Velocity Measurement For Determining Ductility and Nodularity in Cast Iron

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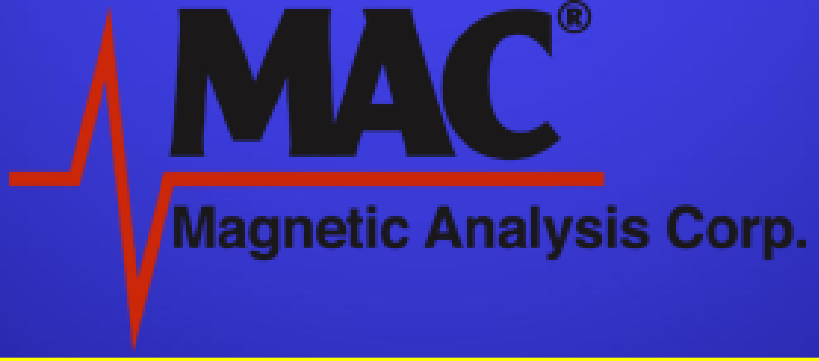

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Background

Traditional Ultrasonic Testing

- Sound travels into the part, reflecting from a defect
  - " Flaw Detection"
- Reflector size is also determined by signal amplitude.
  - "Flaw sizing"
- Sound travels into the part and returns after a measurable length of time.
  - "Thickness Gaging"
- All instrument calibrations are based on these simple principles

Distance = Time times Velocity

D =T X V T= V/D and

V = Distance / Time

Sound Velocity

- Ultrasonic sound Velocity varies in different materials.
- Every material has a measurable velocity
  - Mild Steel = 2.3 inches / sec 10 e-5 (MS) Microseconds
  - Water = 0.584 inches / sec 10 e-5
  - Gold = 1.3 inches / sec 10 e-5
  - Lead = 0.87 inches / sec 10 e-5
  - Iron = 2.3 inches / sec 10 e-5
  - Iron (Cast) = 1.8 inches / sec 10 e-5

Velocity = Distance / Time

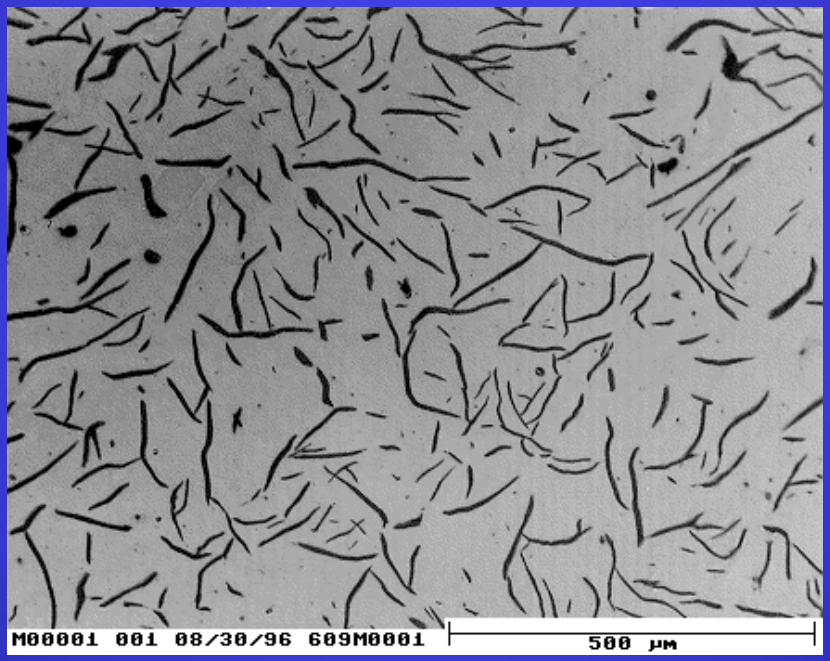
Elastic Modulus

- Velocity is directly related to:
  - Modulus of Elasticity
  - Young's Modulus
  - E Modulus
- E Modulus is related to Ductility/ Nodularity
- Ductility is related to suitability for purpose
  - Brittle Cast iron is not suitable for some structural applications
  - I.e. Safety related auto Parts
    - Brake and steering components

Cast parts can be sorted with Ultrasonics for suitability for these uses.

Graphite Flake
Slower Velocity

Ultrasound →



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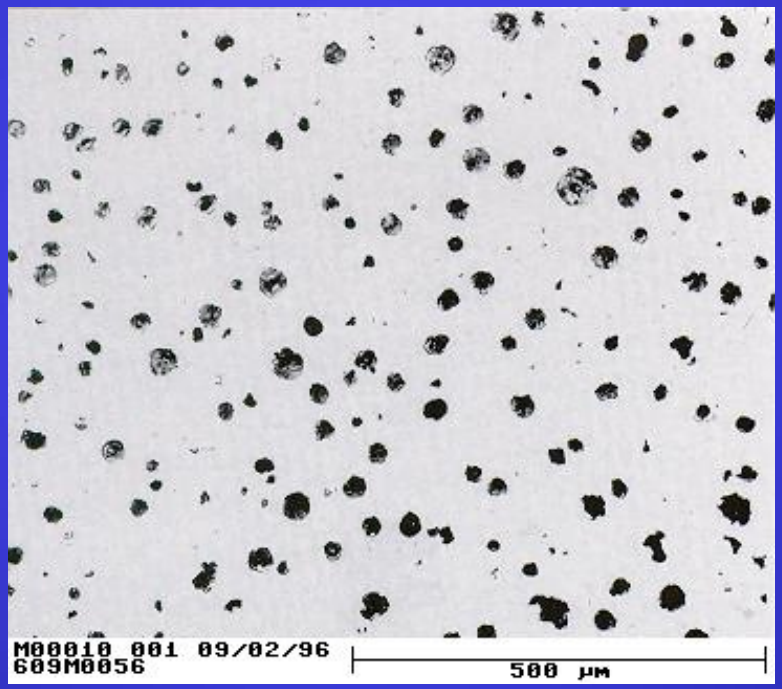
Nodular Grain - Faster Velocity

Ultrasound



Cast Iron - Grey Iron

- Depending on the graphite flake content of the cast iron the ultrasonic velocity of cast iron varies.
- When nodular, the flakes minimally affect the grain boundaries in the iron and therefore the iron is less brittle.
- When it is less brittle it is also Ultrasonically faster than when it is brittle.
- Relate it to
  - Strength
  - Machinability
  - Ductility

Specifications

- Auto Components
  - Automotive companies can specify an ultrasonic test for their safety related components.
- The ultrasonic method is accepted for many test requirements and when the test is put on the production line 100% of the parts are inspected without having scrap with destructive testing.

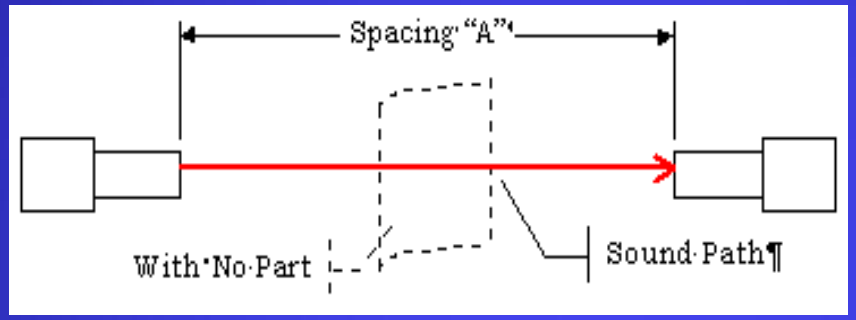
- When incorporated in the production line "Integrity" tests can also be incorporated into multiple channel ultrasonic systems
  - "Flaw Detection" and "thickness measurements"

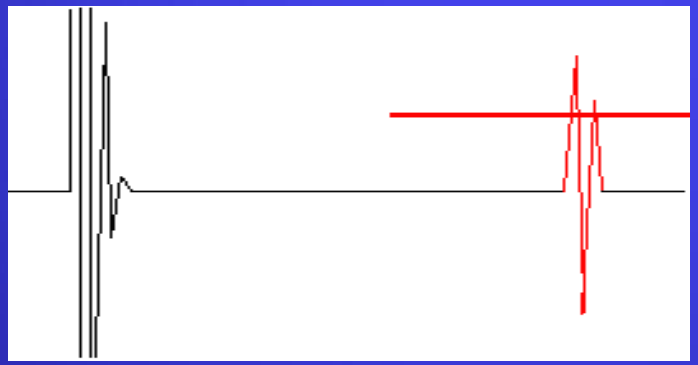
Steering Component

Implementation

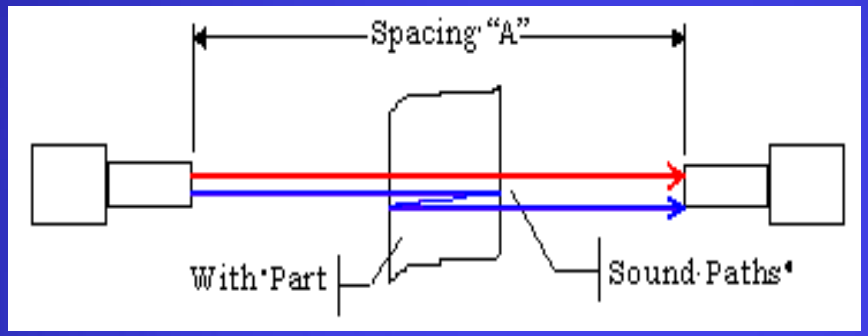

Multi
PART
CHART
BATCH
SYSTM
Vm 0.2237
Tk 0.6061
Vm 0.2205
Tk 0.6027
W 63.384 us
M 5.421 us
Vw 0.05845
Xd 4.15351
W 0.000 us
M 0.000 us
Vw 0.05842
Xd 4.15328
Pieces 219
Accept 160 73%
Reject 52 24%
NoTest 7 3.2%
ACCEPT
Pieces 67
Accept 42 63%
Reject 24 36%
NoTest 1 1.5%
FAIL
MAC
Magnetic Analysis Corp.
Elmsford, New York, 10523-1544 USA
Echomac® VM

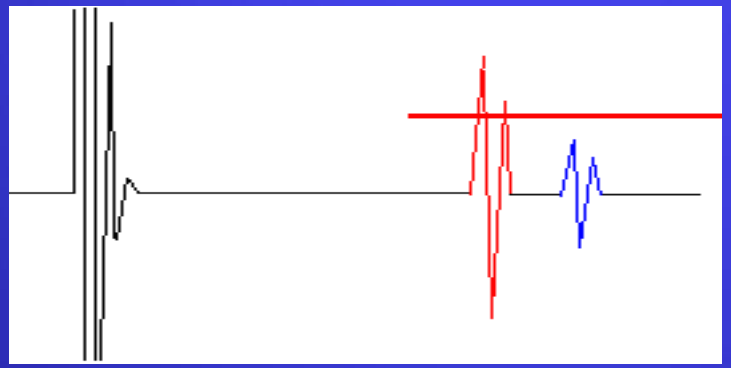
Time measurement (TOF) T1 (only in tank mode)



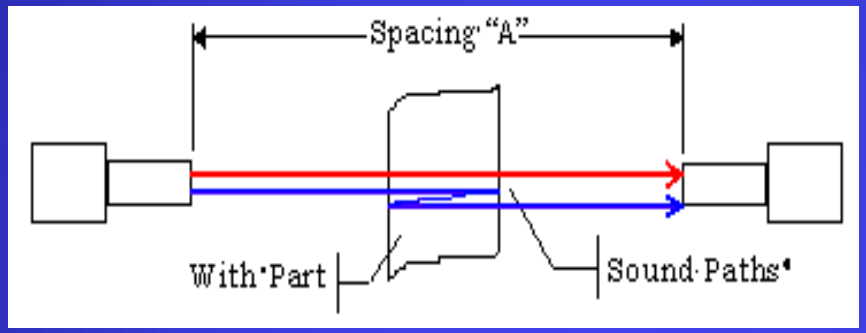


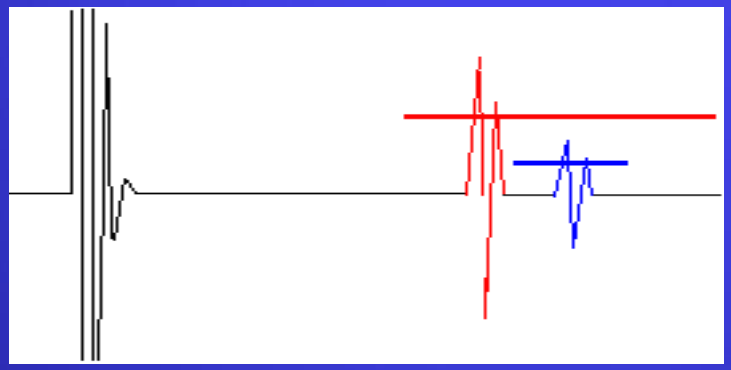
Time measurement (TOF) T2





Time measurement (TOF) T3





Velocity Formula

The following three relationships are used to derive the velocity formula:

$$V_w = \frac{S}{T_1}$$

$$\frac{(S - T_k)}{V_w} + \frac{T_k}{V_c} = T_2$$

$$V_c = \frac{2T_k}{T_3}$$

Key:

V_w	:	Water Velocity
V_c	:	Component Velocity
S	:	Transducer Spacing
T_k	:	Component Thickness
T_1	:	Time of Flight without Component in Place
T_2	:	Time of Flight with Component in Test Position
T_3	:	Time for Round Trip Through Component

The derived formula for velocity is

$$V_c = \frac{2\,S + V_w\,(T_3 - 2T_2)}{T_3}$$

Calibration in Tank Mode

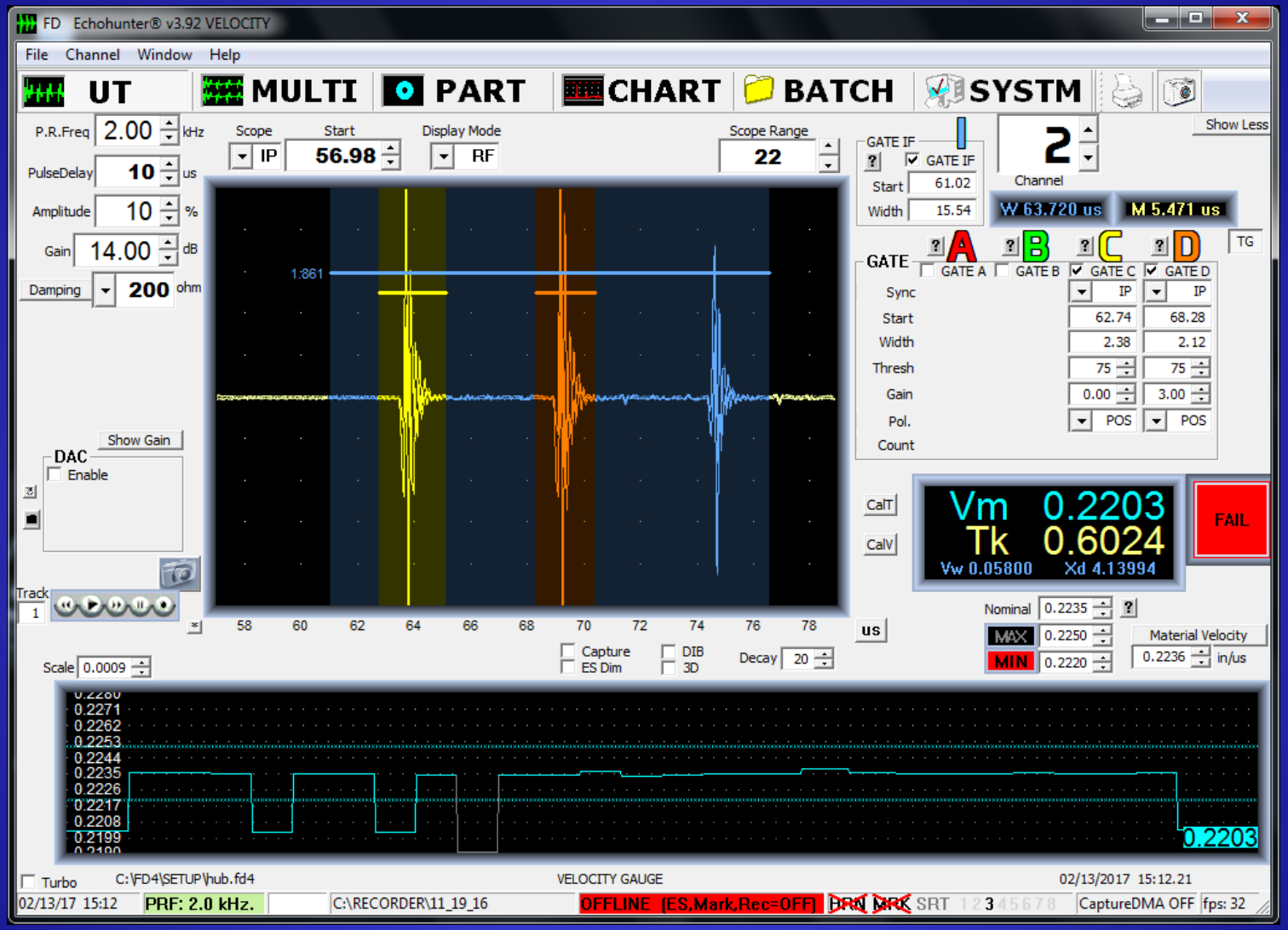
- Calibration process calculates probe spacing and water velocity;
- Input know velocity, click “CalV” to perform calibration,

  Or Input know thickness, using “CalT” to calibrate;
- Time measurement T2, T3 with reference part in place;
- Remove the reference part and read T1 after removing the reference part;
- When calibration is done, system will show “Load Part” indicating ready status;

Calibration in Bubbler Mode

- No T1 (water pass without part) is available;
- Input know velocity, click “CalV” to perform calibration,

  Or Input know thickness, using “CalT” to calibrate;
- Time measurement T2, T3 with reference part in place, then remove the reference part;
- Calibration uses standard water velocity to calculate the transducer spacing and part velocity.
- When calibration is done, system will show “Load Part” indicating ready status;
- Calculate target distance in the reference channel and monitor water velocity through TOF reading of this channel.

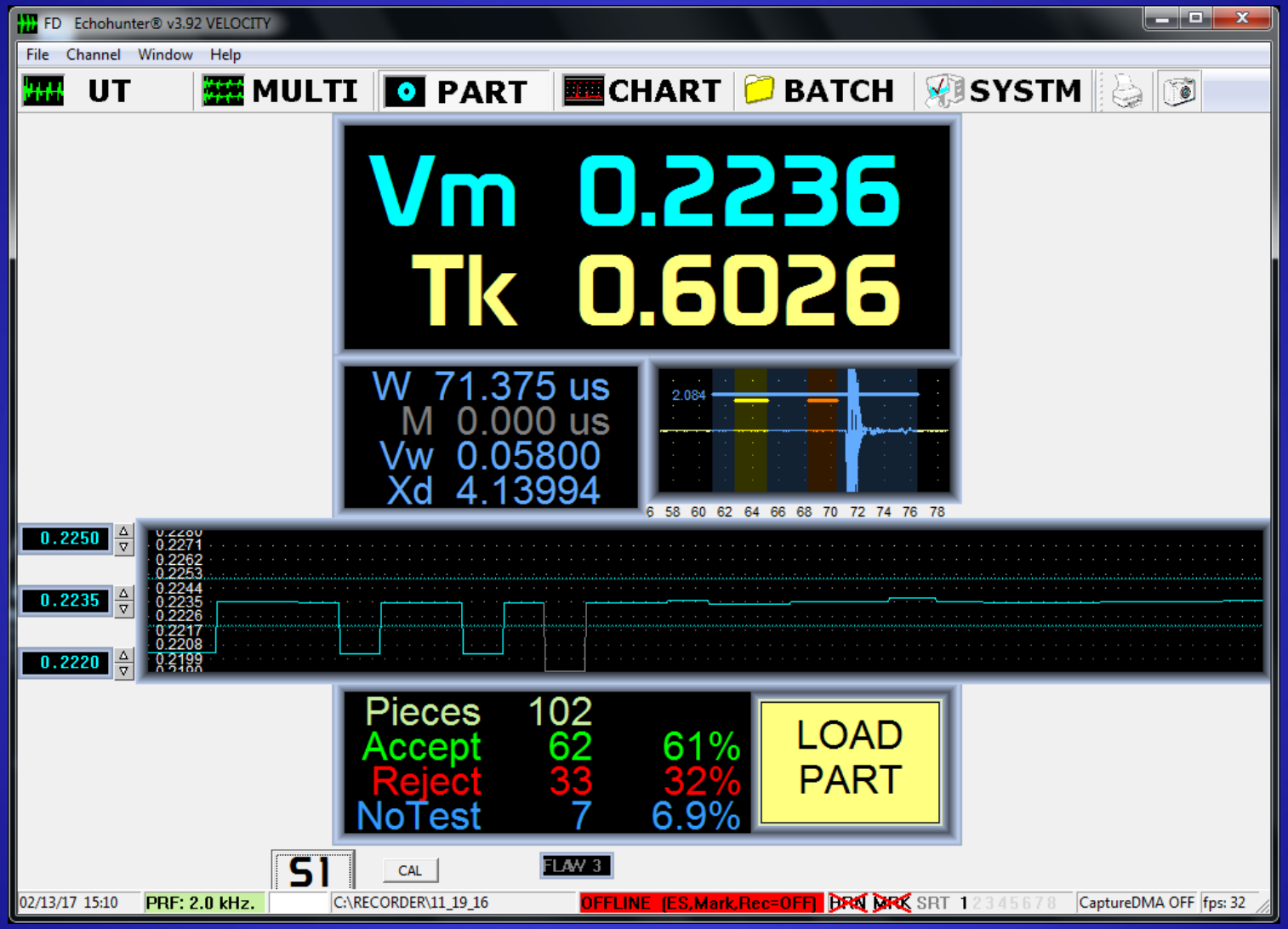

FD Echohunter® v3.92 VELOCITY
File Channel Window Help
UT
MULTI
PART
CHART
BATCH
SYSTM
P.R.Freq 2.00 kHz
PulseDelay 10 us
Amplitude 10 %
Gain 14.00 dB
Damping 200 ohm
Scope IP
Start 56.98
Display Mode RF
Scope Range 22
GATE IF
Start 61.02
Width 15.54
Channel 2
W 63.720 us
M 5.471 us
Show Less
GATE A B C D
GATE A GATE B GATE C GATE D
Sync IP IP
Start 62.74 68.28
Width 2.38 2.12
Thresh 75 75
Gain 0.00 3.00
Pol. POS POS
Count
TG
1:861
58 60 62 64 66 68 70 72 74 76 78
us
Show Gain
DAC
Enable
Track 1
Capture
ES Dim
DIB
3D
Decay 20
Scale 0.0009
CalT
CalV
Vm 0.2203
Tk 0.6024
Vw 0.05800
Xd 4.13994
FAIL
Nominal 0.2235
MAX 0.2250
MIN 0.2220
Material Velocity
0.2236 in/us
0.2271
0.2262
0.2253
0.2244
0.2235
0.2226
0.2217
0.2208
0.2199
0.2203
Turbo
C:\FD4\SETUP\hub.fd4
VELOCITY GAUGE
02/13/2017 15:12.21
02/13/17 15:12
PRF: 2.0 kHz.
C:\RECORDER\11_19_16
OFFLINE (ES,Mark,Rec=OFF)
SRT
CaptureDMA OFF
fps: 32

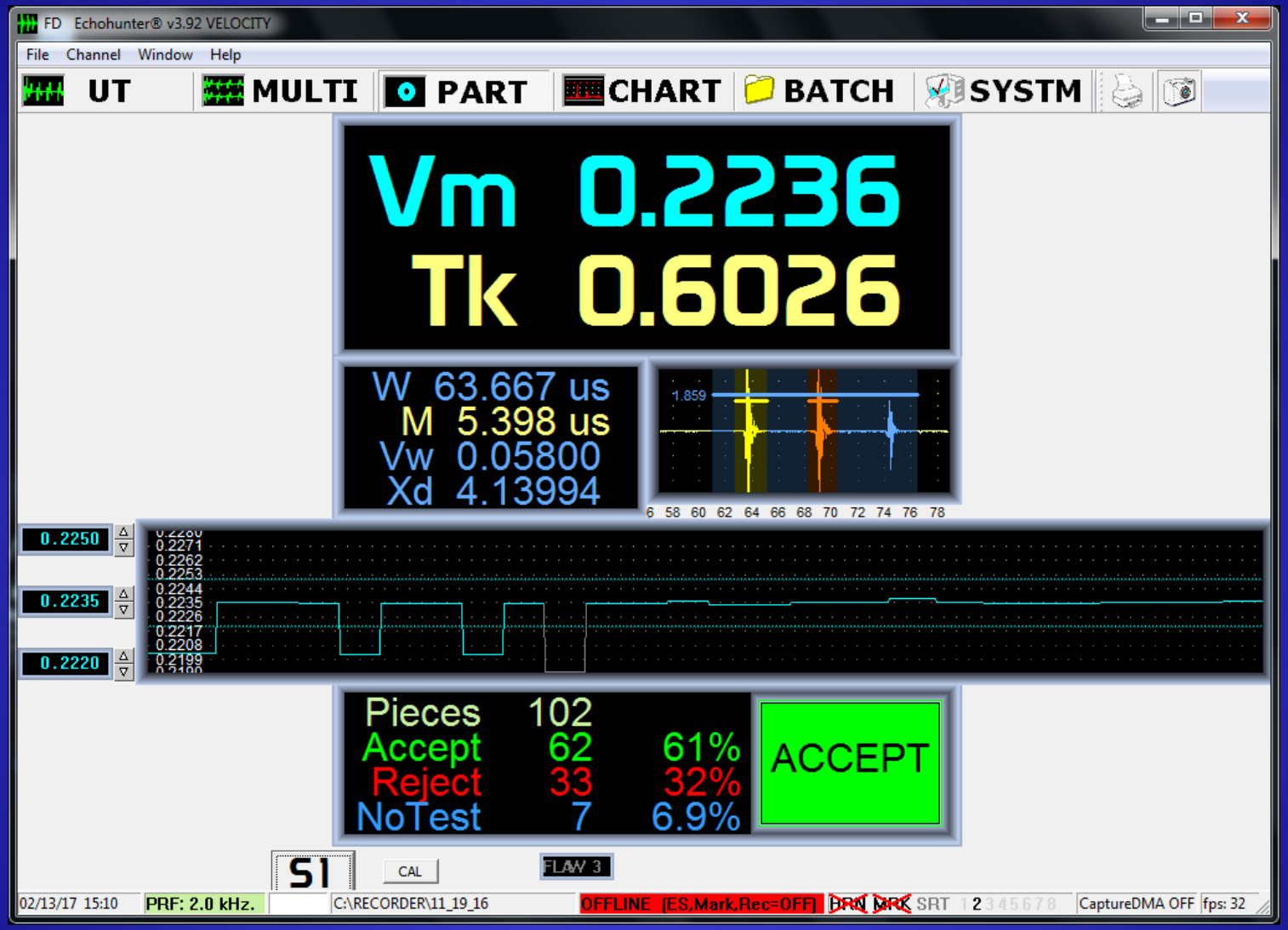
Functions

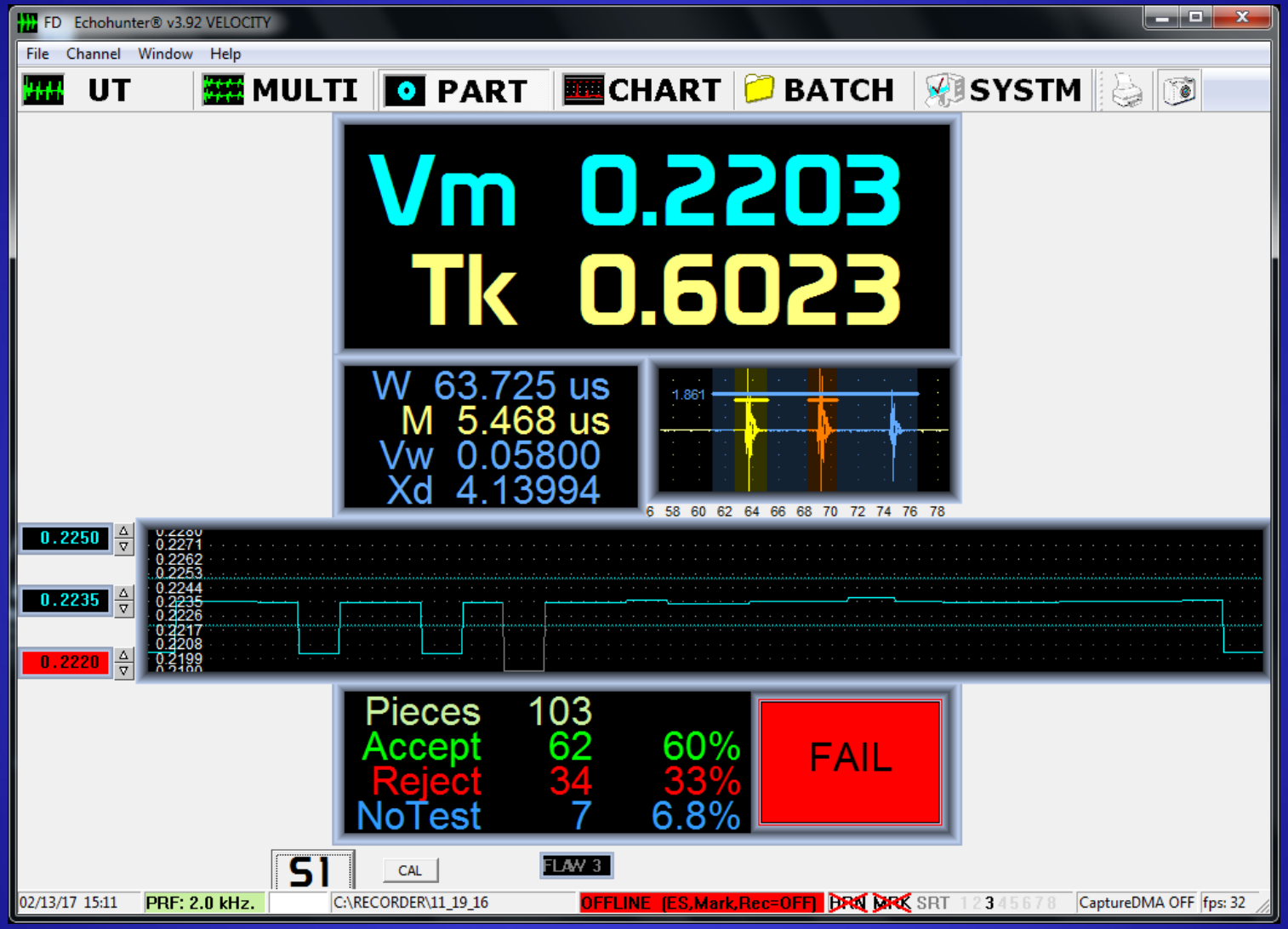
- Measure material velocity and thickness
- One channel UT in Tank configuration, T/R model
- Bubbler configuration requires a separate channel to monitor water velocity (temperature)
- Calibration with known piece velocity or thickness
- One or two velocity stations

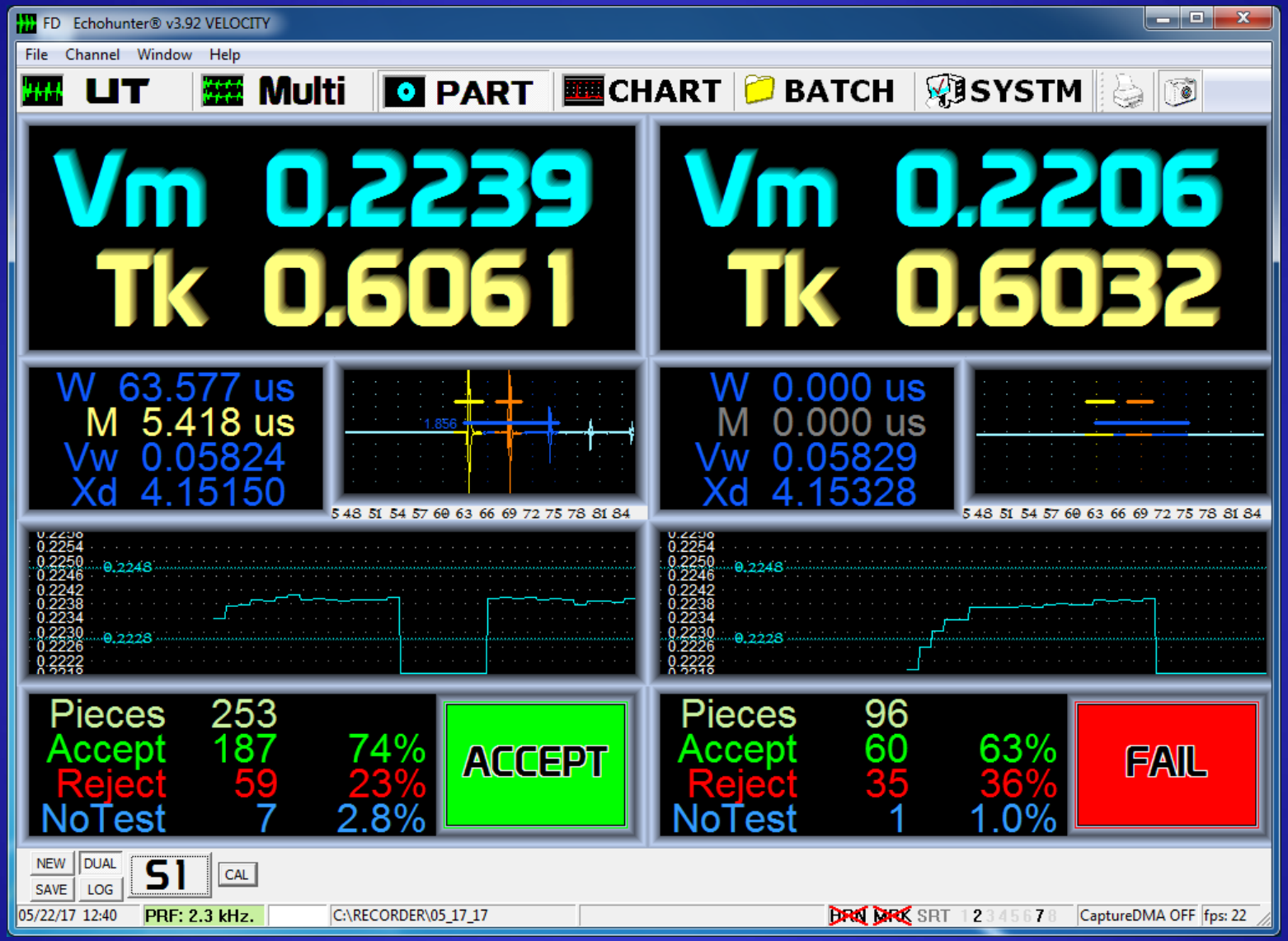
Operation

- In normal operation mode, system displays one of the four modes:
  1. Load Part: System is ready to accept part;
  2. Accept: Part is tested with velocity in the specified range;
  3. Reject: Part is tested but velocity is outside the specification;
  4. No Test: Invalid measurement; no material path or thickness can be read.
- Additional flaw channels are available to monitor other portion of the part. They can contribute to Reject condition;


FD Echohunter® v3.92 VELOCITY
File Channel Window Help
UT MULTI PART CHART BATCH SYSTM
Vm 0.2236
Tk 0.6026
W 71.375 us
M 0.000 us
Vw 0.05800
Xd 4.13994
2.084
6 58 60 62 64 66 68 70 72 74 76 78
0.2250
0.2235
0.2220
0.2271
0.2262
0.2253
0.2244
0.2235
0.2226
0.2217
0.2208
0.2199
Pieces 102
Accept 62 61%
Reject 33 32%
NoTest 7 6.9%
LOAD PART
S1
CAL
FLAW 3
02/13/17 15:10
PRF: 2.0 kHz.
C:\RECORDER\11_19_16
OFFLINE (ES,Mark,Rec=OFF)
SRT 1
CaptureDMA OFF
fps: 32


FD Echohunter® v3.92 VELOCITY
File Channel Window Help
UT
MULTI
PART
CHART
BATCH
SYSTM
Vm 0.2236
Tk 0.6026
W 63.667 us
M 5.398 us
Vw 0.05800
Xd 4.13994
1.859
6 58 60 62 64 66 68 70 72 74 76 78
0.2250
0.2235
0.2220
0.2271
0.2262
0.2253
0.2244
0.2235
0.2226
0.2217
0.2208
0.2199
Pieces 102
Accept 62 61%
Reject 33 32%
NoTest 7 6.9%
ACCEPT
S1
CAL
FLAW 3
02/13/17 15:10
PRF: 2.0 kHz.
C:\RECORDER\11_19_16
OFFLINE (ES,Mark,Rec=OFF)
SRT 2
CaptureDMA OFF
fps: 32


FD Echohunter® v3.92 VELOCITY
File Channel Window Help
UT MULTI PART CHART BATCH SYSTM
Vm 0.2203
Tk 0.6023
W 63.725 us
M 5.468 us
Vw 0.05800
Xd 4.13994
1.861
6 58 60 62 64 66 68 70 72 74 76 78
0.2250
0.2235
0.2220
0.2271
0.2262
0.2253
0.2244
0.2235
0.2226
0.2217
0.2208
Pieces 103
Accept 62 60%
Reject 34 33%
NoTest 7 6.8%
FAIL
S1
CAL
FLAW 3
02/13/17 15:11
PRF: 2.0 kHz.
C:\RECORDER\11_19_16
OFFLINE (ES,Mark,Rec=OFF)
SRT
CaptureDMA OFF
fps: 32


FD Echohunter® v3.92 VELOCITY
File Channel Window Help
UT Multi PART CHART BATCH SYSTM
Vm 0.2239
Tk 0.6061
Vm 0.2206
Tk 0.6032
W 63.577 us
M 5.418 us
Vw 0.05824
Xd 4.15150
W 0.000 us
M 0.000 us
Vw 0.05829
Xd 4.15328
0.2248
0.2228
Pieces 253
Accept 187 74%
Reject 59 23%
NoTest 7 2.8%
ACCEPT
Pieces 96
Accept 60 63%
Reject 35 36%
NoTest 1 1.0%
FAIL
NEW DUAL SAVE LOG S1 CAL
05/22/17 12:40
PRF: 2.3 kHz.
C:\RECORDER\05_17_17
CaptureDMA OFF
fps: 22

Configuration

- Base unit: 4 channel with 2 velocity stations;
- 4 additional flaw channels can be optional;
- Tank and test fixtures can be quoted and supplied through our partner.

Results

With two customer samples marked 0.2235 (accept) and 0.2200 (reject), we have tested with both Tank and Bubbler mode of operations. Each sample is tested for 20 times and the velocity is recorded. Calibration is done on the accept sample (with velocity 0.2235 inch/us). Test results are tabulated as follows:

Tank Mode

Test Sequence	Results	Nominal	Error	Error %	Error square
1	0.2235	0.2235	0	0	0
2	0.2235	0.2235	0	0	0
3	0.2235	0.2235	0	0	0
4	0.2235	0.2235	0	0	0
5	0.2235	0.2235	0	0	0
6	0.2235	0.2235	0	0	0
7	0.2234	0.2235	-0.0001	-0.04474	1E-08
8	0.2234	0.2235	-0.0001	-0.04474	1E-08
9	0.2232	0.2235	-0.0003	-0.13423	9E-08
10	0.2233	0.2235	-0.0002	-0.08949	4E-08
11	0.2234	0.2235	-0.0001	-0.04474	1E-08
12	0.2235	0.2235	0	0	0
13	0.2235	0.2235	0	0	0
14	0.2235	0.2235	0	0	0
15	0.2235	0.2235	0	0	0
16	0.2235	0.2235	0	0	0
17	0.2235	0.2235	0	0	0
18	0.2235	0.2235	0	0	0
19	0.2235	0.2235	0	0	0
20	0.2235	0.2235	0	0	0

Tank Mode (Cont'd)

Test Sequence	Results	Nominal	Error	Error %	Error square	
21	0.2202	0.22	0.0002	0.090909	4E-08	
22	0.2202	0.22	0.0002	0.090909	4E-08	
23	0.2202	0.22	0.0002	0.090909	4E-08	
24	0.2202	0.22	0.0002	0.090909	4E-08	
25	0.2202	0.22	0.0002	0.090909	4E-08	
26	0.2202	0.22	0.0002	0.090909	4E-08	
27	0.2202	0.22	0.0002	0.090909	4E-08	
28	0.2202	0.22	0.0002	0.090909	4E-08	
29	0.2201	0.22	1E-04	0.045455	1E-08	
30	0.2202	0.22	0.0002	0.090909	4-08	
31	0.2202	0.22	0.0002	0.090909	4E-08	
32	0.2202	0.22	0.0002	0.090909	4E-08	
33	0.2202	0.22	0.0002	0.090909	4E-08	
34	0.2202	0.22	0.0002	0.090909	4E-08	
35	0.2202	0.22	0.0002	0.090909	4E-08	
36	0.2203	0.22	0.0003	0.136364	9E-08	
37	0.2202	0.22	0.0002	0.090909	4E-08	
38	0.2202	0.22	0.0002	0.090909	4E-08	
39	0.2202	0.22	0.0002	0.090909	4E-08	
40	0.2202	0.22	0.0002	0.090909	4E-08	
Standard Deviation					0.0001565 inch/us	0.071148%

Bubbler Mode

Test Sequence	Results	Nominal	Error	Error %	Error square
1	0.2236	0.2235	1E-04	0.044743	1E-08
2	0.2236	0.2235	1E-04	0.044743	1E-08
3	0.2236	0.2235	1E-04	0.044743	1E-08
4	0.2236	0.2235	1E-04	0.044743	1E-08
5	0.2236	0.2235	1E-04	0.044743	1E-08
6	0.2235	0.2235	0	0	0
7	0.2236	0.2235	1E-04	0.044743	1E-08
8	0.2236	0.2235	1E-04	0.044743	1E-08
9	0.2236	0.2235	1E-04	0.044743	1E-08
10	0.2234	0.2235	-0.0001	-0.04474	1E-08
11	0.2236	0.2235	1E-04	0.044743	1E-08
12	0.2236	0.2235	1E-04	0.044743	1E-08
13	0.2236	0.2235	1E-04	0.044743	1E-08
14	0.2236	0.2235	1E-04	0.044743	1E-08
15	0.2236	0.2235	1E-04	0.044743	1E-08
16	0.2236	0.2235	1E-04	0.044743	1E-08
17	0.2236	0.2235	1E-04	0.044743	1E-08
18	0.2236	0.2235	1E-04	0.044743	1E-08
19	0.2236	0.2235	1E-04	0.044743	1E-08
20	0.2236	0.2235	1E-04	0.044743	1E-08

Bubbler Mode (Cont'd)

Test Sequence		Results	Nominal	Error	Error %	Error square
21	0.2203	0.22	0.0003	0.136364	9E-08	
22	0.2203	0.22	0.0003	0.136364	9E-08	
23	0.2203	0.22	0.0003	0.136364	9E-08	
24	0.2203	0.22	0.0003	0.136364	9E-08	
25	0.2203	0.22	0.0003	0.136364	9E-08	
26	0.2203	0.22	0.0003	0.136364	9E-08	
27	0.2203	0.22	0.0003	0.136364	9E-08	
28	0.2203	0.22	0.0003	0.136364	9E-08	
29	0.2203	0.22	0.0003	0.136364	9E-08	
30	0.2203	0.22	0.0003	0.136364	9E-08	
31	0.2203	0.22	0.0003	0.136364	9E-08	
32	0.2203	0.22	0.0003	0.136364	9E-08	
33	0.2203	0.22	0.0003	0.136364	9E-08	
34	0.2203	0.22	0.0003	0.136364	9E-08	
35	0.2203	0.22	0.0003	0.136364	9E-08	
36	0.2203	0.22	0.0003	0.136364	9E-08	
37	0.2203	0.22	0.0003	0.136364	9E-08	
38	0.2203	0.22	0.0003	0.136364	9E-08	
39	0.2203	0.22	0.0003	0.136364	9E-08	
40	0.2203	0.22	0.0003	0.136364	9E-08	
Standard Deviation					0.000223 inch/us	0.101385%

For additional information, please contact:

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- 914-703-3790
- zyou@mac-ndt.com
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