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Date:	September 30, 2011	Refer to:	L1100197-v4
Subject:	Trade-off: porcelain coating vs. oxidized polished stainless steel for ACB		
To:	SLC Group		
From:	Michael Smith		

Statement of the Problem

The 1st article arm cavity baffle (ACB) fabricated from porcelainized enameling steel exhibits a significant amount of shedding of the porcelain surface in the vicinity of holes, bent corners, and especially in the areas where fasteners are used to connect separate sections of the baffle assembly. Also, shedding of iron oxide has been observed in the areas where the circumference of mounting holes was purposefully masked and did not receive a porcelain coating.

Characteristics of Alternative Baffle Material

The two determining characteristics for a baffle material are its reflectivity and bidirectional reflection distribution function (BRDF).

Reflectivity

reflectivity of porcelain @ 57 deg	$R_{porc57} := 0.001$
reflectivity of porcelain @ 3 deg	$R_{porc3} := 0.02$
reflectivity of stainless steel @ 57 deg	$R_{ss57} := 0.04$
reflectivity of stainless steel @ 3 deg	$R_{ss3} := 0.02$

The 33 deg apex angle of the ACB results in a minimum of 4 bounces between the opposing baffle surfaces before the reflected beam emerges from the baffle. Therefore, the net reflectivity after 4 reflections is the appropriate reflectivity parameter for comparison.

net reflectivity of porcelain after 4 bounces

$$R_{pnet4} := R_{porc57} \cdot R_{porc3}^{3}$$

$$R_{pnet4} = 8 \times 10^{-9}$$

net reflectivity of ss after 4 bounces

$$R_{snet4} := R_{ss57} \cdot R_{ss3}^{3}$$

$$R_{snet4} = 3.2 \times 10^{-7}$$

The net reflectivity of the porcelain coating is approximately 40 times lower than that of oxidized stainless steel when used in the ACB.

BRDF

The BRDF, which is a measure of the fractional scattering per unit solid angle, is approximately the same for porcelainized steel and oxidized polished stainless steel at angles of incidence >3 deg, with the porcelain coating having a factor 2.5 lower BRDF at best.

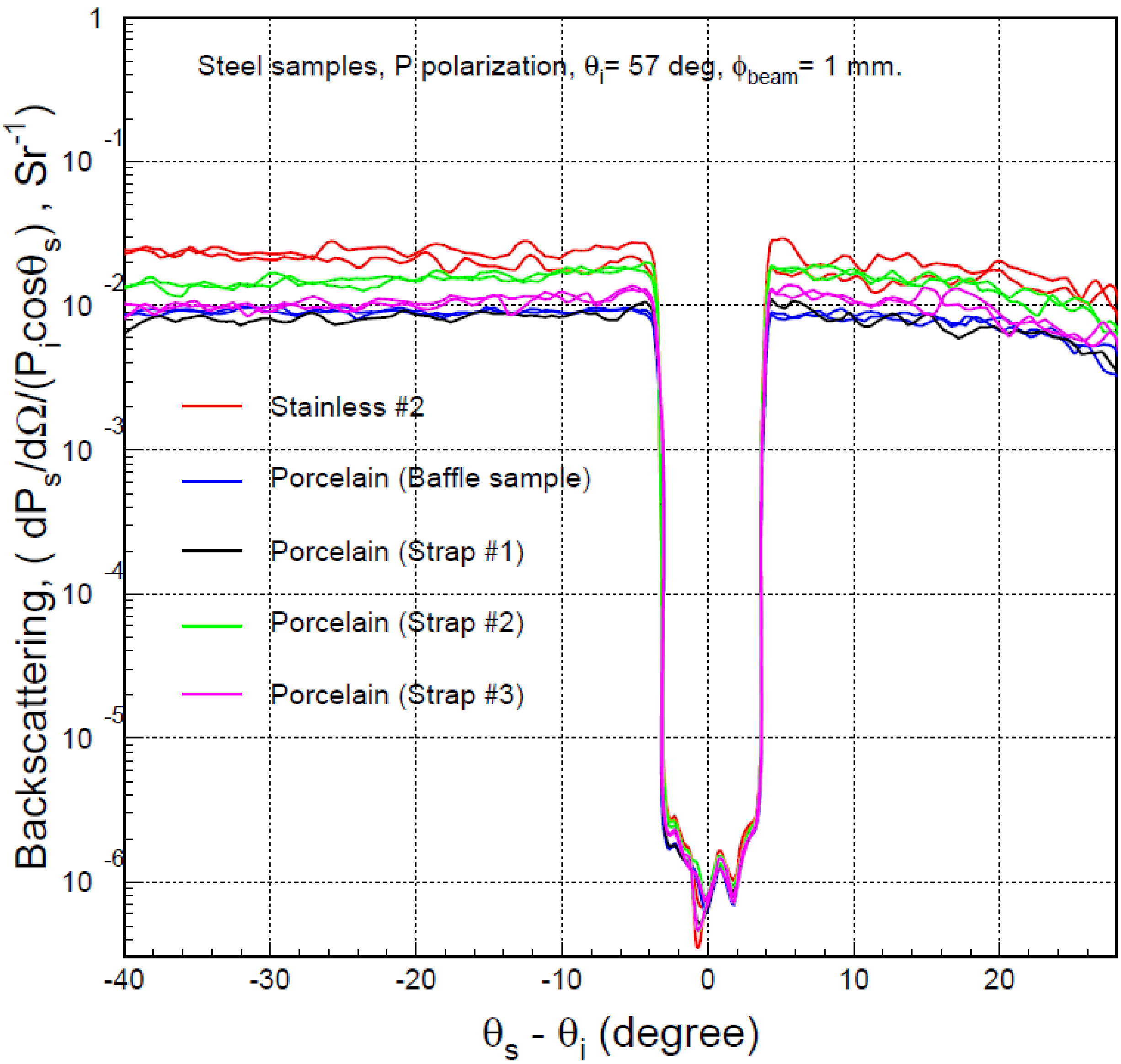

Figure 1: CASI BRDF Measurements

Scattered Light Displacement Noise

Direct Scatter from the ACB due to Arm Cavity Stray Light

The calculated scattered light displacement noise in the aLIGO interferometer from the ACB surface with a porcelain coated surface and with oxidized polished stainless steel are shown below. The displacement noise was calculated at a frequency of 100 Hz. The horizontal axis of the graph is the vertical tilt angle of the ACB; the 0.004 parameter is the radius of the baffle vertical frontal edge in millimeters; the louver surface of the baffle makes an angle of incidence of 57 deg with the incident light from the opposite end of the arm. A BRDF function for the porcelainized steel was derived assuming a large angle BRDF of 0.013, as shown in Figure 1. See T1100056 for the details of these calculations.

Incident power on baffle louvers, W $P_{iacb} = 7.393$

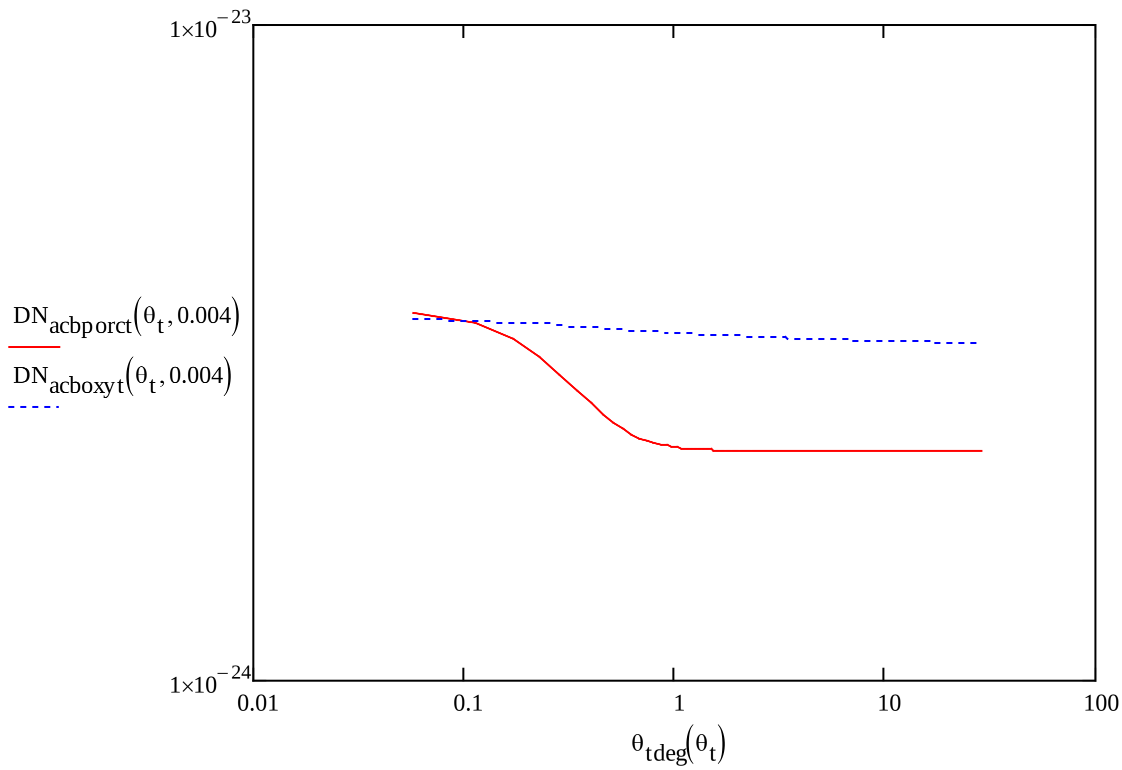

Figure 2: ACB Louver Surface Scattered Light Displacement Noise with Porcelainized Coating and Oxidized Polished Stainless Steel

As shown in the figure, the scattered light displacement noise, m/rtHz, is worse with the oxidized polished stainless steel surface than with the porcelain coating.
For a baffle vertical tilt angle of 3 deg and an edge radius of 0.0015 m, the displacement noise @ 100 Hz from a porcelainized steel baffle and from a polished, oxidized stainless steel baffle is compared below.

vertical tilt angle, rad $\theta_t := 3 \cdot \frac{\pi}{180}$ $\theta_t = 0.052$

$DN_{acboxyt}(\theta_t, 0.0015) = 3.204 \times 10^{-24}$

$DN_{acbporct}(\theta_t, 0.0015) = 2.093 \times 10^{-24}$

$$Ratio\_acboxyt\_acbporct := \frac{DN_{acboxyt}(0.052, 0.0015)}{DN_{acbporct}(0.052, 0.0015)}$$

$Ratio\_acboxyt\_acbporct = 1.531$

Although the displacement noise is 53% worse with oxidized stainless steel than with porcelain, the noise is still 300 times lower than the AOS requirement and is therefore acceptable.

Scatter from Back Side of ACB due to Wide Angle Scatter from Test Mass

The back side of the ACB is un-polished oxidized stainless steel. Back-scatter BRDF data is shown in Figure 2 below for oxidized stainless steel; see T080064-v1. At approximately 50 deg incidence angle, the BRDF of oxidized Super 8 polished stainless steel is 1.5 E^-2 sr^-1; the BRDF of the opposite side of the sample, which is un-polished, was measured to be 3.0 E^-2 sr^-1.

The scattered light displacement noise, m/rtHz, due to the wide angle scattered light of the TM hitting the back side of the ACB and the baffle box was calculated below for 100 Hz frequency, for oxidized un-polished stainless steel; see T1100113.

ACB BACK & BOX

$$DN_{acb\_box} := TF_{itmhr} \cdot \left(\frac{P_{wacbboxifo}}{P_{psl}} \right)^{0.5} \cdot x_{ACB} \cdot 2 \cdot k$$

$$DN_{acb\_box} = 2.051 \times 10^{-24}$$

Un-polished oxidized stainless steel is acceptable for the back surface of the ACB .

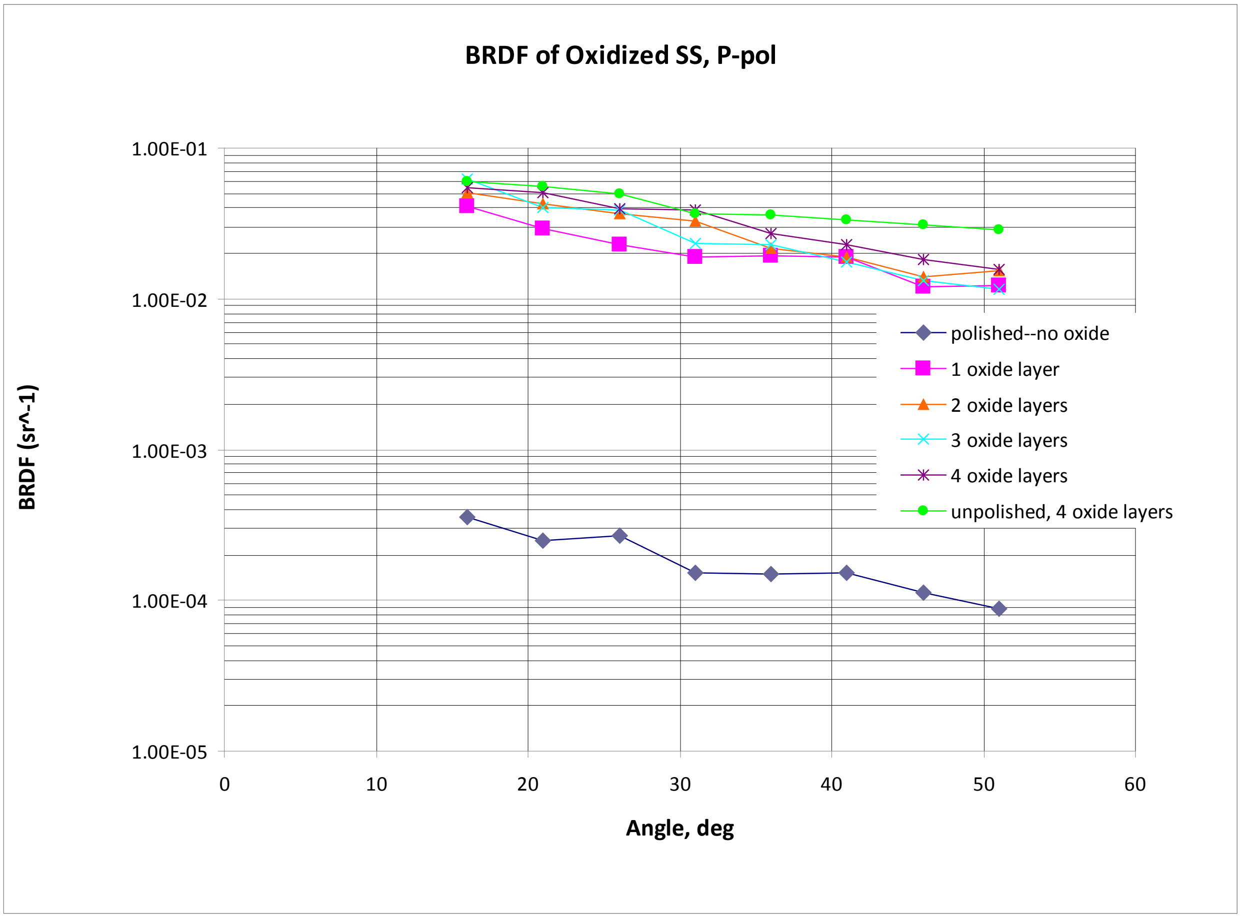

Figure 3: BRDF of Oxidized Stainless Steel, Super 8 Polished with Multiple Oxide Layers

Reflected Scatter from the ACB

In addition to scattering directly from the ACB surface, the light hitting the baffle will make multiple reflections from the baffle surface and eventually emerge and hit the wall of the BSC chamber, or the manifold wall. The reflected light that hits the wall or the chamber will scatter back toward the ACB, retrace the internal reflection path in the ACB, and enter the interferometer mode, causing scattered light displacement noise. This reflected scattering path is dependent upon the net reflectivity of the ACB.

The angle of incidence of the first reflection is 57 deg; we will assume that the angle of incidence for the remaining reflections is 3 deg.

1. Porcelainized ACB

reflectivity of porcelain @ 57 deg $R_{porc57} := 0.001$

reflectivity of porcelain @ 3 deg $R_{porc3} := 0.02$

net reflectivity of porcelain after 4 bounces

$$R_{pnet4} := R_{porc57} \cdot R_{porc3}^{3}$$

$$R_{pnet4} = 8 \times 10^{-9}$$

Power reflected from porc baffle, W

$$P_{acbporcrefl} := R_{pnet4} \cdot P_{ACB}$$

$$P_{acbporcrefl} = 5.914 \times 10^{-8}$$

Power reflected from ACBporc scattered into IFO mode , W

$$P_{acbporcrefls} := \sqrt{4} \cdot P_{acbporcrefl} \cdot R_{pnet4} \cdot BRDF_{wall} \cdot \frac{\pi \cdot w_{ifo}^{2}}{L^{2}} \cdot BRDF_{1}\left(30 \cdot 10^{-6}\right) \cdot \Delta_{ifo}$$

$$P_{acbporcrefls} = 9.93 \times 10^{-33}$$

displacement noise @ 100 Hz, m/rtHz

$$DN_{acbporcrefl} := TF_{itmhr} \cdot \left(\frac{P_{acbporcrefls}}{P_{psl}}\right)^{0.5} \cdot x_{bscchamber} \cdot 2 \cdot k$$

$$DN_{acbporcrefl} = 2.316 \times 10^{-30}$$

2. Oxidized Polished Stainless Steel ACB

reflectivity of stainless steel @ 57 deg

$$R_{ss57} := 0.04$$

reflectivity of stainless steel @ 3 deg

$$R_{ss3} := 0.02$$

net reflectivity of ss after 4 bounces

$$R_{snet4} := R_{ss57} \cdot R_{ss3}^{3}$$

$$R_{snet4} = 3.2 \times 10^{-7}$$

Power reflected from ss baffle, W

$$P_{acbsscrefl} := R_{snet4} \cdot P_{ACB}$$

$$P_{acbsscrefl} = 2.366 \times 10^{-6}$$

Power reflected from ACBss scattered into
IFO mode , W

$$P_{acbssrefls} := \sqrt{4} \cdot P_{acbsscrefl} \cdot R_{snet4} \cdot BRDF_{wall} \cdot \frac{\pi \cdot w_{ifo}^{2}}{L^{2}} \cdot BRDF_{1}\left(30 \cdot 10^{-6}\right) \cdot \Delta_{ifo}$$

$$P_{acbssrefls} = 1.589 \times 10^{-29}$$

displacement noise @ 100 Hz, m/rtHz

$$DN_{acbssrefl} := TF_{itmhr} \cdot \left(\frac{P_{acbssrefls}}{P_{psl}}\right)^{0.5} \cdot x_{bscchamber} \cdot 2 \cdot k$$

$$DN_{acbssrefl} = 9.263 \times 10^{-29}$$

Ratio of reflected scatter from oxidized stainless and porcelainized steel

$$Ratio\_acbssrefl\_acbporcrefl := \frac{DN_{acbssrefl}}{DN_{acbporcrefl}}$$

$$Ratio\_acbssrefl\_acbporcrefl = 40$$

The displacement noise from the reflected-rescattered light is approximately 40 times larger with the stainless steel surface; however, because the reflectivity of either surface type is relatively low, the reflected ACB rescattered light noise is considerably lower than the direct ACB scattered light noise and is therefore negligible.

Conclusion

Based on the data presented above, it appears that oxidized polished stainless steel can be used instead of porcelainized steel with acceptable increase of scattered light displacement noise from the ACB.

Oxidized polished stainless steel has been used successfully in eLIGO to fabricate baffles similar to the ACB, so the risk is low. The fabricated stainless steel baffle parts were oxidized by passing 4 times through the same furnace used to porcelainize the present aLIGO ACB baffle 1st article.