Thickness Measurement with Ultrasound NOT knowing the Sound Velocity

- based on a new Technology -

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Thickness Measurement with Ultrasound

NOT knowing the Sound Velocity

• History of Krautkramer’s digital Thickness Gauges (from DM 1 to DMS 2 TC)
• State-of-the-art procedures to determine the Sound Entrance Point
• State-of-the-art procedures to determine the Sound Velocity

• New Principles 1: 2 Crystals for AutoV
• New Principles 2: plus 2 Crystals forThickness Measurement
• New Principles 3: Through Coat Measuring by DualMulti
• New Principles 4: 2 Crystals for Coating Measurement (TopCoat)
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History of Krautkramer Thickness Measurement
(from DM 1 to DMS 2 TC)

• 1960: TM by superimposing echoes and (sharp) electronic pulses in a USIP
• 1965: Analog TM with artificial Zeroing, 1 Sound Velocity (internally adjustable only: WSG and CM)
• 1970: DM 1: artificial Zeroing, 6 Sound Velocities (externally adjustable with quartz stability)
• 1976: DM 2: artificial Zeroing, 2-Point Calibration available, all Sound Velocities adjustable with quartz stability
• 1983: DM 3: automatic Zeroing (on-block), all Sound Velocities adjustable, simple V-Path correction for all DA 3... probes
• 1992: DM 4: automatic Zeroing (on- and off-block), 2-Point Calibration available, all Sound Velocities adjustable, individual V-Path correction for all DA 4... probes
• 1995: DM 4: plus DualMulti for Through Coating Measurement
• 1999: DMS 2 TC: automatic Zeroing (on- and off-block), 2-Point Calibration available, all Sound Velocities adjustable, individual V-Path correction for all DA 4... probes, improved DualMulti, Auto-V, TopCoat

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State-of-the-art procedures to determine the Sound Entrance Point:
• Presetting of an artificial Zero Signal between SE and 1. RE by hand (i.e by a monostable Flip Flop) in order to compensate the Probe Delay Line:
State-of-the-art procedures to determine the Sound Entrance Point:

- Determination of Probe Delay NOT coupled to the Material to be tested (coupled against Air) Off-Block-Zeroing. Best results to be expected in case of:
  - rough, uneven Material Surfaces,
  - Material with low acoustical impedance (Plastics etc.)
  - Material in ambient temperature only(!)

- Determination of Probe Delay COUPLED to the Material to be tested On-Block-Zeroing. Best results to be expected in case of:
  - Material with higher acoustical impedance
  - Material of all temperatures
  - the need for very stable and reproducible Readings
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Both Crystals as Transceivers

Transmitter Crystal

Receiver Crystal

Material

- Determination of Probe Delay COUPLED to the Material to be tested: On-Block-Zeroing.
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State-of-the-art procedures to determine the Sound Velocity:

• Manual Procedure using two test blocks of different known thickness but same material (2-Point Method)
• Manual Procedure using multiple Backwall Echoes of a test block of known thickness
• Manual Procedure using an artificial Zero Point (from a built-in thickness gauge test block) and the first Backwall Echo of a test block of known thickness (Sound Velocity-Meter (DM V DL))

All those Procedures have one disadvantage in common: the determination of the Sound Velocity happens in separated steps!

How to simplify that ???

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- Determination of Material’s Sound Velocity by using a **Longitudinal Wave Creeping very closely beneath Material’s surface**
- Principle: „fastest traveling wave will be registered first“
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Calibration of System using 2 Materials with different but known Sound Velocities

\[ C_1 \text{ (f.e. Copper) and } C_2 \text{ (f.e. Steel)} : \text{ Goal: } Sm \]

\[ T_{tot1} = Ts + Tm1 + Te \]
\[ T_{tot2} = Ts + Tm2 + Te \]
\[ C_1 = \frac{Sm}{Tm1} \]
\[ C_2 = \frac{Sm}{Tm2} \]

\[ \Delta T = T_{tot1} - T_{tot2} \]
\[ \Delta T = Tm1 - Tm2 \]

\[ Sm = \Delta T \div \left( \frac{1}{C_1} - \frac{1}{C_2} \right) \]

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- After Calibration of the System this Formula is now used to determine the unknown Sound Velocity (AutoV):

\[
Sm = \frac{\Delta T}{(1/C1 - 1/C2)} \quad C1 = \frac{1}{Sm / \Delta T + 1/C2}
\]

Depending on the “Distance” of the unknown Sound Velocity Cun to one of the two known Velocities (Cx = C1 or C2) we’ll get a different \( \Delta T_x \) (= \( \Delta T_1 \) or \( \Delta T_2 \)). The instrument selects the bigger difference value of \( \Delta T_x \):

**Formula for AutoV:**

\[
Cun = \frac{1}{Sm / \Delta T_x + 1/Cx}
\]
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Typical Applications for AutoV:

- Test of steadily changing Materials between 4000 and 8000 m/s (f.e. for almost all Metals)
- Testing of Sound Velocity differences within the same lot of parts made from the same Material
- Testing of Isotropy (dependencies on direction) within the same Material under Test (f.e. rolled Steel)

Advantages of AutoV:

- No further reference blocks needed
- No mechanical measurements needed
- Ideal basis for further Measurements “online”

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The very first practical realization:
The AUTO-V SYSTEM

Measures Thickness When Velocity is Unknown or Variable
AUTO-V System Key Features

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Is that all we can do with AutoV?

No!

Imagine our probe has two more Crystals!
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New Principles 2: plus 2 Crystals for Thickness Measurement

Crystals for Sound Velocity
Crystals for Thickness Measurement

Material

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• By adding two Crystals we are now able to measure the Thickness without knowing anything about the Sound Velocity of the Material under Test!

• Sequence of the complete Measurement Procedure:
  – Determination of Sound Velocity using the two Sound Velocity Crystals
  – Determination of the Delay Line Times (DT) (f.e. by On-Block-Zeroing))
  – Measuring the total Transit Time (TT) of a Backwall Or Flaw Echo
  – Reduction of the TT by DT
  – Calculation of the True Thickness using the already known Sound Velocity
  – Indication of Thickness AND Sound Velocity „online“
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• We reached the Goal of our new Method:

We are able to perform Thickness Measurement with Ultrasound NOT knowing the Sound Velocity

• Advantages of this Method:
  – Easy Measurements at most Materials
  – changing Material w/o manually changing the Sound Velocity Value
  – even at corroded Materials (1. Backwall Echo only !)
  – Thickness and Sound Velocity are indicated simultaneously
  – Good visibility of Isotropy during running Tests
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Is that all we can expect from a 4 Crystal Probe?

No!

Imagine your Material under Test is covered with layers of Painting or Coating...
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New Principles 3: Through Coat Measuring by DualMulti

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• Layers of Paint or Coating influence our Indications:
  – especially thick layers are very inconvenient. If thick enough they produce Echoes with sufficient Amplitude...
  – Thinner layers increase the displayed Values by 2- to 3-times their own thickness!
  – In some Thickness Gauges we therefore know the so called DualMulti – Mode:
  – The Transit time of 2 Backwall Echoes are measured, evaluated by the known Sound Velocity of the base Material (Metal), and displayed.
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Thickness Measurement with DualMulti

- Requirement 1: no or only very little Corrosion
- Requirement 2: Thickness of Layers not too high

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Non-corroded Sheet Metal (ideal)  Corroded Sheet Metal (not useful)
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New Principles 4: 2 Crystals for Coating Measurement (TopCoat)
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Directly retrievable Transit Times:

- w/o Paint: \[ T_{toto} = T_s + T_m + T_e \]
- Paint included: \[ T_{totm} = T_s + T_f + T_b + T_f + T_e \]
- DeltaT: \[ \Delta T = T_{totm} - T_{toto} = 2T_f + T_b - T_m \]
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\[
\Delta T = 2T_f + T_b - T_m
\]

\[
T_m = T_b + 2T_x
\]

\[
C_f = \frac{S_f}{T_f}
\]

\[
C_b = \frac{S_x}{T_x}
\]

\[
\Delta T = 2(S_f/C_f - S_x/C_b)
\]

\[
\sin(a) = \frac{S_x}{S_f}
\]

\[
\cos(a) = \frac{D_f}{S_f}
\]

\[
\Delta T = 2S_f\left(\frac{1}{C_f} - \frac{\sin(a)}{C_b}\right)
\]

\[
\Delta T = \left(\frac{2D_f}{\cos(a)}\right)\left(\frac{1}{C_f} - \frac{\sin(a)}{C_b}\right)
\]

**Formula for TopCOAT:**

\[
D_f = \frac{\Delta T \cos(a)}{2\left(\frac{1}{C_f} - \frac{\sin(a)}{C_b}\right)}
\]

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Measuring Thickness Through Paint Df:

Crystals for Coating
Crystals for Thickness

Df
Paint
Metal

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Requirements for TopCOAT:
- Cf, the Sound Velocity of the Coating/Paint has to be known
- Cb, the Sound Velocity of the Base Material has to be known
- Delay line Material should not be too different from Cf
  \[ a = \text{const} \]

Advantages of the TopCOAT Method:
- Thickness of Coating/Paint and Base Material are displayed simultaneously
- Thickness of layer can be as low as 0 mm (no syst. Minimum Value)
- Rear Surfaces of Base Material may be corroded (1 Echo to be evaluated only!)
- Top Coat Procedure can simply be combined with AutoV
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The described Methods
AutoV and TopCOAT

are protected by patents for Agfa NDT GmbH in

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Europe
Japan

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