Portable, semi-automatic device for non-destructive ultrasonic measurement of residual stresses in samples, parts, welded elements and structures

UltraMARS® - 7

SINTEC

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1. Introduction

The portable, semi-automatic device for **Ultra**sonic **M**easurements of **A**pplied and **R**esidual **S**tress (**UltraMARS®**) is designed for non-destructive measurement of averaged through-thickness and surface/subsurface residual and applied stresses in samples, parts, welded elements and structures.

UltraMARS® device is used to provide the following measurements:

- Magnitude and sign of uni- and biaxial applied and residual stresses in samples and real structural elements.
- Uniaxial stresses and forces in pins and bolts.
- Parameters of the acoustic-elastic characteristics of materials.
- Residual stress change as a result of post-welding treatment and service loading.
- The thickness of parts and structural elements.
- Young Modulus and Poisson Ratio

The main technical characteristics of the UltraMARS® device:

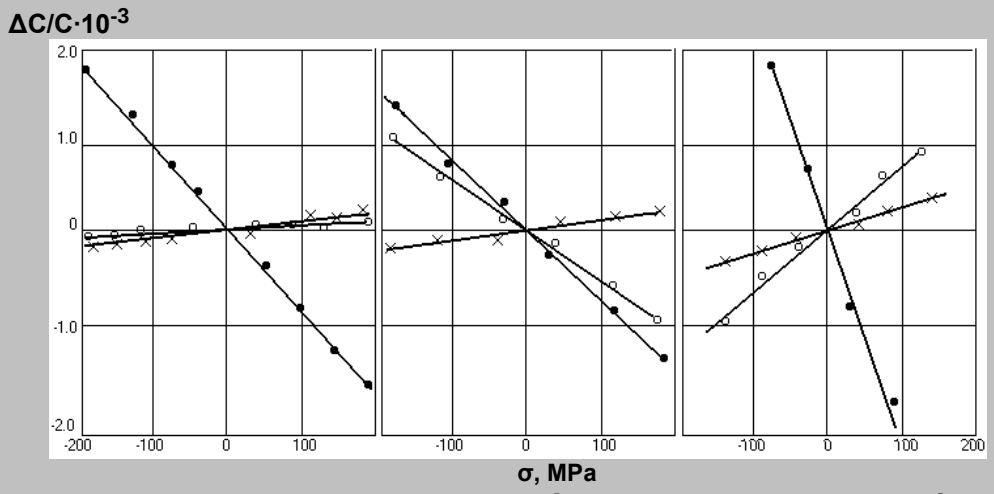
- Stress can be measured in materials with thickness 2 - 200 mm.
- Error of stress determination (from external load): 5 - 10 MPa.
- Error of residual stress determination: 20-30 MPa.
- Stress and force measurement in fasteners (pins) 25-1000 mm long.
- Option of using with independent power supply (accumulator battery 12 V).
- Overall dimensions of the measurement device: 330x215x165 mm.
- Weight of the measurement unit with transducers: 7.7 kg.

The supporting software allows controlling the measurement process, storing the measured and other data and calculating and plotting the distribution of residual stresses. The software also allows an easy connection with standard PC's.

UltraMARS® device could be used to determine the stresses in parts and structural elements during manufacturing, assembly and in service.

2. Principles of Ultrasonic Measurement of Residual Stresses

The principle of ultrasonic measurement of mechanical stresses is based on the acoustic-elastic effect. According to this phenomenon, the velocity of propagation of ultrasonic waves in solids is dependent on mechanical stresses. When material properties are known, the stress measurement could be done by determination of the velocities of propagation of longitudinal and shear polarized (in orthogonal direction) ultrasonic waves.



Change of ultrasonic longitudinal wave velocity (C_L) and shear waves velocities of orthogonal polarization (C_{SX3} ; C_{SX2}) depending on the mechanical stress σ in steel A (1), steel B (2) and aluminium alloy (3)]: ● - C_{SX3} ; ○ - C_{SX2} ; x - C_L

Properties of material are reflected in proportionality coefficients that are defined by elasticity constants of the second and third orders. These coefficients can be calculated or determined experimentally by uni- or biaxial loading (in compression or in tension) of a sample of the material.

- Measurement of the propagation velocity of the elastic waves is done though the measurement of the frequency of recirculation of ultrasonic signals in the material.

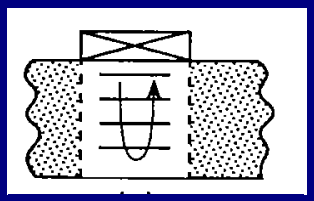
- Sending and receiving of the ultrasonic waves in the material are performed by piezo-electric ultrasonic transducers. The transducers are installed and fixed at a point of stress measurement on the sample, part or structural element using a fixator. The fixator could be attached to the sample/part by a clamping strap, magnet or an electromagnet.

- Results of stress measurement in each point on the sample are recorded and stored in the memory of UltraMARS™ device microprocessor. These data are used for the calculation and drawing of distribution of residual/applied stresses.

UltraMARS® device provides the following operations:

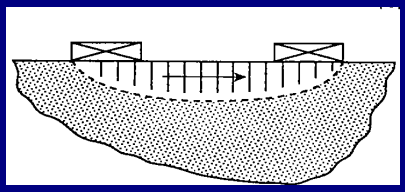
- Control of the ultrasonic transducers.
- Reading and analysis of controlled physical parameters of the sample/part.
- Analysis of operator's actions and providing of the recommendations on the operator's action.
- Control of the technical condition of the device.

The ultrasonic transducers for bulk ultrasonic waves are using quartz plates measuring from 7×7 mm to 10×10 mm and are attached to the object of investigation by special clamping straps and/or electromagnets



Schematic view of ultrasonic through-thickness pulse-echo measurement method

In the proposed technique, the velocities of longitudinal ultrasonic wave and shear waves of orthogonal polarization are measured at a considered point to determine the biaxial residual stresses. The bulk waves in this approach are used to determine the stresses averaged over the thickness of the investigated elements. Surface waves are used to determine the uni- and biaxial stresses at the surface of the material. The mechanical properties of the material are represented by the proportionality coefficients, which can be calculated or determined experimentally under an external loading of a sample of considered material.



Schematic view of ultrasonic surface/subsurface pitch-catch measurement method

Ultrasonic transducers for measurement of surface/subsurface residual or applied stresses in parts and structures.

Supporting software for measurement of residual stresses in materials parts and welded elements was developed. The developed software can control the measurement process, store the ultrasonic measurement data, calculate the residual stresses and allows using the developed technique and instrumentation with standard PC. The developed software and advanced ultrasonic gauges were integrated with the existing measurement module **UltraMARS®**.

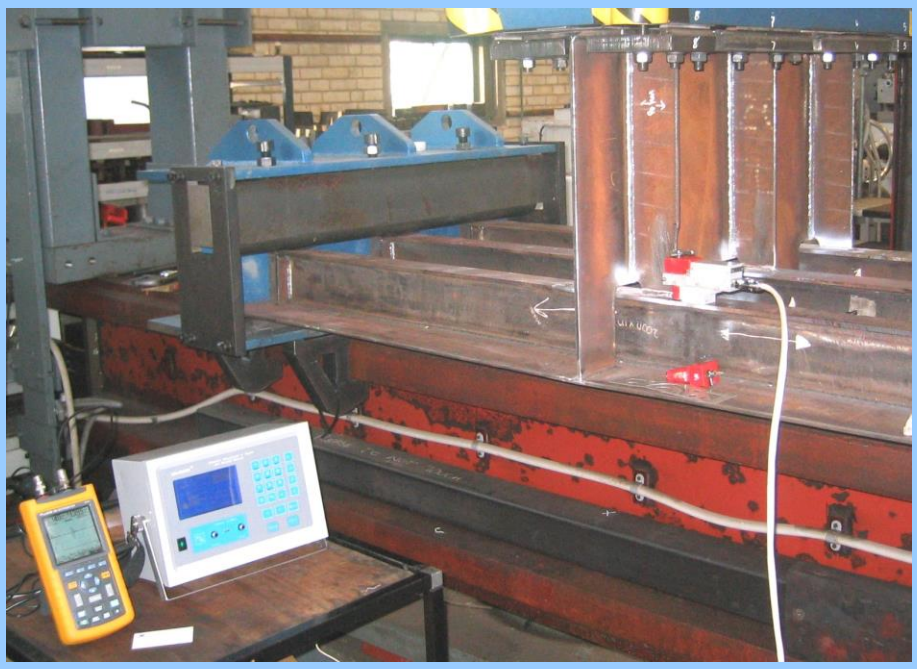
The Ultrasonic Computerized Complex UltraMARS-7 for measurement of residual and applied stresses

SINTEC provides a well established training program on ultrasonic measurement of residual stresses

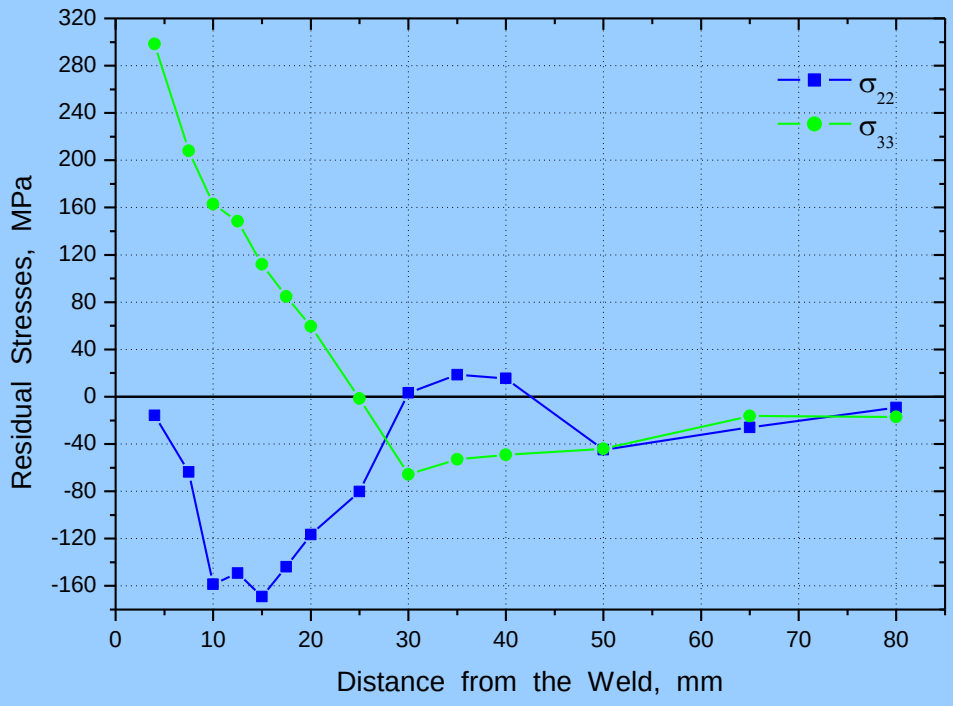
3. Technical Characteristics of UltraMARS

№	Technical parameters	Measurement Unit	Value
1.	Time of stress measurement in one point • Averaged through-thickness • Surface/subsurface	 minute minute	 ~ 1 ~ 1
2.	**Maximum data recorded**: ▪ Sets of acoustic-elastic coefficients ▪ Sets of names/numbers of measurement ▪ Sets of frequencies and stresses	 set set set	 100 200 200
3.	**Power Requirements**: ▪ Voltage ▪ Frequency ▪ Consumed Power	 VAC Hz W	 110/230±10% 50/60-400 20
4.	**Physical Dimensions**: ▪ UltraMARS^{TM} device ▪ PV-UZK unit with fixator ▪ High –frequency Connection Cable ▪ Transducer (bulk waves) ▪ Transducer (surface waves)	 mm mm m mm mm	 330x215x165 180x65x36 5.0 85x50x35 45x45x20
5.	**Weight** of the **UltraMARS^{TM}** device: ▪ Measurement unit ▪ **PV-UZK** unit with fixator ▪ High –frequency Connection Cable ▪ Set of transducers (**XF_1** and **YF_{23}**) ▪ A transducer for surface waves	 Kg Kg Kg Kg Kg Kg	 7.70 6.50 0.44 0.41 0.35 0.15
6.	**Environmental Requirements:** ▪ Permissible operating temperature range ▪ Permissible maximum humidity of environment (at 35 ± 3 °C)	 °C %	 0 ÷ 50 95 ± 3

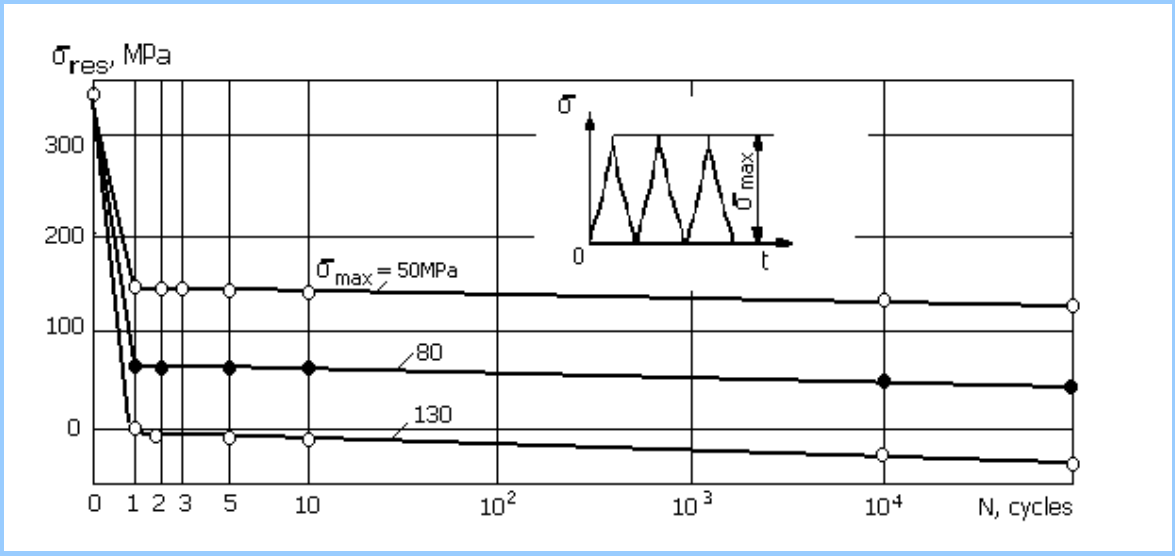
4. Examples of Application



Measurement of residual stresses using developed ultrasonic gauges
and the universal measurement unit **UltraMARS®** in welded panel in as-welded condition
and during the fatigue loading of the panel



Distribution of residual stresses (RS) near the end of welded attachment in as-welded condition:
σ_{33} – component of RS that is parallel to the direction of fatigue loading,
σ_{22} – component of RS that is perpendicular to the direction of fatigue loading.



Relationship between the measured level of residual stresses near the weld and the number of cycles for different level of applied load

Use of the UltraMARS® system in a field project for evaluation of distribution of residual stresses on a transportation bridge in Australia.

About SINTEC

The Structural Integrity Technologies Inc. (SINTEC) is a world leader in the development and industrial application of ultrasonic technologies for fatigue life improvement and residual stress measurement. SINTEC manufactures and provides equipment for ultrasonic impact treatment (UIT/UP) of parts and welded elements and for ultrasonic measurement (UM) of residual and applied stresses.. SINTEC cooperates closely with Integrity Testing Laboratory Inc. (ITL) and Structural Integrity Services Inc. (SINTES) with all three companies being members of the Ultrasonic Testing & Technologies (UT&T) Group of companies.

Two new UltraMARS® -7 systems with accessories prepared for delivery to customers

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