Absorber Windows for Very Low Soot Mass Concentration using a Photoacoustic Instrument

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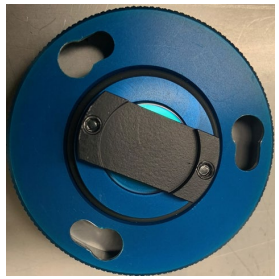
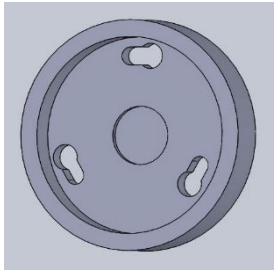




Project Team

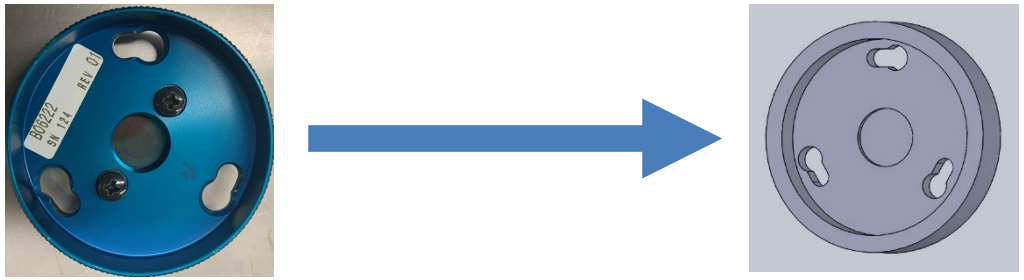
- Imad Khalek, Institute Engineer
- Adam Aussi, Engineer
- Gina Buffaloe, Research Engineer

Background

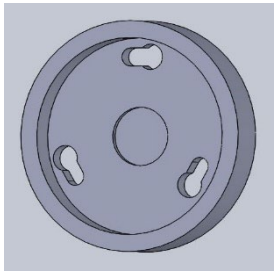
- AVL Microsoot Sensor (MSS) is widely used for:
  - Heavy-Duty In-Use Emissions for EPA & CARB
  - Aircraft Soot Mass Emissions as a part of the International Civil Aviation Organization (ICAO), where the USA is a member
  - Emissions R&D in many other applications for soot measurement
- Motivation
  - An Absorber Window Check is used to check instrument span
  - Current Absorber Window check is done at about 2-4 mg/m³
  - This is typically well above the actual measurement from the tailpipe of modern engines that is typically well below 100 µg/m³ or even 50 µg/m³
    - This is like spanning a gaseous instrument with 3,000 ppm and measuring at below 50 ppm
  - An absorber window check in the range of measurement from 10 µg/m³ to 100 µg/m³ will be good for QA/QC

Objectives

- Develop an absorber window for an AVL microsoot sensor for measurement in the range from 10 µg/m³ to 100 µg/m³
- Make it simple and interchangeable with current absorber window without any additional modifications



Example of New Absorber Window Repeatability and Reproducibility, µg/m³



	Check 1	Check 2	Check 3	Average	stdev	COV, %
W1	84	79	82	81.7	2.5	**3.1%**
W2	88	85	90	87.7	2.5	**2.9%**
W3	81	83	81	81.7	1.2	**1.4%**
	Check 1	Check 2	Check 3	Average	stdev	COV, %
W1	51	48	50	49.7	1.5	**3.1%**
W2	55	48	48	50.3	4.0	**8.0%**
W3	50	50	47	49.0	1.7	**3.5%**
	Check 1	Check 2	Check 3	Average	stdev	COV, %
W1	32	27	26	28.3	3.2	**11.3%**
W2	30	32	27	29.7	2.5	**8.5%**
W3	29	27	24	26.7	2.5	**9.4%**

- We demonstrated the development of new absorber windows that can be used for QA/QC in the range of low soot emissions measurements from engines using MSS

New Absorber Window Comparison with Two MSSs over 25 days of Daily Checks

- The COV ranged from 5.1% at 0.056 mg/m³ to 44% at 0.006 mg/m³
- Unit 11 had a similar COV to Unit 1, but the absolute level was on the order of 50% higher for the non-OEM absorber windows in the range from 0.006 to 0.056 mg/m³
- For the OEM windows, Unit 11 read Unit 1 absorber window 2.1% higher, but Unit 11 absorber window was read to within 0.2% between the two instruments

Absorber Window	1	2	3	4	5	OEM for Unit 1	OEM for Unit 11
	MSS Unit 1 -Absorber Window Concentration mg/m³						
Average	0.008	0.029	0.056	0.006	0.006	3.738	3.519
Stdev	0.003	0.003	0.003	0.003	0.002	0.031	0.013
COV	38.8%	10.1%	5.1%	44.4%	44.0%	0.8%	0.4%
	MSS Unit 11 -Absorber Window Concentration mg/m³						
Average	0.011	0.044	0.088	0.008	0.009	3.790	3.513
Stdev	0.004	0.003	0.008	0.003	0.003	.025	0.024
COV	37.6%	7.6%	8.7%	37.8%	33.4%	0.7%	0.7%
% Difference Unit 11 to 1	46.3%	51.3%	55.5%	43.3%	54.4%	1.4%	-0.2%

Applications

- We used another two calibrated MSSs (not MSS Plus) for absorber window comparison and concentration comparison
  - Below is the **OEM Absorber Window Comparison**
    - The two instruments Unit 2 & 3 read each others OEM absorber windows to within less than 1.1% difference

	Span Check (mg/m3)	Span Check (mg/m3)	
	Unit 2	**Unit 3**	
Repeat	MSS SN 737/1465	MSS SN 1014/1718	Percent Difference
1	3.498	3.478	-0.6%
2	3.492	3.470	-0.6%
3	3.491	3.475	-0.5%
1	3.499	3.480	-0.5%
2	3.504	3.475	-0.8%
3	3.508	3.469	-1.1%
	original window to MSS unit		

Non-OEM Absorber Window Comparison

- Although the OEM absorber window read to within 1.1%,
  - **Unit 3 read non-OEM absorber windows lower than Unit 2**
    - The % difference ranged from 37% at 0.086 mg/m^3 to 73% at 0.047 mg/m^3
  - The question then, does that translate to a similar difference in actual soot concentration?

Average Absorber Window Reading		
mg/m3	mg/m3	% Difference
MSS SN 737/1465, **Unit 2**	MSS SN 1014/1718, **Unit 3**	
0.086	0.054	-37%
0.063	0.042	-32%
0.054	0.033	-40%
0.047	0.013	-73%

Soot Concentration Comparison Using Mini-CAST/Stripper

- No changes in concentration due to split bias
- Both MSSs were used with MSS diluter off
  - Automotive MSS includes a diluter that can be turned on or off, depending on the application and soot concentration level
- Unit 3 read lower than Unit 2, similar to the non-OEM absorber windows, but the % difference between the two units were much smaller on the order of 3% to 12%.

MSS **Unit 2**	MSS **Unit 3**	
mg/m3	mg/m3	
MSS SN 737/1465	MSS SN 1014/1718	% Difference
0.280	0.272	-3.0%
0.102	0.097	-5.4%
0.078	0.073	-5.9%
0.055	0.050	-8.3%
0.025	0.023	-8.0%
0.010	0.009	-11.7%

Summary

- **We developed MSS absorber windows down to 0.006 mg/m³, compared to OEM absorber windows at ~3.7 mg/m³**
  - Based on 25 data points over 25 days
    - The COV for an absorber window at 0.006 mg/m³ was in the range of 38% to 44%
    - The COV for an absorber window at 0.056 mg/m³ was in the range of 5% to 9%
    - The COV for the OEM absorber window at ~3.7 mg/m³ was in the range of 0.4% to 0.8%
- **Using Calibrated MSS Unit 2 and 3, we observed the following:**
  - For OEM-Absorber Windows, Unit 3 read lower than Unit 2 in the range of 0.5% to 1.1%
  - For non-OEM absorber windows below 0.086 mg/m³, Unit 3 read lower than Unit 2 in the range of 32% to 72%, where the difference was higher at lower concentration reading
  - For measured soot concentration, Unit 3 read lower than Unit 2 in the range of 6% to 12%, where the difference was higher at lower concentration

Conclusion

- The non-OEM absorber window could be used as a predictor of the consistency/bias between two MSS instruments at low concentration
  - Although the difference in absorber window reading between two instruments was directionally the same as that for soot concentration, the percent difference for soot concentration was much lower at ~8% vs. ~37% for the absorber window at a similar concentration

Future Work

- Future work should focus on how one absorber window predicts the bias within one instrument
    - E.g. if an absorber window deviates in one instrument over time by 20% (100 µg/m³ to 80 µg/m³), how does that impact actual soot concentration?
- Additional work should also explore the usability of the absorber window in the range at or below 0.01 mg/m³, as a good part of our measurements these days are below 10 µg/m³

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For questions or any other matters please contact:

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