SAND2007-7334C

Time Resolved Energy Absorption in Laser Beam Spot Welds

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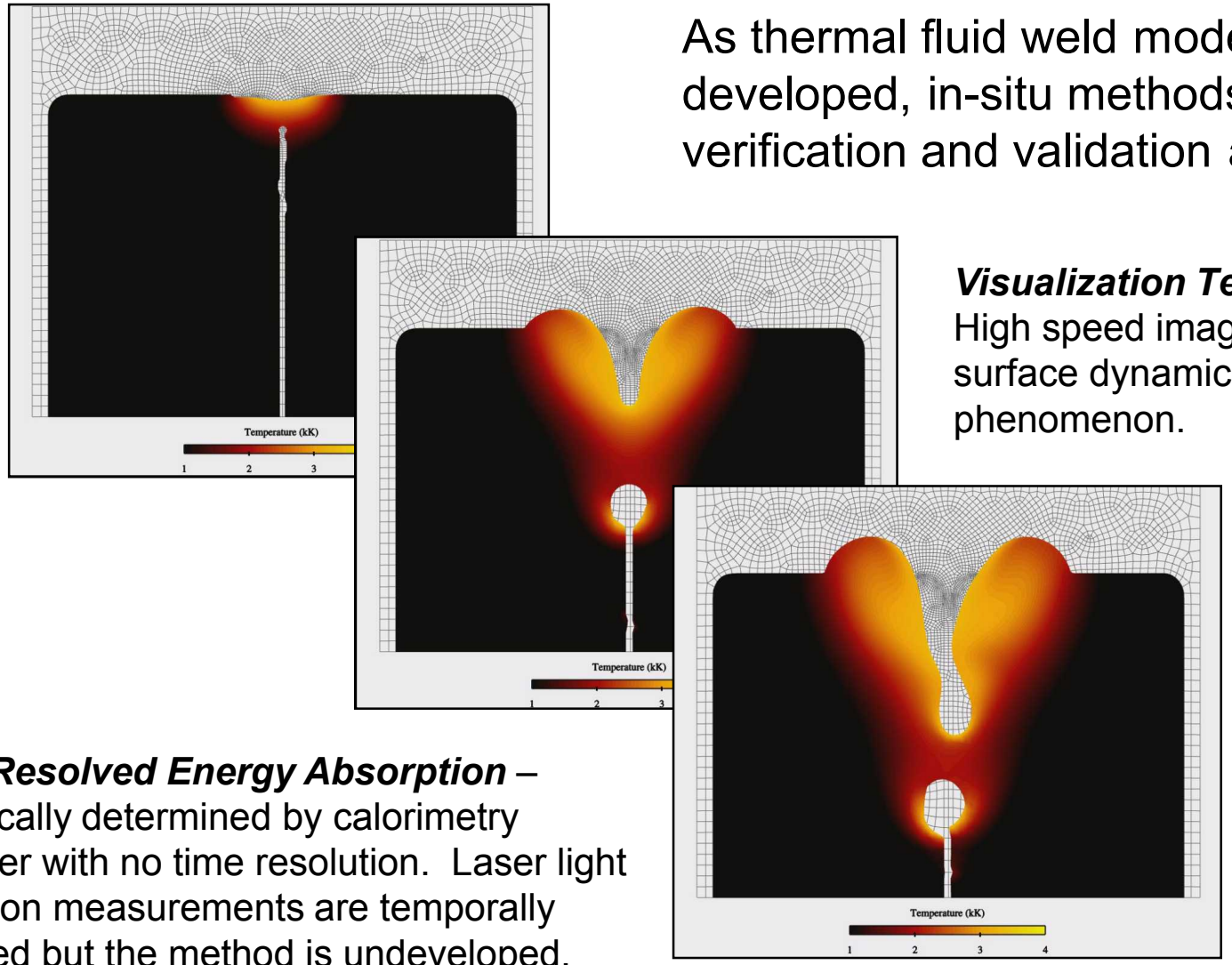
Weld Model Verification & Validation



As thermal fluid weld models are developed, in-situ methods for verification and validation are needed.

Visualization Techniques - High speed imaging of weld pool surface dynamics and keyhole phenomenon.

Time Resolved Energy Absorption – Historically determined by calorimetry however with no time resolution. Laser light reflection measurements are temporally resolved but the method is undeveloped.

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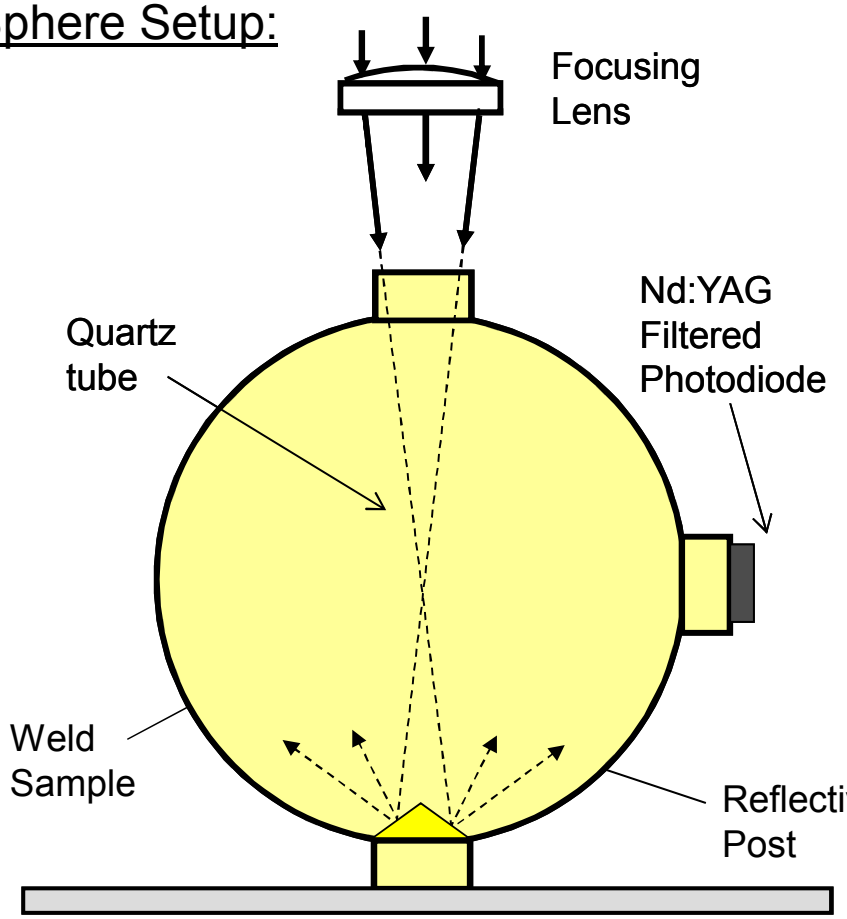
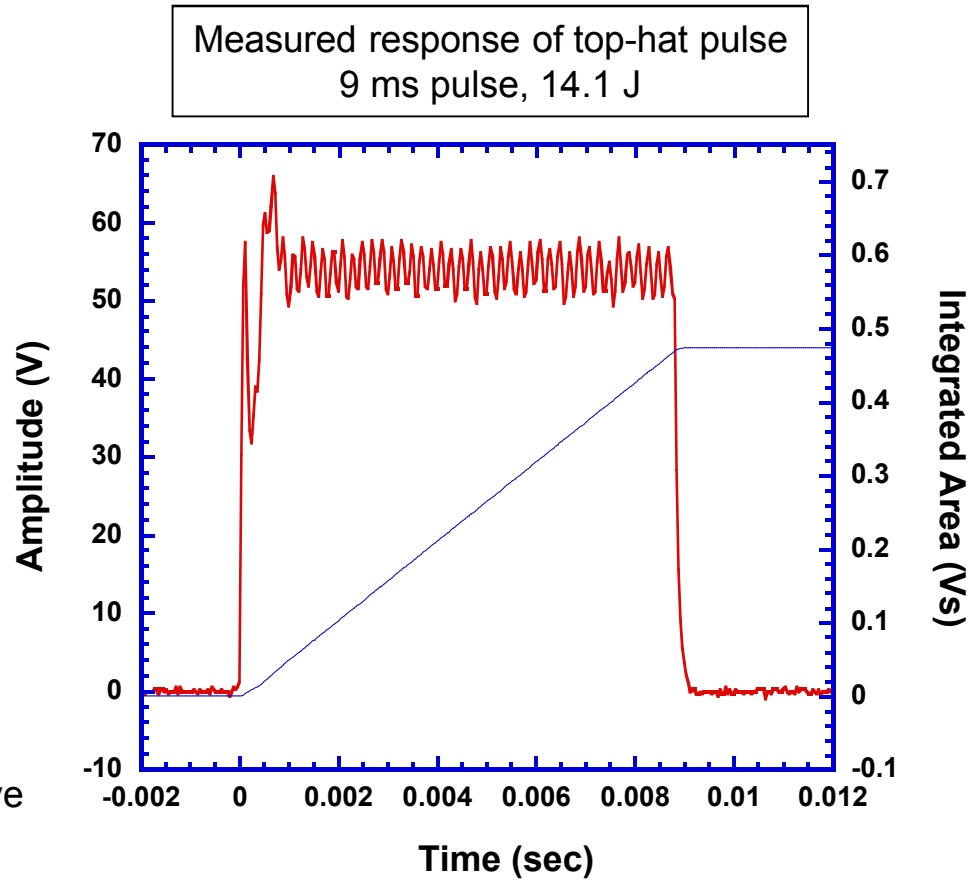
Proof of Concept

By capture and measurement of the reflected Nd:YAG laser light, absorption can be deduced when the total pulse energy delivered is known.

Sphere Setup:





Laser light is measured through a voltage biased Nd:YAG filtered photodiode

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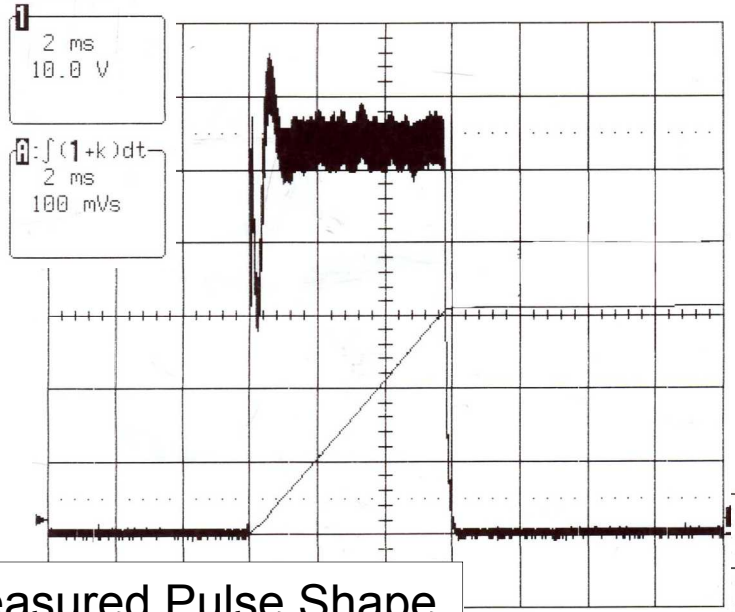
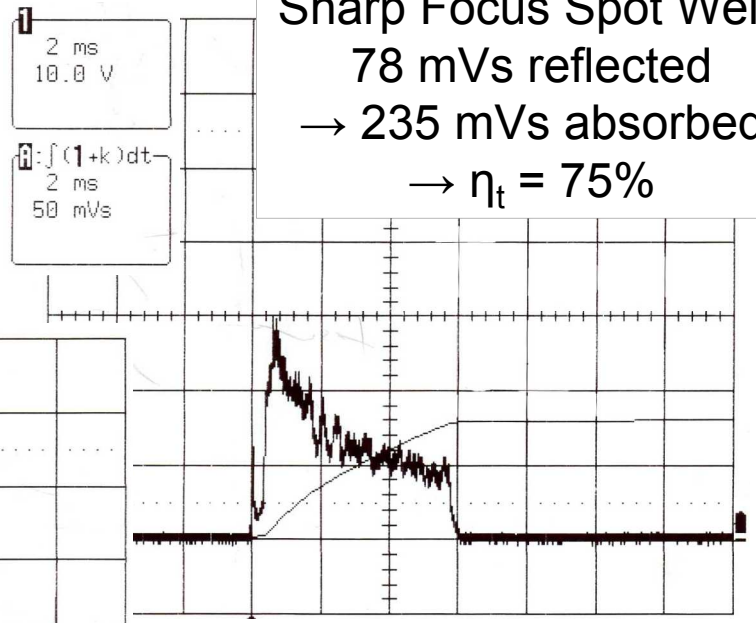
Proof of Concept: Cont.

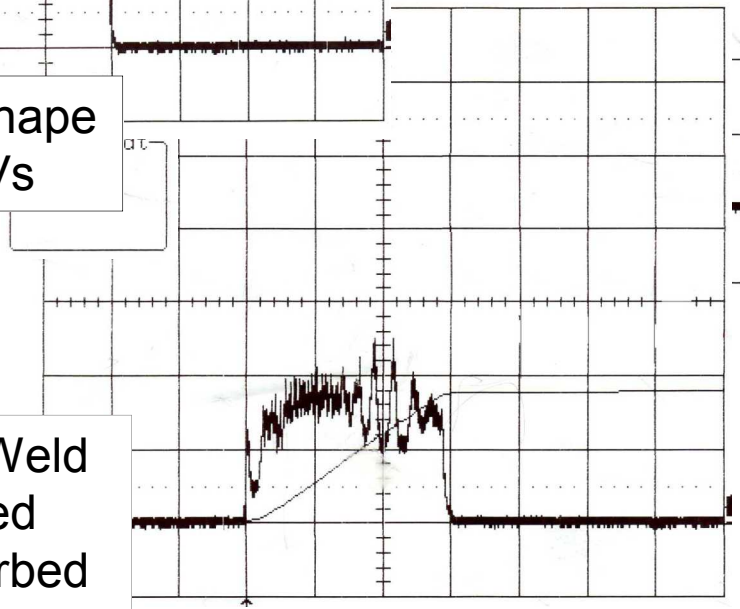
150 mm lens @ S.F., UHP Argon
6 ms, 10.4 J, 1.7 kW_{set}



Measured Pulse Shape
10.4 J = 313 mVs



Sharp Focus Spot Weld
78 mVs reflected
→ 235 mVs absorbed
→ η_t = 75%



Defocused Spot Weld
90 mVs reflected
→ 235 mVs absorbed
→ η_t = 71%

Initial measurements seem to agree with current understanding of keyhole phenomenon.

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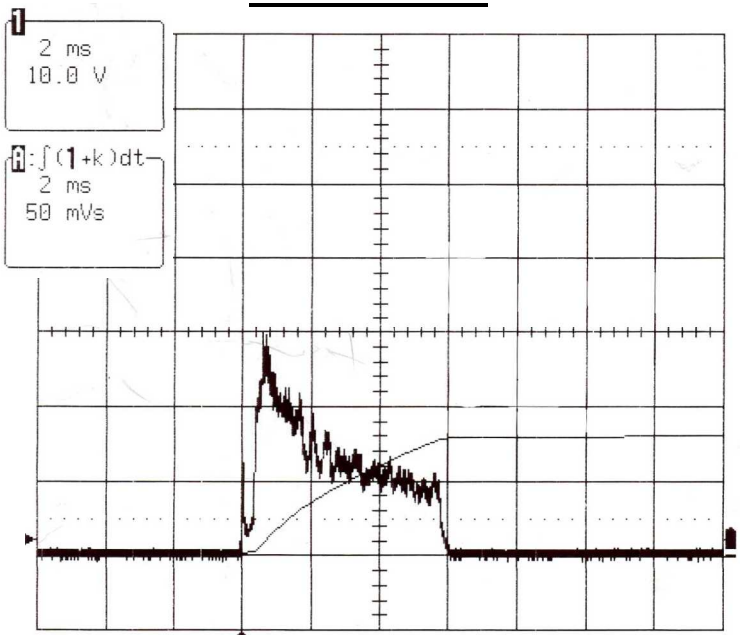
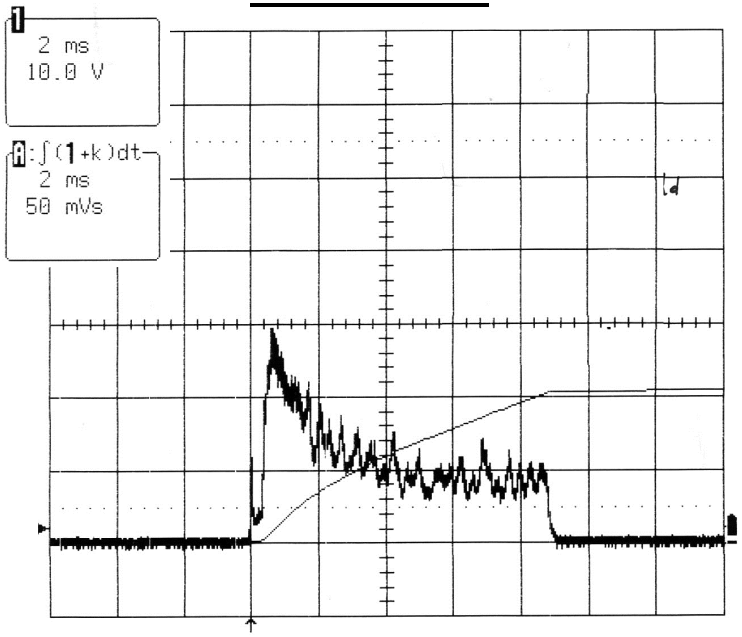
Proof of Concept: Cont.

150 mm lens @ S.F., UHP Ar Shielded
1.7 kW_{set}

6 ms Pulse



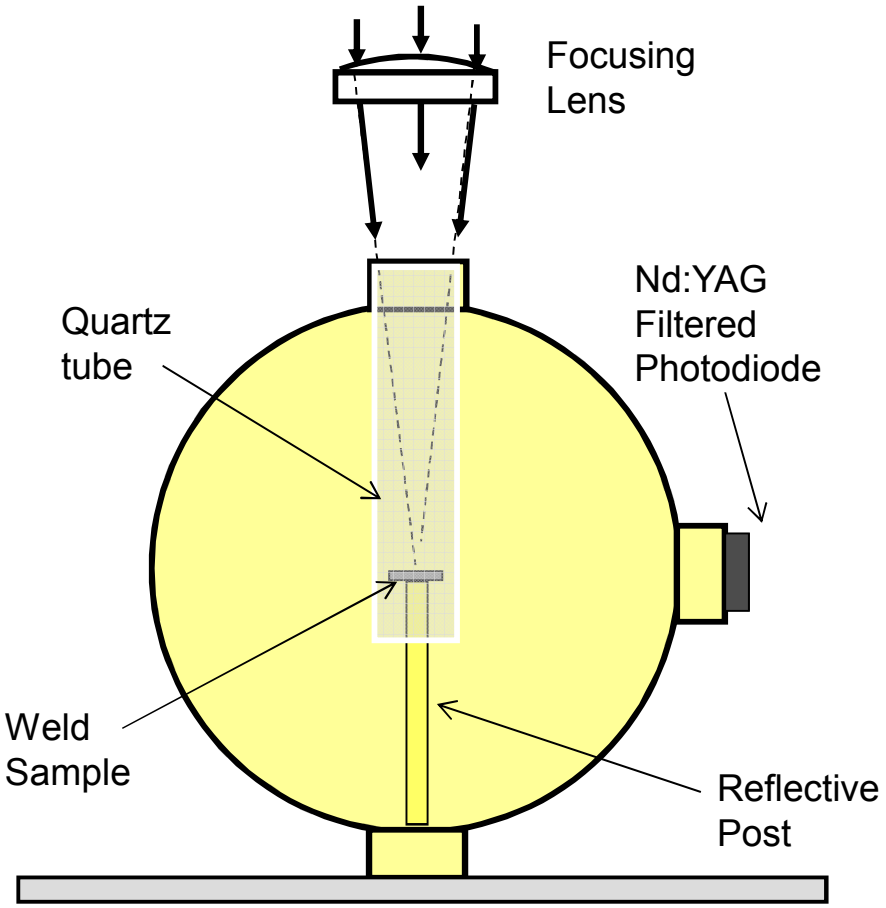
9 ms Pulse



- Low absorption measured prior to keyhole formation
- Keyhole absorption plateaus after ~5 ms at the given peak power
- Maximum instantaneous transfer efficiency (η_t) ~ 80%

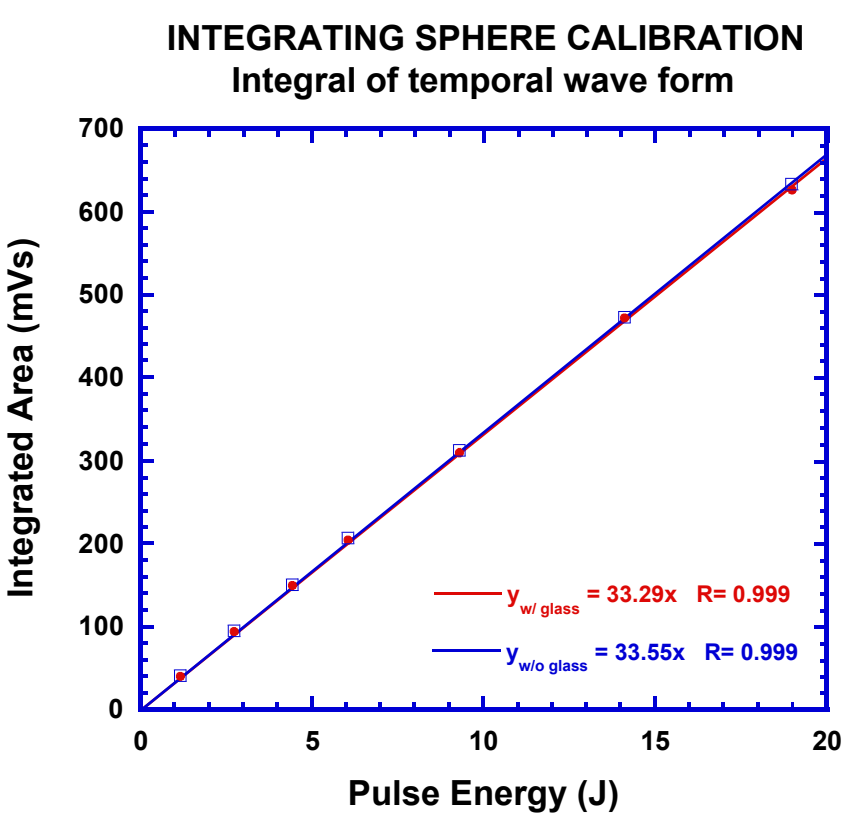
Things to Consider???

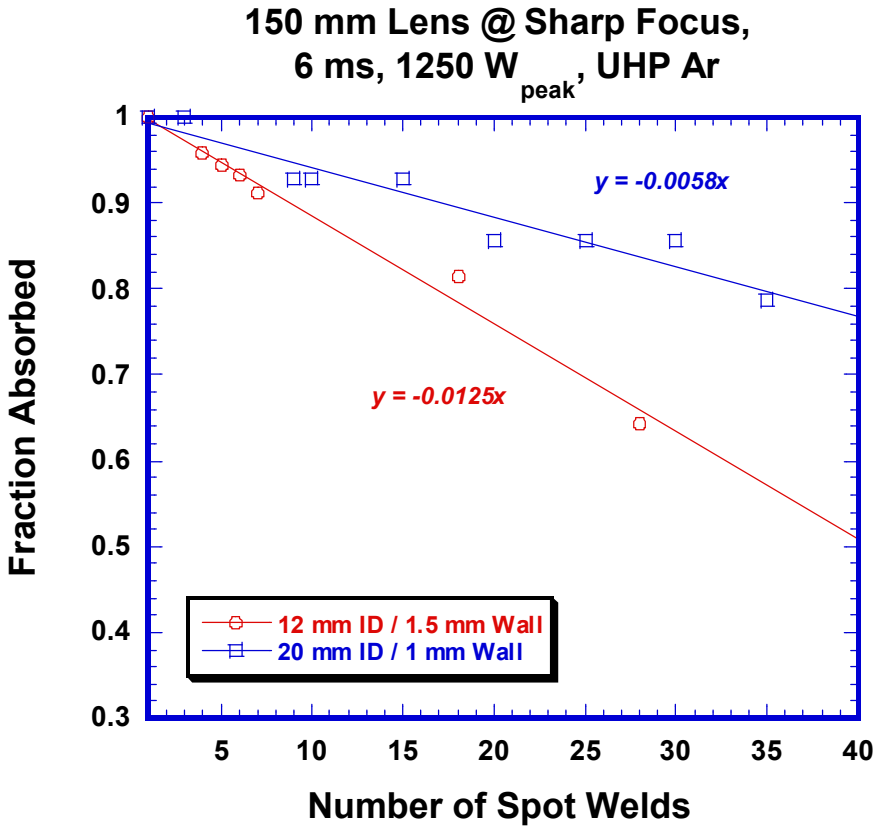
Accurate calibrations and no loss of reflected light is necessary to determine temporal energy absorption.



- *Quartz Tube* – is Nd:YAG light absorbed by the tube?
- *Metal Vapor Layer* – how much energy is absorbed by metal vapors deposited on quartz tubes?
- *Post Height* – is it sensitive to calibration. Does post height (relative to sphere opening and Diode position) alter Voltage output?
- *Scattered Light* – how much is lost through sphere opening. How does it vary in time and with weld mode?

Effect of Quartz Tube





- Quartz tube (1.0 mm wall) appears transparent to the 1064 nm wavelength. Cone position at sphere base.

- 0.6% energy absorption by metal vapor per weld spot. 1250 W peak power

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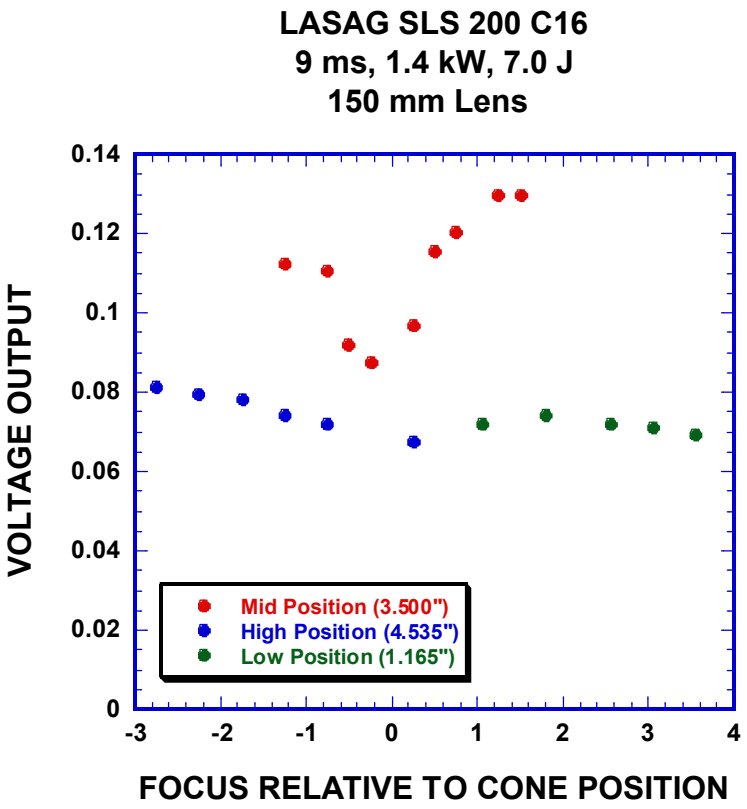
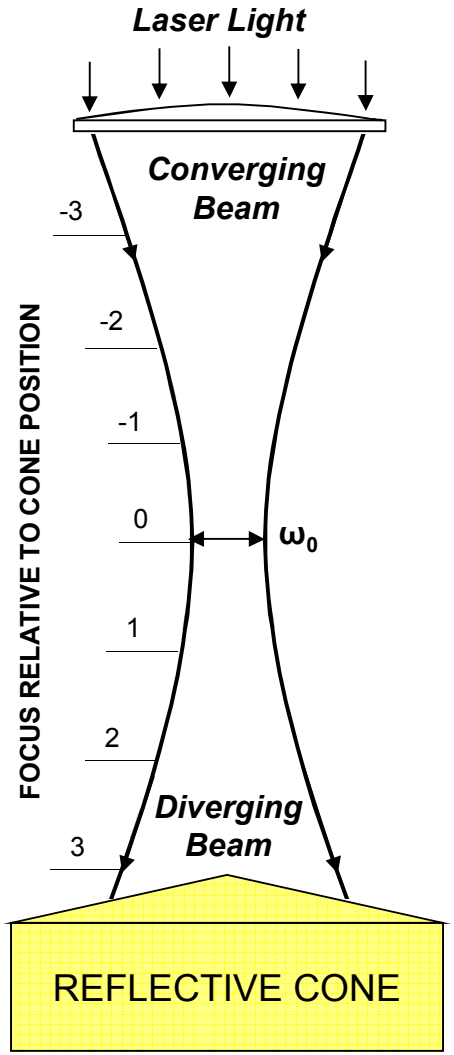
Effect of Post Position and Focus

Position of reflective cone and weld sample is critical to calibration of output voltage.





- Scattered light directly out of the sphere increases near focus reducing measured reflections (output voltage).
- Output voltage is increased presumably by direct reflections in to the detector.
- As such, calibration profiles and welds should be made at the same height relative to detector and sphere opening.

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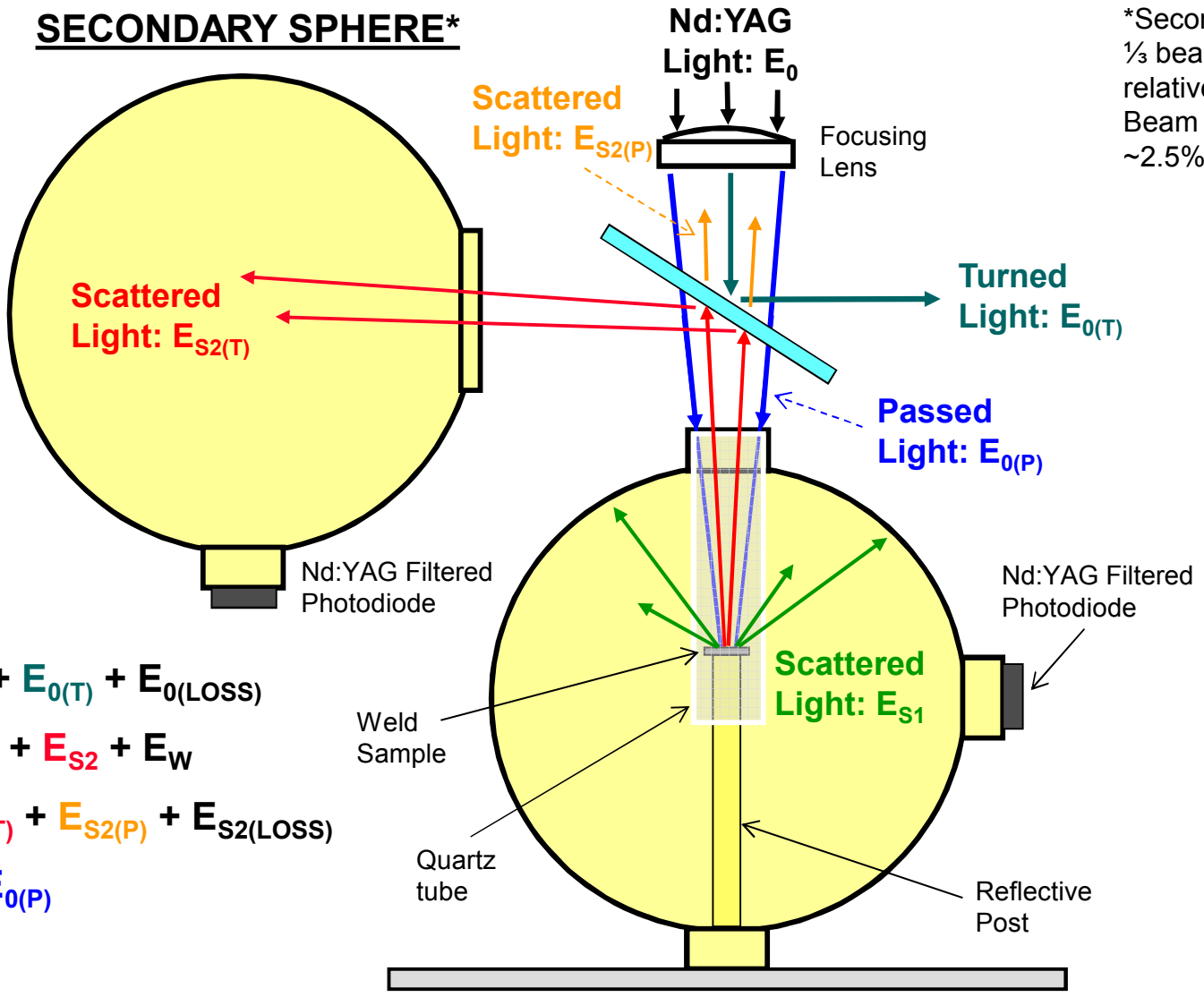
Energy Distribution Diagram – New Setup



*Secondary sphere and ⅓ beam splitter are fixed relative to each other. Beam splitter absorbs ~2.5% per reflection.

$$E_0 = E_{0(P)} + E_{0(T)} + E_{0(LOSS)}$$

$$E_{0(P)} = E_{S1} + E_{S2} + E_W$$

$$E_{S2} = E_{S2(T)} + E_{S2(P)} + E_{S2(LOSS)}$$

$$\eta_t = E_W / E_{0(P)}$$

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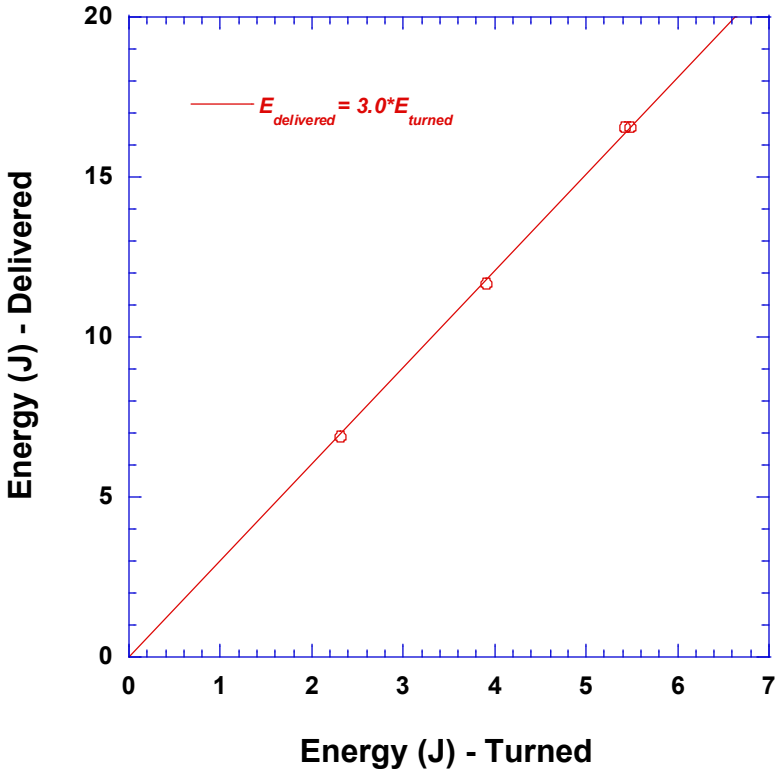
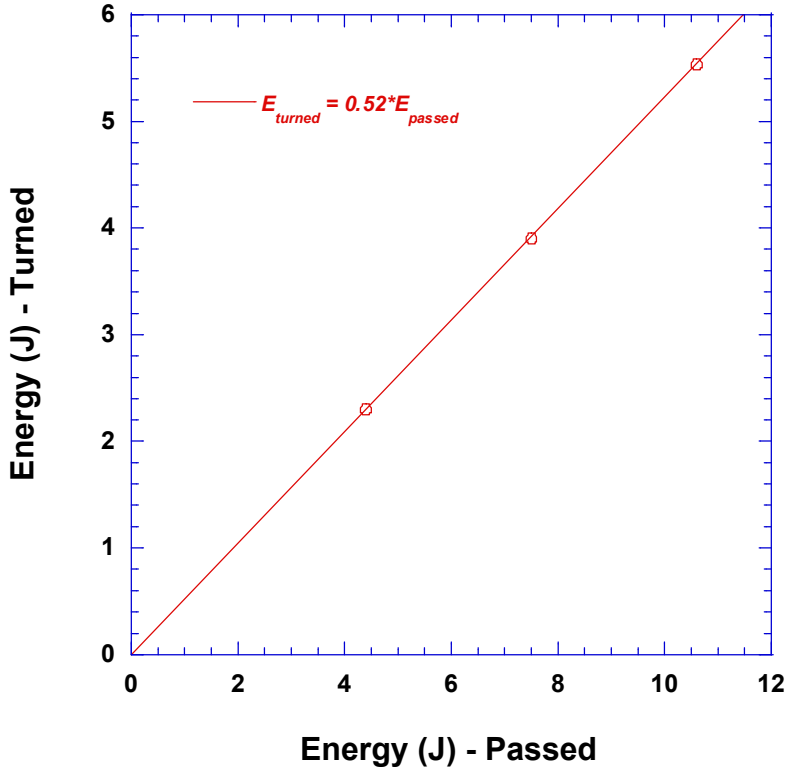
Energy Distribution Correlations

Energy Distribution by Beam Splitter
150 mm Lens, 6 ms Weld Series



Energy Distribution thru Beam Splitter
150 mm Lens, Cone Position at Weld Hight
6 ms Weld Series



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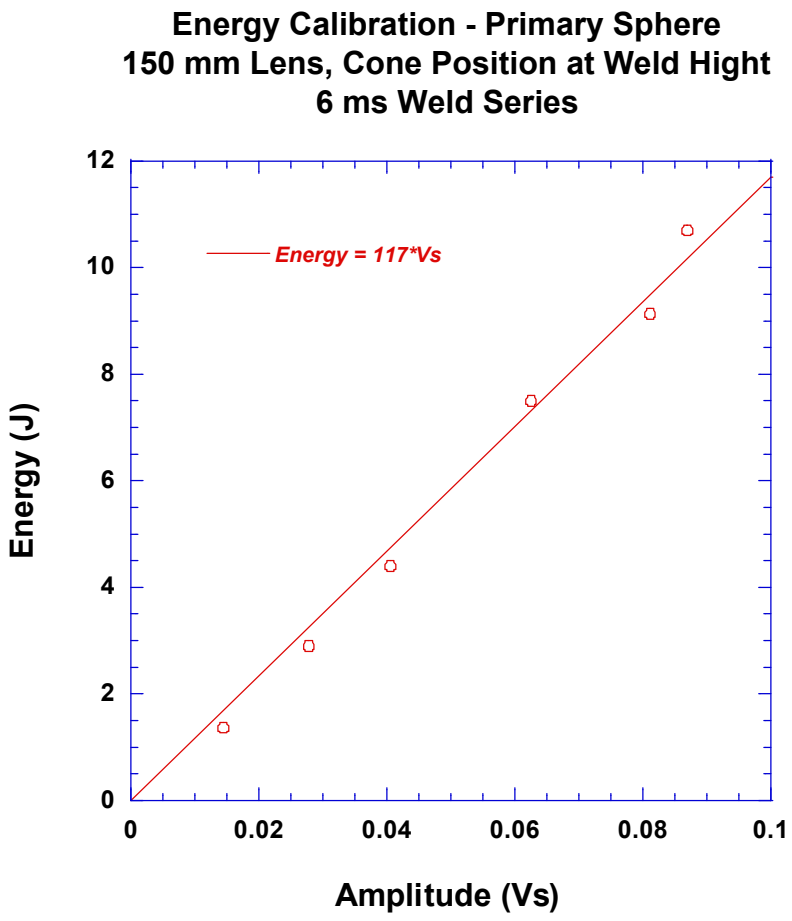
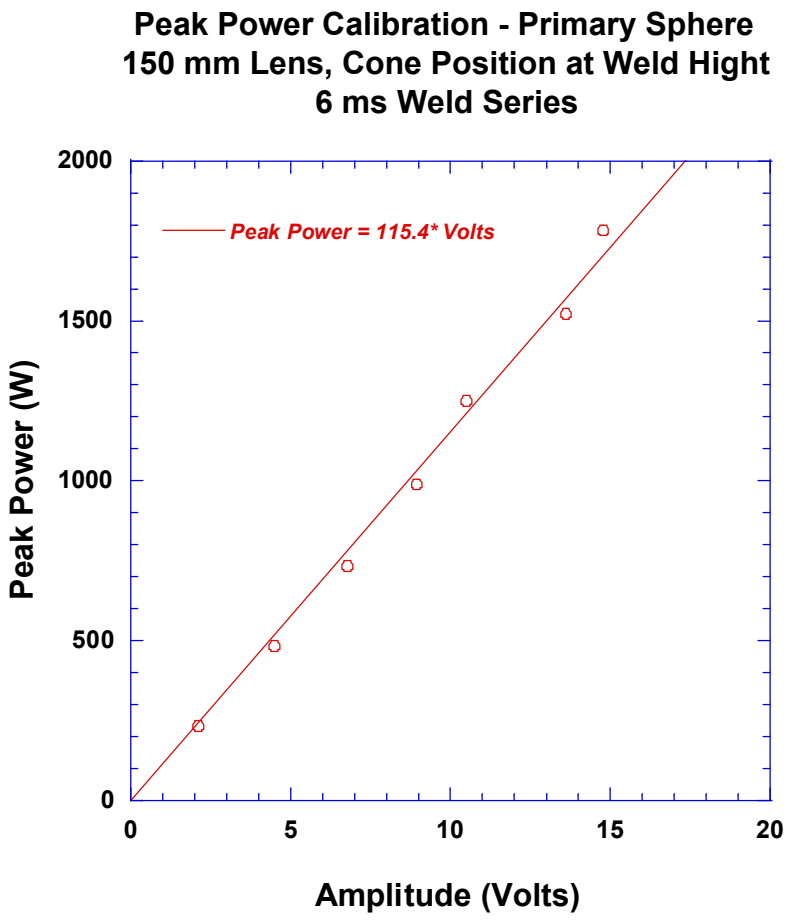
Primary Sphere Calibrations





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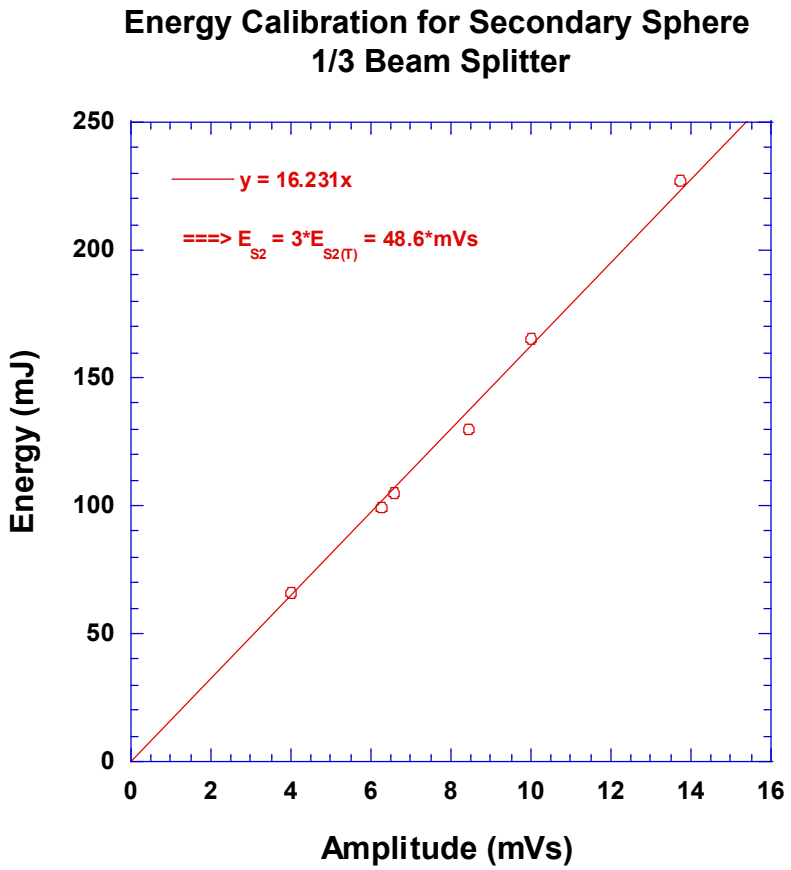
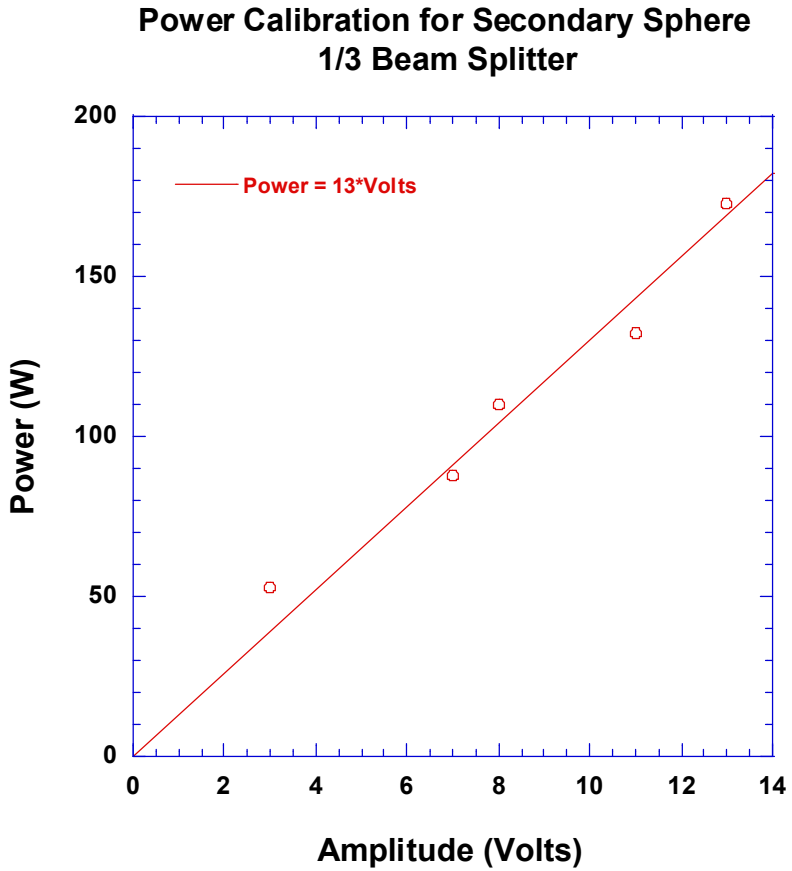
Secondary Sphere Calibrations





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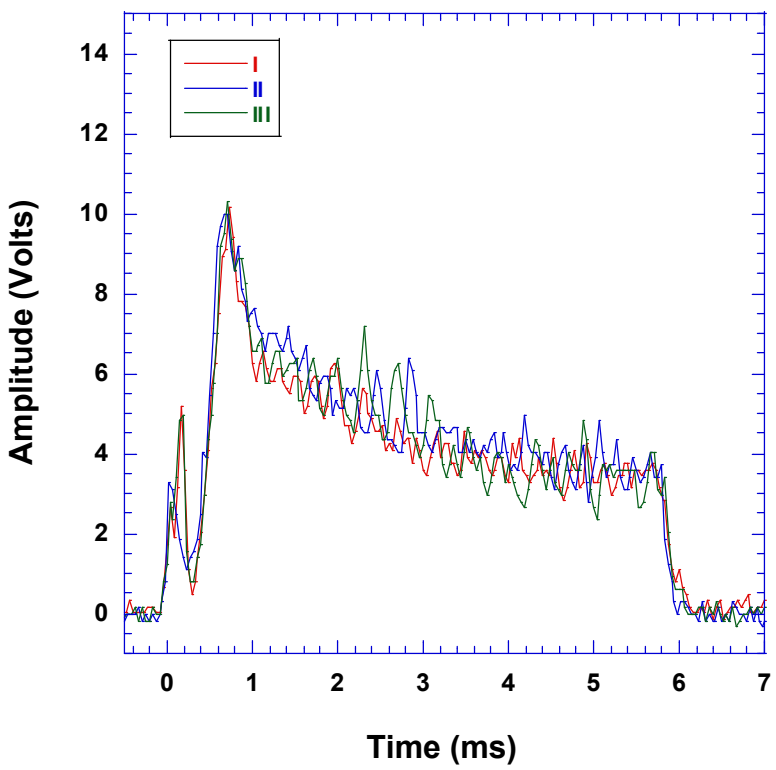
Temporal Profile for Keyhole Mode Weld

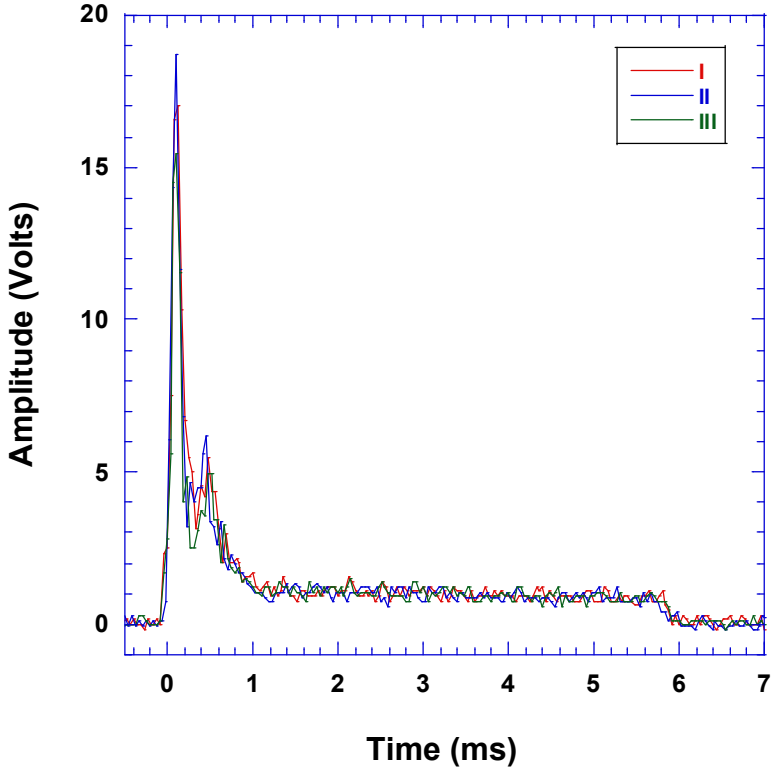
Primary Sphere

Lasag SLS C16 - Pulse Temporal Profile
150 mm lens, Cone position at weld hight
6 ms, 3.5 kWset, 10.69 J



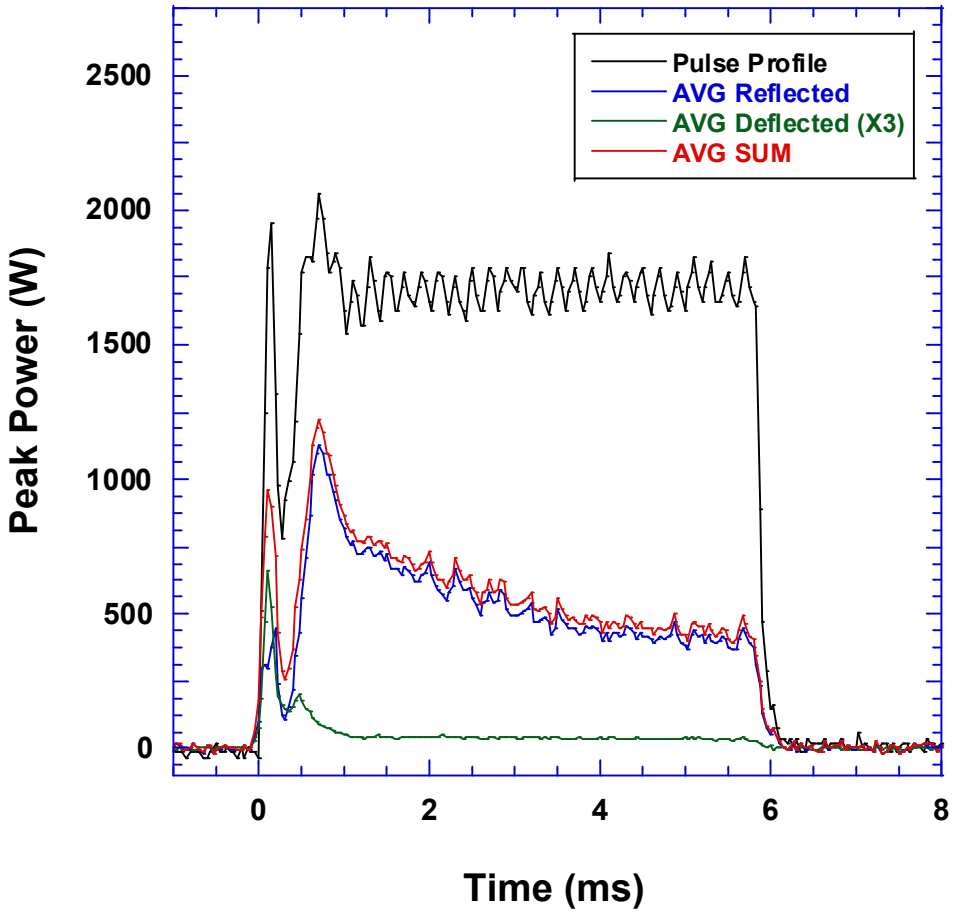
Secondary Sphere

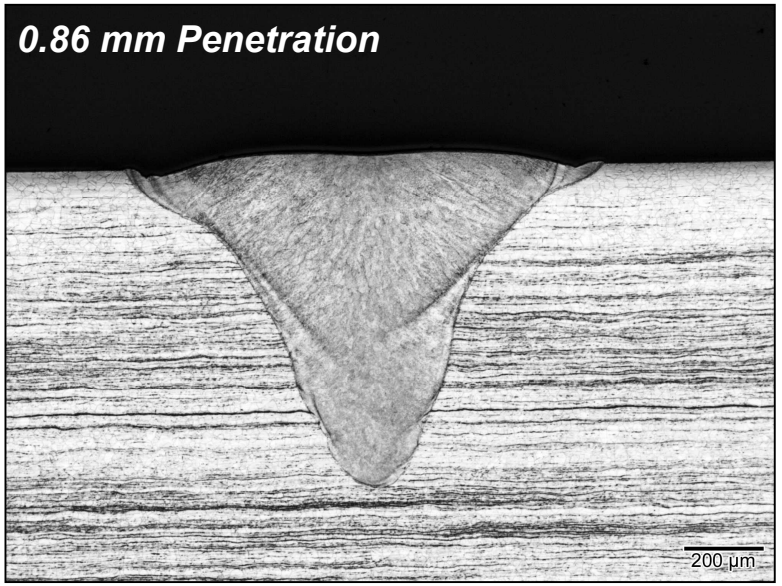
Lasag SLS C16 - Pulse Temporal Profile
150 mm lens, Cone position at weld hight
6 ms, 3.5 kWset, 10.69 J



Keyhole Mode Spot Weld

Lasag SLS C16
150 mm lens, Cone position at weld hight
6 ms, 3.5 kWset, 10.69 J





E_{S1} = 3.51 J, E_{S2} = 425 mJ

$E_W = E_{0(P)} - (E_{S1} + E_{S2})$

E_W = 6.8 J

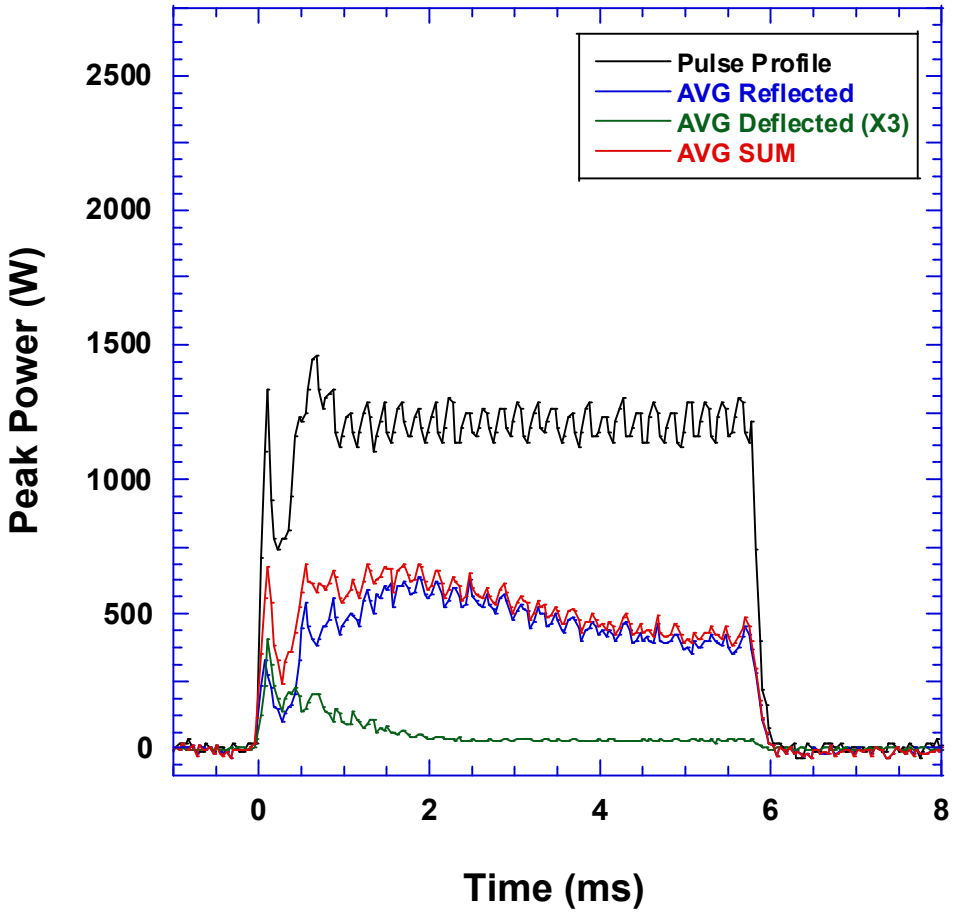
η_t = 63%*, $\eta_{t\text{-}max}$ = 75%

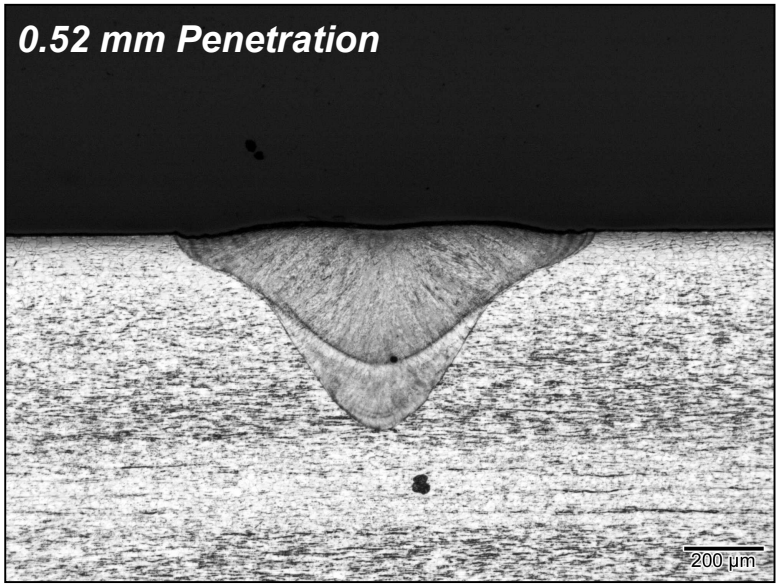
$E_{S2} / (E_{S1} + E_{S2})$ = 11%

*Similar calorimetric results presented by P.W. Fuerschbach *et al.*: STWJ Vol7 No.4

Conduction/Keyhole Mode Spot Weld

Lasag SLS C16
150 mm lens, Cone position at weld hight
6 ms, 2.5 kWset, 7.54 J





E_{S1} = 3.04 J, E_{S2} = 440 mJ

$E_W = E_{0(P)} - (E_{S1} + E_{S2})$

E_W = 4.1 J

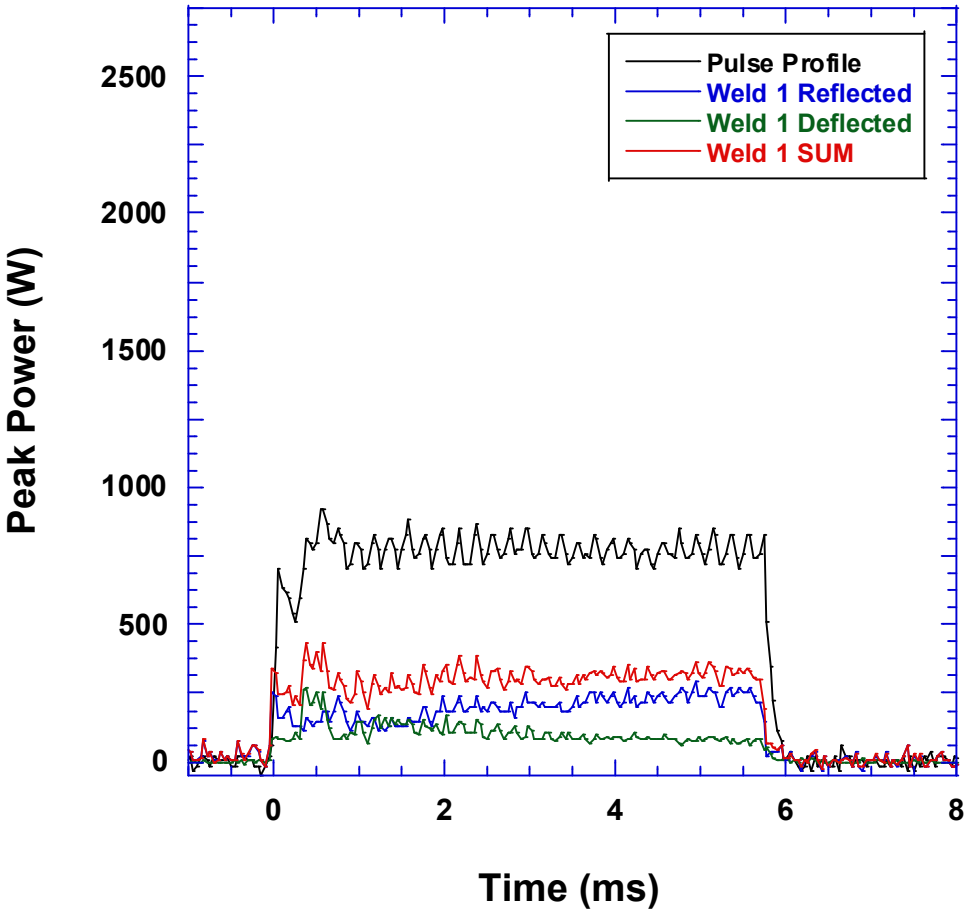
η_t = 54%*, $\eta_{t\text{-}max}$ = 68%

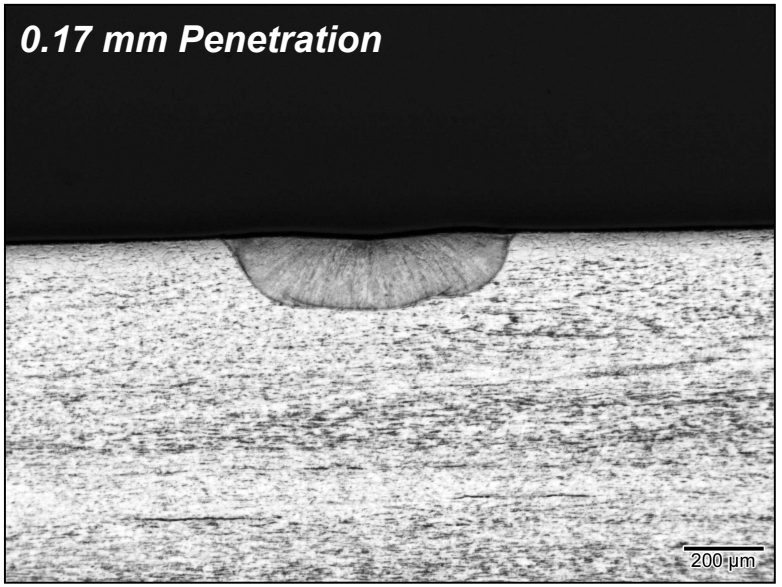
$E_{S2} / (E_{S1} + E_{S2})$ = 13%

*Similar calorimetric results presented by P.W. Fuerschbach *et al.*: STWJ Vol7 No.4

Conduction Mode Spot Weld

Lasag SLS C16
150 mm lens, Sharp Focus (6.006" offset)
6 ms, 1.5 kWset, 4.39 J





E_{S1} = 1.34 J, E_{S2} = 730 mJ

$E_W = E_{0(P)} - (E_{S1} + E_{S2})$

E_W = 2.3 J

η_t = 52%*, $\eta_{t\text{-}max}$ = 62%

$E_{S2} / (E_{S1} + E_{S2})$ = 35%

*Similar calorimetric results presented by P.W. Fuerschbach *et al.*: STWJ Vol7 No.4

Summary

- A method for time resolved energy absorption in laser beam spot welds (LBSWs) has been presented.
- Technique measures reflections via an integrating sphere to infer energy absorption in the weld.
- Exploratory results agree with previous calorimetric work preformed by P.W. Fuerschbach *et al*.: *S&T of Welding and Joining 2002, Vol. 7 No.4.*
- Reflection measurement show a maximum instantaneous energy transfer efficiency for keyhole mode welds to be ~75%; and decreases to ~50% for conduction mode weld.
- Maximum instantaneous absorption is reach quicker in higher peak power welds. In turn, higher overall transfer efficiencies may be measured.