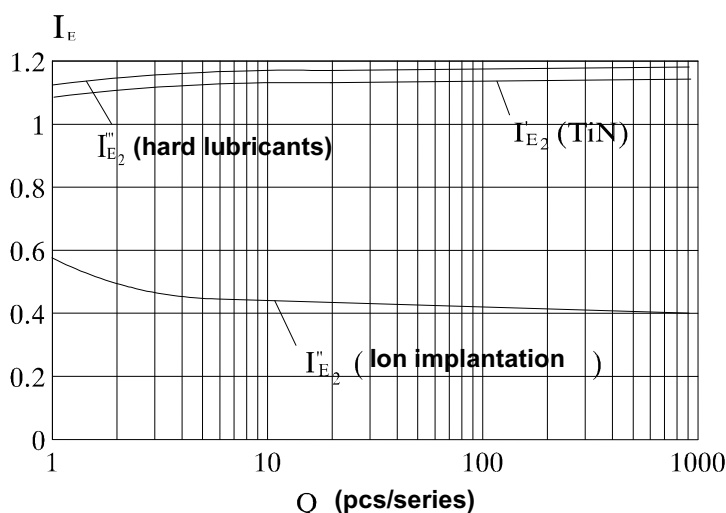


Figure 12: Efficiency indices for different types of modifications.

biological effects of the implanted surface are not sufficient to make up for the high price of the procedure, and by that to ensure the increase of efficiency. Thus, the application of implantation makes sense only there where the specific requirements make it necessary, or at parts that are characterized by extremely low reliability, availability and the working life.

4. CONCLUSIONS

The investigated PVD coatings can contribute to significant improvement of wear resistance of tribologically critical elements made of construction steels. Positive effects of the PVD coatings, from the aspect of decreasing energy losses to friction, are mainly related to stricter contact regimes.

Considering the obtained results, it is real to expect that, with modern procedures of contact surfaces coating, one can contribute to savings of high quality materials, not only through increase of the working life of tribomechanical elements, but also through their substitution by the lesser quality material with high quality contact surfaces.

The choice of criterion for evaluation of tribological effects of modification deserves special attention. In its definition, it is necessary to start from the nature of the tribological problem that is being solved on the real tribomechanical system. The final decision about acceptability assumes precise expression of economical effects.

5. REFERENCES

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