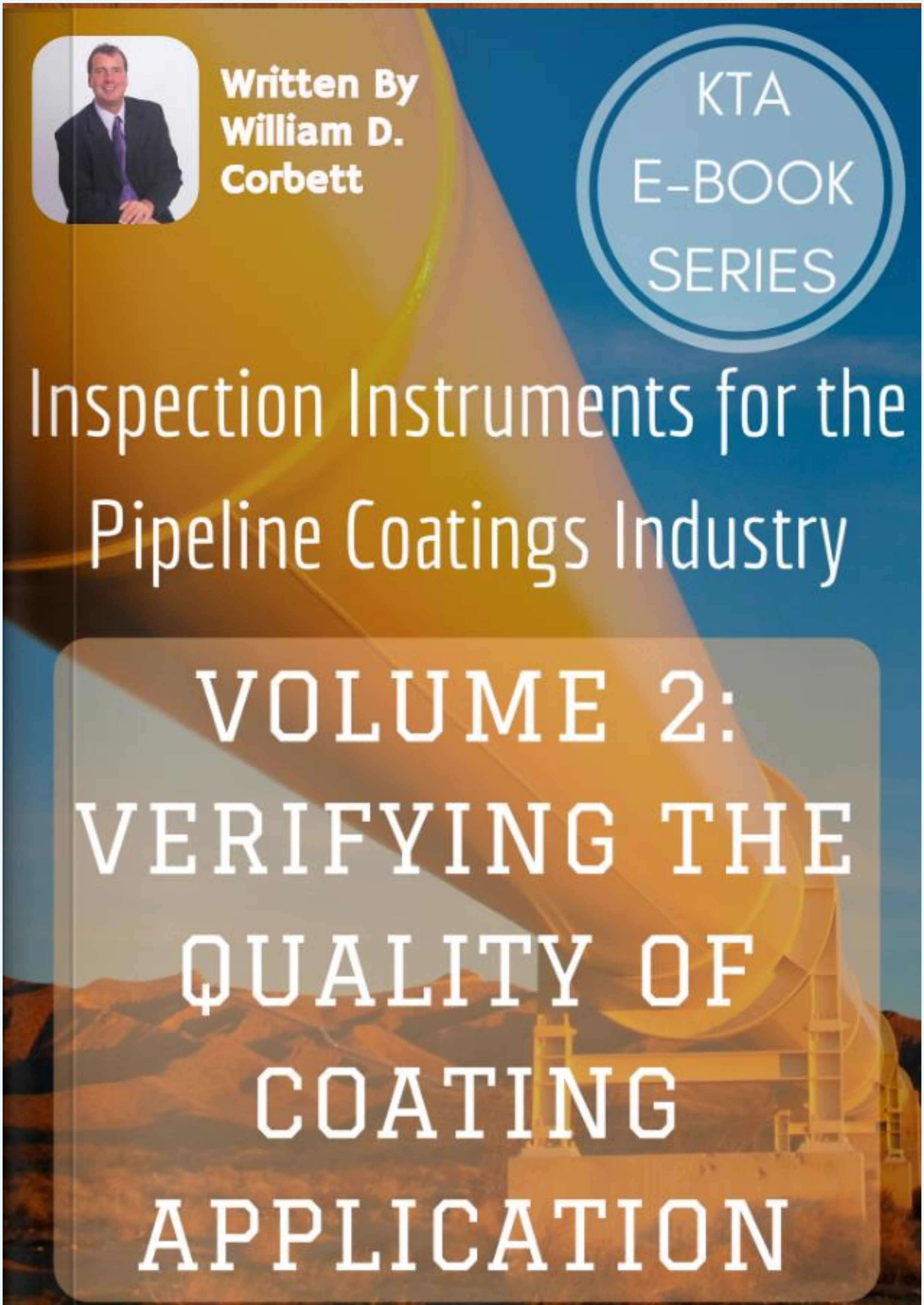
Written By
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KTA
E-BOOK
SERIES
Inspection Instruments for the
Pipeline Coatings Industry
VOLUME 2:
VERIFYING THE
QUALITY OF
COATING
APPLICATION

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Preface

The second of three volumes, this eBook provides information on the proper use of test instruments for verifying the quality of the application of protective coatings. It is applicable to new pipe in the shop, field splices (girth weld areas), existing pipe in the field, and painted steel in general. Verifying the quality of coating application post-application is the subject of Volume 3.

Successful corrosion prevention using protective coating systems is based in part on the quality of the surface preparation and coating system installation. To verify quality, we rely heavily on data generated by coatings inspection instruments and on visual inspection of the prepared surfaces. We rely on this same information to determine contractual compliance with the project specification.

This eBook was prepared with both the novice and the experienced coatings professional in mind. While it does not include *every* inspection instrument from every manufacturer, it does contain a cross-section of common instruments, with references to industry standards throughout. Both traditional methods and novel techniques for verifying quality are explored.

Instrument use, however, is only part of the coatings inspection equation. It must be combined with thorough knowledge of cleaning and painting, the project specification, and field constructability. Formal training in coatings inspection techniques remains a critical component of the process. This publication is not intended to replace formal training, but rather to supplement the learning process before, during and after training.

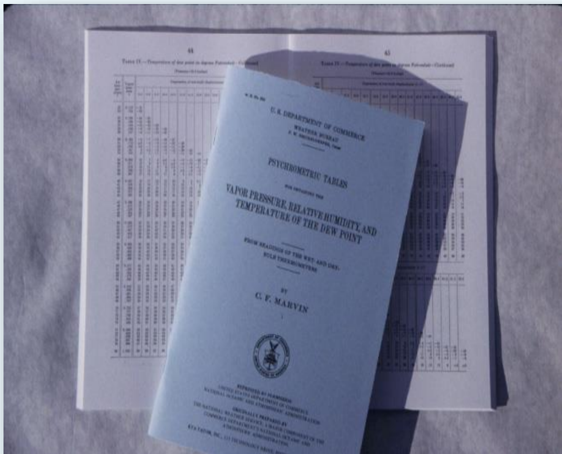
Introduction

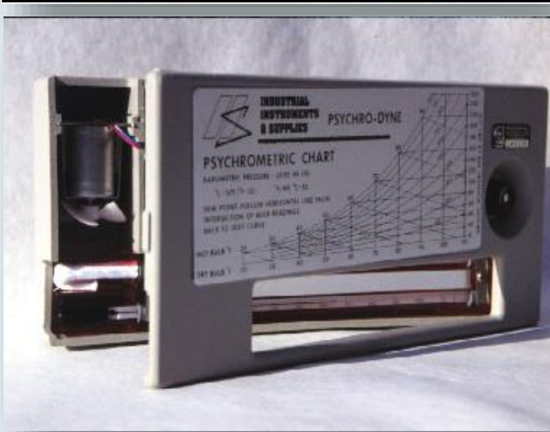
Common quality control checkpoints associated with coating application include:

- Measuring Prevailing Ambient Conditions & Surface Temperature
- Measuring the Coating Temperature
- Calculating and Measuring the Wet Film Thickness
- Measuring Dry Film Thickness

Measuring Ambient Conditions & Surface Temperature

The measurement of air temperature, relative humidity, dew point temperature, and surface temperature is oftentimes required before and during coating application activities *(Figure 1, right)*. Air or surface temperatures above/below the manufacturer's specified range, as well as excessive or inadequate moisture levels in the air (humidity) can contribute to application challenges, inadequate curing and performance problems. In addition, a surface temperature at or below the dew point temperature can result in moisture condensation on the surface. Therefore, it is important to verify that the temperature of the surfaces to be coated is at least 5˚F (3˚C) higher than the temperature of the dew point, and to verify that the air and surface temperatures, as





well as the relative humidity, are all within the coating manufacturers' specified range or as required by the project specification. These values (air temperature, relative humidity, surface temperature and dew point temperature) can be obtained using sling *(Figure 2, top left)* or battery-powered psychrometers *(Figure 3, middle left)* in conjunction with US Weather Bureau Psychrometric Tables (*Figure 4, bottom left*) and surface temperature thermometers (*Figure 5, right)* or can be obtained using electronic psychrometers equipped with surface temperature probes (*Figures 6, bottom left and 7 bottom right).* Each of these procedures is described herein.

Ambient conditions should be measured and recorded prior to mixing the coating materials and at 4-hour intervals thereafter, unless conditions appear to be declining. In this case, more frequent checks may be required. The prevailing ambient conditions at the actual location of the work should be assessed. The location, date, time of day and the conditions of air temperature, relative humidity, dew point temperature, and surface temperature should be recorded.

Traditional and least expensive methods of measuring the prevailing ambient conditions include the use of whirling psychrometers in accordance with ASTM E337, *Standard Test Method for Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures)*, psychrometric charts, and dial-type surface temperature thermometers.

The whirling or battery-powered psychrometer is used to measure the air temperature and to assess the latent heat loss caused by water evaporation from a wetted sock on the end of a bulb thermometer. The psychrometric tables are used to look-up the relative humidity and dew point temperature (based upon temperature readings from the psychrometer and the barometric pressure).

Obtaining Temperature Readings from the Psychrometer

Sling and the battery-powered psychrometers are each equipped with two bulb thermometers. The two thermometers are identical, except that one has a wick or sock covering the end of the bulb. This thermometer is called the wet bulb. The thermometer without the wick is called the dry bulb thermometer (Figure 8 above). Follow Steps 1 through 3 below to obtain the dry bulb and wet bulb temperatures.

Step 1 - Verify that the wick surrounding the wet bulb thermometer is relatively clean.

Step 2 - Saturate the wick with distilled water, or fill the water reservoir at the end of the sling psychrometer *(Figure 9, above)*.

Step 3 – For the sling psychrometer, whirl the instrument (*Figure 10, left)* through the air (away from your body) for approximately 15 or 20 seconds, then obtain a reading from only the wet bulb thermometer. *Without* re-wetting the wick, whirl the instrument for another 10 or 15 seconds and obtain another temperature reading from the wet bulb thermometer. Repeat this process until the two consecutive temperature readings are within 0.5°F of one another. This is considered a stable wet bulb temperature. Then read and record the dry bulb (air) temperature.

If you are using a battery-powered psychrometer, a fan draws the air across the thermometers, rather than whirling them through the air. Allow the fan to operate for approximately 2 minutes, then record the wet bulb temperature after it stabilizes, as well as the stable dry bulb (air) temperature.

Determining the Dew Point Temperature and Relative Humidity

The next step is to determine the relative humidity and the dew point temperature. The relative humidity is the amount of moisture in the air, relative to total saturation at the given temperature. This is expressed as a percentage (e.g., the relative humidity is 56%). The dew point is the temperature that moisture in the air will condense on a surface. The surface temperature needs to remain warmer than the dew point temperature for coating work to begin or continue to be assured that moisture is not present. If the temperature of the surface is at or below the dew point, condensation will form, and it may not even be visible.

The US Weather Bureau Psychrometric Tables contain charts that are used in conjunction with dry bulb temperature and the depression of the wet bulb thermometer from the dry bulb (air) temperature to determine the relative humidity and dew point temperature.

One set of charts is used for calculating relative humidity and another set is used for calculating dew point. The names of the charts are at the top of each page. First, locate the charts of interest (e.g., dew point temperature), and select the ones that correspond to 30-inches barometric pressure. If the exact barometric pressure where the project is located is known (e.g., 29 inches), use those charts instead.

Locate the dew point chart at the appropriate barometric pressure (say 30 inches) and find the dry bulb temperature (air temperature) reading in the far left-hand column, entitled “air temperature t”. Subtract the wet bulb reading from the dry bulb reading. The difference is the “depression of the wet bulb thermometer” (t-t’). Locate the depression of the wet bulb thermometer across the top row of the table. Intersect the depression of the wet bulb thermometer (along the top row) with the air temperature (down the left column). The intersection of the two values represents the dew point temperature in ^{o}F (*Figure 11, next page*).

Repeat this same process using the relative humidity charts at the appropriate barometric pressure (*Figure 12 on Page 17*).

TABLE I.—*Temperature of dew point in degrees Fahrenheit*—Continued

[Pressure=30.0 inches]

Air temperature t	Vapor pressure e	Depression of wet-bulb thermometer $(t-t')$														
		8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0
25	0.130	−51														
26	.136	−32														
27	.143	−23	−45													
28	.150	−17	−29													
29	.157	−12	−20	−39												
30	0.164	−7	−14	−25	−57											
31	.172	−4	−10	−18	−31											
32	.180	−1	−6	−12	−21	−42										
33	.187	+2	−2	−7	−14	−26										
34	.195	5	+1	−3	−9	−17	−32									
35	0.203	7	4	±0	−5	−11	−20	−41								
36	.211	10	7	+3	−1	−6	−14	−25	−58							
37	.219	12	9	6	+2	−3	−8	−16	−29							
38	.228	14	11	8	5	+1	−4	−10	−19	−36						
39	.237	16	13	11	8	4	±0	−5	−12	−22	−47					
40	0.247	18	15	13	10	7	+3	−1	−6	−14	−26					
41	.256	19	17	15	12	10	6	+2	−2	−8	−16	−30				
42	.266	21	19	17	14	12	9	6	+2	−3	−9	−18	−36			
43	.277	22	20	19	16	14	11	9	5	+1	−4	−11	−21	−45		
44	.287	24	22	20	18	16	13	11	8	4	±0	−5	−12	−24	−60	
45	0.298	25	23	22	20	18	15	13	10	7	+4	−1	−6	−14	−27	
46	.310	27	25	23	21	20	17	15	13	10	7	+3	−2	−7	−16	−30
47	.322	28	26	25	23	21	19	17	15	12	9	6	+2	−3	−9	−17
48	.334	29	28	26	25	23	21	19	17	14	12	9	5	+1	−4	−10
49	.347	30	29	28	26	24	23	21	19	16	14	11	8	5	±0	−5
50	0.360	32	30	29	27	26	24	22	21	18	16	13	11	8	+4	±0
51	.373	33	32	30	29	27	26	24	22	20	18	16	13	10	7	+3
52	.387	34	33	32	30	29	27	26	24	22	20	18	16	13	10	7
53	.402	36	34	33	32	30	29	27	26	24	22	20	18	15	13	10
54	.417	37	36	34	33	32	30	29	27	25	24	22	20	18	15	12
55	0.432	38	37	36	34	33	32	30	29	27	25	24	22	20	17	15
56	.448	40	39	37	36	34	33	32	30	29	27	25	24	22	19	17
57	.465	41	40	39	37	36	34	33	32	30	29	27	25	24	21	19
58	.482	42	41	40	39	37	36	35	33	32	30	29	27	25	23	21
59	.499	44	43	41	40	39	37	36	35	33	32	30	29	27	25	23
60	0.517	45	44	43	41	40	39	38	36	35	33	32	30	29	27	25
61	.536	46	45	44	43	42	40	39	38	36	35	33	32	30	29	27
62	.555	47	46	45	44	43	42	40	39	38	36	35	33	32	30	29
63	.575	49	48	47	45	44	43	42	41	39	38	36	35	34	32	30
64	.595	50	49	48	47	46	44	43	42	41	39	38	37	35	34	32
65	0.616	51	50	49	48	47	46	45	43	42	41	40	38	37	35	34
66	.638	52	51	50	49	48	47	46	45	44	42	41	40	38	37	35
67	.661	53	53	52	50	49	48	47	46	45	44	43	41	40	38	37
68	.684	55	54	53	52	51	50	49	48	46	45	44	43	42	40	39
69	.707	56	55	54	53	52	51	50	49	48	46	45	44	43	42	40
70	0.732	57	56	55	54	53	52	51	50	49	48	47	46	44	43	42
71	.757	58	57	56	55	54	53	52	51	50	49	48	47	46	45	43
72	.783	59	58	58	57	56	55	54	53	52	51	50	48	47	46	45
73	.810	60	60	59	58	57	56	55	54	53	52	51	50	49	48	46
74	.838	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48
75	0.866	63	62	61	60	59	58	57	56	55	55	54	52	51	50	49
76	.896	64	63	62	61	60	60	59	58	57	56	55	54	53	52	51
77	.926	65	64	63	62	62	61	60	59	58	57	56	55	54	53	52
78	.957	66	65	64	64	63	62	61	60	59	58	57	56	55	54	53
79	0.989	67	66	66	65	64	63	62	61	60	59	59	58	57	56	55
80	1.022	68	68	67	66	65	64	63	63	62	61	60	59	58	57	56

Table VI.—*Relative humidity, percent—Fahrenheit temperatures*—**Continued**

[Pressure=30.0 inches]

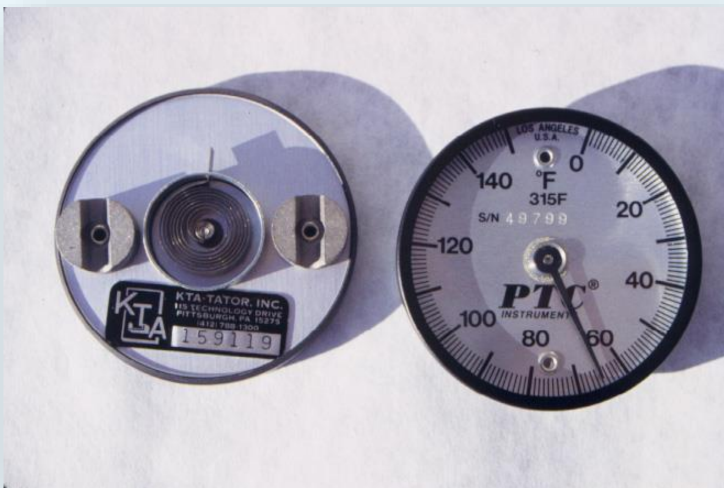
Air temperature *t*	Depression of wet-bulb thermometer ($t-t'$) 0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5
20	92	85	77	70	62	55	48	40	33	26	19	12	5								
21	92	85	78	71	63	56	49	42	35	28	21	15	8	1							
22	93	86	78	71	65	58	51	44	37	31	24	17	11	4							
23	93	86	79	72	66	59	52	46	39	33	26	20	14	7	1						
24	93	87	80	73	67	60	54	47	41	35	29	22	16	10	4						
25	94	87	81	74	68	62	55	49	43	37	31	25	19	13	7	1					
26	94	87	81	75	69	63	57	51	45	39	33	27	21	16	10	4					
27	94	88	82	76	70	64	58	52	47	41	35	29	24	18	13	7	2				
28	94	88	82	76	71	65	59	54	48	43	37	32	26	21	15	10	5				
29	94	88	83	77	72	66	60	55	50	44	39	34	28	23	18	13	8	3			
30	94	89	83	78	73	67	62	56	51	46	41	36	31	26	21	16	11	6	1		
31	94	89	84	78	73	68	63	58	52	47	42	37	33	28	23	18	13	8	4		
32	95	89	84	79	74	69	64	59	54	49	44	39	35	30	25	20	16	11	7	2	
33	95	90	85	80	75	70	65	60	56	51	46	41	37	32	27	23	18	14	9	5	0
34	95	90	86	81	76	71	66	62	57	52	48	43	38	34	29	25	21	16	12	8	3
35	95	91	86	81	77	72	67	63	58	54	49	45	40	36	32	27	23	19	14	10	6
36	95	91	86	82	77	73	68	64	60	55	51	46	42	38	34	29	25	21	17	13	9
37	95	91	87	83	78	74	69	65	61	57	53	48	44	40	36	31	27	23	19	15	11
38	96	91	87	83	79	75	70	66	62	58	54	50	46	42	37	33	29	25	21	17	14
39	96	92	87	83	79	75	71	67	63	59	55	51	47	43	39	35	31	27	24	20	16
40	96	92	87	83	79	75	71	68	64	60	56	52	48	45	41	37	33	29	26	22	18
41	96	92	88	84	80	76	72	69	65	61	57	54	50	46	42	39	35	31	28	24	20
42	96	92	88	85	81	77	73	69	65	62	58	55	51	47	44	40	36	33	30	26	23
43	96	92	88	85	81	77	73	70	66	63	59	55	52	48	45	42	38	35	31	28	25
44	96	93	89	85	81	78	74	71	67	63	60	56	53	49	46	43	39	36	33	30	26
45	96	93	89	86	82	78	74	71	67	64	61	57	54	51	47	44	41	38	34	31	28
46	96	93	89	86	82	79	75	72	68	65	61	58	55	52	48	45	42	39	35	32	29
47	96	93	89	86	82	79	75	72	69	66	62	59	56	53	49	46	43	40	37	34	31
48	96	93	90	86	83	79	76	73	69	66	63	60	57	54	50	47	44	41	38	35	32
49	96	93	90	86	83	80	76	73	70	67	64	61	57	54	51	48	45	42	39	36	34
50	96	93	90	87	83	80	77	74	71	67	64	61	58	55	52	49	46	43	41	38	35
51	97	94	90	87	84	81	78	75	71	68	65	62	59	56	53	50	47	45	42	39	36
52	97	94	90	87	84	81	78	75	72	69	66	63	60	57	54	51	49	46	43	40	37
53	97	94	90	87	84	81	78	75	72	69	66	63	61	58	55	52	50	47	44	41	39
54	97	94	91	88	85	82	79	76	73	70	67	64	61	59	56	53	50	48	45	42	40
55	97	94	91	88	85	82	79	76	73	70	68	65	62	59	57	54	51	49	46	43	41
56	97	94	91	88	85	82	79	76	73	71	68	65	63	60	57	55	52	50	47	44	42
57	97	94	91	88	85	82	80	77	74	71	69	66	63	61	58	55	53	50	48	45	43
58	97	94	91	88	85	83	80	77	74	72	69	66	64	61	59	56	54	51	49	46	44
59	97	94	91	89	86	83	80	78	75	72	70	67	65	62	59	57	55	52	49	47	45
60	97	94	91	89	86	83	81	78	75	73	70	68	65	63	60	58	55	53	50	48	46
61	97	94	92	89	86	84	81	78	76	73	71	68	65	63	61	58	56	54	51	49	47
62	97	94	92	89	86	84	81	79	76	74	71	69	66	64	61	59	57	54	52	50	47
63	97	95	92	89	87	84	82	79	77	74	71	69	67	64	62	60	57	55	53	50	48
64	97	95	92	90	87	84	82	79	77	74	72	70	67	65	63	60	58	56	53	51	49
65	97	95	92	90	87	85	82	80	77	75	72	70	68	66	63	61	59	56	54	52	50
66	97	95	92	90	87	85	82	80	78	75	73	71	68	66	64	61	59	57	55	53	51
67	97	95	92	90	87	85	83	80	78	75	73	71	69	66	64	62	60	58	56	53	51
68	97	95	92	90	88	85	83	80	78	76	74	71	69	67	65	62	60	58	56	54	52
69	97	95	93	90	88	85	83	81	79	76	74	72	70	67	65	63	61	59	57	55	53
70	98	95	93	90	88	86	83	81	79	77	74	72	70	68	66	64	61	59	57	55	53
71	98	95	93	90	88	86	84	81	79	77	75	72	70	68	66	64	62	60	58	56	54
72	98	95	93	91	88	86	84	82	79	77	75	73	71	69	67	65	63	61	59	57	55
73	98	95	93	91	88	86	84	82	80	78	75	73	71	69	67	65	63	61	59	57	55
74	98	95	93	91	89	86	84	82	80	78	76	74	71	69	67	65	63	61	60	58	56
75	98	96	93	91	89	86	84	82	80	78	76	74	72	70	68	66	64	62	60	58	56
76	98	96	93	91	89	87	84	82	80	78	76	74	72	70	68	66	64	62	61	59	57
77	98	96	93	91	89	87	85	83	81	79	77	74	72	71	69	67	65	63	61	59	57
78	98	96	93	91	89	87	85	83	81	79	77	75	73	71	69	67	65	63	62	60	58
79	98	96	93	91	89	87	85	83	81	79	77	75	73	71	69	68	66	64	62	60	58
80	98	96	94	91	89	87	85	83	81	79	77	75	74	72	70	68	66	64	62	61	59

Use of Digital Psychrometers to Assess Ambient Conditions

As an alternative to sling and battery-operated psychrometers, digital psychrometers can be used to determine the prevailing weather conditions (*Figure 13, top left*). These gages digitally display the air temperature, relative humidity, dew point temperature and surface temperature essentially at the push of a button. One manufacturer features a hot wire probe to monitor wind speed (*Figure 14, bottom left*). Although the digital psychrometers provide "instantaneous" results, before taking any readings, they must be acclimated to the environmental conditions in the location of use for up to 30 minutes. This means you should not take the instrument from an air-conditioned office trailer and expect to take readings a few minutes later outside. This is often overlooked, resulting in inaccurate readings. In comparison, the sling and battery-operated psychrometers do not have to be acclimated to the environment before use.

Use of Surface Temperature Measuring Instruments

There are a variety of instruments for measurement of surface temperature, including analog and digital contact thermometers as well as non-contact infrared pyrometers. As discussed earlier, most digital psychrometers have surface temperature measurement capability.



A common surface temperature thermometer is analog and contains a bi-metallic, temperature-sensing spring on the back of the thermometer that expands and contracts with the temperature of the surface (*Figure 15, above).* Since the spring is attached to the indicator needle on the front side of the thermometer, the needle moves across the temperature scale, indicating the surface temperature. Magnets attached to the back of the thermometer enable self-attachment to vertical steel surfaces, although this thermometer can be used on almost any surface, by taping it in place if necessary. Thermocouple digital surface temperature gages are quicker and more accurate than the analog type.

Non-contact infrared pyrometers (*Figure 16, left*) can also be used to measure surface temperature. These gages are often equipped with laser sightings, so that the user can target the location on the surface to be measured. However, the further away from the surface that the "gun" is held, the larger the area of measurement, causing potential error. Also, there is a maximum distance, depending on the make and model of the thermometer.

Calibration of Equipment for Measuring Ambient Conditions and Surface Temperature

Calibration and/or verifying the accuracy of any coating inspection instrument is paramount to the reliability of the data it produces. This section describes the calibration and verification procedures for instruments used to assess ambient conditions and surface temperature.

Calibration of Psychrometer Thermometers

The bulb thermometers in sling and battery-operated psychrometers cannot be "calibrated" per se. However, their accuracy can be routinely verified by comparing the thermometer readings with that of a thermometer traceable to the National Institute of Standards and Technology (NIST), or in a controlled temperature chamber.

Cover the bulb thermometers and the traceable thermometer with a dry cloth until stabilization occurs (30 minutes minimum). The wick must be removed from the end of the wet bulb before placing the thermometers beneath the dry cloth.

Uncover the thermometers and quickly compare the readings of the two psychrometer bulbs to the traceable thermometer reading. If the readings are outside of the tolerance of the psychrometer bulbs (typically +/- 1^{o}F), the psychrometer bulb(s) should be replaced.

Calibrating Analog Surface Temperature Gages

Analog surface temperature gages also cannot be calibrated, but the accuracy against a traceable thermocouple-type surface temperature probe can be plotted on a curve.

Calibrating Digital Psychrometers and Surface Temperature Thermometers/Pyrometers

Digital psychrometers and surface temperature thermometers can be calibrated either by the equipment manufacturer, an accredited calibration laboratory or an authorized service center. Annual calibration is recommended by most manufacturers. Unfortunately, field verification of accuracy is not possible with this type of equipment.

Measuring the Coating Temperature

The induction time and pot life of a mixed coating is based on the temperature of the coating material. Additionally, some coating manufacturers list a minimum coating material temperature for application on their product data sheets. So, the ability to measure the temperature of the mixed coating is an important consideration. Stem-type paint thermometers, immersion-type thermocouples and non-contact infrared pyrometers can all be used. The stem-type thermometers (*Figure 17, above*) will require a few minutes to stabilize and the infrared pyrometers only measure the surface of the coating in the container.

Calculating Wet Film Thickness

Prior to mixing, thinning and applying the coating, the target wet film thickness (WFT) should be determined. Some coating manufacturers list the WFT on the product data sheet (PDS) but many do not. Even when the target WFT is listed on the PDS, the contractor will need to verify that the dry film thickness (DFT) in the PDS that it is based on is the same as the DFT specified for the product. Further, if the coating will be reduced (thinned), the target WFT must be adjusted based on the amount of thinner added, so the target WFT in the PDS will no longer be accurate. While in most cases the facility owner is concerned with the dry film thickness and not the wet film thickness, the contractor must ensure that the proper wet film thickness is applied so that the specified dry film is achieved. If it is discovered that that the coating is too thin or too thick after it dries, costly rework is often required. It is better to confirm that the proper amount of paint is being applied to begin with.

The step-by-step instructions provided below are for calculating a target wet film thickness of both un-thinned and thinned coating, based on the specified dry film thickness (from the specification or PDS), the volume solids content of the coating (from the PDS), and when applicable, the amount of thinner added to the coating.

Calculating the WFT when using a coating as manufactured

To calculate wet film thickness, you will need *two* values:

Value No. 1: The target dry film thickness (DFT) from the specification or PDS
Value No. 2: The solids by volume content of the coating material from the PDS

Formula: WFT = (DFT ÷ % solids by volume)

Enter the values into the formula to arrive at the wet film thickness range.

Example: DFT range of 2-4 mils with no thinner added (solids by volume of 75%):

2 mils DFT ÷ 0.75 = 2.7 mils WFT
4 mils DFT ÷ 0.75 = 5.3 mils WFT

Therefore, the applicator should apply the coating in the range of 3-6 mils WFT to achieve a DFT of 2-4 mils.

Calculating the WFT when using a coating that is thinned

To calculate wet film thickness, you will need *three* values:

Value No. 1: The target dry film thickness (DFT) from the specification or PDS
Value No. 2: The solids by volume content of the coating material from the PDS
Value No. 3: The amount of thinner that will be added to the coating (indicated on the PDS)

Formula: WFT = DFT ÷ [% solids by volume ÷ (100% + % thinner added)]

This formula has two steps:
Step 1: [% solids by volume ÷ (100% + % thinner added)] = adjusted volume solids content
Step 2: DFT ÷ adjusted volume solids content = WFT

Enter the values into the formula to arrive at the wet film thickness range.

Example – DFT range of 4-6 mils, Volume Solids 65% with 15% thinner added:

(65 ÷ 115) = 0.57 adjusted volume solids content

4 mils DFT ÷ 0.57 = 7.0 mils WFT
6 mils DFT ÷ 0.57 = 10.5 mils WFT

Therefore, the applicator should apply the coating in the range of 7-11 mils WFT. Even with the addition of 15% thinner, the coating should reduce to 4-6 mils once dry.

The solids by volume content (as a percentage of the total coating material) remains a key component in the calculation of the wet film thickness. However, the published value may be “theoretical” and based on the formulation, or may not account for complete coating film shrinkage. Therefore, the contractor may choose to apply a test area of the coating (thinned if appropriate), measure the wet film thickness, then after the coating dries on the test area, measure the dry film thickness. This will provide the applicators with a “practical” wet film target. If the resulting dry film thickness meets the requirements of the specification, the actual volume solids content of the coating material becomes a moot point. Conversely, if the resulting dry film thickness is too low or too high, the actual percentage of volume solids can be calculated, provided the wet film and dry film thickness is known. Then the revised target wet film thickness can be calculated. This is illustrated below. Concurrently, the applied coating film can be evaluated for flow characteristics, resistance to sag, etc.

Target DFT (from the specification): 5 mils

Calculated Target WFT (based on 50% solids by volume): 10 mils

Actual WFT (measured): 10 mils

Actual DFT (measured): Only 4 mils

(Actual DFT / Actual WFT) x 100 = Adjusted Percent Volume Solids Content

(4 / 10) x 100 = .40 or 40%

Revised Target WFT = 5 mils DFT / 0.40 = 12.5 mils WFT

Measuring Wet Film Thickness

Once the target WFT is calculated, the thickness of the wet coating film can be monitored as it is applied using a wet film thickness gage. These are known as notch-type gages and conform to ASTM D4414, *Standard Practice for Measurement of Wet Film Thickness by Notch Gages.*

All notch-type gages contain four or eight faces with a series of steps, with notches between the steps. Each step is numbered. The number corresponds to the wet film thickness in mils (0.001”) or micrometers (µm). There are 25.4 µm in 1 mil.

The traditional aluminum (*Figure 18, top left*) and hardened steel (*Figure 19, bottom left*) wet film thickness gages have four (4) measuring faces. Each face contains a different wet film thickness range. The chart below provides the measuring ranges for each of the four faces, for both the aluminum and hardened steel type gages.

WFT Gage Type	**WFT Range on each Face**			
	Face 1	**Face 2**	**Face 3**	**Face 4**
Hardened Steel (low)	½ - 2 mils	2 ½ - 4 mils	5 - 8 mils	10 - 20 mils
Hardened Steel (medium)	4 - 10 mils	12 - 24 mils	28 - 40 mils	45 - 60 mils
Hardened Steel (high)	10 - 40 mils	50 - 80 mils	100 - 160 mils	200 - 500 mils
Aluminum (Side 1-mils)	1 - 6 mils	7 - 12 mils	14 - 30 mils	35 - 80 mils
Aluminum (Side 2-µm)	25-150 µm	175-300 µm	350-750 µm	875-2000 µm

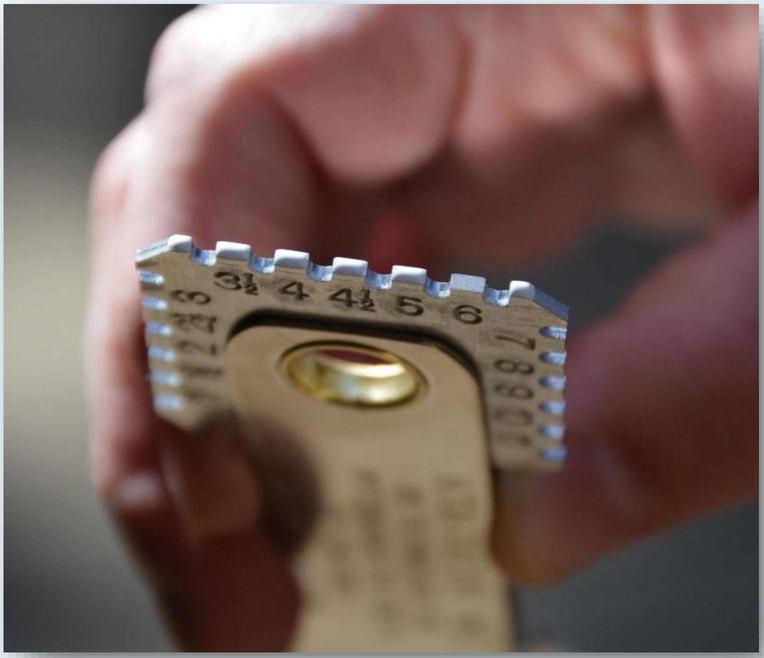
Precision 4-in-1 WFT Gage

Two limitations of traditional WFT gages are: (1) there isn't a single, accurate gage that includes the full range in both mils and microns, and (2) the tolerance of the steps is unknown (Certificates of Accuracy are either not available or very costly). A precision 4-in-1 wet film gage (*Figure 20, top)* eliminates the need for multiple gages to measure the full range, and the need for a gage in mils and another in micrometers. With mils on one side and microns on the other, the gage essentially has eight faces. Even more importantly each gage comes with a Certificate of Traceability that illustrates the precision of the gage, making wet film thickness measurement more reliable and reducing the chances for rework.

Precision 4-in-1 WFT Gage

Face	Mils	Micrometers
A_1	1-5 mils	25-125 µm
B_1	6-10 mils	150-250 µm
C_1	11-15 mils	275-375 µm
D_1	16-20 mils	400-500 µm
A_2	22-30 mils	550-750 µm
B_2	32-40 mils	800-1,280 µm
C_2	42-50 mils	1,050-1,250 µm
D_2	52-60 mils	1,300-1,500 µm

Immediately after the wet coating film is applied, insert measuring face into the wet coating, perpendicular to the surface (*Figure 21, left).* The two "end steps" on the face selected must penetrate down to the previous layer, or the substrate if measuring the thickness of the first coat. Withdraw the gage from the wet film. The two end steps that penetrated down to the previous layer will be coated with paint. Observe the numbered steps between to the two end steps. The



highest numbered step containing wet paint is the wet film thickness (*Figure 22, left*). If all numbered steps are coated, then choose a face on the gage that represents a higher wet film thickness range. If none of the numbered steps are coated, then choose a face on the gage that represents a lower wet film thickness range. Clean the gage, then repeat this step in several other areas and/or as application progresses to verify that the WFT remains consistent.

Measuring Dry Film Thickness (DFT) on Coated Steel

There are two common standards that are frequently referenced in project specifications for measuring DFT, including ASTM D7091, *Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals* and SSPC-PA 2, *Procedure for Determining Conformance to Dry Coating Thickness Requirements.*

The current version of the ASTM standard (2013) focuses on proper gage use, while SSPC-PA2 focuses primarily on the frequency and acceptability of the measurements. These two documents do not contain conflicting information; they were written to complement one another and are designed to be used in conjunction.

Traditional Coating Thickness Measurement

There are two common types of coating thickness gages including Type 1 (magnetic pull-off) (top left) and Type 2 (electronic, with integral probes) (bottom left).

Type 1 Magnetic Pull-off Gages

For the Type 1 magnetic pull-off gages (*Figure 24, left*), a permanent magnet is brought into direct contact with the coated surface. The force necessary to pull the magnet from the surface (created by tightening a calibrated, helical spring) is measured and indicated as the coating thickness on an analog scale. The principle is quite simple - less force is required to remove the magnet from a thick coating, compared to a thinner coating, since the magnet is closer to the steel and will have greater attraction.

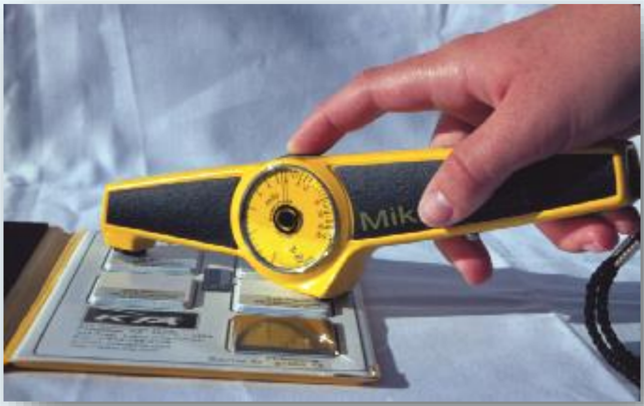
Calibration and Verification of Accuracy

The ASTM D7091 standard practice and the SSPC-PA 2 standard describe three steps associated with assuring accurate measurement processes, including gage calibration, verification of accuracy and adjustment. Each of these steps must be completed before coating thickness measurements are made.

Calibration

Coating thickness gages must be calibrated by the manufacturer, an accredited calibration laboratory or a manufacturer's authorized service center. A Test Certificate or other documentation showing traceability to a national metrology institution is required. There is no standard time interval for re-calibration, nor is one absolutely required. Calibration intervals are usually established based upon experience and the work environment. A one-year calibration interval is a typical starting point suggested by gage manufacturers.

Verification of Accuracy



To verify the accuracy of Type 1 gages, the thickness of a series of coated reference standards covering the expected range of coating thickness is measured (*Figure 25, above).* To prevent acquiring measurements with an inaccurate gage, the gage should be checked at least at the beginning and the end of each work shift. If the gage is dropped or suspected of giving erroneous readings during the work shift, its accuracy should be rechecked. Unless a gage manufacturer explicitly allows it, certified shims used to verify the accuracy of Type 2 electronic gages (described later) are not permitted to be used with Type 1 gages.

Single Point Verification

When verifying the accuracy of Type 1 or Type 2 gages, the user can employ a single point or two-point process. For single point verification, a single reference test block is selected that is at or close to the thickness to be measured. For example, assuming the coating thickness to be measured is 4-6 mils, a reference standard of approximately 5 mils should be used to verify gage accuracy.

Two-Point Verification

For two-point verification, two reference standards are selected - one above and one below the expected film thickness to be measured. For example, assuming the coating thickness to be measured is 5 mils, reference standards of 3 mils and 7 mils are appropriate for establishing a range of accuracy.

When documenting gage adjustment processes, the serial number of the gage, the reference standard used, the stated thickness of the reference standard as well as the measured thickness value obtained, and the method used to verify gage accuracy are recorded. If the same gage, reference standard, and method of verification are used throughout a job, they only need to be recorded once, but the stated value of the standard and the measured value must be recorded each time accuracy is verified.

Adjustment

Type 1 gages have nonlinear scales, whereas any adjusting feature is linear. As a result, any adjustment of these gages will limit the DFT range for which the gage will provide accurate readings, and is not recommended. Furthermore, the application of a single “correction value” representing the full range of the gage to compensate for a gage that is not measuring accurately is not appropriate, since the correction will also be non-linear. Therefore, if the gage reading is outside of the combined tolerance of the gage accuracy and the coated reference standard accuracy, it should be removed from service and repaired or replaced. For example, if the manufacturer’s stated accuracy for the gage is ± 5%

and the tolerance of the traceable coated standards is ± 3%, the combined tolerance is 5.8% (the calculated square root of [$5^2 + 3^2$]). Therefore, the gage reading on a 10-mil coated reference standard can range from 9.4-10.6 mils. A reading outside of this range indicates that the gage is out of tolerance and should not be used, or that the exposed magnetic probe has become contaminated.

Compensating for Surface Roughness

Once the Type 1 thickness gage is verified for accuracy, the next step is to measure and record the Base Metal Reading or BMR, since Type 1 gages cannot be adjusted. This is accomplished by placing the gage magnet on the prepared, uncoated substrate and obtaining a measurement (Figure 26, above).

Let's explore this concept a little closer. The specified dry film thickness of each coating layer is to be measured from the tops of the peaks of the surface profile. However, most coating thickness gages must reach down into the surface roughness to satisfy the magnetic properties of the gage. As a result, the effect of the surface profile (roughness) on the thickness gage must be measured using the same DFT gage and subtracted from the coating thickness measurement. This is known as a base metal reading or BMR. Think of it as a background reading that the prepared, uncoated metal provides.

The BMR is the effect of surface roughness on a coating thickness gage – it is not surface profile. There is no correlation between surface profile depth and the effect of this roughness on a coating thickness gage. The BMR will vary widely, ranging from 0.1 mil to over 1 mil. Therefore, minimum of 10 measurements of the base metal are made and the average BMR is calculated. The average BMR is subtracted from the thickness of each coat, to determine the thickness of the coating film above the peaks of the surface profile.

Type 2 Electronic Gages with Integral Probes

Type 2 electronic gages use electromagnetic principles and electronic circuitry to convert a reference signal and display it as coating thickness (*Figure 27, above*). Generally speaking, Type 2 gages are more accurate than Type 1 gages, are not susceptible to vibration, and data acquisition is typically much faster. Also, most Type 2 gages can store readings and provide statistical analysis of the data, and once the data is generated and stored, it can be uploaded into a computer software program or downloaded to a printer. Measurement frequencies such as those described in SSPC-PA 2 are often programmed into Type 2 gages. The gage probe is placed onto the coated surface and the measurement is revealed on the display (in mils or micrometers).

Calibration

Like Type 1 gages, Type 2 coating thickness gages must be calibrated by the manufacturer, an accredited calibration laboratory or a manufacturer's authorized service center. A Test Certificate or other documentation showing traceability to a national metrology institution is required. There is no standard time interval for re-calibration, nor is one absolutely required. Calibration intervals are usually established based upon experience and the work environment. A one-year calibration interval is a typical starting point suggested by gage manufacturers.

Verification of Accuracy

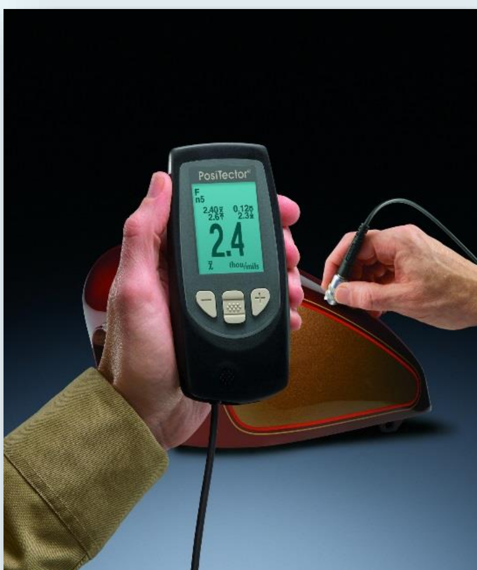
To verify the accuracy of Type 2 gages, the thickness of a series of coated reference standards covering the expected range of coating thickness is measured (*Figure 28, left*) using either the single point of two-point verification process, described earlier for the Type 1 gage. However, in this case, unless strictly prohibited by the manufacturer, the gage is adjusted to match the thickness of the standards. To prevent acquiring measurements with an inaccurate gage, the gage should be checked at least at the beginning and the end of each work shift. If the gage is dropped or suspected of giving erroneous readings during the work shift, its accuracy should be rechecked. As an alternative to certified coated standards, certified shims placed on a smooth steel surface used to verify the accuracy of Type 2 electronic gages.

Adjustment

The final step in verifying gage accuracy is to align the Type 2 gage to a known value to improve gage accuracy on the specific type and design of surface or within a specific measurement range. Some refer to this step as gage optimization. In this case, the gage is adjusted (when permitted by the gage manufacturer) to match the value on a measured shim or certified shim by placing the shim(s) directly onto the prepared, uncoated structure or part under the same conditions of air and surface temperatures that the coating will be measured under (*Figure 29, previous page).* This also compensates for curvature of the component or structure, the alloy of the steel, surface roughness (profile), proximity to edges or other surface conditions.

Novel Approaches to Dry Coating Thickness Measurement

The traditional methods of dry coating thickness measurement have been in existence for decades. Type 2 electronic gages offer novel approaches to gathering DFT data, including remote probes, microprobes and scanning/continuous read probes.



Remote Probes (on a short cable attached to the gage; *Figure 30, above left*), enabling easier measurement access, especially on the underside of pipe, and even wireless probes that communicate with a read-out device using Bluetooth technology, including Smart Phones (*Figure 31, above right).*

Micro-Probes

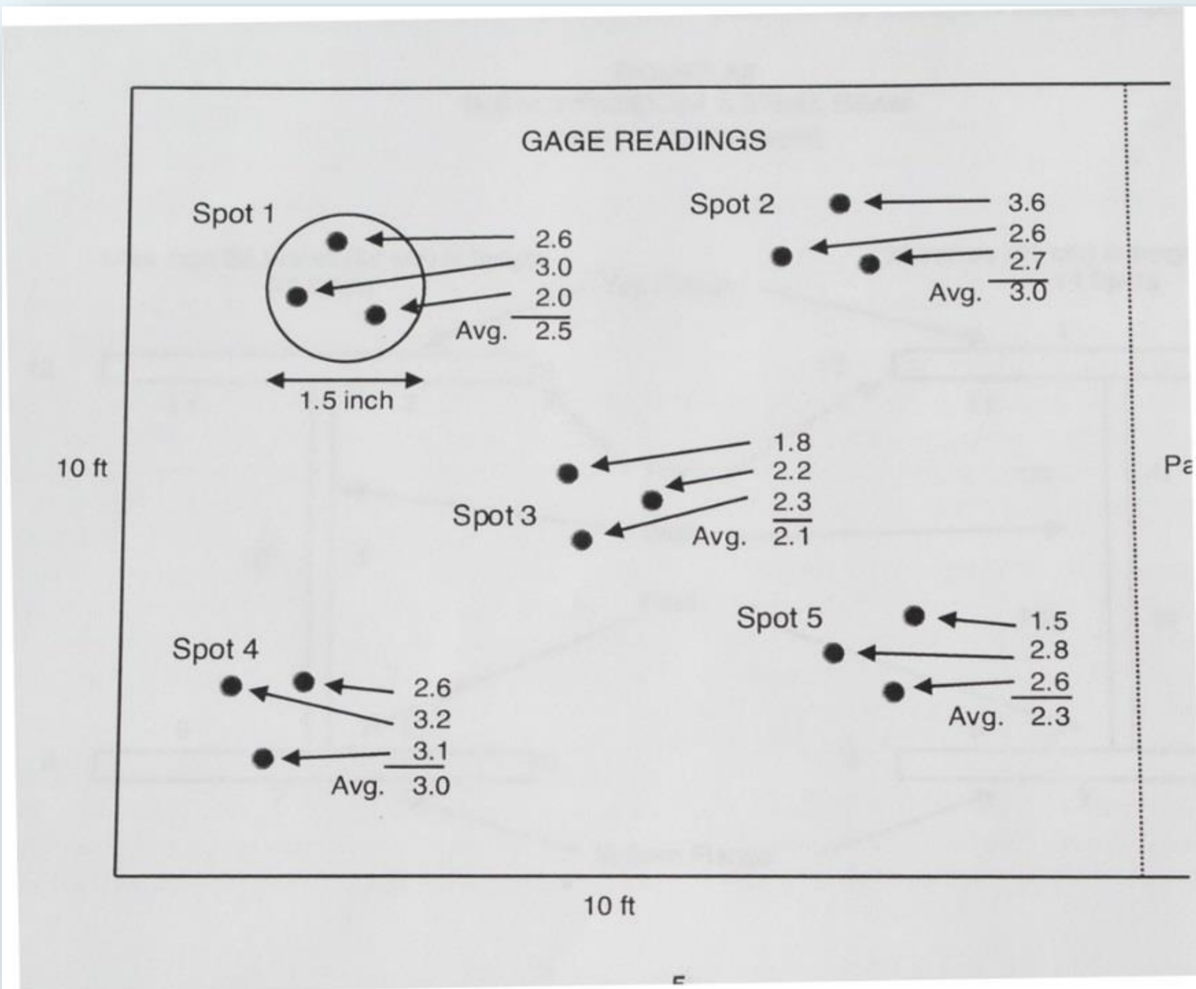
Traditionally we have been taught to stay at least 1" away from all edges when measuring coating thickness. However, coating build on edges, known as edge retention, is a concern particularly in immersion environments. And many gage manufacturers now produce micro probes for measuring coating thickness on small parts, as these probes are less affected by proximity to edges (*Figure 32, above*). Appendix 6 in SSPC-PA 2 describes a procedure for measuring coating thickness on edges, and suggests a minimum of three gage readings along 1.5 linear inches, which is equivalent to a spot measurement. The number of spots will vary depending on the total length of the edge. SSPC Guide 11 adresses edge stripe coating and use of edge retentive coatings.

Scanning Probes

Several manufacturers of electronic coating thickness gages have incorporated “scanning probe” technology, and the associated support software, into the data acquisition process. This newer technology enables the gage operator to obtain large sets of coating thickness data in a relatively short time frame. To illustrate this concept, data was obtained by a certified coatings inspector on a recoating project that included 12 batches of readings (nearly 600 readings) obtained in just under 8 minutes (measurement time only). So, it may be possible to obtain a greater, more representative sampling of the coated area without impeding production. However, there are concerns with acquiring such large data sets, such as management of the data, handling outliers, determining the statistical significance of the data (i.e., what is an acceptable standard deviation), etc. The preparation of a non-mandatory appendix (i.e.,

Appendix 10) to the SSPC-PA 2 standard that addresses the acquisition of large data sets has been proposed.

Frequency of Measurement (SSPC-PA 2, Appendix 7)



SSPC-PA 2 describes a frequency of coating thickness measurements. Figure 33 (above) was extracted from the standard. It illustrates three gage readings taken in each of 5 spots in an area of approximately 100 square feet. The average of the three gage readings in each of the 5 spots has been calculated. The number of 100 square foot areas that are to be measured is based on the total square footage of the coated area:

- *For areas of coating not exceeding 300 square feet, each 100-square foot area is measured. As a result, the maximum number of areas to be measured will be 3.*

- *For areas of coating greater than 300 square feet but not exceeding 1000 square feet, three 100 square foot areas are arbitrarily selected and measured.*

- *For areas of coating exceeding 1000 square feet, three 100 square foot areas are measured in the first 1000 square feet. For each additional 1000 square feet or portion thereof, one additional 100* *square foot area is arbitrarily selected and measured.*

Appendix 7 in the current version of SSPC-PA 2 describes a procedure for measuring coating thickness on the exterior of pipe. Pipe sections on a cart or a rack are considered a complete unit. The total area is determined by multiplying the length of each pipe by the circumference (Pi x diameter), then multiplying that by the number of pipe sections on the cart.

Alternatively, five pipe DFT Frequency Factors (FF) are pre-defined in Appendix 7 to increase the

Example 1:
10 sections of 48-inch long, 9-inch diameter pipe
Step 1: 4' x (3.14 x 0.75 ft.) = 9.4 sq. ft./pipe section
Step 2: 9.4 sq. ft. x 10 pipe sections = 94 sq. ft.
Since the total area is less than 100 square feet, five spot measurements, each composed of at least three gage readings are acquired.

number of readings (2x, 3x, 4x, 5x, 6x) and can be specified. For example, if FF 3 is invoked by the project documents, the number of spot measurements is tripled. As described above, first determine the total surface area: the length of each pipe is multiplied by the circumference, then that value is multiplied by the number of pipe sections on the cart. This will equal the total surface area, which is then used to determine the number of spot measurements. This value is then multiplied by the FF of 3.

Example 2:
Step 1: 4' x (3.14 x 0.75 ft.) = 9.4 sq. ft./pipe section
Step 2: 9.4 sq. ft./pipe section x 10 pipe sections = 94 sq. ft.
Since the total area is less than 100 square feet, five spot measurements, each composed of at least three gage readings are acquired.
Step 3 (Apply the Frequency Factor): 5 spot measurements x FF 3 = 15 spot measurements

Pipe spools are measured individually. Table A7 in the SSPC-PA 2 Appendix 7 describes the frequency and location of the spot measurements and is dependent on the diameter of the pipe (below).

Pipe Diameter	Circumferential Spot Measurements	Interval Spacing
Up to 12-inch	4 evenly spaced	10 ft. apart
14-24 inches	6 evenly spaced	10 ft. apart
> 24 inches	8 evenly spaced	10 ft. apart

- *For pipe diameters up to 12 inches, 4 evenly spaced circumferential spot measurements are taken at 10-foot intervals; for example, 12:00, 3:00, 6:00 and 9:00.*

- *For pipe diameters ranging from 14 to 24 inches, 6 evenly spaced circumferential spot measurements are taken at 10-foot intervals; for example, 12:00, 2:00, 4:00, 6:00, 8:00 and 10:00.*

- *For pipe diameters greater than 24 inches, 2 additional spot measurements, for a total of 8 spots are taken at 10-foot intervals.*

- *For pipe spools less than 10 feet in length, 3 sets of spot measurements are obtained. The number of spots is dependent upon the pipe diameter.*

Conclusion

While surface preparation is considered the foundation for the performance of the coating system, proper installation of the system is critical to the protection of the substrate, and to prevent premature coating failure and preserve pipeline integrity. This includes veryfying that the coating system is applied according to the manufacturer's instructions, and that the wet film and resulting dry film thickness is achieved for each coating layer. This involves quality control check points to verify compliance with the specification and to correct deviations before they become nonconformities. Common quality check points include those described in this Volume 2 of the eBook series - *Surface Preparation and Coating Application Inspection Instruments for the Pipeline Industry.* Instruments used during surface preparation are presented in Volume 1. Instruments used after coating application is completed are presented in Volume 3.

About the Author

Bill is the Chief Operations Officer for KTA-Tator Inc. (KTA), where he has been employed for 38 years. He holds an AD in Business Administration from Robert Morris University. He is an SSPC Certified Protective Coating Specialist, an SSPC Level 3 Certified Protective Coatings Inspector, an SSPC Level 2 Certified Bridge Coatings Inspector, as well as a NACE Level 3 Certified Coatings Inspector. He – is an approved training course instructor for both SSPC and KTA. Bill authored the first, second and third editions of the KTA publication, Using Coatings Inspection Instruments. He received SSPC's Coating Education Award in 2006, the SSPC John D. Keane Award of Merit in 2011, an ASTM Committee D01 Award of Appreciation in 2016, and the SSPC President's Lecture Series Award in 2017. He is the Chair of the SSPC Dry Film Thickness Committee and Chair of the SSPC Education and Certification Committee. He is also a member of ASTM Subcommittees D01.23 and D01.46.

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