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New Engineering Tools

for

Residual Stress Management

and

Optimization of Parts and Welded Elements by Fatigue Criterion

Maximum *Fatigue Life, Corrosion Resistance, Dimension Stability*
with ***Minimum*** *Cost, Material- and Labor-Consumption*

Residual stress can significantly affect engineering properties of materials and structural components, notably fatigue life, dimensional stability, corrosion resistance etc. Such effects usually lead to considerable expenditures in repairs and restoration of parts, equipment and structures. For that reason, the residual stress analysis is a compulsory stage in the design of structural elements and in the estimation of their reliability under real service conditions.

Although certain progress has been achieved in the development of the techniques of residual stress management, a considerable effort is still required to develop efficient and cost-effective methods of residual stress analysis as well as technologies for the beneficial redistribution of residual stresses.

A number of advanced engineering tools were recently developed for efficient residual stress management, fatigue assessment and optimization of parts and welded elements in numerous field of application of aerospace, construction, structural, etc.




- **Advanced Technology and Equipment for Ultrasonic Peening of Parts and Welded Elements**
- **Ultrasonic Computerized Complex for Residual and Applied Stress Measurement**
- **Expert System for Fatigue Assessment and Optimization of Welded Elements**

1.0 NEW ADVANCED SYSTEM FOR ULTRASONIC PEENING OF PARTS AND WELDED ELEMENTS

Intense levels of high frequency acoustic energy, or high power ultrasonics have found practical use in many industrial processes, of which cleaning, welding and drilling are well-known examples. Other applications include metal forming, treatment of molten metals, chemical processing, and even therapeutic and surgical uses in medicine. In most industrial applications, high power ultrasonics involves power levels of hundreds to thousands of watts, and ultrasonic systems operating in the frequency ranges from 15 kHz to 100 kHz. Typical amplitudes range from about 10 to 40 microns. Such ultrasonic system operating at 20 kHz creates a cyclic acceleration of around 50,000 g (acceleration of gravity).

One of the promising directions in using of the high power ultrasonics for industrial applications is the Ultrasonic Peening (UP) of materials, parts and welded elements. The UP technique is based on the combined effect of the high frequency impacts of the special strikers and ultrasonic oscillation in treated material.

The developed system for UP (see Fig.1) includes an ultrasonic transducer, generator and laptop with software for UP optimum application - maximum possible increase in fatigue life of parts and welded elements with minimum cost, labor and power consumption. The UP produces a number of beneficial effects in metals and alloys. Foremost among these is increasing the resistance of materials to surface-related failures, such as fatigue and stress corrosion cracking. The UP technology could be applied effectively for eliminating of distortions caused by welding and other technological processes, residual stress-relieving, increasing the wear and hardness of materials.

In the fatigue improvement the beneficial effect is achieved mainly by relieving of harmful tensile residual stresses and introducing compressive residual stresses into surface layers of metals and alloys, decrease in stress concentration of weld toe zones and the enhancement of the mechanical properties of the surface layer of the material. The fatigue testing of welded specimens showed that the UP is the most efficient and economical improvement treatment as compared with traditional techniques such as grinding, TIG-dressing, heat treatment, hammer peening, shot peening etc.

Figure 1. Computerized Complex for Ultrasonic Peening of parts and welded elements

For the effective application of UP for different applications a software package for optimum application of UP (maximum possible increase in fatigue life of welded elements with minimum cost, labor and power consumption) was developed based on original predictive model. The main functions of the developed software are:

- determination of the maximum possible increase in fatigue life of welded elements by UP, depending on the mechanical properties of used material, the type of welded element, parameters of cyclic loading and other factors;

- determination of the optimum technological parameters of UP (maximum possible effect with minimum labor- and power-consumption) for every considered welded element;

- quality monitoring of UP process;

- final fatigue assessment of welded elements or structures after UP, based on detailed inspection of UP treated zones and computation.

The developed computerized complex for UP was successfully applied in different applications for increasing of the fatigue life of welded elements, eliminating of distortions caused by welding and other technological processes, residual stress-relieving, increasing of the hardness of materials.

2.0 ADVANCED ULTRASONIC TECHNIQUE AND EQUIPMENT FOR RESIDUAL STRESS MEASUREMENT

An Ultrasonic Computerized Complex (UCC) for residual stress measurement was developed recently in a joint project between Integrity Testing Laboratory Inc. and the Paton Welding Institute in Kiev, Ukraine (Fig. 2). The UCC includes a measurement unit with supporting software and a laptop with an advanced database and an Expert System for analysis of the

influence of residual stresses on the service life of welded components. The Complex allows to determine uni- and biaxial applied and residual stresses for a wide range of materials and structures. In addition, the developed Expert System (ES) can be used for calculation of the effect of measured residual stresses on the fatigue life of welded elements, depending on the mechanical properties of the materials used, type of structural elements and parameters of cyclic loading.

Figure 2. Portable Residual Stress Measurement System. Shown with two gages.

The supporting software allows controlling the measurement process, to store the ultrasonic measurement data, to calculate and draw the distribution of residual stresses. The software allows the use of the developed ultrasonic technique and equipment with standard PC's.

Using the ES, it is possible to assess, through calculations, the influence of the residual stresses and their redistribution under the effect of various improvement treatments and cyclic loading on the service life of structural components without having to perform time- and labor-consuming fatigue tests. The program package enables to calculate the fatigue life of structural components after application of heat-treatment, vibration treatment, overloading, UP and other improvement treatments

The developed equipment allows one to determine the magnitudes and signs of uni- and biaxial residual and applied stresses for a wide range of materials as well as stress, strain and force in bolts (pins). Quartz plates measuring from 3×3 mm to 10×10 mm in cross-section are used as ultrasonic transducers. These gages are attached to the object of investigation by special clamping straps and/or electromagnets.

The main technical characteristics of the measurement unit:

- stress can be measured in materials with thickness 3 - 150 mm;
- error of stress determination (from external load) 5 - 10 MPa;
- error of residual stress determination 0.1 σ_y MPa;
- stress, strain and force measurement in bolts (pins) 25-1000 mm long;

- independent power supply;

- overall dimensions of measurement device 300x200x150 mm;

- weight of unit with transducers 5 kg.

3.0 EXPERT SYSTEM FOR FATIGUE ASSESSMENT AND OPTIMIZATION OF WELDED ELEMENTS AND STRUCTURES

The fatigue life of welded elements depends on a number of factors and a complex task should be resolved to find the optimum way for fatigue life improvement of welded structure without the increase in its metal consumption. The Expert System for Fatigue Assessment and Optimization of Welded Elements and Structures (RESIsT) was developed to resolve the above-mentioned problem. Major attention was paid to developing the predictive model for analysis of the influence of the residual stresses and their redistribution under the effect of improvement treatments and cyclic loading on the fatigue life of welded elements. Presently, elaborate, time- and labor-consuming fatigue tests of large-scale specimens are required for this type of analysis.

Optimization of welded elements is based on the fatigue assessment of welded joints in the dialog mode. The following important parameters of welded structures with the goal to enhance the fatigue performance are analyzed:

- material selection,
- preferred design of welded elements,
- weld processes and materials,
- residual stresses,
- application of improvement treatments,
- influence of possible repair technologies,
- realistic service conditions.

The RESIsT includes a package of programs allowing to perform storing, classifying and statistical processing of the fatigue testing results and subsequent comparative analysis of the fatigue life of welded joints in the initial condition (after welding) and after application of improvement treatments. Searching for initial data for comparative analysis is carried out according to the selected combination of design and technological parameters of the welded elements, as well as according to the type and parameters of improvement treatments.

The RESIsT includes the possibility to assess through calculation the effect of welding residual stresses and improvement treatments application on the fatigue life of welded elements without having to perform the time and labor consuming fatigue tests. The program package enables to calculate the fatigue strength parameters of welded joints after application of heat-treatment, vibration treatment, overloading, ultrasonic peening and other improvement treatments. The mechanical properties of the used materials, the type of welded elements and stress concentrations, as well as the cyclic loading parameters are taken into account in an explicit form. Detailed analysis of the influence of residual stresses and their redistribution under the effect of cyclic loading in the zones of stress concentration is performed during such assessment.

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