Ultrasounds Applications in Process Equipment

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There are many engineering fields where ultrasounds are applied, such as: cleaning and degreasing of the surfaces, inspections, residual stress measuring, ultrasonic impact treatment, structures assembling and sealing etc. Examples and characteristics for some ultrasonic applications are presented.

Keywords: ultrasounds, residual stress measuring, ultrasonic impact treatment

For any design engineer is important to take full advantage of the properties of the materials that are utilized in manufacturing. This is generally impossible, because metal properties are altered during the fabrication processes, assembling and working. Welding, casting, forging, rolling, machining and/or working conditions alter material properties, making a product or structure vulnerable to distortion, fatigue and premature failure when subjected to mechanical/thermal cyclical loading or severe environments. To compensate for these alterations, engineers often turn to increasing metal mass or substituting a higher strength material in its place. Both alternatives can significantly increase the product cost. An economical solution is represented by ultrasonic technique. Today's ultrasonic instruments allow higher flexibility than instruments from only a few years ago. Smaller, more powerful electronic components allow for complex data storage and two-way communications with PCs.

The ultrasounds applications in mechanical engineering are very divers and refer to: cleaning and degreasing of the surfaces, ultrasonic testing (corrosion resistance, drive shafts, pins and wheel bearings, measuring the thickness of the hardened surface layer etc.), maintenance (bearing monitoring, leak detection, lubrication etc.), residual stress analysis and ultrasonic impact treatment, structures assembling (plastics welding), sealing etc. In this paper some of these will be presented.

The practical advantages of ultrasounds technology are: indestructible nature, easy to use, facile access to mechanical structure (a single surface is necessary) and the hole surface is covered, utilized during life cycle structure, no special environment protection, utilized *in situ* without dismantle of the structure, can be automated by integration in dynamic systems. The frequencies range used in engineering ultrasonic applications are: 0.5 MHz – 20 MHz for structures testing (between 2 MHz – 20 MHz for steel and light alloys structures) [1], 27 kHz – 55 kHz for surface treatment [2] and for cleaning and degreasing lower frequencies (18 kHz). Many scientists have revealed in their researches [3-21] the importance of the ultrasounds in the technical applications.

The cleaning and degreasing of the surfaces

Ultrasonic cleaning and degreasing of the surfaces have became extremely popular after the introducing of international regulations concerning environmental protection (Montreal Protocol) which restricted the utilization of chlorine–fluorocarbons for cleaning, beginning with 1996. The object to be cleaned is placed in a tank that is full of liquid. The ultrasonic cleaning is done by transmitting ultrasonic waves into the tank. High frequency sound waves are used to produce more than 30,000 alternating high and low pressures per second. These waves create millions of microscopic bubbles, which collapse or "implode", releasing large amounts of energy. This pulse of energy is like a very small explosion, a sound wave actually hits and moves across the object surface and physically pushes foreign matter away from the surface, thus cleaning it. This process, known as cavitation, creates a scrubbing action capable of cleaning up to 16 times more efficiently than hand scrubbing. This technology is mild for the surfaces and for environment too and can be applied to industrial sector (oil tanks, plastics and metals moulds, alimentary devices etc.), automotive, navy and aerospace sector (small spaces cleaning).

Ultrasounds used in equipment maintenance

Ultrasonic testing for measuring the thickness or reveal defects

Ultrasonic testing is used in the examination of high speed rotating engine parts and full penetration groove welds and to determine material thickness or reveal defects. It involves the use of complex electronic equipment that is connected to one or more transducers. These transducers generate and detect high-frequency sound waves that, after being transmitted through a test specimen, bounce back to reveal defects or to calculate the material thickness. Because it requires access to only one side of the test specimen, ultrasonic testing is often used in situations where radiographic examination is not possible.

Ultrasonic test system is the fastes and the most efficient, economical and reliable method to control the tightness of underground fuel tanks. The test uses a pump which creates a gradual vacuum in the tank (fig.1).

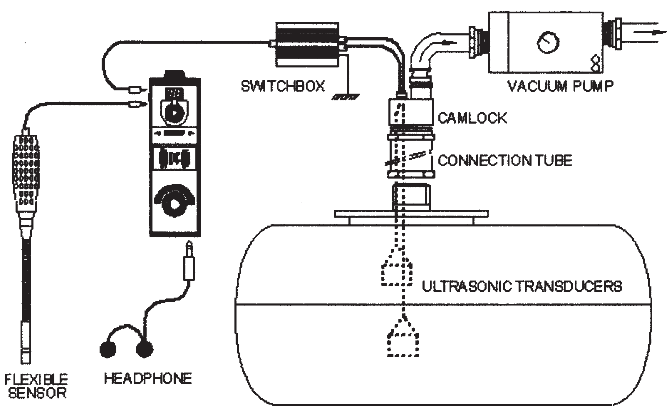

Fig.1. Ultrasonic underground fuel tank test system [20]

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As soon as the vacuum created becomes higher than the hydrostatic pressure due to the height of liquid, leaks start to generate ultrasonic sounds or signals. Two ultrasonic sensors placed inside the tank, one above and the other in the liquid, reveal even the smallest leaks and therefore control the tightness of fuel tanks, as prescribed by the environmental regulations. The test is not influenced by temperature, humidity, amount of liquid or the angle of the tank. It is effective for tanks in either dry or wet environment. The system is economical and ergonomical (the test takes only a small amount of time and the system is portable and constructed for good fieldwork), simple and very easy to use (it needs about 2 h of training) and ecologically very sound or environment-friendly (in the event of a leak, no fuel is spilled on the ground during the control, due to the used vacuum technique).

Ultrasounds are used to test so called weld drifts (drive shafts), external pins and wheel bearings applying the immersion technique too.

Ultrasounds used in preventative maintenance

Unscheduled maintenance and premature failure of mechanical components have a significant negative impact on operating efficiency and profitability. To overcome these unscheduled maintenance and breakdowns, additional routine inspections and preventative maintenance practices must be put in place.

In acoustic vibration monitoring of the bearings, high frequency energy are used to determine proper lubrication intervals and predict when the bearing is entering its first stage of wear. Over lubricating bearings can damage seals, build pressure on the bearing and cause premature failures. Over greasing an electric motor can push lubricant into the windings causing shorts and more severe damage. Under lubricating bearings negatively affect the life of rotating machinery also. At the outset, the goal is to establish a baseline or normal operating range for each bearing to be checked. Throughout the life of a bearing its ultrasonic level should remain relatively constant (+/- 3 or 4 dB). As the condition of the bearing changes, increases in acoustic energy due to either lubrication breakdown or structural breakdown will be observed. Increases correspond with an elevated reading (dB) on the instrument. Trending acoustic energy with data logger software allows the user to accurately predict when lubrication should be applied to a bearing and when the bearing itself is entering early failure stages. Remember, trending acoustic vibration warns us of the earliest signs of change in a bearing. Diligent use of the information gathered results in better lubrication practices and extended bearing life. The desired result is a much larger window through which to schedule repairs and changes.

Leak detection

All pipe connections, flanges, seals and access doors should be inspected to detect leaks. Compressed air leaks are the most expensive utility waste in manufacturing. Turbulence from leaks creates noise with a strong ultrasonic component. For leak detection, must be scanned an area with the ultrasonic technology and hear the turbulent rushing sound through the headphones. Finding leaks can save a lot of money.

Pump cavitation

Cavitation is usually the result of a pump being asked to do something beyond its specification. Small cavities of air develop behind the vanes. These pockets have a destructive effect on the pump's internal components (pitting and scarring the surface of the vanes etc.). With the ultrasounds technology may be isolated the pump vanes and listen for small air pocket explosions. Comparing similar pumps will help the uninitiated, but with some experience an operator will quickly be able to detect pump cavitation.

The residual stress analysis

Metallic materials exhibit a variety of response mechanisms during deformation processes including: diffusion, stress-induced phase transformations and twinning in the crystal structure. Which mechanism will dominate the deformation process depends upon temperature, pressure and strain rate.

Ultrasonic stress measurement techniques are based on the acoustic-elasticity effect, according to which the velocity of elastic wave propagation in solids is dependent on the mechanical stress [9]. Being non-destructive, the ultrasounds technique can measure induced stresses (created directly by loads) or residual stresses and their evolution during the structures life (fabrication processes, assembling and working). The causes of residual stresses

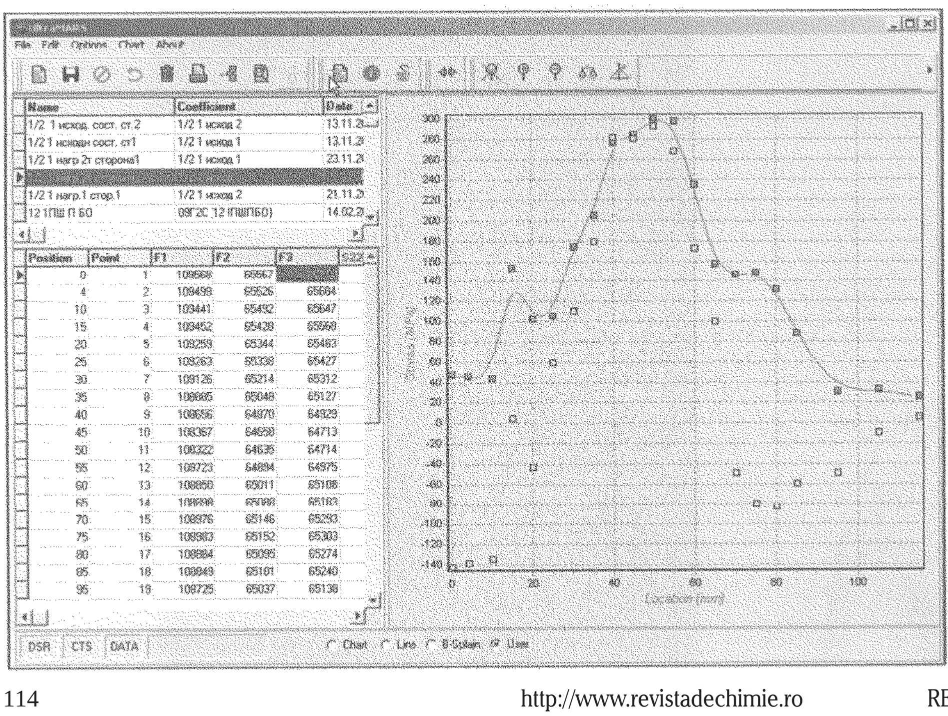


Fig.2. Graphic presentation of the residual stress measurement data [9]

appearance are: elastic-viscosity behavior of materials (viscosity component determines time material dependence), plastic deformations during working, fatigue working conditions, deformation in fabrication processes, working temperature and configuration of the structure.

In the example presented in figure 2, a plate made of low carbon steel, with yield strength of 296 MPa, was heated locally, with the focal point of heating located approximately 50 mm from the left side of the plate. The distribution of both components of residual stresses in the specimen (longitudinal-yellow and transversal-red), as a result of this local heating is shown in the right side of figure 2. As can be seen, in the heating zone, both residual stress components are tensile and reach the yield strength of the considered material. In the compression zone, located between the edge of the plate and the centre of the heating zone, the longitudinal component of residual stresses reaches – 140 MPa.

The ultrasounds systems allows analyzing residual stresses redistribution under the effect of cyclic loading and various improvement treatments on the fatigue life of welded elements, depending on the level of residual stresses, mechanical properties of material used, type of joint and parameters of cyclic loading.

Ultrasonic impact treatment

The experience on production and use of structures shows that their quality is influenced by welded zones for which:

-load-carrying ability is the major reliability criteria;

-fatigue strength or fatigue limit of a welded joint represents an endurance criteria;

-size stability, proprieties variations, the level of residual welding stress and deformations are major influence factors cracking initiation;

-corrosion and fatigue resistance in aggressive media affect the level of the bearable load;

-working in low temperature may produce a disaster.

The ultrasonic treatment is one of the most importance methods for improving welded structures safety, especially fatigue resistance. The development of these methods dates back to 1950's and is associated with the efforts of I.I. Mukhanov [11], A.V. Mordvintseva [12].

The ultrasonic treatment applies wherever metal fatigue is the cause of premature failure of the structure

In recent years, in the context of fatigue life improvement methods, Ultrasonic Impact Treatment (UIT) has attracted a particular attention. UIT technique controls the quality, properties and characteristics of the surface, modifies material properties in the treatment area, improves the fatigue and corrosion resistance, as well as the resistance to abrasion, reduces residual stresses and deformations, stabilizes and improves quality and reliability characteristics in mechanical engineering.

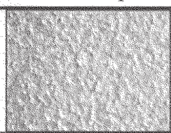
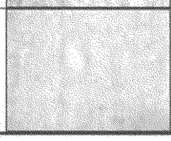
<u>UIT applied to the surfaces</u>

The UIT process is accompanied by a quick local heating of material in the ultrasonic impact point and quick heat removal from the area. In addition, intense plastic deformation occurs in this area. The combination of the above conditions produces the material with new properties. The influence of UIT on the metal surfaces is presented in table 1. The fatigue resistance, after UIT first application, increase with 100% (case 2) and the surface is smoother.

<u>UIT influence on fatigue strength of weld T-joints at low temperatures (fig.3, fig.4)</u>

The samples in initial state were tested under conditions of harmonic loading at a room temperature device and under conditions of ramp loading at the temperature of -60°C, before and after UIT. These tests show increasing fatigue strength of the welded joints after UIT (curve 1, fig.4).

Table 1
INFLUENCE OF UIT ON THE STEEL COMPONENTS (OPTICAL ANALYZE, 8 TIMES INCREASED)

Case	Treatment	Roughness (μ)	Surface aspect
1.	Initial surface of the steel (before UTI application)	6,6 ± 2,1	
2.	First UIT applied to initial steel	4,4 ± 0,4	
3.	Second UIT applied to steel	2,9 ± 0,3	

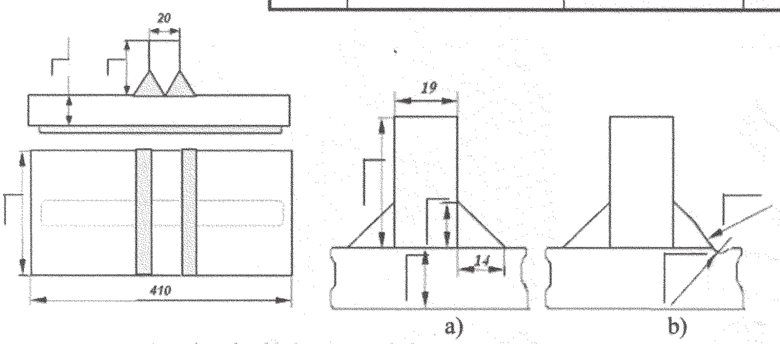


Fig.3. Samples of welded joints: a – before treatment, b – after UIT [21]

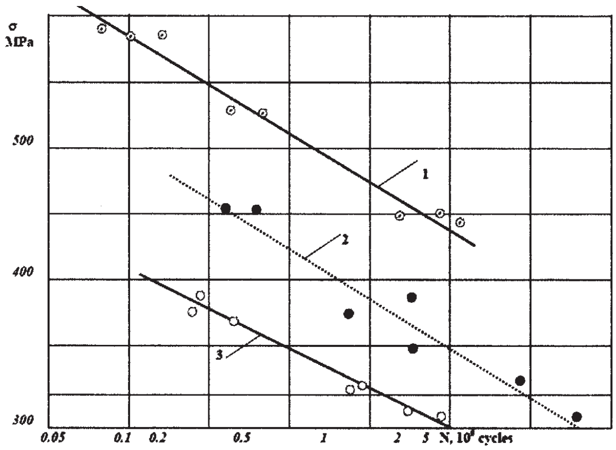


Fig.4. Fatigue strength of a T-joint of steel: 1- after UIT (fig. 3b), ramp loading at - 60^{0}C; 2, 3 - in an initial state (Fig. 3a), harmonic loading at a room temperature and ramp loading at - 60^{0}C respectively [21]

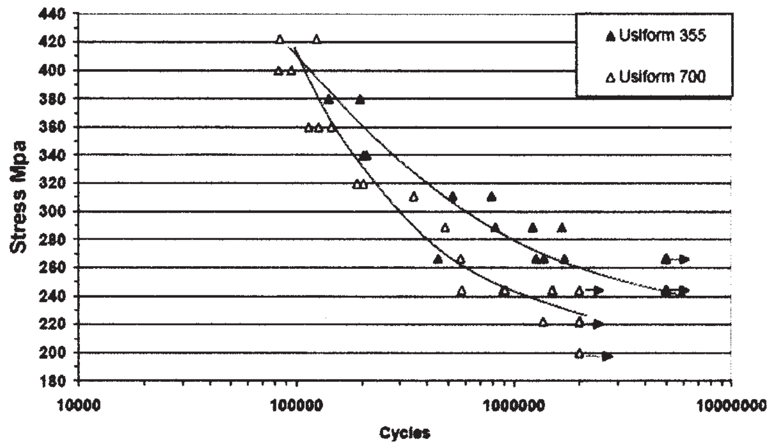


Fig.5. Fatigue curves for welded joint in high-strength steel before UIT [13]

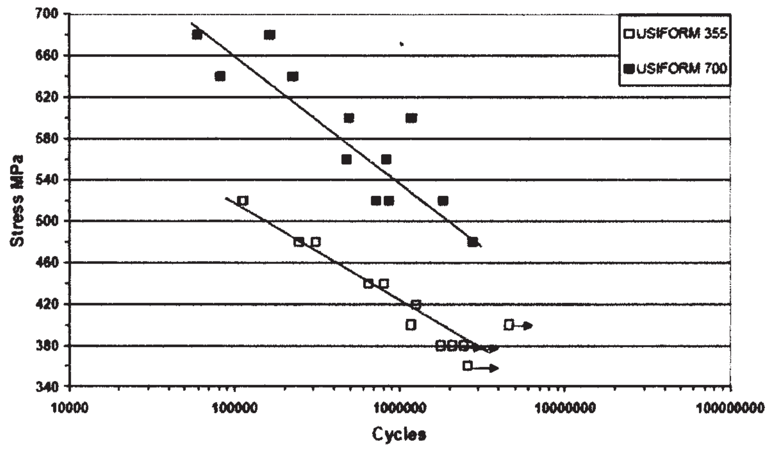


Fig.6. Fatigue curves for welded joint in high-strength steel after UIT [13]

UIT of the welded structures for improving the fatigue resistance (fig.5, fig.6)

The integrity of the welded structures and components depends always on the welding performances. UIT has radically improved the fatigue limit of welded joints (fig.5, fig.6), made of different materials, under various conditions including aggressive environments and subzero temperature, with more than 36% (USIFORM 355) and 61% (USIFORM 700).

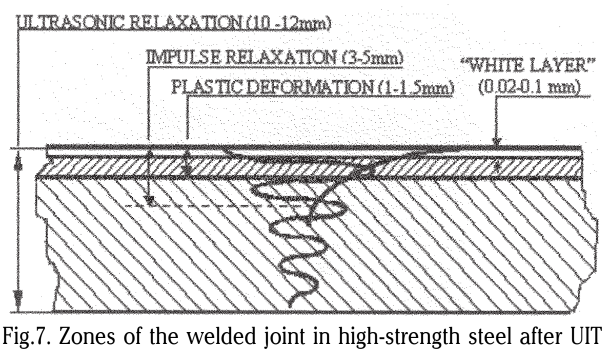


Fig.7. Zones of the welded joint in high-strength steel after UIT

Table 2
UIT MECHANICAL EFFECT ON THE STRUCTURE

Nr.crt.	Zones	Mechanical effect
1.	"White layer"	Wear-resistance, corrosion resistance
2.	Plastic deformation	Cyclic endurance, compensation of deformation, corrosion-fatigue strength
3.	Impulse relaxation	Reduction in residual welded stress and strain of up to 70% of the initial state
4.	Ultrasonic relaxation	Reduction in residual welded stress and strain of up to 50% of the initial state

UIT of the structures for improving the mechanical resistance

Depending on the desired effects of ultrasonic treatment a combination of different frequencies (between 27 kHz and 55 kHz) [14] and displacement amplitude can be applied on a welded structure for improving its resistance (fig.7).

Thus, it is shown that the level of residual welding stress relaxation by ultrasonic impact treatment is consistent with the level of residual stress reduction during heat treatment and attains 10-15% of the yield strength of the material being treated. The following table [14] describes the beneficial effects that can result due to UIT on a welded join.

Such data, including relaxation and replacing tensile stresses by compressive stresses, were obtained from rigid non-resonant in thickness plates made of carbon steels of various strength, titanium alloys, aluminum alloys and copper.

Conclusions

Incredibly precise, fast and economical, ultrasonic technique has a wide range in process equipment field: equipment fabrication, repair and equipment maintenance, surface preparation and hardening. From all presented in this paper IT results that ultrasounds techniques can control the surfaces features, modify mechanical proprieties of welded joints (increase fatigue strength in aggressive environments and subzero temperature, increase corrosive and wear resistance), can reduce residual stresses and deformations in welded structures and reduce the risk in engineer processes (leak detection, preventive maintenance).

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