DIAGNOSTICS AND FORECASTING OF WELDED STRUCTURE RESIDUAL LIFE
(State of the Art and Prospects of Development)

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ABSTRACT

The paper describes the modern approaches to the problem of diagnostics and forecasting of the welded structure residual life. Several methods capable of solving this task are analyzed and compared to each other. It is shown that the predominant position is now occupied by the method based on the analysis of the acoustic emission phenomenon arising in the materials during deformation. The state of research and developments in this field is considered.

KEYWORDS

Diagnostics, actual service life, acoustic emission, quantum fracture mechanics.

The features of formation of the issues considered in the paper were for the most part determined by the fact that when the structures are developed the designers usually do not give enough attention to the diagnostics and forecasting of the actual service life, as a rule, confining themselves to calculations. Without sufficient improvement the developed structures in many cases cannot be subjected to in-service analysis using special sensors and equipment. In other words they are not suitable for inspection in the sense in which it is required for taking the scientifically based decisions about their condition. The question of forecasting the service life, especially the actual one, is complicated and insufficiently studied. The study subjects of this kind are practically absent from the curriculum of colleges offering training in material strength. There are not enough experts. Therefore, most of the solutions in this respect are limited to searching for gross deviations in the performance of separate parts of the object and providing the possibility of its repair in service and, as was earlier mentioned, to calculated estimation of their service life. Today we can speak about the insufficient scope of application of the welded structure diagnostics means during structure testing and service. The industry so far does not have sufficient information to plan their application. The work still has the nature of individual jobs, whereas life makes more and more urgent the wide-scale application of the diagnostics methods and means. Such a task is quite real, because the study of the material and welded joint behaviour during testing showed that certain physical parameters accompanying failure which are characteristic of its certain moments can be found. Such parameters together with the initial and additional data derived in the process of structure fabrication, testing and service allow to evaluate and forecast their serviceability. Special automatic systems and instruments can be developed for this purpose, whose operation will be based on the above-mentioned parameters.

What tasks have to be solved by the engineering diagnostics systems and equipment? Here, we should indicate first of all the specific features of this equipment which are as follows: for diagnostics purposes its functional capabilities should be expanded towards analyzing the processes running in material deformation. In other words, it should measure such parameters which accompany the material deformation process and can characterize this process to the degree sufficient for decision taking. Under these conditions the equipment and its software should solve the following tasks:

1. Measurement, processing and presentation with the specified accuracy of the initial data required for estimation of the structure load-carrying capacity.
2. Extrapolation of the derived initial data in the direction of the assumed forecasting coordinate.
3. Calculation of the structure load-carrying capacity by the obtained forecast information and additional information characterizing structure fabrication and service conditions.
4. Estimation of the structure condition and possible consequences of the accident. Analysis of the variants of consequences by the degree of their criticality.
5. Selection of the optimum variant. Decision taking.
6. In keeping with the taken decision issuing of a command to service mechanisms to change the structure operation mode in order to go out of the critical condition, as well as informing about the possibility of repair-restoration work performance, and need for a partial or complete interruption of the component or structure functioning.
7. Transfer of structure condition information to central diagnostics station for taking decision on the whole object.

Diagnostic concepts are now becoming part of our life. And here we should define some of them more precisely, so that the terminology used in the papers allows to understand in the same way the processes behind it. The diagnostics of materials, welded joints and structures could be defined as defect detection in them with the estimation of their effect on strength at the moment of detection (material condition assesment). Then,if a crack is simply detected in the material - it is defectoscopy. But, if a crack is detected in the material

and this material condition is assessed, it is already diagnostics, and this is where it differs from defectoscopy.

The concept of defect should be considered in close connection with the above, as the local deviation of material or welded joint properties from the standard ones. In this case we link the two considered concepts in one logical chain. The third important concept in the sequence of our studies is the term of forecasting the residual service life. Let us somewhat more precisely define the concept of residual service life proper. We can speak about two kinds of this concept, i.e. calculated service life, when its value is determined by calculations at the design stage and is further determined more accurately during testing, and the actual service life, when the built-in inspection means or performance of inspection at certain time intervals provide sufficient information to take a decision about the actual condition of the structure with specified validity. Then, forecasting of the actual service life of materials, welded joints and structures will mean prolongation (extrapolation) with a certain degree of probability of their serviceability up to failure in the direction of the assumed forecasting coordinates. Thus, we can forecast the breaking pressure of the vessel, or the time during which the structure will be losing its strength. In the first case, the pressure will be the forecasting coordinate and in the second case it will be the time. The final reference points of both coordinates will be either the values of the collapsing pressure, or the time after which the structure will fail.

Futher we shall have to deal with one more concept, namely guaranteeing initial service life of structures and materials. We shall assume it to mean working out and implementation of conditions, deviation from which later in service should lead to failure. Such conditions should be worked out in technical documentation on service, and controlled using the sensors mounted in the structure in service.

The strain measurement or ultimate load testing became a traditional method of load-carrying capacity estimation. Its disadvantage for application in the field of diagnostics is the fact that except for destructive methods, all procedures require the availability of theoretically and experimentally based laws, hypothesis of strength, incorporating the measured stresses as initial data, in order to take a decision about the structure condition. As a rule, the interdependence of the parameters included into such relationships is complicated enough, and in practice it is almost always simplified. Hence, it would be too impudent to give a high degree of guarantee about the validity of such hypotheses for particular structures, especially under service conditions. That is why, when using these methods we can only speak about a calculated approximate estimation of the service life. Only the destructive methods, not requiring cumbersome and complex computations, can answer the posed question, since the decision is taken by ultimate loads at which failure occured. However, it is the structure breaking which is the main drawback of these methods as was mentioned above.

Note one specific point arising when the residual service life of materials and structures is determined. It is the nature of its failure. If the material under consideration has no cracks, any kinds of inclusions and can be considered as homo- geneous from the viewpoint of deformation, the above-men- tioned methods of the stressed state estimation can provide answers to the questions raised. In practice such cases are not frequent, and can mostly pertain to the structures manu- factured without noticeable defects, which have just gone into service or have been in service for a short period of time. If the structure has been in service for a long time, the mecha- nical properties of materials can undergo essential changes especially in structures contacting the aggressive medium, which creates the conditions for delamination and defect pro- pagation. In these cases it is necessary to change the method of estimation of their load-carrying capacity, by applying the fracture mechanics laws. In order to take a decision about the structure material condition in this case we not only have to know the stress level in certain locations of the structure, but also should have information about the presence and sizes of defects in these locations, mechanical properties of the material at the moment of analysis and measurement (Taylor et al.,1974). In the structures in service the complexity of the measurements grows with their volume, because here we have to apply the non-destructive testing methods. Part of them have not yet been sufficiently developed, and another part are ab- sent at all, so that the appropriate indirect estimates of the above-mentioned parameters are required. Hence, the conclusion that estimation of the actual residual service life of the structure requires a method which would integrate without cal- culation the majority of the above-mentioned functions, issu- ing the final decision about the construction condition, skip- ping the stage of using the data of these multi-step prelimi- nary investigations and calculations, sometimes rather loosely associated with the actual objects.

In this connection a big advantage is gained by the load-car- rying capacity estimation methods which involve only the ana- lysis of those locations where the stressed state is above the standard one, where intensive plastic deformations develop and failure occurs. As a rule, such locations are not numerous, and then the assessment and calculation of their criticality become possible in real time. Among such methods is the one based on recording the "sounding" of material individual zones in the deformation process. Here, proceeding from the sounding zone parameters it is possible to integrally assess the criti- cality of the processes developing in the material long before failure. What are its fundamentals? How did it become possible at a comparatively low cost not only to estimate the structure performance, but also, without breaking it, to indicate the locations in need of repair and to guarantee its subsequent normal service? It is already clear now that the processes of material deformation run in a discrete manner, the energy is

evolved in pulses, resulting in wave formation. By subjecting the samples to simple tension in pull-test machines and ana- lyzing their deformation graphs depending upon the load, we can visually detect in most cases the sharp peaks at the final stage of deformation, which are accounted for by the discrete increment of strain. The acoustic equipment has a much higher resolving power, and senses these peaks practically on the entire deformation curve, which shows that the deformation process runs with a different intensity at different stages.

The practical investigations in the field of metal physics provided a considerable amount of information about the pro- cesses running in the materials during strain development and emergence of the future fracture sites. These investigations have revealed that in the overwhelming majority of cases the predecessors of defects are dislocations whose clustering and coalescence result in the tangible local changes of the mate- rial structure. It was shown that at insignificant forces the dislocations begin to move, overcoming the resistance of the bond with the adjacent atoms one by one (Ionov, 1987; Pana- sjuck et al.,1988). It is natural to assume that each such ab- rupt change of the individual dislocation position will gene- rate a quantum of radiation, i.e. the quantum of acoustic emission (Nedoseka, 1989; Tripalin et al., 1986; Gusev, 1982; Bojko et al., 1989; Ivanov, 1986; Geranoglu et al., 1981; Dru- zhinin,1979). As the dislocations advance, these quantums will be summed up, forming an elementary AE signal. Such a situa- tion is typical for the initial stages of material deformati- on, when comparatively small forces, acting on the material, cause dislocation movement to the grain boundaries. If the me- tal structure is imperfect enough (there are many dislocation sites), there occurs an active emission of AE signals of in- significant amplitude characterizing the stage of larger de- fect formation. At the subsequent stages, when the forces con- tinue growing, there may arise stronger AE signals in some lo- cations which are indicative of the interatomic bond breaking and crack initiation. In this case it is necessary to overcome the higher energy barriers for the discontinuity to occur (Collacot,1989).

What is the situation at present as far as this question is concerned? First of all, the experience of successful applica- tion of AE diagnostics in welded structure testing should be noted. So, vessel testing by static pressure allowed to fore- cast the failure initiation site and the collapsing pressure already under the loads amounting to 30% of the breaking load. In fatigue testing of fixed offshore platform welded members the first initial cycles already enabled to detect the site of the future crack initiation, and the number of cycles after which it appears. Interesting results were obtained in stan- dard testing of structures in service. The AE equipment simply enough detected the imperfections in vessels caused by their long-term service. Good results were obtained in testing the boil unit drums in thermal power stations. Dangerous defects were found when testing the aircraft panel under simple ten- sion. It is also necessary to mention the great possibilities for this method application in the development and improvement of the welding technologies. The special sensors and software developed for these purposes allowed to apply the AE for weld defectoscopy. The experiments showed that it is possible to detect some types of defects with sufficient confidence. The visual information about their location on the weld line was shown on display screen and documented in the printer device.

At present the work in the field of AE diagnostics is going more and more deeply into the area of studying the physical processes of fracture. This is understandable. The first comparatively simple tasks of the AE method application have already been solved and mastered well enough. The problem today is the method application for a more complete and detailed analysis of the fracture processes. So, in sample testing by simple tension, using the AE technique it was possible to trace the initiation and propagation of all fracture sites in the sample material. The coordinates of these locations could be determined with the accuracy of one millimeter using the AE sensors, and the material deformation process itself could be watched in its dynamics on the display screen. It enabled to observe and assess the influence of various technological effects on the sample material with the visualization of initiation site and nature of propagation of the defects developing as a result of material deformation.

In view of such virtually unique capabilities of the method, its metrology now started to be developed to a considerable extent. In this connection the quantum fracture mechanics is advancing intensively, it relating the fracture process to the strain waves emerging in material deformation, crack propagation and initiation. So, it is now already possible to discuss the first analytical works in this field which reveal the inner processes running in the materials during the fracture propagation, on the basis of the AE data analysis. It is already possible, although along rather general lines yet, to analytically assess the nature of these processes on the dislocation level (Cherepanov,1990; Nedoseka,1990; Andrejkiv et al.,1989). Beginning from 1984 the work in this direction has been done systematically, although the prior preparatory work and, in particular, the selection and mastering of the effective body of mathematics, started much earlier.

The AE problem is now being intensively developed all over the world through the efforts of a number of companies. And here I would like to note the work of AET, PAC (USA), AVT (Great Britain, Norway), CGR (France), KFKI (Hungary), CVUT (Czechoslovakia), Institute of Mechanics in Bulgaria, Institute of Welding in Glivice (Poland). A big contribution to the development of works on AE diagnostics is due to the activity of the American working group on AE established in 1968, European working group (1972), working group in Japan (1969) and SMEA working group (1982). In our country the work in the field of diagnostics is concentrated in a number of the country's research centers. The research staff working in such cities as Moscow, Leningrad, Kiev, Kharkov, Khabarovsk, Kishinev, L'vov,

Rostov-on-Don, Severodvinsk contribute a great deal to the acoustic emission method development and introduction into industry.

We have here tried to describe the state-of-the-art in the development of theory, methods and means of engineering diagnostics of materials, welded joints and structures. Naturally, we were only able to dwell on some part of the main aspects of this vast problem. However, it is already possible to draw the conclusion that the AE method is now one of the few, if not the only one, which was developed to the stage of concrete industrial systems and enables at optimum cost to analyze the structure condition in the process of their deformation, because long before failure it allows to detect its source. But it should still be noted that the actual conditions of structure service, use of materials in them which do not always yield sufficient "sound" information about their condition, complex geometry of welded joints and the structures proper lay the appropriate restrictions on the method, require serious sophistication of the equipment and software. As can be seen, by far not all the problems have yet been solved. We can only say that there is a foundation, i.e. the physical processes have sufficiently well-grounded theoretical and experimental base. It opens up the possibilities of its improvement, coming closer to reality, development of procedures and special software. Here, the difficulties involved are, as a rule, caused by the features of the structures proper, materials they are made of, and service conditions. So, for AE method, such a foundation is the quantum fracture mechanics, which develops the general mechanics in the field of wave quantum mechanics where the processes should be considered, generalized and postulated on the dislocation level. It is a new and rather big problem of mechanics. For statistical methods the foundation is the decision taking theory, whose further development in the field of strength will enable to create the software for forecasting the structure residual service life.

We have considered the state-of-the-art in the forecasting method development on the basis of statistical models for AE (Ilyakhinskii A.V. et al., 1987) and we can state that this process has emerged, and that there already exists the software permitting to solve this task in some cases. The equipment is also quickly developing, following the advance of theory. We should certainly speak about the closely interconnected development of both fundamentals of the problem. One should complement the other. All the above-said permits to assess the considered scientific approach as an intensively developing one, which is overcoming the difficulties of the mastering stage, the main of them being its metrology. A greater attention should be paid to this problem. The future of the structure and material condition assessment methods will depend upon its successful solution. Theory should give the clue to understanding many problems arising during investigation of the material deformation and failure.

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