EPO No. 16

Appendix B (Supplement 2)

Determining Scale Error When Applying the Substitution Test Method

This supplement is intended to further clarify how scale error is determined from hypothetical results, made up to imitate those that might be recorded by an official who applied the various steps of the substitution test method to perform an increasing-load test on a scale with digital indication. The results of having applied each step of the test are shown with sufficient notation to make clear how the substitution test loads were created and scale error determined from using error weights. Shading is used to differentiate between values associated with the most current step from those of previous steps.

Types of Error:

When using the substitution test method, there are two types of errors you will need to consider:

1) The error associated with each step of the increasing-load test in which test weight is applied from a proper starting reference. These are referred to herein as "step errors." You will see these errors recorded in the column of the example tables titled: "Error (E_n)"
2) The error associated with the cumulative results of one or more steps in which test weight is applied during of the increasing-load test. These errors are referred to herein as "cumulative errors." Cumulative errors are determined by summing the results of consecutive increasing-load steps. You will see these errors recorded in the column of the example tables titled: "Error ($\sum E_n$)"

Tolerance Application:

The tolerances apply to the total cumulative test load for the successive increasing-load tests.

Establish a proper reference at no load (high-level step 1)

Test Description	Test Weight (L)	Substituted Bulk Material	Starting Reference (R_s)	Ending Reference (R_e)	Scale Indication (I_x)	Error (E_n)	Error ($\sum E_n$)	
Zero load	0	0		6	10/20			

Apply the test weight, establish proper reference, and determine the total amount of scale error (high level steps 2 and 3)

Test Description	Test Weight (L)	Substituted Bulk Material	Starting Reference (R_s)	Ending Reference (R_e)	Scale Indication (I_x)	Error (E_n)	Error ($\sum E_n$)	
Zero load	0	0		6	10/20			
Increase	3 000		6	9	3 010/20	-3	-3	Step 1

The following formula is used to determine the amount of error (i.e., step error) in the scale at the first applied test weight load:

$$E_n = I_e - I_s - L + R_s - R_e$$

Where:

"E_n" *(Error)* represents the amount of error in the scale relative to the applied test weight portion of the total applied test load;

"I_e" *(Indication ending)* represents the scale indication after the test weight has been applied and proper reference established;

"I_s" *(Indication start)* represents the scale indication before the test weight was applied;

"L" *(Load)* represents the value of the applied test weight excluding any substituted load;

"R_s" *(Reference start)* represents the value of the error weights on the load-receiving element that established proper reference prior to the test weight being applied; and

"R_e" *(Reference ending)* represents the value of the error weights on the load-receiving element that established proper reference after the test weight had been applied.

Thus, from the values recorded in the Table above:

"I_e" is equal to 3 015
"I_s" is equal to 15
"L" is equal to 3 000
"R_s" is equal to 6
"R_e" is equal to 9

To determine the amount of error in the scale, insert the appropriate corresponding values obtained during testing into the formula and solve the equation as follows:

$$E_n = I_e - I_s - L + R_s - R_e$$

Actual test result values (from Table above) inserted into the formula:

$$E_n = 3\,015 - 15 - 3\,000 + 6 - 9$$

Completed formula calculation step 1: Error = - 3

Evaluating the Results:

Since only test weights have been applied thus far during testing, the cumulative results are the same as the error for Step 1.

Verify return to no-load reference (high-level step 4)

Test Description	Test Weight (L)	Substituted Bulk Material	Starting Reference (R_s)	Ending Reference (R_e)	Scale Indication (I_x)	Error (E_n)	Error ($\sum E_n$)	
Zero load	0	0		6	10/20			
Increase	3 000		6	9	3 010/20	-3	-3	Step 1
Zero Return	0	0	6	7	10/20	-1		

Create the first substitution test load and establish proper reference (high-level step 5)

Test Description	Test Weight (L)	Substituted Bulk Material	Starting Reference (R_s)	Ending Reference (R_e)	Scale Indication (I_x)	Error (E_n)	Error ($\sum E_n$)	
Zero load	0	0		6	10/20			
Increase	3 000		6	9	3 010/20	-3	-3	Step 1
Zero Return	0	0	6	7	10/20	-1		
1st Sub.		3 000		5	3 010/20	-3	-3	

Apply test weight to first substitution test load, establish proper reference, and determine the total amount of scale error (high-level steps 6 and 7)

Test Description	Test Weight (L)	Substituted Bulk Material	Starting Reference (R_s)	Ending Reference (R_e)	Scale Indication (I_x)	Error (E_n)	Error ($\sum E_n$)	
Zero load	0	0		6	10/20			
Increase	3 000		6	9	3 010/20	-3	-3	Step 1
Zero Return	0	0	6	7	10/20	-1		
1st Sub.		3 000		5	3 010/20	-3	-3	
Increase	3 000	3 000	5	9	6 010/20	-4	-7	Step 2

To determine the amount of error in the scale corresponding to the test weight portion of the test load (i.e., step error), insert the appropriate values obtained during testing into the formula and solve the equation as follows:

$$E_n = I_e - I_s - L + R_s - R_e$$

Actual test result values from the table above illustrating the results of high-level steps 6 and 7 inserted into the formula:

$$E_n = 6\ 015 - 3\ 015 - 3\ 000 + 5 - 9$$

Completed formula calculation step 2: Error = - 4

Evaluating the Results:

Tolerances apply to the cumulative results of the first two increasing-load steps which is - 7 pounds.

In order for the example scale to meet applicable tolerances the cumulative results (error) of the two increasing-load steps completed thus far, must also be within tolerance. That is, the sum of the error recorded in each of the increasing-load steps completed thus far in relation to the sum of the test weight applied in each of those same steps must be within tolerance. In the two increasing-load steps completed thus far, the cumulative error is - 7 pounds and the sum of the test weight applied is 6 000 pounds.

Create the second substitution test load and establish proper reference (high-level step 8)

Test Description	Test Weight (L)	Substituted Bulk Material	Starting Reference (R_s)	Ending Reference (R_e)	Scale Indication (I_x)	Error (E_n)	Error ($\sum E_n$)	
Zero load	0	0		6	10/20			
Increase	3 000		6	9	3 010/20	-3	-3	Step 1
Zero Return	0	0	6	7	10/20	-1		
1st Sub.		3 000		5	3 010/20		-3	
Increase	3 000	3 000	5	9	6 010/20	-4	-7	Step 2
2nd Sub.		6 000		3	6 010/20		-7	

Apply test weight to the second substitution test load, establish proper reference, and determine the total amount of scale error (high-level steps 9 and 10)

Test Description	Test Weight (L)	Substituted Bulk Material	Starting Reference (R_s)	Ending Reference (R_e)	Scale Indication (I_x)	Error (E_n)	Error ($\sum E_n$)	
Zero load	0	0		6	10/20			
Increase	3 000		6	9	3 010/20	-3	-3	Step 1
Zero Return	0	0	6	7	10/20	-1		
1st Sub.		3 000		5	3 010/20		-3	
Increase	3 000	3 000	5	9	6 010/20	-4	-7	Step 2
2nd Sub.		6 000		3	6 010/20		-7	
Increase	3 000	6 000	3	4	9 000/10	-11	-18	Step 3

To determine the amount of error in the scale corresponding to the test weight portion of the test load (i.e., step error), insert the appropriate corresponding values obtained during testing into the formula and solve the equation as follows:

$$E_n = I_e - I_s - L + R_s - R_e$$

Actual test result values from the table above illustrating the results of high-level steps 9 and 10 inserted into the formula:

$$E_n = 9\,005 - 6\,015 - 3\,000 + 3 - 4$$

Completed formula calculation step 3: Error = - 11

Evaluating the Results:

> Tolerances apply to the error corresponding to the cumulative results of having applied the test weight three times (i.e., once in each of the three consecutive increasing-load steps). The cumulative error corresponding to the three increasing-load steps completed thus far is - 18 pounds.

In order for the example scale to meet applicable tolerances the cumulative results (errors) of all increasing-load steps completed thus far, must also be within tolerance. That is, the sum of the error recorded in each of the increasing-load steps completed thus far in relation to the sum of the test weight applied in each of those same steps must be within tolerance. In the three increasing-load steps completed thus far, the cumulative error is - 18 pounds and the sum of the test weight applied in each of those same steps is 9 000 pounds.

Create the third substitution test load and establish proper reference (high-level step 11)

Test Description	Test Weight (L)	Substituted Bulk Material	Starting Reference (R_s)	Ending Reference (R_e)	Scale Indication (I_x)	Error (E_n)	Error ($\sum E_n$)	
Zero load	0	0		6	10/20			
Increase	3 000		6	9	3 010/20	-3	-3	Step 1
Zero Return	0	0	6	7	10/20	-1		
1st Sub.		3 000		5	3 010/20		-3	
Increase	3 000	3 000	5	9	6 010/20	-4	-7	Step 2
2nd Sub.		6 000		3	6 010/20		-7	
Increase	3 000	6 000	3	4	9 000/10	-11	-18	Step 3
3rd Sub.		9 000		7	9 000/10		-18	

Apply the test weight to the third substitution load, establish proper reference, and determine the total amount of scale error (high-level steps 12 and 13)

Test Description	Test Weight (L)	Substituted Bulk Material	Starting Reference (R_s)	Ending Reference (R_e)	Scale Indication (I_x)	Error (E_n)	Error ($\sum E_n$)	
Zero load	0	0		6	10/20			
Increase	3 000		6	9	3 010/20	-3	-3	Step 1
Zero Return	0	0	6	7	10/20	-1		
1st Sub.		3 000		5	3 010/20		-3	
Increase	3 000	3 000	5	9	6 010/20	-4	-7	Step 2
2nd Sub.		6 000		3	6 010/20		-7	
Increase	3 000	6 000	3	4	9 000/10	-11	-18	Step 3
3rd Sub.		9 000		7	9 000/10		-18	
Increase	3 000	9 000	7	5	11 980/90	-18	-36	Step 4

To determine the amount of error in the scale corresponding to the test weight portion of the test load (i.e., step error), insert the appropriate corresponding values obtained during testing into the formula and solve the equation as follows:

$$E_n = I_e - I_s - L + R_s - R_e$$

Actual test result values from the table above illustrating the results of high-level steps 12 and 13 inserted into the formula:

$$E_n = 11\ 985 - 9\ 005 - 3\ 000 + 7 - 5$$

Completed formula calculation step 4: Error = - 18

Evaluating the Results:

> Tolerances apply to the error corresponding to the cumulative results of having applied the test weight four times (i.e., once in each of the four consecutive increasing-load steps). The cumulative error corresponding to the four increasing-load steps completed thus far is - 36 pounds.

In order for the example scale to meet applicable tolerances the cumulative results (errors) of all increasing-load steps completed thus far, must also be within tolerance. That is, the sum of the error recorded in each individual increasing-load step completed thus far, in relation to the sum of the test weight applied in each of those same steps. In the four increasing-load steps completed thus far, the cumulative error of - 36 pounds and the sum of the test weight applied in each of those same steps is 12 000 pounds.

Additional Testing to Achieve Maximum Test Load (If Necessary)

If maximum test load has not been achieved after the test weights are applied to the third substitution test load, remove the test weight and conduct a strain load to make possible additional testing. Up to three additional substitution tests may be conducted after proper reference has been established at any strain-load. The unshaded portion of the table below shows example results of a single strain-load and two substitution tests that were necessary to achieve a maximum test load to used capacity.

Test Description	Test Weight (L)	Substituted Bulk Material	Starting Reference (R_s)	Ending Reference (R_e)	Scale Indication (I_x)	Error (E_n)	Error ($\sum E_n$)	
Zero load	0	0		6	10/20			
Increase	3 000		6	9	3 010/20	-3	-3	Step 1
Zero Return	0	0	6	7	10/20	-1		
1st Sub.		3 000		5	3 010/20		-3	
Increase	3 000	3 000	5	9	6 010/20	-4	-7	Step 2
2nd Sub.		6 000		3	6 010/20		-7	
Increase	3 000	6 000	3	4	9 000/10	-11	-18	Step 3
3rd Sub.		9 000		7	9 000/10		-18	
Increase	3 000	9 000	7	5	11 980/90	-18	-36	Step 4
Strain Load				5	18 300/10	N/A	N/A	
	3 000		5	8	21 300/10	-3	-3	Step 1
1st Sub.		3 000		2	21 300/10		-3	
Increase	3 000	3 000	2	6	24 300/10	-4	-7	Step 2
2nd Sub.		6 000		8	24 300/10		-7	
Increase	3 000	6 000	8	8	27 290/00	-10	-17	Step 3

Tolerance application for increasing-load tests conducted from strain loads: With a strain load applied and proper reference established, the scale's indication and the amount of error weight used to establish the proper reference provides a new starting point for additional increasing-load tests. For those additional tests, tolerances apply to the total cumulative test load for successive increasing load tests applied from the strain load, including substitution tests.