NAWI

A strain-load methodology for fast verification of medium capacity nonautomatic weighing instruments

Dott. Ing. Giuseppe Ardimento, Weights & Measures Officer, Camera di Commercio, Industria, Artigianato ed Agricoltura di Napoli, Italy

Introduction

The classification adopted by a Local Authority for non-automatic weighing instruments (NAWI's) that are within its jurisdiction often depends on the type and quantity of standard weights required to carry out their verification.

Typically at the Local Metrology Authority of Naples, the following classification criteria are used:

- ***Small capacity NAWI*:** Class III accuracy weighing instruments up to 20 kg capacity. For these instruments, one officer can perform the verification alone according to the relevant technical standard [1] by using a complete set of M_1 20 kg standard weights [2].
- ***Medium capacity NAWI*:** Class III accuracy weighing instruments up to 1 000 kg capacity. For these instruments, a verification officer should have a sufficient number of M_1 20 kg standard weights available in order to test the instruments to full capacity. In these instances extra labor might be required or, alternatively, a Local Metrology Authority technical assistant may have to accompany the officer to help lift and place the weights onto the load receptor. The main concern when verifying this type of NAWI is having to carry up to 25 M_1 20 kg standard weights to many locations (from 5 to 10 per day).
- ***High capacity NAWI*:** Class III accuracy weighing instruments from 1 t to 60 t capacity. Italian Regulations specify that these NAWI's have to be verified by an officer using high capacity standard weights that meet the relevant OIML Recommendation requirements, and which have to be made available by the NAWI owner or by the service agency responsible for the NAWI maintenance program. The traceability of standard weights to the national mass standard is, in these cases, to be clearly demonstrated to the officer performing the verification. The total number of standard weights to be used is specified by the relevant technical standard (see subclause 3.7.3 of [1]).

Since carrying 25 M_1 20 kg standard weights around can be somewhat problematic, this paper describes a strain-load methodology to perform fast routine verifications of medium capacity NAWI by using an error characteristic estimating model based on the concept of the "sensitivity error" [5].

This method is intended for performing routine verifications of NAWI's that have a good compliance history: if a NAWI subjected to the present fast verification method fails the test, it shall not be considered as rejected, but rather as needing to be further examined according to the full verification procedure set out in the relevant standard [1]. Since the global population of NAWI's consists of a majority of compliant devices and not that many non-compliant ones, the time needed to complete the whole routine verification program can be reduced, resulting in an advantage for the Local Metrology Authority responsible for the program management.

1 Error sources in a NAWI

In a medium capacity NAWI the load receptor dimensions are small, especially when the NAWI is equipped with load cells; this occurrence in notably true for single point load cell equipped NAWI's. Thus the influence of off-center loading can be considered as a marginal factor affecting the accuracy in a well calibrated NAWI.

The offset error [5] can be clearly detected and (in a certain weight value range) can be cancelled by activating the NAWI zero-setting mechanism.

The linearity and hysteresis error [5] are mainly due to the load cells: these items can only be investigated in a restricted way during a routine inspection. Linearity performance can be evaluated by means of the accuracy test according to the relevant standard [1]. The hysteresis contribution to the error characteristic can be evaluated by determining errors during the loading and unloading processes in the course of the NAWI accuracy test: an acceptable performance criterion is that in both processes, the error characteristic must be within the in-service mpe values as laid down by the regulation or standard.

Since the relevant European Directive [6] stipulates that electronic NAWI's have to be submitted to pattern approval, it can be assumed that the NAWI's behave in such a way that offset, linearity and hysteresis error characteristics were more thoroughly investigated at the time of pattern approval, and found to be within the mpe. Moreover, if the initial verification result is "OK", this can be considered as confirming that circumstance. Thus in a routine inspection, it can be assumed that the sensitivity error [5] is the main source of error when a NAWI is in service due either to incorrect calibration procedures or to electronic shift phenomena occurring in the analog components that process the signal emanating from the load transducers.

2 The sensitivity error model

The reasons described in section 1 above show that the NAWI's accuracy performance may be described by assuming that the relationship between the applied load L and the NAWI indication is a linear one: a NAWI having no error regardless of the load applied on the receptor would have the dotted straight line representing the unity function as shown in Fig. 1.

A NAWI having an error due to a sensitivity value (dI/dL) other than 1 would have the continuous red line plotted in Fig. 1, which is described by the equation:

$$I = aL \quad (1)$$

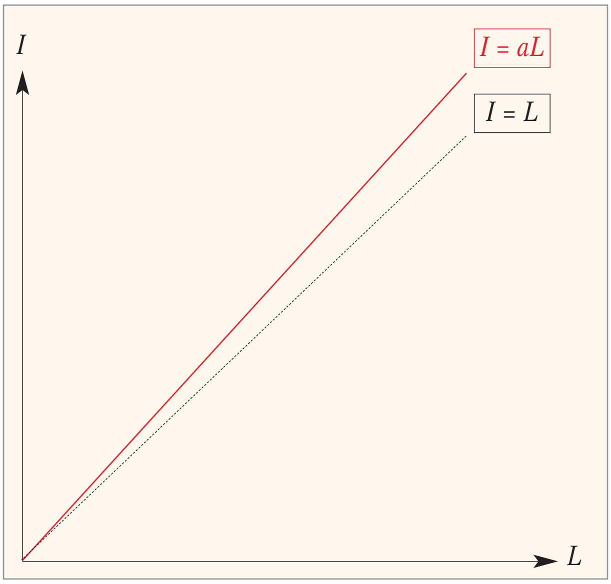

Fig. 1 Relationship between NAWI indication and applied load

where a is the slope (dI/dL). Thus the NAWI sensitivity error:

$$E = I - L \quad (2)$$

is proportional to the applied load, and in fact:

$$E = aL - L = (a - 1)L \quad (3)$$

Because of (3), the NAWI can be considered as having a behavior that is influenced by a predominant sensitivity error when the accuracy error rises proportionally as the applied load increases.

3 The strain-load fast verification approach

Once a NAWI has been installed and verified according to the relevant technical standard, it may be assumed that it is likely to retain the correct accuracy characteristics throughout its whole operating life. Thus subsequent verifications could be performed using an abridged procedure, only focusing on the main error sources such as the sensitivity error. This abridged verification can be deemed as being satisfactory provided that full verification tests and fast verification tests are performed alternately during the NAWI's operating life.

3.1 The strain-load method as a NAWI fast verification procedure

According to [4] a strain-load test is *"the test of a scale beginning with the scale under load and applying known test weights to determine accuracy over a portion of the weighing range. The scale error for a strain-load test are the errors observed for the known test loads only. The tolerances to be applied are based on the known test load used for each error that is determined".*

Since the relevant European technical standard does not allow for strain-load to be performed, but does allow for a substitution test to be performed (see subclause 3.7.3 of [1]) provided that the NAWI under test meets given repeatability requirements, the possibility has been investigated to combine the substitution test procedures with the strain-load method (which is faster) by means of an error characteristic estimating model. This model analyzes the error characteristic in the initial weighing range near to zero by using a limited number of test weights (up to 500 times the interval, e), extrapolates a linear characteristic from the initial weighing data and explores the error characteristic by means of a strain-load beginning with the NAWI loaded at 50 % (or more) of the maximum capacity.

Table 1 The initial loading process

Load	I_i ↑	I'_i ↓	Corrected I_i	Corrected I'_i
L_1	I_1	I'_1	$I_{1c} = I_1 - E_0$	$I'_{1c} = I'_1 - E_0$
L_2	I_2	I'_2	$I_{2c} = I_2 - E_0$	$I'_{2c} = I'_2 - E_0$
L_3	I_3	I'_3	$I_{3c} = I_3 - E_0$	$I'_{3c} = I'_3 - E_0$
L_4	I_4	I'_4	$I_{4c} = I_4 - E_0$	$I'_{4c} = I'_4 - E_0$
L_5	I_5		$I_{5c} = I_5 - E_0$	

(*Note:* E_0 is the near zero error determined according to subclause A.4.4.3 of [1]. In order to only consider the error due to the applied load and without including the zero error, the corrected indication $I_{ic} = I_i - E_0$ is calculated, E_0 being the near zero error as referred to above).

3.2 The estimating linear model

To determine the estimating linear model, the NAWI is loaded up to 500 *e* in progressive steps of 100 *e* each. The procedure is shown in Table 1, where L_i (i varying from 1 to 5) represents the known test loads, I_i the corresponding indication when the load on the NAWI is increased, and I_i' the corresponding indication when the load is decreased.

In order to draw the straight line characterizing the estimating linear model, use is made of the random variable ε_k, defined as follows:

$$\varepsilon_k = I_{kc} - aL_k \tag{4}$$

where the I_{kc}'s are the corrected indications and the L_k's are the corresponding applied loads; a is the slope of the estimating model straight line.

To achieve on average a zero variation ε for optimizing the fitting of the estimating model, the expected value of ε_k is calculated and let to be equal to zero:

$$E[\varepsilon_k(a)] = E[I_{kc}] - a \cdot E[L_k] = 0 \tag{5}$$

From (5) the slope of the estimating model straight line is:

$$a = (\Sigma_k (I_{kc} + I'_{kc}) / (\Sigma_k L_k)) \tag{6}$$

In (6) use has been made of the unbiased average estimator (arithmetic mean) for the mathematical expectation operators appearing in (5):

$$E[I_{kc}] = (\Sigma_k(I_{kc} + I'_{kc})) / 9$$
$$E[L_k] = (2 \cdot (L_1 + L_2 + L_3 + L_4) + L_5) / 9$$

The first condition which the NAWI has to meet to pass the fast verification is that the corrected errors be within the in-service mpe's for the five test loads.

The further condition with which the NAWI has to comply is based on the strain-loading process: an unknown load L^* equal to 50 % Max or more is applied to the NAWI, then the corresponding indication I_U is noted; starting from this load a known test load ΔL, preferably of the same amount as 500 *e*, is applied to the NAWI: the new indication I_F is noted. The corrected indications (I_{Uc} and I_{Fc}) are then calculated. The situation is shown in Fig. 2; as indicated, the error that is likely to characterize the NAWI at the load $L^* + \Delta L$ is:

$$E_p = (I_{Uc} + \Delta I) - (L^* + \Delta L) =$$
$$= I_{Uc} + (I_{Fc} - I_{Uc}) - L^* - \Delta L \tag{7}$$

By using the estimating linear model $I_c = a \cdot L$, (7) can be written as:

$$E_p = [(a - 1)/a]\, I_{Uc} + (\Delta I - \Delta L) =$$
$$= [(a - 1)/a]\, I_{Uc} + (I_{Fc} - I_{Uc} - \Delta L) \tag{8}$$

By means of (8), the error at the load $L^* + \Delta L$ can be estimated: the NAWI passes the fast verification only if the E_p value remains within the mpe value corresponding to the load $L^* + \Delta L$ $((I_{Uc} / a) + \Delta L)$.

3.3 Statistical consideration of the estimating linear model

The error determined by (8) is based on an estimating model which makes use of a parameter a, based on the hypothesis that the NAWI's main source of error is due to its sensitivity properties and that, at least in the initial weighing range, other influence factors affecting the NAWI's accuracy balance each other (this is the meaning of (5)).

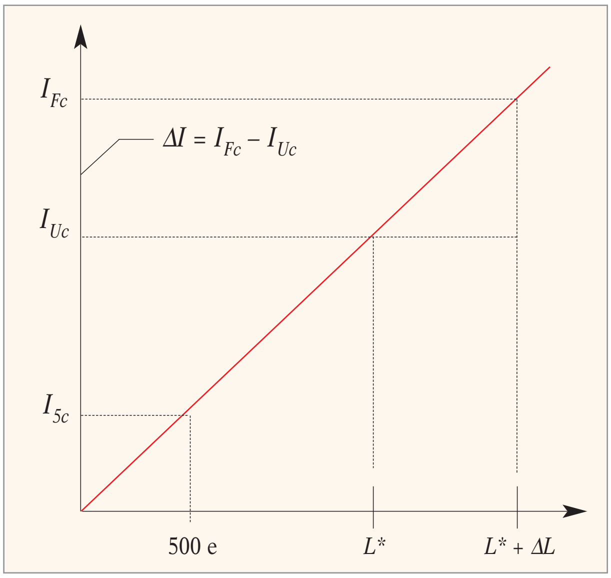

Fig. 2 The strain loading process

Thus (8) is in fact an estimate; for this reason it calls for a valuation of its reliability.

In order to do that, reckoning with constraint (5) a standard deviation estimate s_a could be defined as:

$$s_a^2 = \mathrm{E}[(\varepsilon_k(a) - \mathrm{E}[\varepsilon_k(a)])^2] = 1/8\ \Sigma_1^9 (I_k - a \cdot L_k)^2 \qquad (9)$$

Because of definition (4) the following can be written:

$$I_k = \varepsilon_k(a) + a \cdot L_k \qquad (10)$$

From (10) the indication variance can be evaluated as:

$$s_I^2 = s_a^2 \qquad (11)$$

because a and L_k are known values that are not subject to variations once they are determined.

From (8), in the following form:

$$E_p = [(a - 1)/a]\ I_{Uc} + (I_{Fc} - I_{Uc} - \Delta L)$$

due to the fact that the indication I_{Uc} is not determined but only extrapolated by the estimating linear model, the error variance can be written as:

$$s_E^2 = ((a - 1)/a)^2 \cdot s_I^2 + s_I^2 =$$
$$= s_I^2 \cdot \{1 + [(a - 1)/a]^2\} \qquad (12)$$

Tchebicheff's Theorem [7] can help estimate the reliability of the error calculated by means of (8): indicating by E the "true" error and by k a constant, the probability that the error falls far from the estimated E_p by more than the quantity $k \cdot s_E$ is given by:

$$\mathrm{P}\{|E - E_p| \geq k \cdot s_E\} \leq 1/k^2 \qquad (13)$$

The criterion for considering the estimate (8) as reliable could be that the distance $k \cdot s_E$, defining the uncertainty of the estimate, be less than or equal to 1/3 mpe, i.e.:

$$k \cdot s_E \leq (1/3)\ \text{mpe} \qquad (14)$$

In (14) k has to be greater than or equal to 3 in order to ensure that:

$$\mathrm{P}\{|E - E_p| \geq k \cdot s_E\} \leq 1/9 \qquad (15)$$

i.e. that the probability that the true error E is far from the estimated error E_p by more than $k \cdot s_E$ is 11.1 % or less.

Thus when performing the strain-load test a NAWI passes the fast verification procedure if the estimated error E_p corresponding to the virtual applied load is within the mpe value, *and* $[(\text{mpe})/(3 \cdot s_E)] \geq 3$. If the latter condition is not verified, then a full verification procedure according to the relevant technical standards has to be performed.

3.4 Form for the fast verification procedure

To better summarize the strain-load fast verification procedure, a Verification Form example is given in Annex 1 (opposite).

4 A worked out example

In order to establish whether the strain-load fast verification procedure satisfactorily fulfills the purpose for which it is intended, an experiment was prepared with the aid of a NAWI manufacturer, the firm "Adriano Gomba & C. S.a.s.", based in Naples.

A NAWI was first calibrated as best as possible, to keep it within the mpe's. The strain-load fast verification procedure was then applied: the results are shown in Annex 2 (page 14).

Then the error at the maximum virtual load was determined in the classical way by means of test loads. The former error (estimated) was found to be – 0.27 kg at a 400 kg load; the latter error (determined) was found to be – 0.22 kg at the same 400 kg load.

5 Acknowledgement

The author wishes to thank the "Adriano Gomba & C." management staff, Mr. Massimo Cappelli and Mr. Mario De Rosa, as well as Mr. Vincenzo Anastasio, Quality Management System Supervisor and Mr. Sabato Rea, NAWI Head Technician, for their courtesy in providing a type approved NAWI and technical assistance to perform the test described in section 4. ■

References

[1] EN 45501: *Metrological Aspects of Non Automatic Weighing Instruments*

[2] OIML R 111: *Weights of classes E_1, E_2, F_1, F_2, M_1, M_2, M_3*

[3] OIML R 47: *Standard weights for testing of high capacity weighing machines*

[4] NIST Handbook 44: *Specifications, Tolerances and other technical Requirements for Weighing and Measuring Devices*

[5] Aurel Millea, *Some fundamental concepts in metrology* - OIML Bulletin No. 91, June 1983

[6] Council Directive on the Harmonization of the laws of the European Member States on Non Automatic Weighing Instruments 90/384/EEC

[7] Sergio Benedetto, Ezio Biglieri, *Teoria della probabilità e delle variabili casuali* - 7, Collana "Quaderni di Elettronica", Ed. Boringhieri Torino

Annex 1 Fast verification data registration form

Strain-load fast verification procedure

NAWI's data:

Manufacturer ______________________
Model ______________________
Serial No. ______________________
Max ______________________
(Max_1, Max_2, Max_3) ______________________
Interval d, e ______________________
(e_1, e_2, e_3) ______________________

Step 1

Zero error E_0: ____________

	Load L_i	Ind ↑	Ind ↓	I_c = Ind ↑ – E_0	I'_c = Ind ↓ – E_0	Corr. Error↑	Corr. Error↓
1							
2							
3							
4							
5							

$\Sigma L = 2 \cdot (L_1 + L_2 + L_3 + L_4) + L_5 =$ ________________
$\Sigma I_c =$ ________________
$\Sigma I'_c =$ ________________

Check as appropriate:

❑ Corrected errors are all within maximum permissible in-service error values ⇒ **GO ON TO STEP 2**
❑ One or more corrected errors are out of the maximum permissible error values ⇒ **NAWI FAILS**

Step 2

Estimating linear model slope: $a = (\Sigma I_c + \Sigma I'_c) / \Sigma L =$ ________________________________
Indication variance s_I^2:

Load L	aL	I_c	$I_c - aL$	$(I_c - aL)^2$	I'_c	$I'_c - aL$	$(I'_c - aL)^2$

$s_1 = \Sigma(I_c - aL)^2 =$ ________________ ; $s_2 = \Sigma(I'_c - aL)^2 =$ ________________
$s_I^2 = (s_1 + s_2)/8 =$ ________________ ; $s_I =$ ________________

Corrected indication at the strain load: $I_{Uc} =$ ______________
Known test load after the strain load: $\Delta L =$ __________
Corrected final indication: $I_{Fc} =$ __________
Virtual applied load: $L_V = I_{Uc}/a + \Delta L =$ ________
Maximum permissible error at L_V: mpe = __________
Error estimate at L_V: $E_p = ((a - 1)/a)\, I_{Uc} + (I_{Fc} - I_{Uc} - \Delta L) =$ ______________
Standard deviation of the error estimate: $s_E = s_I(1 + ((a - 1)/a)^2)^{1/2} =$ ____________
mpe/($3s_E$) = ________

Is ($E_P \leq$ mpe ***and*** (mpe/($3s_E$)) ≥ 3)?⇒ ❑ **YES: NAWI passes**
❑ **NO: Apply full verification procedure according to EN 45501**

Annex 2 overleaf ▶▶▶

Annex 2 A worked out example of the strain-load fast verification procedure

Strain-load fast verification procedure

NAWI's data:		
	Manufacturer	Gomba
	Model	SG
	Serial No.	
	Max	600 kg
	(Max_1, Max_2, Max_3)	
	Interval d, e	0.2 kg
	(e_1, e_2, e_3)	

Step 1

Zero error E_0: ***0***

	Load L_i	Ind ↑	Ind ↓	I_c = Ind ↑ – E_0	I'_c = Ind ↓ – E_0	Corr. Error↑	Corr. Error↓
1	***20***	***19.98***	***19.98***	***19.98***	***19.98***	***– 0.02***	***– 0.02***
2	***40***	***39.96***	***39.98***	***39.96***	***39.98***	***– 0.04***	***– 0.02***
3	***60***	***59.94***	***59.92***	***59.94***	***59.92***	***– 0.06***	***– 0.08***
4	***80***	***79.92***	***79.92***	***79.92***	***79.92***	***– 0.08***	***– 0.08***
5	***100***	***99.92***		***99.92***		***– 0.08***	

$\Sigma L = 2 \cdot (L_1 + L_2 + L_3 + L_4) + L_5 = \mathbf{500\ kg}$
$\Sigma I_c = \mathbf{299.72}$
$\Sigma I'_c = \mathbf{199.8}$

Check as appropriate:

❑ Corrected errors are all within maximum permissible in-service error values ⇒ **GO ON TO STEP 2**
❑ One or more corrected errors are out of the maximum permissible error values ⇒ **NAWI FAILS**

Step 2

Estimating linear model slope: $a = (\Sigma I_c + \Sigma I'_c) / \Sigma L = \mathbf{0.99904}$
Indication variance s_I^2:

Load L	aL	I_c	$I_c - aL$	$(I_c - aL)^2$	I'_c	$I'_c - aL$	$(I'_c - aL)^2$
20	***19.98***	***19.98***	***0***	***0***	***19.98***	***0***	***0***
40	***39.96***	***39.96***	***0***	***0***	***39.98***	***0.02***	***0.0004***
60	***59.94***	***59.94***	***0***	***0***	***59.92***	***– 0.02***	***0.0004***
80	***79.92***	***79.92***	***0***	***0***	***79.92***	***0***	***0***
100	***99.90***	***99.92***	***– 0.02***	***0.0004***			

$s_1 = \Sigma(I_c - aL)^2 = \mathbf{0.0004}$; $s_2 = \Sigma(I'_c - aL)^2 = \mathbf{0.0008}$
$s_I^2 = (s_1 + s_2)/8 = \mathbf{0.00015}$; $s_I = \mathbf{0.012}$

Corrected indication at the strain load:	$I_{Uc} = \mathbf{299.96}$
Known test load after the strain load:	$\Delta L = \mathbf{100}$
Corrected final indication:	$I_{Fc} = \mathbf{399.98}$
Virtual applied load:	$L_V = I_{Uc}/a + \Delta L = \mathbf{400.25}$
Maximum permissible error at L_V:	mpe = ***0.6***
Error estimate at L_V:	$E_p = ((a - 1)/a)\, I_{Uc} + (I_{Fc} - I_{Uc} - \Delta L) = \mathbf{-\ 0.27}$
Standard deviation of the error estimate:	$s_E = s_I(1 + ((a - 1)/a)^2)^{1/2} = \mathbf{0.012}$
	$\text{mpe}/(3s_E) = \mathbf{16.67}$

Is ($E_P \leq$ mpe ***and*** (mpe/($3s_E$)) ≥ 3)?⇒ ❑ **YES: NAWI passes**
❑ **NO: Apply full verification procedure according to EN 45501**