Analysis of the information and diagnostic capability of processing technologies

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Abstract. The possibility of informational diagnostic application of various combinations of traditional processing technologies is considered. By means of expert analytical analysis the potential diagnostic performance of combinations of laser and ultrajet machining of materials is shown. Outlined prospects for the development of research results.

Keywords: diagnostics, quality, expert analysis, processing technology, ultra-jet-impact, laser, rational combination

1. Introduction

Dominant physical processes (ДФП) of form and structure-forming technologies such as fracture, friction, plastic deformation and phase transformations in the material being processed have, in addition to the direct functional purpose, significant information and diagnostic potential [1]. This circumstance is due to the similarity of the ДФП at the stage of manufacturing parts of the product and ДФП, which can lead to their failure during operation. Therefore, purposeful disclosure of the information potential of the ДФП processing technologies is a reserve in improving the quality of the manufacturing processes of various production facilities and ensuring their reliable operation. The essence of the control and diagnostic use of processing technologies is that the object of analysis (OA) has a certain, usually local, physical and technological impact FF in the form of a functional-rational combination of ДФП, and the result of this influence RR has the necessary information about the material state parameters OA. Examples of such application of ДФП are well known, in particular, they include various methods for determining the hardness and microhardness of the surface layer of parts, evaluation of its wear resistance by frictional impact, etc.

2. Objects and research results

In recent years, other methods of mesodiagnoses have developed, which methodologically occupies an intermediate position in terms of the impact on the material under study between traditional invasive (destructive) tests and classical methods of non-destructive testing. In particular, in the works [2, 3] the information-physical capabilities of minimally invasive ultra-jet diagnostics (UJD) are analyzed in detail, which is based on the analysis of the results of local hydroerosion destruction of a high-speed jet of liquid (water) of the surface layer of OA material. However, the necessary scientific and applied research, aiming at the formation of a full-scale apparatus of information technologies of

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mesodiagnosis, based on the ДФП of various methods of processing materials, has not yet been carried out. This circumstance hinders the development of this potentially very promising direction of ensuring the quality of workmanship and the reliability of operation of products in the leading sectors of the industrial economy.

It should be emphasized that one of the options for the effective use of "processing" technologies in the development of methods and means of mesodiagnosis of the quality of materials and parts is to use a rational combination of ДФП, including physically different effects of FF on OA, mainly on its surface layer [4, 5].

The diagnostic result $R$ obtained with such a consistently combined effect can significantly exceed the result of a single exposure in terms of informational significance. Thus, using a rational combination of ДФП, it is possible to diagnose not only traditional indicators of the quality of a material, but also to evaluate its functional latent characteristics due to the manifestation of the effects of physico-technological inheritance [6, 7]. We formalize the above in the form of a visual linear performance model of hybrid diagnostic technologies [8, 9], based on a rational combination of the effect of ДФП on OA material.

Let the source material OA to be effected by the diagnostic impact $F_1$, and then $F_2$. In general, the result $R_{12}$ can be represented as:

$$R_{12} = k_m F_1 + k_n F_1 + k_m F_2$$

(1)

where:
- $k_m$ – is a parameter that comprehensively reflects the property and / or ability of an OA material to structurally respond to an applied impact;
- $k_n$ is the parameter that characterizes the hereditary change in the properties of the OA material, for example, an increase in the defectiveness of its surface layer at the site of the effect $F_1$.

Then, the OA material in the zone of hybrid diagnosis is affected by $F_2$, and then by $F_1$. The formalized final result $R_{21}$, by analogy with (1) we will present in the form:

$$R_{21} = k_m F_2 + k_n F_2 + k_m F_1$$

(2)

For clarity, suppose that:

$$F_2 > 1 \text{ and } R_{21} > R_{12}$$

(3)

Then subtracting from (2) the expression (1) in view of (3), we get

$$\Delta R = \Delta F \to k = \Delta R / \Delta F$$

(4)

where:

$$\Delta R = R_{21} - R_{12}; \Delta F = F_2 - F_1$$

(5)

Thus, a certain combination of ДФП allows you to get not only traditional information about the parameters of the state of the object of analysis from relationships like (1) and (2) - coefficient $k_m$, but also to highlight the hereditary-latent characteristic, the functional quality of the material OA - the parameter $k_n$. In fact, it reflects the ability of a material to change its structural and phase state, for example, the degree of damage (defectiveness) under the influence of previous influences and thereby affect the performance of subsequent ones.

It is obvious that linear informational diagnostic models in the form of relations of the type (1) - (5) can be formulated for the most diverse combinations of structure and form-generating technologies with their characteristic DFT. However, the quantitative determination of the rationality of these combinations at this stage of the analysis of the information and technological capabilities of the
The proposed device mezodiagnostics is almost impossible [10-13]. Therefore, to solve the problem of defining diagnostically rational combinations of “processing” technologies, we will use the method of expert-analytical analysis (EAA). This method makes it possible to give subjective and quantitative assessments of functionally difficultly formalized categories, which provides flexibility and the necessary accuracy of EAA when considering the most diverse problems [14].

In this case, to use the EAA apparatus, it is necessary to formulate criteria for assessing the diagnostic quality of individual varieties of “processing” technologies, with subsequent processing of the results of expert questionnaires using the standard weighted-sum method:

\[ U_j = \sum_{i=1}^{n} k_i u_{ji} \quad (6) \]

where: \(U_j\) – the final expert and analytical assessment of the considered quality parameter OA, in this case the diagnostic capabilities of the \(i\)-th “processing” technology; \(k_i\) - significance of the \(i\)-th criterion of the quality assessed; \(u_{ji}\) - specific expert-criterial evaluation of the technology under consideration; \(j = 1,2 \ldots m\) - total number of compared combinations of technologies; \(i = 1,2 \ldots n\) - the number of criteria that in this case characterize the diagnostic capabilities of a particular processing technology.

As a result of the preliminary EAA, criteria for evaluating the expected diagnostic quality of technologies were formulated and their significance in points was determined (0 - \(\text{min}\); 10- max points). The results are presented in Table 1 and do not need detailed comments.

### Table 1. Significance of performance evaluation criteria and hybrid diagnostics of the quality of materials and structures

| Criterion abbrv. | ИТ | ТП | ФВ | МП | ВМ | ЖЦ | ТО | КО | ЗО | СИ |
|------------------|----|----|----|----|----|----|----|----|----|----|
| Rate of Significance | 9.2 | 9.0 | 8.9 | 4.8 | 3.1 | 6.8 | 7.5 | 6.8 | 9.6 | 4.1 |
| Spread of opinions | ±0.3 | ±0.2 | ±0.3 | ±0.6 | ±0.7 | ±1.1 | ±0.6 | ±0.5 | ±0.2 | ±0.8 |
| Ratio of orientation | 0.06 | 0.04 | 0.05 | 0.21 | 0.34 | 0.38 | 0.28 | 0.31 | 0.03 | 0.41 |

Table 1 adopts the following abbreviations for the significance criteria:
- ИТ – information content of technology, i.e. the fundamental possibility of obtaining the necessary information about the object of analysis;
- ТП – technical feasibility, as a set of available methods and means of implementing this type of hybrid diagnosis;
- ФВ – functionality; consist in providing technological flexibility and variability of the implementation of the diagnostic procedure;
- МП – the scale of application of the considered variant of hybrid diagnostics; is determined by the number and type of diagnosed materials used in various industries;
- ВМ – the possibility of modernization is associated with the prospect of further improvement of the considered hybrid diagnostics;
- ЖЦ – the life cycle of the analyzed hybrid diagnostic technology is determined by the expected duration of its effective use in practice;
- ТО - the technical support of the considered hybrid diagnostics lies in the possibility and accessibility of the technological and instrumental support tools used for its realization;

Further, typical representatives of processing technologies were selected and EAA potential of their hybrid diagnostic quality was carried out using a weighted sum method, according to [15, 16]. It was taken into account that when assessing the relevance of a future study of a specific combination of processing methods for information technology purposes, the criteria for the cost and study of the analyzed version of the future hybrid diagnostic method in (6) are entered with a (-) sign. This is fully consistent with the logic of the problem being solved by the EAA by definition of rational, in this case, two homogeneous or different types of structure and form-building technologies, with its characteristic composition of the ДФП.
Table 2 contains the final results of this very large-scale work of several experts, specialists in the field of manufacturing technologies and methods for controlling the quality of engineering products.

### Table 2. Matrix of possible combinations of processing technologies in the synthesis of new hybrid diagnostics

| ItemNo. | PДВ | КДВ | ОР | ПД | ЭЭ | ЭХ | ХО | УО | УЗ | ЛО | ЭЛ | ПР |
|---------|-----|-----|----|----|----|----|----|----|----|----|----|----|
| 1       | ОР  | 39  | 41 | 33 | 26 | 26 | 0  | 0  | 35 | 0  | 28 |
| 2       | ПД  | 41  | 34 | 37 | 29 | 34 | 0  | 0  | 29 | 26 | 31 |
| 3       | ЭЭ  | 37  | 39 | 69 | 32 | 34 | 0  | 0  | 34 | 0  | 0  |
| 4       | ЭХ  | 26  | 29 | 44 | 35 | 41 | 0  | 0  | 29 | 26 | 27 |
| 5       | ХО  | 24  | 34 | 41 | 26 | 0  | 0  | 31 | 0  | 0  |
| 6       | УО  | 47  | 51 | 52 | 39 | 38 | 74 | 41 | 69 | 29 |
| 7       | УЗ  | 27  | 21 | 41 | 28 | 31 | 41 | 38 | 0,27 | 0,26 | 0,32 |
| 8       | ЛО  | 22  | 39 | 36 | 34 | 27 | 27 | 29 | 0,36 | 0  | 0  |
| 9       | ЭЛ  | 21  | 22 | 31 | 27 | 0  | 26 | 0  | 0  | 0  | 0  |
| 10      | ПР  | 0   | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |

The following abbreviations are used in Table 2:

- РДВ - working defect-forming effect; КДВ - control and diagnostic effects; ОР - machining; ПД - plastic deformation; ЭЭ - electroerosive processing of conductive materials; ЭХ - electrochemical machining of metals and alloys; ХО - chemical treatment of the type of chemical milling; УО - ultra jet hydrophysical treatment; УЗ - ultrasonic treatment; ЛО - laser treatment; ЭЛ - electron beam processing; ПР - plasma cutting of materials. Score (0) means obvious extremely low technology rating ($R < 0,25$) of the considered combination РДВ and КДВ. Rating values obtained by ЭАА were normalized to the maximum value $U_i$ at $u_{ij} = 10$ by the dependence (6). Therefore, the rating values of the elements of the synthesis matrix of hybrid technologies are presented in % of this maximum achievable value. Based on a review of the data in Table 2, the following features of the ЭАА performed can be distinguished.

1. The integral rating of the effective and universal application of processing technologies for the synthesis of hybrid diagnostic methods suggests that the potential of the greatest significance is in the ultra-jet (УО) and laser (ЛО) methods of form and structure formation.

In addition, electroerosion effects (ЭО) for conductive materials and ultrasonic effects (УЗ) for fragile materials such as ceramics and some types of composites, such as carbon-carbon compositions, are very effective.

2. It should be noted the practical futility of using a plasma jet (ПР) as a structural-functional element of the hybrid diagnostic effects.

Some positions in Table 2 are controversial, but in general they adequately reflect the picture of rating assessment of the potential of the diagnostic use of processing technologies.

According to the results of an expert-analytical study, it is possible to draw certain conclusions and formulate preliminary generalizations.

1. According to the ЭАА presented in Table 2, the possible combinations of processing technologies have the greatest informational and diagnostic potential of combinations of ДФП, which approach as closely as possible the real thermal-force, including pulsed or continuous-cyclic, operational effects on the material of the structure. These combinations include: laser ultrajet diagnostics ($R86$) electroerosion and ultrasound diagnostics ($R37$).
The last type of hybrid diagnostics is very promising for assessing the quality of conductive fragile materials such as carbon-carbon compositions.

2. Hybrid ultra-jet diagnostics of structural materials operating in non-thermally stressed conditions may be of considerable scientific and practical interest. However, adding ultra-jet diagnostics with the help of thermal impact on the material [17–20], it is very likely that the potential of the effective-scale application of this information technology to ensure the quality of products from a wide variety of materials, primarily composite ones, will significantly increase.

3. The prospect of the formation of new, modified types of hybrid mesodiagnostics of the quality of materials and products from them consists in the additional introduction of special methods of damaging or strengthening effects on the material to the main ДФП. A typical example of the validity of this statement is the analysis of changes in the physicomaterial properties of polymer composites after thermal and / or radiation exposure, through the use of ultra-jet hydrophysical diagnostics. The possibility of express-diagnosing the effectiveness of various strengthening technologies should include the possibility of express determination of the optimal modes of chemical-thermal treatment by the method of laser-ultra-jet diagnostics at the preparatory stage of manufacturing products from the corresponding structural materials.

Conclusions
Thus, the analysis performed showed the potential information and physical performance of the minimally invasive application of known structure and form-generating technologies in solving diagnostic problems of ensuring the quality of typical and promising functionally different materials and products from them.

List of abbreviations
ДФП – dominant physical process;
ОА – object of analysis;
УСД – ultrajet diagnostics;
ЭАА – expert and analytical analysis;
КО – staffing; consists in the difficulty of training specialists for the implementation of the analyzed type of hybrid diagnostics;
ЗО – the cost of technology implementation; comprehensively reflects the totality of financial investments in the implementation of this type of hybrid diagnostics;
СИ – the degree of knowledge of the technology under consideration, the higher the value of this criterion, the less relevant its further scientific and applied research.

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